Book of Abstracts

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Theory

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Training of technical and engineering staffs
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Creation of an international student program or PhD/Post-doc exchange
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BEAMS + TARGETS

Targeted drug delivery guided by particle beams

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General description (methodology, goals,..): The effectiveness of cancer therapy can be much improved by combination of high conformal radiation dose provided by hadron therapy and local drug release to the tumor activated by the proton beam on drug nanocarriers. We aim for the first time to develop a drug-loaded nanocarrier system that release its cargo by application of a proton beam. The nanocarrier containing the drug and sensitizer agents that can be activated with ionizing radiation from protons and carbon ions. The effectiveness of this technique will be studied in silico, in vitro and in vivo. Nanoparticles with different composition will be tested under different irradiation conditions (dose, dose rate, particle) and the release of the cargo will be analyzed.

Background: According to the World Health Organization, cancer is a major cause of morbidity and mortality, with approximately 14 million new cases and 9.6 million cancer-related deaths in 2018, affecting populations in all countries and all regions. Many cancer treatments are available that will be chosen according to several factors, such as the type and stage of cancer and general health. Most common cancer treatment options include surgery, chemotherapy, and radiation therapy. Radiation therapy uses high-powered energy beams, such as X-rays or protons, to kill cancer cells. Proton therapy. Proton therapy is a type of radiation therapy. The appropriate application of proton therapy has led to fewer adverse effects and higher therapeutic efficacy compared with conventional radiation therapy using X-ray beams. Thus, facilities for proton therapy are being built worldwide, despite the requirement for costly equipment. The rationale for using proton beams instead of photon beams is the feasibility of delivering higher doses to the tumor while maintaining the total dose to critical structures or maintaining the target dose while reducing the total dose to critical structures. The major advantage of proton therapy treatment over standard radiation therapy is that protons slowly deposit their energy as they travel towards the cancerous tumor and then due to a unique physical characteristic called the Bragg Peak, deposit the majority of the radiation dose directly in the tumor and travel no further through the body. This results in less healthy tissues and organs receiving unnecessary radiation thereby reducing unwanted complications and side effects. In addition, the rate of energy loss per unit distance, i.e., the linear energy transfer (LET), increases first slowly and linearly and then very sharply near the end of the particle range. Increasing LET also leads to increasing ionization density along the particle track, which, in turn, leads to increasing amount and complexity of biological damage. The best way to reduce chemotherapeutic drug side effects is to ensure their release at the tumor site only. There has been a steady growth in research on intratumoral chemotherapy during the past few decades as an alternative to the conventional systemic delivery approach for patients with unresectable lesions. Safety and efficacy of locally delivered chemotherapies have been tested in combination with concurrent radiation therapy. These studies demonstrated that this local chemo-radiation combination is safe and effective in prolonging survival. Ionizing radiations are generally characterized by their ability to excite and ionize atoms of matter with which they interact. This capability can be also used to induce drug delivery from nanocarriers. In this way, nanocarriers containing the desired drug are administered to the patient and by application of radiation to the treatment volume the drug release is locally induced. Radiation-induced drug release base on X-rays has been suggested. In addition, proton beams have the potential to produce an accurate control of drug release as the physical dose deposition is concentrated and the end of the proton path right where the tumor is. Therefore, radiation-induced drug release by means on proton beams might combine the advantages of proton therapy in dose conformation with an accurate drug delivered locally to the tumor.

Original aspects: This is the first time hadron beams are propose for targeted drug delivery in nanomedicine. Due to the unique properties of the energy deposition and ROS formation when using hadron beam for radiation therapy, they could be use to provide access to combined chemotherapy with high accuracy.

Unique expertises: We have a unique expertise that combines radiation therapy, nuclear physics detectors, nanotechnology and radiobiology, which is a perfect match to accomplish this project. Samuel España has worked in the Department of Radiation Oncology of the Masschusetts General Hospital where he performed research on dose verification and treatment planning accuracy on proton therapy and was able to apply those techniques to clinical patients. At Ghent University he participated in the FP7-funded ENVISON project where he contributed to develop new technology for dose verification in proton therapy. At Universidad Complutense he currently participates in an ambitious project to improve the effectiveness of proton therapy through dose monitoring. However, no overlap exists between that project and the one presented here. He also has extensive experience in the development of remotely activated nanoparticles through the use of external stimuli and preclinical studies working with animal models of human diseases. Prof. José Manuel Udías, full professor, co-director of the Nuclear Physics Group at UCM, with +15 years of experience in medical physics, IP of 15 national and international projects including large consortia. JM Udias began the activities of the group related to applications in medicine in 2002. He team brings together a unique combination of backgrounds that suits the multidisciplinary nature of this project, with ample experience in R&D of medical devices.Prof. Luis Mario Fraile, full professor, expert in nuclear physics and detector development, with an outstanding career at CERN. Specialized in nuclear structure and reactions, spectroscopy, nuclear instrumentation, nuclear astrophysics and applications in dosimetry, hadronotherapy and medical imaging. Since 2018 he has been the principal investigator of the PRONTOCM project: "Protontherapy and nuclear techniques for oncology" funded by the Comunidad de Madrid.

Within EURO-LABS, we are looking for a facility that can host our experiments including access to hadron beams at clinical energies and that allows research experimentation in cells and animals. In addition, access to lab equipment for the analysis and preparation of nanoparticles, cells, and animal models would be required. We believe that one of the best options to perform those experiments is PARTREC facility at University of Groningen (Netherlands), which meet all the requirements.The PARTREC facility has a superconducting cyclotron for the acceleration of both light and heavy ions and irradiation experiments can be performed in air which is critical for our project.

Development of fast and rad-hard sensors for Radioactive Ion Beams tagging and diagnostics

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Title:

Development of fast and rad-hard sensors for Radioactive Ion Beams tagging and diagnostics

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General description (methodology, goals,..):

The study of reactions involving Radioactive Ion Beams (RIBs) constitutes one of the most interesting items of the modern nuclear physics. RIBs of large intensity (10^5 pps or more) have been made world-wide available in the last decades and many facilities are currently under construction and will go into operation in next years. As an example, the INFN-LNS in Catania is currently undergoing an upgrade of the research infrastructures; the Superconducting Cyclotron is expected to increase the power of delivered beam of about 2 order of magnitudes, up to about 10 kW, for light and medium nuclei (A<40). A new fragment separator, FraISe, is under construction in order to exploit the increase of primary beam power for the production of RIBs by in-flight technique. The fragment separator will consist in 2 couples of dipoles, in double achromatic arrangement, and will be able to deliver RIBs in a range of intensity going from 10^2 pps, as typical values for very exotic isotopes, those very far from stability valley, to 10^7 pps, as a typical value for exotic isotopes near to the stability valley. It is expected to have about $1.4*10^3$ pps for ^{14}Be, $6.8*10^6$ pps for ^{16}C, $2*10^7$ pps for ^{13}N. This will open new and very interesting perspectives for nuclear physics studies. Physics cases as clustering, resonances (GMR, Pygmy) in exotic nuclei, new/exotic decay modes, reactions/decays of astrophysical interest, reactions with high isospin asymmetric nuclei can be addressed.

Challenges:

Rad-hard diagnostics devices capable of sustaining high rates are a key ingredient in order to efficiently produce and make us of intense RIBs. In fact, the production and optimization of RIBs in a fragment separator are not easy tasks and often are time and man-power consuming. The development of diagnostic systems able to characterize RIBs production and, via Artificial intelligence techniques, semi-automatically optimize the production can allow a more efficient production and use of the RIBs. Similarly, the development of new tagging systems capable of working for long periods and with high rates is needed by user carrying-out experiment with RIBs. Our idea is to develop sensors based on SiC technology, well known for being fast, in term of response, and rad-hard. Building a large ($\approx 8*4$ cm^2) multi-pad devices, with a single pad of $\approx 4*4$ mm^2, it will be possible to distribute the rate over several pads, being able to sustain about 10^7 as total rate. Thickness of 100 um appears to be the best choice in the case of RIBs in the Fermi energy regime. Highest thickness will be needed at relativistic energies as the ones used at GSI. Coupling the info from two adjacent sensors, also trajectory and beam profile can be well measured.

Thus, what we ask here is the establishment of a collaboration network, including economical resources, to develop and implement new sensors systems, based on fast and rad-hard detectors, able to sustain large rates and to characterize, on an event-by-event base, the beam impinging on the target point of the experiment, such as well, inside the fragment separator. This includes ion species, energy, spatial and angular distribution of the RIBs. Info provided by these detectors can be coupled with dedicated Front-End, DAQ and intelligent software able to characterize the beam envelope inside the fragment separator and automatically optimize the RIBs production, making use of AI techniques.

Original aspects:

Implementation of rad-hard and high rate sensors for beam transport characterization and tagging is a novelty that opens new perspectives. A dedicated fast and integrated electronics is also challenging and a point of novelty. The use of artificial intelligence to manage the amount of data coming from the sensor systems, characterize the beam transport, and auto-tune the fragment separator will allow to maximize the performance of a fragment separator, saving time, man-power and economical resources and facilitating experimental activities

Unique expertises:

We propose to establish a collaboration between different key figures, nuclear physicists with expertise in fragment separator techniques and rad-hard detectors, electronics engineers with expertise in fast and integrated front-end, DAQ experts, informatics engineers with experience in improved techniques of data management and implementation of artificial intelligence techniques, accelerator staff with experience in beam transport and tuning, and, again, nuclear physicist community acting as final users of the produced RIBs needing also tagging systems for that.

Common expertises and collaborations:

The joint efforts, collaboration and exchange of idea and know-how among the previous mentioned expertises are needed and are, also, a strength for the multi-disciplinary challenges we aim to face-up. Devices and techniques we propose can find use not only at INFN-LNS fragment separator, working here as work horse, but also in other European Laboratory delivering RIBS produced by In-Flight technique such as GANIL and GSI.

Synergies with other research/technical groups:

The collaboration will keep high-level of interaction with research groups working on fragment separators, with experts on new material for detectors, fast electronics, DAQ and AI technique, and with users of RIBS for nuclear physics experiments. We foresee a significant exchange of know-how and cross-fertilization in different fields.

Synergies with other communities:

The outcomes of this project can trigger the interest also by communities different from the basic nuclear physics one. We can mention the tuning and optimization of the fragment separator for radio-chemical isotopes production, tuning of beam for medical applications, technologies used for homeland security, use of the developed devices as detectors in other physics communities, use of AI techniques for stable beam tuning, diagnostic systems for photon beams.

(with reference to the categories described in the “Instructions for submission page”, https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Main category of your contribution:

Beam+Targets

Connections with other categories:

What we propose is a multi-categories project and we expect to contribute also to

- Improved Access
- Data Acquisition + Analysis, Simulations
- Detectors + Electronics

And to impact also on

- Training, Education, Outreach, Social Impact

Establishment of technical infrastructure across European laboratories for developments of reliable high intensity target ion source systems

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All content in the file in attachment.

Title: Establishment of technical infrastructure across European laboratories for developments of reliable high intensity target ion source systems

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General description (methodology, goals, …):

The facilities participating in this initiative aim at providing the physics community with a rich and exciting panel of exotic Radioactive Ion Beams (RIBs) produced with the Isotope Separation On Line (ISOL) method. The ISOL method relies upon cutting edge techniques in applied science which concern the core processes of Radioactive Ion Beam (RIB) production. The operation of high power targets, plasma ion sources under high irradiation, the optimization of the release of radioactive isotopes, require an innovative R&D in material science, radiochemistry and plasma physics which would benefit from coordinated efforts at a European level. The **main goal in this project is to ensure access to several infrastructures** necessary for a joint development and testing of target and ion source systems towards higher efficiency and higher reliability for ISOL facilities. **Sharing expertise and access to the various test benches** from major facilities such as ISOLDE and MEDICIS at CERN (CH), SPIRAL 2 at GANIL (FR), ALTO in IJCLab (FR), SPES at INFN-LNL (IT) and the future ISOL@MYRRHA at SCK CEN (BE) will enable leading a coordinated cutting-edge R&D in the following joint topics:

- **Development of Tantalum target container/ovens**: for ISOL facilities large target containers are used for both cooling (high power facilities) and heating (low power facilities) of the target materials exposed to proton-beam irradiation usually operated at temperatures in the range of 2000 °C over a period of up to 4 weeks. Their development towards temperature uniformity and reliability (endurance at harsh operational conditions), including the study of chemical interaction with other materials is very important. Due to the on-going research in most ISOL facilities, **most of the research and development is either truncated or repeated, which can be avoided with having access to an European infrastructure where all the necessary development and test systems are being made available.**
- **Development of target materials**: development of micro/nanostructured materials from refractory compounds which are tailored for the isotope to be released (element and half-life) have the potential to increase the release rates by orders of magnitude and thus the beam intensities the facilities can provide. In addition, such target materials can degrade over time, especially when operated at 2000 °C or more, which usually results in the reduction of the overall beam intensities due to reduced isotope release**. There are developments on-going across most of the partners** in this direction.
    - **Target material characterization**: ISOL facilities worldwide share interest in characterizing their target materials with respect to macroscopic properties (high-temperature stability, target-isotope chemistry, endurance, etc.) as well as microstructural properties (grain size, porosity, pore size, pore size distribution). In that regard, the various ISOL facilities accommodate different experimental analysis methods and expertise. In addition, some facilities have these characterization techniques in controlled areas, allowing the analysis of actinide materials or even irradiated materials. As a result, **fostering access among the different facilities, more complete characterization possibilities will be possible**. In addition, it grants the opportunity to develop a consistent experimental protocol, thereby **enabling the generation of comparable data between the target developments across different facilities**.
- **Diffusion and release studies**: for ISOL radioactive ion beam production systems the production yield is the most crucial property. If one wishes to determine yields from direct measurements, **on-line beam time is required, which is scarce**. Two possible approaches, which can be

performed offline, exist for examining the release properties of a given target-isotope pair, which results in a large amount of physical data usually not available in literature:

1. Fractional release studies can be performed by activating the target materials at suitable irradiation sites, followed by activity determination, heat treatments to promote release and re-measure of the activity. This technique offers a combined efficiency which gives an overall release fraction but does not cover the individual physical phenomena (e.g. diffusion, effusion) and usually, these studies are usually performed at online facilities.
2. The other approach includes examination of the individual processes (diffusion, (inter-grain) effusion). While being significantly more complex as it requires deliberate experimental campaigns, the results of such studies foster a **better understanding of the underlying fundamental processes**, as well as **synergies with other research communities and fields** (e.g. material science, high-temperature chemistry, etc.).

ISOL facilities throughout the world share the interest in such studies, and have complementary infrastructure available. As a result, easier **access to online facilities with available beam time** (such as ISOLDE/MEDICIS, GANIL and ALTO) by facilities under design/construction is of great importance. **A shared research would significantly contribute to this domain of research, as well as to the outlined synergetic research fields**.

- **Development of high intensity and efficient ion sources**: one of the most limiting steps in the ISOL chain for producing high intensity beams, is the lack of efficient high intensity ion sources. Even if the target is able to release the isotopes it was designed for, in high quantities, the ion source may be quenched and limit the maximum extracted beam intensity and thus the whole ISOL process. Being the latter a hot topic in ion source R&D, **facilitating the communication, access and traveling would greatly benefit all partners**. Additionally, ion sources across the different ISOL facilities are similar, but not identical. Nonetheless, **by sharing (or fostering more easy access) respective off-line research infrastructure** (off-line separators, gas systems, laser labs, etc.) and by developing a **shared ion source characterization protocol, research efforts would no longer be duplicated**. Moreover, **data that is collected at the different facilities would be comparable**, which would strongly benefit the respective field of research.

Such **research topics are transversal to all ISOL institutes** and the **participation in a partner experiment and sharing of characterization and testing equipment is of great value avoiding duplicated research**. This would also join the expertise strength of the different facilities boosting the outcome of each R&D.

The **list of accessible experimental facilities** would be:

ISOL@MYRRHA at SCK CEN:

- Thermal test stand (for container and target material tests)
- Test stand for off-line isotopes-release measurements and assessment of isotopes-target/target-container chemical interaction
- Offline laser laboratory at SCK (up to 3 step ionization schemes)
- ISOL offline at SCK CEN – available in 2022
- Available materials characterization equipment at SCK CEN (available also in controlled areas either in glove boxes or in hot cells for the characterization of irradiated materials): Gas sorption, diameter and surface roughness analysis, freeze drier, He-gas picnometer,

granulator, laser granulometer, sieving particle size analysis, muffle, tubular and sintering furnaces, Raman spectrometer, TGA-DSC-MS, dilatometry, UV-B spectrophotometer, X-ray diffractometer, optical microscopy, Transmission Electron Microscopy (including sample preparation), Scanning Electron Microscopies (including energy dispersive X-ray, electron backscattered diffraction and focused ion beam), Induced Coupled plasma mass spectrometry, thermal ionization mass spectrometry (TIMS), electron MicroProbe analysis (EPMA), positron annihilation and lifetime spectroscopies, coincident Doppler broadening spectroscopy and others.

ISOLDE/MEDICIS at CERN:

- ISOLDE online facility (online prototype target and ion source tests)
- MEDICIS facility (target material irradiation and offline isotope extraction)
    - Fractional isotope release studies setup can be available
- ISOLDE offline separator at CERN (ion source prototype testing, ion source efficiency measurements, etc.)
- ISOLDE pump stand (for container and target material tests) at CERN ?
- ISOLDE Nanolab (development and production of nanostructured actinide target materials)
- ISOLDE chemical lab (development and characterization of micro- and nanostructured target materials)
- Available materials characterization equipment: He-gas pycnometry, Gas sorption, TGA-MS, Laser particle size analysis, Carburization stand, Scanning Electron Microscope

SPES at INFN-LNL:

- ISOL Offline at SPES (extraction of stable beams of interest, ion sources characterization)
- SPES Thermal test stand (thermal characterization of target-Ion Source units and prototypes)
- SPES target production/sintering furnace (high temperature treatment of non-radioactive target materials)
- SPES thermal characterization furnace (thermal characterization of refractory material samples)
- Other materials characterization equipment: Permeameter (measure gas permeability of porous materials) and He-picnometer

SPIRAL 2 at GANIL:

- ISOL Target and Ion Source test bench, requiring service connections identical to services of SPIRAL1 Target and Ion source System, equipped with an energy profile analyzer
- Large cooled vacuum chamber for oven and target heating tests

ALTO at IJCLab:

- ISOL facility at ALTO (ion source prototype testing, target production and release efficiency measurements)
- ISOL Offline separator at ALTO (ion source prototype testing, ion source efficiency measurements and optimization of beam production parameters)
- Thermal test stand (thermal characterization of target-ion source units and prototypes) – available in 2022

Challenges:

Highly multidisciplinary field: the community involves engineers, physicists, chemists, material scientists, etc.

Intellectual property (IP) distribution amongst different institutes in the different research projects.

Original aspects:

Infrastructure distributed along many European laboratories – a coordinated access to the various infrastructures allows optimization of the technical developments and this will be reflected in an increase of performance translated in better RIBs for a large and multidisciplinary scientific community.

Unique expertises:

SPES at INFN-LNL:

- Thermal characterization of non-radioactive target materials (emissivity, thermal conductivity)
- Thermal-electric simulation of high temperature components for ISOL Target and Ion Sources

ISOLDE/MEDICIS at CERN:

- >60 years operational experience with ISOL and target and with advanced ion source prototype developments at ISOLDE
- Pulsed proton beam allows to study in detail the release time-structure of short lived isotopes
- Offline isotope extraction experience at MEDICIS from irradiated materials at ISOLDE or externally produced radioactive sources

ISOL@MYYRRHA at SCK CEN:

- Experience in modeling with various codes several physical phenomena including radioisotope production, thermomechanical analysis, structural analysis, fluid-dynamics analysis, beam optics, ionization, …
- Long experience and availability of installations for material development (so far, largely dedicated to nuclear-reactors fuel and structural materials) and varied characterization techniques (pre- and post-irradiation)

SPIRAL 2 at GANIL:

- Operational experience of SPIRAL 2 facility for isotope production using ions beams (fragmentation and fusion-evaporation)
- Experience with various beams at different energies and high intensities to test materials in real/varied operational conditions
- Experience in thin targets (in the range of a few mg/cm^2) and thermal measurements (e.g. IR cameras)

ALTO at IJCLab:

- Operational experience of ALTO facility for isotope production using an electron beam converter to gamma rays (photo-fission) and yield measurements
- Experience in using scientific codes for radioisotope production, thermomechanical analysis and charged particles transport.

Common expertises and collaborations:

All the authors are experienced in the multidisciplinary field of target and ion source development. The mentioned organizations work together in different collaborations.

Synergies with other research/technical groups

Fuel materials and Structural Materials research groups, Radiochemistry group and Conditioning and Chemistry Programme group, Microstructure and Non-destructive Analysis Group at SCK CEN.

Mechanical and Materials Engineering – Materials, Metrology and Non-destructive Testing Section and ISOLDE Physics users group at CERN.

Synergies with other communities: materials science and engineering community (target materials) in ultra-high temperature, refractory and porous materials, medical physics community (medical use of ISOL produced nuclides), chemistry community (molecular beams and high temperature chemistry (1000-2300 °C)), liquid dispersion using suitable surfactants/dispersants, laser physics, vacuum technology.

Main category of the contribution: Beams + targets

Connections with other categories: Improved access (strengthen the collaboration, and access to young researchers and students - possibility to host researchers/students from the involved organizations, if/when allowed by the pandemic situation)

Accurate delivery of short and intense beam pulses and mini-beams

Authors: Stefan Both[1]; Sytze Brandenburg[1]; Peter Dendooven[1]; Björn Poppe[2]; Joao Seco[3]; Emiel van der Graaf[1]; Marc Jan van Goethem[1]

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General description:

Goal

At the UMCG-PARTREC facility (formerly KVI), we aim to develop the capabilities to very accurately deliver short and intense beam pulses as well as beams of sub-mm size. Beam pulses as short as 5 microseconds and switching on and off times below 1 microsecond, with accurate intensity measurement and control, will be developed. These capabilities will be developed for proton, helium ion and carbon ion beams. The objective is to achieve instantaneous dose-area product rates of 10^5 Gy cm^2/s.

Users

- Exploratory preclinical research using electrons and X-rays at ultra-high dose rates (so-called FLASH irradiations using short and intense beam pulses) suggests that in such irradiations the ratio of tumour control over normal tissue damage can be significantly improved. This intriguing result is the topic of extensive research. Because essentially all results so far were obtained with electrons/X-rays, there is a big need to investigate the FLASH effect with proton/ion beams. It is thus essential that proton/ion beams that have the same characteristics can be offered to users. We will therefore develop the capability to achieve a dose-area product rate of 10^5 Gy cm^2/s and pulse periods of 5 microseconds or less to match the characteristics of the electron and X-ray FLASH irradiations. In addition, we will develop the methods to accurately measure radiation dose and control delivered dose at such high dose rates. The testing of novel technology for the verification of proton/ion FLASH irradiations will become possible.
- Sub-mm size beams (so-called mini-beams) of protons, helium ions and carbon ions are used for very precise irradiations of e.g. biological (e.g. cells, organoids) or electronic structures. Such irradiations require a good knowledge of the linear energy transfer (LET) of the beam particles.
- In general, the new capabilities will be attractive to users needing very small beam spots and/or requiring short and well-controlled beam pulses for the investigation of nuclear states.

Methods/requirements

We will develop novel devices for measuring the radiation dose as well as the LET of small and intense beams and increase the attainable beam intensities. The challenge to overcome is the very high beam density in both space and time. Handling the correspondingly high ionisation densities and rates requires the development of dedicated detectors. Such development needs an understanding/modelling of the detectors' behaviour under ultrahigh dose rate irradiation.

Irradiations typically require a deposited dose of at most a few tens of Gray with an accuracy of better than 5 %. FLASH irradiations (i.e. ultrahigh dose rates) thus imply the ability to switch off the beam at a very short timescale, down to microseconds. A stable dose rate of the beam pulses at such a timescale requires high stability of the ion source output at that timescale.

An instrumented vacuum chamber to study effects of the production of high LET fragments produced in the irradiated material will be part of this development.

The development discussed above needs to be supported by very realistic and detailed Monte Carlo simulations. At the PARTREC accelerator facility, flexible Monte Carlo models encompassing all beam line components and user setups are available to users for planning and optimizing experiments as well as the interpretation of experimental data/results.

We propose to extend our Monte Carlo framework to include the small beam sizes that will be developed. For many experiments (e.g. in the field of proton radiography), the correct implementation of multiple Coulomb scattering is imperative. We thus propose to expand our Monte Carlo simulation capabilities also in this direction. The development of ultrahigh dose rate detectors requires Monte Carlo modelling of dose rate related recombination effects in ion chambers or leakage currents/induced resistances in semiconductors; with higher accuracy than present phenomenological methods.

Challenges:
The characterization and control of the properties of beams with a high density in time and space entails the following challenges:
• High stability of the ion source output at the microsecond timescale.
• Understanding the high ionisation currents in the detectors as a result of ultrahigh dose rates irradiation, taking the particular time structure of the beam into account.
• Monte Carlo modelling of dose rate related recombination effects in ion chambers or leakage currents/induced resistances in semiconductors.
• Improving the accuracy of the dosimetry of small fields to a level comparable to standard dosimetry protocols.

Original aspects:
• combination of high intensity in time and in space
• full control over the beam time structure
• availability of beams with a wide range of LET
• defining a set of detectors and dosimetrical methods to reach high accuracies (5%) under all dose-rates, field sizes and particles used

Unique expertise:
• detectors for dosimetry
• dosimetrical methods for small field and FLASH irradiations of proton/ion beams
• accurate beam delivery control in time and space
• experiment design and execution
• Monte Carlo simulations of detectors and beam lines

Synergies with other communities:
Radiotherapy, radiobiology

Collaboration/Networks
• RADNEXT (https://radnext-network.web.cern.ch/main/)
• RADSAGA (https://radsaga.web.cern.ch)
• UHDPulse (http://uhdpulse-empir.eu)
• German Standardization Board DIN Sub-Committee Dosimetry (involved in development of more than 20 DIN Norms on dosimetry within the last years)

Main categories of this contribution: Beams + Targets, Detectors, Simulations

Connections with other categories: Training, Education, Outreach, Social Impact

Purification 48-Ca

Authors: Mikael Dubois[1]; Frederic Lemagnen[1]; FRÅNBERG DELAHAYE Hanna[1]

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The neutron rich 48Ca beam is largely requested by nuclear physicist, especially for production of Super Heavy Elements ions and studies, like S3, SHE factory. This ion beam is produced by evaporation of material with an oven whose geometry is link to the ion source. To reache the best intensities, the used of enriched isotope of 48Ca is necessary. Moreover, this sample have to be free from other element (like C, O) to limit the plasma contamination in the ions source.
Usually, the 48Ca is stocked in 48CaCO because of the stability of the molecule. To be usable in an ion source, this sample has to be transform on 48Ca and in an crucible usable on dedicated oven.

Title: Purification 48-Ca

Authors and affiliations: M. Dubois, H. Franberg, F. Lemagnen, (GANIL, France)

General description (methodology, goals,..):

The neutron rich 48Ca beam is largely requested by nuclear physicist, especially for production of Super Heavy Elements ions and studies, like S3, SHE factory. This ion beam is produced by evaporation of material with an oven whose geometry is link to the ion source. To reach the best intensities, the used of enriched isotope of 48Ca is necessary. Moreover, this sample have to be free from other element (like C, O) to limit the plasma contamination in the ions source.

Usually, the 48Ca is stocked in 48CaCO because of the stability of the molecule. To be usable in an ion source, this sample has to be transform on 48Ca and in a crucible usable on dedicated oven.

Challenges:

The needs for stable 48-Ca for the experimental campaigns on our accelerators are of a non-discussable need.

Today several laboratories has 48-Ca samples that are oxidised or in different molecular form not adapted for vaporisation in the ion sources ovens…..

The challenges consist on development of chemical methods, test benches and formed personnel to be able to adapt the sample, recycling to device used by laboratories.

The goal is the cost reductions, reuse of rare metals.

Original aspects:

The main stocks of 48-Ca, are today not in a purified form, in the laboratories and there is a lackage of natural sources available. The purification of the samples existing will increase the availability of 48-Ca beams in the future.

Unique expertise:

The chemistry behind is not developed today. The Nuclear physics laboratories operating today were based and constructed on well-established competences in nuclear chemistry. While developing the accelerators and the other equipment's for the accelerators and the beam transport , the Human resources and knowledges for chemical aspects has been lost. Today the laboratories that maintain oxidised samples of 48-Ca can no longer use them.

Common expertise and collaborations:

GANIL, GSI : Production of 48Ca ions
IPHC : Chemical Laboratory

Synergies with other research/technical groups :

ERI2B'S : ion beam Service

Synergies with other communities :

Collaboration can be proposed with IPHC-in2p3 -France, GSI-FAIR, ESS, PSI and others.

<u>Main category of your contribution :</u>

Definition of the shape for the sample, usable on GANIL-SPIRAL2 ion sources

Beams + Targets *Improvements in techniques and varieties, machine learning*

Experimental accelerators approaching medical beam delivery techniques

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Title:

Experimental accelerators approaching medical beam delivery techniques

Authors and affiliations:
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[1]IFIC - CSIC/UVEG

General description (methodology, goals,..):
European research accelerators are fundamental not only for the development of new physics but also in prototype development for medical applications, for example in range verification for particle therapy. In this field, the AGOR KVI-CART research accelerator (now PARTREC), which accelerates protons as well as heavier positively charged ions, has played a key role in the discovery and proposal of, among others, the prompt gamma-ray timing technique, in-beam PET of short-lived emitters, as well as the testing and evolution of multi-layer Compton cameras. This kind of accelerator offers flexible beam energies, controllable beam current, repeatable irradiation conditions, and more space and time for performing hardware stress tests than their clinical counterparts, that are only available during limited slots when no patients are treated. As such, these experimental accelerators are an invaluable tool for translational research from the lab to the clinics.
While their experimental features are essential for testing purposes, there are some fundamental differences that hinder their potential usefulness as translational tools. In the case of particle therapy, medical accelerators comprise scanning magnets that are used to sweep the beam along the treatment area. The absence of these scanning magnets in most experimental accelerators is thus a limitation, that facilities like OncoRay – Dresden have tackled by coupling an auxiliary scanning magnet unit to their experimental beamline. Another example would be the absence of cone-beam CT devices in experimental rooms, that are used in some medical facilities to provide simultaneous imaging of the target during irradiation, specifically in areas with significant organ motion. A third point would be the availability of realistic clinical phantoms (heterogeneous and anthropomorphic) to any users rather than homogeneous targets, more indicated for basic physics research. These phantoms could then be aligned with the cone-beam CT system with respect to the beam line, and a clinically realistic treatment plan could be delivered with the scanning magnets. The inclusion of additional accurate positioning tables, actuators and verification tools would also allow higher precision tests to be carried out.
Such complements would enrich the testing possibilities in experimental accelerators and mimic in a more realistic way the clinical irradiation conditions; thus enabling more efficient and reliable clinical translation of experimental prototypes.

Challenges:
The main challenge is to integrate these complements (scanning magnets, cone-beam CT, anthropomorphic phantoms) in a modular manner, letting the user the choice of using them or not, so that its passive presence does not interfere with physics experiment by other users.

Original aspects:
Implementation of a subset of medical devices into experimental beam lines to make irradiation test conditions more clinically realistic.

Common expertises and collaborations:
Our group collaborates with several proton therapy facilities (Dresden, Madrid, Krakow) and can thus provide a good insight and connection of the required tools.

Synergies with other research/technical groups:
Medical particle therapy facilities with a strong research team like OncoRay - Dresden or PSI – Villigen have unique expertise on how medical complements can be integrated in a non-invase manner with already existing experimental beamlines.
Furthermore, this development would be strongly related to range verification in particle therapy, as well as the development of new technologies and testing platforms for FLASH therapies within an experimental environment with more clinically realistic tools.

Synergies with other communities:
Our group was part of the MediNet collaboration and has been part of the ENLIGHT network for over a decade, with a strong focus on medical accelerators.

Main category of your contribution:
Beams + Targets

Connections with other categories:
New physics cases

DRIFT - Developing Research Infrastructure For Target Technologies

Authors: Manuela Cavallaro[1]; Federico Pinna[2]

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Title:
DRIFT - Developing Research Infrastructure For Target Technologies

Authors and affiliations:
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INFN - Laboratori Nazionali del Sud, Catania, Italy
DISAT - Politecnico di Torino, Torino, Italy
INFN - Sezione di Torino, Torino, Italy

General description (methodology, goals,..):
In any nuclear physics experiment, the choice of a proper target is a crucial issue, as important as the choice of the impinging beam and of the detection systems. However, the benefits of a careful development and characterization of the target foils is often overlooked. The availability of high intensity beams in different laboratories in Europe and all over the world pushes the requests for demanding target foils, which are able to resist at high intensity ion flux while maintaining the characteristics in terms of thickness, uniformity, isotopic enrichment, and so on. An example, well known to the proponents of the present proposal, is given by the upgrade of the Laboratori Nazionali del Sud (INFN-LNS) cyclotron and the challenges of the NUMEN project [1]. In such a setup, an intense heavy-ion beam (up to 10^{13} pps) will hit thin target foils, made of specific isotopic enriched material, and the reaction ejectiles will be selected and detected with high resolution by the MAGNEX magnetic spectrometer [2].
With the present proposal, the authors suggest the creation of a distributed research infrastructure contributing to the development, production and characterization of target foils of interest for the european and international nuclear physics community. Such infrastructure would promote collaboration and networking among different laboratories and research groups interested in these aspects, as well as the sharing of ideas and projects.
The main objective of the proposed action is to provide a service, initially based in Italy, at INFN-LNS and Politecnico di Torino (PoliTo), but that can be extended to all the users of EU and non-EU nuclear physics laboratories.
Among the deliverables of this activity, one should mention not only the definition of techniques and procedures necessary to produce and characterize the targets of interest for the community, but also the creation of a database listing the target systems already studied and produced in various laboratories and their main features.

In these years, while developing NUMEN targets, a protocol was established to produce some samples suitable for the stringent NUMEN experimental requirements [3]. Every sample is characterized in each production step, guaranteeing reproducibility and control over the process. Concerning the target production itself, Physical Vapor Deposition (PVD) techniques were chosen. PVD techniques are very well suited for producing targets for nuclear physics experiments, since they do not need gaseous precursors or large quantities of material. However, producing targets by using equipment not specifically designed for the task (e.g. general purpose equipment owned by private laboratories or electronic oriented production lines) may lead to poor results in terms of uniformity and purity or scarce reproducibility. Thermal and e-beam evaporators were extensively used, since they can evaporate a large variety of materials; such evaporators are also versatile and can be optimized to address different deposition requirements (adjustable crucible-substrate distance, heated/cooled sample stage, …). They also offer a good control on the film thickness, the discrepancy between the nominal and actual thickness being within 5%.

Different nuclear physics experiments require noble-gas isotopes to be used as a target. These targets should contain a sufficient number of noble-gas atoms (~ 10^{18} atoms/cm^2), should be as pure as possible, should be uniform to ensure a good energy resolution on the reaction products, and, for application with intense ion beams, should be stable under irradiation. Of course, in such cases, the commonly used evaporation or rolling methods cannot be applied. In this context, the use of ion-implantation techniques can represent a solution. The new-generation Electron Cyclotron Resonance (ECR) source, AISHa [4], at INFN-LNS, together with its implantation chamber, is an interesting opportunity to exploit the already available technology of ECR source for ion-implantation purposes. This source will be particularly well adapted for producing for example Ne, Kr and Xe ions with high charge states that will be extracted by a voltage of up to 30 kV, to give ions with energies up to hundreds of keV. The influence of the implantation conditions on the saturation values will be studied, in particular the ion energy, the implantation current density, the implantation of multiple layers at different energies.

In order to obtain targets that can withstand the high intensities available for example after the INFN-LNS cyclotron upgrade, special attention will be dedicated to backing materials allowing an efficient target cooling, such as highly oriented pyrolytic graphite. For both evaporated and implanted targets, the thickness of inactive (backing) materials should typically be smaller or similar to that of the target isotope, in order to limit background from nuclear reactions and the effect of straggling on the energy resolution [5].

Instruments used for target production must be paired necessarily with a fully equipped characterization laboratory, to be able to study the samples before and after the deposition. A laboratory as such exists at DISAT, PoliTo, where several apparatuses (Scanning Electron Microscope, Energy-dispersive X-ray spectroscopy, Raman Spectroscopy, alpha-particle spectroscopy, etc) are already available and extensively used. The alpha-particle transmission spectroscopy setup (APT), located in the Nuclear and Subnuclear Physics Laboratory (NSPL, DISAT, PoliTo), could be enhanced to allow for serial analysis of multiple targets, to select different collimators or radioactive sources. Also, a system for the sample movimentation along (x,y) could be added, to allow automated sequential scanning of several points of a target. An additional silicon detector, mounted upstream, could provide a Rutherford Backscattering Spectroscopy (RBS) measurement while running an APT measurement. RBS characterization may also be performed in several other small accelerator facilities, using low energy alpha or proton beams.

The combination of state-of-the-art characterization equipment and target production-oriented laboratory would be an invaluable asset for the users of National Laboratories and external research groups as well. In a time of ever-growing demand for precision and accuracy of the data, creating such a network would provide an accessible and reliable way to produce and characterize targets for high accuracy measurements.

Challenges:

- Use of isotopically enriched material of interest for the nuclear physics experiment (minimization of isotope waste during deposition)

- Use of thin foils with high intensity beams (heat dissipation and radiation damage)
- Uniformity of the deposited or implanted material to satisfy the demanding energy resolution requests for heavy-ion induced experiments
- Creation and maintenance of a distributed infrastructure for target development, production and characterization, keeping the connection among different nuclear physics institutions in Europe and associated Countries

Original aspects:

Creating a network of research groups and facilities aiming at the production and the characterization of state-of-the-art targets suitable also for very intense heavy ion beams. Techniques and equipment which already exist will be optimized for the Nuclear Physics field, to improve target production reliability and the accuracy of the measurements.

Unique expertises:

The feasibility of the project relies on the expertise and knowledge of both LNS and PoliTo technicians and researchers, built over several years of work. The research group in PoliTo is directly involved in the design, production and characterization of target prototypes for NUMEN, and has developed a robust experience in the field. The APT setup in NPSL was established to specifically study targets for nuclear experiments [6], while the many other laboratories in PoliTo are steadily used by a large community of researchers and private companies (link to website). At LNS, the personnel of the target laboratory provided targets, part of which made of peculiar or rare isotopes, for many years, both to LNS and other users. During this period, they gathered a vast knowledge of specific deposition processes which are seldom studied elsewhere, and for which little literature exists.

Common expertises and collaborations:

Collaborations with other groups which typically face the problems of target production are welcome.

Synergies with other research/technical groups and communities:

A consistent part of the above mentioned characterization techniques is used to investigate quantities (sub-micrometric thickness, elemental purity, crystal structure,..) which are routinely studied by material scientists, condensed matter physicists and chemists. The production of nuclear experiment targets is facing challenges which those communities may help in solving, benefitting from mutual experience. Direct collaborations with other groups interested in challenging targets for specific experiments of interest for the EURO-LABS community are also envisaged.

Main category of your contribution:

Beams+Targets

Connections with other categories:

- New physics cases
- Improved access
- Training, Education, Outreach, Social Impact

Preliminary budget estimate:

- Upgrade of the instrumentation (evaporator, mechanics and electronics for alpha-source measurements)- 400 k€
- Personnel (three-years researcher fellowship for characterization activity at PoliTO - 150 k€ + two-year post-doc at INFN-LNS 100 k€). Total 250 k€
- Travel - 30 k€

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Artificial intelligence for Accelerators and Ion Beam Transport. Machine Learning techniques for predictive maintenance.

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Title:

Artificial intelligence for Accelerators and Ion Beam Transport. Machine Learning techniques for predictive maintenance.

Authors and affiliations:

G. Vecchio – INFN-LNS, Italy

General description (methodology, goals):

A new software and a modern control system with interactive graphics user interfaces have been developed to optimize and speeding up the beam transport procedures from the accelerators to the experimental areas at Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud. We designed and developed an architecture with powerful front-end applications and databases for the large amount of data to be stored for such purpose. The innovative interactive Graphical User Interface has significantly improved the efficiency in all the beam tuning operations, by reducing the beam preparation time of a significant factor down to 50% to respect the previous one [1].

In our experience the difficulties of ion beam tuning generally arise because simulation and prediction of beam dynamics based on physical models are often difficult to reproduce in the real case, due to the several uncertainties in the beam transport components that not always is possible to include in the models. The main sources of uncertainties include time-varying beam phase space, misalignments, hysteresis, thermal cycling, parameters that change over the time, and so on. Therefore, even if local controllers maintain exactly the defined set points, the performances in terms of beam transport efficiency can change, with the obvious consequence that the beam operators continually need to follow them, by modifying the required parameters in order to maintain the steady-state conditions. In case of fine-tuning requests, such as in the case of high intensity and secondary beams by projectile fragmentation, lot of time could be spent to maintain the required stability, with significant loss of efficiency in the beam service towards the experimental teams.

The most difficult challenge we would like to undertake concerns the automatic transport of the beam using artificial intelligence and robust control techniques. An automatic control system of the beam tuning parameters can allow to maintain stable in real time the beam transmission along a beam line, in particular when high intensity beams are involved. A control system based on a machine learning algorithm collecting the in-field data from the beam tuning elements (dipoles, quadrupoles, steerers, etc.), from the not interceptive beam diagnostics, the beam loss monitors, the environmental temperature and any other parameter will be considered needed, should allow to correct any possible cause that can give rise to beam losses. This approach will significantly improve the safety related to the beam transport as well as to ensure the required stability of the beam transmission and in general to improve the global efficiency in the management of the beam line.

For what concerning the asset management of the Accelerator Division, in order to determine the condition of in-service equipment, thus to estimate when maintenance should be performed, we would like to use predictive maintenance techniques. This approach promises cost savings over routine or time-based preventive maintenance because tasks are performed only when warranted. Compared to reactive maintenance in which repair is carried out only after a malfunction or breakdown has occurred, or to preventive or scheduled maintenance in which interventions are carried out based on the time or intensity of use of a given asset, predictive maintenance is a methodology that uses condition monitoring tools and techniques to track the performances of the equipment during normal operation. It allows to identify any anomalies and resolve them, before they give rise to failures, as well as to reduce the costs and the complexity of repairs, ensuring better manage stocks of materials and spare parts.

All equipment present in our laboratories can be monitored through these automatic systems that can optimize the balance between corrective and preventative maintenance, by enabling just in time replacement of components.

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Challenges:

Use of artificial intelligence techniques for automatic control system of the beam tuning parameters and predictive maintenance.

Synergies with other communities:

Collaboration with other EU and non-EU research centers.

Main category of contribution:

Beams + Targets

Connections with other categories:

Data acquisition + Analysis

ERIBS: European Research Infrastructure – Beam Services

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Please see the attached document.

ERIBS: European Research Infrastructure – Beam Services

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General description (methodology and goals):
The main objective of the ERIBS proposal is to develop and disseminate the know-how of the European ion source groups in order to ***improve the properties and variety of available ion beams to better service the scientific program of the EURO-LABS research infrastructures (RI)***. All the main accelerator facilities in Europe rely on electron cyclotron resonance ion sources (ECRIS) for the production of high charge state heavy ion beams, and several other facilities utilize these sources as injectors or independent research installations. The final performance of all these facilities depends on the properties of the initial highly charged ion beams produced with the ion sources. Thus, the continuing source development is crucial for the future competitive operation of these laboratories on a global scale.

In the European community of heavy ion accelerator users (for fundamental nuclear physics, interdisciplinary research, applications, medicine, etc.) there is a steady increase in the requests for a larger variety of beams, in particular beams from metallic (even refractory) elements, rare isotopes, etc. as well as requests to have improved beam stability and quality. Synergic activities among the principal European laboratories will ensure unique capability to improve the physics and technology of ECR ion sources for the production of multi-charged ion beams from gaseous and solid elements beyond the present limitations. This will allow a broader portfolio of beam species, intensities and achievable energies to the European Nuclear Physics community.

The improved services will be realized through an innovative and active development collaboration and knowledge transfer between the participating teams. The work described here-after aims at providing high-level ion beam services for the EURO-LABS research infrastructures by focusing on improvements in four key categories:

1) ion beam variety and production efficiency,
2) short and long-term ion beam stability,
3) ion beam quality, intensity and diagnostics.
4) training and dissemination of know-how within the community

Innovative and original approaches will be developed to make a significant step forward in terms of overall ion source performance, exploring non-conventional solutions in the source hardware design (e.g. new geometries of plasma chambers, new microwave injection systems, etc), plasma and ion beam monitoring and material evaporation techniques. A key issue underlying all the above-mentioned items is that variety, stability and beam quality can be improved by a better control of the evaporation and plasmas dynamics, which can be achieved by improved diagnostics methods and techniques.

1) *Ion beam variety and production efficiency (subtask 1)*: The users of the European nuclear physics infrastructures have increasingly requested ion beams of rare isotopes and of elements presently unavailable. This requires further development of techniques and methods currently in use, like the resistively heated ovens (higher temperatures, larger capacities) and the MIVOC method (expanding

to e.g. new refractory elements), but especially to develop new techniques, like controlled sample sputtering and inductively heated oven, presently largely unavailable for the European ion source community. The afore-mentioned techniques will ***provide an access to the use of new refractory elements often requested by the users of the RI'***s. In addition to the beam variety improvement, the efficiency of the production methods has to be improved to minimize the material consumption of rare and expensive isotopes and to minimize the unwanted contamination of the ECR ion source.

Concerning the development of the oven technique, the system has to be capable of reaching reliably a working temperature of 2000˚C and maintaining a stable evaporation rate, within ±10 %, for the duration of at least one week. In this work the main focus will be on the development of the ***induction ovens and their operation life-time***, as these systems have demonstrated reliable high-temperature capability. The sputter method can be used to produce metal ion beams and is particularly appropriate for the refractory elements that are beyond the capabilities of the oven technique. Sputtering is a well-proven technique in the case of ECR ion sources with an open sextupole structure, allowing radial access to the plasma. In ERIBS project the ***sputter method will be applied and developed for the closed sextupole structure***, present in most modern ECR ion sources, making new ion beams of refractory elements available for the user community.

The atom to ion beam conversion efficiency for gaseous elements is very high in ECR ion sources (~80%) while the conversion yield ranges from 0.1% to around 20% for condensable elements, depending on the production method and element. Two approaches will be studied to improve the production efficiency. First, the so called ***"stable 1+/N+ method" focusing on the material injection into the plasma*** will be developed further. In this method the metallic element of interest is introduced into the ion source plasma as monocharged ions. This method has been originally developed for radioactive ECR charge breeders and low 1+ beam intensities (< hundreds of nA). In the context of this work the method will be applied to high-intensity metal ion beam production. The advantage of this method is to separate the 1+ production at high pressure in a dedicated ion source from the multi-ionization stage at very low pressure in a multicharged ion source. Second, ***new geometrical solutions to further enhance material injection and recirculation*** from the plasma chamber walls will be studied. For example, the hot-liner method has been found to be very efficient way to improve the circulation of some solid elements and therefore improve their production efficiency. A remarkable improvement has been obtained especially in the case of the ^{48}Ca ion beams tested with the Phoenix V3 ECRIS at GANIL and with CAPRICE ion source at GSI. The methods will be developed further and related new know-how will be distributed between the partner teams.

2) *Short and long-term ion beam stability (subtask 2)*: The ECR heating mechanism results in an anisotropic electron energy distribution, which makes ECR plasmas prone to kinetic instabilities, limiting the stable operation phase-space. The time between the subsequent instability events is smaller or in the same order of magnitude as the production time of highly-charged ions. The negative impact of the instabilities increases with the ion charge state and also with the microwave power. The multiple frequency heating has been demonstrated to be an effective mean to mitigate those instabilities. In this work the plasma stability related know-how ***to mitigate destructive plasma instabilities*** will be further developed and transferred between the participating teams.

Changes in plasma conditions and changes in material feed rate, especially in the case of metal ion beams, cause a negative impact on the long-term beam stability. Different ***innovative and non-invasive diagnostic methods to monitor plasma conditions and evaporation oven operation during the ion beam production*** will be developed in this subtask. As an example, optical emission spectroscopy can be used to monitor the emission lines of the ion of interest in the plasma or the infrared spectrum from the oven. ***As a result, self-adaptative tuning procedures can be realized to keep the beam intensity inside the preset values.*** Implementing machine learning as a part of the ion source controls is one potential way to realize this goal.

3) *Ion beam intensity, quality and diagnostics (subtask 3)*: Higher ion beam intensities are required by EURO-LAB research infrastructures to perform experiments with particularly low reaction cross sections. The available ion beam intensity is limited by the ion production capacity of the ion source and how much of this ion intensity can be extracted and transported within a given emittance, as defined by the acceptance limit of the accelerator. The ion source group of IAP-RAS has proposed an ***innovative and unique extraction system*** capable of forming ion beams with previously inaccessible intensity with a given extraction voltage and emittance, thus significantly improving the beam brightness. The physical background of the new concept is to use a strongly inhomogeneous electric field distribution in the extraction to provide high gradient ion acceleration at the edge of the plasma where the beam is formed. The first experimental campaign with a proton source has shown an excellent agreement between the ion beam simulations and the experimental results. As a next step the feasibility of this innovative solution needs to be tested with high charge state ion beams. This will be realized in collaboration with the IAP-RAS ion source group by designing, constructing and testing the novel extraction system with an ECR ion source. The successful realization of the work can have a significant impact on the production of high intensity beams with previously unattainable brightness, thus allowing a better utilization of the available highly charged ion population produced in the ECR plasma.

New plasma chamber geometries will be designed and tested with the goal to improve the ECR heated plasma conditions for ion production. Reshaping of both the plasma chamber and the EM wave launching system by breaking the traditionally used cylindrical symmetry can offer many improvements. For example, the cooling properties of the plasma chamber can be enhanced to allow higher RF power input, new electromagnetic wave-plasma coupling schemes can be implemented for improved heating and the confinement properties of the highly charged plasma can be optimized. This leads to higher ion beam intensities due to the optimization of power deposition in the plasma and mitigation of disruptive phenomena such as kinetic plasma turbulences.

In order to achieve high acceleration efficiencies and to deliver intense beams (especially for beam on target RIB's production), sufficiently high beam quality is essential. For this regard, the goal is to achieve as high beam intensity as possible within an adequately small emittance. The extraction system as well as the plasma characteristics are key points for defining the initial beam quality. To measure the fine structure of the beam and quantify these parameters, it is necessary to develop the techniques for reliable emittance measurement. The European ion source community has strong experience in this field (GANIL, LPSC, UMCG-PARTREC). Precise determination of the extracted beam composition and ion currents is also essential to optimize the source plasma to produce the ion species of interest. In the case of ECR ion sources, the currents of different ion species in the charge state spectrum of the extracted beam can vary by many orders of magnitude. In order to reliably identify all the peaks of interest, the measurement system must have a dynamic range of at least 5 orders of magnitude. This poses remarkable challenges to the analysis of the extracted beam composition and tuning of the ion source, especially in the case of very low intensity ion species. In this work the ***signal-to-noise-ratio of the beam diagnostics will be improved which will result in a better ability to identify low intensity ion species*** in a charge state distribution, especially in the presence of beam contaminants of unwanted elements.

4) Training and dissemination of know-how within the community (subtask 4): The project continues the successful training program developed during the MIDAS-NA (ENSAR2). The objective is to offer high-level and diverse training for young researchers and PhD students and to attract new talent to the ion source field. The beam database, also originally developed during MIDAS-NA, will be further developed into a more comprehensive knowledge repository ***to improve the dissemination of the know-how, new development and results, and to provide virtual access to this knowledge***.

Challenges:
The main challenges of the project can be listed as follows:
- The life-time and the performance of the evaporation ovens are not adequate to all elements requested by the user community. In addition, the beam variety has to be improved.
- Long-term beam stability needs to be developed (several weeks e.g. Super Heavy elements).
- Plasma instabilities, which strongly affects the performance of the ECR ion sources and limit the stable operational space, have to be mitigated.
- Emittance of the initial high intensity beam limits the beam intensity available for the users, increasing the beam brightness is of importance for future accelerators.
- Stability of metal ion beams has to be improved. As an example, the beam stability requirement is ±2.5% (24 hours) in the case of medical applications. This has been achieved e.g. for C beams but for many other elements this level of stability is a challenge.
- Low intensity beams are difficult to resolve from the high-intensity spectrum making the tuning of the source difficult.
- The signal-to-noise ratio of the beam current diagnostics used at the ion source is insufficient to reliably determine the beam contamination degree, especially for low intensity ion beams.
- Realization of tunable multi-frequency, high power microwave injection systems for plasma heating is a technical challenge that requires development of new innovative solutions.
- Maintaining a “clean plasma” to ensure high performance operation is a challenge, especially with metal beams. Techniques are required to mitigate the plasma contamination, e.g. from gas line impurities and the interaction between the chamber structures and the plasma particles.

Original aspects:
The achievement of the goals through the methodology proposed above is feasible only by developing innovative plasma and beam diagnostics methods and ***exploring non-conventional solutions for the key components of the ion source systems, such as plasma chamber geometries, microwave injection and beam extraction.*** This new approach can provide several performance improvements, as previously described.

Introducing more comprehensive online monitoring of the source conditions provides a novel approach for ECR ion source operation. Non-intrusive tools in radio-frequency and optical range are the most suitable diagnostics for highly charged plasma. For example, ***advances made in the ion source community in the field of optical spectroscopy provides new possibilities to online plasma monitoring which has not been available previously.*** This allows unprecedented possibilities to determine and follow the overall conditions and the temporal stability of the highly charged plasma. In the RF range non-intrusive probes provide access to monitor plasma self-emissions which are a signature of plasma turbulences and instabilities.

Unique expertise:
For many years, European laboratories have developed strong expertise related to different technological aspects of the ECRIS. In our field, the generation of highly charged plasma is of utmost importance for the accelerators to provide high energy beams to the user community (all the institutes). As the gaseous elements represent only a few elements of the Mendeleev table, metal ion beam technology and production with ECR ion sources grew up (GANIL, JYFL, GSI). In order to

better understand the ECR plasma to enhance the ion source performance, a wide range of plasma diagnostics have been developed. For example: plasma imaging combined with simulations (ATOMKI), RF probes and Optical Emission Spectroscopy (OES) (JYFL, INFN), RF coupling with plasma combined with simulations (INFN), plasma instabilities (JYFL) and many more. Beam diagnostics are also required for measuring the beam characteristics, e.g. 4D beam transverse emittance (UMCG-PARTREC, LPSC). Also, GSI developed a first OES diagnostic applied to monitoring a metal beam production (^{48}Ca). This rich background of unique expertise and experience in this field forms a strong basis for further developments in ERIBS.

Common expertise and collaborations:
Many European accelerator institutes and facilities are nowadays equipped with ECR ion sources to provide highly charged heavy ion beams for the accelerator community. Expertise to manage and operate the systems and sub-systems of an ECR ion source is shared over decades between collaborators within an active network. Through the European network activities many aspects of this expertise were shared among laboratories. For example, in the last ENSAR2 MIDAS-NA this exchange included such topics as: oven techniques, multiple frequency heating, plasma probing and diagnostics, charge breeding and beamline design. These interactions have become a place for hatching and developing new innovative ideas and solving commonly shared problems as specialists of each field came together to discuss.

Synergies with other research/technical groups:
- Know-how transfer between ERIBS and the project developing ion sources and targets for ISOL facilities, especially their subtask “Development of Ta target container/ovens”. (Beams + targets, “Development towards high intensity ion sources and more reliable and release efficient targets”, Coordinator T. Stora (CERN)).
- Synergy with the Newgain project for SPIRAL2 new injector funded by the ANR French Agency. There is a strong need to develop and use large capacity, reliable and high temperature ovens for ECRIS. Possibility to use the developed ovens to produce target coatings with metals.
- Synergy between other groups (accelerator and control groups) in developing machine learning and self-adaptive tuning.

Synergies with other communities:
- PANDORA facility (Plasmas for Astrophysics, Nuclear Decay Observation and Radiation for Archaeometry) can be used as a test-bench for plasma diagnostics (New Physics Cases, see the proposal IRIDES - Interdisciplinary Research Infrastructure for nuclear Decays Experiments in plasma Sources, Coordinator D. Mascali, INFN).
- Development of services as described in this abstract will benefit the EURO-LABS community but it can benefit also a broader community of users and research groups, both in fundamental and applied research. Likewise, information exchange with other proposals (e.g. HIgh POwer TargEt Systems) will give directions to studies proposed in that abstract.

Main category of your contribution:
Beams + targets (Improvements in techniques and varieties, machine learning).
Preliminary Budget Estimation: 690 000 €

Cryogenic targets

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General description:
Direct reactions provide a unique opportunity to investigate the single-particle structure far from stability.
The availability of radioactive beams re-accelerated at energies around 10 MeV/u at facilities like ISOLDE or SPES or Spiral1 & 2, points outs the issue of light a-priori gaseous targets (^{1,2}H, ^{3,4}He) to perform transfer reactions in inverse kinematics. The weak intensities of exotic beams (10^{4-6} pps) calls for target with a density $> 10^{20}$ at/cm^2 to have sufficient statistics for coincident particle-γ-ray spectroscopy. This implies the need for targets at cryogenics temperatures, in either gaseous or liquid/semi-solid state.

Challenges:
The first challenge is to design a target of ^{3,4}He having a thickness around 10^{20-21} at/cm^2 allowing for the largest possible angles for the outgoing particles both in the forward and backward directions to fully exploit 4π Si arrays like GRIT. The target body should by as light as possible in order not to lose γ-ray efficiency or induce a large Compton scattering.
The second challenge is the integration of the semisolid ^{1,2}H target CHyEMENE with that AGATA-GRIT array at LNL. The challenges span from the mechanical compatibility issue to the vacuum degradation occurring in the reaction chamber and the ensuing problems for ancillary detectors as well as coupling to the beam line.

Original aspects: Use of a cryogenic source like a Pulse Tube or Gifford-McMahon device to cool down the target. Possibility of turning the target around its axis on at 45 degree to measure the Rutherford scattering at 90 degrees in inverse kinematics.

Synergies with other research/technical groups: Reaction group and engineers at at IJCLab Orsay

Synergies with other communities: Gamma-ray spectroscopy, reaction study communities

Main category of your contribution: Beams+targets

Connections with other categories: Analysis+simulations, new physics cases

Targets for nuclear Physics

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Targets for Nuclear Physics

Version: March 5th 2021

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We propose within this contribution some ideas for the development of targets for nuclear physics and their associated systems.

Irradiation targets and thin (or thick) foils in general (used as strippers, converters or material for nuclear reactions) are essential ingredients for accelerators and nuclear experiments either in fundamental physics or for applications (radioisotopes, nuclear data…).

Each physics case constraints the required characteristics of the target (thickness, homogeneity, geometry, chemical purity, isotopic enrichment, quantity…). Regarding the fabrication process of targets, it can differ from one material to another one because of its intrinsic physical properties (melting point, toxicity, stability under air, elasticity, conductivity, activity, chemical form, potential reaction with other material …). The fabrication process has then to be chosen according to these specifications; but as well, it should be highly efficient for rare material.

Hence the availability of high quality targets implies target laboratories **equipped with a comprehensive set of instrumentation** for fabrication (evaporators (resistant heating, electron or ion guns …), rolling, press, electrodeposition cells, glove boxes, exhaust hood …) and operated by **qualified persons** offering multidisciplinary know-how, essential and advanced skills (in chemistry, radio chemistry, metallurgy, crystallography, vacuum technology) and personal qualities (patience, dexterity ...).
In addition, before delivery, targets have to be characterized in order to select a set corresponding to the request from the experiments. In addition, the available methods are various and more or less complex depending on the parameter to be qualified.

For future experiments, required targets will be more specific, challenging and requested in larger amount.
As shown in the picture below, in Europe and worldwide, the community of nuclear target makers is restricted, the number of laboratories is not so large and none of them covers all the techniques.

Moreover, up to now, these fragile and precious objects are mainly in solid form but exposed to ever-higher intensities and the need for heaviest, high-Z projectile nuclei impinging on them, their integrity and lifetime can become a major concern. The investigation of the limitations of present

material, of alternative methods of fabrication and of gaseous or liquid targets technologies have to be carried out jointly.
These considerations are complementary to the development of high-power targets stations, which are designed based on challenging simulations and taking into account the feedback of existing systems. These stations consist of various sophisticated instrumentation often exposed to very constraining conditions, such as motorization under high vacuum, large wheels at high velocity, systems of control under high irradiation dose….. *(to be detailed for the call)*

As the community is spread over Europe and internationally, with a certain level of specialization at each accelerator research infrastructure, mutual exchange of know-how is mandatory in order to foster successful research and development, and to guarantee high-quality production capabilities at all sites. The Trans National Access (TNA) program will make this exchange possible and efficient by supporting shorter and longer periods of personal visits for training, education, mutual know-how exchange, and development of methods and instrumentation, and facilitating access to all RIs with active groups working on target technology throughout Europe. The wide variety of different beams, in terms of energy, intensity, ion species and availability, provided by the different facilities are essential to develop new production methods and test performance, quality and stability of the various types of targets under conditions optimized for a wide range of applications.

Figure 1: European Map of nuclear targets' laboratories

N.B.: Techniques, constraints, parameters and list of laboratories that could be interested in this proposal will be detailed later.

Challenges:

Original aspects:

Unique expertises: Targets fabrication and characterization & targets' systems development (station, instrument of control…)

Common expertises and collaborations:

Synergies with other research/technical groups: *This contribution is in relation with some proposals on "target ion-sources systems" for which some common expertise is required.*

Synergies with other communities:

These propositions would help to reinforce the work done by the International Nuclear Target Development Society (INTDS), which encourages the sharing of techniques and knowledge (mainly on target fabrication and characterization) through conferences, and training of newcomers.

Main category of your contribution: Beams + Targets

Connections with other categories: Training, Education

Laser-driven beams for future clinical applications at LNS-INFN

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The radiation oncology community is incessantly exploring new chances to increase the radiotherapy efficacy raising the normal tissues sparing probability. Technological developments and innovations in radiation treatment delivery and patient imaging allow for more accurate tumour targeting whilst minimizing the damage to the surrounding healthy tissues.
In the last decades, ion acceleration from laser-plasma interaction has become a popular topic for multidisciplinary applications and opened new scenarios in the protontherapy framework, representing a possible future alternative to classic acceleration schema. The high-intensity dose rate regime that can be obtained with this approach is also strongly attracting the radiation oncologist community thanks to the evident reduction of the normal tissue complication probability. Recent in vivo studies have shown that ultra-high dose-rate irradiations, known as FLASH radiotherapy, based on delivery of therapeutic doses at dose-rates (over four orders of magnitude higher than those currently used in conventional radiotherapy) leads to a remarkable reduction of normal tissue toxicity with respect to conventional dose-rate radiotherapy. One of the challenges that need to be addressed prior to the translation of FLASH studies into the clinical stage is the development of a simple and compact accelerator machine able to accelerate photons and charged particles (protons, ions and electrons). At the LNS-INFN was already funded the installation of a high-intensity power laser to accelerate several particle species. We therefore request the funds to investigate the possibility to use the laser for future clinical applications. The upgrading of the LNS-INFN infrastructure will include a dosimetric and diagnostic system for extremely high dose-rate beams also.

Target characterization using Rutherford Backscattering Spectrometry

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Target characterization using Rutherford Backscattering Spectrometry

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We propose to use Rutherford Backscattering Spectrometry (RBS) to characterize the targets used in nuclear physics experiments. The method can be implemented and applied as a service for the experiments proposed at the accelerators operated by IFIN-HH but also for the other facilities from the current proposal and collaboration.

RBS is a well-known characterization method which uses accelerated ion beams in the MeV range in order to obtain accurate depth information (accuracies of a few percent, with 10-30 nm in depth resolution) related to the quantification of thickness in terms of elemental area density, stoichiometry of various samples and impurity distributions [1]. This method is sensitive to the near surface region of bulk materials and thin films. Depending on the sample type thicknesses from 1 nm up to 1-2 μm can be profiled using an alpha beam while for thicker samples protons can be used to probe various samples. It is worth to mention that prior to any sample measuring it is recommended that simulations should be performed in order to check the possibility to obtain reliable and accurate information regarding the samples. The method is very sensitive to high Z elements, light elements profiling is a more difficult task but can be approached using the non-RBS mode where specific energies are used in order to enhance the cross-section corresponding to the light elements that one wants to profile. For example an ideal sample, from the RBS point of view, would be a very thin layer of gold (2-3 nm) deposited on graphite (or glassy carbon) substrate. Besides measuring thin films self-supported targets can be measured, for instance thin layers of Zr, Mo, Ru, etc. deposited on various foils (Ta, Au, etc.) with various thicknesses (1-2 μm or even more). Please note that for instance the roughness of the samples is influencing the RBS measurements. We also need to mention that in terms of target characterization using the RBS method not everything can be measured with this method and, as stated before, the measurements simulations should be performed to check their feasibility. There are also some requirements in terms of sample dimensions. Our target holder is a metallic disc with a diameter of 40 mm. Samples to be measured should be smaller than this value. Minimum dimensions for samples would be: 5 mm x 5 mm. The target holder is presented in ref. [2]. Samples should be vacuum compatible.

Below we present one example for some targets that were measured in our laboratory using RBS. For some experiments there were necessary Os targets [5]. They were deposited as thin or thick films on an Al foil. Their thicknesses were an important parameter and for this reason RBS was used. Some depositions were very thin and others were expected to be in the μm range. For this reason we have used an alpha beam to characterize the thinner samples and a proton beam for the thicker ones. Thickness and stoichiometry of the thin films were determined by means of RBS using 3 MeV He ions from a 3 MV Tandetron™ accelerator available at the "Horia Hulubei" National Institute for Physics and Nuclear Engineering—IFIN-HH [2]. The measurements were performed using a back scattering angle of 165°. Backscattered α particles were registered with an AMETEK type BU-012-050-100 charged particle detector, having a solid angular acceptance of 1.641 msr, connected to a standard spectrometric chain and acquisition system. The typical energy resolution of the spectrometer was 18 keV. The RBS spectra were simulated using the SIMNRA software package [3]. Areal density or thin film units (10^{15} atoms/cm^2) are the natural units for ion beam analysis (IBA) since the energy loss is measured in eV/(atoms/cm^2), and one monolayer is of the order of 10^{15} atoms/cm^2 [4]. In Fig. 1 we present the RBS spectrum for the Os/Al thick deposition.

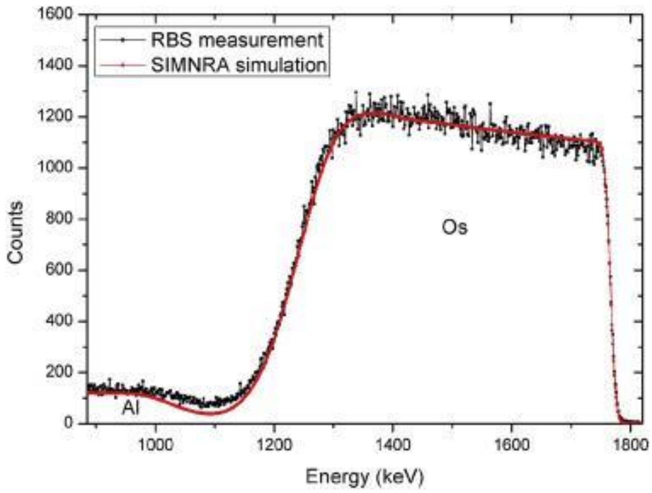

Fig. 1. RBS spectrum of Os/Al thick deposition measured with an 1.8 MeV proton beam.

The results were the following: the simulations fit with 0.705×10^{18} atoms/cm^2 for Os/Al for the thin depositions and 16×10^{18} atoms/cm^2 for Os/Al for the thick depositions. It corresponds to 0.22 mg/cm^2 and 5.05 mg/cm^2 respectively or to 98.6 and 2240 nm considering a bulk density of Os of 22.57 g/cm^3. The uncertainty in RBS data analysis is about 5%.

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Title: High precision MeV single ion Irradiation

Valentino Rigato (INFN-Laboratori Nazionali di Legnaro)

Exploitation of ultraprecise single ion implantation/irradiation is the basis of a next generation of advanced materials and micro/nano-devices. The precise positional control of energetic single ions (keV, MeV or even GeV) at micrometric, nanometric or even atomic scale offers a wide range of emerging applications in fields as diverse as quantum technology, novel detectors, single photon sources and detectors, biomedicine and materials science. This e.g. includes investigating single ion irradiated novel topological materials (2D materials and nano-wires), biological cells or nano-assembling qubits in ultrapure solid-state crystal by deterministic single ion implantation.

Europe has a broad diversity of ion beam centres with manifold research interests and complementary technological features which condition the available ions and the accessible energy range. The accelerators at the National Laboratories of Legnaro (LNL) are recognized as user oriented research facilities comprising several MeV ion accelerators devoted to multi-disciplinary research and in particular to single ion irradiation.

In order to achieve significant scientific and technological advances, it is mandatory to develop an efficient networking between centres, laboratories and universities to promote cross-fertilisation between the different research themes and communities and building or improving the future European single ion implantation/irradiation facilities.

The aim of this project is twofold: a) improve the precision of MeV single ion implantation with existing facilities, b) share knowledge and facilities for applications, research and technology of single ion implantation/irradiation.

To this purpose, we have identified a program including hardware improvements and networking activities with an open, proactive and inclusive approach to other research partners. This program will make use of the LNL MeV accelerators, especially the AN2000 accelerator equipped with a precision targeting single ion irradiation system. We encourage the involvement of inclusive target countries and young researchers. The resources and skills necessary for the development of this emergent area will be optimized allowing achieving a European leadership position.

Challenges and original aspects. Today, recent advances in ion beam technology have enabled the control of the ion fluence down to the single ion precision on sub-micrometer to nano-meter regions. This great, globally present achievement has been accomplished by few laboratories in Europe. Importantly, such a high precision technology enables unprecedented single ion studies as well as processing, so it actually has the potential to truly impact fields as diverse and important as quantum technologies, materials science and biomedicine.

Ion implantation is an industrial standard technique for doping semiconductors that enables modern processors used in all electronic devices, from computers to mobile phones. Yet, the continuous downsizing of electronic devices requires increasingly higher accuracy in doping techniques. Both the number and position of the incorporated dopant atoms must be precisely controlled and ultimately single ion implantation would be needed. In parallel, such a deterministic implantation of impurities in materials also requires a new understanding of the ion-solid-interaction processes to be generated.

This proposal addresses the following challenges in MeV single ion irradiation: **1) enhance control on position of radiation delivery, 2) promote single ion applications in quantum technologies, 3) develop advanced topological materials 4) process and test space environment materials and instrumentation 5) test new 2D/3D high resolution semiconductor detectors and 6) training young reserchers with particular attention to promoting a quantum-ready workforce**.

Unique expertises. Existing expertise is based on long lasting single ion and ion microprobe experience and on a newly developed achromatic system based on highly engineered micro-collimators for single MeV light ions precision targeting.

Common expertises and collaborations. Microprobe, ion beam analysis, ion implantation, single ion handling and detection, radiation damage, materials processing users groups.

Synergies with other research/technical groups. Ion beam microanalysis and processing groups, collaboration with quantum technology and topological materials groups. Novel 2D/3D detectors for nuclear physics and high energy particles physics experiments.

Synergies with other communities. Quantum technology, single photon sources and novel semiconductor 2D/3D detectors.

Main category of contribution: Beams + Targets

Connections with other categories: Improved access, Training

Title: Machine learning and AI for RIB facilities

Authors and affiliations: S.Rothe, E.Piselli (CERN)

General description (methodology, goals,..):

RIB facilities are multi-parameter systems that require tuning and optimization to provide best experimental conditions for its USERS.
To date, the majority of the tuning is performed manually by machine supervisors.

There are many different aspects of the matching with different parameter sets, which may also be operated by different teams involved

- Target conditions
- Ion source parameters (including laser ion source which has >12 parameters alone)
- Mass separation
- Beam delivery to experiments

It is assumed that all the parameters are already computer controlled.
A machine learning tool has been developed (https://cds.cern.ch/record/2305963?ln=en) that can maximize the signal depending on a large (5+) parameter space (via the nelder mead algorithm). This tool is currently further developed internally to be used at ISOLDE (again, where it was originally proposed).
In parallel at CERN, an interface tool is being developed that can on one side connect to different machine learning and artificial intelligence algorithms and can on the other side interact with CERN's machine elements.

Here we propose to develop the tool further to meet requirements for ISOLDE users. This includes provision of a bidirectional interface to parameters of the USER beamlines which are otherwise inaccessible to the CERN control system such that a global optimization can be performed. For example: The algorithm can act on a focusing element in the beamline (ISOLDE) on deflector plates (part of the USER's experiment) and can read the signal from a counter (part of the USER's experiment)

These algorithms could be guided to some extent by physical models of the beam lines and the ion source which may also be included at some stage.

The next step of this development could be the definition of a common interface between different facilities, such that the code for the optimization tool can be used across facilities. Again the code should be shared via a gitlab repository.

Challenges:

Combining the available tools using interfaces for USERS at ISOLDE and other facilities.
Number of different control paradigms might be too high.
Different facilities might not allow use of specific software to control their beam parameters.
Development and testing time is needed -> with a common interface, the algorithms can be fine-tuned at the different facilities

Original aspects:

Combine AI with ion source and beam tuning through an interface which allows swapping algorithms and ML approaches.

Unique expertises:

ISOLDE has successfully developed tools to optimize beam tuning (Nelder Mead)
CERN is working on a tool that can interface ML algorithms to its infrastructure.

Common expertises and collaborations:

Proposed collaboration with SCK (pending)

Synergies with other research/technical groups:

At CERN ML and AI is looked at seriously
ML tools developed can be interesting for USERS as well. Example fine tuning electrostatic mirrors of an MR-ToF device.
Phasing of RF cavities (https://cds.cern.ch/record/2693005?ln=en)

Synergies with other communities:
(with reference to the categories described in the "Instructions for submission page", https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)
Main category of your contribution:
Connections with other categories:

Title: A dedicated yield station for target developments

Authors and affiliations: S.Rothe (CERN)

General description (methodology, goals,..):

Beam development is the mainly driven by the requirements of our USERS, but mainly restricted by the available beam time.
At ISOLDE we have two independent target stations which can be alternately supplied by protons, yet the main infrastructure used for beam development and target prototype testing is located in the central beam line. Which on one hand is required to be able to send beams from GPS and HRS to it, on the other hand it severely limits the available time and therefore systematic studies required for development.

a)
We hereby propose to install a yield station permanently to the GLM beam line. This will enable us to independently operate development targets on the GPS and perform systematic and long-term studies while ISOLDE delivers beam from the HRS target station to the experiments in the ISOLDE hall.
b)
The yield station shall be equipped also with single-ion counting capabilities to detect lowest beam intensities.
c)
We would also like to launch a feasibility study to implement a compact high resolution mass spectroscopy setup (e.g. MR-tof device) to the yield station which could be employed for identification of beam composition.

Challenges:

While the hardware (vacuum chamber, and tape system) of the tapestation is already available, the low-level control system (PLC + motor drivers) as well as the high level control system (integrated analysis software) required development. While the beta detectors are already available, the tape station would need to be completed with alpha and gamma spectroscopy setup and the respective data acquisition system and control software.

Original aspects:

Dedicated tapestation for target development at a unique location which generates development time whenever an HRS target is operates.
This tapestation would itsself be a development machine to test future detectors and yield measurement protocols that would be used in the operational yield station.
The complete system then will have alpha, beta, gamma detection for short-lived isotopes, can measure lowest beam intensities and time profiles and beam composition.

Unique expertises:
Fast tape station developed by CERN.
Yield measurement protocols established, (but should be validated in a collaboration.)

Common expertises and collaborations:
Collaboration with other facilities on yield assessment techniques.

Synergies with other research/technical groups:
All ISOL facilities could benefit from systematic target material studies. While beam energies 1.4GeV are unique for ISOLDE, the requirements to target materials (microstructure, chemical reactivity with Isotopes of interest, long life time at elevated temperatures) are common among ISOL facilities. Additionally new techniques in beam purification
The developed beams or improvements in terms of purity will immediately become available to the USERS of ISOLDE and many results can be translated to other ISOL facilities.

Synergies with other communities:

BELINA (beam line for nuclear astrophysics): a neutron Time of flight beam line at Laboratori Nazionali di Legnaro

Pierfrancesco Mastinu, LNL, INFN, Italy
Guido Martín-Hernández, CEADEN, Cuba
Elizabeth Mussacchio, LNL, INFN, Italy

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Description: A beam line for nuclear astrophysics (BELINA) was created and is in use at the 7-MV Van de Graaff accelerator in the Laboratori Nazionali di Legnaro (LNL). The purpose of this line is to produce kT tunable Maxwell-Boltzmann-like neutron spectra for stellar (*n,γ*) cross section measurements [1]. This setup is intended as a test bench for the high flux LENOS facility in preparation at the LNL [2]. The neutron field is produced from the ^{7}Li(p,n)^{7}Be reaction, either in CW or pulsed mode. The CW mode is used for the irradiation of the studied sample and the pulsed mode is used to measure the neutron spectrum by neutron time-of-flight.

The beam line is equipped with a variable Repetition rate in multiple of 3 MHz in Order to fit the different Needs of TOF measurements. The Lithium Target is self produced as pure natural metallic state and is foced Air cooled.

The line is equipped with Li-Glass scintillator Detectors and CAEN desktop digitizers of different Models.

The BELINA line was primary Born to measure Neutron spectra for nuclear astrophysics, but it is currently used for many other purposes and different Communities (detector tests and calibration, biomedical physics, etc…).

The goal: To measure Maxwellian-averaged (*n,γ*) cross section of isotopes of interest for astrophysics. Our current ability to measure this cross section is limited to a few isotopes due to two facts: i) the lack of a HPGe detector for good energy-resolving gamma ray spectrometry and the limit of the performance of the different parts of the variable repetition rate pulsing system.

The challenge: To boost the accelerator performances in terms of beam energy precision measurements and widening the repetition rate and beam energy available spectra.

Original aspects: A methodology to produce thermal energy-tunable Maxwell-Boltzmann-like neutron spectra and a system of variable repetition rate that allows us to select the best frequency of the pulsed beam according to the experimental requirements.

Synergies with other groups: Boosting the performances for pulsed mode will work for several research group and experiments carried on or intended at LNL. The beam line is already used for training students, both coming from high school and Universities, which are involved in the setup, data taking and subsequent data analysis. With modest amount of financial support, modules can be substituted with much higher performances allowing to give to users a wider range of beam energies and repetition rate. The HPGe can serve also a larger communities that can perform neutron activation measurements.

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Title: Targetry for nuclear and applied physics

Authors and affiliations: J. Esposito et al.

General description (methodology, goals,..):

The current proposal aims at building a European and international community with specific expertise in the field of target manufacturing and irradiation, both for nuclear and applied physics purposes. At the INFN-LNL, new experts in targets design and manufacturing are growing up, collaborating with the well-known target laboratory of the research division. The goal is to broaden the materials used and improving the thickness that can be achieved, by exploring new manufacturing techniques, and properly characterize the innovative targets to acquire a deep knowledge of the unexplored methods. In addition to basic nuclear physics measurements, that requires thin homogeneous targets (0.1-1 mg/cm^2), a possible application field is the production of radionuclides for nuclear medicine by using solid targets (thickness up to 0.1-1 mm). In both cases the use of expensive isotopically-enriched materials is often necessary, thus requiring as low as possible losses during target manufacturing. In addition to that, in case of solid targets for radionuclide production the major goal is sustain larger beam-currents, than the ones currently used, thus increasing the thermal-mechanical features of the target itself and surfaces interface with the backing material. Indeed, the target must be conceived in a way to offer the best structural resistance and heat dissipation capability in relation to target material, while ensuring manufacturing feasibility. Proper cooling systems, based upon heat sinks embedded in the backing, have thus to be properly designed to meet the required performances. For this reason, at the INFN-LNL deep expertise has been acquired in modelling the target behaviour under bombardment.

Challenges, Original aspects and Unique expertise:

Target preparation is often a crucial step for the achievements of nuclear physics experimental results. The precise knowledge of target properties, e.g. thickness in terms of areal density (At/cm^2 or mg/cm^2), homogeneity over the surface, purity either isotopically or chemically is essential for proper analysis of experimental data. The heat transfer effectiveness is not a concern since the energy deposition is very low and the beam current used are usually of the order of 1-100 nA. A set of most standard techniques for nuclear target preparation includes vacuum evaporation with e-beam and resistive source, FIB-sputtering, powders pressing, lamination, electrodeposition, different types of sedimentation, etc. These techniques are used to support the deposition of a huge number of materials with some exceptions. For the refractory metals, like Ti, Mo, W, Zr, Hf, standard target preparation techniques are often inefficient. In addition, when enriched isotopes are used for target preparation, the technique providing minimal material losses is absolutely required. In 1997 Isao Sugai has proposed the HIVIPP (High energy Vibrational Powder Plating) method providing a solution to both described problems: minimal losses and deposition of "problematic" refractory metals. In the next decade, several modifications of this technique were proposed by the same group, increasing the set of deposited materials. In the framework of E_PLATE project (2018/2019, INFN CSN5), a HIVIPP set-up was realized at Legnaro Laboratories and the parameters influencing the process have been thoroughly studied. Moreover, this technique was successfully used for the preparation of enriched ^{48}Ti targets (0.2-2 mg/cm^2). Once characterized, by weighing and RBS techniques, targets were used for nuclear cross-section measurements in the framework of the PASTA project (2017-2018, INFN CSN5). For the new project REMIX (2021-2024, INFN CSN5) several ^{49}Ti and ^{50}Ti targets are planned to be prepared and characterized. Again, IBA analysis technique will be adopted for the exact quantification of Ti deposited amount (At/cm^2), thickness uniformity and oxidation level, crucial data for nuclear cross-section analysis.

As for nuclear physics experiments, the aspects dealing with design and manufacturing of a tailored solid target for radionuclide production is of crucial importance because from it depends the quantity and the quality of the final product, and it is considered one of the most critical technological challenges to be overcome in cyclotron-based radionuclides production. Indeed, a cyclotron solid target must meet several strict requirements, which may be summarized as follows:

- uniform and optimized layer thickness, able to exploit the favourable beam energy range of the nuclear reaction route concerned, while limiting the yield of isotopic contaminants

• high chemical purity level

• high heat transfer effectiveness, to quickly remove the heat power deposited inside the target during the irradiation, considering that it depends on the beam current intensity as well as the equivalent accelerating voltage

• good mechanical properties, to allow for easy mounting/dismounting operations

• suitable chemical composition, allowing for a feasible post-irradiation dissolution step.

Unfortunately, not always the standard manufacturing techniques already available and used in this field (e.g. electrodeposition, evaporation, electrophoretic, conventional sintering and brazing, lamination, and laser melting) meet the aforementioned requirements. Moreover, to achieve an acceptable radionuclidic purity level for the final product, the starting target materials are often supplied under an isotope-enriched form, being therefore very expensive. It is thus necessary to get, as low as possible, material losses during the target manufacturing process. The choice about the most appropriate manufacturing technique will then mainly rely on the starting material properties and form available on the market.
In recent years, the LARAMED research group at INFN-LNL has put an intense effort to probe some non-standard techniques. Among them, the Spark Plasma Sintering (SPS) has started to be explored, due to its promising features. It is noteworthy to highlight that this technique allows to obtain high quality sintered objects (both metallic and oxide type), starting from the material under powder form. In addition, SPS may ensure the bonding of different materials (i.e. the sintered pellet to a backing plate) thus avoiding the use of brazing fillers in between. The advantage of the minimal losses of the starting material during the SPS process makes this technique quite feasible from the economic point of view, mainly when highly-enriched isotope materials are involved.
Concurrently to these research activities, the LARAMED group has also started to investigate the possibility to implement inside the target body, complex-shaped heat sinks configurations, made by additive manufacturing. Through extensive experimental campaigns with dedicated apparatus developed at INFN-LNL, it has been demonstrated the potential of this technology to further increase the heat dissipation performances. This, coupled with the possibility to simulate complex geometries with the aid of cloud computing, allows the group to provide effective target cooling solutions in small time.

Common expertise and collaborations:

In addition to the LNL experts in target manufacturing and characterization, a collaboration with Pavia INFN-Department for the SPS technique, with the ARRONAX facility (Nantes, France) for the nuclear cross section measurements, with the department of Industrial Engineering of the Padova University for target characterization is ongoing.

Synergies with other research/technical groups:

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Synergies with other communities:

Synergy with the Sacro Cuore Don Calabria hospital, for the development of solid targets suitable for radionuclides production (e.g. agreement for the manufacturing of Y targets for ^{89}Zr production).

(with reference to the categories described in the "Instructions for submission page", https://agenda.infn.it/event/25373/page/5621-instructions-for-submission) Main category of your contribution:

Beams + Targets

Connections with other categories:

Training, Education, Outreach, Social Impact

Title: Advanced Gas-filled Stopping Cells for Exotic Nuclei

Authors and affiliations:

W.R. Plaß (GSI Darmstadt, Germany; Justus Liebig University Gießen, Germany)
T. Dickel (GSI Darmstadt, Germany; Justus Liebig University Gießen, Germany)
D. L. Balabanski (ELI-NP, IFIN-HH, Magurele, Romania)
P. Constantin (ELI-NP, IFIN-HH, Magurele, Romania)
I. Mardor (Soreq Nuclear Research Center, Yavne, Israel)
I. D. Moore (University of Jyväskylä, Finland)

General description (methodology, goals, …):

The use of gas cells to stop and thermalize exotic nuclei produced in-flight or by reactions in a target in the gas cell is becoming an important technique for the production and preparation of cooled exotic nuclei. It has its origin in the IGISOL technique and is now being implemented or already being employed at many accelerator laboratories in Europe and worldwide. Recent technical developments have improved the method, but still today it is only applicable to some of the productions processes, and the efficiency, speed and rate capability of the stopping, thermalization and extraction process and thus the range of accessible nuclides and their yield is limited.

The goal of this action is to significantly increase the performance of gas cell techniques and thus to remove the performance bottleneck of present devices. Gas cells for both the in-flight production and the IGISOL method will be addressed. It will help boost the efficiency of the stopping process, increase the ion survival and ion transport efficiency as well as the speed of ion transport in the gas cell and the rate capability, enable the coupling of further production techniques (photo-fission, neutron-induced fission and multi-nucleon transfer (MNT) and enable efficient removal of contaminants. At the IGISOL facilities at ELI-NP and Jyväskylä, at SARAF-II, at the FRS Ion Catcher at GSI and at the Low-Energy Branch (LEB) of the Super-FRS at FAIR it will thus help to make new exotic nuclides available, which cannot be produced presently, and increase the intensity of low-energy beams of exotic nuclei.

The enhanced capabilities and universal nature of the improved gas cell techniques will make it a method of choice for broad systematic investigations of nuclear properties, needed to extend our basic knowledge towards the limits of nuclear existence, and provide crucial input for nucleosynthesis and neutron star research. It will further generate data needed for important applications, such as nuclear waste transmutation, which will strongly profit from the implementation of neutron-induced fission at LEB facilities.

Challenges:

Basic physical and technological limitations make it very difficult to thermalize beams of exotic nuclei and to couple new productions techniques (photo-fission, neutron-induced fission and MNT) with high efficiency and with fast extraction and high purity, in particular from high-intensity, large-emittance beams.

Original aspects:

Novel approaches for gas-filled stopping cells will be implemented, such as high-density, orthogonal extraction cryogenic stopping cells (HADO-CSC), small-structure size RF carpets, charge state manipulation of thermalized ions for efficient extraction.

Unique expertises:
The authors have long (20+ years) experience with gas-stopping techniques and have developed novel approaches to perform thermalization of exotic nuclei.

Common expertises and collaborations:
Collaboration between ELI-NP, GSI, Justus Liebig University Gießen, University of Jyväskylä, Soreq NRC

Synergies with other research/technical groups:
All experiments employing low-energy beams of exotic nuclei, such as mass measurements, laser spectroscopy, mass-selected decay spectroscopy, will greatly profit from this action.

Synergies with other communities:
Applications for nuclear waste management, reactor safety, etc.

(with reference to the categories described in the "Instructions for submission page", https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Main category of your contribution:
Beams + Targets

Connections with other categories:
Possibly: Detectors + Electronics, New physics cases

Title: Artificial Intelligence and Machine learning for accelerator control

Rahul Singh, Sabrina Appel

GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

General description: The Facility for Antiproton and Ion Research (FAIR) is a unique accelerator complex which provides high-energy and high-intensity primary and secondary beams of antiprotons and ions. Big Data, High Data Rates, High-Power are common challenges of RIs including FAIR. We propose to use artificial intelligence for accelerator control and design, beam diagnostics and instrumentation and data reduction, exploring applications of machine learning, deep learning and advanced optimization algorithms. For the beam diagnostics and instrumentation we plan to develop ML predictive algorithms with the capability of removal of distortions, pile-up mitigation, reconstruction of ionization profiles etc. For the Accelerator control, machine optimization and automation are planned, as well as development of ML predictive algorithms with the capacity to diagnose and protect high-power accelerator.

Challenges: Implement algorithms and verify performance under the realistic conditions of the FAIR facility.

Original aspects: Optimization of a new pile-up detection and mitigation for particle counters to increase rate capabilities. Data reduction, including archiving and accelerator fault prediction, data assimilation from accelerator components (e.g. magnets, cavities). Interdisciplinary research with detector technologies (e.g. position sensitivity and event characterisation in scintillators or other existing technologies).

Unique expertises: The FAIR team will provide the accelerator and beam instrumentation systems, based on their long-term expertise on programming and system implementation.

Common expertises and collaborations: the proposal is planned in collaboration with CEA Saclay and CERN

Synergies with other research/technical groups: the activity is strongly related to the problem of Big-Data, IT, and applications of nature-inspired optimization algorithms and machine learning for heavy-ion synchroton

Synergies with other communities: The AI activities are embedded in the Accelerator department that has submitted an abstract for EURO-LABS

Main category of your contribution: Beam diagnostics and instrumentation, Accelerator Controls, Beam line optimization, Data Acquisition + Analysis, Simulations.

Connections with other categories:

Beams + Targets

Detectors + Electronics

RIB-AT: exploiting the Active Target Technology at RIB facilities

Authors and affiliations:
GANIL : T. Roger
CEA: M. Vandebrouck
CNRS/IJCLab: Y. Blumenfeld
CENBG: J. Giovinazzo
USC/IGFAE: B. Fernández-Domínguez
UHU-CEAFMC: A. M. Sanchez Benitez.
KU Leuven: R. Raabe
INFN: T. Marchi
Non-EU partners (I would add everyone, at least at this level. Then we'll see what the call will allow to do)
U. Regina: G. Grinyer
RIKEN: D. Suzuki

Others partners welcome to join

General description:

The Active Target technology for low energy nuclear physics has been widely improved in the last decade. The main drivers of the most recent developments have been the ACTAR TPC project at GANIL and the SpecMAT project at KU Leuven. Those detectors have been designed, built and characterized with particular emphasis on their use with low-intensity exotic beams produced at facilities like SPIRAL2 at GANIL, HIE-ISOLDE at CERN and SPES at LNL.
The devices are complex and versatile but the experience gained showed that the feasibility of any experiment proposal needs to be carefully evaluated. Degrees of freedom that are normally independent like target species and thickness vs detector dynamic range and sensitivity, become strongly correlated and require experiment by experiment feasibility evaluation.
On the hardware-side, the technology has now reached a high level of readiness but its exploitation needs: the aforementioned specific development/adaptation of the setup to the different experimental requests, local management of complex situations involving safety and regulation fulfilment (e.g. in the use of explosive gases like H2 or D2), training of new generation of users.
On the software-side, a lot still needs to be done for developing complex tracking algorithms and a common framework for both **analysis and simulation** to provide to the users a tool for designing the experiment prior to proposal's submission and post experiment first-step analysis tools.

We propose, therefore, to create a group of trans-laboratory experts capable of fulfilling the hardware and software needs of the experimental setups as well as training new generation of users and detector specialists.

Unique expertise:

Development and use of Active Target Detectors

Main category of your contribution:

Improved Access

Title: Developments for medical isotope production using accelerators

Authors and affiliations: A. Cadiou (Subatech), G.deFrance (GANIL), A. Guertin (Subatech), F. Haddad (GIP Arronax and Subatech), A. Ouadi (IPHC)

General description (methodology, goals,..) :

Most of proton rich radionuclides used in nuclear medicine are produced using accelerators. After selection of the best production route, a light ion (p, d, helium, lithium,…) beam is accelerated and sent to the target where nuclear reactions are taking place. After irradiation, the target is recovered from the irradiation vault and send for processing (mostly wet chemistry) in order to extract and purify at the proper level the radionuclide of interest.

Targets can have different sizes and chemical forms. People are using liquid targets (F18 production), solid targets, gas targets and liquid metal targets. The main goal is to increase the intensity on target in order to produce more efficiently.

Sometimes, it is necessary to develop a beam energy degrader to optimize the production and the use of target material that are often enriched. A good control of the beam characteristics after the beam energy degrader is of great importance to control the level of contaminant.

The goal of this project is to develop tools (diagnostics, targetry and beam energy degraders) for isotope production at high intensity

Challenges:

Increasing beam on target is not an easy task, as it requires both a good beam monitoring at high intensity and a target design accounting all thermal constrains and possibility chemical processing for radionuclide recovery.

Original aspects:

Nuclear physics laboratories have all technical expertise to tackle this kind of problems
Thermal conditions on target are very stringent (up to 15kW on a 2cm diameter spot). The same holds for beam energy degraders.
High intensity beam loss monitors and beam positioning monitors need to be developed
Can help prepare next generation neutron sources

Unique expertise:

Liquid and solid target design have been developed within the GDR MI2B at GANIL, IPHC, Subatech and GIP Arronax
Several target designs are in routine use at high intensity for protons, deuterons and alpha beams

Common expertise and collaborations:

Collaborations between laboratories of the GDR are active
Collaborations exists with INFN and CERN

Synergies with other communities:

Title

Advanced RF and cryogenics control and fault detection for superconducting accelerators exploiting machine learning algorithms

Authors and affiliations

PE Bernaudin [1,2] ; J. Branlard [3] ; B Bonnay [4] ; P Duthil [4] ; A. Eichler [3] ; A Ghribi [1,4] ; M Di Giacomo [1,2] ; C Haquin [1,2] ; F Millet [2] ; JP Thermeau [4]

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[4] *Centre National de la Recherche Scientifique* (CNRS)

General description

Superconducting accelerators such as ISOLDE, PIAVE, FAIR, ESS, MYRRHA, SPIRAL2, FLASH or European XFEL face specific challenges ranging from high dynamics of thermal loads, drastic level and pressure control of superconducting cavities, long distribution lines, vacuum pressure degradation, field emissions, cavities quenches and detuning among other ponderomotive effects. All these effects are completely different and might seem uncorrelated at first sight but they can all be linked either to the process-control or to one or several related sub-systems by some elaborated relations. Moreover, these correlations may depend on the beam parameters. When tackling these challenges from the Machine Learning and Artificial Intelligence perspective, the usual approach uses a model of the accelerator that relies on particle tracking codes. While this is a promising approach, it suffers from a high complexity and requires important computing resources. In this project, we propose a different yet complementary approach. It relies on utilities and sub-system level modelling, control and diagnostics. Two main sub-systems are considered: Cryogenics and Radio-Frequency. Cryogenics for superconducting accelerators has been, for some time now, mistakenly considered as a simple process utility. Yet this sub-system proved to be more complex than imagined with control parameters that heavily depend on the RF system control and, to a lower extent, on the beam configuration. Model-based control allowed to optimize the cryogenic operation of SPIRAL2 while opening a new gateway into Machine Learning approaches for dynamic operation and intelligent fault detection through virtual sensors [1]. However, RF and cryogenics are heavily interlaced and the models need to be completed with their RF counterpart. At European XFEL, it has been shown that combining model-based with data-based machine-learning approaches can be exploited for robust and efficient fault detection [2,3]. The resulting algorithms applied to RF signals can cope with the challenging real-time requirements and are highly modular, so that they can be extended including information from further subsystems such as cryogenics. This could become a necessity considering the continuous wave operation upgrade of the European XFEL [4].

From these two examples, it becomes clear that a combined approach making use of cryogenic and RF signals can yield promising results. This work has been initiated for MYRRHA [5]. We propose to continue this effort in the frame of SPIRAL2 and the European XFEL, which offers real life accelerator validation of developed models. The fault detection framework such as the one under development at European XFEL can be further developed for on-line operation, and extended to fault classification (allowing for adequate counter measures) using time series classification techniques.

The second essential part, which determines if such approaches of optimized control and fault detection can be applied both online and offline, is the availability and the quality of the data. In this part, we propose to develop and deploy a data pre-processing pipeline matched to the use of classification learner algorithms such as decision trees, support vector machine (SVM), logistic regression and nearest neighbors. Offline physics-informed supervised learning is also considered for hyper parameter tuning with the use of GPU facilities at the CNRS calculation platform CCIN2P3 Lyon.

The benefits of the proposed developments are many. They span from increasing beam availability and accelerator reliability to cost saving thanks to predictive maintenance and monitoring slow performances deviations such as degradation of cavity quality factors.

Challenges

Several challenges arise in this project. The first is the possibility to use multi-physics modelling to generate models that are simple enough to be integrated in Multiplatform C and python libraries for extensive use in control, optimization and features extraction algorithms. A compromise is therefore to be found here. The second challenge is to adapt existing distributed acquisition system to a single data pre-processing pipeline, using for example clock synchronization and adaptive sampling. In some cases, data from different subsystems is being hosted in two separate control systems. Building bridges across these systems is a necessary step towards combined data usage.

Original aspects

The project considers RF and Cryogenics from a different perspective for optimized control and fault detection. It also uses machine learning, data handling and analysis techniques for fields that remained decoupled for too long. We are also fully aware that this kind of development is still in its infancy in the accelerator community and that open data and open libraries will play a major role in having reliable tools widely used in the community.

Expertise

A joint R&D program between GANIL and CEA has led to the development of a thermodynamic model of the SPIRAL2 LINAC fully applicable to other superconducting accelerators [6]. The resulting models are light enough to be used in the main control systems yet precise enough to significantly optimize the cryogenic control with respect to alternative approaches. On the other hand, other R&D programs using similar modelling approaches allowed to model superconducting cryomodules from the RF side [7]. In the frame of the SPIRAL2 project, several control and data acquisition systems based on FPGA[1] and EPICS[2] have been developed. The participating groups also have extensive experience in designing, deploying and operating cryogenics and RF systems for accelerators. All this expertise is within the collaboration and allows us to set the ground for machine learning type approaches for accelerators cryogenics and RF.

Synergies with other research/technical groups

- Artificial intelligence for Accelerators and Ion Beam Transport/ Machine Learning techniques for predictive maintenance.
- Theory-experiment interconnections in studies of nuclear moments conducted at European facilities.
- Machine learning and AI for RIB facilities
- ERIBS: European Research Infrastructure – Beam Services
- Artificial intelligence for superconducting and RF control of free electron lasers

Synergies with other communities

Data analysis, main control systems, Radiofrequency, Cryogenics, Beam dynamics, Beam diagnostics, Vacuum.

Main category of contribution

Beams + Targets

Connection with other categories

Data acquisition + Analysis

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[1] Field Programmable Gate Array
[2] Experimental Physics and Industrial Control System

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Data Acquisition + Analysis, Simulations

Laser controls, operation and monitoring

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Laser controls, operation and monitoring

By Thomas Elias COCOLIOS (KU Leuven)

General description

Pulsed lasers as well as continuous wave lasers have become an integral part of our infrastructures and experimental facilities, for either the selective and efficient production of radioisotopes (e.g. RILIS) or for the study of ground-state properties (COALA, COLLAPS, CRIS, …). The laser systems required to maintain the high standards of operation for the state-of-the-art infrastructures and experiments have become more and more complex, and the demand on those systems in terms of stability and reliability have equally increased.

Meanwhile, the laser sub-community from our wider community remains somewhat fragmented and many groups face the same technical issues. There are clear benefits in further collaborations or synergies that can be provided within a general framework such as EURO-LAB. A specific example in which collaboration among groups has been successful, is the necessary understanding of systematic effects from wavelength meters used in both laser spectroscopy experiments as well as for RILIS activities. The impact of these effects on the accuracy of laser spectroscopy data led to the recent publication of two articles within the ENSAR2 RESIST Joint Research Activity: *On the performance of wavelength meters: Part 1* by M. Verlinde et al, Applied Physics B **126** (2020) 85 and *Part 2* by K. König et al, Applied Physics B **126** (2020) 86. This work involved research teams from COALA (Darmstadt), CRIS (CERN), IGLIS (KU Leuven), LARISSA (Mainz) and IGISOL (Jyvaskyla). This exception highlights the benefit of cross-community support however is by no means representative of the standard practice in laser-related research.

It would be beneficial to the entire laser sub-community to have a control systems (CS) framework from which they may build up a common approach, as has been done for many years in the ion trapping community where a common CS has been established. This forms the basis upon which all Penning traps, and more recently MR-ToF-MS devices, operate. This CS is developed and maintained thanks to 2x 0.5FTE (1 person in Europe and 1 person in North America). The establishment of such a framework for the controls, operation and monitoring for the entire laser sub-community would require at this stage a full-time person (1 FTE) which could then become a similar part-time profile, once the baseline is established.

Challenges

The diversity of the lasers&RIB sub-community is not conducive to a single framework. A workshop held with representatives from this sub-community, highlighted how each facility operates with its own framework, whether it is based on LabView (e.g. at CERN), on EPICS (e.g. at IGISOL) or whether it is a bespoke software (e.g. at CRIS).

Finding a common ground where the developments might benefit all will thus be a challenge. However, many aspects, algorithms, devices, etc. are based on the same concepts, and wrapping them to fit the specific language of each facility would only be a necessary technical step, once the conceptual challenges have been answered.

Those challenges could be clearly established within the proposal after a targeted consultation of the sub-community, but shall certainly include some of the following points:

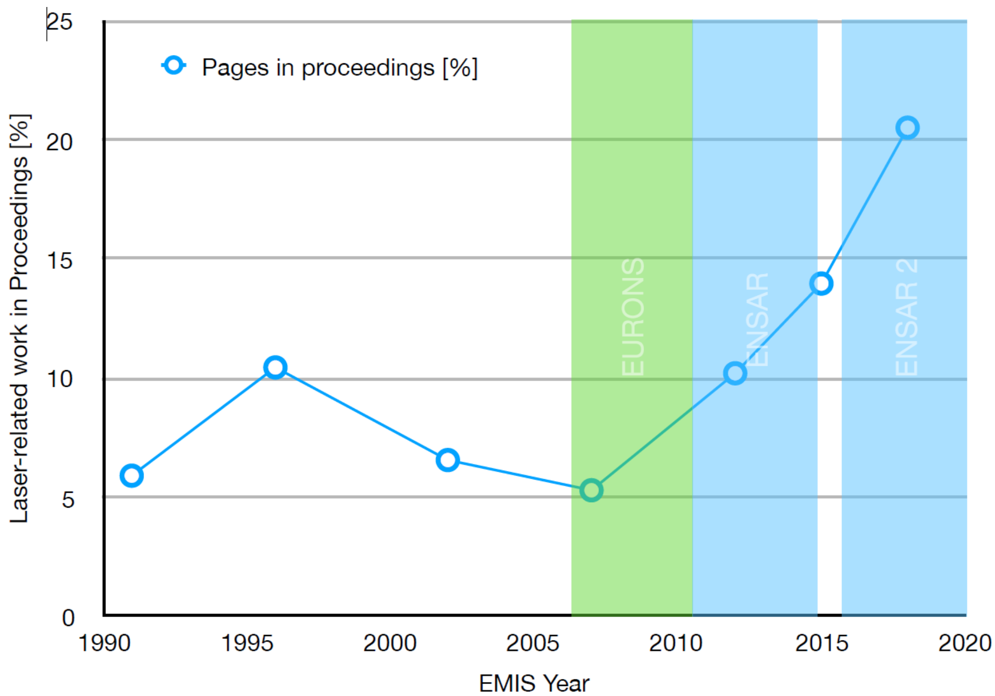
- Frequency tuning and stabilization
- Power stabilization
- Laser timing and pointing stability
- Automated operation

Original aspects

This approach would mark a dramatic turn in the way research with lasers is performed in European RIB facilities, directing the attention in those experiments from becoming laser operator experts, to becoming atomic and nuclear physicists where the laser is a reliable tool. While our teams are not developing photonics, their training today has to be focused on these aspects as they are crucial to the reliable operation of facilities and experiments. Naturally, these aspects take away time and opportunities for the topics that should be most relevant to the EURO-LAB consortium. Moreover, those developments are very time consuming and dramatically impact other development areas of the research.

Unique expertise/Common expertise & collaborations

Laser-based research forms a sub-category within the wider community of this EURO-LAB proposal. However, its expertise is essential for the production of high-quality beams, as well as in atomic and nuclear structure, in molecular physics and search of physics beyond the standard model. The two latter topics will surely become a higher priority in the coming years, offering new possibilities for multi-disciplinary research at RIB facilities. The laser sub-community has been expanding in the last years, as evidenced for example by its presence in the Proceedings of the past EMIS Conferences.



Some of the most active laser collaborations in Europe are listed below:

- ALTO (Orsay)
- COALA (Darmstadt)
- COLLAPS (CERN)
- CRIS (CERN)
- IGISOL (Jyvaskyla)
- IGLIS (KU Leuven → GANIL)
- LARISSA (Mainz)
- LASPEC (FAIR)
- RILIS / LIST (CERN)
- RADRIS (GSI)

- TRIGA (Mainz)
- VITO (CERN)

Further partnership with the industry may be considered as well in this framework, either from large photonics industries with ties to our community (e.g. Hubner Photonics, LIOPTEC, M2Lasers, IREPA Lasers participate in the LISA ITN), or from small developing companies (e.g. ANGARA Technology, also part of the LISA ITN)

Synergies

Laser systems are used as part of the RIB production chain within the ion source. Developments within the laser sub-community therefore impact the beam developments.

Lasers are used for beam manipulation and purification (e.g. beam manipulation in the cooler-buncher at Jyvaskyla, polarized RIB at VITO as well the future MORA ion trap at Jyvaskyla and DESIR, isomer separation at CRIS) which can be combined with other experimental techniques downstream.

Experience from the trap community would be a natural starting point, upon which a basis could be built but also supporting a novel push in this form of activity and potentially leading to a critical mass for cross-community support.

Lasers may be used for multiple forms of research. The study of nuclear ground-state properties is naturally of interest to the core members of this consortium, but they also allow the study of atomic and molecular properties (energy levels, hyperfine properties, ionization thresholds, …) which can challenge the state of the art atomic and quantum chemistry calculations, hereby branching out to different communities. Lasers are key to selective trace analysis applications, which may well form a new multidisciplinary avenue of direct societal impact in the future. One may note the immediate benefit for ion beam purity of novel radioisotopes used in medical applications (e.g. at CERN MEDICIS).

Finally, the advent of radioactive molecule spectroscopy opens a new window to the study of effects that may reveal physics Beyond the Standard Model (BSM), requiring advanced laser technology for spectroscopy as well as for laser cooling and manipulation.

Main category

Data Acquisition + Analysis, Simulations

Other categories

Beams + Targets

Detectors + Electronics

DMP + Data sharing

New physics cases

Title:

Innovative Hadron Applications for Therapy

Authors and affiliations:

Prof. Aleksandra Ristic Fira; Prof. Ivan Petrovic; Assoc. Prof. Milos Djordjevic; Asst. Prof. Otilija Keta; Vladana Petkovic, PhD student.

Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia

General description (methodology, goals,..):

Based on the experience in biophysics of the researchers from the Vinca Institute of Nuclear Sciences (VINS), that is gained through many years of collaboration and work at INFN-LNS, the continuation of the research would be focused, depending upon availability of RI, in several directions:

1. Investigations on cellular level of the effects of ions being beyond current therapeutic ones (protons and carbon ions), i.e., helium, nitrogen and oxygen, as a potential tool in cancer treatment. (to be performed at INFN-LNS, CAN Sevillia)
2. Analyses of the innovative approach based on site-specific boosting of cell killing by protons through proton – boron reaction within cancer cells are planned as another direction of research. (to be performed at APSS Trento, CNAO Pavia)
3. Effects of proton beams in "flash configuration" i.e. with dose rates higher than 40 Gy/sec are intended to be studied on normal and malignant cell lines. (to be performed at INFN-LNS)
4. Laser-accelerated proton beams would give the opportunity to study new radiobiology regimes, particularly regarding forms of cell death. (to be performed at ELI-beamlines Dolni Brezani)

Besides standard evaluation of radiobiological parameters (SF2, α, β, RBE), the list of biological endpoints would include the evaluation of cell death modalities (apoptosis, autophagy and senescence), cell cycle and immunochemical analyses of DNA double-strand breaks of the cell lines having different radiosensitivity levels. In addition to various cancer cell lines, experiments would be performed on three-dimensional (3D) cell cultures being a step forward tissue response, thus more accurately reproducing the *in vivo* conditions. The results will provide data in an adequate form for the crosstalk between known physical phenomena, numerical simulations and experimental results that are of preclinical relevance.

To design experimental setups, particularly regarding irradiation positions within the depth dose distribution of the specific ion specie, i.e., LET values, simulations using GEANT4 toolkit as well as microdosimetric measurements would be used. For the interpretation of the obtained results, such as DNA DSB, survival and RBE, *in silico* data provided by GEANT4-DNA are envisaged.

Challenges:

Each of the four proposed directions of research are innovative, thus a challenge itself with potential use in hadrontherapy.

Original aspects:

The proposed research activities are novel and not yet sufficiently elucidated.

Unique expertise:

The proposer of this contribution is the group from VINS having multidisciplinary character, since it is composed of nuclear physicists and molecular biologists, thus complying with the needs in field of biophysics. They have an extensive experience in *in vitro* and *in silico* studies of radiobiological effects of different radiation qualities on cell lines as well as in nuclear physics.

Common expertise and collaborations:

Research groups from INFN-LNS and VINS have combined their efforts for many years in the field of medical physics and radiation biology, specifically concerning the studies of cell lines irradiated with the therapeutic proton and carbon ion beams. Both groups are members of the GEANT4 and GEANT4-DNA International Collaborations. Within this proposal also a group from CNRS-IN2P3, CENBG, Université Bordeaux, will participate regarding simulation tasks with the mentioned toolkits.

Synergies with other research/technical groups:

The group from INFN-LNS would predominantly contribute to the proposed activities regarding dosimetry and microdosimetry. Within this proposal also a group from CNRS-IN2P3, CENBG, Université Bordeaux, will participate regarding simulation tasks with GEANT4 and GEANT4-DNA toolkits.

Synergies with other communities:
(with reference to the categories described in the “Instructions for submission page”, https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Main category of your contribution:

Data Acquisition + Analysis, Simulations

Connections with other categories:

Improved Access
Theory

Title : GATE, a simulation platform for imaging and radiation therapy
Authors: the OpenGATE collaboration

General description:
GATE is an opensource Monte Carlo simulation platform based on the Geant4 toolkit dedicated to medical physics application. Originally designed for PET and SPECT applications, GATE has now become essential in radiation therapy applications (internal as well as external) and especially in hadrontherapy. The scientific OpenGATE collaboration has raised the GATE-RTion project to propose to the community a set of tools to integrate GATE into the clinics and has been used at the moment in Centre Antoine Lacassagne (Nice, France), the Christie NHS Foundation Trust (Manchester, UK) and MedAustron Ion therapy center (Wiener Neustadt, Austria).

Challenges:
GATE is making a wide range of Geant4 functionality available through a user-friendly interface and is offering dedicated outputs for dose calculations or image analysis. In order to propose computationally efficient simulations, researchers are proposing hardware acceleration solutions but also variance reduction techniques as hybrid modeling approaches combining either Monte Carlo and analytical simulations or using advanced machine learning processes such like artificial neural networks (ANN) or Generative Adversarial Networks (GAN). The GATE platform offers also the possibility to save outputs in image or Python format to facilitate the analysis. The Python programming language is taking an increasingly central place in our platform.
Further, the collaboration has established thorough bridges to the Geant4-DNA collaboration and other groups developing interesting features to simulate radiation biology outcomes when irradiating patients. In a near future, the collaboration will propose dedicated tools to calculate the biological dose for clinical treatments but also will adapt the biophysical models to FLASH therapy.
For two years now, the collaboration has launched an intensive training program to gather young researchers from public and private institutions into the community of users that has reached more than 2000 members in 2021. In partnership with European medical physics Master programs, the collaboration is working on a set of course materials dedicated to master students in particle and medical physics.

Members of the collaboration and expertise:

In France:
- U1101 Inserm, Brest (Hybrid modeling and machine learning)
- IJCLab, CNRS-IN2P3, Paris-Orsay (PET and SPECT imaging)
- LPC, CNRS-IN2P3, Clermont-Fd (Radiation therapy, micro and nano dosimetry, radiation biology)
- IPHC, CNRS-IN2P3, Strasbourg (Radiation therapy and radioprotection)
- CPPM, CNRS-IN2P3, Marseille (Python programming and medical imaging)
- UMR5515, CREATIS, Lyon (Python programming, medical imaging, ANN)
- IP2I, CNRS-IN2P3, Lyon (physico-chemistry, chemistry and radiation biology)
- BioMaps, CEA, Paris (medical imaging)
- CRCT, U1037 Inserm, Toulouse (internal radiation therapy and medical imaging)

- LPSC, CNRS-IN2P3, Grenoble (radiation therapy, micro-nano dosimetry, BNCT and biological dose)

In Europe:

- University of Julich, Germany (PET imaging)
- University of applied sciences, Aachen, Germany (PET imaging)
- Medisip, Ghent university, Belgium (optical photon and PET imaging)
- Technological Educational Institute of Athens, Greece (medical imaging)
- BioemTech, Athens, Greece (internal radiation therapy and medical imaging)
- Medical University of Vienna, Wiener Neustadt, Austria (hadrontherapy)
- MedAustron, Wiener Neustadt, Austria (hadrontherapy)
- ACMIT, Wiener Neustadt, Austria (hadrontherapy)
- The Christie Medical Physics & Engineering, Manchester, UK (proton therapy)
- JPET collaboration, Jagiellonian University, Krakow, Poland (PET imaging)
- University of Patras, Greece (radiation dose optimization)

Elsewhere:

- MSKCC, New-York, USA (radio-guided surgery, real-time PET/CT guided interventions and trans-arterial radioembolization)
- UC Davis, Davis, USA (optical photon imaging)
- Sogang University, Seoul, South Korea (medical imaging)
- NIRS, Chiba, Japan (TOF PET and novel imaging systems in ion beam therapy)

Synergies with other communities:

Geant4 & Geant4-DNA

Main category of the contribution:

Data Acquisition + Analysis, Simulations

Connections with other categories:

Training, Education, Outreach, Social Impact

Title: Interfacing theoretical models with Geant4 using Deep Learning

Authors and affiliations: C. Mancini-Terracciano[1,2], B. Caccia[3], G. A. P. Cirrone[4], M. Colonna[4], R. Faccini[1, 2], S. Giagu[1, 2], P. Napolitani[5], L. Pandola[4], C. Voena[1]
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General description (methodology, goals, ...): A reliable Monte Carlo (MC) code to simulate the interaction of particles with matter is fundamental for many applications, beside the success of a fundamental Physics experiment. Nowadays, Geant4 is one of the most comprehensive and widely used MC packages; however, the physics models currently available in Geant4 fail to reproduce the nuclear fragmentation process below 100MeV/u. This proposal aims at improving the Geant4 performances exactly in this field. A reliable MC simulation in this energy domain is of utmost importance for several application, the first one being hadron therapy (the treatment of tumors with an external beam of hadrons), where MCs are used to:

- compute the input parameters of the treatment planning software,
- validate the deposited dose calculation,
- evaluate the biological effectiveness of the radiation,
- correlate the β+ emitters production in the patient body with the delivered dose,
- and to allow a non-invasive treatment verification (e.g., emitted prompt gamma and secondary charged particles).

MC simulation also supports dosimetric and radiobiological experiments. For instance: Geant4 contains a dedicated extension of models to simulate early biological damage (Geant4-DNA). Finally, simulations for space radiation dosimetry and nuclear spallation sources will greatly benefit from such an improvement in the Geant4 models.
To achieve our goal, we interfaced a dedicated model to nuclear interaction below 100 MeV/u to Geant4, BLOB ("Boltzmann-Langevin One Body"), with Geant4 obtaining promising results. However, the BLOB computation time is of the order of several minutes per interaction. Even if from the BLOB final state it is possible to sample many physical states, such a running time is too large for any practical application. To overcome this limitation, we are testing several generative Deep Learning (DL) algorithms to emulate the BLOB final states. Indeed, there are classes of DL algorithms able to generate "synthetic" data once trained on "real" data. We will develop and train a DL algorithm to reproduce the BLOB results and then we will interface the generative part of the DL algorithm with Geant4. Even without a dedicated GPU, a DL algorithm takes a negligible time to generate synthetic data. In this way we will enable the Geant4 users' community to have the state-of-the-art model results without its running overhead. We will test this technique also with other theoretical models.

Challenges: the DL algorithm has to "learn" all the theoretical model variability and it must have the possibility to sample the final state as a function of several parameter, for instance the projectile and target charge and mass, the interaction energy and the impact parameter.

Original aspects: our effort is the only one to our knowledge to use DL to emulate a nuclear interaction model. Moreover, we will test new kind of generative algorithms using also graph neural networks.

Common expertise and collaborations: this project is born in collaboration with the original authors of the model and will use the experimental data to benchmark the results.

Synergies with other research/technical groups: reproducing the results of a theoretical model with a DL generative algorithm could help also in improving the model itself. For instance, the clusterization of events in the latent space that the DL algorithm builds to represent all the training events could help in understand features and bifurcation in the nuclear reaction dynamics.

Synergies with other communities: we collaborate with the Geant4 development collaboration and our results are of interest for all the Geant4 users' community. It has to be noted that the Geant4 applications in medicine are so many that several software have been developed on purpose for MC applications in the medical cases. For instance, TOPAS is a Geant4 wrapper developed on purpose for hadron therapy.

Main category of your contribution: Data Acquisition + Analysis, Simulations

Connections with other categories: Improved Access**,** Theory, New Physics cases

Title: Machine learning in particle therapy for moving organs

Christian Graeff, Marco Durante

GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

General description: Particle therapy (PT) offers highly conformal dose distribution but also unique challenges to delivery with high precision. Treating tumors in moving organs is especially challenging due to the variable beam ranges to the target. A modern concept to generate PT treatment plans is 'robust 4D-optimization', where *a priori* available information on the target motion is included in the plan optimization process. Moreover, expected deviations in tumor positioning and motion is included in a set of error scenarios. Both 4D and robust optimization drastically increase the degrees of freedom of the optimization problem, posing a challenge to computational efficacy and convergence to an optimal solution.
We propose to use machine learning to identify both relevant error scenarios and relevant components within the optimization problem of each scenario to provide more robust treatment plans with a high computational efficacy.

Challenges: Data availability (4D- CT of cancer patients), achieve competitive performance to other solver strategies

Original aspects: While AI has been used extensively in diagnostic radiology radiotherapy treatment planning, for example in automated planning, it has not been used to structure the optimization problem itself to improve robustness and performance

Unique expertises: GSI Biophysics has been developing particle therapy treatment planning and delivery strategies for moving tumors since >15 years. Strategies are implemented in our own treatment planning system TRiP98 and are experimentally validated in the research therapy cave of GSI.

Common expertises and collaborations: the proposal is planned in collaboration with FIAS in Frankfurt, where a strong AI group is located

Synergies with other research/technical groups: the activity is strongly related to the problem of big-data, IT, and to the biomedical applications of nuclear physics

Synergies with other communities: The AI in medicine activity is embedded in the Biophysics Collaboration that has submitted an abstract for EURO-LABS

Main category of your contribution: Data Acquisition + Analysis, Simulations

Connections with other categories:

Beams + Targets

Detectors + Electronics

Title: Measurements of secondary fragments from Galatic Cosmic Rays and the related radio-chemical damages to biomolecules

Authors and affiliations: M. Vanstalle[1], Q. Raffy[1], N. Arbor[1], J. Colin[2], D. Cussol[2], Ch. Finck[1], S. Higueret[1], D. Husson[1], S. Salvador[2]

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[2] Laboratoire de Physique Corpusculaire (LPC), 6 Bd du Maréchal Juin, 14050 Caen Cedex, France

General description (methodology, goals,..): Light charged and neutral particles produced during interaction of galactic cosmic rays (GCR) in tissues and shielding materials can lead to significant dose to astronauts during a space flight. In this context, a precise knowledge of the radiation field and its expected effects on living tissue is crucial. Many radiobiological studies have already been carried out with living cells to estimate these effects, most of them being mainly focused on DNA induced-damages. Even though these studies provide essential information on the radiation risks associated to high-energy ions, the detailed processes occurring in biomolecules inside the cells remain far from being fully understood.

Our project aims at measuring the fragments produced by ions interaction with shielding materials and biomolecules in living tissues, in the energy range of GCR, and the related effects on biomolecules.. In this project, we aim at measuring both neutral and charged particles with two different types of detection systems: (i) a Time-Of-Flight (TOF) system to measure secondary charged fragments (ii) a crystal scintillator and a Recoil Proton Telescope (RPT) for neutral particles detection. The radiolysis products of amino acids and peptides in diluted solutions will be identified and quantified under high-energy ions irradiation, and compared to those formed by the fragments This experimental setup should allow correlating the damages observed on biomolecules with the charge and the energy of the incoming charged and neutral fragments.

To perform these experiments, particle accelerators can deliver ion beams of charge and energies of interest for space radiation protection applications. Therefore, we wish to perform experiments at KVI-AGOR facility or GANIL for low energy experiments (below 100 MeV/u), at CNAO, HIT, MedAUSTRON (if they become members of the EURO-LABS consortium) and HIMAC for middle energies (below 400 MeV/u), and at the SIS-18 of GSI. The obtained data will be used to benchmark hadronic and molecular models used in Monte Carlo codes, such as Geant4 and Geant4-DNA.

Challenges: The main challenge of this project is to correlate the measurements of charged and neutral secondary fragments produced by GCR and the damages observed in biomolecules. The proposed setup will be able to measure the charge and the kinetic energy of the different emitted fragments.

Original aspects: To our knowledge, such measurements have never been carried out yet. The knowledge gained on the chemical processes occurring under ions irradiation and the mechanisms of the modifications of biomolecules will be of great interest, to better understand phenomena observed under irradiation in a living cell, and therefore the effect of the radiation at the biological stage.

Common expertises and collaborations: This project gathers researchers from IPHC and LPC Caen with recognized expertise in cross-sections measurements for applied physics, and in radiochemistry.

Synergies with other research/technical groups: Some authors of this project are members of the IBC (International Biophysics Collaboration), and collaborate with the Space Radiation

Group of the GSI Biophysics Department. This project could fully be integrated in the working group on cross-section measurements of the IBC. Furthermore, the authors also collaborate with the NIRS laboratory in Japan.

Synergies with other communities: the collected data can be of interest for the nuclear physics and radiobiology communities, as well as for space research. Contacts with members of space community of Strasbourg have already been taken.

Main category of your contribution: Data Acquisition + Analysis, Simulations

Connections with other categories: Detectors + Electronics

DETECTORS

GAMMAPOOL

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Category: “Detectors + Electronics”

Title: European Gamma-ray Spectroscopy Pool (GAMMAPOOL)

Web site: http://gammapool.lnl.infn.it/index.htm

Authors:

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General Description:

The objective of the GAMMAPOOL Steering Committee is to coordinate and optimise the use of the valuable EUROBALL resources (Germanium detectors and BGO shields, the Neutron Wall and EUCLIDES ancillary detectors and associated electronics). These resources are available to the European nuclear physics community for experimental campaigns in order to continue to exploit their enormous potential thereby offering new physics opportunities. The GAMMAPOOL policy of favoring large-scale unique physics campaigns assures the optimal use of the detectors and of the resources that each research community invests on the campaigns. Notable campaigns using the equipment have been Jurogam at JYFL, Finland; nu-Ball at IJCLab, France; EAGLE at HIL, Poland; CLARA and GALILEO at LNL, Italy, RISING at GSI, Germany and EURICA at RIBF, Japan to give some examples.

In addition to the world-class experiments that are performed it is also important to point out the strong role that these resources have in the training of students and young researchers: 75 PhD thesis have been obtained in the period 2004-2019 from JYFL data for example. More details can be found in the 10 year report located at: http://gammapool.lnl.infn.it/index/home/Gammapool_10_years_celebration.htm

Challenges:

However, a major concern is that some of these Germanium detectors, the main workhorse for these experiments, are approaching 30 years old. The maintenance required to keep them in working condition is becoming, more often than not, beyond the capabilities of the detector laboratories of the hosting infrastructures and repairs need to be affected by the manufacture. This is becoming prohibitively expensive for smaller University funded collaborations.

We would like to take advantage of this European Call:

1) To request funds to perform factory refurbishment of the Ge detectors and upgrade the front-end electronics (preamplifier) to permit their continued use for several more decades
2) Funds for staff working at the detector maintenance laboratories at European infrastructure sites to share knowledge and experience and to train new technical staff
3) Where necessary, to expand and modernize the capabilities of these detector maintenance laboratories to ensure that day-to-day repairs and maintenance can be performed at more sites in Europe.
4) Request financial aid for the specialist transport of fragile equipment between sites and to support experimental campaigns

Synergies:

European TransNational Access (TNA) sites performing high resolution gamma-ray spectroscopy have used and continue to use these resources.

New challenges for online irradiation control at various nuclear physics accelerators

Authors: Denis Dauvergne[1]; Marc Verderi[2]; Ferid Haddad[3]; Samuel Salvador[4]; Etienne Testa[5]; Marc Rousseau[6]; Marie-Laure Gallin-Martel[7]; Charbel Koumeir[8]

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See attached file

Title: New challenges for online irradiation control at various nuclear physics accelerators

Authors and affiliations: Denis Dauvergne (CNRS-IN2P3), on behalf of several research teams of IN2P3, participating to the Research Network GDR MI2B: LPSC-Grenoble, IP2I-Lyon, LPC-Caen, IPHC-Strasbourg, LLR-Palaiseau, Subatech-Nantes, ARRONAX-Nantes

General description (methodology, goals,..):

We propose to test and to implement ongoing developments for innovative ion beam monitoring devices, and ion range verification methods. Such developments can be beneficial for various ion accelerators: from proton beams to heavy ions, for various types of beam time structures (pulsed or continuous beam delivery), and intensities ranging from single ion counting mode to intense bunched modes.

For such purpose, we develop:

- beam monitors, using different strategies depending on their finality:

High intensity beam monitors require low charge-recombination in the active detection volume and radiation hardness; solutions under study consist in ultra-thin or low-density ionization chambers (LPC and LPSC), large area diamond detectors (LPSC), secondary-electron emission-based detectors (LLR). Such monitors are primarily intended for FLASH therapy.

Single particle identification (position and time-stamp) require beam hodoscopes consisting in arrays of scintillating fibers (IP2I) and large-area multistrip diamond detectors (LPSC) providing timing resolutions between 10 ps and 1 ns rms at count rates exceeding 10 MHz.

- Range verification based on the time-resolved detection of secondary radiation, like prompt-gamma detection techniques using time-of-flight by means of the coupling with the hodoscope or to the accelerator HF (CLaRyS collaboration), or bremsstrahlung and X-ray photon detection (Subatech).

Therefore, access to various research infrastructures is envisaged : GANIL, ARRONAX-Nantes, CYRCé-Starsbourg in France, but also PARTREC (former KVI-CART) which delivers protons and light ions with particularly suited time structure for timing measurements, GSI, and even particle therapy dedicated facilities such as CNAO and MedAustron, if they become members of the EURO-LABS consortium.

Common expertises and collaborations:

IN2P3 labs benefit from a complete scientific environment comprising physicists, electronics-, instrumentation- and accelerator-engineers.

Part of the developments cited above were included in the frame of ENSAR2/MediNet, which is now ended, and lead to international collaborations within this framework.

Synergies with other communities:(with reference to the categories described in the"Instructions for submission page",https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

The proposed developments can be applied for nuclear physics and biophysics studies (including radiolysis and particle therapy). Part of the teams contribute to the IBC (International Biophysics Collaboration)

Main category of your contribution: Detectors + electronics

Connections with other categories: Improved access

Optical TPC developments

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The advantages of position-sensitive gas-filled detectors have been proven many a time in direct reactions involving ionising participants. The large solid-angle coverage, the efficient background rejection, and the possibility of reaching very low-energy kinematics allowed the success of detectors such as MAYA and ACTAR-TPC at GANIL or AT-TPC at MSU.

However, these devices still have some difficulties inherent to the use of drift electric fields, and charge amplification and collection. Among them, the acquisition electronics becomes cumbersome and very expensive due to the large number of channels involved; the use with heavy/highly ionising particles needs to deal with field distortions, large charge spaces, delta electrons, etc; the dynamic range is somehow limited for measuring high and low ionising particles in the same reaction; and any ancillary components within the gas are prone to modify the characteristics of the electric field.

In order to avoid some of these difficulties, we propose to explore the possibility of replacing the usual charge-induced collection with optical reading. In these proposed optical devices, the light produced during the ionisation is recorded with a series of commercial cameras, placed around the filling gas. The treatment of the separate pictures for each camera would allow to reconstruct a 3d image of the tracks. The use of commercial cameras and their in-built electronics would ease the need of custom-made, complex acquisition setups; recording the light emitted during the ionisation would spare the presence of electric fields and amplification stages to collect the charge produced; and in addition, the dynamic range of the commercial reading can reach one order of magnitude larger than current setups. The main drawback of such devices would be the relatively small light yield. This can be overcome with optimal gas mixtures and maximum light sensitivity (commercial cameras can reach one-photon response).

Given these initial constraints, reactions with high-ionising participants would be an ideal test for such devices. The study of fission reactions, particularly in direct kinematics, would be a straightforward candidate for a first application of this technique. Recent experiments have shown that it is possible a rough fragment identification from the energy loss profile, which it should be possible to measure with these optical devices. At GANIL/Spiral2, the NFS facility would be an ideal place to study angular and yield distributions from fragments as a function of the initial energy in neutron-induced fission reactions. Should it be successfully applied to fission, this technique may be then extended to other reactions with highly ionising participants.

A new modular array for simultaneous detection of neutrons and charged particles

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Title

A new modular array for simultaneous detection of neutrons and charged particles

Authors and affiliations

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General description

The aim of the project is to investigate the possibility of using of innovative scintillators material coupled with compact photo-sensors as read-out devices to be the basic elements of a segmented and modular versatile multi-detector prototype, detecting at the same time neutrons along with light charged particles, both with high angular and energy resolution. Time of flight measurement will provide the particle energy while the analysis of the signal shape will allow the discrimination of gamma rays. Finally, the array structure will provide angular resolution of the order of 1°, an easy multiple hit reconstruction and a neutron detection efficiency larger than 10% in the expected broad energy range (En <200 MeV).
A suitable scintillator material with the requested characteristics will be chosen, coupled to an optimized readout to be identified with appropriate tests, using either particle beams or neutron sources. The final array will be highly segmented in all directions, included the flight one; total thickness must be enough to ensure a reasonable interaction probability, while segmentation in reduced size will ensure a precise position measurement. The geometrical characteristics and the multiple-hit reconstruction capability of the detector will be defined both by dedicated simulations, also related to the physics case under study, and by different experimental tests. A dedicated VLSI frontend with versatile readout modalities will be developed, coupled to a multi-channel data acquisition system with real-time digital processing, enabling the study and validation of Pulse-Shape Discrimination algorithms.
The device could be coupled with an active veto system (silicon strip or fast plastic) that may also provide the reconstruction of the trajectories of the incident charged particles. Moreover, it will work in air or under vacuum, either in stand-alone configuration or coupled with other detection systems, e.g., the CHIMERA or FARCOS detectors at INFN-LNS.

Challenges

The development of the project is made possible by several technological advancements in the field of photodetectors, scintillators, interconnection and micro-electronics. New scintillator materials with peculiar characteristics have to be tested, coupled to compact and fast photosensor, providing also pulse shape analysis of the light signal. A devoted electronics and data acquisition system has to be developed, matched to the chosen photodetector technology, to fulfil the demanding requirements in noise, speed and provide full pulse-shape signal analysis capability.
One of the main points of the project is to carefully understand cross talk phenomena coming from neutron interacting in two or more detection cells and from re-scatterings of neutrons and gammas in the environmental structure, simulating unreal reaction events. The segmented geometry will help in studying this effect, as well as the measurement of the time of flight and the time pattern reconstruction, used to disentangle between true and spurious coincidence. An accurate study of cross talk problems requires the implementation of extensive simulations to be performed with powerful tools.

Original aspects

This final device will be a unique and innovative example of simultaneous measurement of neutron and charged particles in the same detection material, using the segmented and modular geometry to optimize detection efficiency, energy resolution and detection pattern reconstruction, fundamental to disentangle cross talk effects.
The device will be potentially useful to produce advancements in the study of heavy ion collisions at Fermi energies and related applications. The present and future facilities delivering radioactive ion beams (RIBs) with high value of beam current, such as the new fragment separator at INFN - LNS, will give new insight on the effect of neutron richness, on nuclear matter properties and on reaction mechanisms. In this contest, the direct detection of the neutron signal coupled with charged particle detection with second generation array can become an original aspect, fundamental for a full comprehension of the involved phenomena.

Common expertises and collaborations

The project will require a strong collaboration between different key figures, like nuclear physicists with expertise in particle and neutron detectors, electronics engineers with experience in fast and integrated front-end and in data acquisition systems, as well as well experimented nuclear physicists acting as final users of the device.

Synergies with other research/technical groups

The project will require a strong synergy with technical groups for the realization of various component, like the dedicated VLSI frontend electronics, the multi-channel data acquisition system with real-time digital processing, the mechanical structure, and the cooling system.
Various innovative physics cases demanding for peculiar neutron detection will benefit from this project, involving several other research groups; examples are the particle-particle correlations (n-n; n-LCP; n-IMF), aiming at the space-time characterization of the emitting sources in the reaction, Nuclear density measurements of transient states of short mean life, Fusion-Fission reactions, Multifragmentation reactions, Nuclear Halo in stable and exotic nuclei.

Synergies with other communities

The device can have applications in subjects studied by other communities, like for example the nuclear fuel cycle, nuclear fusion, dosimetry science and biology. In such fields the proposed device will be a powerful tool to measure flow, energy, and position wherever neutrons are involved.
Application to medical instrumentation, such as diagnostic of the radiation field induced by ions used in hadron therapy could be envisaged, to monitor secondary neutrons, that are among the main sources of dose absorbed by the patients undergoing treatment.

Main category of your contribution

Detectors + Electronics

Connections with other categories

Improved Access

Data Acquisition + Analysis, Simulations

Detectors - Electronics / 59

Design study of a superconducting recoil separator for HIE-ISOLDE

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General description

The radioactive beam facility "Isotope mass Separator On-Line facility" (ISOLDE) at CERN started operation 50 years ago [1], and since then several transformations and upgrades have made it a world leading nuclear infrastructure. Most remarkably was the recent commissioning of the "High Energy and Intensity – ISOLDE" (HIE-ISOLDE) linac accelerator [2], able to drive the radioactive species produced at ISOLDE form 0.5 up to about 10 MeV/A. The facility can produce the largest range of isotopes worldwide —over 1300 isotopes of more than 70 elements-, from 6He up to as 229Rn.

What is now proposed is an important upgrade with a new detector system, the Isolde Superconducting Recoil Separator (ISRS). A compact mass separator will significantly increase the number of accessible
exotic nuclei, allowing critical studies with sufficient precision using the beam intensities and energies available at the HIE-ISOLDE. The coupling of ISRS to the available detector systems will open up new horizons for nuclear structure, dynamics and astrophysics.

Ray-tracing spectrometers like PRISMA [3] at INFN-LNL (Legnaro, Italy), VAMOS [4] at GANIL (Caen, France) and MAGNEX [5] at INFN-LNS (Catania, Italy) can achieve both large momentum acceptance and high resolution. A recent improvement using isochronous design and RF systems is the novel spectrometer ISLA [6] being developed at NSCL/FRIB (Michigan, USA).

Recently, our collaboration carried out the study of a very compact recoil separator for HIE-ISOLDE beams, the Isolde Superconducting Recoil Separator (ISRS) using a different approach. The proposed spectrometer is based on a compact superconducting (SC) mini-ring [7]. Preliminary simulations show that this system is able to analyse a much larger range of masses and momentum spread, reducing the size with respect to standard non-SC recoil separator configurations.

A Letter-of-Intend for carrying out a proof-of-concept study was recently submitted to the ISOLDE and Neutron TimeofFlight Experiments Committee last February 2021 [8]. The purpose of this initiative is to explore the performance of this innovative spectrometer design and the feasibility of building a future instrument.

Challenges

The unambiguous identification of heavy mass reaction fragments is quite challenging and for low intensity radioactive beams a high-efficiency, high-resolution recoil separator is needed. Traditional technologies based on warm magnets present limitations due to size, efficiency and mass resolution. With present technologies ToF resolutions around ~ 1 ns can be achieved, and for a flight time of about 1 μs the m/q resolution can reach values close to 1/2000. The mini-ring design concept can provide larger storage times and therefore able to reach unprecedented resolution. A preliminary design-study was already carried out [7] with a ring concept of only 3.5 m length and a FFAG [9] lattice of 10 SC combined-function nested magnets, achieving large solid angle > 100 msr and momentum acceptances $\Delta p/p > 20\%$. There are several challenges involved:

1. Beam dynamics study to optimise the ring configuration and operation for the physics program.
2. Design/prototyping of multifunction SC magnets, with straight and curved configurations.
3. Design/prototyping of the SC magnet test bench for the above configurations.
4. Design/prototyping of in-ring beam diagnostic systems.
5. Design/prototyping of the injection/extraction system based on SC magnets and RF kickers.
6. Design/prototyping of a multi-harmonic buncher system (MHB).
7. Design/prototyping of a re-buncher system (RBS).
8. Design/prototyping of focal plane detectors and particle trajectory reconstruction.
9. Detailed study of the charge breeder EBIS to optimise the operation of the facility.

Original aspects

1. Innovative compact mini-ring design concept [7] combining SC magnets and RF systems.
2. Fixed-Field Alternating-gradient (FFAG) beam dynamics. The FFAG concept was proposed in the early 1950s [9], and it has recently used for different applications in high energy physics [10] and charged particle therapy [11].
3. Strongly curved superconducting accelerator magnets. This technology allows for large apertures and large momentum acceptance, and has several advantages in terms of design flexibility, field quality, and low expected operating costs compared to the classical magnet structures [12]. The use of strongly curved superconducting magnets is also being considered for the new generation of medical gantries [13] and can produce a very compact design.
4. Injection and extraction systems. Combination of a septum magnet and a RF kicker based on a Superconducting Shield (SuShi) septum [14], an opposite-field septum [15], or a RF helical strip-line chopper [16].

Common expertise and collaborations

Physics cases and particle detectors

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Superconducting magnets and particle accelerators

CERN, Geneva, Switzerland.
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Synergies with other research/technical groups

The technical developments foreseen in this project can be extended to other devices used for ion cooling and beam manipulation, storage rings, and mini accelerators for radioisotope production and medical beam therapy.

Synergies with other communities
• Medical physics

Main category of your contribution
• Detectors + Electronics

Connections with other categories
• Beams + Targets
• New physics cases
• Training, Education, Outreach, Social Impact

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FAZIA@ZD (FAZIA at Zero Degrees)

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This proposal is supported by INDRA-FAZIA, LISE and ACTAR-TPC communities.
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General description

We propose to develop a new hodoscope, meant as an upgrade of the Zero Degree detector for phase 2 at the LISE radioactive beam facility at GANIL. The apparatus, expected to operate in experiments with a beam current such as 100 kpps and energies ranging from 20 to 50 MeV/u, would be designed to detect ions from Z=3 to Z=28. Light charged particles (Z=1 and Z=2) measurements with this setup is an option but it is not its main task. The present design (phase 1) of the apparatus is composed of a pressurized gas chamber (typical pressures from 50 to 200 mbar) and an HPGe detector, placed outside the chamber. This HPGe detector would be used to detect gamma rays produced in the decay of isomeric states with long lifetimes. Inside the chamber, there are two multi-wire parallel plate detectors (MW1, MW2) used for precise position tracking, followed by a fast ionization chamber (FastIC, 44 cm thick) used as a ΔE sensor and a plastic wall (PLW) used as residual energy detector. This setup is intended for detection and Z identification of heavy ions coming from reactions and transfers in the target induced by LISE beams. Mass identification is not possible due to the scarce PLW energy resolution and the intrinsic limitation of the ΔE in FastIC.

To improve the particle identification, we propose to replace the PLW with an "almost" zero degree FAZIA-type telescope array. We plan to achieve isotopic separation up to Z=20-24, as it has already been demonstrated in FAZIA experimental campaigns. One multi-wire (MW1) will remain to provide the momentum vector direction of heavy ions after transfer. The basic idea is to start from the existing well established FAZIA electronics and then to develop a new telescope array using FAZIA expertise. We should still adopt Si-Si-CsI telescopes, but in a new geometry with respect to the existing FAZIA blocks: a possible practical way is to adopt a ring configuration (with a minimum hole for unreacted beam transmission). We are currently studying some reasonable modifications of the FAZIA electronics in order to separate the analogue chains from the digital stage. Thus we propose to install the analogue chains inside the gas chamber, close to telescopes, while the rest of the electronics will be placed outside, connected with a twisted pair cable via specific feedthroughs in flanges. This option mostly preserves the FAZIA electronics while optimizing the detector performances in order to achieve its physics goals.

Challenges

Since the new hodoscope will be located very close to 0° with respect to the beam line, we expect a rather high particle count rate. So, the main aspect which should be taken into account will be the radiation damage of the silicon detectors. Then, a certain challenge will be the achievement of enough isotopic discrimination to be able to identify all the detected species. Another additional improvement in phase 2 will be the detection of clusters at forward angles, beside that of the major QP fragment; thus a specific study needs to be performed in order to optimize the thicknesses of the telescope layers in order to fully absorb light energetic particles at Fermi energies. As for silicon sensors, an additional challenge will be the construction, for a given layer, of an azimuthal symmetric array with many channels obtained from a single wafer, possibly 6'' diameter or more.

Original aspects

FAZIA was not specifically designed to directly operate under beam. Here we plan to use it at almost 0° with respect to the beam axis. This possibility was already successfully tested in 2018 during an experiment at LNS. The detection and identification, in the covered cone, of all the particles from protons to ions with Z~25 will allow a rich variety of beam-target combinations to be studied with LISE.

Unique expertises

The FAZIA isotopic discrimination capabilities are almost unique in the field of heavy ion collisions for modular arrays. This goal was achieved thanks to special detector preparation and to the dedicated digital electronics.

Common expertises and collaborations

Like many experimental groups, we strongly rely on ΔE-E telescopes, pulse shape discrimination techniques and digital acquisition electronics. A collaboration among the involved groups will certainly exploit these techniques at their best. From the acquisition point of view, the FAZIA detector guarantees full integration with the general GANIL system exploiting CENTRUM timestamps.

Synergies with other research/technical groups

We plan to ask support from technical staff of GANIL. Then we foresee possible synergies with other research groups in order to develop more resistant sensors, for instance Silicon-Carbide (SiC) detectors. Furthermore, there is interest in developing ancillary detectors capable of identifying neutrons.

Multi-mode imaging for hadron-beam characterization and real-time range verification

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Multi-mode imaging for hadron-beam characterization and real-time range verification

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The objective of this project is to develop and demonstrate a prototype of a new multimodal imager of secondary radiation produced in hadron-therapy and demonstrate it at hadron-therapy facilities, including the Fondazione Centro Nazionale Adroterapia Oncologica (CNAO). The method offers the capability of detecting prompt and annihilation gamma rays, neutrons, and charged particles produced by the primary beam, enabling the characterization of the interaction of the ion beams with tissue and imaging of the ion-range in-vivo. The overall goal of this project is to leverage recent developments in radiation detection materials, our experiences in radiation imaging and hadron beam design and delivery to overcome technological challenges in demonstrating the first multi-mode imager for hadron-therapy beams.

The high ballistic precision of hadrontherapy generates sharp dose profiles at the tumor edges. Therefore, any deviation with respect to the treatment planning may cause under-dosage of the tumor and high-dose delivery to healthy tissues surrounding the treatment volume (TV). Safety margins of up to a centimeter in deep-seated tumors are applied to minimize this risk. The beam range in the actual patient anatomy is typically inferred from the comparison of secondary radiation associated with the treatment and the ion range which would yield the same secondary contribution, as simulated by Monte Carlo codes. Current uncertainties in the estimated beam range are on the order of 2.5 – 4.5% or up to approximately 3 mm in proton therapy and derive from low accuracy of the used reaction cross sections and tissue stopping power ratios. We will present feasibility simulated data that show how the combined use of multiple signatures, namely prompt gamma rays, annihilation gamma rays, neutrons and charged particles (Figure 1) yield a more accurate range estimate as compared to using only one of these techniques. The project aims at demonstrating this improvement in phantom and possibly in vivo. This multi-modal system, in telescope mode (Figure 1), will also enable the measurement of reaction cross sections that are relevant in particle therapy and semiconductor survivability in space, with inherent capability of discriminating correlated background radiation through the other two measurement modes. Within the scope of this project, we propose to develop and use the **multi-modal imager (M2I)** for range verification and to characterize a set of cross section measurements for a series of targets and ion beams that are relevant to the abovementioned applications at the CNAO. To achieve the latter aim, the target interacting with the beam will be replaced by pulse-shape discrimination (PSD) capable and composite scintillation detectors, allowing the direct detection of fragmentation on materials including carbon, nitrogen, and oxygen. This strategy will enable the simultaneous characterization of the recoil nuclei and the scattered primary beam or produced fragments, when present. The hardware work proposed will synergistically develop the associated analytical methods and software to handle, assure and visualize data via three work packages:

WP1 Develop the M2I and validate its performances using well-characterized phantoms. The M2I is based on two pixelated scintillation detector planes, each plane encompassing two arrays, to enable the detection of annihilation gamma rays in positron emission tomography (PET) mode, the imaging of prompt gamma rays (PG) and neutrons via scatter-based detection, and the detection of high-energy charged particles (produced when the primary ions have Z $\geq$ 5) via pulse shape discrimination and telescope-mode detection. Systematic testing of each module of the instrument will be performed. Using standard phantoms, M2I performance is compared with PET and PG only performance.

WP2 Model the image formation process and develop the Monte Carlo methods for M2I. Inaccurate cross-section databases and heterogeneous materials can potentially complicate the measured data and interpretation. A Monte Carlo model of radiation transport based on GEANT4 or FLUKA will guide instrument development and provide greater accuracy, precision, and assurance in interpreting measured data.

WP3 Cross section measurement. We plan to use PSD capable detectors as beam target, in conjunction with the M2I for the quantification of fragmentation cross sections. For example, we will use stilbene to study carbon fragmentation.

Owing to its favorable physics and biological properties, and related clinical benefits, hadron therapy facilities are spreading worldwide. However, uncertainties in the ion range and limited knowledge of fragmentation products when using ions heavier than protons are limiting the treatment effectiveness or increasing the exposure of radiosensitive healthy tissue. Optimized design and theory for M21 will be tested both in proton and carbon ion beams at the CNAO, providing a comprehensive characterization of both types of treatments. The developed system can be used as a comprehensive and reference instrument to characterize the clinical beams of the facilities participating in Eurolabs, as well as enable measurements of interest to be performed by the Eurolabs members.

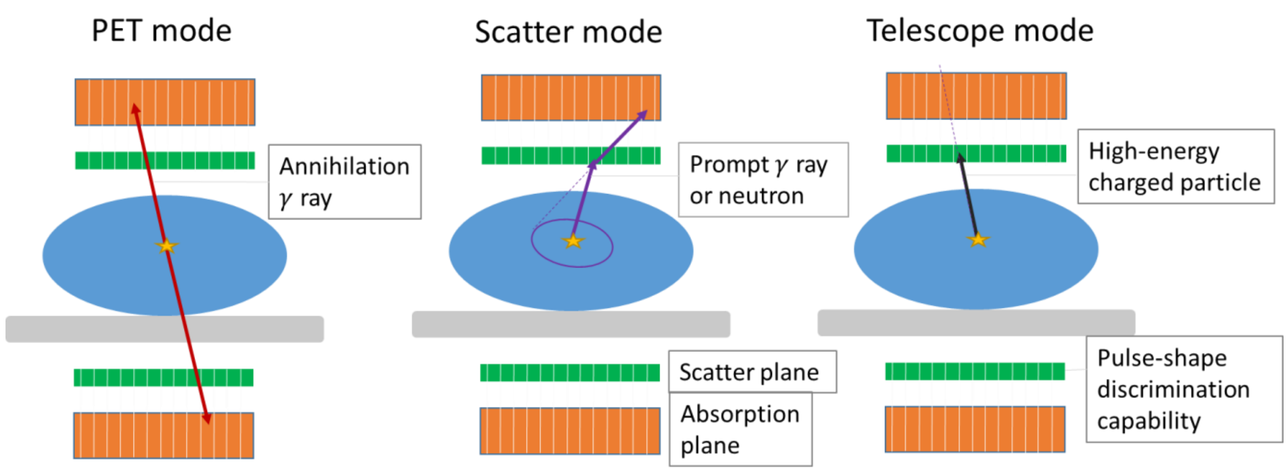

Figure 1. Schematic of the three working modalities and imaged signatures.

Beam monitoring using a-Si:H devices

Authors: Leonello Servoli[1]; Mauro Menichelli[1]; Giuseppe Cirrone[2]; Giada Petringa[2]; Anna Paola Caricato[3]; Cinzia Talamonti[4]

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We are proposing new kind of devices for monitoring in transmission different type of beams, based on hydrogenated amorphous silicon structures. See proposal attached.

Beam monitoring using a-Si:H devices

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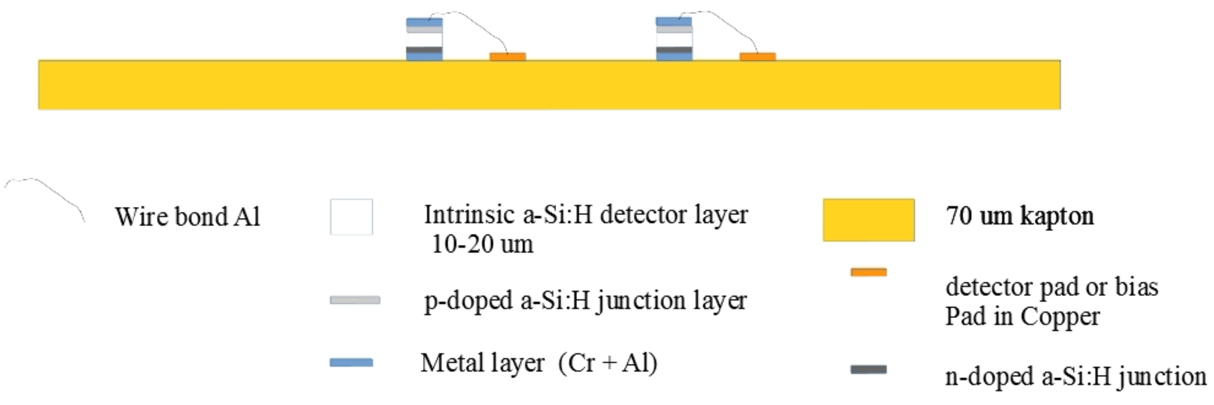
One of the main challenges of beam monitoring in beam transport lines is the availability of transmission detection systems that do not disturb beam characteristics giving at the same time both beam profile and beam energy spectra. Moreover, especially in Reaccelerated Ion Beams (RIBs), the flux measurement ranges from a few thousand Hz to GHz or more. Hence it is difficult to have a single system capable of measuring all regimes.
We propose a new approach to solve this problem based on hydrogenated amorphous silicon (a-Si:H) detectors. This kind of material has the following important properties:

1) it is intrinsically radiation-resistant;
2) it could be deposited both on thin flexible substrates, like Kapton or directly on some readout chip;
3) the charge collection is smaller than in crystal silicon devices; however if the single charged particle is an ion, with an energy deposition higher than the standard MIP, the signal/noise should be high enough to allow detection with high efficiency.
4) it could be deposited on large areas, as demonstrated for applications like solar cells or flat panel X-ray detection.
5) it could be read out in both current mode (high flux) and pulse mode;
6) it is relatively cheap compared to other detectors.

Figure 1 shows a possible scheme for a p-i-n diode structure deposited on a Kapton substrate, whose thickness could be as low as few tens of micrometers. The thickness of the diodes would be of the order of 5-10 micrometers or less. The diode area would be of the order of 1x1 mm^2 or smaller.

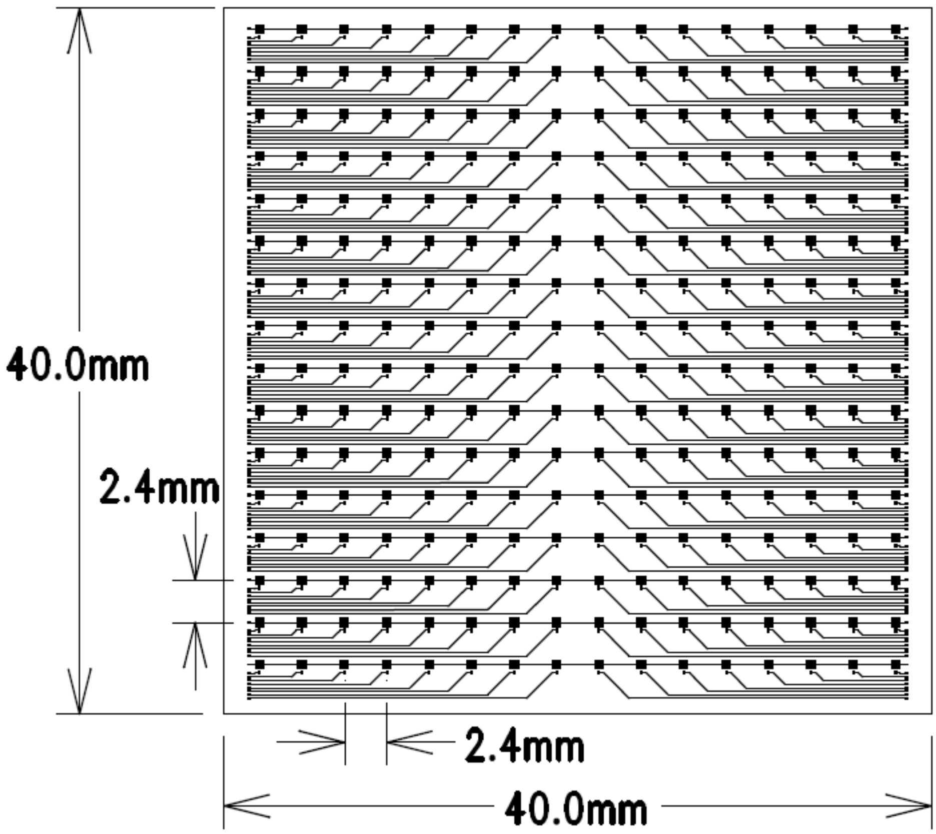


Lateral view of 2 x 2 matrix of a-Si:H p-i-n diodes deposited over a kapton surface,

Fig. 2 instead shows a possible arrangement of diodes to cover a 2-D surface and measure the 2-D beam profile, together with the proposed routing of signals from all pixels.

As already pointed out previously, two readout mode are foreseen for such kind of devices, possibly connecting a subset of the diodes to the single-particle readout (pulse mode) and the other part with the flux readout (current mode). A relatively high density of readout channels is needed, pointing to some ASIC device for the solution. A possible candidate is a high precision current amplifier like the Texas

Instrument DDC264 (64 channel chips) for the first mode, . The second readout mode could be satisfied using some of the front-end chips developed for High-Energy physics detectors (strips, pixels), containing pre-amplification, shaping and ADC sections.



Proposed arrangement for a 16 x 16 diode matrix   with routing for readput lines.

Preliminary results with test structures show a linear response to both X-ray flux (dose rate) and clinical beams (dose) [***Fabrication and preliminary tests of a Hydrogenated Amorphous Silicon detector in 3-D geometry.*** M. Menichelli, L. Servoli et al., *accepted for publication in "Frontiers in Physics"*].

Self-Powered Particle Detectors for high flux, beam-target secondary emission measurement

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General description (methodology, goals,..):
The production of secondary particles by beam-target interactions is a relevant process for several accelerator-based experiments and irradiation facilities. Examples of this are high flux proton and ion irradiation facilities, and also neutron time-of-flight experiments exploiting proton-on-target spallation sources or electron beam photoproduction sources. Typical secondary particle fluxes in the proximity of experimental setups or targets on such beam lines can reach the order of 1010-1011 neutron/cm2s and likewise for photon/cm2s, an extremely harsh environment for any active detector. Direct monitoring of the generated flux close to the experiment would allow to monitor on-line the flux and integrated fluence on setups and irradiated samples, and also to diagnose variations which can be due to misalignments, structural modifications or malfunctioning of the experimental assembly. Such monitoring would not be sensitive to similar local anomalies if made through the measurement of integral flux at distance from the target assembly.
A promising technology for such high flux measurement are Self Powered Neutron Detectors (SPND). These detectors have a coaxial structure, typical dimensions of few mm diameter, few cm length; their working principle is the direct detection of secondary gamma and/or beta radiation emitted by neutron-induced activation of the central electrode. Photon fluxes can also be measured by exploiting electron production through Compton and photoelectric interactions. Beta delayed emission has a response time of the order of tens of seconds or more, depending on the daughter nuclei decay time, while prompt emission can be due to both neutron interaction and external photons interaction.
The proposed activity is to develop novel Self Powered Particle Detectors (SPPD), sensitive to the mixed fields generated close to experiments and production targets at proton/ion accelerator facilities. New designs, including sensitive and structural materials, shapes and dimensions, will be developed starting from use cases in existing facilities. The starting point will be the development of harmonized Monte Carlo models of the experimental areas on beams, which will simulate particle spectra, fluxes and time distribution, in collaboration with the teams running the facilities involved. Feasibility studies for installation positions of the monitor SPPDs will be carried out, and in the candidate facilities and positions the simulated particle fluxes will be studied to optimize the dimensions and sensitive materials of new SPPD prototypes, in order to find the best configuration to maximize the response to the different components of the spectrum. Once designed, the best candidate SPPDs in terms of expected sensitivity, time response and particle identification will be realized and tested exploiting running facilities.

Challenges:
On line monitoring the particle flux in the above outlined conditions is a challenging task: existing detector technologies can't withstand such high fluxes without modification of their response or permanent damage, in particular when the location does not allow to substitute or maintain the detectors for long periods of time while the facility is running. SPND-like detectors instead are intrinsically rugged, no microelectronics, biasing or radiation-damageable components are used.
The realization of new SPPD design and prototypes, tailored to measure the complex yield of proton and ion beam experiments and test facilities, will allow both managing teams and users to gain a better, on-line knowledge of particle flux yield of the targets. This knowledge will allow on one side to monitor the particle flux in specific high-rate irradiation positions where other detector technologies would not be capable to operate, with great benefit through on-line dose measurement otherwise unfeasible, and on the other side to diagnose malfunctioning or displacements of the beams, setups and targets, potentially harmful for the infrastructure.

Original aspects:
SPNDs are currently used in thermal fission reactors to monitor in-core neutron flux, therefore up to now material choices have been optimized considering typical energy spectra of those environments. Among common SPND materials are Rhodium, Silver, Cobalt, whose cross section for (n,g) processes

is maximum in the thermal region. Use of these materials in higher energy neutron fields, in presence of photons and other charged particles, would not allow to efficiently separate the neutron or photon contribution due to their flux ratio and lower neutron cross-section. In order to optimize the signal for proton and ion beam environments, both new materials and geometries have to be chosen based on the relative yield of photons, neutrons and charged secondaries, in order to maximise the relevant signal components. Moreover, the signal induced by charged secondary particles other than electrons could also add a relevant signal component, but has never been investigated: in the context of proton and ion beam facilities this could be performed and exploited to allow a more general use of such detectors in even more complex environments.

Unique expertises:
Dr. Salvatore Fiore, Dr. Maurizio Angelone and Dr. Mario Pillon have already gained deep knowledge of the use of SPNDs in non-conventional environments, through experimental activities at the Frascati Neutron Generator FNG, the GELINA and n_TOF facilities, where they conducted experiments with standard and custom-made SPNDs close to the neutron production targets.

Common expertises and collaborations:
The proponents possess a blend of expertises and experience in several nuclear physics and technology fields. They are well experienced in experimental and computational neutronics, neutron detector development, testing under different particle sources, in the framework of European collaborations and with colleagues of international research institutes and universities. Other than the SPNDs, they are developing diamond and SiC detectors for neutrons in harsh environments.

Synergies with other research/technical groups:
The proponents are deeply involved in joint research activities on detector development within EUROfusion, Fusion For Energy, ITER, H2020 projects, where similar challenges in terms of high particle fluxes, high radiation doses and high temperature are addressed.

Synergies with other communities:
Monitoring a very high flux of neutrons, up to 1014 neutron/cm2s, in a mixed gamma and charged secondary particles field and high-temperature, is also a challenge for fusion Tokamaks and for the future DONES irradiation facility for fusion materials that is being constructed in Granada (Spain). Exploiting the SPND technology by improving sensitivity in complex, harsh beam-target environments would be beneficial for both the Nuclear Physics and the Fusion communities.

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Main category of your contribution: ***Detectors + Electronics***

Connections with other categories: ***Beams + Targets***

(with reference to the categories described in the “Instructions for submission page”,https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Study of the radiation damage and recovery effects in organic and inorganic scintillators for future detection systems

Author: Valerii Dormenev[1]

Co-authors: Hans-Georg Zaunick [1]; Rainer Novotny [1]; Kai-Thomas Brinkmann [1]; Pavel Orsich [1]

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The goal of the proposed irradiation studies is driven by ongoing research projects, which are either directly connected to the developments for the electromagnetic calorimeter for PANDA at FAIR and a submitted work package within the HadronPhysics2020 proposal for further improvement of the overall performance of scintillation materials like plastic based scintillators, PbWO4, YAG, LuAG, GAGG/GYAGG and DSB Based on the experiments performed in the past using the 150 and 190 MeV proton beams at KVI, radiation damage due to hadrons appears to be a dominating factor for the radiation hardness of different scintillation materials. Hadron induced fission or spallation processes creating highly ionizing secondaries lead to clustering of defects which cause a significant loss in optical transmittance. Those absorptions can be recovered by intense thermal treatment or in some cases an illumination with visible or IR light. Therefore, new materials and detector concepts have to be developed focusing on inorganic crystals, glasses or ceramics based on components of low Z value with a significantly lower fission probability. Alternatively, to homogeneous calorimeters sampling concepts are to be considered implementing fibers or thins sheets of inorganic materials into the absorber structure.

Therefore, a research program has been started to search for new materials. Besides the irradiation with low energy gamma rays (at the radiation center at Giessen), protons are an excellent probe with extremely high sensitivity. Complementary studies are foreseen using relativistic hadrons (24 GeV/c) at CERN.

In this project, we plan to irradiate scintillator samples of different sizes up to fluences of 1014-1015 protons/cm2 and the full characterization of the optical and luminescence properties before and after the irradiation. In addition, a technology optimization of different garnet families allowed to obtain bright and fast materials that in the combination with high density and satisfied radiation hardness to the electromagnetic part of the radiation field makes garnets perspective candidates for future high energy physics applications. It is crucial to verify the radiation resistance of these materials to the hadron irradiation as well. Other important task will be a development and testing of an experimental setup based on a compact spectrophotometer with fiber readout subsystem. Such kind of the setup should allow to test a degradation of the optical transmittance in situ and investigate a profile of the radiation damage with short time intervals after the irradiation sessions. At present moment one must wait months after the irradiation with relatively high fluences. So, some possible damage and recovery processes remain unexplored.

Title of experiment:
Study of the radiation damage and recovery effects in organic and inorganic scintillators for future detection systems

V. Dormenev, K.-T. Brinkmann, R. W. Novotny, P. Orsich, H.-G. Zaunick

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Main category of the contribution: **Detectors + Electronics**

Connections with other categories: **New physics cases**

Abstract

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1 Motivation

The PANDA collaboration at the future FAIR facility (Darmstadt, Germany) will employ antiproton annihilations for a widespread physics program. Lead tungstate ($PbWO_4$, abbreviation- PWO) scintillating crystals have been chosen for the Electromagnetic Calorimeter (EMC) [1] for the detection of high-energy photons, electrons and neutral mesons. Since PWO has a relatively low light yield (see table 1), the detector is based on an improved quality (PWO-II) for improved light yield and radiation hardness. An additional increase of the crystal light yield is accomplished by cooling the scintillator to a temperature of -25°C. However, under these conditions any statistical recovery of the radiation damage caused by populating defect centers is completely hindered. In spite of the significantly lower level of the radiation dose compared to the environment of LHC experiments in particular with respect to the hadronic component, the stability of the optical transmittance of the crystals represents a major impact on the achievable resolutions.
Since the Bogoroditsk Technical-Chemical Plant (BTCP Bogoroditsk, Russia) the major supplier of high quality PWO crystals went out of business, PANDA requires still more than 8000 crystals. A new manufacturer CRYTUR (Turnov, Czech Republic) has restarted the PWO production aiming for similar quality [2]. In that technical process of optimization and the need for additional suppliers of raw material, the irradiation with protons of ~ 50-190 MeV energy is an ideal probe for the achieved quality.

Table 1: Properties of crystals used for scintillation detector devices.

crystal type / properties	**PWO**	**GAGG:Ce**	**LuAG: Ce**	**DSB: Ce**	**YAG: Ce**
density (g/cm^3)	8.28	6.7	6.7	3.8	4.5
radiation length X_0 (cm)	0.89	1.61	1.4	3.6	3.5
decay time (ns)	<20	80, 800	50	30, 500	100
emission wavelength (nm)	420-440	520	530	430-460	550
Number of emitted photons / MeV at RT	100-200	46000	12500	500	24000

Table 1 shows a comparison of a few selected inorganic scintillators which are under consideration even for additional and future projects. Fig. 1 demonstrates the effect of radiation damage due to high energy protons. The shown spectral distribution of the optical transmittance shows a dramatic shift of the absorption edge at shorter wavelength which has a dramatic impact on the transmittance of the scintillation light near 420 nm. The results obtained at CERN have been nicely reproduced using 150 MeV protons at KVI indicating that the proton induced fission in the crystal leads to severe damage [3].

As a consequence, several groups have started to search for alternative scintillation materials as well as detector concepts such as sampling calorimeters. One of the directions is the investigation of scintillators composed of ions of lower Z such as GAGG/GYAGG: Ce, LuAG: Ce, YAG: Ce or even LYSO: Ce to reduce the fission probability. In parallel, detector setups for future accelerator such as the ILC need large volumes of active material at moderate costs. Therefore, glasses or glass ceramics have been investigated such as DSB:Ce even loaded with Gd^{3+} ions. This material is composed of $BaO*2SiO_2$ as a glass matrix treated later in several annealing processes to form scintillating nano-structures [4-5].
In order to reduce the absolute loss of detectable scintillation light due to the degradation of the optical transparency concepts for sampling detectors are investigated. The sandwich of absorbing and active layers reduces the thickness of the individual scintillator plate and reduces the sensitivity to damage. Prototypes based on CeF_3 and LYSO:Ce are under investigation for a replacement of the endcaps of the CMS-ECAL. In that respect even radiation hard organic plastic scintillators could be considered [6].

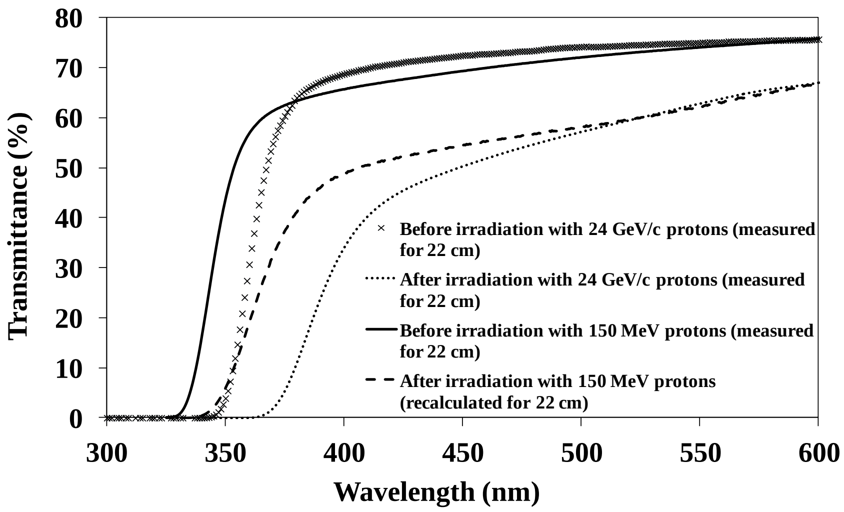

Fig. 1. Comparison of the experimental data for the irradiation damage due to 24 GeV/c and 150 MeV protons. The results at lower energy have been rescaled to a crystal length of 22 cm using the experimental absorption coefficient d$k(\lambda)$ obtained for the 5 cm sample.

In the framework of sampling calorimeters even with the concept of dual read-out to identify event-wise the hadronic and electromagnetic component of a jet, for example, inorganic fibers become of interest [7]. Based on new technology, quadratic fibers with typical dimensions of 1 mm^2 cross section can be produced using hot wire cutting from bulk scintillators in a cost and time effective procedure.
However, common to all new concepts is to establish and confirm the radiation hardness.

Research objectives:

- Study of irradiation and recovery processes in $PbWO_4$ scintillation crystals of different shapes and sizes.
- Test of the radiation hardness of $PbWO_4$ samples grown from different raw materials.
- Irradiation of various samples of garnet scintillation materials available as blocks or fibers.

- Irradiation studies of new organic scintillators.
- Irradiation studies of new glass and glass ceramics scintillators

2 Irradiation programs

2.1 Radiation damage in PWO crystals

The program based on PWO will focus on the quality and radiation hardness of small and full-size samples provided by the new manufacturer CRYTUR. In case of large samples, the focused proton beam can be used to study the homogeneity of the crystal in longitudinal direction which is strongly dependent on the appropriate local doping concentration.
Due to the limited availability of already tested and quality confirmed raw material new supply has to be collected and carefully investigated. Finally, it requires the test of radiation hardness which goes beyond the sensitivity of any chemical analysis. Contaminations have a direct impact on the concentration of defects and created color centers. Therefore, several series of small samples have to be irradiated and investigated with respect to changes of the optical transparency.

2.2 Radiation hardness of inorganic garnet scintillation crystals and new organic materials

As a continuation of the already started survey samples of garnet materials will be compared with respect to sensitivity to radiation damage due to protons. There are only selective studies published in literature and additional measurements are required to understand the underlying mechanisms. The materials will not be restricted to applications in calorimetry but also might be candidates for medical tomography or neutron detection. It was established that polyethylene naphthalate (PEN) demonstrates scintillating properties without any additives and has great potential as a scintillation material for radiation detection [8-9]. A radiation damage study of the material will be an important task for future possible application.

2.3 Radiation hardness various scintillators shaped as fibers

The application of inorganic fibers is a new task and became available and attractive due to the development of the so called micro-pulling-down technicque. However, it turned out that there are general problems which exclude some materials in particular in case of doping. One can overcome that problem by growing large volume crystal ingots which are later on cut into fibers. It takes advantage of the long experience on growing large crystals by the Czochralky or Bridgeman method to reach homogeneous raw crystals. The irradiation with protons allows not only to test the radiation hardness but also the overall attenuation of the light within the fiber.

Summary

The availability of a 50-190 MeV proton beam creating up to high fluences of particles per cm^2 represents an excellent tool for studying the quality of scintillators and to contribute to the understanding of the damaging mechanisms. These investigations provide substantial information for a wide range of application in detector technology, not only restricted to the direct impact on the PANDA calorimetry.

period / shifts	Crystal rad. damage study	Scintillating fiber response	total
phase 1	3	1	3
phase 2	3	1	5
total	**6**	**2**	**8**

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Development of a high-efficiency neutron detector with direction identification capability

Authors: Cristian Massimi[1]; Agatino Musumarra[2]; Maria Grazia Pellegriti[3]; Francesco Romano[2]; Francesco Leone[2]; Nikolas Patronis[4]; Anastatios Lagoyannis[5]; Sotirios Harissopulos[5]; Michail Axiotis[6]; Mauro Villa[1]; Roberto Spighi[1]

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Title:
Development of a high-efficiency neutron detector with direction identification capability

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General description:
Within the Euro_labs framework we propose the realization and study of the performance of a Recoil Proton Track Imaging (RPTI) system suitable for fast neutron tracking. In fact, neutron detectors are an essential tool for developments in many research fields, as nuclear, particle and astroparticle physics as well as radiotherapy and radiation protection. Since neutrons cannot directly ionize, their detection is only possible via nuclear reactions with nuclei constituting the matter. In particular, the study of fast neutrons is often based on the neutron-proton elastic scattering reaction. In this two-body reaction, the ionization caused by recoil protons in a hydrogenous material constitutes the basic information for the design and development of neutron detectors. So far, proposed RPTI detectors using n-p elastic scattering show clear limits in terms of detection efficiency, complexity, cost, and final implementation [1,2]. To address this deficiency, we propose a novel recoil-proton track imaging system in which the light output of a fast scintillation signal is used to perform a complete reconstruction in space and time of the event.
The proposed project requires the access to research laboratories (INFN-Legnaro, Open Physics Hub – OPH - Bologna) and neutron beam facilities (NCSR "Demokritos"-Athens and n_TOF-CERN) in order to develop the detector, test different aspects and benchmark Monte Carlo simulations. We have estimated a cost of 80 kE for the R&D of the proposed detectors. In particular, 20 kE are needed for the transnational access to INFN-Legnaro, OPH, Demokritos and CERN 50 kE for the instrumentation and 10 kE for consumables.
It is worth mentioning that, if successful, this novel detector will play a relevant role in nuclear and subnuclear physics as well in applications in the next years. For instance, the n_TOF collaboration at CERN intends to perform a measurement of the neutron-neutron scattering length in a wide energy range (10-100 MeV), using the neutron induced deuteron breakup reaction. On the other hand, the FOOT (FragmentatiOn Of Target) collaboration aims to improve the tumor treatments in hadrotherapy by studying the behavior of the used particle beams and is planning to start a dedicated measurement campaign on neutron production.
The feasibility of these challenging experiments depends on the availability of a neutron detector with particle discrimination capability, able to reconstruct the neutron trajectory in order to operate in an experimental environment highly contaminated by the presence of background.
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Challenges:
Demonstrate the possibility to reconstruct with sufficient precision the tracks and the vertices of neutron interactions inside a plastic scintillator. Different approaches are under study.

Original aspects:
The proposed system represents a novel technique in the field of neutron physics as well as in the one of particle detection.

Unique expertises:
Cristian Massimi is a senior researcher and is currently the chairman of the italian n_TOF Collaboration (43 researchers). He has gained a consolidated experience in the field of neutron physics and related topics.
Mauro Villa is a full professor with longstanding expertise in particle physics, detectors and, in particular, in electronics and acquisition systems development.
Agatino Musumarra led several research activities in the field of nuclear physics and astrophysics, with a particular interest for radiation detection technology.
Francesco Leone has gained a longstanding experience in astrophysical techniques, in particular optical spectrometry and imaging.
Francesco Romano, researcher at INFN-Sezione di Catania, is a Geant4 developer with skills and competences in the field of simulation, dosimetry and medical physics.
Maria Grazia Pellegriti is a researcher at INFN-Sezione di Catania, with skills and competences in data analysis in the field of nuclear physics and astrophysics, nuclear detection techniques and detectors for astro-particle physics.
Roberto Spighi is a senior researcher at INFN-Sezione di Bologna, with skills and competences on data analysis in the field of particle physics, nuclear physics for medical applications and particle detection techniques.
Nikolas Patronis is a professor at the university of Ioannina with longstanding experience in the neutron physics field, leading experiments at ISOLDE, NCSR "Demokritos" and n_TOF.
Sotirios Harissopulos and Anastatios Lagoyannis are Directors of Research at NCSR "Demokritos" at the Institute of Nuclear and Particle Physics. Both of them, as well as Michael Axiotis, who is also a researcher at NCSR Demokritos, have long experience and significant contribution in neutron physics and on the development of nuclear physics instrumentation.

Common expertises and collaborations:
Some members of the research team have been collaborating within different project since more than 10 years (for instance, n_TOF, ATLAS, ISOLDE and FOOT).

Synergies with other communities:
Interesting research area which can benefit from the viability of the proposed neutron detector is the one related to the study of energetic particles emitted by solar flares such as solar neutrons. Experimental systems with neutron-veto requirements, as for example dark matter experiments, could be interested on the application of the present detection approach after some developments required to apply it to larger scale detectors. Finally, the neutron detector proposed in this project could have a relevant impact for radiation protection, possibly overcoming some of the limitations of the current technologies.

Main category of your contribution: Detectors + Electronics
Connections with other categories: New Physics Cases, Training, Education, Outreach, Social Impact

New radiation hard detectors for nuclear physics measurements at RIB facilities.

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Title:

New radiation hard detectors for nuclear physics measurements at RIB facilities.

Authors and affiliations:

M. La Cognata (on behalf of the ASFIN collaboration) & S. Tudisco – INFN-LNS

General description (methodology, goals,..):

This project proposes to develop groundbreaking detection systems, which will be of great benefit for the nuclear physics community and the TNA RIs. The availability of increasingly intense stable and radioactive ion beams and the new questions coming from multimessenger astronomy call for a parallel development of detector physics.

Challenges:

Nuclear astrophysics aims to measure cross sections of astrophysical importance, vanishingly small at astrophysical energies (of the order of few hundreds keV), making it necessary to push beam intensity as much as possible. On the other hand, emitted particles often have energies making their identification extremely complicated due to the detection thresholds and, in the case of identification of pulse shape analysis, to the short tracks in the detector.

Also, studies using e.g. radioactive ion beams will need to cover angles as close as possible to the beam axis, due to the highly inverse kinematics in the case of the measurement of reactions involved in the r-process, synthesizing heavy nuclei in neutron star mergers.

In both cases, present-day silicon detectors though guarantying high performances in terms of angular and energy resolution, cannot stand the high doses deposited in the duration of a typical experiment. Also, their thickness would not allow to perform particle identification by means of the standard DE-E approach.

Original aspects:

The main aim of the project will be the development and test of a class of radiation-hard detectors, made of silicon carbide wide-band-gap semiconductor, especially suited for applications in nuclear astrophysics experiments both at accelerator laboratories and at laser facilities, where an even larger radiation field is expected.

Unique expertises:

Silicon carbide (SiC) is one of the high band gap (3.28 eV), fast (saturated electron velocity vSiC > vSi) compound semiconductors which has been considered as a potential alternative to silicon for the fabrication of radiation hard detectors; it is particularly attractive for laser driven experiments because SiC devices show large thermal stability and are insensitive to photons in the visible range. Also, thanks to their radiation hardness, it will be possible to stand the high radiation flux and also present a better signal-to-noise ratio at high temperature.

We will especially aim at studying the possibility to implement monolithic multilayer SiC device, combining the advantage of radiation hardness and very-low threshold particle identification through the DE-E approach, with a clear benefit for RIs offering TNA.

Common expertises and collaborations:

Nuclear astrophysics, applied physics

Synergies with other research/technical groups:
Groups working at laser facilities, where intense burst of particles are produced

Synergies with other communities:

Main category of your contribution:
Detectors + Electronics

Connections with other categories:
Beams + Targets
Data Acquisition + Analysis, Simulations
Theory
Training, Education, Outreach, Social Impact
New physics cases

Proposal for test of high radiation hardness of thin (23 μm), self-biased, epitaxial silicon detectors operated in build-in-field bias potential

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Abstract.

The problem of detector radiation hardness is very important for experimental physics. In an attempt to improve detector radiation hardness special detector technologies and new materials like diamond or silicon carbide have been tried. The aim of this proposal is to test a thin silicon epitaxial detectors operated in a built-in-field bias potential without any external bias. It seems to be more resistant to radiation damage due to the extremely low bias potential generated by internal built-in-field potential and low detector thickness. Low detector thickness prevents doping of the detector material since all heavy ions are not stopped in it.

Test detectors were constructed using silicon epitaxial n^+ - n structures of resistivity epitaxial layer of resistivity ρ > 400 Ω•cm and thickness about 23 μm. The detector junction n^+ - n - p^+ was obtained using B^+ implantation into epitaxial n - type side using low-temperature technique [1]. The self-biased thin detectors were mounted in detector housings supplied with entrance windows of diameter 2 mm.

The radiation damage tests of self-biased detectors were performed using 90 MeV ^{14}N beam scattered by 10 μm Au target during 5 days at Heavy Ion Laboratory of Warsaw University. Self-biased thin epitaxial detectors were irradiated with the total dose of 90 MeV, ^{14}N ions about $7.1x10^{14}$ ions•cm^{-2} without any observed considerable detector radiation damage [2]. Its means that detector internal built-in-field potential was independent on the exposed dose which is justified by the formula below: The difference of carriers concentration between detector substrate (n^+) and epitaxial layer (n^-) created the build-in-field potential difference as [3]:

$$V=-(kT/q)\ln(n^+/n^-)$$

where k is the Boltzmann constant, T is the absolute temperature and q is the electron charge. Since 90 MeV ^{14}N ions punch through a thin detector, therefore concentrations n^+ and n^- remain unchanged. According above formula built-in-field potential difference should not be sensitive on the 90 MeV ^{14}N ions exposed dose. It is very important to check this above conclusion.

To do this now we propose proposal for continuation of radiation damage experiments with high dose of heavy ions directly hitting the thin silicon detectors operated in internal built-in-field potential.

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Title: **MICRODOSIMETRY FOR HADRON THERAPY**

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General description:

In everyday practice of proton radiotherapy planning, a constant RBE of 1.1 is assumed all along the proton penetration depth, despite the biological evidence of an increased RBE at the distal edge, in correspondence of a fast LET increase. Advanced treatment modalities that take into account the LET and RBE variation along the proton beam could help limiting the dose to the surrounding healthy tissue and critical organs, thus resulting in a higher therapeutic gain. Treatment planning systems that take into account the LET or RBE variations would therefore benefit from the availability of detectors that enable both LET and RBE assessment. With this purpose, at the INFN laboratory in Legnaro a miniaturized microdosimeter (mini-TEPC) has been developed to cope with high fluence rates of hadron therapy. To be introduced in the clinical practice, microdosimeters must be simple to use and reliable, the repeatability on the short term and reproducibility of the measurements must be guaranteed. These detectors need to be tested in the well-known neutron fields that are available at the CN accelerator of LNL.

Challenges:

Engineering of the mini-TEPC is ongoing, with the construction of several prototypes that must guarantee the reproducibility of the response and the capability to monitor both the LET and the RBE of therapeutic beams along their penetration depth. **The new detectors must be first characterized in well known radiation fields available at the INFN accelerators.**

Original aspects:

Microdosimetry offers unique tools for the quality assurance of LET or RBE based treatment planning systems.

Unique expertises:

LNL has unique expertise in the design and construction of miniaturized TEPCs.

Common expertises and collaborations:

Collaboration with Universities (Milano, Napoli, Trento, Hasselt in Belgium) and metrological Institutions (SCK in Belgium, NPL in UK, PTB in Germany), ICRU (International Commission on Radiation Units & Measures)

Synergies with other research/technical groups:

Radiobiology, Mechanical Engineering, Data acquisition

Synergies with other communities:

Community of medical physicists and radiation oncologists

Main category of your contribution:

Detector and Electronics

Connections with other categories:

- Data Acquisition + Analysis, Simulations
- New physics cases (for instance, study of physical aspects in the proton boron capture therapy)
- Health Science

Title:

PRIMADER: Proton and **I**on beams for **Ma**terial and **De**tector **R**esearch

Authors and affiliations:

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[1]) IFJ PAN Krakow, [2]) HIL UW Warsaw

General description (methodology, goals,..):

Since many decades particle accelerators are being used at IFJ PAN Kraków and HIL UW Warsaw for basic nuclear physics research and for studies in biology, medicine and material engineering. Nowadays, the two operational accelerators at the CCB cyclotron center at IFJ PAN are the isochronous cyclotrons: *PROTEUS-235* for 70-235 MeV protons and AIC-*144* for protons, deuterons and α particles, up to 60 MeV. In addition, IFJ PAN runs a Van de Graaff Accelerator for up to 2.5 MeV for protons and He+ ions and 5 MeV for α particles. The isochronous U200P cyclotron of HIL UW accelerates heavy ions from ^{11}B to to ^{40}Ar to energies of 3-8 MeV per nucleon.

This complementary set of accelerators provides light ion beams, which in case of protons cover full range of energies up to 235 MeV and heavy ion beams with the most intense ones of: ^{14}N, ^{18}O and ^{20}N, which can be offered, also to external users, for scientific research and for applications.

In the current proposal we consider a service aimed at providing the ion beams available in the both institutes for testing components of various detector systems prepared for large scale European nuclear physics experiments. As well, it will enable in-beam material research, including radiation hardness tests.

Challenges:

Experimental setups in large scale EU laboratories (FAIR, SPIRAL, SPES) which will provide radioactive ion beams (RIB) require novel detection systems enabling precise determination of position and energy of projectiles. Such a beam tracking procedure involves monitoring and selecting accelerated ions as they pass through several stages of an ion separator, characterizing them upon impact on a reaction target, and possibly identifying the reaction products. The use of RIB will enable breakthrough scientific experiments; however, they will depend on multidetector systems to measure with high precision the radiation and particles emitted in the reactions induced by the beam. High resolution in energy, time and position are basic requirements for these detector systems. Both applications- the projectile tracking and the radiation detection, will take advantage of an easy to access and versatile facilities, as CCB at IFJ PAN and HIL UW, enabling in-beam tests of the detector components.

On the other hand, space sciences and industry rely on radiation hard materials used in mechanical constructions and electronics. The proton beam in the energy range up to 60 MeV at high intensity, delivered by the AIC-144 cyclotron, can be used for radiation hardness tests of the electronic components, construction materials as fiber optics, glues, materials for 3D printing, etc. and also for determination physical parameters for radiation detectors.

Heavy ion beams of the U200P cyclotron in Warsaw can be very useful for extensive tests of the experimental electronics: detectors and signal processors. Irradiation by heavy ions causing a large dose deposit can simulate real conditions of experiments, for example with intense radioactive beams.

Unique expertises:

The medical cyclotron Proteus C235 at CCB provides proton beam with energies between 70 MeV to 230 MeV, with energy spread �E/E < 0.7%. Change of the beam energy can be done within a few minutes thanks to the automatic energy selection system. The precision of a beam spot positioning is of the order of 1mm^2. Intensity of the proton beam available for the detector testing may vary from 20 nA at 230 MeV to 30 pA at 70 MeV. The proton beam can be used to irradiate samples installed at the two medical treatment stands, equipped with gantry systems, but it can be also transported to the

independent experimental hall where complex detection setups can be arranged. In particular, a facility for fast scanning of large area detectors in terms of their energy response and position resolution can be implemented there. The experimental site is equipped with: large vacuum chamber with diameter of 1.5 m; laser system for easy alignment of the setup components; "clean" power supply; crane with maximum load of 2T. General purpose digital data acquisition allows to monitor a detector response on line and to store data on discs.
The proton beam from the AIC-144 cyclotron can be flexibly configured and formed both in terms of the energy prepared for particular irradiation (energy can be changed through degradation by quasi-continuous or stepwise mechanical degrader) and spatial distribution (beam collimation, scattering). Beams with Gaussian distribution as well as wide parallel beams are available. Irradiation facilities provide a wide range of beam parameters: flux 10^5 - 10^9 particles*$cm^{-2}s^{-1}$, fluence: $2x10^5$– 10^9 particles*cm^{-2}, total dose deposition during one run of irradiation from 0.001 Gy to 100 kGy. The movable XY table with the dedicated sample holders allows for easy mounting of the user's equipment during tests in beam.
Irradiation with heavy ion beams (e.g. ^{12}C, ^{14}N, ^{16}O, ^{20}Ne, ^{32}S) at energy up to 8 MeV/nucleon available at HIL, can be performed with fluence from 10^9 to 10^{15} particles*cm^{-2}. Maximum size of the sample is $1cm^2$. The fluence and its homogeneity can be monitored. A temperature monitoring of samples is under development.

Common expertises and collaborations:
In 2019, successful scanning of novel position sensitive active target detector- bPLAST for DESPEC experiment at FAIR was carried out with 70MeV protons, providing results valuable for the detector prototype evaluation. As well, several in-beam tests of detectors prepared for the FAZIA telescope array and the CALIFA- scintillator array for R3B-FAIR and SPIRAL2 experiments were performed, taking advantage of the full proton beam energy spectrum available at CCB.
The proton beam from the AIC-144 cyclotron were recently used for determination of radiation hardens for electronic components and construction materials specially designed for the CBM/FAIR experiment. The radiation protection shielding for camera matrices for the first Polish satellite LEM has been tested. Irradiation of the CMOS prototype detectors for LHCb has been carried out. A typical application of the AIC-144 proton beam are studies of the properties of diametric detectors (TLD, OSL, alanine, RPL) and parameters of materials for proton radiotherapy applications. Also, irradiation of the Low Gain Avalanche Diode (LGAD) sensors, the emerging detector technology, are planned to be performed at AIC-144 in view of their potential application at the High Luminosity LHC and Electron-Ion Collider detectors.
At HIL there were preformed commissioning experiments of various detection systems (e.g. CUP- a scintillator detector and diamond charge particle detectors). Also, radiation hardness tests of semiconductor detectors were done using the irradiation station. This station is routinely used at HIL for the radiobiology studies.

Synergies with other research/technical groups:
HISPEC/DESPEC and R3B at NUSTAR/FAIR, SPIRAL2 at GANIL, SPES at LNL INFN, LGAD Consortium – LGAD sensors for High Energy Physics and Nuclear Physics experiments

Synergies with other communities:
FAIR, CERN, EIC, BNL, space agencies, radiobiology and radiomedicine research groups.

Main category of your contribution:
Service

Connections with other categories:
Improved access to RI

Title: R&D for a Target Recoil Tracking Detector

Authors and affiliations: R3B collaboration; D. Cortina[1], T. Aumann[2,3], O. Tengblad[4], R. Gernhäuser[5], J. Cederkall[6], JL. Rodríguez[1], N. Kurz[3], O. Kiselev[3], M. Labiche[7], S. Pachalis[8], M. Petri[8],T. Kröll[2], H. Simon[3], D. Savran[3], J. Taieb[9] , …

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General description:

FAIR (Facility for Antiproton & Ion Research https://fair-center.eu) is the largest project for nuclear physics research worldwide. R3B (Reaction with Radioactive Relativistic Beams) is a major facility of the NUSTAR pillar (Nuclear Structure, Astrophysics and Reactions http://www.fair-nustar.de/en/) of the FAIR experimental program and will be the first facility to get beam during the FAIR Phase-1 in 2026.

R3B is the facility to perform reaction-experiments in Full Inverse Kinematics at Relativistic energies with exotic nuclei. The facility is composed of five main components; Incoming tracking, Target-region, GLAD, Outgoing tracking, NeuLAND. In order to obtain full kinematics i.e. be able to sum-up all the energy and momentum released, the Target-region detection is crucial. A major component here is the CALIFA γ-spectrometer partly developed during the ENSAR and ENSAR2.

What is here proposed is R&D on an inner Target Recoil Tracking Detector (TRTD) that should detect, identify and track the recoils emitted from the target at large angles. This part is particularly challenging as a very high angular resolution is required which implies very high segmentation and at the same time very thin multi-layer sensors to minimize multiple scattering. Moreover, the requirement to minimize the scattering of emitted gamma rays sets an additional limit to the overall material content the target area that introduces further complications in the design.
The general need for such a silicon solution is supported by similar attempts, e.g. by using gaseous detectors (like MINOS) or dedicated detector telescope arms with constraints in the viewed solid angle. The particular advantage and importance here is a closed geometry around the extended target, where the vertex can be reconstructed in nearly 4π geometry.
Another example is the fact that such a detector array can be operated without constraints, in strong magnetic fields.

The TRTD consists of multiple layers that track light charged particles and allows for reaction-vertex reconstruction and angular reconstruction. Several possible solutions are already under investigation for the different layers of the TRTD; highly segmented Si-detectors, Si-Pixel-detectors, but also Fibre detectors can be a robust and cost-effective solution, especially for a 2nd or 3rd layer tracking.

Challenges

The unambiguous identification of target recoils is challenging, especially to minimize the material content and on the same time obtain an extremely high segmentation. We are aiming for sensors for the 1st layer of 50-100 μm thickness, an angular resolution of better than 1 mrad, large angular coverage, low noise level to allow detection of minimum ionising particles (MIP) but at the same time sufficient dynamic range up to x50 MIP, spark protection when highly ionising particles hit the detector, high multi-hit capability and sufficient time resolution in the ns region.

1. Evaluate the existing detector solutions
2. Evaluate possible ASIC
3. Evaluate/Design/prototyping Si-pixel solution, in particular for the 1st layer
4. Design/prototyping Fibre-detectors that can fit around the target inside vacuum
5. Design/prototyping Fibre-readout inside/outside vacuum
6. Optimize/minimize the material content

Original aspects:

The very special conditions in nuclear reaction experiments apply a need for specific adopted readout electronics in order to take full advantage of the sensors.

Common expertise and collaborations:

- ***Si detector***

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IGFAE, University of Santiago de Compostela, Spain
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- ***Fiber detectors***

GSI Helmholtzzentrum für Schwerionenforschung
Institut für Kernphysik (IKP), Technische Universität Darmstadt, Germany

- ***Multi wire proportional chambers***

DPhN, CEA-Irfu, France
Institut de Physique Nucléaire, CNRS/IN2P3, France
IGFAE, University of Santiago de Compostela, Spain

- ***ASIC & related electronics***

Institut de Physique Nucléaire, CNRS/IN2P3, France
Department of Physics, Technical University Munich
Institut für Kernphysik (IKP), Technische Universität Darmstadt, Germany
GSI Helmholtzzentrum für Schwerionenforschung
Nuclear Physics Group, STFC Daresbury Laboratory

- ***Simulation and detector response***

IGFAE, University of Santiago de Compostela, Spain
Nuclear Physics Department, Lunds University
Nuclear Physics, IEM – CSIC, Madrid, Spain

Dpt. of Physics, Univ. York, UK.
Nuclear Physics Group, STFC Daresbury Laboratory

Synergies with other research/technical groups:

The technical developments foreseen in this project can be extended to other facilities and experiments where very precise tracking of fragments is needed, as well as for beam-observation.

Synergies with other communities:

- Medical physics; proton CT scanner for treatment planning
- High energy physics; particle tracking

Main category of your contribution:

- Detectors + Electronics

Connections with other categories:

- New physics cases
- Training, Education, Outreach, Social Impact

DMP + Data Sharing

Nuclear Physics initiative for Open Science (NuPhOS)

Authors: Antoine Lemasson[1]; Adrien Matta[2]; Emmanuel Clement[3]; Nicolas MENARD[3]; Diego Gruyer[4]; Jérémie Dudouet[5]; Olivier Stezowski[6]; Simone Bottoni[7]; Thomas Roger[3]; John Frankland[3]; Diego Ramos[3]; Gilles de FRANCE[3]; Marek Lewitowicz[3]; Eric Legay[8]

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The quest for Open Science represent an opportunity for the nuclear physics community to improve the management and use of the large data sets produced in main nuclear physics facilities, including resident and traveling detectors.

As a goal towards an Open Science nuclear physics, the development of suited data workflow that could be shared among the European facilities would represent a major step forward. The data produced in these facilities should follow the FAIR principles (Findable, Accessible, Interoperable and Reusable) to ensure a long term storage and possible future use by the community.

With this goal we propose the creation of a joint European network/council on the standardization of data, meta-data and associated software within the nuclear physics community. The scope will cover main nuclear physics facilities, resident and traveling detectors. The aim is :

1. to define the required standard and associated good practice across all major European laboratories towards the definition of a common Data Management Plan for the community.
2. to define and implement the required software environment.
3. develop and/or deploy homogeneous analysis platform for the community

Below we draw a non exhaustive list of points that could be addressed by the network:
- Create a catalog/database of existing data set, and the associated meta-data (documentation, exploitation software, digital logbooks, unique identifier, …)
- Generalise the adoption of open data policies, standard metadata and FAIR data stewardship, and define the Access stewardship.
- Define the requirement in term of long lasting data storage (life time, redundancy, format, analysis environment) and identify existing facility.
- Define data workflows covering the various environment of data production (large collaborations, local setup, …)
- Define the organization necessary within each data producing installation to coordinate this effort (Data Officer, …)
- identify the synergies with existing and new data acquisition systems and the development of the required software and platforms
- promote the good practice in analysis software development, integration and deployment
- Define the framework for open access to data and their associated meta-data to ensure their use beyond their initial scope (data mining, AI, training and outreach purposes …)
- Define guide lines on the different level of data processing that should be offered to user (raw data, pre-processed data, refined data…)
- Study and develop synergies with existing European Open Science Clouds scientific clusters in the

communities of astronomy and particle physics (ESCAPE) and photonics and neutronics (EXPANDS, PANOSC).

The network or council could be composed of representative of the involved laboratories, as well as the main collaborations. The goal is to establish the basis and framework for a workable Open Science initiative that will accelerate discoveries, increase scientific value by sharing data and knowledge within scientific communities and would allow nuclear physics to broaden its impact in both science and society.

Title**: A common infrastructure for isotope production data**

Authors and affiliations: S.Rothe, J. Ballof(CERN)

General description (methodology, goals,..):

In order to plan experiments at rare isotope facilities, most of them provide extensive databases in which the available beams are listed. These information can be based on in-target production from theoretical models or list actual measurements obtained under real conditions.
Examples:
https://mis.triumf.ca/science/planning/yield/beam
https://isoyields2.web.cern.ch

Scheme for laser ionization
https://riliselements.web.cern.ch/

There are different aspects:

The database model or schema
Describes how different entries are linked together

The user interface
Simple Data display and maintenance
Data analysis tools (correlation, yield prediction, etc)

Application programming interfaces:
Necessary for meta-databases
Providing data to application of users

The data
Simulation data
Measurement data
Target information, link to logbooks etc.

The maintenance and development of such a database depends strongly on qualified personnel, knowledgeable about the three aspects mentioned above.
Typically the (three) aspects are treated differently in the different facilities which definitely counts as duplication of efforts, which should be avoided.

The development of the CRIBE database has already shown that there is common interest to share at least the data in one platform (http://eurisol-jra.in2p3.fr/wp-content/uploads/sites/3/2019/04/JRA-EURISOL-Task3-cribe-Milsestone-MS52.pdf).
Here we propose to go one step further and co-develop the database framework (schema and user interface) using common tools such that common expertise is generated that can benefit all facilities. The developed code shall be shared using tools like gitlab (https://about.gitlab.com/) (e.g. hosted by CERN). On top of that, a common hosting of all applications and databases could be considered, so that the software is provided as a service to all facilities.

A secondary aspect could be to formulate common methodologies to assess yields. This could be useful due to often similar infrastructure (like tape stations) to measure yields and contribute to the data quality.

The important factor would be that each institute is responsible for their own data, but contributes to improvement of the code commonly used.

Challenges:
Defining a common database model and type, programming language and framework for the user interface.
Definition of common protocols for the yield assessment.

Original aspects:

Open software code sharing using a common repository across facilities.

Unique expertises:

- Pulsed beam
- Yield Prediction tool

Common expertises and collaborations:

Databases
Web applications
Yield measurement and in-target production simulation

Synergies with other research/technical groups:

Basically all RIB facilities

Synergies with other communities:
All users would benefit from similar look and feel across the facilities.
Integration of a meta database like CRIBE would be simplified.

Title:
FAIR experiment data: Findable, Accessible, Interoperable, Re-usable.
Develop the management of large-scale data sets and complex experiment data to serve large international user communities in different laboratories in Europe in a performing way.

Authors and affiliations:
Thorsten Kollegger, Christoph Scheidenberger (GSI)

General description (methodology, goals, …):
The broad physics program enabled by the access facilities relies on different data-streams from various experiments, accelerators and related major research instruments (e.g. FRS, PRISMA, REX, etc.). This project aims to make these data easily accessible to the users according to the *FAIR* principles (Findable, Accessible, Interoperable, Re-usable). By adding enriched meta-data information to the data-streams, synchronizing them and making them available via a common portal the end-user analysis will be significantly enhanced; and sharing and re-use of the unique data will be facilitated. The implemented tools and methods will be embedded in the existing European and international frameworks where applicable, thus making the data easily accessible for the international user community.
It is planned to develop platforms and gateways, which are accessible remotely (so that users can access and use them where ever they are, in particular from their home institutes) and which are largely harmonized (so that users find unified portals and tools at all access facilities).
The suggested work plan will proceed as follows:

- analysis of the present status of available data platforms at different user laboratories
- collection of needs (of user groups, laboratories)
- development of concepts and definition of common goals
- implementation of common portals and tools
- test and validation

Challenges:
Currently much of the data is collected in “silos”, which are not easily findable and accessible for the user groups.

Original aspects:

Unique expertises:
GSI is supporting a large and diverse user community and leading in many areas the data acquisition, curation and analysis organization activities, both for GSI experiments but also for experiments at other laboratories. GSI is involved in many national (e.g. Helmholtz Data Federation) and international activities (e.g. EU-project ESCAPE for the connection of ESFRI's to the European Open Science Cloud). In this context a broad set of tools and methods has already been developed, which can be used and adopted to the special challenges of the broad physics program with radioactive beams at GSI.

Common expertises and collaborations:
This should be discussed and implemented in ideally all TA laboratories.

Synergies with other research/technical groups:
The proposed project is based on technologies developed together with a broad set of partners. Examples on the national level are the Helmholtz programs, e.g. Data Management and Analysis (DMA) in the research area "Matter", in close collaboration with the activities of the research area "Information" and the activities in "Information and Data Science". Collaborations with other international partners exist as well. By basing this project on these activities, and by adding the unique and challenging aspects of the EURO-LABS physics program requirements, large synergies can be realized.

Synergies with other communities:
GSI is leading or participating the in common development of tools for data acquisition, simulation and analysis. Many of these tools are shared with other communities e.g., high energy physics, astroparticle physics, hadron physics, atomic physics. An example for the synergies is the EU-project ESCAPE, in which a common toolset is developed to connect the ESFRI's of the various communities to the European Open Science Cloud (EOSC).

Main category of your contribution:

Connections with other categories:

Improved Access

Need of a large size chamber at INFN-LNS to exploit Radioactive Ion Beams delivered after Cyclotron upgrading

Author: Paolo Russotto[1]

[1] *LNS*

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Title:

Need of a large size chamber at INFN-LNS to exploit Radioactive Ion Beams delivered after Cyclotron upgrading

Authors and affiliations:

P.Russotto[1], M. La Cognata[1], B. Gnoffo[2], S. Tudisco[1]

[1] INFN - Laboratori Nazionali del Sud, Catania, Italy
[2] INFN - Sezione di Catania, Catania, Italy

General description (methodology, goals,..):

The INFN-LNS in Catania are currently undergoing an upgrade of the research infrastructures. In detail, the upgrade of the LNS Superconducting Cyclotron is expected to increase the power of delivered beams of about 2 order of magnitudes, up to about 10 kW, for light and medium nuclei (A<40). A new fragment separator, FraISe, is being built in order to exploit the increase of primary beam power for the production of Radioactive Ion Beams (RIBs) by in-flight technique. The fragment separator consists in 2 couples of dipoles, in double achromatic arrangement, and will be able to deliver RIBs in a range of intensity going from 10^3 pps, as a typical value for very exotic isotopes, those very far from stability valley, to 10^7 pps, as typical for exotic isotopes near to the stability valley. Such an example, it is expected to have about $1.4*10^3$ pps for ^{14}Be, $6.8*10^6$ pps for ^{16}C, $2*10^7$ pps for ^{13}N. Selection slits on symmetry and exit planes will be used for the tuning of beam properties; the use of the so called degrader technique on the symmetry plane will be also foreseen for a better selection of the isotopes of interest among the cocktail beam. This will open new and very interesting perspectives for nuclear physics studies at LNS. Physics cases as clustering, resonances (GMR, Pygmy) in exotic nuclei, new/exotic decay modes, reactions/decays of astrophysical interest, reactions with high isospin asymmetric nuclei can be addressed.

Challenges:

The installation of a large and multi-purpose chamber at the exit of FraISe (focal plane of the fragment separator) will constitute a great opportunity for research groups, both internal and external, interested in using RIBs delivered by FraISe. This will be an ideal point where the maximum intensity of the RIBs, without need of further transport, can be pursued. A cylindrical large size chamber, GiRa, (length ≈ 2 m, radius ≈ 60 cm) is currently existing at LNS and could be adapted to the needs of the users and installed at the focal plane of FraISe.

Original aspects:

The possibilities of a large chamber will allow measurements with big and complex detectors, covering a large portion of solid angle and allowing ID techniques such as time of flight, needing relatively long base of flight. Coupling of different detectors will be also possible. In order to exploit the whole length of the camera, a new target holder systems needs to be designed and built. The installation of a rotating goniometric platform will be also envisaged.

Unique expertises:

Coping the opportunities of RIBs delivered by FraISe with the detection capabilities offered by high-performant detectors, made possible by a large size chamber, will greatly enhance possibilities and results achievable at LNS in a forthcoming years.

Common expertises and collaborations:

The joint efforts and collaborations of LNS groups and external groups, aiming to use the chamber as reaction point, will be envisaged to define the better technical solutions for the adaptation of the GiRa chamber.

Synergies with other research/technical groups:

As stated before, we expect that, in addition to local groups, also different international groups will make a large and successful use of possibilities offered by a large-size chamber.
Considering the broad impact that this proposal would have on the activities of a large number of LNS users, the LNS Users Committee supports the current initiative of adapting the GiRa scattering chamber for the use with RIBs soon available at LNS

Synergies with other communities:

A vacuum chamber in the focal plane of the fragment separator could be an opportunity also for the optimal use of selected radioactive beams for material science and radiobiological applications, such as radioisotope harvesting. The vacuum chamber equipped with a fast extraction system will avoid background and degradation of the beam due to its interaction with air and the exit window of the beam line.

(with reference to the categories described in the “Instructions for submission page”, https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Main category of your contribution:

Improved Access

Connections with other categories:

Beam+Targets

Toolkit for Remote Operations

Authors: Helena Albers[1]; Juergen Gerl[2]; Magdalena Gorska[1]; Giovanna Benzoni[3]

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Title: Toolkit for Remote Operations

Authors and affiliations:

[1]H.M. Albers, [1]J. Gerl, [1]M. Gorska, [2]G. Benzoni

[1]*GSI Darmstadt,* [2]*INFN Milano, plus any other interested collaborators. As yet, this proposal has not been widely circulated but other interested partner institutions will be invited to join in the near future. We anticipate a very positive reaction and support from the wider community.*

1 *General description (methodology, goals,…):*

The advent of the coronavirus pandemic has propelled a global shift towards remote and distance working. This fundamental change has affected all areas of business, economy, education and research. In response to this, the NUSTAR Collaboration has been actively developing new and innovative ways of establishing monitoring and control of detector hardware, data acquisition (DAQ) and data management/analysis from outside of the GSI campus. In particular, the R3B, HISPEC-DESPEC and FRS groups have begun to establish hardware, software and procedural changes required to run experiments at GSI from off site in order to limit the number of people on campus to a core minimum.

Although it is hoped that the COVID-19-related restrictions will begin to ease in the near future, it is clear that the ability to remotely access and control experimental features significantly benefits all kinds of nuclear physics experiments via:

a) minimization of on-site operations (reducing 'downtime' due to opening of experimental areas to access equipment, minimizing requirement of on-call experts to come in person to the facilities)

b) early problem recognition and intervention

c) fast and effective information and expertise exchange between collaborators

d) training and development of early-career researchers

The goal of this proposal is to build on the expertise and infrastructure developed for NUSTAR experiments aiming for a flexible 'toolkit' to enable remote operation of experiments both at large-scale as well as smaller nuclear physics facilities across Europe. Such an evolution towards off-site monitoring and control would not only significantly reduce experimental downtime but also enable far greater accessibility to global collaborators.

In order to reach this goal, not only hardware/firmware/software developments are required, but also sufficient infrastructure at facilities to operate and monitor remotely is needed. Advancements in the following areas are foreseen:

<u>On-site:</u>

- hardware control modules for (e.g. dedicated CFDs, bias supplies, scalers, temperature/water sensors, crates,...)
- other necessary hardware (e.g. dedicated PCs, Raspberry Pis, connectors, adaptors,...)
- significant software development (firmware, GUIs, web-browsers, on-line histogramming, daq control software,…)

<u>Off-site</u>

- PCs with sufficient processing power
- Other hardware (monitors, projectors,...)

<u>On-site and Off-site</u>

- Online, nearline and offline data management and data sorting
- Improved training of students and postdoctoral researchers
- Multi-speaker sets, cameras etc…

2 *Challenges:*

The development, setup and testing of hardware and software, as well as subsequent maintenance and growth, requires a significant amount of manpower and expertise. Funding available to visiting students or postdoctoral researchers to gain experience with the necessary architecture, as well as carry out the tasks related to hardware/software advancements, will be necessary. Additionally, the individual needs of each experimental facility, as well as the established organizational or procedural aspects already in place, will need to be tailored to. Moreover, as experimental setups become increasingly complex in nature over the next years, the hardware/software components required for remote operations will require constant evolution.

3 *Original aspects:*

While remote monitoring and control is well established at some international large-scale facilities (including CERN), a flexible toolkit providing

a) a complete package of hardware/software components,
b) standardized operation rules and procedures, and
c) support and training tailored to the individual facility needs

is not currently available.

4 *Unique expertises:*

Some facilities have started to work on remote operations capabilities and developed already some unique expertise. It is noticeable that different solutions have been found for various aspects. To become more efficient and ease the practice, harmonization of the approaches will enhance the capabilities.

5 *Common expertises and collaborations:*

Modern nuclear physics experiments are characterized by an increasing complexity forcing the community to continuously develop methodologies and techniques. This fostered collaborative efforts. Common developments and networking approaches are being practiced and form a solid basis for the proposed project.

6 *Synergies with other research/technical groups:*

One goal of the project is to investigate synergies.

7 *Synergies with other communities:*

One goal of the project is to investigate synergies.

8 *Main category of your contribution:*

Improved Access

Easier procedures, increase of number of RI involved, opening to new communities

9 *Connections with other categories:*

Strong links and inter-dependences with:

Detectors + Electronics: *Upgrades, travelling detectors and connected electronics, common pool, sharing R&D*

Data Acquisition + Analysis, Simulations: *New possibilities, machine learning, Artificial Intelligence*

Training, Education, Outreach, Social Impact: *Complementary hands-on training, Lab-University collaboration, coordinated outreach, gender equality*

Radioactive molecules for fundamental science

Authors: Ruben de Groote[None]; Iain Moore[1]; Gerda Neyens[2]; Kieran Flanagan[3]; Stephan Malbrunot[4]; Ronald Fernando Garcia Ruiz[4]; Ivana Belosevic[None]

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Radioactive molecules for fundamental science

These are preliminary ideas, and need to be discussed within a much wider community. The contents have also not been discussed with all interested facilities yet.

Proposers:

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S. Malbrunot-Ettenauer, CERN
I. Belosevic, TRIUMF

Related facilities (non exhaustive)

JYFL, ISOLDE, S3@GANIL, …
Potential non-European facilities: FRIB and TRIUMF

General description

Precision studies using molecules are increasingly important for a variety of research domains. In particular, searches for physics Beyond the Standard Model (BSM) using molecular probes have flourished in recent years. For example, the current limits on the value of the electric dipole moment of the electron are set by measurements performed using YbF , HfF^+, and ThO, having long overtaken the results achieved using atomic thallium. All these studies have so far relied on molecules with only stable atoms. However, a wealth of theoretical work has shown that heavier **molecules containing radioactive atoms represent much more sensitive probes for new physics**, often by many orders of magnitude, and with unique access to symmetry-violating nuclear properties.

However, at present, the radioactive isotope (RI) community does not have the expertise to complete such challenging measurements, while the Atomic, Molecular and Optical (AMO) sciences which currently perform these studies do not have the required expertise in the use of radioactive beams. **We wish bring together RI and AMO experts through the organization of workshops, schools and related training activities** under the EURO-LABS framework**.** These meetings will enable the required knowledge exchange, facilitate new collaborations, and will enable integration of new domains of research into RI laboratories. Through schools and other training activities, young scientists can be trained in the skills required for successful research in those fields. Thus, technical developments can be realized which will overcome the challenges presented in the next section.

Furthermore, we aim at triggering the interest for the following developments at RI facilities, which will not only benefit the science case of this project, but will also open opportunities for scientific projects in other research domains.

1. Trigger interest for the development of a variety of molecular radioactive beams (ISOL-type) at a European and international facilities (ISOLDE, JYFL, TRIUMF have already expressed interest).
2. Trigger interest from the RI and the laser- and ion trap communities to develop cooled ion beams with energies down to a few eV, required for these studies, which will also serve other research communities (e.g. to study the interaction between RIB beams and anti-matter, studies of 2D materials using RIB probes, …).

The ultimate goal will be to provide cross-community, transnational **access to intense beams of radioactive molecules** with the required beam properties for high-precision studies, potentially in ion (or atom) traps. These are expected to provide unprecedented sensitivity in precision tests of the Standard Model at low energy, tests of fundamental symmetries, and searches for new physics, but will also serve other scientific domains.

Challenges

In order to meet the needs of this exciting new research frontier, the following technical challenges will need to be addressed at our radioactive ion beam laboratories.

1. Developing a reliable way to produce a variety of different molecules, containing different radioactive isotopes. For example, diatomic molecules are of marked interest for studies of fundamental symmetries such as RaF, RaO, RaOH and more complex polyatomic molecules.
2. Deceleration and cooling of molecules. Precision experiments requires long coherence times and cold environments. Such development can of course also be used for providing cooled and decelerated radioactive ion beams, of interest to other scientific communities (as highlighted above).
3. Improving the stability and capabilities of laser laboratories, suited to the needs of experiments which search for BSM physics, and training in skills and expertise required to operate such state-of-the-art laser technology.

In doing so, molecular beams with the conditions required to perform high-precision experiments can be made available to a wide community outside of the traditional radioactive isotope research groups. Hence, this will attract new users and new field of research to radioactive beam facilities in Europe. This will require an active dialogue and knowledge exchange with e.g. the AMO sciences, but also links to industrial partners in e.g. mass spectrometry may prove highly beneficial.

Original aspects

RIB facilities have the unique capability of producing radioactive molecules, and in particular those molecules containing heavy (actinide) atoms. Merging this production capability with precision searches for new physics represents a new opportunity for both fields, and provides a **unique way to improve our understanding of the fundamental forces of nature. This is therefore a highly innovative proposal.** Radioactive molecules first produced explicitly for molecular spectroscopy and BSM search purposes in 2018. Up until now, radioactive molecules were mainly considered a contaminant, or were used as a means to produce isotopes otherwise not accessible e.g. at ISOLDE. This project aims to bring an new community (AMO) to our facilities. The developments that are proposed will also benefit the solid-state physics community, as well as e.g. projects concerning interactions of radioactive ions with antiprotons.

The proposed work is timely and relies on present-day, cutting-edge capabilities of the nuclear physics and AMO research groups. The integration of BSM searching molecular physics experiments also would allow for the first-ever study of the molecular structure of many radioactive molecules, and may also allow for the extraction of nuclear structure properties which have so far remained out of reach, e.g. the nuclear quadrupole moment of potassium isotopes via the study of molecules containing a radioactive potassium isotope.

Unique expertise and common expertise and collaborations

The production of molecular beams containing one or more radioactive isotope has been demonstrated extensively at the Isotope Separator On-Line Device (ISOLDE) in- CERN (Geneva) as well as at the Ion-Guide Separator On-line (IGISOL) in Jyväskylä (Finland). A highlight of the work at the

ISOLDE facility is the recent spectroscopic characterization of the molecular structure of several RaF isotopologues, containing radioactive $^{223-228}$RaF isotopes. This milestone result highlights that ISOLDE can extract heavy fluoride molecules from its targets, even many weeks after their proton irradiation ended. Thus, extending the use and science opportunities in radioactive beam facilities.

Meanwhile, at the IGISOL facility, reaction products are stopped by helium buffer gas, before they are guided towards experimental setups. By seeding the gas with suitable atoms, these reaction products can be extracted from the gas cell in molecular form. A variety of actinide-oxides have in this fashion been extracted, e.g. ThO, UO, PO, and may therefore be delivered to new users in the future.

Despite these promising and flexible production capabilities, the use of these molecular beams for precision BSM searches is totally unexplored. Through this EUROLABS initiative, our expertise in the production and manipulation of radioactive isotopes can be made available to a new community.

Synergies with other research/technical groups and communities

There is clear synergy with the AMO community; specifically those who perform precision measurements of for example electron Electric Dipole Moments or parity violating effects using molecular probes. There is significant potential synergy with cold-ion and cold-atom community as well, as experimental techniques placed in our RI expand into that direction.

Main category:

Improved access

Connections with other categories

Beams and targets, New physics cases, Training and education

Advancing inter-disciplinary research at European radioactive ion beam (RIB) facilities

Authors: Karl Johnston[1]; Magdalena Kowalska[2]; Gerda Neyens[3]; Lino Pereira[3]; Ulrich Wahl[4]; Tommaso Marchi[5]; Jarno Van de Walle[6]

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Advancing inter-disciplinary research at European radioactive ion beam (RIB) facilities
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Others partners welcome to join
General description
In addition to their main research activity in nuclear physics, radioactive ion beam facilities across the world have long supported a diverse research programme in other fields: in particular medicine, solid state physics, chemistry, biology and life sciences. At well-established facilities such as ISOLDE, radioactive isotopes are provided mostly for characterizing samples of different kinds and 20% of the annual research programme is in these domains. Such research has been recognised at CERN, and ISOLDE is now integrated in the recently established CERN Quantum Technology Initiative.
Although active, the user community in Europe remains relatively small and most of the activity in this domain has been concentrated at the ISOLDE facility at CERN. Among the reasons for this, has been the limited investment in people and equipment to realize experiments in these areas of research at other facilities. At ISOLDE, dedicated offline characterisation laboratories have been put in place, along with a suite of on- and off-line experimental set-ups that use the large variety of isotopes produced, for the study of magnetic and electric properties of materials, the implantation behaviour of impurities, as well as binding properties of particular elements (e.g. metals) in chemical and biological systems. The advantages of using radioisotopes are especially appealing in terms of the gain in sensitivity – in some cases several orders of magnitude – compared to more standard techniques, and the ability to obtain direct chemical information which is often otherwise unavailable. Efficient usage of those advanced and dedicated setups could benefit large (new) user communities. As technologies evolve very rapidly and standard techniques might give less detailed (but sometimes quicker responses to questions at hand) opening other facilities providing fast and regular access to radioisotope for applied materials research, is very important to realize this. With this proposal, we aim at extending materials research techniques towards new RIB facilities, so that the methods would become more standard and find their way towards a larger audience.
With the prospect of new facilities which have expressed a strong interest in applications of nuclear science across Europe – both in the near and further future e.g. SPES and ISOL@MYRRHA, it is timely to promote interdisciplinary research across Europe at RIB facilities. The goal is to strengthen current activities in these domains by attracting new users who are often unaware of such techniques – and who would be well served by the unique opportunities that applied nuclear methods offer.
This project aims to focus on building links to new user communities and to transfer the knowledge which has been accumulated at ISOLDE to other labs across Europe. This would be done through training of a new generation of researchers and with the putting in place of a Europe-wide coordination of such activities where the possibilities and advantages of various RIB labs could be identified and long-lasting links between facilities would be established ensuring that this research activity becomes more accessible allowing it to reach its full potential.
Challenges:
Currently ISOLDE is the principal centre for interdisciplinary research with RIBs. This inherently

limits the number of groups who can be serviced with radioisotopes and has also limited the transmission and knowledge of many of the techniques to a wider user community. Limited access to beam time can also compromise the relevance of measurements, as condensed matter physics has a faster time-frame than nuclear physics (typically months to a year). As such the benefits of using radioisotopes can be lost due to such lack of access. It is essential that the expertise developed at ISOLDE be transferred to new facilities across Europe who will be able to produce similar – and in some cases isotopes not available at ISOLDE – so that the potential of applied nuclear physics can be realised, increasing its impact and attracting new scientific communities.

Local infrastructure is vital and this needs to be built up over time: e.g. offline laboratories and experimental setups. In addition, the presence of experts is vital to service the needs of user communities often unfamiliar with carrying out measurements in a radioactive facility. As restrictions become more common at home labs (in domains not directly related to nuclear methods), suitable infrastructure will likely only be found at large scale facilities. In addition to attract new users, more user-friendly experimental setups need to be prepared along with more modern methods of data analysis.

Transnational access is of importance to all users, but especially to researchers in the "applied" domain. To attract new users beyond nuclear physics TNA is vital to allow them to travel to learn and participate in experiments. Travel budgets in e.g. life sciences are not comparable to those in nuclear physics where travel to large-scale facilities is expected.

This project aims to build the foundations for a network of labs across Europe where this research will be carried out, both short and long-term. A central coordinator would liaise with the already existing groups of experts and users, as well as with the facilities. This central coordinator would also actively disseminate the TNA portfolio of RIB applications, assist new users to identify the best facility and technique(s) to achieve the users' research goals; and be responsible for identifying new trends and opportunities across the RIB landscape. Three local experts, positioned at the each of the facilities (ISOLDE, SPES and ISOL@MYRRHA) will support the central coordinator in the general dissemination of the TNA portfolio of RIB applications and help the users to realize and prepare their experiments. This team of experts would be particularly focused on establishing strong links with local research groups in the host (and neighbouring) country universities and research centres. Such local networks would provide crucial support for the sustainable development and implementation of the TNA portfolio of the new facilities in areas such as biophysics, condensed matter physics etc. New users will be addressed through workshop exploring the capabilities and potential of using radioisotopes in scientific fields such as condensed matter physics, quantum materials research biochemistry and radiobiology research and biomedical research. A common website detailing the opportunities available across Europe in this domain will be prepared to act as a landing site, which will give an overview of the possible measurements and equipment available at the various RIB facilities.

Original aspects:

• Moving to a Europe-wide vision of activity in fundamental research in material science and biophysics using radioactive isotopes and targeting the most suitable facility for the appropriate technique.

• Reaching out to new user communities and facilities.

• Putting in place the foundations for sustainable research in this domain for the future by training of researchers and transfer of experimental knowledge beyond the core community and between laboratories.

• Developing more user-friendly methods in the area of applied nuclear methods.

Unique expertise:

This project brings expertise in a wide area of techniques related to applied radioisotope research. Although several of the techniques are not unique, their combination with radioactive isotopes often is. Theoretical calculations using density functional theory applied to solids and molecules are crucial for the interpretation of the obtained data to extract the material properties of interest. Hyperfine techniques rely heavily on such calculations:

o Perturbed angular correlation
o Mossbauer spectroscopy
o Beta-NMR

Other methods are:

• Radiotracer methods
o Optical spectroscopy e.g. Photoluminescence
o Electrical measurements e.g. DLTS
o Diffusion in materials
• Channelling methods
o Emission channelling
• Handling/control of implantation for wide range of scientific areas, from solid state physics to biophysics.
• Development of specialised means of controlling irradiated samples e.g. annealing.

Common expertise and collaborations:
A community which is already focused on conducting research with radioisotopes in various fields: solid state and condensed matter physics, biophysics, chemistry, life sciences. Sample of specific expertise among the partners:
ISOLDE/CERN (Switzerland) application of nuclear physics to solid state, biophysics and beyond.
KU Leuven (Belgium) Quantum solid state physics
IST Lisbon (Portugal) Semiconductors, ion implantation
INFN-LNL SPES (Italy) Material Science / Material Characterization with Nuclear Techniques
SCK CEN: radiochemistry; reactor produced isotopes.
Synergies with other research/technical groups:
Theoretical groups e.g University of Aveiro
University of Linz: Materials growth/characterisation
IMEC (Belgium): industrial player with intimate connections with academics and research institutes
Univesrtiy of Copenhagen Inorganic biochemistry
Universities of Essen, Gottingen and Ilmenau: novel techniques for radioactive ion beams
University of Torino: quantum materials
University of Padua: material science, Mossbauer spectroscopy
Institute of Microelectronics and microsystems, Milan: magnetotransport
University of Marburg/University of Witswatersrand: 2D materials
Detectors e.g. Timepix/MEDIPIX
Positron community: usage of radioactive sources (positron emitters) for quantum material research
Conventional NMR community: biophysics
Synergies with other communities:
Material science and life science researchers performing studies at synchrotrons (similar challenges: large scale facilities, timescale of measurements) and doing their research only in their home institutes (complementary methods for sample characterisation and easier interpretation of data).
Synergies possible with any groups working in the domain of solid state physics, chemistry and condensed matter physics. Areas such as geophysics also possible.
Main category of your contribution:
Improved Access
Connections with other categories:
Training, Education, Outreach, Social Impact

Advancing inter-disciplinary research at European radioactive ion beam (RIB) facilities

Authors and affiliations:
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KU Leuven: Lino Pereira, GN
IST Lisbon: Ulrich Wahl
SPES (LNL): Tommaso Marchi
SCK CEN: Jarno Van de Walle
Others partners welcome to join

General description

In addition to their main research activity in nuclear physics, radioactive ion beam facilities across the world have long supported a diverse research programme in other fields: in particular medicine, solid state physics, chemistry, biology and life sciences. At well-established facilities such as ISOLDE, radioactive isotopes are provided mostly for characterizing samples of different kinds and 20% of the annual research programme is in these domains. Such research has been recognised at CERN, and ISOLDE is now integrated in the recently established CERN Quantum Technology Initiative.

Although active, the user community in Europe remains relatively small and most of the activity in this domain has been concentrated at the ISOLDE facility at CERN. Among the reasons for this, has been the limited investment in people and equipment to realize experiments in these areas of research at other facilities. At ISOLDE, dedicated offline characterisation laboratories have been put in place, along with a suite of on- and off-line experimental set-ups that use the large variety of isotopes produced, for the study of magnetic and electric properties of materials, the implantation behaviour of impurities, as well as binding properties of particular elements (e.g. metals) in chemical and biological systems. The advantages of using radioisotopes are especially appealing in terms of the gain in sensitivity – in some cases several orders of magnitude – compared to more standard techniques, and the ability to obtain direct chemical information which is often otherwise unavailable. Efficient usage of those advanced and dedicated setups could benefit large (new) user communities. As technologies evolve very rapidly and standard techniques might give less detailed (but sometimes quicker responses to questions at hand) opening other facilities providing fast and regular access to radioisotope for applied materials research, is very important to realize this. With this proposal, we aim at extending materials research techniques towards new RIB facilities, so that the methods would become more standard and find their way towards a larger audience.

With the prospect of new facilities which have expressed a strong interest in applications of nuclear science across Europe – both in the near and further future e.g. SPES and ISOL@MYRRHA, it is timely to promote interdisciplinary research across Europe at RIB facilities. The goal is to strengthen current activities in these domains by attracting new users who are often unaware of such techniques – and who would be well served by the unique opportunities that applied nuclear methods offer.

This project aims to focus on building links to new user communities and to transfer the knowledge which has been accumulated at ISOLDE to other labs across Europe. This would be done through training of a new generation of researchers and with the putting in place of a Europe-wide coordination of such activities where the possibilities and advantages of various RIB labs could be identified and long-lasting links between facilities would be established ensuring that this research activity becomes more accessible allowing it to reach its full potential.

Challenges:
Currently ISOLDE is the principal centre for interdisciplinary research with RIBs. This inherently limits the number of groups who can be serviced with radioisotopes and has also limited the transmission and knowledge of many of the techniques to a wider user community. Limited access to beam time can also compromise the relevance of measurements, as condensed matter physics has a faster time-frame than nuclear physics (typically months to a year). As such the benefits of using radioisotopes can be lost due to such lack of access. It is essential that the expertise developed at ISOLDE be transferred to new facilities across Europe who will be able to produce similar – and in some cases isotopes not available at ISOLDE – so that the potential of applied nuclear physics can be realised, increasing its impact and attracting new scientific communities.

Local infrastructure is vital and this needs to be built up over time: e.g. offline laboratories and experimental setups. In addition, the presence of experts is vital to service the needs of user communities often unfamiliar with carrying out measurements in a radioactive facility. As restrictions become more common at home labs (in domains not directly related to nuclear methods), suitable infrastructure will likely only be found at large scale facilities. In addition to attract new users, more user-friendly experimental setups need to be prepared along with more modern methods of data analysis.

Transnational access is of importance to all users, but especially to researchers in the "applied" domain. To attract new users beyond nuclear physics TNA is vital to allow them to travel to learn and participate in experiments. Travel budgets in e.g. life sciences are not comparable to those in nuclear physics where travel to large-scale facilities is expected.

This project aims to build the foundations for a network of labs across Europe where this research will be carried out, both short and long-term. A central coordinator would liaise with the already existing groups of experts and users, as well as with the facilities. This central coordinator would also actively disseminate the TNA portfolio of RIB applications, assist new users to identify the best facility and technique(s) to achieve the users' research goals; and be responsible for identifying new trends and opportunities across the RIB landscape. Three local experts, positioned at the each of the facilities (ISOLDE, SPES and ISOL@MYRRHA) will support the central coordinator in the general dissemination of the TNA portfolio of RIB applications and help the users to realize and prepare their experiments. This team of experts would be particularly focused on establishing strong links with local research groups in the host (and neighbouring) country universities and research centres. Such local networks would provide crucial support for the sustainable development and implementation of the TNA portfolio of the new facilities in areas such as biophysics, condensed matter physics etc.

New users will be addressed through workshop exploring the capabilities and potential of using radioisotopes in scientific fields such as condensed matter physics, quantum materials research biochemistry and radiobiology research and biomedical research. A common website detailing the opportunities available across Europe in this domain will be prepared to act as a landing site, which will give an overview of the possible measurements and equipment available at the various RIB facilities.

Original aspects:
- Moving to a Europe-wide vision of activity in fundamental research in material science and biophysics using radioactive isotopes and targeting the most suitable facility for the appropriate technique.
- Reaching out to new user communities and facilities.

- Putting in place the foundations for sustainable research in this domain for the future by training of researchers and transfer of experimental knowledge beyond the core community and between laboratories.
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This project brings expertise in a wide area of techniques related to applied radioisotope research. Although several of the techniques are not unique, their combination with radioactive isotopes often is. Theoretical calculations using density functional theory applied to solids and molecules are crucial for the interpretation of the obtained data to extract the material properties of interest. Hyperfine techniques rely heavily on such calculations:

  - Perturbed angular correlation
  - Mossbauer spectroscopy
  - Beta-NMR

Other methods are:

- Radiotracer methods
  - Optical spectroscopy e.g. Photoluminescence
  - Electrical measurements e.g. DLTS
  - Diffusion in materials
- Channelling methods
  - Emission channelling
- Handling/control of implantation for wide range of scientific areas, from solid state physics to biophysics.
- Development of specialised means of controlling irradiated samples e.g. annealing.

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A community which is already focused on conducting research with radioisotopes in various fields: solid state and condensed matter physics, biophysics, chemistry, life sciences. Sample of specific expertise among the partners:

ISOLDE/CERN (Switzerland) application of nuclear physics to solid state, biophysics and beyond.
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INFN-LNL SPES (Italy) Material Science / Material Characterization with Nuclear Techniques
SCK CEN: radiochemistry; reactor produced isotopes.

Synergies with other research/technical groups:

Theoretical groups e.g University of Aveiro
University of Linz: Materials growth/characterisation
IMEC (Belgium): industrial player with intimate connections with academics and research institutes
Univesrtiy of Copenhagen Inorganic biochemistry
Universities of Essen, Gottingen and Ilmenau: novel techniques for radioactive ion beams
University of Torino: quantum materials
University of Padua: material science, Mossbauer spectroscopy
Institute of Microelectronics and microsystems, Milan: magnetotransport
University of Marburg/University of Witswatersrand: 2D materials
Detectors e.g. Timepix/MEDIPIX
Positron community: usage of radioactive sources (positron emitters) for quantum material research
Conventional NMR community: biophysics

Synergies with other communities:

Material science and life science researchers performing studies at synchrotrons (similar challenges: large scale facilities, timescale of measurements) and doing their research only in their home institutes (complementary methods for sample characterisation and easier interpretation of data).

Synergies possible with any groups working in the domain of solid state physics, chemistry and condensed matter physics. Areas such as geophysics also possible.

Main category of your contribution:

Improved Access

Connections with other categories:

Training, Education, Outreach, Social Impact

Advanced accelerator-based radiobiology for cancer therapy and human space missions

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see attached file

Title: Advanced accelerator-based radiobiology for cancer therapy and human space missions

Authors and affiliations

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General description (methodology, goals,..)

GANIL in Caen, France, and GSI Helmholtz Zentrum für Schwerionenforschung in Darmstadt, Germany, represent important research infrastructures for heavy ion radiobiology and cover a broad spectrum of ions and energies that are relevant for charged particle therapy and space radiation biology. Small radiobiology labs are available allowing successful irradiation campaigns with a multitude of biological systems. However, these facilities are too small for campaigns with several external groups and limit thereby the efficient use of the beamtime. For biological research, independent repetitions of the experiments are crucial, therefore, multiple accesses to short beamtimes (6-8 h) per year would be more useful than one long beamtime per year. Cultivation of cells, organ cultures, organoids or other relevant models under physioxic or hypoxic conditions could also improve the scientific outcome for tumor therapy and space radiation risk assessment and countermeasure development. The goal is to improve the biological research capabilities at heavy ion accelerators in Europe by expanding irradiation capabilities (at different positions in the Bragg peak for carbon ions; flash ion irradiation with proton, helium and carbon ions), advanced online dosimetry, increasing laboratory space, upgrade of the equipment, and a more flexible availability of beamtime throughout the year.

Challenges

Concerning radiobiological research, the demand of beamtimes for space radiation biology will remain high as fundamental questions concerning the mechanisms of heavy ion-induced degenerative alterations are still open and the risk assessment is incomplete. It can be expected that a shift from two-dimensional cell culture to three-dimensional culture and organoids will occur and that more complex structures will be irradiated – adaptations to sample holders and the irradiation field might be necessary. Furthermore, experiments with low dose rates are of high relevance and might be possible in piggy-back to other experiments. Tests of radioprotective substances could help to develop space radiation countermeasures, but also reduce normal tissue toxicity during cancer radiotherapy.

Original aspects

The proposed improved of the biological research infrastructure goes beyond enlargement of existing facilities by introducing new irradiation (Bragg peak; flash) and cultivation possibilities (e.g. hypoxia benches), implementation of three-dimensional culture and organoids and piggy-back experiments for low-dose rate exposures to heavy ions which require temperature and CO_2 control during irradiation which is currently not possible.

Unique expertises

The Biodiagnostics Group of the DLR Radiobiology Department performed 21 beamtimes at GANIL since 2002, using the following ions: ^{12}C, ^{13}C, ^{36}Ar, ^{208}Pb, ^{20}Ne, ^{22}Ne, ^{58}Ni, ^{16}O. These beamtimes enabled the working group to address fundamental questions of space radiation biology such as the relative biological efficiency of space-relevant heavy ions to activate transcription factors and induce gene expression. Using the large set of ions, a broad range of linear energy transfer (LET), from 30 to 10,000 keV/µm was covered, resulting in a unique LET dependency of activation of the transcription factor Nuclear Factor κB (NF-κB) which is central in the immune including inflammatory responses and survival pathways of irradiated cells. Furthermore, the response of bone cells to heavy ion exposure was investigated, and the genotoxic potential of heavy ions was assessed using a bacterial reporter assay.

Common expertises and collaborations

e.g. GSI, Darmstadt; NTUA, Athens;

Synergies with other research/technical groups

Cimap / LARIA; LRCM/IP2L; LRMed/IRSN; ISTCT/CERVOxy

Synergies with other communities

Radiotherapy

Main category of your contribution

Improved Access

Connections with other categories

Beams + Targets

Unified interfaces for remote planning and conduction of medical related experiments

Authors: Thomas Kormoll[1]; Theresa Werner[1]

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Unified interfaces for remote planning and conduction of medical related experiments

Theresa Werner and Thomas Kormoll, AG Strahlungsphysik, Institut für Kern- und Teilchenphysik, Technische Universität Dresden

General Description

Many experiments related to the exploration of novel methods or devices in percutaneous cancer irradiation require very similar setups. This includes the use of tissue equivalent phantoms, beam shaping, dosimetry and often enough online beam monitoring and in-beam data acquisition systems. User groups prepare and test their setup in the lab before heading off to an accelerator facility, where the setup is assembled. This proposal suggests to significantly improve the *service to users* by implementing a unified interface in terms of

- phantoms (and interfaces to phantoms)
- beam monitoring
- dosimetry
- IT-infrastructure to connect data acquisition systems

in a way that enables to accurately plan and *conduct* experiments remotely. The standardization of physical interfaces requires on the one hand a precise and careful preparation of experiments, but allows on the one hand the same setup to be deployed on different facilities. On the other hand permits the adherence to a strict standard that the experiment can be set up by others. Through standardized interfaces, the experimentalist can even operate the equipment remotely while having access to all monitoring parameters and interact with the operators via a suitable conferencing system. The unified interface system allows portability of experiments. Beam time could be used more efficiently by reduction of setup time. And the advantages in pandemic times of sending equipment instead of people are obvious.

Challenges

The implementation of true standards in all of these fields is a major technical and administrative challenge. However, technologically all solutions exist. In case of the phantoms the process includes the definition of mounting points at which the responsibility from the irradiation facility ends and at which is user defined probe starts. In the case of movable devices like water phantoms, electronic and portable interfaces and protocols must be established. Successful conduction of remote experiments relies on an efficient communication system between experimentalists and local staff. A conferencing system which incorporates the crucial beam parameters and the experimental schedule should be developed.

Expertise

Especially at the PARTREC (former AGOR) facility there is an excellent cooperation between the local staff and external users concerning interfaces to phantoms and remote access. Defined and well documented mounts on phantoms have enabled the use of 3D-printed adapters for various probes. Concepts like the availability of electrical interfaces to movable phantoms have been successfully explored at the PARTREC facility in the past. The efficiency of beamtime was dramatically improved.

The spread of the Corona virus accelerated not only remote teaching in terms of lectures. Also labs are being offered for remote students who handle equipment like small robotic arms which move radioactive sources around arrangements of detectors. These new approaches have been implemented successfully in the AG Strahlungsphysik at the TU Dresden.

Synergies

Obvious synergies emerge in the case of consequent implementation of standards. Savings can be made in the on-site preparation work and increase the portability of experiments. Both facts increase the scientific output of research groups and accelerator facilities. Time slots possibly become available to other users and beam is used efficiently.

Communities with slightly different but similar requirements will also highly profit. Especially fundamental physics experiments are often layed out similarly in terms of detector arrangements, data acquisition and beam monitoring.

Collaboration with other groups

There is a very fruitful collaboration between E.R. van der Graaf and M.J. van Goethem from the PARTREC facility and the Dresden group in which many of the above mentioned concepts are being explored. It is intended to further continue this work, especially in the field of novel fibre optical dosimetry devices.

Main Category

Improved access

Connection with Other Categories

Beams + targets, data acquisition

Atomic and molecular collision physics

Authors: Jean-Christophe Poully[1]; Jean-Yves Chesnel[1]; Bernd Huber[1]; Alicja Domaracka[1]; Patrick Rousseau[1]; Violaine Vizcaino[1]; Alain Méry[1]; Jimmy Rangama[1]; Lamri Adoui[1]; Amine Cassimi[1]

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Atomic and molecular collision physics at ion-beam facilities

L. Adoui, A. Cassimi, J.-Y. Chesnel, A. Domaracka, B. A. Huber, A. Méry, J.-C. Poully, J. Rangama, P. Rousseau, and V. Vizcaino

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Department of Physics, Stockholm University, Stockholm, Sweden
Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
J. Heyrovský Institute of Physical Chemistry v.v.i., The Czech Academy of Sciences, Prague, Czech Republic
Faculty of Applied Physics and Mathematics, Gdansk University of Technology, Gdansk, Poland
Faculty of Sciences, Siedlce University of Natural Sciences and Humanities, Siedlce, Poland
Zernike Institute for Advanced Materials, Univ. of Groningen, 9747AG Groningen, Netherlands
Tokyo Metropolitan University, Tokyo, Japan
Institut für Kernphysik, Goethe Universität, Frankfurt, Germany
Inter-University Accelerator Center (IUAC), New Dehli, India
Instituto de Física - Universidade Federal do Rio de Janeiro, Cidade Universitária - Rio de Janeiro, Brazil

Since about 35 years, the community of atomic and molecular collision physics has widely used large scale facilities providing ion beams, such as GANIL (Caen, France) or IGOR (Groningen, Netherlands) for countless experiments performed within numerous national and international collaborations. Recent reviews of the advances achieved at GANIL in this field are available here: X. Fléchard et al JPCS 629 (2015) 012001 and H. Zettergren JPCS 629 (2015) 012003. These experiments have been focusing on the study of the interaction of ions with dilute matter ranging from isolated atoms and molecules to molecular clusters, as well as nanoparticles nowadays. Thanks to the wide range of projectile energies and species available on the different beam lines of these facilities, elementary processes such as electron capture, ionization and excitation have been extensively studied. More recently, the relaxation processes of the collision partners after the collision emerged as another specific source of interest. The majority of these studies have been performed within international collaborations, which is why translational access as well as funding of the missions of external users was crucial for their success.

The community of atomic and molecular collision physics aims to provide valuable upstream information relevant for both fundamental and applied physics issues. In the field of molecular collision physics, a major goal of the present and future short- and medium-term experiments is the investigation of the stability and the fragmentation dynamics of multi-atomic systems after their excitation/ionization by ion impact at kinetic energies ranging from keV to GeV. These studies provide new insights into radiation damage processes by describing – at the molecular level – the early physical stages of ion-induced excitation and ionization of molecular systems and their subsequent fragmentation. Another emerging foremost goal is the investigation of the formation of new molecular species in excited and ionized molecular clusters, in order to gain insights into the molecular growth occurring in the interaction between solar/stellar wind ions and the interstellar medium (ISM) and planetary atmospheres.

The uniqueness of the GANIL and IGOR facilities is that they offer complementary state-of-the-art beamlines producing a variety of ion species ranging from light ions (down to protons) to heavy ions (up to uranium) with a large range of charge states, and with energies ranging from a few keV per charge unit at ARIBE (GANIL) to 0.25-1 MeV/u at IRRSUD (GANIL) and even up to 95 MeV/u at the high energy beamlines. The wide relevance and versatility of these beamlines makes GANIL and IGOR very attractive for our community. This attractiveness results in the fact that each call for proposals issued by iPAC leads to numerous proposals for experiments in our field, a majority of them coming from external and often foreign teams. In view of the success of the calls for proposals, a general increase of the beam time allowance at GANIL and IGOR would be very welcome.

An emerging topic is the time-resolved investigation of collision-induced molecular fragmentation dynamics. While high harmonic generation sources (HHG) and free electron lasers (FEL) provide short temporal resolutions (as-ps), ion storage devices give access to relaxation processes over very long time scales (up to seconds). Moreover, it is possible to prepare well-defined target states with laser excitation and in a more general way to perform laser spectroscopy on ions. It is noteworthy that such laser spectroscopy in an electrostatic linear ion trap is under development as well in nuclear physics (MIRACLS project at CERN) and is foreseen for DESIR. Thus to extend the possibilities offered by the ion beam facilities, it would be very valuable to equip a beamline with a linear electrostatic trap coupled to lasers.

As a last recommendation, we would like to emphasize that the construction of a Very Low Energy (range of a few eV) beamline at GANIL or IGOR would allow reaching the completeness of the range of energies. We anticipate that this beamline would open the way for new series of systematic studies of broad interest, because this range of kinetic energy has very scarcely been explored.

Access to the ALTO facility of IJC Lab

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[1] *CNRS*

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Access to the ALTO facility of IJC Lab

Authors and affiliations: J.N. Wilson & K. Turzó, ALTO facility + IJC Laboratory, CNRS

General description (methodology, goals,..):

The ALTO facility contains two accelerators. A Tandem accelerator is dedicated to a wide range of stable beams from protons to heavy ions, and can also be used for neutron production in inverse kinematics. A linear electron accelerator is dedicated to the production of low energy radioactive beams via photo-fission of Uranium targets and isotope separation on line (ISOL). This combination provides unique opportunities for a very broad range of activities from nuclear physics, nuclear astrophysics, diverse R&D and interdisciplinary research.

Tandem Accelerator:

The Orsay Tandem Van de Graaff accelerator is of the MP type. Its nominal voltage is 15 MV and it is usually operated up to 14.6 MV. Stable ion beams ranging from protons to ^{127}I can be delivered. Available beam currents depend on the particular ion and can be as high as several µA. The beam pulser/chopper allows pulsed beams in the 100 ns – 100 µs range with a pulse width of around 2 ns. Cluster beams and micro-droplets can also be delivered, but at lower voltage (10 MV). Rare ion beams (^{14}C, ^{48}Ca ...) are also available. The LICORNE neutron source is a unique converter which produces intense, kinematically focused, quasi-mono-energetic beams of neutrons with energies between 0.5 and 4 MeV using primary beams from the tandem of ^{7}Li. High fluxes up to 10^8 n/str/s are achievable.

e-LINAC:

The e-LINAC accelerator is an electron accelerator (50 MeV 10 µA) used as a driver to induce fission in a thick heated uranium-carbide target. The number of fissions reached in the target is 10^{11} fissions per second. Separated beams of neutron-rich nuclei are available for studies in nuclear structure, decay heat in reactors and solid-state physics. The fission products released are ionised by the RIALTO laser ion source and the resulting low energy beams are mass-separated with the PaRRNe separation magnets system.

Associated research instrumentation:

For the tandem accelerator, five beam lines are available for experiments with stable beams. One is used for gamma-ray spectroscopy, one for nuclear astrophysics and a third is used as a universal beam line for diverse setups constructed/imported by the user. The remaining two beam lines are dedicated to industrial irradiation. The split-pole spectrometer is available for nuclear-astrophysics and other experiments as well as state-of-the-art hybrid Germanium (Ge) multi-detector arrays for gamma ray spectroscopy.

Associated research instrumentation for physics with the low-energy radioactive beams produced by the e-LINAC consists of the BEDO/TETRA/COECO decay stations to measure gamma rays, neutrons and conversion electrons from excited states in coincidence with beta-decays. Additionally, ground state properties can be measured with the LINO collinear laser spectroscopy setup. The MLL Trap, Penning trap and the POLAREX low temperature nuclear orientation system for magnetic moment measurements are coming online soon.

Services currently offered by the infrastructure:

All the above-mentioned experimental setups are open for access. Other services are offered by the infrastructure such as a detector laboratory, a target laboratory, an experimental hall service, a computer centre and data-acquisition service, a radioprotection and security service and a laser laboratory.

Challenges:

widen access to industrial users. A current project (SPACE ALTO), funded at regional level, is being developed with this aim.

Original aspects:

Outreach to new users:

The call for proposals at ALTO is advertised on the web pages (http://ipnwww.in2p3.fr). In addition, there is an e-mail list which is rather complete as it includes also PhD students and post-doctoral fellows and is distributed to the users. Furthermore, the minutes of the meeting of the Laboratory user groups (every 6-12 months) are distributed to inform the community on practical questions such as the time schedules related to work (maintenance, upgrade or new implementation) at the installation. The beam scheduling is also available online and regularly updated, along with the list of available beams and news on development of new ones.

Unique expertises:

- The ALTO facility has unique expertise in the ISOL technique and performing research and development to optimise exotic isotope production and observation.
- ALTO also has expertise in producing neutrons using the unique inverse kinematics technique for high naturally-directional fluxes and low backgrounds.
- The ALTO target laboratory produces thin targets for academic and industrial user all over the world and has particular competences and expertise in this rare field such as production of deuterated plastic, and actinide targets.
- ALTO also has unique expertise to produce nanoparticle beams from the TANDEM accelerator: these aggregate projectiles are unique for bombarding nanometer-scale surfaces with hundreds of atoms at once. the concentrated energy deposited can induce profound changes, allowing, for example, the creation of nano-scale diamonds in carbon, and the ejection of intact molecules from biological tissues.

Data Management and storage: virtual data, open data

- ALTO is a research platform of IJC Laboratory. The newly created IJC Laboratory has a particular expertise in grid computing, data management and storage due to its strong participation in major high-energy physics projects such ATLAS@CERN. This expertise is available for use in the context of a European TNA Research Network for nuclear physics, and IJC Laboratory could act as a unique storage, data management and open data node in such a network.

Common expertises and collaborations:

The ALTO facility is involved with a broad range of national and international collaborations involving many different university groups, laboratories and other institutions in both France and Europe. ALTO has particularly strong relations with laboratories such as GANIL, CEA/IRFU/DAM, CENBG Bordeaux, ILL Grenoble, ISOLDE@CERN, INFN Legnaro/Catania Italy, Jyvaskyla Finland, JRC-Geel Belgium, HIL Warsaw, IFJ PAN Krakow Poland, OCL Oslo Norway, JINR Dubna Russia, NPL UK, and iThemba labs South Africa.

Synergies with other communities:

The ALTO facility has a long tradition to work with different research communities such as: atomic physics, solid state physics, accelerator physics, nuclear physics, high-energy physics, dark matter research, geochronology, nanotechnology, interaction of ions with matter, and biology with around 250 external users (150 international).

(with reference to the categories described in the "Instructions for submission page", https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Main category of your contribution: Improved Access

Connections with other categories:

- Beams + Targets
- Data Acquisition + Analysis, Simulations
- DMP + Data sharing
- New physics cases
- Training, Education, Outreach, Social Impact

Remote user access to monitor and control nuclear physics experiments

Author: Constantin Mihai[1]

[1] *IFIN-HH, Romania*

Corresponding Author: constantin.mihai@nipne.ro

Title: Remote user access to monitor and control nuclear physics experiments
Authors: C. Mihai et al, IFIN-HH, Bucharest, Romania
General Description:
The global COVID-19 pandemic affected travel in general and work from home became the new normal. Nuclear physicists were no exception and as a result the experimental program at accelerator facilities were severely affected in 2020. The Bucharest 9MV Tandem delivered 50% less beam time in 2020 compared with 2019, with the users being mostly local.
While accelerator facilities and nuclear physics experiments were never intended or designed to be performed remotely, there are a number of software solutions that allow to monitor and control key parameters, thus allowing for a reduced physical presence on site. At the Bucharest 9MV Tandem accelerator, we implemented tools to display key parameters of the ROSPHERE array (DAQ status, detector rates, LN2 refiling status, HV status), providing users with a way to monitor their experiment. Control of the DAQ and HV system was provided separately, while the data was shared via cloud. This allowed for experiments to be performed by external groups with limited local support. Similar software was proposed to be used at other facilities within Europe and probably will be generally used within the future ENSAR.
Our proposal here is to create a framework within the accelerator facilities in ENSAR that will allow to collaborate in the development and implementation of remote control and display software and ultimately adopt a generally accepted solution. Having such a general software solution represent an added advantage both for users who will easily perform experiments in any ENSAR facility and for the facilities that will share the costs related to development and implementation.
Challenges: Develop and/or adapt software to display and/or control a wide category of parameters from different systems
Original aspects:
Common expertise and collaborations: Synergies with virtually all the accelerator facilities in ENSAR
Main category of your contribution: user support

Improving access to facilities through better dissemination, streamlined procedures, harmonised user management and common best practices

Author: Salvatore Fiore[1]

[1] *ROMA1*

Corresponding Author: salvatore.fiore@roma1.infn.it

General description (methodology, goals,..):
The large number of users that will be accessing the research infrastructures (RI) through Transnational Access (TA) for performing experiments, will actually deal with a number of independently managed facilities for the detailed planning and execution of their experiments; this, undoubtedly, is a source of inefficiency in the exploitation of the RI network.
The difficulties for user access start from the planning phase: detailed knowledge of beam characteristics (energy range, footprint, management), infrastructure (cabling, support and available setup volume, services), logistics and safety (material access, training, documentation, nuclear transports) is often difficult to obtain and compare without direct experience in each single facility. Application for beam time is also a source of delay and uncertainty, as the local Committees meet a few times or once per year, and available time slots can be far in the future. At the same time, an equivalent facility with the required characteristics could have more availability, but the lack of an integrated beam provision planning wouldn't allow to exploit the best possibilities.
On the facilities' management side, users' access also poses frequent and often new difficulties. Communication with users, managing the access requests through the local committees, arranging the facility's support infrastructures, coping with the needs of the whole accelerator complex while organising beam schedule, setting up the necessary formalities for the access, and more in general managing a large amount of data related to the user access are the typical duties of a facility management. Finding the best way to deal with these issues is not only time and resource consuming, but in many cases similar facilities deal with similar problems without gaining from each other's experience.
The proposed strategy to improve the access to an excellent network of RIs for accelerator-based science is based on three main objectives:

- Improved dissemination of scientific and practical facility characteristics for users
- Streamlined beam granting and access procedures
- Harmonised user management and exploitation of common best practices

In order to improve the dissemination about facilities' characteristics, information about facilities would be gathered in a structured way through surveys and interviews to the managing teams, taking into account users' needs and suggestions, then digested and presented in a comprehensive online portal. A search-and-compare functionality will allow users to find the best match between their proposal and the facility to exploit, including lead time estimates to get the beam.
To streamline proposal evaluation and beam awarding, a centralised Proposal Selection Panel would be appointed to evaluate user requests. This panel would evaluate the proposals according to their scientific excellence, impact on the scientific community, implementation and feasibility. The panel would run evaluations quarterly and benefit from pre-approved beam time slots at each facility in order to reduce the lead time between the scientific proposal and its execution.
The large number of users that are expected to apply for TA requires a proper management of their data among the facilities, also in compliance with GDPR regulations. Moreover, the large number of devices and prototypes that will be exposed to high intensity beams and sources will have to be traced in their life-cycle within the facilities, taking also into account possible material activation and related Radiation Protection procedures. A data model to manage the information provided to and by the users (beam conditions, sample characteristics, dose, fluence, other environmental information, etc.) will be established to achieve standardisation and to improve quality assurance levels. Best practices, proven to be successful in the relationship between the facility and its users,

will be disseminated within the consortium to harmonise the access procedures, benefiting from the different experiences within the consortium concerning application processes, access formalities, administrative issues, safety training for users and in general communication with the users. Harmonisation of dosimetry techniques, providing cross-reference results amongst the various facilities, and promotion of remote access to irradiation facilities would also be addressed, the latter also in view of possible travel restrictions due to the recent COVID-19 pandemic.

Challenges:

- simplify beam time access formalities;
- make efficient use of available resources in terms of beam type for the scientific proposals, beam time availability, optimal exploitation of the facilities network by the users;
- maintain a high quality of the approved proposals;
- improve users' management by the facilities;
- improve the facilities' compliance with the European Charter for Access to Research Infrastructures.

Original aspects:

- centralised Proposal Selection Panel, with frequent proposal evaluations and pre-approved beam time slots at each facility in order to reduce the lead time between the scientific proposal and its execution;
- definition of a unified data model for users and experiments;
- harmonisation of support infrastructures, procedures, safety, training, exploiting the best practices developed within the consortium.

Unique expertises:
The proponent is the Transnational Access coordinator for the RADNEXT H2020 project, a network of European facilities for Radiation Hardness testing with a strong commitment in improving and easing the access to the beam infrastructures. He is also the User Program Manager for the Frascati Neutron Generator and has conducted experiments in several beam test and irradiation facilities in Europe.

Common expertises and collaborations, Synergies with other research/technical groups:
The proponent possesses a blend of expertises and experience in several nuclear physics and technology fields. He is well experienced in experimental particle physics, detector development and testing under different particle sources, in the framework of European collaborations and with colleagues of international research institutes and universities. He has been part of several research collaborations, is currently part of the n_TOF and PADME collaborations and task responsible for EUROfusion Early Neutron Source WP.

Synergies with other communities:
An effort like the one proposed would easily find synergic application within all the scientific communities exploiting particle beams and sources for experimental research activities, such as accelerator R&D, collider physics detector development, Radiation Hardness testing, neutron physics, and in general all the communities that routinely access large research infrastructures on a proposal basis.

Title: Improving access to facilities through better dissemination, streamlined procedures, harmonised user management and common best practices

Authors and affiliations:

S. Fiore

ENEA, Department of Fusion and Technology for Nuclear Safety and Security, Frascati (RM), Italy

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Harmonisation of dosimetry techniques, providing cross-reference results amongst the various facilities, and promotion of remote access to irradiation facilities would also be addressed, the latter also in view of possible travel restrictions due to the recent COVID-19 pandemic.

Challenges:

- *simplify beam time access formalities;*
- *make efficient use of available resources in terms of beam type for the scientific proposals, beam time availability, optimal exploitation of the facilities network by the users;*
- *maintain a high quality of the approved proposals;*
- *improve users' management by the facilities;*
- *improve the facilities' compliance with the European Charter for Access to Research Infrastructures.*

Original aspects:

- *centralised Proposal Selection Panel, with frequent proposal evaluations and pre-approved beam time slots at each facility in order to reduce the lead time between the scientific proposal and its execution;*
- *definition of a unified data model for users and experiments;*
- *harmonisation of support infrastructures, procedures, safety, training, exploiting the best practices developed within the consortium.*

Unique expertises:

The proponent is the Transnational Access coordinator for the RADNEXT H2020 project, a network of European facilities for Radiation Hardness testing with a strong commitment in improving and easing the access to the beam infrastructures. He is also the User Program Manager for the Frascati Neutron Generator and has conducted experiments in several beam test and irradiation facilities in Europe.

Common expertises and collaborations, Synergies with other research/technical groups:

The proponent possesses a blend of expertises and experience in several nuclear physics and technology fields. He is well experienced in experimental particle physics, detector development and testing under different particle sources, in the framework of European collaborations and with colleagues of international research institutes and universities. He has been part of several research collaborations, is currently part of the n_TOF and PADME collaborations and task responsible for EUROfusion Early Neutron Source WP.

Synergies with other communities:

An effort like the one proposed would easily find synergic application within all the scientific communities exploiting particle beams and sources for experimental research activities, such as accelerator R&D, collider physics detector development, Radiation Hardness testing, neutron physics, and in general all the communities that routinely access large research infrastructures on a proposal basis.

Main category of your contribution: Improved Access

Connections with other categories: DMP + Data sharing

(with reference to the categories described in the “Instructions for submission page”,https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Chart of Ion Beams for EURO-LABS – CIBEL

Author: Marek Lewitowicz[1]

Co-authors: Adam Maj [2]; Piotr Bednarczyk [2]

[1] *GANIL*

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The main idea of this project is to collect available data (essentially intensities and energies) of stable and radioactive-ion beams produced in the existing European ion-beam facilities. These data will be easily accessible and visualised through a nuclear chart and a periodic table of elements.
This data basis and its user-friendly interface will be essential for attracting new users and will largely facilitate proposals for new experiments. The chart will be publicly accessible via a website and will be largely distributed to potential academic and industrial users.

Proposal: Chart of Ion Beams for EURO-LABS – CIBEL

Coordinator (GANIL) Person.months (EU/Own): GANIL (12/10); participant IFJ (12/10) and all EURO-LABS infrastructures

A huge volume of data concerning produced or developed stable and radioactive-ion beams (RIBs) available at different nuclear facilities in Europe exists today. Access to these data, which is of great interest for researchers in many fields of science, is however quite complicated. A unique, homogeneous and easily accessible database for all present and future European ion-beam facilities is not available today.

The main idea of this project is to collect available data (essentially intensities and energies) of stable and radioactive-ion beams produced in the existing European ion-beam facilities. These data will be easily accessible and visualized through a nuclear chart and a periodic table of elements. The experience already gained at GANIL and IFJ in this type of collaborative projects (see ECOS https://u.ganil-spiral2.eu/chart-ecos/ , Chart of GANIL beams https://u.ganil-spiral2.eu/chartbeams/ and CRIBE https://u.ganil-spiral2.eu/cribe/) will be used to carry out this project successfully. This chart will present beams that are already available in the numerous ion-beam facilities in Europe and that which will become available during the EURO-LABS project.

The first step of the project will consist in collection of the existing facilities and available beams in Europe.

A dedicate mechanism will be developed to ensure that the data basis will be updated in an automatic or/and semi-automatic way periodically in order to ensure its sustainability.

The goal of the task is to construct a unique and powerful entry point for all users of ion-beam facilities. This data basis and its user-friendly interface will be essential for attracting new users and will largely facilitate proposals for new experiments. The chart will be publicly accessible via a website and will be largely distributed to potential academic and industrial users.

The 14 MeV and 2.5 MeV Frascati Neutron Generator FNG: a unique facility for high flux neutron experiments.

Author: Salvatore Fiore[1]

[1] *ROMA1*

Corresponding Author: salvatore.fiore@roma1.infn.it

General description (methodology, goals,..):
The Frascati Neutron Generator FNG is a 14 MeV neutron source that exploits the T(d,n)α fusion reaction to produce up to 1011 n/s over 4π, in continuous mode. This is currently the most powerful 14 MeV generator available in Europe, and among the very few in the world of such intensity. FNG can also produce 2.5 MeV neutrons via the D(d,n)3He fusion reaction when using a deuterium-implanted target. FNG is housed in a large shielded hall (11.5 x12 m2 , 9 m tall) and the target is more than 4 m far from walls, floor and ceiling, in order to reduce as much as possible neutron backscattering and preserve the monoenergetic nature of the source.
FNG started operations in 1992 to conduct neutronics experiments in the framework of the controlled thermonuclear fusion. Several benchmark experiments have been performed at FNG since the 90's, to validate models for JET, ITER and the future generation of nuclear fusion reactors. (ITER, DEMO). The results of most of the FNG neutronics experiments are available on SINBAD database (OECD-NEA) and are routinely world-wide used to test and validate new neutron transport codes and nuclear data files. The FNG portfolio of activities was widened since then, including neutron detector R&D for high energy physics, fusion and radiation dosimetry, radiation hardness assessment, fundamental research and radionuclides production studies for medical use. Users from Universities and international research institutes exploit FNG for their activities as well as users from private companies.

Challenges:
14 MeV neutrons can be unique probes for measuring physical quantities relevant to several research fields, since DT generators like FNG can yield high intensity, monoenergetic neutrons in the "fast" energy range. This is crucial in order to study phenomena in the high energy domain that require high incident neutron fluxes, with a well defined energy. Following are just some of the possible measurements that can exploit FNG.
Several nuclear cross sections, both capture and (n,cp), are lacking or have discordant experimental data in the 14 MeV range. Improved knowledge on these cross sections can be also useful to the improvement of EXFOR database, or to assess the integrity of structural materials for fusion reactors.
14 MeV neutrons are also promising for the production of radioisotopes for medical use: recent studies showed that both 99Tc and 64Cu could be massively produced using DT fusion neutrons, a possibility worth further studies.
In the activation cross section measurement domain, the short lifetime of the daughter nuclei is often the outstanding limitation. At FNG, a rabbit system could be implemented to rapidly feed the samples to the measurement area: the infrastructure could allow such measurements, as it was recently exploited for a challenging experiment on water activation for ITER.
For measurements that need a broader energy spectrum, a dedicated moderator structure could be designed and implemented on the neutron production target in order to obtain either a Maxwellian-like spectrum or an atmospheric (<14 MeV) one, or even more specific custom shapes. A neutron flight path could also be implemented for TOF measurements: in this sense, the deuteron source would also have to be modified in order to have a pulsed beam.

Original aspects:
The FNG puts together a high-intensity, absolutely calibrated, monoenergetic neutron source with a large experimental hall with low backscattering, online measurements capability, ancillary technical areas and characterisation labs, including well-type 4π gamma detectors calibrated with metrologic reference samples. This is a fairly unique combination of characteristics in the international scenario of 14/2.5 MeV and, in general, high-energy neutron facilities. The facility's infrastructure also offers room for specific, large experimental setups and major upgrades: an aluminum tower can easily support experimental setups up to 6 T weight and 2 m3 volume in front of the neutron source, and

still in a reduced backscattering environment; even larger experiments can be hosted in the hall. Rabbit systems or flight paths can also be constructed to serve specific experiments.

Unique expertises:
Dr. Mario Pillon, head of the facility, and Dr. Maurizio Angelone, responsible for experimental activities, have worked with the FNG since its construction, gaining deep knowledge of the machine parameters optimisation, and tritiated targets operation, necessary to obtain such high neutron yield. Dr. Salvatore Fiore is Transnational Access coordinator for the RADNEXT project, a network of European facilities for Radiation Hardness testing with a strong commitment in improving and easing the access to the beam infrastructures. Dr. Antonino Pietropaolo is the Scientific coordinator of the Sorgentina project, aiming at the construction of a high-intensity neutron source exploiting DT fusion reactions with an innovative rotating target design. Dr. Stefano Loreti has been member of BPIM (CCRI(III)) for the neutrons metrology and the reference person for Italian Neutron metrology.

Common expertises and collaborations:
The research team that is running the FNG and conducting experiments possesses a blend of expertises and experience that allows the facility to be competitive in several nuclear physics and technology fields. Dr. Mario Pillon and Dr. Maurizio Angelone are both well experienced in experimental and computational neutronics including benchmark experiments, neutron detector development, experimentation with tokamaks. Dr. Salvatore Fiore, currently in charge of the user program at FNG, has long term experience in detector development and testing under different particle sources, including radiation hardness tests. Dr. Stefano Loreti is an experienced metrology research scientist, expert in absolute radioactivity measurements with HPGe and scintillation detectors and detector calibration with primary standards. Dr. Antonino Pietropaolo has wide experience with neutron experimentation in a broad range of energies, from neutron spectroscopy up to detectors and radioisotopes experiments with fast neutron sources. A research team for computational neutronics, involved in the design of present and future Tokamak fusion reactors within international consortia, works in collaboration with FNG on complex Monte Carlo modeling of experiments.
Synergies with other research/technical groups:
The FNG team is deeply involved in joint research activities on Nuclear Science with Universities and Research Institutes across Europe; its members take part in EUROfusion, Fusion For Energy, ITER, H2020 projects and cover responsibility roles in IAEA and OECD-NEA. The proponents also participate to the CERN n_TOF scientific collaboration, and often collaborate in research projects with the JRC Geel scientists of the GELINA facility.

Synergies with other communities:
The experimental activities with 14 MeV neutrons, in addition to the nuclear science and fusion applications community, find application also in the Radiation Hardness measurements field, space technological applications and the radioisotopes production for medical applications.

Main category of your contribution: Improved Access

Connections with other categories: Beams + Targets

Title: **The 14 MeV and 2.5 MeV Frascati Neutron Generator FNG: a unique facility for high flux neutron experiments.**

Authors and affiliations:

S. Fiore, M. Angelone, S. Loreti, A. Pietropaolo, M. Pillon

ENEA, Department of Fusion and Technology for Nuclear Safety and Security, Frascati (RM), Italy

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Main category of your contribution: Improved Access

Connections with other categories: Beams + Targets

(with reference to the categories described in the “Instructions for submission page”,https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Particle Therapy Interuniversity Center Leuven

Authors: Sofie Isebaert[1]; Filip Vanhavere[1]; Edmond Sterpin[1]; Karin Haustermans[1]

[1] *KULeuven*

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General description:

The first proton therapy center in Belgium, called PARTICLE – Particle Therapy Interuniversity Center Leuven – has been built on the Health Sciences campus Gasthuisberg of UZ Leuven. PARTICLE is a joint effort of UZ Leuven· KU Leuven and Cliniques universitaires Saint-Luc· UCLouvain and other clinical partners including UZ Gent, CHU UCL Namur, UZ Brussel and UZA. Furthermore, research on proton therapy is being performed in close collaboration with various national and international leading academic centers and research institutes (such as e.g. SCK CEN, the Belgian Nuclear Research Centre), as well as industrial partners (such as IBA, the supplier of the proton therapy device).

Original aspects:

The center is fully embedded with the clinical and research environment of the academic hospital and encompasses two main areas: one for patient's treatment and one specifically dedicated to (fundamental and strategic basic) research purposes. Unique to this layout is the fact that each vault is equipped with its own accelerator, a superconducting synchrocyclotron, which implies that both rooms can function completely independent from each other. As such, there is no need to perform the experiments outside clinical treatment hours (during the evening, night or weekends) since there is no interference with the clinical workflow. Vice versa, beam up or down time in the clinical gantry room will not affect experiments to be performed in the research room. Furthermore, one is able to leave complex experimental apparatus in position for an extended period of time. Another advantage of our proton research infrastructure is the close proximity and access to the research buildings and facilities of the university (KU Leuven), which hosts amongst others a lab for experimental radiotherapy, an animal facility, a small animal radiation research platform (SARRP) and Molecular Small Animal Imaging Center (MoSAIC) core facility. A separate access door is also foreseen to bring in animals or other experimental models/set-ups into the proton research vault without any interference with the clinical part.

The clinical part of the center is operational since the summer of last year, with the first patient being treated on July 22, 2020. The installation of the proton research beam line is currently still ongoing. The basic configuration is currently in place and the acceptance tests are planned for end of April, beginning of May. This basic configuration consist of a superconducting synchrocyclotron, called S2C2 (pulsed beam, 1 kHz; max energy 230 MeV) and a fixed horizontal beam line of which the major components are the ionization chamber (IC) cyclo, slits, quadrupoles, beam profile monitor, and scanning magnets (cf. Figure 1).

The current scope however has some limitations (e.g. only one fixed energy of 230 MeV; lack of beam line control unit, BCLU, and scanning controller; SC). Hence, in order to get the maximum out of this research infrastructure we are upgrading the research beam to be able to use the configuration in such a way as to approach clinical proton delivery as close as possible. The following components are still to be added:
- Beam line control software: This includes the BCLU and SC to operate the different elements of the beam line. The control system will also be connected to the safety system and will communicate with the different sub-systems as well as the accelerator.
- Integral dose control: the control system will consist of the beam management software (BMS). On the hardware side, this includes a simplified nozzle frame with accessory holder and 2 IC connected to dedicated electrometers and to the beam delivery control unit (BDCU). Upstream, an energy degrader with a beam stop (faraday cup) will be placed behind the accelerator on the extraction table in the S2C2 vault.

The repeatability of spot positioning, relative spot position accuracy and field size at target point

will be ensured by scanning magnet calibration. With this, a field of 5 x 20 cm^2 will be available with a spot position accuracy of +/- 1 mm. The beam spot size will be 4 x 4 mm^2 measured at beam target point at maximum energy. The energy degrader will be calibrated on a 3 g/cm^2 range to allow small energy modulation. Finally, the dose linearity calibration in Monitor Unit will be performed. Repeatability characteristic will be +/-1.5% or +/-3nC. With this additional feature, the user will be able to perform "PBS layers" irradiation.
The installation of these modifications will take about 18-24 months.

Challenges:

This proton research beam line will enable to address several issues raised by clinical practice and recent proton therapy research, involving a wide range of expertise from basic physics to the most applied radiobiology. Some anticipated research topics include:
- Proton FLASH therapy
- Ultrasound contrast agent based range verification system
- Testing and validation of patient specific devices for proton therapy
- Flat panel for quality assurance, proton radiography and proton CT
- Radiobiology research
- Cardiovascular research
- Radiation protection and dosimetry

Unique expertises:

Within the PARTICLE group together with the collaborating centres, there is unique expertise present to set-up research projects and to collaborate with other groups in all of the above mentioned topics.

Synergies with other research/technical groups:

The PARTICLE proton therapy center and its collaborators are open to collaborations on the above-mentioned research topics, but also to other topics that are of interest to the research community.

Main category of your contribution:
- Improved access to a proton therapy research beam
- R&D on detectors for proton therapy applications
- R&D on AI and simulations for proton therapy applications
- E&T aspects, Lab-University collaborations

PARTICLE
PROTON THERAPY CENTER • LEUVEN

Title: Particle Therapy Interuniversity Center Leuven

Authors and affiliations: Sofie Isebaert, Filip Vanhavere, Edmond Sterpin, Karin Haustermans, KU Leuven, Belgium

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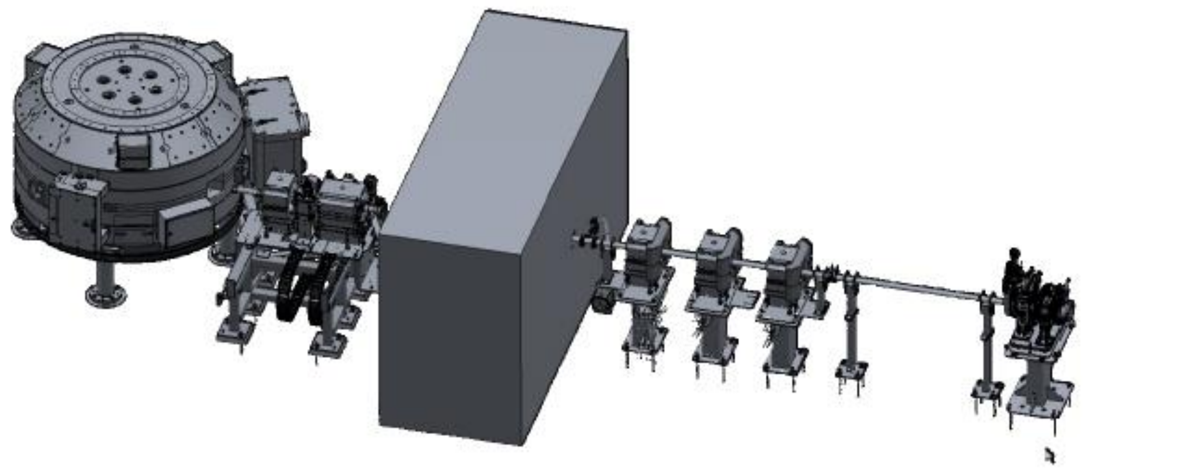

Figure 1 Illustration of the infrastructure that is already installed in ParTICLe. From left to right: in the cyclotron vault the S2C2 cyclotron, slits and the cyclo ion chamber; in the experimental room, three quadrupoles and scanning magnets.

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Main category of your contribution:

- Improved access to a proton therapy research beam
- R&D on detectors for proton therapy applications
- R&D on AI and simulations for proton therapy applications
- E&T aspects, Lab-University collaborations

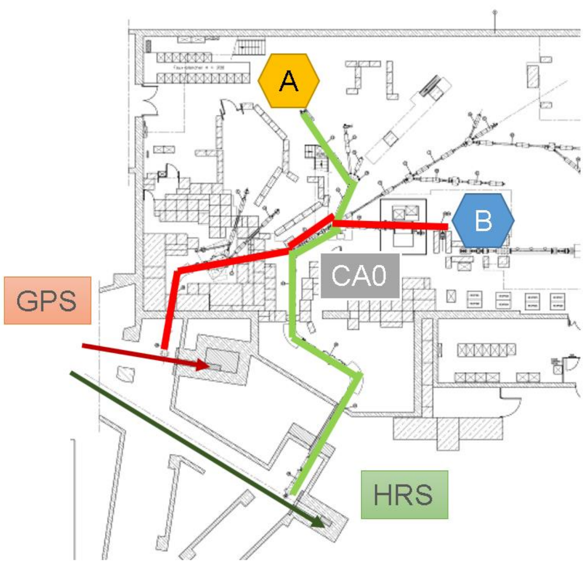
Title: Beam sharing and alternate operation of target stations at CERN ISOLDE
Authors and affiliations: S.Rothe, A. Rodriguez (CERN)
General description (methodology, goals,..):

Beam time at RIB facilities is scarce and has to be shared by different stakeholders: the USERS for their experiments , the machine supervisors for setup an tuning and the machine development teams for beam developments.

a. Alternate operation

In most cases, ISOLDE is used as single user facility for USERS connected to beam lines downstream of the merging switchyard which allows either beams from the HRS target station or the GPS target stations to be passed to the experiments downstream. The exception are users located at the GLM and GHM beamlines, however the majority of low energy beam lines and HIE ISOLDE have to pass through the bottleneck of the merging switchyard.

Here we propose a technical solution to overcome this issue through fast (ms) switching the electrostatic elements of the merging switchyard between settings optimised for transport of either the HRS or the GPS beams, synchronized to the PSB supercycle.



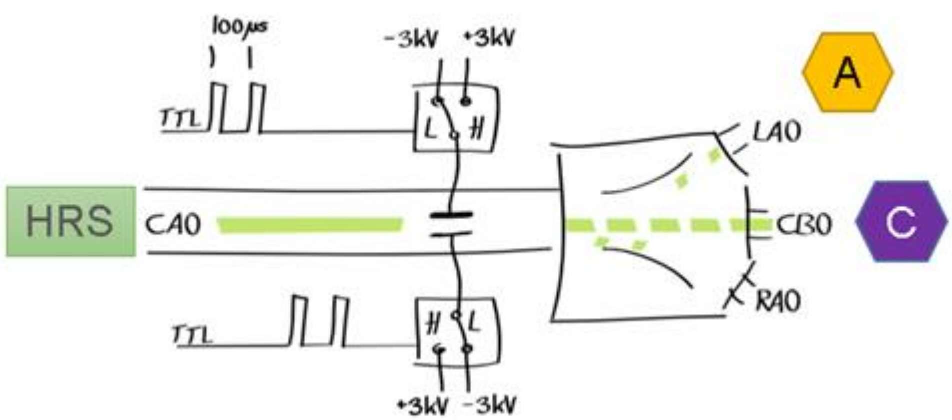
There are a multitude of applications for this :

One user takes beam to station a with a short lived isotope. While the isotope of interest is extracted from the target (just after proton impact) the beam is delivered to the user (e.g. HRS to exp A). In the remaining time ions are extracted continuously (stable isotopes or slow released) from GPS and can be delivered to Experiment B for background measurements or beam tuning.
Especially HIE ISOLDE would benefit already from additional setup time using stable beams for setup.

A second important application will be increased time for beam preparation and yield checks: The next target could already be a secondary user of the machine (e.g. main user on HRS, target to be optimised on GPS). For the yield measurements and proton scan, only a fraction of the proton intensity and cycles is required - most time is spent changing target or ion source parameters or for the activity measurement itself on the tapestation. Therefore, the proposed operation mode would be to deliver beam to the main user on HRS and only interrupt for the actual measurement time (100s of ms) required for the tapestation measurement.

b)
Beamline sharing

Here we propose a simple solution to allow two users to use the beam produced from one target station.



The duty cycle can be varied continously and high repetition rates up to 10kHz have been demonstrated such that the beam is quasi continous for most beam instrumentation equipment.

Again here one can describe a multitude of applications:
One will be simultaneous beam tuning in multiple beamlines. (Imagine beam tuning day at ISOLDE and all users can tune their beam lines at the same time)
Sending the same beam to different experiments for simultaneous measurements e.g. in-source laser spectroscopy could send the beam to MT-tof and alpha decay spectroscopy at the same time.

The idea here would be first, that a mobile beam line infrastructure is being purchased

Challenges:

a)
Cost of additional equipment : All electrostatic supplies need to be doubled up.
Synchronisation has to be carefully taken care of by dedicated hardware (FPGA) such that the isotope does not end up in the wrong experiment. Requires good user interface.
Also scheduling of the experimental campaigns to fully exploit this new technology might be challenging.

Prove of concept to be tested offline.
Prototype can be rolled out to ISOLDE during a winter shutdown.

b)

Cost of the fast switches and development time to go from POC to first prototype. The timing infrastructure needs to be adapted.
User interface needs to be written.

Original aspects:

New for ISOLDE

Unique expertises:

Fast switching has been tested (https://edms.cern.ch/ui/#!master/navigator/document?D:1050615167:1050615167:subDocs, https://doi.org/10.1016/j.nimb.2016.02.060)

Common expertises and collaborations:

None aware

Synergies with other research/technical groups:

Fast beam gate switches required for laser ion beam purification at ISOLDE require the same technology (https://doi.org/10.1016/j.nimb.2016.02.060). (Suppression of DC surface ionized background through microgating)

Synergies with other communities:
(with reference to the categories described in the "Instructions for submission page", https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)
Main category of your contribution:
Connections with other categories:
ML and AI for ion beam tuning: having beam at all beamlines simultaneously would be useful to find global maximum beam transmission.

Title: GSI-TNA

Authors and affiliations:

Christoph Scheidenberger (GSI)

General description (methodology, goals, …):

GSI is operating a large accelerator complex consisting out of the linear accelerator UNILAC, the heavy-ion synchrotron SIS and the experimental storage-cooler ring ESR. With the UNILAC, ions from p to U can be accelerated up to 11 A MeV, at SIS up to 2 A GeV and in ESR stable or radioactive ion beams can be stored and cooled at energies up to 0,56 A GeV (for U).

The storage ring CRYRING is in operation since few years and offers cooled beams in the energy range between 4A MeV and 10A keV. The CRYRING is equipped with a 1.44 Tm beam line to the ESR and will open a new window for atomic and nuclear physics experiments with highly-charged stable and radioactive heavy ions at GSI. The CRYRING is equipped with an internal ion source and an injection system which can be operated independently of the main accelerator complex of GSI.

During the next years the FAIR facility (www.fair-center.de) will be built close to the GSI sites with the GSI synchrotron SIS as injector. GSI has taken over the responsibility not only for parts of the FAIR accelerators and detectors but also for the link of the existing facilities to the FAIR complex. In addition, the existing accelerator facilities are being upgraded for FAIR operation. For the years to come, the operation of SIS-18 will be continued with on the average three months per year available beam time until the FAIR accelerators will become operational. First FAIR experiments will be realized presumably in 2026.

Various equipment and experimental setups for broad fields of EURO-LABS related physics are available, in particular nuclear structure and astrophysics, but also atomic, bio-, and plasma-physics and material science:

Beyond free access to the experimental facilities the services and support provided by GSI include:

- office space and access to the GSI computing facilities;
- training courses and briefings on the general safety regulations at GSI and on the specific regulations at the experimental facilities;
- access to the GSI detector and target laboratories, as well as access to a maintained workshop for experimentalists and assistance from the GSI general mechanics shops;
- a Guest Office providing logistic support with regard to accommodation, travel and payments;
- bus shuttle from the nearby train and tram stations from Mon. to Fri.;
- lodging facilities: On site guest house with 28 bed/office rooms, within walking distance from the institute, for long-term visitors, one guest house is available, with 9 apartments.

Web based submission of applications for experiment proposals, for users support under the EC access program, and after allocation of experiment time and access funding: web-based application for scheduling, for registration as access user.

The deliverable is “beam on target” (measured in hours) for experiments.

Deliverable n.	Unit of access	Unit cost (EUR)	Min. quantity of access	Estimated number of users	Estimated number of days spent at	Estimated number of projects

			to be provided		the infrastructure	
D-TAx.1	Hours	116,00	540	60	400	8
D-TAx.2	Hours	116,00	540	50	400	8
D-TAx.3	Hours	116,00	1750	140	1120	20

Challenges:

Original aspects:

Unique expertises:

Common expertises and collaborations:

Synergies with other research/technical groups:

Synergies with other communities:

(with reference to the categories described in the "Instructions for submission page", https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Main category of your contribution:

Connections with other categories:

Title: Toward common practices in ion radiobiology experiments

Authors and affiliations: Michaël Beuve, on behalf of GDR MI2B

General description (methodology, goals,..):

Several Research Infrastructures (RI) participating to EURO-LABS offer the possibility to perform radibiologiy and dosimetry experimentation. For the sake of increasing the benefit of the produced and published data, it is crutial to favor their completeness and intercomparison. This includes:

- Developing and sharing dosimetric protocols, including tools and methods
- Stimulating intercomparison of data and coordination for their acquisition, implying coordinated protocols and common database
- Intercomparing of radiobiological models
- Simulating and sharing the beam line and irradiation delivering

Challenges:

New challenges are opened with a large variety of irradiation modes (Flash irradiation, minibeams and micro-beams) and quality (ion, neutron, electron, photon). Each of them require comprehensive protocols and interpretations.

Unique expertises: some expertises have been developed within the GDR teams :

- ion beam dosimetry has been developed at LPC-Caen and widely spread among the French platform network ResPlanDir (coordinated by GDR)

- the predictive models for tumor/healthy tissue response NanOx, developed at IP2I-Lyon, has been benchmarked for several series of cell lines and ion irradiation species.

Common expertises and collaborations:

- The GDR teams contribute to the GATE and Geant4-DNA simulation collaborations (see separate contribution)

- Experience of pluridisciplinary collaborations (physics , radiochemistry, biology, medicine)

Synergies with other research/technical groups:

A part of the expertise is shared with the International Biophysics Collaboration (see separate contribution)

Main category of your contribution:

- Improved Access : improve dedicated access to radiobiology experiments – this may also include the integration of new RIs

Connections with other categories:

- Beams + Targets: Irradiation techniques such as scanned beams, Spread-Out Bragg Peak, flash, minibeams, require dedicated developments

- Detectors + Electronics : online dosimetric tools

- Data Acquisition + Analysis, Simulations: Simulation-based modelling of biological dose

- DMP + Data sharing : inter-comparison of data?

Cluster for Low-Energy Acceleator-based Research – CLEAR[1]

Proposal for Transnational Access at Small- and Medium-scale facilities in EUROLABS

J. Gomez-Camacho (CNA-Seville), M. Jaksic (RBI-Zagreb), S. Harissopulos (NCSRD-Athens)

The participation of small- and medium-scale accelerator facilities in a joint modality to the transnational access is an opportunity and a challenge to consolidate their integration in the European landscape of research facilities, to increase further the quality of their research, and to face the demanding requests of the selected proposals. Transnational access will bring new users, with new ideas, that will have a multiplicative effect in the future development of these multidisciplinary facilities. *Though CLEAR is proposed by the three low-energy accelerator laboratories*, i.e. the Tandem Accelerator Laboratory of NCSR "Demokritos" (NCSRD), Athens, the Centro Nacional de Aceleradores (CNA), Seville, and the Ruđer Bošković Institute (RBI), Zagreb, *it is open for further synergies with additional accelerator labs with similar or complementary scientific profiles.*

The proposing laboratories are currently collaborating with many European groups performing accelerator-based interdisciplinary research from which new users could be attracted. Due to their geographical location in combination with its existing scientific infrastructures, the lab could act as a bridge between Europe and groups from associated countries eligible for TA support.

A variety of low-energy ions as well as secondary fast neutron beams are currently available at the proposing laboratories which host following accelerators:

- *CNA – Seville:* 3 MV Tandem, with 6 beam lines for nuclear physics and ion beam analytical techniques and a neutron beam line; 18 MeV p / 9 MeV d Cyclotron, for radiopharmaceuticals, with an external beam line for nuclear physics experiments and irradiation; 1 MV Tandetron, used for Accelerator Mass Spectrometry; 200 kV compact accelerator MICADAS, used for 14C measurements.
- *IRB – Zagreb:* 6 MV EN Tandem VdG accelerator and 1 MV Tandetron accelerator with nine (9) beamlines for a wide spectrum of nuclear analytical techniques, dual and in-air irradiations.
- *NCSRD – Athens:* 5.5 MV Tandem with 6 beamlines for nuclear physics and ion beam analytical techniques and a neutron beam line; a 250-keV Single-stage accelerator (PAPAP) capable of delivering high current (up to 1 mA) proton and deuteron beams.

CLEAR aims at actively contributing to EuroLABS by offering their research facilities for nuclear physics basic and applied research, data management, instrumentation development and testing and personnel training.

Transnational Access to CLEAR labs will be granted on the basis of scientific proposals which will undergo a peer review evaluation based on scientific merit feasibility. For this purpose, a common PAC and/or USP will be established. In support to external users, a contact person will be assigned at each facility with the task to provide all technical guidance to scientists interested in carrying out experiments. Scientific and technical support will be provided during all phases of an approved project. The spokesperson of a project will be receiving all necessary documents assisting in the preparation of an experiment, such as available beams and corresponding intensities, operational status of the instrumentation, technical manuals etc. Special care will be given to safety, security and radioprotection requirements. External users of PAC approved projects will be supported for travel, accommodation and subsistence. The primary target areas for TA would be: support in research and training programs

[1] Tentative title / acronym

of the large scale facilities, as well as application of techniques available at CLEAR labs in other areas of research, education and technology transfer.

Hands-on training: the CLEAR labs will establish hands-on training programs on key nuclear physics techniques and equipment (vacuum, target handling, detector use, data analysis), specially dedicated to early stage researchers (PhD candidates and postdocs), who rarely have the opportunity to relevant training at the large scale facilities. In addition, transnational access support could be available to facilitate the attendance of the early stage researchers, not just for their participation in accepted TA experiments, but also as proposers for a specific 'hands-on training'. A quality control of the courses to be offered will be assigned to an independent training committee comprising University faculty members and EuroLABS scientists with representation of the CLEAR labs.

Common open data policy: CLEAR will establish a common open data policy, which will allow to make available, in a common format, and with common access protocols, all data produced in experiments which received transnational access funds from the EUROLABS project. This common data policy will be in-line with already applied good practices such as the FAIR principles (Findability, Accesibility, Interoperability and Retrievability) or any other modality to be proposed by the EuroLABS Management/Advisory Bodies. The CLEAR common open data policy, which will cover a proper set of data, could be taken as a test case, where technical, legal and other questions are dealt with, which could facilitate the eventual evolution of EuroLABS facilities to an open data environment. It also aims to probe the interoperability with open data from theoretical calculations and simulations.

Science and instrumentation capabilities: The proposing CLEAR labs have unique facilities allowing for carrying out a wide spectrum of time-demanding fundamental nuclear physics experiments at low energies, the employment of innovative analytical techniques as well as instrumentation tests of key relevance to the EUROLABS scope. These include:

- Detector testing facilities, such as radiation hardness tests and energy and timing responses to different radiation, single event effects on electronics, etc., which are very important in the setting of detector arrays in large scale facilities. These tests are already being done in the framework of international collaborations such as RD50 and IAEA Coordinated Research Projects, or former EU projects that funded TA (AIDA 2020, RADIATE), and could result in more efficient use of available resources and expansion of the user communities expected to strongly benefit from Transnational Access.
- Accelerator-based neutron beams. There are presently neutron beam lines, which time of flight capabilities, which allow not only to investigate neutron induced reactions of relevance to nuclear structure and a wide variety of nuclear applications but also to study the response and overall performance of neutron detector arrays.
- Target preparation and analysis facilities allowing for evaluating the thickness, composition and homogeneity of targets, as well testing under in-beam conditions the behavior of novel target systems.
- Dual beam and in-air irradiations as well as IBA techniques with unprecedented analytical accuracy and irreplaceable role in studying problems of key societal impact relevant to human health, environmental monitoring and climate change, energy, culture and many more. These techniques can also provide a unique training framework for young nuclear physicists.

New Physics cases

Synthesis of SHE via reactions with forward emission of an energetic alpha particle

Authors: Catalin Borcea[1]; Mihai Stanoiu[1]; Cristina Petrone[1]

[1] *IFIN-HH*

Corresponding Authors: borcea@nipne.ro, cristina.petrone@nipne.ro, mihai.stanoiu@nipne.ro

Experiments performed at FLRN-JINR Dubna [1-3] using a magnetic spectrometer revealed that the energy spectra of alpha particles emitted at zero degree in heavy ion induced reactions at energies slightly above the Coulomb barrier extend up to the so-called kinematic limit. The kinematic limit (KL) is the maximum energy an alpha particle may have in the given colinear configuration of a two-body process, the reaction products emerging unexcited. The KL is easily calculated from the conservation laws and masses of the reactants. The observed cross sections for alpha production close to the KL span, depending on the chosen combination projectile-target, covers a range of cross sections that are between 4 and 6 orders of magnitude lower that the cross section at the maximum of the emission spectrum which is displayed close to the Coulomb barrier in the exit channel. Higher values of the cross section at the KL are observed for nuclei that have high positive values of the alpha separation energy from the target nucleus, a common situation for alpha active actinide targets. The fact that at the kinematic limit the reaction products are unexcited is an exceptional circumstance for the synthesis of SHE. Indeed, the heavy residue partner of the alpha particle can be a SHE and the presence of alphas with energies close to the KL guarantees the weak excitation energy (close to zero) of the heavy residue.

Another complementary observation resulted from these studies is that for alpha energies 25-35 MeV smaller than the KL, only two body reactions can produce alphas with such energies (many body channels should provide energy for all emerging particles, in particular their reciprocal Coulomb repulsion). This observation is also very important because in the case of a smaller alpha energy, the heavy residue takes the excess energy and becomes excited. If the excitation energy is higher than the neutron separation energy Sn, the excited residue may decay by neutron(s) evaporation, resulting in lighter isotope(s) of the residue.

A final remark concerns the already studied combinations of interest for SHE synthesis. Three reaction have been studied: 40Ar+Th, 48Ca+238U and 56Fe+238U, all at energies slightly higher (about 10 MeV) than the Coulomb barrier. All these reactions have alpha spectra extending in energy up to the vicinity of the KL, with cross sections of the order of μb/MeV/srad (as observed for example in Figure 1; data on 56Fe experiment are preliminary). All these experiments used thick targets (1mg/cm2). GANIL can use the FULIS device (LISE Wien filter in a special configuration) for identifying the resulting heavy residue (HR) from such a reaction. However, a gas filled separator can do a much better job.The idea of using VAMOS filled with gas was already discussed in the past and can be considered. First experiments could be for synthesis of pre-SHE nuclei (Z from 99 to 105) for comparing the production cross section with the usual fusion-evaporation reaction in order to ensure the advantage of this new method (higher cross section). It will be not a waste of beam time because spectroscopy of these nuclei can be studied with presumably better statistic.

The method offers the possibility to use projectiles above 48Ca and consequently lower Z targets easier to prepare and use.

The success of the method will confirm that GANIL belongs to the constellation of labs with results in the studies for new superheavy elements or new isotopes of already discovered elements, as the method gives access to more neutron rich isotopes.

The ideas presented above were discussed with many colleagues; they could join this effort and their participation will be a guarantee for the success of the endeavor.

[1] C. Borcea et al., Nucl. Phys. A351, (1981), 312

[2] C. Borcea et al., Proc. Int. Symp. On Exotic Nuclei 2016 Kazan, Russia, World Scientific ISBN 978-981-3226-53-1, p. 132

[3] C. Borcea et al., Nucl. Phys. A391, (1982), 520

Extending the reach of RIB facilities by means of indirect methods

Author: MARCO SALVATORE La Cognata[1]

[1] *LNS*

Corresponding Author: lacognata@lns.infn.it

Title:

Extending the reach of RIB facilities by means of indirect methods

How nuclear physics can contribute to the field of multimessenger astronomy

Authors and affiliations:

M. La Cognata (on behalf of the ASFIN collaboration) – INFN-LNS, F. De Oliveira - GANIL, S. Cristallo - INAF, A. Moro - University of Seville, S. Typel - Technische Universitaet Darmstadt

General description (methodology, goals,..):

The origin of the chemical elements is a key question in physics. In particular, nuclei heavier than iron are mostly produced by neutron captures, either slower (s-process) or faster (r-process) than the beta decay rates. Observations of gravitational waves (e.g. the event GW170817) and the concurrent measurements of electromagnetic radiations opened a new era in physics, leading to multimessenger astronomy. In particular, such observations proved that the r-process is taking place during Neutron Star Mergers, by observing and interpreting the electromagnetic transient (the so-called kilonova) following the gravitational event.

To model such events, the time evolution of their emission (the light curve) and the nucleosynthesis processes, whose results both power their emissions and pollute the surrounding interstellar medium with freshly synthesized nuclei, it is necessary a great number of physical inputs. In this framework nuclear cross sections play a key role, especially those of reactions involving neutrons and short-lived nuclei.

Challenges:

At the status of the art, in the case of short-lived nuclei, for which a target cannot be produced, no neutron-capture cross section data are available, so it is necessary to use nuclear models, often inaccurate, to calculate the relevant cross sections. Indirect methods such as the Trojan Horse Method (THM) could be fruitfully used to measure the relevant cross sections and benchmark the theoretical models, making many physical problems connected with the leading field of multimessenger astronomy accessible to laboratories for which transnational access will be available.

Original aspects:

European research institutions are strongly committed both in the investigation of gravitational events and multimessenger astronomy, and in the field of the physics of radioactive nuclei. Here we aim at linking the efforts, by extending the reach of existing radioactive ion beam facilities and of the next generation ones, to provide crucial input for modeling r-process nucleosynthesis and the sources to be targeted in multimessenger studies.

Unique expertises:

The THM has the advantage of requesting fixed beam energies to span the whole excitation function including energies of astrophysical interest. Moreover, the need to break the TH nucleus and the intercluster motion would make it possible to fine tune the effective interaction energy of the indirectly measured reaction. Both features perfectly match the possibilities of most RIB facilities for which it is not easy to carry out energy changes in small steps, as it would be required to measure cross sections for astrophysical energies. Furthermore, very often beams are delivered at energies quite larger than those needed for astrophysical applications, so THM would make it possible to reach them in the lab.

However, further developments would be necessary to extend the application of THM to r-process studies. For the experimental perspective, it is necessary to develop compact, 4pi and high granularity detectors with angular resolution of the order of 0.2° to perform high-precision excitation function measurements.
On the other hand, an improved theoretical description of THM will be necessary based on general principles of direct reaction theory with three particles. In contrast to previous approaches, the off-shell propagation of the transferred particle needs to be considered explicitly before it interacts with the second nucleus in the initial state of the THM reaction to participate in the reaction of astrophysical interest. The interactions in the initial and final state of the THM reaction need also to be considered by optical potentials avoiding plane-wave approximations.

Common expertises and collaborations:
Nuclear astrophysics with indirect methods

Synergies with other research/technical groups:
Theoretical physicists working on direct reactions. Other nuclear astrophysics groups such as n_TOF working on r-process using activation techniques

Synergies with other communities:
Theoretical astrophysicists working on astrophysical models

Main category of your contribution:
New physics cases

Connections with other categories:
Beams + Targets
Detectors + Electronics
Data Acquisition + Analysis, Simulations
Theory
Training, Education, Outreach, Social Impact

IRIDES - Interdisciplinary Research Infrastructure for nuclear Decays Experiments in plasma Sources

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IRIDES - Interdisciplinary Research Infrastructure for nuclear Decays Experiments in plasma Sources

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General description (methodology and goals)

Impact – This project aims to develop joint research activities and common efforts among the partners for supporting a challenging new approach in nuclear physics, with high potentiality of discovery, which could place Europe on the cutting-edge about **in-laboratory plasma studies about beta-decays, also for nucleosynthesis in stars and in general in the cosmos, with disruptive impact in nuclear physics and astrophysics**, multimessenger astronomy, and supporting applied research in plasmas for ion beams and accelerators, thermonuclear fusion, etc. **This proposal deals with the idea of further developing and performing joint research activities with the magnetized plasmas of the PANDORA** (Plasmas for Astrophysics, Nuclear Decay Observation and Radiation for Archaeometry) facility at INFN-LNS, **with the main goal of measuring, for the first time, beta-decay rates in plasmas; meanwhile, the facility will be open to the community** for performing experiments and tests of tools and methods relying to nuclear physics experiments in plasmas, diagnostics and methods for new ion sources for particle accelerators, etc.

Summary of the goals

- make joint efforts in **focusing relevant physics cases for nuclear physics and astronomy** about beta-decay studies in plasmas;
- **perform joint activities that will provide an added value to reach sooner and better the goals and also to broaden the potentialities of the PANDORA facility** to additional new physics cases;
- **develop more advanced plasma modelling techniques** for higher robustness in predictions of experimental results and the following data interpretation;
- **develop and test vaporizing tools:** ovens and sputtering systems assuring long-term operations during beta-decay observations; **PANDORA may also become a unique facility for developing beams never produced in the past.** At the same time the research program in ERIBS (this Call, Beams+Targets) can support feasibility study for some of isotopes relevant to PANDORA;
- **further development of plasma diagnostics tools** supporting nuclear physics goals but also experiments about Electron Cyclotron Resonance (ECR) plasmas and ECR Ion Sources physics and technology;
- **training of young PhD students and post-docs** in a new and interdisciplinary field of Physics.
- **Use of facilities/setups in the partner laboratories is considered**, supporting feasibility studies and preparatory phase (AISHa at LNS, ATOMKI about plasma diagnostics, GANIL for testing challenging metallic for SPIRAL2, among the ones included in the PANDORA list; GSI testbench for development of some isotopes injection method).

In PANDORA, the beta-decay measurements will be done through the detection of the gamma-rays emitted by the excited daughter nuclei in a plasma whose conditions can mimic some stellar conditions in a temperature range – in units of kT_e – around kT_e~0.1-30 keV. This new approach will open up the possibility to investigate tens of physics cases, in particular, in nuclear-astrophysics (*BBN, r- and s-processing, CosmoChronometers*). Indeed, in the last decades experimental and theoretical efforts have been dedicated investigating nuclear decays in matter at extreme thermodynamical conditions. It has been predicted that sizeable variations in the beta-decay properties (i.e. mean lifetime) can be observed in highly ionized nuclides. Few experimental evidences, showing variations in the beta-decay rates as a function of the atomic ionization state, have been collected, up to now, mainly using Storage Rings. A totally new and challenging approach, viable in a benchtop facility, is here proposed.

New Physics Cases – Among the different processes of nucleosynthesis occurring in stars, we here focus our attention on s-process. The relative abundances of elements and isotopes produced depend on the interplay between neutron abundances (neutron fluxes coming from reactions producing neutrons and their evolution over time are critical parameters), nuclear cross sections and decay rates; the latter, have been not deeply investigated up to now and their relevance is discussed hereby.

Modern stellar evolution and nucleosynthesis codes include thousands of nuclear processes. A significant fraction are neutron capture reactions on more than 120 unstable nuclei close to the valley of beta stability. Examples include: **^{32}Si, ^{35}S, ^{36}Cl, ^{37,39}Ar, ^{41,45}Ca, ^{32,33}P, ^{46,47}Sc, ^{55,59}Fe, ^{60}Co, ^{59,63}Ni, ^{64}Cu, ^{65,67}Zn, ^{72,73}Ga, ^{71,75}Ge, ^{76,77,79}As, ^{79}Se, ^{80,82}Br, ^{81,85}Kr, ^{86}Rb, ^{89,90}Sr, ^{90}Y, ^{93,95}Zr, ^{94,95,96}Nb, ^{97,98,99}Tc, ^{93,99}Mo, ^{103}Ru, ^{104}Rh, ^{107,109}Pd, ^{108}Ar, ^{109,115}Cd, ^{114}In, ^{120,121,123}Sn, ^{122,124,125}Sb, ^{127}Te, ^{128,129,130}I, ^{133}Xe, ^{134,135,136,137}Cs, ^{139}Ba, ^{140}La, ^{141}Ce, ^{142,143}Pr, ^{147,149}Nd, ^{145,146,147,148,149}Pm,^{151,153,155}Sm, ^{152,154,155,156}Eu, ^{153,159}Gd, ^{160,161}Tb, ^{163,165}Dy ^{163,164,166}Ho, ^{165,169,171}Er, ^{170,171,172}Tm, ^{175}Yb, ^{176,177}Lu, ^{181,182}Hf, ^{179,180,182}Ta, ^{181,185}W, ^{186,188}Re, ^{191}Os, ^{192,194}Ir, ^{193,197}Pt, ^{198}Au, ^{203}Hg, ^{204,205}Tl, ^{205}Pb. In some cases (e.g. ^{163}Dy, or ^{205}Tl) the nuclides are stable in terrestrial laboratories, but become unstable when they are ionized. The high-temperature stellar plasma, in fact, introduces enormous uncertainties on the lifetimes of many radioactive isotopes**, which are exposed to neutron captures over a wide range of time durations: from less than 20 years in the thermal instabilities of shell He-burning in low mass stars, up to several thousand times longer intervals in core He-burning conditions.

In addition, **in-laboratory plasma's opacity investigation is envisaged in an environment resembling thermodynamic conditions typical of the ejecta of compact binary mergers containing at least a neutron star.** We aim to advance knowledge on the physics of kilonovae, the electromagnetic transients following a merger, which are relevant for the study of the origin of heavy nuclei in the Universe produced via r-process nucleosynthesis.

Methodologies – **This proposal in particular aims to reinforce synergies and joint research among the partners supporting the challenging operations and R&D around the PANDORA facility**, now under construction at INFN-LNS. This setup is based on a complex system consisting in a minimum-B magnetic trap, a plasma diagnostics system made of a **set of diagnostics simultaneously operating in RF, optical and X-ray domains** for the non-intrusive monitoring of the plasma and the measurement of plasma parameters to be correlated with the nuclear decays (Silicon Drift Detectors for soft X-ray at E<30 keV; high purity germanium (HPGe) detectors for hard X-rays E>50 keV, up to hundreds keV; CCD pin-hole cameras with energy and spatial resolution around 250 eV and 500μm, respectively, for space resolved soft X-ray spectroscopy at E<20 keV; Space Resolved Optical Emission Spectroscopy having spectral resolution of about 10^{-2} nm in the range 200-900 nm; microwave interferometry and polarimetry based on Faraday-rotation for line-integrated density measurements, etc.). An Array of HPGe detectors for γ-ray spectroscopy will be used to detect the in-plasma nuclear decays via the gamma-rays emitted from the excited states of the daughter nuclei and to measure the expected variation in the decay rate due to a reduction of the half-life of radioactive nuclei.
The experimental procedure is rather complex and it consists in creating a "buffer plasma" by He, O or Ar up to densities of 10^{13} atoms/cm^{-3}. The isotope whose decay rate we want to measure is then directly fluxed (if gaseous) or vaporized by appropriate ovens or sputtered into the chamber and then turned into plasma-state and magnetically confined. After the isotope decay, the daughter nuclei still confined in the plasma emit γ-rays in the range of hundreds of keV; Gamma-rays will be detected through the **γ-ray detector array made of HPGe detectors surrounding the magnetic trap**.
The in-plasma measured radioactivity can be directly correlated to the plasma density and temperature, that will be monitored by the multi-diagnostics setup.

All the synergies among the partners of this proposal can be very hugely beneficial for any of the experimental phases mentioned above, since there are complementary **skills, know-how and expertise that can be merged together to improve the methodology** and make soon a proof-of-principle experiment with the first considered physics cases, i.e., the **measurement of the decay rates of ^{134}Cs, ^{94}Nb, ^{176}Lu, but also ^{85}Kr and ^{7}Be.**

Each of the experimental methodologies needed to achieve the PANDORA's goals has to be at the state of art: injection of metallic elements via sputtering or oven techniques (with stable in-plasma concentration, for weeks or months); monitoring of plasma parameters with high precision and for long operations (weeks or months); measurement of gamma-rays in a harsh environment such as an Electron Cyclotron Resonance plasma, emitting a strong background of X and gamma rays even above 1 MeV, etc. This motivates synergic activities among the actors in the European community which have expertise and skills really relevant in all the above mentioned fields of research.

Interdisciplinary Impact – At the same time, other than an experimental setup with a specific scientific goal, **PANDORA is conceived as an interdisciplinary facility, equipped with a plasma multidiagnostics system** (RF probes, microwave interfero-polarimeters, X-ray detectors in soft and hard domain, X-ray pinhole camera for plasma imaging and space resolved spectroscopy, fast X-detectors for time-resolved spectroscopy) **allowing experiments about plasma physics, ion sources physics, astrophysics in laboratory (turbulence and instabilities, etc.), material analysis**.
Many of the activities here presented can in principal benefit from the **PANDORA facility availability to test detectors and diagnostics methods, to make ECR plasma experiments, for investigating innovative vaporizing methods, study of new tuning techniques and plasma heating methods.**

Challenges

In this document, we propose to develop a totally new and complementary approach to measure, for the first time, nuclear beta-decay rates of nuclear physics and nuclear astrophysics interest in a plasma simulating stellar-like conditions.
This includes a series of breakthroughs that require the collaboration of the most relevant research groups in the several fields in order to reach the goals. In particular, main operational challenges are:

- **Operate a big plasma trap with stable plasma parameters for days, weeks, months**;
- **Evaporate or sputter metallic species in the ECR plasmas keeping stable fluxes** of vapours during the experimental running (weeks or months);
- **Monitor precisely and in on-line mode the plasma parameters** by a plethora of diagnostics systems;
- **Measure the beta-decay rate maximizing the signal over noise ratio** in a harsh environment;

The proposed approach is based on the possibility to keep under control the plasma parameters (volume, overall density, temperature and isotope concentration) with high accuracy (within 5% in terms of temperature and densities). These parameters determine the plasma energy distribution function, defining an effective temperature and, thus, the ion charge states distribution (CSD).

Original aspects

The activity here described represents **the first attempt ever to measure nuclear beta decays in high temperature plasmas. This proposal aims at enlarge as much as possible the reliability and feasibility of the method for exploring a plethora of new physics cases**, also improving the accessibility of the PANDORA facility to the community for interdisciplinary purposes. Experimentally, the investigation of the decay properties of highly ionized ions represents a complex challenge to overcome. Early attempts to investigate the stability of the decay constant of natural radioactive elements, significantly varying the temperature, the pressure or the magnetic field, firmly established the constancy of the nuclear lifetime, with the variations observed being lower than about 0.05%. An important

breakthrough in the field was achieved with the use of Storage Rings, where experimental results showed strong variations of the half-life, for example, for the bare $^{187}Re^{75+}$ ions decay, due to a process known as bound-state beta decay, by 9 orders of magnitude faster than neutral ^{187}Re atoms with a half-life of 42 Gyr. As a further example, bare $^{163}Dy^{66+}$ nuclei, being stable as neutral atoms, become radioactive, thus allowing the s process, with a half-life of 33 days. Anyway, **no data are available up to now about decays in plasmas** resembling astrophysical temperatures (and thus, about similar CSD). Until now, decay rates used in nucleosynthesis models are mainly extracted from theoretical calculations in *Takahashi K. and Yokoi, K., 1987, Atomic Data and Nuclear Data Tables, 36, 375,* where a phenomenological method was used. This approach is sometimes insufficient in stellar conditions since inaccuracies in decay rates have large effects whenever they control the abundances of s-process nuclei, as for ^{134}Ba and ^{136}Ba, whose ratio (in the solar material and in pre-solar grains) is set by the competition of n-captures and beta decays on Cs isotopes (mainly ^{134}Cs). Similar uncertainties affect other nuclei along the s-chain where poorly known bound-state decays and the presence of isomeric states make the scenario rather complex. **A deeper knowledge of weak interactions represents the most important remaining bottleneck for nucleosynthesis calculations, and it is mandatory to improve accuracies of the model predictions.**
Laboratory ECR plasmas represent a unique environment that can reproduce an ion charge distribution of the isotope of interest, i.e., like-astrophysics scenario, thus representing a totally new and **complementary approach to the few previous experiments performed in Storage Rings** (where fully-stripped ions only have been investigated).

Unique expertise

- **INFN, University of Perugia and ENEA teams have well-established experience in theoretical and experimental nuclear physics, astrophysics and nucleosynthesis**
- **All the involved laboratories**, institutions and related research groups have a **well-established know-how to produce dense and hot plasmas from gaseous and/or metallic elements** (for metals, especially GANIL, GSI, Jyvaskyla Univ., INFN-LNL).
- **Groups of INFN-LNS and LNL, ATOMKI, Jyvaskyla University have developed and used technologies, technical tools, methodologies, etc. to monitor "on-line"** the local density and temperature of the plasma, i.e. in a non-intrusive way (optical spectroscopy, X-ray spectroscopy and imaging, etc.), also in time- and space-resolved way.
- **INFN, UniPerugia and INFN-TIFPA groups have been working on theory and models** about nuclear physics, nuclear astrophysics and astrophysics and are worldwide recognized experts in nucleosynthesis in stellar environments;
- **INFN-LNL and INFN-LNS have a long-term expertise in γ-spectroscopy**;

Common expertise's and collaborations

Partners mentioned in this proposal have a well-established experience of close collaborations and joint activities since years. Experimental site and test bench available at **ATOMKI-Debrecen** have been used in the past years **for developing several diagnostics tools** now considered as standard equipment of the PANDORA facility: CCD cameras, CCD pinhole X-ray cameras for plasma imaging, X-ray detectors, etc. **Joint measurements have been done also with GSI group and Jyväskylä University group. INFN and GANIL recently are collaborating about modelling in plasma CSD using different numerical tools,** and also about GEANT4 simulations for gamma-rays detection during the experiments about beta-decays. **INFN and Jyväskylä University have been in contact about Ion Cyclotron Resonance Heating** studies in plasmas: this would be really relevant to check feasibility of β-decay studies in hot ions plasmas, investigating excited heavy nuclei.
In addition, **an agreement with GSI is now active for the testing of the GSI oven for the Lu production** and injection in the PANDORA plasma, that is one of the first physics cases to be focused, as well for developing vaporizing methods and ovens for other metallic isotopes. First tests are expected to be carried out with the AISHa source at LNS.

Joint activities are expected using facilities, testbenches and setups in the partner laboratories: these are considered supporting feasibility studies and preparatory phase (AISHa at LNS, ATOMKI about plasma diagnostics, GANIL for testing challenging metallic for SPIRAL2, among the ones included in the PANDORA list; GSI testbench for development of some isotopes injection method)

Synergies with other research/technical groups

Synergies with the wide community of nuclear astrophysicists are intrinsically conceived in this proposal: in particular, synergical activities are thought with the **ASFIN collaboration**, having partners in UE, USA and Japan, which runs accelerator-based experiments on nuclear reactions for astrophysical nucleosynthesis scenarios, as well as with the **n-TOF collaboration based at CERN**, which aims at studying neutron captures reactions which are fully complementary to the beta-decays here discussed.
The cooperation is then straightforward with the groups-network that is proposing the ERIBS proposal (European Research Infrastructure – Beam Services), since activities on plasma-based ion sources are full synergic with the ones hereby proposed.

Synergies with other communities

Project activities are thought to have interdisciplinary applications. **Concerning fundamental research, the mentioned nuclear physics, nuclear astrophysics and astrophysics are the main fields of research that will benefit of this joint research activities,** providing new services to the community. Concerning outcomes and applied research, PANDORA plasma will be an exceptional source of electromagnetic radiation suitable for material science and Archaeometry.
Techniques and methods developed as diagnostics (e.g. microwave interferopolarimetry, X-ray spectroscopy and imaging, etc.) and/or plasma heating methods (ECR heating launching systems and diagnostics, as well as ion heating and other ancillaries) have high relevance and **impact in the field of thermonuclear fusion research** (among the others, for specific contributions to the Divertor Tokamak Test facility). Concerning nuclear physics, instruments and methods involved in this project, to reach the scientific goals a strong **synergy with HPGe detectors community** has been activated (e.g., with the **GAMMA-GALILEO collaboration**): a new test/repair/maintenance laboratory will be arranged at LNS (DetLab) for the optimal use of these gamma-ray detectors. INFN is running a similar laboratory at the LNL since several decades and their know-how will be also transferred to LNS facility. This DetLab could become strategic not only for the LNS, but for the whole community using gamma detectors (HPGe detectors are used also in homeland security, environmental monitoring, i.e. radioactive contamination issues, geological explorations such as volcanic studies, etc).

Estimated budget and main items

Around 600 k€ especially for hiring new manpower: young post-doc scientists and cotutelle of PhD students; consumables for ovens and sputtering system, tools for improving the diagnostics systems, travels

Main category of the contribution

New Physics Cases (*Discoveries, impact in other fields****)***

Neutron capture reactions at the new experimental area of n_TOF for heavy elements nucleosynthesis

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A new experimental area, very close to the spallation target is being constructed at n_TOF – the neutron time-of-flight facility at CERN. The aim of this new station, the n_TOF NEAR Station, is to take advantage of the extremely high neutron fluence expected at a position very close to the spallation target (of the order of 3 m), to perform activation measurements on extremely small-mass samples (~ a few ng) and on radioactive isotopes that could be produced by implantation of Radioactive Ion Beams. The possibility to experimentally determine MACS (maxwellian averaged capture cross section) for short-lived unstable nuclei will open the possibility to investigate with enhanced reliability the branching points in the s-process, as well as some explosive scenarios such as the weak r-process. An important advantage of the NEAR Station is its proximity to the ISOLDE facility, from which sample material to be irradiated could be produced.

Title:
Neutron capture reactions at the new experimental area of n_TOF for heavy elements nucleosynthesis

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General description:
A new experimental area, very close to the spallation target is being constructed at n_TOF – the neutron time-of-flight facility at CERN. The aim of this new station, the n_TOF NEAR Station, is to take advantage of the extremely high neutron fluence expected at a position very close to the spallation target (of the order of 3 m), to perform activation measurements on extremely small-mass samples (~ a few ng) and on radioactive isotopes that could be produced by implantation of Radioactive Ion Beams. The idea and concept behind this new measuring station have been briefly outlined in the document on the European Strategy [1], and in [2]. More in detail, a Maxwellian-like neutron spectrum can be produced, corresponding to thermal energies in the range of astrophysical interest (from a few keV to a few tens of keV) thus allowing us to derive Maxwellian Average Cross Sections (MACS) by means of the activation technique. The possibility to experimentally determine MACS for short-lived unstable nuclei will open the possibility to investigate with enhanced reliability the branching points in the s-process, as well as some explosive scenarios such as the weak r-process. An important advantage of the NEAR Station is its proximity to the ISOLDE facility, from which sample material to be irradiated could be produced.
[1] E. Chiaveri (on behalf of the n_TOF Collaboration), Status and Perspectives of the neutron time-of-flight facility n_TOF at CERN, European Strategy for Particle Physics 2018-2020, contribution #17.
[2] http://cds.cern.ch/record/2737308/files/INTC-I-222.pdf

Challenges:
Measure the neutron fluence characteristics in the NEAR station by means of the multi-foil activation technique, a standard methodology typically used at neutron sources of various types.
Perform (n,γ) measurements on short-lived isotopes.

Original aspects:
The combination of NEAR and ISOLDE in its proximity provides a unique opportunity in the world to measure (n,γ) cross sections on short-lived isotopes. It is worth mentioning that these reactions play a key role in the nucleosynthesis of heavy elements.

Unique expertises:
The team has a longstanding experience in the field of neutron physics (neutron-induced cross section measurement and neutron beam characterization), activation measurements and stellar models.

Common expertises and collaborations:
Some members of the research team have been collaborating within different projects since more than 10 years. For instance, n_TOF, LUNA, LENA.

Synergies with other research/technical groups:
Similar measurements can be performed at radioactive beam facilities using indirect methods (THM), and therefore with complementary experimental approaches.

Synergies with other communities:
The installation will be relevant also to provide information on the behaviour of non-metallic materials for accelerator and experiment in radiation fields. The radiation field present in the experiments and accelerators can damage non-metallic materials (e.g. polymers) posing a threat to the adequate operation of the systems they form part of. Therefore, there is a need for irradiating such materials and/or equipment up to levels compliant with their lifetime requirements, and to verify that they are still capable of fulfilling their intended function (e.g. insulation, structural, etc.).
Another possible application of a physics program at the NEAR Station, is for material irradiation with a wide-spectrum neutron beam, including the high-energy tail, of interest for a variety of applications, in particular for energy production (fusion and fission reactors), radiation damage and others.

Main category of your contribution:
Improved Access

Connections with other categories:
New Physics Cases, Training, Education, Outreach, Social Impact

Proposal for developing a simultaneous (dual-ion beam) irradiation facility at GANIL to simulate reactor like environment for radiation damage studies

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Materials are subjected to energetic particles/ions in a number of radiation environments during service. A typical example is the nuclear industry (reactors, waste immobilization & disposition) where the materials are under constant irradiation by neutrons, alpha particles, fission fragments (particles of mass 70 − 160u & having typical energies of ~ 70 − 100 MeV, slowing down in the target material via inelastic electronic energy loss (Se)), alpha recoils (typical energies of few hundred keV, slowing down in the target material via elastic nuclear energy loss (Sn)) etc. Such exposure of materials to energetic particles, commonly referred to as irradiation, is a detrimental process as it results in defects creation and subsequent micro-structural changes in the material, eventually leading to a degradation of its properties (i.e. radiation damage). Understanding the radiation response of nuclear materials, and thus designing them to be more radiation damage tolerant, is therefore of immense technological significance. A common way to simulate the effects of such irradiations, within a limited time, is to use energetic ion beams from accelerators. The accelerated effect of fission fragments can be simulated by using high energy (swift) heavy ion beams (E ~ 70–100 MeV), whereas that of α-recoils can similarly be investigated by employing ion beams of typical ions (such as Kr, Xe, etc.) with energies of a few hundred keV (low energy heavy ions). Note that for such studies (aimed at understanding the radiation response) to be truly relevant, it is crucial that they are carried out at the corresponding 'in-service' (irradiation) conditions.
Despite the decades of research devoted to understanding the radiation damage in nuclear materials, studies concentrating on the effects of simultaneous Sn and Se irradiations are very scarce, i.e., the effects of separate/individual and sequential irradiations with low and/or high-energy ions have been studied extensively and are well understood, but the same is not the case with simultaneous particles irradiations. At this juncture, it is vital to explicitly point out that materials used in nuclear reactors and/or waste matrices are actually exposed to simultaneous (and not separate) irradiation with low and high energy particles. In other words, in the context of nuclear materials, simultaneous irradiations with high energy and low energy particles (and not individual and/or sequential low or high energy irradiations (as has been usually done till now)) correspond to the in-service conditions of actual relevance.
The reason for such scarcity of investigations under simultaneous low and high energy irradiations is quite possibly the acute lack of such dual-ion beam irradiation facilities. To my best knowledge, there exists only one such facility in the world, viz. JANNUS-Saclay [1, 2], where simultaneous low energy and high energy irradiations are possible. The maximum energy that can however be supplied at the JANNUS-Saclay facility is around 50 MeV, which in the context of investigating the radiation damage in nuclear materials (caused by fission fragments) is far too low. Note that, as mentioned earlier, fission fragments have typical energies in the range of 70 − 100 MeV.
The GANIL facility can deliver heavy ions of energy ~ 100 MeV which are ideal for simulating/mimicking fission fragments. What is also required however is a low energy ion beam irradiation/implantation facility that can be used to study the radiation damage caused by alpha recoils (E ~ few hundred keV). Moreover, this low energy irradiation facility should be integrated to the high energy (~ 100 MeV) irradiation facility to accurately simulate a typical nuclear reactor irradiation scenario. As elaborated earlier, materials used as nuclear waste matrices and/or in the design of nuclear reactors are actually exposed to concomitant irradiation with low and high energy particles.
Finally, since a high temperature (~ 1000 K) environment is an integral part of a nuclear reactor core, a high temperature irradiation setup/chamber should also be developed/installed at this proposed simultaneous (dual-ion beam) irradiation beam-line(s). Note that the environmental temperature is a vital fundamental factor that influences the radiation damage.
The proposed simultaneous low (few hundred keV) and high (70 − 100 MeV) energy irradiation at typical reactor temperatures (~ 1000 K) would very accurately simulate the actual nuclear reactor environment to a large extent, and would thus benefit the vast nuclear materials community and research.

References:
1) Journal of Nuclear Materials 386–388 (2009) 967–970
2) Nuclear Instruments and Methods in Physics Research B 273 (2012) 213–217

Proposal / Suggestions for developing a simultaneous (dual-ion beam) irradiation facility at GANIL to simulate reactor like environment for radiation damage studies

Materials are subjected to energetic particles/ions in a number of radiation environments during service. A typical example is the nuclear industry (reactors, waste immobilization & disposition) where the materials are under constant irradiation by neutrons, alpha particles, fission fragments (particles of mass 70 – 160u & having typical energies of ~ 70 – 100 MeV, slowing down in the target material via inelastic electronic energy loss (S_e)), alpha recoils (typical energies of few hundred keV, slowing down in the target material via elastic nuclear energy loss (S_n)) etc. Such exposure of materials to energetic particles, commonly referred to as irradiation, is a detrimental process as it results in defects creation and subsequent micro-structural changes in the material, eventually leading to a degradation of its properties (i.e. radiation damage). Understanding the radiation response of nuclear materials, and thus designing them to be more radiation damage tolerant, is therefore of immense technological significance. A common way to simulate the effects of such irradiations, within a limited time, is to use energetic ion beams from accelerators. The accelerated effect of fission fragments can be simulated by using high energy (swift) heavy ion beams (E ~ 70−100 MeV), whereas that of α-recoils can similarly be investigated by employing ion beams of typical ions (such as Kr, Xe, etc.) with energies of a few hundred keV (low energy heavy ions). **Note** that for such studies (aimed at understanding the radiation response) to be truly relevant, it is crucial that they are carried out at the corresponding 'in-service' (irradiation) conditions.

Despite the decades of research devoted to understanding the radiation damage in nuclear materials, studies concentrating on the effects of simultaneous S_n and S_e irradiations are very scarce, i.e., the effects of separate/individual and sequential irradiations with low and/or high-energy ions have been studied extensively and are well understood, but the same is not the case with simultaneous particles irradiations. At this juncture, it is **vital to explicitly point out** that materials used in nuclear reactors and/or waste matrices are actually exposed to simultaneous (and *not* separate) irradiation with low and high energy particles. In other words, in the context of nuclear materials, simultaneous irradiations with high energy and low energy particles (and *not* individual and/or sequential low or high energy irradiations (as has been usually done till now)) correspond to the in-service conditions of actual relevance.

The reason for such scarcity of investigations under simultaneous low and high energy irradiations is quite possibly the acute lack of such dual-ion beam irradiation facilities. To my best knowledge, there exists only one such facility in the world, viz. JANNUS-Saclay [1, 2], where simultaneous low energy and high energy irradiations are possible. The maximum energy that can however be supplied at the JANNUS-Saclay facility is around 50 MeV, which in the context of investigating the radiation damage in nuclear materials (caused by fission fragments) is far too low. Note that, as mentioned earlier, fission fragments have typical energies in the range of 70 – 100 MeV.

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Finally, since a high temperature (~ 1000 K) environment is an integral part of a nuclear reactor core, a ***high temperature irradiation setup/chamber should also be developed/installed at this proposed simultaneous (dual-ion beam) irradiation beam-line(s)***. Note that the environmental temperature is a vital fundamental factor that influences the radiation damage.

The proposed simultaneous low (few hundred keV) and high (70 – 100 MeV) energy irradiation at typical reactor temperatures (~ 1000 K) would very accurately simulate the actual nuclear reactor environment to a large extent, and would thus benefit the vast nuclear materials community and research.

References:

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https://scholar.google.co.in/citations?hl=en&user=un3AbbMAAAAJ&view_op=list_works&sortby=pubdate

DoubleGaTe - Double Gamow Teller resonance search by Nuclear Reactions: connection to Neutrinoless Double Beta Decay

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Title:

DoubleGaTe - Double Gamow Teller resonance search by Nuclear Reactions: connection to Neutrinoless Double Beta Decay

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General description (methodology, goals,..):

The novel idea of DoubleGaTe project is to use nuclear reactions of double charge-exchange (DCE) as a tool to access the Double Gamow Teller giant resonance (DGTGR), which can contribute to the determination of the neutrinoless double beta (NDB) decay Nuclear Matrix Element (NME).
The tool proposed is the (^{12}C,$^{12}Be(0_2^+)$) DCE reaction, connecting ^{12}C projectile ground state to the second 0+ excited state of ^{12}Be at 2.2 MeV, in an unexplored energy range with high beam intensity, using a specific tagging technique.
The NDB decay is considered the best potential resource to determine the neutrino absolute mass scale. If observed, it will signal that the total lepton number in not conserved and neutrinos are Majorana particles [1-3]. To date, this physics case is one of the most important research "beyond the Standard Model" with fundamental implication in several aspects of physics. Since NDB decay involves nuclei, its analysis necessarily implies nuclear structure issues. The NDB decay rate can be expressed as a product of independent factors: the phase-space factors, the NME and a function of the masses of the neutrino species. The knowledge of the NME thus can give information on the neutrino mass, if the NDB rate is measured. State-of-art- shell model calculations have recently predicted that a connection is expected between the NDB NME and the strength of the Double Gamow Teller giant resonance (DGTGR) built in the same nucleus [4-5]. However, no experimental evidence of the DGT has been reported to now, which makes its possible discovery a ground-breaking result in its own. DoubleGaTe plans to carry out a campaign of experiments using the INFN-LNS k800 Superconducting Cyclotron (CS) accelerated beams on different targets candidates for NDB decay. The DCE channel will be populated using (^{12}C,^{12}Be) reaction by the MAGNEX large acceptance spectrometer [6] at INFN-LNS, which is unique in the world to measure very suppressed reaction channels at high resolution. The absolute cross-sections will be extracted. The development of microscopic state-of-the-art-calculations will give access to the DGT strength and the NMEs.
To implement the DoubleGaTe research plan we need to design a detector array, to be coupled with the detectors of the Focal Plane (FPD) of MAGNEX, in order to identify, with reasonable efficiency (about 0.4%), the two 511 keV photons emitted back-to-back from the decay of the $^{12}Be_{(met)}$ state (see later in Original aspects). An important aspect of DoubleGaTe is the availability of a hundred of NUMEN [7-10] $LaBr_3$(Ce) detectors. They will be coupled in a smart topological way with the MAGNEX FPD, in order to point toward the sensors where ^{12}Be ejectiles stop. We propose to study, design and build up a new mechanical support for the $LaBr_3$(Ce) detectors and their ancillary equipment. The detectors shall be positioned on different arrays around the FPD. A proper mechanical structure shall be designed to support these elements. The structure shall guarantee the correct and accurate positioning of the detectors, also allowing their adjustments. Since the radiation level in the environment will not be negligible, about 10^5 n/(s*cm^2), it is necessary to study radiation tolerant robotized system to perform remotely all operations required from the experiment without the presence of human operators. This system shall be conceived either in the fully automatic form or for teleoperation use. The robotized system shall allow the handling of the full mechanical structure, as well as positioning and removal of every single array, when necessary, the set up developed can also be used for other experiments under similar conditions. The design of the new mechanical structure shall take into account all necessary constraints for correct integration with the existing devices.
Also a study and design of suitable shielding for the gamma detectors will have to be carried out, as the integration of these parts is challenging anyway.
The project will cover experimental and theoretical aspects from the set-up of the experiment to the interpretation of the results and comparison with theoretical models. A specific R&D activity will be carried

out to optimize the existing facility to the search of the DGTGR mode, with the aim to achieve a clear signature of the DGTGR mode against the underlying background.
DoubleGaTe project can provide unique information to the worldwide scientific community with major consequences in nuclear, particle and fundamental physics. The project also aims at giving a relevant impact to the social awareness of modern research activities as well as at the development of new valuable technologies.
In addition, DoubleGaTe will be in line with the strategies foreseen by nuclear physics community at European level. Indeed, in the Long-Range Plan 2017 (http://www.nupecc.org/lrp2016/Documents/lrp2017.pdf) the NuPECC (Nuclear Physics European Collaboration Committee), in its scientific recommendations, mentions the fundamental importance of the studies of the DCE as tools to extract information on the NME of NDB decay. In particular, reference is made to the enhancement of the INFN-LNS research infrastructure (page 36).

Challanges:

The DoubleGaTe project proposes an original way to provide a key contribution to the determination of NMEs for NDB decay by measuring DCE nuclear reaction cross sections, searching for the DGTGR mode. The goal of the project is to explore with unprecedented sensitivity the nuclear response to DCE reactions of isotopes candidates for NDB decay and determine, for the first time, the DCE strength distribution as a function of the excitation energy. The main challenges are:

- to overcome the experimental difficulty of searching rare events in a large background
- to overcome the technological difficulty of working in an environment with a high radiation level
- to extract the relevant nuclear structure information from the measured cross sections by means of advanced theoretical methods
- to determine the strength for DGT distribution, specifically that associated to the DGTGR mode, that would made it possible to extract the NME for DCE, to infer that for NDB decay and to provide a data-driven information about the possible need of quenching of the coupling constant by the comparison with the model independent sum rule.

Original aspects:

The basic idea of DoubleGaTe project is to use the (^{12}C,$^{12}Be_{(met)}$) DCE reaction, connecting the ^{12}C projectile ground state to the metastable 0+ excited state of ^{12}Be at 2.251 MeV, because of two main peculiarities. First the time constant ($^{12}Be_{(met)}$) = 331 ns for this state is longer than the Time Of Flight (TOF) of the ^{12}Be ejectiles along the MAGNEX spectrometer. At the beam energies proposed for DoubleGaTe, spanning from 15 to 30 MeV/u, the TOF of ^{12}Be ejectiles from the production target to the implantation point at the spectrometer focal plane detector (FPD) is about 100-120 ns, depending on the different ion trajectories. This corresponds to a survival probability of about 70% of the ^{12}Be ejectiles in the $^{12}Be_{(met)}$ state. As consequence about 70% of the $^{12}Be_{(met)}$ ejectiles will be implanted before decaying in the MAGNEX FPD and identified, as demonstrated in several experiments [6]. We plan to select the transitions to the $^{12}Be_{(met)}$ state by detecting the e+e- generated by the 0+0+ decay of $^{12}Be_{(met)}$ state to the $^{12}Be(0+)$ ground state. The occurrence of this decay gives a specific signature, with two gamma rays at 511 keV from e+ annihilation, emitted back-to-back. Imposing such energy and topological conditions, together with a tight time coincidence between the two gamma-rays detection signals allows for a very clean event tagging of the 0+0+ decay. The coincidence of the e+ annihilation with the ^{12}Be ejectile detection by the MAGNEX FPD allows to unambiguously separate target excitation in the DCE reaction spectra (delayed gamma-ray tagging technique). Thanks to the large momentum acceptance of MAGNEX the energy spectra will be measured up to unexplored regions (up to 40-50 MeV excitation energy), thus covering the region where DGTGR is expected (around 30 MeV).
A second positive aspect of the selected DCE channel is that the projectile transition to the metastable state is expected to be significantly fed [B($^{12}C_{(gs)}$ $^{12}Be_{(met)}$); DGT] about 0.2 [11]. This strength is similar to that characterizing the (^{20}Ne, $^{20}O_{gs}$) reaction (about 0.15). A simple estimation of the expected cross section gives about $30*10^3$ nb for ^{76}Ge(^{12}C, $^{12}Be_{(met)}$)$^{76}Se_{(gs)}$ DCE at 15 MeV/u; the strengths for the projectile transitions for the two DCE reactions; a factor at least 1000 enhancement for the collective DGTGR and DIAS modes compared to the transition to ground state of the residual nucleus [12]. NUMEN and POTLNS [13] upgrades are designed to allow a sensitivity of few nb for the MAGNEX+$LaBr_3$(Ce) array in coincidence measurements, when the beam intensity is 10^{12}pps, the collecting time is 30 days, the efficiency of the $LaBr_3$(Ce) array is 4% and the target thickness is about 1mg/cm^2. Assuming a conservative efficiency 10 times smaller for the delayed gamma tagging technique proposed here considering a background, underneath the DGTGR peak, with the same cross section as the DGTGR [14], a clear evidence of this mode is expected, shall it exist, in less than

one week data taking for a single target. For the Double Isobaric Analogue State (DIAS) the situation is even better due to the narrow peak associated with it and consequently to the smaller background. In addition, since DIAS energy and strength are well known, as a direct consequence of the isospin symmetry for nuclear forces, the exact location of the DIAS in the spectra and the measured cross section will allow for a careful evaluation of systematic errors in the energy and strength of the DGTGR mode. The above features make the proposed strategy particularly appealing for DGT studies, assigning to DoubleGaTe a discovery potential about two order of magnitude larger than previous attempts.
In addition, this technique is general: high intensity beams together with the delay tagging technique, here proposed, can be extended to the study of other nuclear reactions with metastable targets, isolating the contribution of the target and allowing for cleaner measurements than in the past. In this way, a new facility will be available for all researchers in Europe at LNS.

Unique expertise:
The feasibility of challenging DCE measurements at INFN-LNS was demonstrated by the NUMEN collaboration. The results recently published [10] indicated that, despite the very low cross-sections (a few nb), suitable information on NMEs can be extracted and that the transition from the initial to the final state of the DCE can unambiguously be separated from other reaction channels. In this scenario it is useful to mention that the present DoubleGaTe project group includes, among others member of NUMEN, both the Coordinators (F.Cappuzzello and C.Agodi), the responsible of integration (D.Calvo) strongly involved in the mechanical projects, including robotic, the responsibles of the theory group (M.Colonna and E. Santopinto), the responsible of experiment set up and P.I. of the ERC-NURE project (M. Cavallaro), the responsible of data reduction and FPD PID system (D. Carbone), the responsible of electronics and gamma-array (P. Finocchiaro), the responsible of the IT system (L. Pandola), the responsible of the FPD gas tracker (D. Torresi).
The present DoubleGaTe project group includes also a senior scientist of NUMEN (C. Ferraresi) strongly involved in the mechanical projects, including robotics, a senior scientist of collaborating in many articles of NUMEN on nuclear structure aspects (A. Gargano).
This fruitful collaboration has a long-term basis, started with a wide range of experimental common studies and developed with the activities of NUMEN project. Moreover, C.Agodi has relevant responsibility within the POTLNS (MIUR-ESFRI) project, related to the upgrade of the LNS research infrastructure to produce high intensity beams. Within POTLNS she is Scientific Responsible of the MAGNEX upgrade and member of the Management Committee of the project. F.Cappuzzello has been committed since the very beginning in the design, construction and upgrade of MAGNEX. He is also coordinator for UNICT of the ERC-NURE project, related to an experimental study of selected DCE experimental case of NDB decay interest.
The ion beam LNS accelerator, upgraded for high intensity beams, the MAGNEX spectrometer, the FPD detectors and LaBr3(Ce) detectors will be available and operating at the INFN-LNS. They constitute the basic research infrastructure that will give an essential contribution to the accomplishment of Double GaTe.

Common expertises and collaborations:
The NUMEN collaboration group has already established a worldwide net of collaborations with prestigious experimental and theoretical nuclear physicists, on this research field which will be consolidated and enriched with DoubleGaTe project. The collaboration is made by about 100 researchers of 40 Institutions from 15 Countries (https://web.infn.it/NUMEN/images/Documents/WP_NUMEN_Gennaio_2021_v7.pdf).

Synergies with other research/technical groups:
The DoubleGaTe project will promote an active exchange of ideas with other researchers from different Countries. Among others of South Africa National Research Foundation (NRF) - iThemba LABS the mutual benefits lie in the enrichment derived by the different facilities used, the mutual exchange of methodologies, that would bring an added value to the project. Moreover, exchange of researchers and their skills, exchange of students especially young, will be supported by Short Term Visits in both directions, enriching scientific and cultural knowledge in both directions.
Synergies also with Japan, through the RCNP of Osaka, will have an indisputable benefit from the RCNP's long experience in experiments of interest for DoubleGaTe, whose data will be a source of discussion in the two countries, for future theoretical and experimental developments in common fields.

Synergies with other communities:

The relevance of NDB decay in the search for physics beyond the Standard Model today is extremely well established: the observation of this decay would prove that neutrinos are Majorana particles and thus do not get mass (only) from the Higgs mechanism, with an enormous impact on particle and nuclear physics, as well as on cosmology. The emerging connections and synergies among other communities and the relations with neutrino and nuclear physics are manifold. The physics of neutrinos is unthinkable without a detailed, quantitative understanding of their interactions with nucleons and nuclei.
The DoubleGaTe project allows to faster progress on the intersection between Nuclear and Neutrino Physics, towards New Physics beyond the Standard Model, by having the different communities discuss in close contact on well define problems in Workshops, Training Schools, and Short -Term Scientific Missions that will create a lively and strong interaction and a network within Europe, that will support recently flourishing, or new experiments (Connection with other categories: Training, Education, Outreach, Social Impact).
From DoubleGaTe different important benefits could stem out also in application fields. The development of modern technologies fostered by the project is likely to contribute to specific sectors. In particular, the foreseen development of mechanical and electronic technologies for the robotic arms, compliant with the challenging radiation levels during beam operation, has an immediate application on the development of radiation tolerant technologies. Studies in this sector are nowadays very much requested for space missions, including future missions on the Moon and Mars, for nuclear waste management and nuclear power plant decommissioning. The experiments, proposed in the project, indeed, aiming at a well-defined physics case, offer unique opportunities to create harsh radiation conditions in safe and controlled laboratory conditions, which deserve to be exploited to benchmark radiation tolerant technologies (Connection with other categories: Detectors+Electronics).

Preliminary budget estimate:

- Instrumentation (mechanics, electronics, control system) -150 k€
- Personnel (two-years researcher fellowship for mechanical project activity - 50 k€ + one-year research fellowship for electronics activity -25 k€, two-year post-doc for simulations and experimental activity and two-year post-doc for reduction and data analysis activity 200 k€). Total 275 k€
- Workshop, Short Term Mission, Dissemination - 50 k€

Main category of your contribution:

- New physics cases (Discoveries, impact on other fields)

Connections with other categories:

- Beams+Targets
- Training, Education, Outreach, Social Impact
- Theory
- Detectors+Electronics

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Search for X17 boson

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SEARCH FOR X17 BOSON

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General description (methodology, goals,..):
Two striking anomalies have been observed recently in the emission of electron-positron pairs in $^{7}Li(p, e^+e^-)^{8}Be$ and $^{3}H(p, e^+e^-)^{4}He$ reactions. These anomalies have been interpreted as the signature of a new particle, a boson (hereafter X17), not foreseen in the particle physics standard model. It has also been speculated that X17 could be a mediator of a fifth force, characterized by a strong coupling suppression of protons compared to neutrons (protophobic force). Even more interestingly, this scenario could explain, at least partially, the long-standing (recent) anomaly on the muon (electron) magnetic moment. Besides these speculations, it is clear that the possible existence of a new particle is of paramount importance in particle physics and cosmology. This proposal aims to clarify the present scenario by searching for the X17 boson in the decay of excited levels of ^{4}He, ^{8}Be and ^{12}C nuclei through reactions induced by neutron and proton beams.
The feasibility of the proposed experimental program requires the development of a suitable Ring Imaging Cherenkov (RICH) detector surrounding the target, acting as unconventional tracker and PiD detector. The conceptual detector consists of aerogel radiators with proper refractive indices surrounding the target and equipped with a dense array of Silicon Photomultiplier (SiPM). The relativistic (few MeV) electron/positron pairs produced by the X17 decay produce rings of Cherenkov light while crossing the aerogels, that in turn are completely blind to most of the environmental (beam or cosmic-ray induced) radiation. The detector is also almost insensitive to high energy photons produced by the radiative decay of excited ^{4}He, ^{8}Be and ^{12}C, because of the large radiation length of aerogels. The RICH detector is conceived to be portable, and can be easily moved to different sites as the ones proposed in the following.
The $^{7}Li(p, e^+e^-)^{8}Be$ reaction will be firstly studied at the PSI facility, where the MEGII experiment is running. Afterwards, we propose to study the A=4 reactions $^{3}He(n, e^+e^-)^{4}He$ and $^{3}H(p, e^+e^-)^{4}He$ at the n_ToF facility at CERN and at the LUNA-MV facility at the LNGS, respectively. In order to identify the possible e^+e^- pairs in the final state, we will first of all realize a setup able to determine event by event kinematics and particle identification of the ejectiles in a wide energy range. At the n_ToF facility, we plan to also study the $^{7}Be(n, e^+e^-)^{8}Be$ reaction. Being the ^{4}He and ^{8}Be nuclei created by neutrons instead of protons, these studies at n_ToF can give additional information about the proposed protophobic nature of the fifth force. Finally, at the LUNA-MV facility, the study of the $^{11}B(p, e^+e^-)^{12}C$ reaction is also at reach. These extensive measurements will allow for a possible independent confirmation of the recently announced anomalies, and, if confirmed, will provide the X17 quantum numbers, mass, coupling, etc. All the above reactions are also of great interest in nuclear physics, being very sensitive to the structure of the excited levels of ^{4}He, ^{8}Be, and ^{12}C. Even in the case of no

observed anomalies, the experimental results would be a stringent test for ab-initio theoretical studies. Calculations for A=4 appear to be feasible with state-of-the-art techniques, while the extension to A=8 is part of the present project. The calculations also provide accurate estimates for the standard internal pair conversion process, the most significant background in the X17 search. We finally plan to analyze the results in order to get information on the nature of the X17-nucleus interaction, modelled starting from the underlying interaction with quarks and gluons.

Challenges:

X17 existence and properties as quantum numbers, mass and coupling costant.

Original aspects:

Signature of new physics, existence of protophobic fifth force, implication for dark matter. Use of a novel detection technique for simultaneous tracking and particle identification.

Unique expertises:

Outstanding knowledge of theoretical and experimental nuclear physics: low energy/low background measurements and “ab initio” theoretical calculations.

Common expertises and collaborations:

The team members have a longstanding expertise in LUNA, MEG and n_ToF collaborations. The theoretical group of this team successfully collaborated with many experimentalists of the present project.

Synergies with other research/technical groups:

As mentioned, the team belong to different and complementary experiences (LUNA, MEG, n_ToF experiments, theoretical nuclear physics modeling and calculations).

Synergies with other communities:

The developed detectors and equipment can be used in other contexts in nuclear physics. The most expensive part of the detector (SiPM array and related electronics) can be easily coupled also to highly segmented, large acceptance scintillator detector for gamma spectroscopy.

Main category of your contribution:

New physics cases.

Connections with other categories:

Detectors + electronics, beams + targets.

New Judicious Experiments for Dark sectors Investigations

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New JEDI collaboration :
GANIL (France): Beyhan Bastin++ (scientific coordinator), François de Oliveira, Marek Lewitowicz, Jean-Eric Ducret, Olivier Sorlin, Dieter Ackerman, Christelle Stodel, Abdelouahad Chbihi, Jean-Charles Thomas, Gilles De France, Marek Ploszajczak.... ; **IJCLab (France):** Jürgen Kiener++, Alain Coc, Isabelle Deloncle, Clarisse Hamadache, Adrien Laviron, Jérôme Bourçois, Vincent Tatischeff, Fairouz Hammache, Nicolas de Séréville and Brigitte Roussière ; **IAP (France):** Cyril Pitrou++ ; **Minnesota University (USA):** Maxim Pospelov++ ; **NPI (CZ Rep.):** Jaromir Mrazek++, Giuseppe D'Agata and Anastasia Cassisa ; **ULB (Belgium):** Pierre Descouvemont++ ; **INFN LNS (Italy):** Livio Lamia++, Marco La Cognata and Gianluca Pizzone.
(++ contact person of the New JEDI project for each laboratory)

ABSTRACT :
The Standard Model of Particle Physics describes pretty well ordinary matter but is not able to describe the dark side of the Universe and, despite all efforts, there is still no clear proof of dark matter particles existence. Last decades, **an alternative approach to our current understanding of the Universe has been considered through a new theory, named the Dark Sectors theory**.
Currently there is a lot of activity in both North America and Europe, evaluating various proposals, attempting to see how different experiments can better probe dark sectors. In all these discussions, the potential contribution of nuclear physics is largely ignored. **The New JEDI project is a complete scientific program to study dark sectors through nuclear physics measurements at different European facilities**.

The New JEDI project has very ambitious goals. **Its main goal is to check, through tailor-made nuclear physics experiments, the EXISTENCE or NOT of a new particle (called boson) that will act as the messenger of a new fifth force**.
The New JEDI project addresses the following key questions:
- **What are the dark sectors of the Universe made of? Do dark forces exist?**
- **Can we produce and detect dark bosons in laboratory? What is the nature of such particles?**
- **Could nuclear physics make a systematic contribution to the studies of dark sectors?**

Our investigation is **further motivated by the recent claim of the anomaly observed in the e+e- decays of excited states of 8Be interpreted as the signature of a hypothetical dark boson**. If we prove that it is indeed a real experimental signature of a new boson and not some spurious effect related either to an experimental error or a subtle effect of NP in such a complicated system as 8Be, it would open up an entire new field in Particle Physics Beyond the Standard Model. **Should such a particle exist, it will manifest itself in many reactions with light nuclei**. For that purpose, focus of this proposal is the study of simplest nuclear systems to reduce as much as possible nuclear structure uncertainties. **Some of foreseen reactions may also shed additional light on the dynamics of few nucleon systems, relevant for the precision Big Bang Nucleosynthesis studies**, and that constitutes the second scientific motivation of this project.

To realize this ambitious scientific program, **a dedicated new detection setup has been designed, built up and coupled to a new generation digital data acquisition system, developed at GANIL**.

The New JEDI experimental program will be carried out at ARAMIS-SCALP, ANDROMEDE, NPI tandetron and SPIRAL2 facilities. SPIRAL2 is an European Strategy Forum on Research Infrastructure facility located in GANIL at Caen (France). It will deliver the most intense stable beams in Europe at an energy range from 0.75 to tens MeV. **These four facilities will cover the full set of beams required for the project, keeping Europe at the heart of dark sectors studies.**
The consortium of partner labs gathers worldwide-recognized experts in the different fields of experimental and theoretical Nuclear Physics, Dark Sectors theories and Big Bang Nucleosynthesis modelling, that should ensure the success of the new JEDI project and the quality of the incoming associated scientific results.

The New JEDI experimental **data will validate state-of-the-art nuclear structure calculations and guide for further theoretical developments in dark sectors physics, as well as in physics beyond the standard model**.

New Judicious Experiments for Dark sectors Investigations
(New JEDI)

Collaboration :
GANIL (France): Beyhan Bastin* (scientific coordinator), François de Oliveira, Marek Lewitowicz, Jean-Eric Ducret, Olivier Sorlin, Dieter Ackerman, Christelle Stodel, Abdelouahad Chbihi, Jean-Charles Thomas, Gilles De France, Marek Ploszajczak…. ; **IJCLab (France): Jürgen Kiener***, **Alain Coc**, Isabelle Deloncle, Clarisse Hamadache, Adrien Laviron, Jérôme Bourçois, Vincent Tatischeff, Fairouz Hammache, Nicolas de Séréville and Brigitte Roussière ; **IAP (France): Cyril Pitrou*** ; **Minnesota University (USA): Maxim Pospelov* ; NPI (CZ Rep.): Jaromir Mrazek*,** Giuseppe D'Agata and Anastasia Cassisa **; ULB (Belgium): Pierre Descouvemont*** ; **INFN LNS (Italy): Livio Lamia***, Marco La Cognata and Gianluca Pizzone.
(*contact person of the New JEDI project for each laboratory)

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New methods to produce exotic nuclei

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In the last decade intense discussions arose on the possibility to apply Deep Inelastic Transfer (DIT) or multinucleon transfer reaction (MNT) reactions for the synthesis of new exotic heavy and superheavy isotopes; it is now well established that the only way left to produce exotic nuclei is the multinucleon transfer reactions. It has been, recently, demonstrated that MNT reaction is a powerful method promising to synthesize neutron rich nuclei around N = 126, which are relevant for the rapid neutron capture process and important for understanding the synthesize of the nuclei heavier than iron in nature. Moreover, it would seem that the only way possible to produce super-heavy nuclei, due to the limited number of beam-target combinations, are multinucleon transfer reactions, allowing reaching the well-known island of stability predicted to exist at Z=118 and N=184. The deep-inelastic collisions (DIT) or multinucleon transfer reaction (MNT) represents, therefore, the only alternative to fusion-evaporation reactions. All of this corroborated by recent theoretical calculations that predict high cross sections (of the order of micro barn) for the production of neutron-rich heavy elements in deep inelastic reactions close to zero degrees.

Many MNT experiments have been carried on in recent ten years aimed at production of new isotopes, such as $^{238}U+^{238}U$ and $^{238}U+^{248}Cm$ carried out at the UNILAC accelerator at the GSI, $^{136}Xe+^{238}U$ performed at the INFN Laboratori Nazionali di Legnaro. Important conclusions about the reaction dynamics of these reaction systems have been drawn, but no sizable yield of new neutron-rich heavy isotopes is found yet. One of the key bottlenecks is that it is difficult to identify these elements by current experimental detection methods, since most of them are beta emitters and/or having very long lifetimes, therefore impossible to apply the usual technique based on the recoil decay tagging technique.

Meanwhile, the possible application of DIT for synthesis of new heavy and exotic neutron rich nuclei has become a topical subject in various laboratories and appropriate separation techniques together with new detections systems are being developed. Different concepts of detection systems allowing a full identification of reaction products are going to be explored in the various laboratories worldwide. Different solutions are under considerations: selective laser ionization, Penning trap or multiple reflection time-of-flight mass spectrometer, E-TOP telescopes with calorimeter. At GSI for example they are exploring precision mass measurements with Penning traps or multiple reflection time-of-flight spectrometers where a resolving power of (10^5–10^6) is already sufficient for an isobaric separation of most of the isotopes.

This type of reaction that could revolutionize the field of nuclear physics not only from experimental point of view. Indeed, although most of the present theoretical models can show good description of available experimental data, uncertainty still remains in the values of several parameters used to describe the low-energy nuclear dynamics. Consequently, it is not possible to obtain very accurate predictions for the production of new heavier-than-target (trans-target) nuclei in multinucleon transfer reactions. Most of these parameters (nucleon transfer rate, nuclear viscosity, and fission barriers) are fundamental properties of low-energy nuclear dynamics. Determination of their values, as well as their temperature dependence, is of significance in its own right, and consequently obtaining new experimental data on the production of heavy nuclei in low-energy multinucleon transfer reactions becomes crucial. Moreover, such data are needed to understand the role of shell effects in the reaction dynamics.

In addition, this type of reaction paves the way to the production of radioactive beams. Radioactive beam induced reactions could enhance the cross sections strongly. In present experimental facilities, the beam intensities of radioactive beams are still very low. With the development of modern radioactive equipment, the radioactive beams could be favorable for producing neutron-rich nuclei far from the stable line.

In conclusion the multinucleon transfer process will be one promising approach for producing neutron-rich light nuclei, neutron-rich heavy nuclei, neutron-rich superheavy nuclei, and neutron-deficient heavy nuclei. For producing unknown nuclei in multinucleon transfer reactions, the main difficulties in the experiments are how to separate a given nucleus from other transfer products and their identification. This is a major challenge in the nuclear field and it is in the focus of activities at many laboratories worldwide. In fact, several technological developments are taking place in many laboratories in order to increase the efficiency of experimental process, detecting the products with very low production cross sections during multinucleon transfer reactions. Many efforts are being made also at theoretical level, where new models are being developed in order to reproduce the experimental cross sections, and the first results are encouraging.

The goal of this project is to create a platform among European laboratories (GANIL, GSI, JYVASKYLA, LPC Caen, INFN Legnaro, etc.) bring together an entire community around the topic of nuclei created using multinucleon transfer reactions. Through the sharing of knowledge obtained so far from different communities (nuclear physicists, astrophysicists, etc…) it is possible to advance and push the limits of physics knowledge. Having as first objective to create a network where experience and theory are shared and can benefit from.

The group of nuclear physicists at **CEA** has been involved in the last two decades in the study of heavy and super heavy nuclei with the development of several detection systems and with the development of the super separator spectrometer S3 at SPIRAL2. Since a few years it is involved in the measurement of effective cross section through the use of multinucleon transfer reactions at AGFA spectrometer at Argonne to produce heavy nuclei.
The **SHIP/TRAP group at GSI** is focused on precision measurements on exotic radionuclides, mostly in the region of the heaviest elements, by mass spectrometry, laser spectroscopy and nuclear spectroscopy. They were the pioneer to perform mass spectrometry and laser spectroscopy measurements on the heavy nuclei and super heavy nuclei. They were the first to develop a new technique based on the phase-imaging ion cyclotron-resonance (PI-ICR) technique allowing mass measurements of long-lived and stable nuclides with a precision of tens of electronvolts.
The **University of Jyvaskyla**, since long time is involved in the studies of heavy elements with RITU/ MARA separators and with the IGISOL mass separator, they are able to deliver and study low energy and radioactive beams. They are expert in MNT reaction with the project MAIDEN at IGISOL using MNT reactions to probe the N=126 region.
Collaboration with other U.S. laboratories, such as Argonne, is clearly expected.
Scientists from the U.S. Department of Energy's (DOE) Argonne National Laboratory led an international nuclear physics that utilizes novel techniques developed at Argonne to study the nature and origin of heavy elements in the universe, e.g. direct mass measurements in conjunction with detailed β-decay studies.

Title: Rare Ion Beams in the Terra Incognita by Multi Nucleon Transfer Reactions

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General description (methodology, goals, …):

There are running and upcoming programs at many laboratories around the world to study and use multi-nucleon transfer (MNT) reactions to produce new neutron-rich isotopes, which are hardly or even not at all accessible by other means. First experiments have been performed in recent years. We now want to expand this to wider variety of stable beams and energies and later extend this to secondary beams program at the upcoming European facilities. Our goal is to expand this research program and the equipment used for it. We plan to shape and build-up a world-leading research program on multi-nucleon transfer reactions. We will use complementary approaches (reaction kinematics and mass spectrometry) to get an in-depth understanding of the underlying processes. This knowledge will enable us to design and run experiments (e.g. mass and decay spectroscopy) with optimal conditions to reach the most exotic nuclei, especially those not accessible by other methods and experiments currently running worldwide. MNT reaction have been recognized as the next step in rare ion beam production, especially of the neutron-rich heavy isotopes. In the US and Japan user-facilities, based on beams produced by on MNT reaction, are in operation or close to this. In Europe that is at the moment not yet the case.

Challenges:

The theoretical description of the MNT reaction process is not fully understood, thus we are in urgent need for more experimental data. These is limited sofar, because the identification and quantification of the reaction products and measurement of the productions cross-section before and after evaporation are the major challenges. Especially for the heavy target-like fragment, there exists until now no methodology to unambiguously identify the produced isotopes, if there is no extensive nuclear structure information for the ion of interest already available.

Original aspects:

We intend to launch a program that will bring together leading experts from different fields (reaction theory, reaction kinematics, separators, gas-filled stopping cells, mass spectrometry …) and laboratories to join forces and unite communities and develop, build and run unique experiments for MNT studies at various laboratories in Europe using mass spectrometry methods for the identification of the reaction products.

Unique expertises:

The authors are the spokespersons of many past and ongoing proposal on MNT at different laborites in Europe. They have built and run the needed instrumentation for more than a decade.

Synergies with other research/technical groups:

Decay and mass spectrometry of exotic nuclei. Reaction studies. Gas-Cells.

Synergies with other communities:

Analysis methods will coincide with in-flight and spontaneous fission experiments inside stopping cells, of interest to nuclear reactor operation and nuclear waste management.

Main category of your contribution:

Beams + Targets, Detectors + Electronics, New physics cases

Connections with other categories:

Theory, Training + Education

Others

Instrumentation and Training for In-beam Nuclear Spectroscopy and Reaction Studies

Authors: Silvia Monica Lenzi[1]; Magdalena Gorska[2]; Andres F. Gadea Raga[3]; Andrew Boston[4]; Araceli Lopez-Martens[5]; Emmanuel Clement[6]

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INTRANS: Instrumentation and Training for In-beam Nuclear Spectroscopy and Reaction Studies

S. Lenzi, A. Boston, E. Clément, A. Gadea, M. Górska, A. Lopez-Martens and the AGATA, FATIMA, GRIT, NEDA and PARIS collaborations

The origin and existence of the atomic nucleus, the nature of the forces that make it stable or of very short lifetime, its decay modes, the nuclear structure and the reaction mechanisms that are at the basis of the dynamical processes between nuclei are at the frontier in nuclear research. Experimental advances in the instrumentation and production of radioactive beams allow to explore new regions of the nuclear landscape and to understand numerous key scientific problems related to nuclear structure and reactions. In particular, one can mention the evolution of the shell structure far from stability, exotic shapes and excitations, nuclear symmetries, dissipative processes and the equation of nuclear state, together with reactions and decays related to fundamental symmetries and nuclear astrophysics related problems.

Historically, the nuclear spectroscopy and reaction studies communities have grown in parallel with limited interactions and overlap between them. With the advent of the radioactive beam facilities and the research of rare nuclear species produced in very weak reaction channels, the combination of gamma-ray detectors with ancillary detectors for charged particles and neutrons has become mandatory to select the reaction channels of interest and obtain clean spectra. At the same time, gamma-ray detectors are becoming a very useful tool to study reaction mechanism at the different energy ranges where in-flight separation using magnetic spectrometers and tracking detectors are involved. The necessity of combining the nuclear structure models and methods with those regarding the reaction dynamics in order to have a global theoretical description of the observed cross sections has been identified by the community and some encouraging efforts are now being pursued in this direction.

The proposed initiative aims at creating a common forum to fully integrate these communities and to facilitate the exchange of information, expertise and resources. The main goal of this research initiative is the optimization of the use of European instrumentation at the different facilities in Europe and beyond. The fundamental prerequisite of INTRANS will be the training of new users and young scientists together with the dissemination of nuclear techniques for industrial and societal applications; completely free of charge, with open sources software and on equal bases for all participants of the initiative.

Large research collaborations in nuclear spectroscopy and nuclear reactions are investing huge efforts and resources in developing new instrumentation (such as, e.g., AGATA, to name the most challenging one), experimental methods and techniques for frontline research at the different research centres and universities across the world. Most of these techniques are of common interest and the exchange of information as well as the pooling and maintaining of resources will be of great benefit to the whole research community working at all facilities. The united effort of different collaborations owning detectors and experimental resources that can travel and be shared among the infrastructures of EUROLABS will enhance the quality and the scientific output of the experimental programs.

This new initiative will assure the exchange of information and transfer of knowledge by organising collaboration meetings and workshops, training courses on data analysis, detection techniques and simulation software to plan and project new experiments. INTRANS will promote and support the exchange of key personnel to disseminate expertise and new techniques. The main actors of INTRANS will be the Working Groups (WG) that will focus on specific issues. INTRANS will promote the interaction and collaboration between the different WG by organizing topical workshops. These activities will be performed in a multidisciplinary environment within the expertise areas of gamma-ray, particle detector and beam-tracking detector technologies, microelectronics, front-end and back-end electronics, detector signal characterization and simulation, pulse-shape and data analysis, including machine learning techniques. It is expected that collaboration with theorists will help optimising the choice of the most relevant experiments and in defining the order of priorities and more generally the physics campaigns.

INTRANS goals:

-Dissemination of knowledge

-Training & exchange of technical experts

-Facilitate the pooling and sharing, the exploitation and the maintenance & upgrade of instrumentation used at EUROLABS infrastructures (large instruments developed in the framework of large collaborations as well as smaller equipment) and support dedicated personnel for these tasks

-Data management

-Build bridges between scientific developments & applications for society

The institutions involved in this proposal are:

INFN (LNL, LNS, Padova, Milano, Firenze, Napoli, Catania, Perugia), IN2P3, CNRS, CEA, GANIL, IJCLab-Orsay, IP2I-Lyon, IPHC-Strasbourg, JLU, FAIR/GSI, U-Köln, TU-Darmstadt, STFC Daresbury, U-Liverpool, U-Manchester, U-Birmingam, U-Surrey, U-York, U-West Scotland, U-Lund, KTH Stockholm, U-Uppsala, JYFL, HIL-Warsaw, U-Warsaw, IFJ-PAN Krakow, NIPNE Bucharest, ININ-HH/ELI-NP, Demokritos-Athens, IFIC-Valencia, U-Huelva, UAM-Madrid, U-Huelva, U-S. de Compostela, GFN-U-Complutense-Madrid, U-Salamanca, IEM-CSIC, ATOMKI- Debrecen, ELI-NP, HIM, KU Leuven, UMAN, INRNE-BAS, UCO, LMU.

The collaborations involved in this proposal are the builders of the following travelling instrumentation:

AGATA, FATIMA, GRIT, NEDA and PARIS.

In the following, 4 specific proposals related to AGATA are detailed.

Pillar 1: Access to facility

E. Clément, S. Leoni, J. Simpson, A. Lopez-Martens, A. Gadea for the AGATA Collaboration

The AGATA array is a major instrument of the nuclear physics community in Europe. This device is a travelling detector, producing a significant amount of data and requires high-level expertise to be maintained, operated and to be able to produce high quality scientific results.

The objective of the AGATA collaboration is to complete the construction of the full 4π array, with the initial goal of 3π by the end of the decade. As this is being achieved the collaboration will perform experiments in the field of the nuclear science at different Europeans facilities such as SPES/LNL, FAIR/NUSTAR, at the university of Jyvaskyla, CERN/HIE-ISOLDE and GANIL.
Each installation of the AGATA array in the host laboratory requires the essential support from skilled technicians, engineers and physicists from laboratories across Europe. Their contribution at the host laboratory is essential to the preparation, the operation and the success of the experimental campaigns. We request to the Program a financial support for the travels cost of technicians and engineers from their home institute to the AGATA host labs to install, maintained and upgrade the infrastructure. Also, with the increase of the solid angle covered by AGATA, its operation will require sufficient local physicist, such as dedicated Post-doc. We request the financial support of two permanent Post-Doc contract dedicated to the array at the host laboratories.

In this proposal, we are proposing to financially support this effort and in particular the travel and subsistence of the technicians and engineers.

A second aspect is to strengthen the relationship between the AGATA user community and the AGATA collaboration involved in the construction and operation of the array. The AGATA Collaboration Council (ACC) represents the AGATA user community and advises the AGATA management on the scientific aspects and planning of the instrument. In this proposal, we are proposing to reinforce the financial support of the ACC in order to increase the number of AGATA user's at the international level. This involves supporting the annual ACC collaboration meeting. This meeting gathers users from across the AGATA community and the AGATA management to meet and discuss the science and technical progress and planning.

We also require support to develop the numerical access to the infrastructure (user data base, ACC website and social network, contribution to major scientific event, etc …).

Pillar 2 : Training of young researchers

E. Clément, S. Leoni, J. Simpson, A. Lopez-Martens, A. Gadea for the AGATA Collaboration

The AGATA array is a major instrument for the nuclear physics community in Europe. This device is a travelling detector, producing a significant amount of data and requires high-level expertise to be maintained, operated and to be able to reach high quality scientific results. The AGATA collaboration is willing to contribute to the training of young researchers in the field of nuclear science.

AGATA produces several tens of Tb per week and is coupled to a large variety of complementary detectors running with different electronic systems, data acquisition systems and data format and analysis software. The AGATA data processing involves complex algorithms such pulse shape analysis, tracking filters and software triggers. In the next decade, the collaboration is willing to evaluate and implement in real time, i.e. in the online data flow, technologies such as neural network and A.I to enhance the sensitivity and capabilities of the array. All these new technologies are obviously very attractive for the new generation of data scientists.

This proposal is related to the training of young researchers in the framework of the AGATA collaboration:

1. The collaboration is willing to organize an annual school on AGATA data analysis, for Master and PhD student analyzing AGATA data and also from complementary instruments coupled to AGATA.
2. The collaboration is willing to organize specific schools related to experimental techniques involving AGATA and complementary instrument data such as nucleon transfer, knockout, Coulomb excitation, nuclear lifetime measurements or high multiplicity gamma events.
3. Experiments might require a significant input from the simulation packages. The data analysis school will include this aspect for AGATA and its complementary instrument.
4. The collaboration is willing to organize specific workshops on next generation computing capabilities applied to nuclear science, which will attract and train the next generation of data scientists for fundamental research and in a more general perspective for the society

For all these events, the collaboration requires financial support.

Pillar 3 : Data Management

E. Clément, S. Leoni, J. Simpson, A. Lopez-Martens, A. Gadea for the AGATA Collaboration

The AGATA array is a major instrument for the nuclear physics community in Europe. This device is a travelling detector, producing a significant amount of data and requires high-level expertise to be maintained, operated and to be able to reach high quality scientific results. The AGATA collaboration is willing to contribute in the domain of data management.

In the next decade, AGATA will be installed at major laboratories in Europe including SPES/LNL, FAIR/NUSTAR, the university of Jyvaskyla, CERN/HIE-ISOLDE and GANIL. AGATA produces several tens of Tb per week and is coupled to a large variety of complementary detectors running with different electronic systems, data acquisition and data formats, and analysis software.

The objectives of the AGATA collaboration in this initiative is to contribute in the European nuclear community to:

1. Define a common framework for data and meta data format for travelling and local instrument associate to electronic
2. Define a common framework for data storage, data access, long term archive and re-processing, open data policies, data analysis and simulations
3. Provide an infrastructure for large set of data processing
4. Developing the skills of data scientists and a data management Chief Officer
5. Defining a high level of quality control of the produced and stored (raw, pre-processed and final) data sets.

This proposal is compatible with the contribution by E. Clement, A. Lemasson and A. Matta, also submitted.

In this call, the AGATA collaboration requests financial support for short-term contracts, equipment investment and budget for travel and subsistence and workshop organization.

R&D on Position Sensitive Detector Technologies

D. de Salvador, E. Napolitani, G. Maggioni, S. Carturan,, A.Boston, D. R. Napoli, E. Clément, S. Leoni, J. Simpson, A. Lopez-Martens, S.Lenzi, M. Górska, A. Gadea for the AGATA Collaboration

High purity germanium (HPGe) detectors are diodes obtained starting from Ge single crystals with an extremely low net impurity concentration (around 10^{10} atoms cm^{-3}). The electron-barrier and hole-barrier contacts of the diode are placed on the opposite sides of the Ge crystal in order to achieve the full charge depletion of the intrinsic volume, without giving rise to sizable leakage currents, the surface of the intrinsic Ge between the two contacts needs to be passivated.
In commercial detectors, boron implantation is commonly used for producing a thin (< 300 nm) electron-barrier contact, which can be segmented in a variety of geometries. It provides thin dead layers for gamma detection. This last feature, which assures a very limited decrease of the active volume of the detector, is particularly important for complex HPGe detectors (such as highly segmented detectors used, e.g., for new spectrometers like AGATA or GRETA), wherein each point of the HPGe crystal concurs to the reconstruction of the gamma-ray tracks.

Presently n-type Ge detectors are the only ones that can be used as position sensitive Ge detectors in tracking detector arrays for in-beam gamma spectroscopy, since position sensitivity is achieved by segmenting the outer contact. The actual limitations are related with the creation of the electron collecting contact (n+ contact) and the segmentation. The traditional and very reliable n+ contact based on Li diffusion is too thick and continue diffusing also at normal temperatures, moreover Li segmentation is too deep and unstable. For these reasons, it cannot be applied in highly segmented detectors. Amorphous Ge and Si, hydrogenated and not, are commercially used for both contacts (n+ and p+) and for the passivation in between segments, but their limited stability during thermal cycles and even during detector storage still remains a crucial issue and severely restricts their applications. During the early investigations on materials for the n+ contact, performed in the framework of the ENSAR2 grant, it was found that the most promising candidate for n-contact, the antimony (Sb) has proven to match the requirements and to be compatible with the required purity and production conditions. New technology for production of segmented contacts, in Ge detectors, based on Pulse Laser Melting has been tested. Fully functional, small dimension prototypes, of segmented n-contacts in p-type HPGE crystals have been produced during the aforementioned grant and coaxial prototypes will be produced in the framework of the N3G INFN grant.

Other fundamental ingredient of the position sensitive Ge detectors is the Pulse-shape analysis (PSA). The PSA algorithms use the position-dependent response of large volume HPGe detector signals to identify where γ rays interact within the detectors. The spectroscopic performance metrics of efficiency, peak-to-total and position uncertainty manifest in the γ-ray tracking capability, which is strongly dependent on the performance of the PSA algorithm. The algorithm relies on the generation of a signal basis set for each detector typically calculated on a 1-mm grid, which contains ~$4x10^5$ points. The quality of the signal basis relies on knowledge of the physics of the detector, the impurity profile, corrections for energy calibration, neutron damage and cross talk, application of the detector response function to the calculated signals and the accurate time alignment of the signals. The optimization of the algorithm for performance both computationally and in terms of the resultant spectroscopic metrics is non-trivial and exciting opportunities exist to leverage new computation techniques to make a step change in this key signal processing step. The use of novel machine learning approaches utilising topologic data analysis and Graphical Processor Unit (GPU) acceleration is showing great promise as a technique that would facilitate the real time solution to:

- The full grid search problem for with simple single interactions
- Complex multiple interactions in the detector volume, which is very common for gamma-rays that interact via Compton Scattering
- The optimization of these algorithms for a wide range of detectors and auto-correction for radiation damage

The proposed program of work will focus on these areas where there is potential for a huge impact on performance to be made for a wide range of existing and future detector systems.

In addition to the use of the position sensitivity technology in large coaxial Ge detectors, it will be applied as well to gamma-ray imaging planar detectors, to be used for applications as well as fundamental research. In the energy range, where Compton interaction prevails (150keV - 4MeV) hyper-pure germanium (HPGe) stands out for its best resolution, wide energy range and big detection volume. For these reasons, highly-segmented HPGe detectors are a fundamental brick to build gamma-imaging systems.

The outcome of this project will be decisive to go beyond the limitations and/or weaknesses of present technologies in a wide field of applications such as nuclear waste identification, nuclear plants decommissioning, homeland security, medical diagnostics and radiotherapy monitoring and gamma-ray astronomy. The stability and reliability of these new detectors will push to keep going on their application.

In the present grant application, we propose to fund personnel and budget for travels and workshop organization, in order to continue with the development of the aforementioned technologies, to be applied to both planar and coaxial (AGATA) detectors with the goal to update the production technology, the radiation hardness and performance of Position sensitive high resolution gamma-ray detectors, to be used in the European Nuclear Physics Laboratories.

CIRIL contribution for interdisciplinary research

Author: CIRIL/CIMAP[None]

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A couple of months ago the users of GANIL were asked for ideas concerning the future development of GANIL. The international, interdisciplinary scientific community has given several proposals (see for detail https://indico.in2p3.fr/event/20534/contributions/). The principal proposals concerning improvements at the GANIL facility, useful for future scientific research, are given as follows:

The main advantage of GANIL is that several users can have access simultaneusly to a large choice of ions and a wide range of energies (SME, ARIBE, IRRSUD and HE) at one place and to many unique online experimental devices. They can vary the linear energy transfer as well as the electronic to nuclear stopping power ratio. The variety, the versatility and the accessibility of GANIL's ion beams open a huge amount of opportunities to different scientific communities as well as to industrial partners. The requirements to maintain the dynamism of the different communities are the following:

- the availability of the beam lines of the actual GANIL facility have to be guaranteed (at least 6 month per year) and new on-line experiments have to be proposed. For instance, a new EPR (electronic paramagnetic resonance) spectrometer would be particularly useful for studying metal complexes or organic radicals in order to better understand the formation of intermediate species under irradiation.
- In the EMIR&A network, we have also pointed out that it would be very interesting to expand the possibilities of the ion beam energies at the GANIL facility by adding an accelerator with an intermediate energy range between that of ARIBE and that of IRRSUD, with the possibility of in-situ RBS measurements and dual beam irradiations coupling "low" and "high" energy beam line for material science community. Furthermore, for astrophysical applications, to simulate the complete cosmic ray fields, simultaneous or subsequent irradiation with proton beams would be a major unique development to expand the possibilities of the future GANIL.

-the construction of a Very Low Energy (range of a few eV) beamline at ARIBE would allow GANIL to cover the complete range of energies that are relevant for experiments dedicated to stellar wind ions. We anticipate that this Very Low Energy beamline would open the way for a new series of systematic studies of astrophysical and atmospheric interest, as well as of radiobiological interest.

- An other evolution concerns the construction of an industrial machine exclusively devoted to membrane irradiations for ITT (Ion Track Technology) at the high energy beam line. This machine will be of great use to maintain a dynamic and agile research around innovative high value-added devices. It will advantageously enlarge the GANIL offer, which will undoubtedly drive the attention of many industrials. However, for this to become viable, set-ups enabling irradiations under inert and controlled atmospheres should be developed.
- The laboratory for radiobiology (LARIA) has already reached the limits of its capacity during beamtimes with several groups, and enlargement of the cell culture area would help to improve the quality of the biological experiments.
- The time-resolved experiments would also strongly benefit from a unique equipment of GANIL known as the "suppresseur de paquets" (a pulse selector) which is not operational anymore (too old technology not worth repairing) but would be of great interest if an up-to-date version could be built. This new version could benefit from the development of the same kind of device which is under study for SPIRAL 2.

- The scientific communities will remain attentive to new possibilities that will be offered by the new developments of GANIL (SPIRAL2, NFS, DESIR, interdisciplinary room, NEWGAIN….) to enlarge the possibility for interdisciplinary research.

- To conclude, in order to maintain a high level of quality in welcoming experiments at GANIL beamlines in interdisciplinary research fields, it is necessary to guarantee a reasonable level of the workforce (technicians, engineers, researchers) in the CIRIL platform.
  We are confident that GANIL and CIMAP/CIRIL can expand their role as pioneers and pacemaker of accelerator-based, non-nuclear physics in the decades to come by making the right strategic decisions and implementing appropriate experimental techniques.

Integrating the NURA targeted radionuclide as well as particle therapy preclinical platforms with high throughput omics infrastructures and customized E&T programmes at SCK CEN

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The Belgian Nuclear Research Centre SCK CEN has a strong, long-standing expertise evaluating the potential risks of ionising radiation on human beings to develop new cancer treatment modalities, such as targeted radionuclide therapy and particle therapy. By pooling its knowledge and expertise in terms of radiopharmaceuticals (NURA) and particle research project, SCK CEN significantly increases its contribution to the fight against cancer. SCK CEN contributes to the development of the next-generation cancer treatments. More specifically, NURA performs game-changing research into radiopharmaceuticals for treating different types of cancer in cooperation with clinical and industrial partners.

Challenges:

Within TRNT (Targeted Radionuclide Therapy), a large number of emerging radiopharmaceuticals are under development. In their development phase, they are first tested in vitro on specific cell types, next they are tested in vivo on mice, before they can enter a first phase clinical trial. Still a lot of research is needed before new radiopharmaceuticals can be brought to the patient: on the production and radiochemistry side, understanding the radiobiological effects, and providing good dosimetry to allow personalized medicine.

Original aspects and unique expertises:

▸ High-throughput technologies for precision medicine
From a radiobiological point of view, we work at developing novel high performance and high throughput biomarkers (transcriptomic, methylomic, or proteomic) which can be valuable for the development of patient-specific treatment protocol and reveal potential cytotoxic in normal tissues as well as improve cancer modality treatment.

▸ Networking activities
• through the set-up of an integrated and active student and researcher exchange network programme to foster co-operation amongst the various institutions and mobility between the various infrastructures
• through integrated and customised education and training courses althrough Europe (SCK CEN Academy has a very strong track record of courses like the Radiobiology Summer Schools and Eur MSc in Radiation Biology)
• through an active use of social media platforms in order to involve stakeholders outside the field and increase the knowledge of the general public related to this innovative cancer treatment modalities

▸ Joint research activities, offering preclinical work for the study and development of innovative radiopharmaceuticals and particle research:

• Preclinical evaluation of newly developed radiopharmaceuticals, in terms of pharmacodynamics (binding characteristics, internalization degree, cell inhibiting efficacy) pharmacokinetics (biodistribution/imaging, radiometabolite analysis) and toxicity, in vitro as well as in vivo
• Investigation of the therapeutic and cytotoxic effects of radiopharmaceuticals on a molecular level and identification of radiobiological markers, in vitro as well as in vivo, for more effective treatments preventing or mitigating the adverse side effects
• Set-up a strong dosimetry framework to support the future success of novel radiopharmaceuticals. In most studies, biological effects are mainly related to the activities added, which is often not a good predictor of biological response. We seek to build further on improving dosimetry both on in vitro

(cellular dosimetry) as in vivo (small animal dosimetry) level, adapted specifically to the radionuclide and emitted radiation and scale of interest, going from organ, to sub-organ, to voxel-based, to cellular and microdosimetry.
• With these research activities we aim to investigate the relationship between absorbed dose and treatment-related radiobiological effects and as such contribute in better understanding the mechanisms behind TRNT

Common expertises and collaborations: To be explored

Synergies with other research/technical groups: To be explored

Synergies with other communities: To be explored

Main category of our contribution:

SCK CEN offers improved access to the following infrastructures:

• Radiopharmacy and chemical synthesis laboratories for radiopharmaceutical development (radiolabelling and stability testing):
• Radioisotope R&D and production facilities
• Omics platform for high-throughput proteomic, transcriptomic and methylomic analysis as well as high precision imaging platform for extensive radiobiology studies
• Radioactive animal facility including imaging platform (mSPECT and autoradiography systems), expertise in mouse mutants for various diseases, various normal and (2D and 3D) cancer cell models and organoids as well as biobank authorisation for patient samples
• Simulation framework for personalized dosimetry in TRNT
• Customised training and education courses and other outreach activities

RandD_inBeamTest

Authors: Gilles de FRANCE[1]; Jean-Eric DUCRET[1]; Thomas Roger[1]; julien pancin[1]

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R&D detectors and in-beam test facilities

Advances in experimental nuclear physics rely on beam variety and quality delivered by research infrastructures as well as on detector developments. To exploit in an optimal way the beam times, vigorous efforts in detector performances must be pursued at any stage. Our research field relies for a large fraction on complex detectors, using the most advanced technologies. The identification in mass and charge of heavy ions/fragments, the detection and tracking of electromagnetic radiations, of light charged-particles or neutrons; detectors able to sustain very high rates and doses, etc. All these requirements demand continuous efforts in research and developments. Pushing the limits of detector capabilities and performance is therefore of the highest priority.
For a given collaboration, pursuing an intense R&D activity and in the same time building and/or exploiting the experimental resources is extremely challenging. On the one hand human and financial resources are needed and on the other hand beam time to investigate, test, characterize and validate the developments are crucially missing. One way to optimize all these R&D activities in an optimal environment is to organize the availability of the required infrastructure items and beam times in a network of research infrastructures, hence optimizing access to available test beams at European facilities by creating the relationship between the characterization requirements of the detectors and the available-beam properties such as intensities, beam species or energy ranges. This proposal is aiming to address this point.
In many aspects, source measurements are sufficient to evaluate a large fraction of detection system performances. However, in many other cases, in-beam measurements are mandatory, e.g. the detection of light charged particles, high-energy neutrons, coincidence measurements, high-rate and dose capabilities of detectors, detection of exotic decays, beam tracking detectors. Furthermore the beam time cost strongly depends of the facility. One important aspect is therefore to evaluate the balance between the facility and the requirement of the developments. We propose here a project to financially support the setup of dedicated beam lines in well-identified and complementary facilities. At GANIL for instance, an experimental area (G3) is identified which could be used to provide the user community with this service if this adequate resources are made available. This support should fund the construction of beam lines dedicated to detector tests, associated human resources, the installation of the required infrastructure items to host detectors (pumping systems, power supplies, mechanics, acquisition systems, etc), the access of physicists and technical teams, the beam time, the consumables, etc.) An ad-hoc committee should be established to coordinate and optimize these R&D in-beam measurements in Europe.

IBC@EURO-LABS

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Title: **Applied nuclear physics at accelerators: the Biophysics Collaboration in EURO-LABS**

Authors and affiliations:

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General description (methodology, goals,..):
The International Biophysics Collaboration (IBC: www.gsi.de/bio-coll) is a network of accelerator-based facilities with programs in applied nuclear physics, especially biomedical applications. The inclusion of biomedical applications is of paramount importance in EURO-LABS, for its scientific interests and social impact. It is also in line with the previous MediNet activity in ENSAR2. The goal is to have coordinated and synergistic biomedical programs in the different accelerator facilities of EURO-LABS, as well as to promote access to the facilities via TNA for applied physics studies.

Challenges:
The main challenge in our field is to exploit the new opportunities offered by new or upgraded particle accelerators, and to coordinate the programs in different facilities under the umbrella of EURO-LABS.

Original aspects:
IBC@EURO-LABS is a unique attempt to coordinate and promote biomedical applications at particle accelerators in Europe. A full description of the IBC plans is provided in Patera *et al., Front. Phys.* 2020. The whole volume 8 of the journal *Frontiers in Physics* has been prepared by the IBC and attracted 56 manuscripts (https://www.frontiersin.org/research-topics/11851/applied-nuclear-physics-at-accelerators), a clear sign of the extreme interest and relevance of the topic.

Unique expertises:
In the field of the physics and biophysics applied to medicine and radioprotection in space, IBC acts as a network of the major accelerators in Europe used for research, such as GSI in Germany, GANIL in France, KVI-PARTREC in The Netherlands, and the INFN accelerators in Italy (LNS, LNL). It is also open to medical accelerators with research programs such as HIT, CNAO, TIFPA and to facilities under construction (FAIR, ELI). We essentially aim to include all the EU expertise in biomedical research at particle accelerators.

Common expertises and collaborations:
IBC is also in close collaboration with extra-EU facilities such as NICA in Russia, HIMAC in Japan, iThemba in South Africa and RAON in Korea.

Synergies with other research/technical groups:
Biomedical applications are strongly linked to the developments in accelerators (e.g. for reaching high intensities necessary for FLASH therapy) and detectors.

Synergies with other communities:
IBC community has a large overlap with the previous MediNet and includes large experimental collaborations already working at accelerators, such as the FOOT collaboration (http://web.infn.it/foot) and the ERC-BARB collaboration (www.gsi.de/BARB).

Main category of your contribution:
Improved access

Connections with other categories:
New physics cases
Training, Education, Outreach, Social Impact

THEORY

MICROSCOPIC MODELLING OF HEAVY-ION COLLISIONS

Authors: Paolo Napolitani[1]; Abdou Chbihi[2]; John Frankland[2]; Olivier Lopez[3]; Giuseppe Verde[4]; Emmanuel Vient[None]

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See attachment

Abstract EUROLab

Title : MICROSCOPIC MODELLING OF HEAVY-ION COLLISIONS

Authors and affiliations: :

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John Frankland (GANIL, Caen, France),

Olivier Lopez (LPC, Caen, France),

Giuseppe Verde (L2IT, Toulouse, France)

Emmanuel Vient (LPC, Caen, France)

General description :

The proposal consists in a twofold action focused on the microscopic modelling of heavy-ion collisions, divided into (1) a support task and (2) a development task, sketched thereafter. The present proposal is meant to involve progressively more scientists and possibly grow into a European community focused on the activity of the European Research Infrastructures. The preparation of such a consortium has just begun. Based on a a collaboration between experimentalists and theoreticians, the goal is to boost innovation on the developing and use of heavy-ion-collision models and on the analysis and proposal of new experimental observables. Similar communities already emerged outside of the European context.

The "support task" (1) is aimed at providing the users with validated state-of-the-art modelling tools for heavy-ion-collision processes and give support for specific needs, especially at the stage of the interpretation of observables or in the planning of experiments. In particular:

- Simulation tools for heavy-ion collisions, tailored to specific systems, from low energies (few MeV per nucleon) to intermediate energies.
- Preparing complex heavy-ion-collision calculations in a "user-friendly" form. For example, heavy-ion collisions include several stages, from the contact of the colliding nuclei to the decay of the reaction products. A complete calculation requires therefore to combine more numerical tools and handle experimental filters. A useful task would be to smooth and automatise the whole procedure.

- Organising meetings and tutorials to train users, in particular the students.
- Organising discussions and exchanges with the authors of the calculation tools directly, possibly in combination with specific applications to the experimental analysis.
- Conceiving a platform where validated numerical tools are directly provided or where they can be requested to the authors (according to authorship and protection requirements).

The goal of the "development task" (2) is to conceive a more recent microscopic modelling framework for heavy-ion collisions in a range covering low energies (few MeV per nucleon) to intermediate energies, and possibly reinforce and extend a collaboration of experts from different laboratories. There exist already a vast list of heavy-ion-collision models. However, they rely on approximations (mean field, with or without a Brownian contribution, or molecular dynamics, antisymmetrised or not) which spoil the microscopic description of the process to some extent and imply different physical scenarios. This robustness issue may discourage extrapolations to unknown situations, such as future experiments, or very remote contexts, such as astrophysical scenarios, and weaken the consensus in physical interpretations. For example, processes of cluster and fragment formation may be associated to different density conditions, so that chronology and associated collective behaviours are hard to determine independently of the model. The purpose of this task is therefore not to add one more candidate to the list of existing models, but to construct a new incremental configuration where improvements in specific sectors could be continuously added. The modelling environment should be a "living project" intended to be continuously updated and innovated, and it should be as versatile as possible. While in the past much effort has been invested in comparing available models, it is now timely to revisit the modelling framework on the basis of a degree of approximation which makes it possible to handle more information and to achieve higher accuracy. The goal is to progress towards the construction of a new-generation modelling framework which reduces the use of semiclassical approximations (relying on the TDHF formalism with extensions, as handling at the same time mean-field dynamics and exploiting nucleonic correlations to generate dissipative contributions and stochastic fluctuations). This effort has already been initiated on the formal level and in the numerical implementation and it is currently progressing in Orsay.

Challenges :

The general goal is building a large-scale predictive modelling environment for for heavy-ion collisions. In parallel with supporting use of recent available and fully validated approaches for the "productive" part of the project, the challenging side of the project is building a new large-scale predictive modelling framework together with a dedicated collaborative environment, with taste for innovation.

Original aspects :

The innovating goal is disposing of a more explanatory modelling framework with respect to current approaches. At variance with comparing various models in the attempt of interpreting experimental results, we would start constructing a new model where usual approximations are gradually dropped (among many others, usual approximations are Wigner transforms, restriction to single Slater descriptions, average contributions for dissipative sources, simplification of the wavefunction descriptions).
The different current modelling approaches should then be recovered from reintroducing the removed approximations.

Unique expertise :

Authors of reference transport models for heavy-ion collisions and ongoing developments. Expertise in complex data analysis. Expertise in combining experimental and theoretical research. Expertise in advanced computing solutions for manybody systems.

Synergies with other research/technical groups :

Theory pole of IJCLab, theoretical collaborations with LNS-Catania.

Synergies with other communities :

INDRA and FAZIA collaborations.

Main category of your contribution :

Theory.

Connections with other categories :

New possibilities, machine learning, Artificial Intelligence.

NESDUU

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Abstract from FAZIA-collaboration.
Purpose : detector/electronics and theory

Title: Nuclear Equation of State Data for the Understanding of the Universe (NESDUU)
Authors and affiliations: FAZIA collaboration

General description:
Knowledge of nuclear physics is crucial for understanding the evolution of stars, the chemical evolution of galaxies and the history of their structure. Nuclear Physics in a sense is driving the Universe.
Heavy-ion induced reactions offer unique opportunities to probe nuclear properties far from the ground state under laboratory-controlled conditions. Such reactions are of paramount importance in astrophysics and in astro-particle research for the description of the core-collapse of supernovae, as well as for the formation and static properties of proto-neutron stars. In this framework, the knowledge of nuclear equation of state for asymmetric uniform matter constitutes one of the most important topics for Nuclear Physics. At low densities, warm matter is clusterized and light nuclear clusters play an important role in core-collapse supernovae for example. Their main role is to affect the weak interaction rates, and, as a consequence, the dynamic evolution of these violent events. Heavy-ion experiments can provide useful constraints to settle the in-medium modifications of cluster properties. Such modifications can then be implemented in theoretical models adapted to the astrophysical context.
It is important to explore low-density matter with the wide range of isotopes expected to be produced in European laboratories: heavy-ion collisions studies with 4π detection arrays will indeed allow comparisons with the properties of matter constituting the neutrinosphere in core-collapse supernovae explosions. In this respect, new perspectives are being opened with high intensity neutron-rich radioactive beams in the Fermi-energy domain. A possible evolution of the GANIL accelerator complex with post-acceleration of fission fragments will play a major role. Meanwhile the use of existing GANIL beams and light exotic beams at LNS-Catania are important. While future GANIL will provide the necessary tools to explore the sub-saturation density EoS, the future FAIR facility will provide exotic beams at E>100 A MeV to explore the high density domain. This research program may profit from the versatility of FAZIA telescopes to be implemented and coupled to other arrays developed at NUSTAR for neutron and pion detection.
It is envisaged to increase the number of FAZIA detection blocks and to update the equipment in order to increase the versatility. This would basically implies a modification of the electronics complex. The coupling of FAZIA with correlation apparatuses in order to measure fundamental quantities as the density of formed nuclear matter is also envisaged.
Within the same scientific context, it will also be important to develop a computing platform to be used for simulations performed with the best available transport models of heavy-ion collisions at both GANIL and FAIR energies. These models, ranging from mean field BUU-like approaches to molecular dynamics approaches, are the only means to link experimental observables to fundamental quantities such as the EoS and the symmetry energy, thus interfacing to other fields where investigations are performed with astrophysical observations and multi-messenger astronomy. The new availability of high quality data over a wide range of beam energies will allow a world unique investigation of transport code comparisons, thus increasing our insights into the fundamental in-medium interaction between nucleons. To fulfill these goals, the experimental data will cope with (Findable, Accessible, Interoperable and Reusable) principles as required for Open Science, in order to deliver these high-quality data for the nuclear physics community.

Challenges:
Modification of the FAZIA blocks in order to make them more easily usable together with other apparatus also in relatively small scattering chambers.
Exotic beams at Fermi energies.

Original aspects:
Accumulate EoS data at different densities and temperatures and provide cross-measurements in the same experiment in order to minimize analysis hypotheses. Such attempts will also allow unique tests of reaction models to tune fundamental quantities and extract quantitative information on the symmetry energy at both sub- and supra-saturation regimes. The data management plan will comply with Open Science requirements.

Unique expertises:
Expertise in detection of particles (Silicon detectors, CsI(Tl), Pulse Shape Discrimination), low noise electronics, data acquisition.
Providing high-quality experimental data coming from heavy-ion induced reactions around Fermi energy for EoS studies complying with Open Science requirements
Grouping together in a common platform transport models used in low energy nuclear Physics for the benefit of the community

Common expertises and collaborations:
Memorandum of Understanding (France, Italy, Poland, Spain, South Korea).
Collaboration with LPCCaen theory group, France.
Collaboration with CFisUC, Department of Physics, University of Coimbra, Portugal.
Sharing with Horizon Europe work program NuPhOS for data management.

Synergies with other research/technical groups:
NUSTAR/R3B/Asy-EoS and CHIMERA groups.
GdR RESANET and Action COST NewCompStar.

Synergies with other communities:
Transport code comparison projects. Such an initiative is already ongoing and would significantly profit from a strong participation by experimentalists (from the INDRA-FAZIA collaboration) to develop a common platform and database to run codes and compare to experimental observables.
Possible collaborations with colleagues in Europe involved in the study of the EoS in the astrophysical context. It will be possible to expect exchanges with researchers engaged in the study of neutron star mergers (and their gravitational wave phenomena) and neutron star radius-mass constraints on the EoS (both theoretical and experimental). Due to the relevance of the sub-saturation EoS to Core-Collapse Supernova neutrinospheres, exchanges with colleagues involved in supernova neutrino studies at ground-based observatories (JUNO, DUNE, etc.) will be mutually beneficial for the scientific community.

Main category of your contribution:
Detectors/Electronics. Nuclear transport codes for heavy-ion collisions. Open Science data management.

Connections with other categories:
Education: the program will benefit to students of the Erasmus Mundus JMD on Nuclear Physics (Caen, Sevilla, Madrid, Barcelona, Salamanca, Catania and Padova Universities).

European Theoretical Network for Nuclear Physics

Authors: Francesco Pederiva[1]; Marcella Grasso[2]; Antonio Moro[3]; JAVIER ROCA MAZA[4]

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⇒ Please see the attached pdf file containing the text of the proposal. The text has been written in collaboration with different research units form different institutions in different European countries, as specified in the document.

⇒ As authors I just indicated the contact persons of the initiative within the different research units and myself as speaker. However, the authorship of this document should be attributed to the whole collaboration

Sincerely,

Xavier Roca-Maza on behalf of the theory collaboration

European Theoretical Network for Nuclear Physics

General description

The study of the structure and reactions of nuclear systems is currently in a stage of rapid development to which both theory and experiment are contributing. On one hand, the development of new effective interactions rooted in QCD and the increase in computing power have made it possible to carry out unprecedented microscopic calculations of the properties of atomic nuclei based on rigorous many-body approaches. On the other hand, the advent of radioactive beams has led to the exploration of whole new regions of the atomic mass table in terrestrial laboratories, reaching the edges of nuclear stability, while the detection of gravitational waves together with impressive progress in the observation of compact stars is transforming the research on dense matter. At the same time, nuclear theory plays a fundamental role in the physics of electroweak interactions, including neutrino-oscillations and double-beta decay. Applications to nuclear medicine are widely pursued.

Within such a promising context and such a vast field of applications, coordinated theoretical efforts would provide a crucial support to the experimental activities presently running or foreseen at the Research Infrastructures operating in the nuclear physics domain.

Theoretical research in this field is mostly pursued by many small groups throughout Europe. While often strong collaborations have been built with experimental groups working in nuclear physics, only a few theoreticians are based at the major experimental facilities. One can notice the absence of large collaboration networks. The field suffers from an excess of fragmentation, as compared to other fields of physical research, like for example particle physics (think of the role of CERN) or of condensed matter (where extensive theoretical networks, like the European Theoretical Spectroscopy Facility, https://www.etsf.eu/, play a strong role). Specific areas which are particularly relevant for the interpretation of experiments, like the theory of nuclear reactions, should be strengthened.

We propose the build-up of a network of researchers carrying out state-of-the-art research on theoretical and computational methods for studying low-energy nuclear physics. Many of the (small) groups that will belong to the network are world leaders in their respective sectors. The present EU project may provide the ideal framework to make some important steps in the direction of better coordinating the experience and know-how of active researchers in Europe, fostering collaborations and rapid knowledge transfer, complementing and enhancing research capabilities, promoting synergies with the experimental community. This initiative would also embrace the recommendations of the last NuPeCC Long range Plan (2017) for nuclear theory.

Methodology and goals

Among the goals and advantages linked to the initiative, one can foresee:

i) the implementation of an integrated framework for the physics of atomic nuclei, nuclear reactions, and strongly interacting matter. This would strengthen the synergy between the theoretical groups active in different domains of nuclear physics and would provide a reference platform for a constructive dialogue and exchange of ideas between theoreticians and experimentalists.

ii) the sharing of software resources and the setup of friendly interfaces, which would facilitate the proper use of theoretical calculations and simulations for the interpretation of experimental findings;

iii) the optimization and the access to new computational resources by the whole network, to support theoretical methods that capitalize on high-performance computing (HPC) resources;

iv) the development of a scientific environment for the training and mobility of Ph.D. students in the field of nuclear theory. This would include the organization of courses at the Ph.D. level shared by different Units of the network, also open to interested experimentalists, as well as the organization of seminars and specialistic conferences.

The groups involved in the network will also aim at devoting efforts towards evolving technologies and applications. A relevant growing aspect of research in nuclear physics is the development of high-performance computing techniques, including quantum computing, aiming for instance at the direct simulation of nuclear reactions with microscopic potentials. Moreover, one could foresee the setting up of a "task force" aimed at applying modern techniques such as machine learning and AI to theoretical nuclear physics. These developments will be carried out in strict connection to the general effort of experimental and technological activities in this direction.

A second aspect regards theoretical support and guidance in nuclear processes for strategic laboratory projects in applications, such as programs for the production of innovative radionuclides and radiolabeled compounds for advanced medical therapies and diagnostics.

Aiming at the benefit of the whole nuclear physics community, the human resources requested by the project will be devoted to the implementation of the framework outlined above, beyond the specific research interests of the groups involved.

Main topics and Collaborations

We aim at bridging the efforts of theoretical groups distributed in Universities and major research Institutes across Europe, whose activities cover different complementary aspects of modern nuclear physics, namely:

● *Ab initio* approaches to few- and many-nucleon systems. These offer a privileged laboratory to validate and constrain our modern understanding of the nuclear interaction, the nucleon-hyperon interaction, and the interaction of nuclei with external probes, based on the (chiral) effective field theory (EFT) paradigm. These techniques are innovative important tools to eventually investigate light and medium-mass nuclei.

● Many-body methods including the nuclear shell-model, density functional theory, optical potentials, IBM and algebraic models, which are employed in the calculation of bulk, spectroscopic, and decay properties in finite nuclei throughout the mass table.

● The search for new reaction mechanisms involving projectiles at or beyond the dripline, as suggested by the spectroscopic factor measurement anomaly between reactions with different types of targets (protons vs heavy ions).

● The consistent merging of structure and reaction theories, that offers the opportunity to directly compare theoretical calculations with data obtained from experiments employing probes and reactions for nuclear systems under extreme conditions, such as weakly bound systems at the edge of nuclear stability.

● The nuclear matter Equation of State and its astrophysical implications (modeling of neutron stars, mergers, gravitational wave emission,..)

● Important applicative aspects like those related to nuclear medicine.

The following groups, involved in the research topics outlined above, represent the initial core of the proposal:

- ***INFN** sites* (Bologna,Catania,Genova,Lecce,LNS,Milano,Napoli,Padova,Pisa,Trento - Italy)

  Contacts: A.Kievsky (Pisa), F.Pederiva (Trento)

- ***University of Seville – University of Madrid*** (Spain)

  Contacts: A.Moro (Seville), E.Garrido, T.Rodriguez (Madrid)

- ***IJCLab, Paris-Saclay University*** (France)

  Contacts: M.Grasso, D.Lacroix

We aim at enlarging this initial structure, involving the European theory groups that will manifest interest in joining the project.

Training initiatives for low energy nuclear physics and theoretical developments

Authors: Marek Ploszajczak[1]; David Boilley[1]; Piet Van Isacker[1]; Anthea Fantina[1]; Gilles de France[1]

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Research Infrastructures provide beams for users in order to realize experiments testing the models. Our research infrastructures also provide theory support for the community and this service to the users is of prime importance: a comprehensive and continuous exchange between experimentalists and theoreticians are indeed crucial to move forward in our understanding of nuclear reactions and structure. These discussions need some frameworks to organize informal meetings, training sessions, in-depth studies, etc. and the EURO LABS initiative is the tool of choice to enhance exchanges and promote cross-fertilization. Some actions have already been setup in this direction but a more vigorous support is needed to ensure long-term benefits, especillay in training aspects ofr youngsters and forefront theoretical developments. In this proposal we highlight the need to support some of the existing actions and to move on with new ones.

- ECT*ECT* is the only existing platform to organize collaboration meetings in nuclear theory and related fields and incite the discussion between theorists and experimentalists. It should receive strong financial support from EURO LABS to develop its activity especially in low-energy nuclear theory.

- Training in Advanced Low Energy Nuclear Theory (TALENT)
The TALENT initiative aims at providing an advanced and comprehensive training to graduate students and young researchers in low-energy nuclear theory. The network aims at developing a broad curriculum that will provide the platform for a cutting-edge theory for understanding nuclei and nuclear reactions. These objectives are being met by offering intensive three-week courses on a rotating set of topics, commissioned from experienced teachers in nuclear theory. In this context, it is essential that EURO LABS is involved in financial support of at least one program a year in Europe (~40-50 k$/year). More about TALENT initiative can be found on: https://fribtheoryalliance.org/TALENT/

- Training in Advanced Low Energy Nuclear Experiment (TALNEX)
Even though TALENT programs are opened to the participation of experimentalists, it would be most useful to initiate the TALNEX to propose advanced training, enlarging scientific horizons of graduate students and preparing them to work in the most advanced experimental projects/facilities, and/or the most up-to date analysis of the data.
Each program should become an important part of curriculum of the participants, with credits/certificate given by the local university (see TALENT which is an excellent model of such an initiative!), eg. University of Caen if a given module of a program is organized at GANIL. Key role in the organization, at least in the first few years of existence of TALNEX, should be played by big European labs which are also the largest beneficiaries of EURO LABS funds.
At first, TALNEX should be the purely European initiative opened to the best students from the whole world. In future, it could be enlarged by joining/involving American and Asian research centers, universities and funding agencies. One should aim at organizing of at least 2 programs/year, supported by the EURO LABS.

- Funding local initiatives in low-energy theory
Essential aspect of low-energy collaborations are meetings in (very) small groups to discuss or start new scientific projects and/or obtained results. These aspects do not enter in the standard activity of the ECT* Center. It would be good to have a relatively small, flexible budget to cover these discussions/small meetings (2-3 persons) for a limited time from few days to 2 weeks, at most.
These funds could also support meetings between theorist(s) and experimentalist(s) to discuss experiment(s) in preparation, experimental proposal(s), or future experimental initiatives.

- Transnational internship
  An internship program to support students willing to be trained at the European facilities. This program could include participation to an experiment or a theoretical project as well as some dedicated lectures and other activities.

Investigation of the Oxygen dependency in FLASH irradiation of living cells

Authors: Joao Seco[1]; Jeannette Jansen[1]

[1] *DKFZ - German Cancer Research Center*

Corresponding Authors: j.jansen@dkfz.de, j.seco@dkfz.de

Title: Investigation of the Oxygen dependency in FLASH irradiation of living cells

Authors and affiliations: Joao Seco, PhD , DKFZ, Heidelberg
Jeannette Jansen, DKFZ, Heidelberg

General description (methodology, goals,..): FLASH irradiation effects are poorly understood. The current project will focus on studying in-vitro the FLASH effects for different oxygen pressures and for varying pulses structures. We will evaluate FLASH effects for both continuous and discrete beam pulse structure, while measuring in-vitro the dissolved oxygen content with a fluorescent layer in the sensor. The sensor will be read-out with the system FireStingO2 (FSO2-4, PyroScience GmbH) to allow non invasive assessment of dissolved oxygen. The cells lines of interest will be lung (A549,H460), prostate (PC3), neuroglioma (H4), breast (MCF7), bladder (T24). The FLASH effect is well known to be present for oxygen pressures of 5% atm or less, where accurate measurement of the dissolved oxygen content is vital. In addition, to allow preparation of in-vitro conditions with the correct oxygen pressure, an InvivoO2 hypoxia glove box is needed where oxygen pressure is controlled from 0.1% to 21% atm.

An additional goal of the project will be to evaluate if the oxygen measurements in-vivo with fluorescent sensor can provide an indirect measurement of the amount of free-electrons available in the medium, thus providing an indirect dosimetric assessment. Oxygen plays a vital role in FLASH effects, but it is highly reactive with free-electrons. Therefore any change in oxygen concentration is directly correlated with changes in free-electrons within the medium.

Challenges: The are several challenges related to creating the correct biological conditions to study FLASH An InvivoO2 hypoxia glove box [1] is needed to allow preparation of the in-vitro samples with correct oxygen conditions. A fluorescent layer sensor is needed with readout system FireStingO2 (FSO2-4, PyroScience GmbH), which allows accurate measurement of both dissolved oxygen and pH. Accurate dosimetry is needed from the physics detector group to allow accurate correlation between radiation dose, dissolved oxygen and FLASH effects. Several dosimetric approaches should be investigated to understand which is ideally suited for in-vivo FLASH rates. In-vitro dose measurements under FLASH conditions needed to be investigated for different dissolved oxygen conditions, where both the fluorescent sensor and InvivoO2 glove box are needed

<u>Reference</u>

[1] InvivO2 Hypoxia Workstations
https://scipro.com/wp-content/uploads/2016/01/Invivo2-Brochure-with-SciPro.pdf

Original aspects:

The assessment of the Oxygen dependency of the FLASH FLASH effect living cells for varying beam pulse structures.

Unique expertises:

1-In-vitro oxygen measurement using fluorescent layer sensor;
2-Prepartion of in-vitro cells with InvivoO2 hypoxia glove box;
3-The radiation biology understanding of the FLASH effect and its molecular mechanism;
4-In-vitro nuclear chemical dosimeter for measuring real-time radiation dose delivered to the DNA.

Main category of your contribution: Theory: Investigation of Oxygen effect during FLASH

Shape coexistence effects on exotic nuclear structure and dynamics

Author: A. Petrovici[1]

[1] *IFIN-HH, Romania*

Corresponding Author: spetro@ifin.nipne.ro

Title: **Shape coexistence effects on exotic nuclear structure and dynamics**

Authors and affiliations: **Prof. Alexandrina Petrovici et al., IFIN-HH, Bucharest, Romania**

General description (methodology, goals,…):

With the advantage of the considerable experimental progress ongoing or expected in the near future essential new frontiers will be opening in low-energy nuclear science allowing to address the properties and origin of atomic nuclei.

Proton-rich and neutron-rich medium mass nuclei offer an ideal testing ground for fundamental symmetries and interactions. Essential open questions will be raised: how does the effective nuclear force depend on proton-to-neutron ratio; which are the relevant degrees of freedom of nuclear systems at extremes of isospin; how does the shape coexistence and mixing influence the structure and weak interaction processes of nuclei to the limits of the nuclear landscape.

The efforts will be focused on structure and dynamics of medium mass proton-rich nuclei around N=Z line up to ^{100}Sn and neutron-rich nuclei in the A~100 region. We will study exotic nuclei expected to significantly influence the astrophysical scenarios concerning the rp-process and r-process path, the nature of low- and high-spin isomers, and the forbidden weak decays of nuclei dominating the reactor antineutrino anomaly.

We will use the VAMPIR beyond-mean-field nuclear models aiming to a comprehensive understanding of the structure and weak decay properties governing exotic nuclei dominated by shape coexistence and mixing. Our goal is to offer robust predictions on stellar weak interaction rates based on a realistic description of the available experimental data. A reliable description of the structure and dynamics of exotic nuclei will provide support and guidance for the future experiments.

Challenges: Continuous effort will be devoted to the systematic derivation of suitable effective interactions in large model spaces for medium mass nuclei with extreme N/Z ratios.

Original aspects: Effects of shape coexistence and mixing on exotic structure phenomena and weak interaction processes.

Unique expertises: Beyond-mean-field description of coexistence phenomena.

Common expertises and collaborations: We collaborate with different groups involved in experiments proposed for FAIR, FRIB, GANIL, ISOLDE, Jyvaskyla, Riken, Tandem-IFIN-HH.

Synergies with other research/technical groups: Relevant comparison is expected within a collaboration with Shell Model Configuration Mixing people.

Synergies with other communities: Collaboration with nuclear astrophysics groups would be worthwhile.

Main category of your contribution: Theory

Connections with other categories: New physics cases

RIB > Fundamental Science > Light Nuclear Critical Systems

R. Crespo, E. Cravo, A. Arriaga, A. Deltuva, E. Garrido, N. Timofeyuk

Radioactive Ion Beams (RIB) is an unique and expanding field, with impact in **Emergent Technologies** (as for example Materials, Health and Space) and **Fundamental Science**. It plays a *major role into the unification of our understanding of the Universe as a whole, from the Macro Structures to the Micro ones*.

The advent of the RIB´s has allow us to recreate in the Laboratory many nuclear elements that appear in Astrophysical scenarios, therefore allowing us to have insight into those macro structures.

The understanding of **bare interactions embedded in nuclear medium and its associated correlations** plays an essential role in describing phenomena in a broad range of systems, starting from few-nucleons to nuclear matter, being a key milestone for experimental and theoretical studies of nuclear structure and reactions. Moreover, it is crucial for meeting the challenges of new experimental developments in multidisciplinary research.

To achieve the understanding of nucleon interactions in nuclear medium, the light-mass part of the nuclear Segré chart, with mass range $A < 40$, is a convenient sample of nuclear systems where one can find many features that can occur in heavier systems too, for example, *the coexistence of single-particle and collective degrees of freedom and critical thresholds for particle/cluster emission near the ground state. These features ultimately trace back to the nuclear interaction*. Therefore, **light nuclear critical systems** will allow us to have a deep insight into the understanding of bare interactions embedded in nuclear medium.

In the mass range $A \leq 12$ ab initio models have been developed which solve the Schrodinger equation for the many-body system of protons and neutrons, assuming nucleons to be the relevant degrees of freedom, along with realistic nuclear interactions, to levels of very high sophistication. Hopefully, calculations for increasing A will be possible in the near future. Moreover state-of-the art reaction models are being developed and their interplay with structure addressed.

To harness nuclear correlations, significant progress can be achieved from a consistent **theoretical, experimental and computational** program together with **data analysis** devoted to these light critical systems. Such a challenging program comprises studying and measuring from nuclear properties, such as high precision mass radii, to nuclear reactions, such as knockout and transfer.

Title:

DUDWARE+ : User-Friendly Interface to the Advanced Nuclear-Structure Theory Calculations

Authors and affiliations:

J. Dudek[1], A. Maj[2], P. Bednarczyk[2], I. Dedes[2], J. Dobaczewski[3], B. Fornal[2], P. Napiorkowski[4], K. Rusek[4]

[1]) IPHC and UDS, Strasbourg, [2]) IFJ PAN Kraków, [3]) University of York, [4]) HIL UW Warsaw

General description (methodology, goals, …):

The goal of the proposed action is to construct a user-friendly, web-based interface allowing to access the theory databases with results of the large-scale calculations in the nuclear structure theory; a partial, specifically formatted database allowing to test the project-principles has been constructed and exists already at the disposal of the proponents. We envisage providing as well the possibility of performing on line an automatized modeling of the nucleus and the experimental data of interest for an experimentalist-user with the help of the standard theory tools (some details below). To our knowledge the present project represents the world-first initiative of its kind and dimension in nuclear structure physics; it emerges from many years of working towards excellence. The main action on our side would consist in elaborating the necessary informatics tools allowing nuclear-structure experimentalists to obtain directly the standard these days nuclear-structure theory information, the first-principle modeling replaced by focusing on phenomena. The corresponding tools and associated graphical interface would allow producing, among others, diagrams of direct comparisons experiment-theory `with a few simple clicks'. The theory component will be based on a solid record of extrapolability and predictive power. As an example, experimentalists could accede appropriately pre-calculated theory results such as, e.g., very often sought, nuclear potential-energy surfaces showing equilibrium deformations as well as competing shape coexisting minima, their relative energy positions thus indicating candidates for shape isomerism, the potential barriers like fission barriers, etc. The proponents of the present project can offer access to many more forms of nuclear structure information whose only small part can here be mentioned in this document for illustration, due to space limitation. It is understood that the information in question will be provided according to the Open Data principles and the Internet site of the discussed service will be placed at the IFJ PAN in Cracow.

One observes today that the present-day nuclear theory activities evolve, very roughly speaking, between two extremes:

a. Establishing new theory methods, often aiming at new microscopic approaches, and

b. Application of the established theory methods to interpretation of the performed experiments and, equally importantly, helping to optimize the experimental and instrumental conditions for the propositions of new experiments.

The theory methods and computer programs applied in this second case represent for the present project our experience-based modeling. They have been developed and improved over the years *(detailed information can be provided, see also `unique expertise' item below*) and became standard today, with relative simplicity accompanying uncompromised quality. They can be seen as elementary tools of theory for experiment and became extremely powerful at the research frontiers offering unparalleled precision and agreement with data. These computer programs are often easy to apply in obtaining elementary information today such as the single-nucleon energy diagrams or single-nucleon Routhians (in jargon: `spaghetti diagrams') and many-many other forms of information. The main problem for the experimentalists wishing to profit from this information source is that needed modern computer programs were often constructed by theory experts. These experts usually remain the only persons who can employ such programs on the `run when needed basis', yet employing simple physics principles in service of data.

Challenges:

The proponents of the present project, experienced theorists and experimentalists, have at their disposal both the modern set computer programs and advanced data bases related, among others, to potential energy surfaces. They succeeded recently in modernizing, testing and installing the newest versions on the computing facilities in France and Poland. This represents the prerequisite for successful realization of the present project.

The main challenge consists in the fact that we would wish to complete a relatively long list of theory-to-experiment service items, which will require a careful ordering of priorities.

Original aspects:

The present proposition addresses for the first time the issue of providing to the experimentalists, users of the EURO-LAB network, a theory service on the unprecedentedly large scales both in terms of the number of nuclear structure effects tractable (see the following item) and the possibly rich choice of system-generated graphical-output formats allowing directly for the theory-experiment comparisons.

In the projects like the presented one it is of utmost importance to provide to an experimentalist the information within clearly understandable format while communicating in a simple (slang-free) language. We believe that out team has long-lasting experience with this type of interactions and interfaces and will be in a position for providing such a service. We also believe that the project will contribute towards understanding the nuclear structure phenomena contributing at the same time to progress and advances in science.

Unique expertises:

Theory proponent of the present project was engaged during many (over 30) years of his activity in developing both the nuclear structure methods and the associated high-performance computer codes addressing the calculations of the physics observables directly related to experiment. These efforts have been a part of collaboration projects with the late Prof. Z. Szymanski, University of Warsaw, Poland, and followed with the projects involving elaboration of the realistic phenomenological and microscopic (Hartree-Fock) nuclear mean-field methods. Several projects and their original solutions have been developed under the impact from the late Prof. Aage Bohr (the present theory proponent was employed by the Niels Bohr Institute, Copenhagen, Denmark, during several long-time periods for over several years period in total). The proponent was also intensively using the above-mentioned computer programs for helping preparation of experimental proposals and for the data analysis.

Incomplete list of nuclear structure physics keywords addressed in the present project includes:

1. Isomer-physics and related (K-isomers; shape isomers; exotic-symmetry generated isomers; new, exotic symmetry guided physics of isomer-bands, etc.);
2. Collective-modes and related (rotational band features; band crossings; spin alignment effects; band evolution and termination; Coriolis induced phase transitions; super- and hyper-deformed configurations; unprecedented band structures related to new symmetries, etc.; Worth emphasizing the long time experience in collaboration with the experimental communities of Euroball, Eurogam, Gammasphere international projects);
3. Nuclear spin-temperature impacts, physics of `hot nuclei' (spin and temperature driven shape transitions, in particular Jacobi and Poincare shape transitions; description of giant dipole resonances (GDR); indicative electromagnetic transition probabilities, etc.);

4. The newest and particularly important for cooperation experiment-theory — providing information about estimates of the theory prediction uncertainties.

Let us emphasize that the symbol "+" included in the nickname of the project (DUDWARE+) indicates, that the project even though based on the already existing software, will be constructed as adaptable — to accept extensions compatible with the original core.

Common expertises and collaborations:

The theory proponent of the present project associated with the Strasbourg Subatomic Physics Centre have collaborated over more than 25 years with experimentalists in several laboratories in France and Poland. The implied collaboration projects have led to publishing between 100 and 200 experiment-theory or theory-experiment profile articles in the refereed international journals with over a 100 experimentalist-coauthors. We recall these observations at this point because they are indicative of the long-date practice of the theory proponents of the present project in searching and enlarging upon the experiment-theory contacts. We believe that this type of the knowhow is a prerequisite for successful constructing of the interface between theory modeling and experiment related applications on the every-day working basis.

In this context the proponents from the Nuclear Physics Institute (IFJ PAN) of the Polish Academy of Sciences in Cracow were particularly supportive especially in the recent years; over 20 experimentalists from the IFJ PAN have become co-authors of over 50 experiment-theory or theory-experiment publications together with the theory proponents. This expertise can be seen as strongly encouraging factor contributing to the success of the present project.

To be able to complete the project we will need to employ a long-term post-doc within full duration of the project, working in a theory, but having also experience with graphics and web software.

Synergies with other research/technical groups:

HISPEC/DESPEC and R3B at NUSTAR/FAIR, SPIRAL2 at GANIL, SPES at LNL INFN collaborations
AGATA and PARIS collaborations

Synergies with other communities:

Main category of your contribution:

High-level theory service to EURO-LAB users.

Connections with other categories:

Improved access to RI, new physics cases, training, education, outreach, social impact.

Theory-experiment interconnections in studies of nuclear moments conducted at European facilities.

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General description (methodology, goals,..):

We propose supporting European facilities involved in precision measurements of nuclear magnetic and quadrupole moments with novel advanced modelling of these observables within nuclear density functional theory (DFT) approaches. Nuclear moments undoubtedly belong to the class of nuclear properties where intense theory-experiment collaboration can bring us rapid progress in understanding complex nuclei. Nuclear DFT is a unique method that can deliver a global description of nuclear properties regardless of mass, or proton or neutron excess. As its input, it uses energy density functionals, which cannot yet be fully derived *ab initio* and must be systematically adjusted to experimental data by employing general effective-theory principles. In particular, the so-called time-odd components of density functionals require dedicated adjustments to time-odd observables such as nuclear magnetic moments. To refine the functionals in this channel which, to date, is poorly known, is one of the principal goals of the present-day nuclear DFT. At the same time, the improved description will be essential for interpreting, systematizing, and understanding experimental data that are intensely gathered at several European large-scale facilities.

The majority of nuclear electromagnetic moments are currently performed using laser spectroscopy techniques. These techniques can routinely access isotopes produced at rates below 100 ions/s (and even much less using in-source resonance laser ionization methods), provided the lifetime is longer than a few ms. Thus, a wealth of data throughout the nuclear chart is currently being collected. Within Europe, the most active laboratories currently performing laser spectroscopy experiments are the ISOLDE laboratory at CERN and the IGISOL laboratory in Jyväskylä. Hence, this research proposal is co-written by representatives of those communities. Furthermore, in the coming years, there are several more international research laboratories which will initiate an extensive campaign on nuclear moment measurements. This includes (but is not limited to): GANIL: REGLIS experiment at S3 and the laser spectroscopy experiments at DESIR; GSI/FAIR: MATS&LASPEC, JYU: MARA-LEB.

The training of students, young researchers, and seasoned practitioners willing to improve or perfect their expertise in theoretical and experimental studies of nuclear moments will be an essential element of the project. Along with building systematic paths to provide direct theoretical support, we envisage the following training activities:

- Series of lectures on the DFT description of nuclear moments through finding self-consistent solutions, symmetry restoration, and configuration mixing.
- Series of hands-on workshops dedicated to using advanced DFT codes that determine nuclear moments.
- Series of developer workshops devoted to building new capabilities of theoretical infrastructure in response to requests of experimental groups and to physics-driven challenges encountered in pursuing the main goals of the project.

All training activities will be open to the entire community and conducted in-person or at a distance, whichever channel of communication will turn out to be more effective.

Challenges:

A global systematic description of nuclear moments is still missing. The standard approach within the shell-model requires using effective gyromagnetic factors and effective charges in limited valence spaces. Nuclear DFT, which uses full single-particle space, has seldom been used to describe nuclear moments. Its global applicability can give us invaluable information on whether two-body and meson currents are required in the description of magnetic operators. Now the time is ripe to offer the DFT modelling in support of experiments and to base nuclear DFT modelling on using state-of-the-art experimental results. The standard optimisation of density functionals consists of adjusting the time-even sector only, performed in even-even systems, whereas the time-odd sector is supposed to follow unconstrained. Our recent systematic investigations based on the linear response theory have shown that this procedure is problematic since the time-odd sector may play a very important role in the determination of excited states. A poorly constrained time-odd sector can lead to the appearance of unphysical configurations such as spontaneous polarisations. To overcome such a problem, it is thus mandatory to use experimental information on nuclear magnetic moments, which constrain the time-odd sector efficiently.

Original aspects:

The DFT description of nuclear moments implemented at York includes full self-consistent polarization effects, by which the odd neutron and/or proton modifies properties of the underlying even-even core. As it turns out, models based on using states of even-even neighbours are not adequate, as the true cores are significantly polarised both in the time-odd sector (spin polarisation) as in the time-even sector (deformation). We therefore propose to develop functionals which are constrained using time-odd information as well. This will enable us to provide experimental groups with a truly globally performant theoretical framework for understanding magnetic dipole and electric quadrupole moment data. Furthermore, our approach would also enable the defining of statistical uncertainties on the theoretical calculations. A theoretical model with all these features is at present not available for electromagnetic moments.

Unique expertise:

The York-Jyväskylä-Lyon collaboration has already developed a full suite of DFT codes that allow for efficient calculations of nuclear moments with full symmetry breaking, symmetry restoration, complete treatment of aligned angular momenta in odd nuclei, and pairing. When combined with capabilities of using advanced finite-range non-local density functionals, the collaboration is worldwide uniquely positioned to conduct the projected research. Intense analysis based on using the developed infrastructure is now being started and a substantial workforce is needed to bring this activity to fruition and to full alignment with experimental efforts.

Indeed, nuclear magnetic dipole moments have already been measured for hundreds of isotopes. The current experimental state-of-the-art is now approaching important benchmark isotopes, e.g. ^{53}K, ^{79}Cu, ^{99}In or ^{101}Sn, which feature single valence nucleons outside of very exotic doubly-magic cores. Hence, global theoretical models which can describe isotopes throughout the nuclear chart in a consistent and accurate way are critically required. Furthermore, on the precision frontier, new experimental developments are underway which will enable the measurement of magnetization distributions or magnetic octupole moments, for which a theoretical underpinning is also largely lacking.

The York group has developed several tools based on machine learning algorithms that can help to speed up the procedure of parameter optimisations. At present the most promising method is based on the Gaussian Process, which was successfully tested for the identification of absolute minima guided by the expected improvement function. The use of statistical tools is not only important to reduce the computational cost, but also to obtain a robust estimate of statistical errors, which are vital in order to have a meaningful comparison between theory and experiment. Presently, experimental uncertainties are typically well below one percent, and in some cases even below 1 part per million. However, the rich information content that this high precision could provide on the underlying nuclear structure is currently hard to extract due to this lack of theoretical uncertainties.

Common expertise and collaborations:

Theoretical work proposed here will be conducted within the York-Jyväskylä-Lyon collaboration. At York, we will continue developing the capabilities of calculating nuclear moments within the 3D code HFODD. The work at Lyon will focus on adjustments of novel functionals within the spherical code FINRES4, to which the information and constraints coming from the experimentally measured moments will be passed on by implementing novel technology of gradients in the parameter space. In parallel, at Jyväskylä we will implement symmetry restoration and calculations of nuclear moments within the axial code HFBTEMP, which is performant enough to be used at Lyon for direct parameter adjustments. All existing and developed codes will be published under the Open Source licence (code HFODD has already been published). In synergy and in parallel to the theoretical work, the foreseeable experimental campaigns in the coming years will focus on key regions of the nuclear chart, for example the neutron-rich Ca region (K-Sc near N=32,34), proton-rich nuclei between Ca and Ni (towards the N=Z line), the ^{100,132}Sn region (Ag-Te), and multi-quasi particle isomers in Bi.

Synergies with other research/technical groups/communities:

This research proposal predominantly focuses on the ground-state nuclear moments and naturally has synergy with the optical spectroscopy community. Recent efforts towards development and use of actinide beams for novel avenues of research for example, in tests for New Physics beyond the Standard Model (BSM), will clearly benefit from a close collaboration with the theoretical developments proposed here. A second important category of moment measurements applies to short-lived excited nuclear states. The present developments will naturally also benefit that community, through the development of a common, global theoretical framework suitable to nuclear electromagnetic moment studies. **Our proposal is**

fully open to the participation of other current and/or future research groups, both from theory or experiment, not directly mentioned here but which would be able to provide theory support to experimental research on nuclear moments.

Main category of your contribution:

Theory
Search for new effects, interpretation of experiments

Connections with other categories:

Application of machine learning algorithms has a connection with **data acquisition, analysis and simulations**. In general, machine learning is a tool becoming more widely used both in theory and experiment. As an example, such tools are in use in optimization of beam delivery and therefore one may make a loose connection to the beams and targets category.

Members of the collaboration are involved in providing joint lectures in the use of theoretical methods for the interpretation of nuclear structure data. Such lectures could foreseeably be promoted through training opportunities and will be made more widely available through remote platforms, of wider benefit to students from different disciplines.

Training

Training schools in relevant topics to RiB research

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Training Schools in relevant topics to RIB research

By A. Borschevsky (RUGroningen), T.E. Cocolios (KU Leuven), V.N. Fedosseev (CERN), D. Hanstorp (Gothenburg), B.A. Marsh (CERN), K.D.A. Wendt (JGU Mainz) on behalf of the LISA MSCA ITN

General description

The European landscape features a wide range of summer schools and training opportunities that have varied history and focus, providing a fragmented picture that may be challenging for young researchers to identify and might prevent them from attending the most relevant event for their interest.

By labeling recognized events and providing financial support, EURO-LAB can help create a more cohesive training landscape, direct the trainings in directions beneficial to its consortium, and guide the young researchers in their development.

Challenges

Each school has its own structure, its history – whether it is over 25 years like the Euroschool on Exotic Beams, or whether we consider the LISA Winter School that will have its first edition in 2022 – and its identity. Each school also has its own committees that autonomously determine their content and format, and this should not be interfered with.

However, while this variety results in a broad offer for young researchers, it also results in a very confusing landscape that is counter-productive to the training of the new generation of researchers in the fields of research of interest to EURO-LAB.

Original aspects

We propose that the new INFRA program opens itself to the following possibilities:

1. Offering a recognized label to schools which contribute to the education of the new generation of researchers within our field. This label can be applied for by the schools and results in the promotion of those events via the dissemination platform of the program and its visibility next to the other events.
    a. We may consider adding emphasis on that platform that links with specific topics/ domains/WP/… within the program to enhance their integration.
2. Offering the opportunity to bid for funding to support those schools. These could take the form of funding a prize at the school, supporting a specific lecture of high relevance to the consortium, … The idea is not to replace existing funding structures, but rather to complement them and hereby enhance the trainings offered.
3. Propose a label/diploma to young researchers who complete a series of trainings within labeled events from the consortium, in the same fashion as was done in the past with the FANTOM Schools, how is done within PRISMAP (an INFRA starting community for the production of medical radioisotopes for research that grew from the MEDICIS-Promed ITN), or within the LISA ITN.

Unique expertise/Common expertise and collaborations

Here is a list schools which might be relevant to consider within this context. The list is not exhaustive.

- Euroschool on Exotic Beams: https://www.euroschoolonexoticbeams.be/pages/home
- Ecole Joliot-Curie: https://ejc2020.sciencesconf.org/
- School on the Physics & Chemistry of the Actinides: https://jda2020.sciencesconf.org/
- Events arising from ITN, such as LISA: https://lisa-itn.web.cern.ch/training
- TALENT School: https://fribtheoryalliance.org/TALENT/
- CERN Accelerator School: https://home.cern/tags/cern-accelerator-school
- STFC Nuclear Physics Summer School: https://stfc.ukri.org/research/nuclear-physics/np-summer-schools/

Synergies

This approach would allow to establish the training of young researchers within an existing framework while benefiting those events as well as the consortium, hereby creating a true synergy.

Category

Education

Training of technical and engineering staffs.

Authors: FRÅNBERG DELAHAYE Hanna[1]; Cyrille BERTHE[2]

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Training for staff working on developments or upgrades of current and new installations. The main goal is to accord hands on experiences of different systems to technical and engineering staff.

Title: Training of technical and engineering staffs.

Authors and affiliations: H. Franberg-Delahaye, C. Berthe, GANIL, France

General description (methodology, goals,..):
Training of technical and engineering personnel from different laboratories. The training is for persons working on developments of upgrades of current installations or on new installations. The main goal is to accord hands on experiences of different systems.

Challenges:
The category of persons towards which these training will be proposed do commonly not have a culture of travel, collaborations and exchanges outside their laboratories or national research structures. These kind of exchanges for several months should be strongly pushed by the institutes.

Most installations have a limited numbers of personnel and during a training exchange period as proposed the laboratories might be in a temporary difficulty for their personnel that might be covered by the financing of short-term contracts at the institute that send their personnel or by exchange of personnel between the laboratories.

Original aspects:
Most of time, our technical personnel and engineers are already fully busy by their own work in their home laboratories and institutes and have seldom time to dedicate to study the advances and upgrades going on in other laboratories to increase and develop their knowledge's of operational issues. A solution could be the funding of long-term visits of engineers organized between two RI to have real transversal work between labs. This can be applied for routine running as for upgrades and in case of specific technical difficulties.

We also would like to propose a Master program with theoretical studies on distance, together with 6 months technical and operational practice in a laboratory, similar to the proposition of J.Piot for scientific studies. One year master classes could be proposed by engineering schools and universities on different technical subjects with technical work in one of our installations during 6 months. The courses could be given at distance while the students are housed at one of the installations. During the year one of the semesters are devoted to take part of the technical, maintenance or operational work in one of the groups at the laboratory. This would help to train and form young technical staffs on the specific techniques of cryogenics, vacuum, electroncs for the diagnostics equipment's, high power electronics or other specific fields where we search trained personnel in our laboratories.

The category of personnel we are looking for are personnel with technical background, with in different levels education. All from a 2-3 years technical superior studies up to well-recognised Engineering schools.

We propose to adapt this program for permanent and non-permanent personnel working in the installations, with or without the theoretical master classes.

The mayor installations in Europe all have technical personnel and engineers that need to be trained at different levels when they are newly hired or when new projects or upgrades of the installations is foreseen. The major projects and upgrades of the installations are commonly developed and constructed by partner institutes and unfortunately the personnel at these institutes do not follow the instruments ones there are in operation but they will go on to another project that their laboratory or institute need to work on.

While the housing institute need to form their personnel on new technics and technologies to be able to do maintenance and operation. The personnel working on the development that has already practical knowledge of the operation of an equipment in an installation will consider this in their development.

The idea is to exchange personnel in the different running installation to gain in know-how and experiences.

Unique expertise:

Gain in expertise through hands-on training of technical personnel on a running installation for nuclear research. Expertise and know-how that the personnel will be able to use while working on development for future projects or operations and maintenance in other installations or institutes.

Common expertise and collaborations:

Scientists with higher educations and PhD often have a natural tendency of national and international collaborations due to their studies, this is naturally less developed for the technical and engineering personnel by the classical educational systems. The exchange program and housing installation, shall also propose help of housing and practical issues for the visiting personnel.

Such an exchange program will also benefit the installations while facing technical difficulties during running periods by one hand through the contacts and network created and on the other hand through temporary exchange of personnel if needed.

Synergies with other research/technical groups:

The categories for the personnel can cover all different fields of our installations (radioprotection to operation and maintenance)

Synergies with other communities:

Main category of your contribution:

Improved Access:

Easier procedures, increase of number of RI involved, opening to new communities

Training, Education, Outreach, Social Impact *Complementary hands-on training, Lab-University collaboration, coordinated outreach, gender equality*

Creation of an international student program or PhD/Post-doc exchange.

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In the last decades, most of the European laboratories have spent considerable effort in upgrading even constructing new accelerators and experimental set-ups. Even though the type of measurements is similar, there is lots of subtilties between experimental devices that makes each of those instruments unique and complementary.
Large international collaborations seed light grouping the different type of measurements, i.e. laser spectroscopy, mass measurements, transfer reactions, decay-spectroscopy…
With the large number of different type of experiments and their increasing complexity, the research infrastructures are confronted to a lack of human resources to optimally host highly complex setups. Even more, the students that perform their thesis in a unique laboratory becomes focus in an unique experimental device. This proposal is aiming at building a long-term training network of infrastructures where PhD students and postdocs could benefit from a complementary education to significantly enrich the cursus. This would be realized through visits and running experiments in other laboratories, where devices that are complementary to the one available in the home laboratory/university can be use.
Within this context and considering the existing synergies of the experimental techniques for each type of experiments, it will be very fruitful to have a "pool" of common student of all these labs that apart of spending their time in the host laboratory travels over the different partner institutes to increase their knowledge and expertise on the specificities of the different devices. The idea could be to have minimum 5 students that will spend considerable time of their first year of thesis traveling to the labs for periods of 2-3 months to learn about the techniques, the rest of time will be devoted to the work on the host laboratory/institute, at least 1/3 of the first year time. This will imply that each laboratory/institute will welcome several students at the same time, which will allow to the different research group to advance on their programs thanks to the increase on human resources. Moreover, the system will allow a transfer of knowledge and expertise between laboratories. This will be very useful in i.e. experiment preparation and participation in the different laboratories, development of different experimental set-ups, data analysis… etc.
Same mode could be applied on the second year of thesis, while the third one will be spent at the respective host institute. Therefore, students of third year of thesis will be able to form those of the first and second year, assuring the transfer of knowledge and know-how.
Finally, the students would attend summer programs hosted on the different facilities to increase their theoretical background (eg TALENT school as promoted in another proposal).
This program would strongly benefit to students that are continuing their research career by a post-doc.

Gender Equality and Diversity

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Gender Equality and Diversity

Authors and affiliations: J. Wilson & K. Turzó, CNRS

General description (methodology, goals,..):

As mentioned in HorizonEurope Model Grant agreement, *"The beneficiaries must take all measures to promote equal opportunities between men and women in the implementation of the action and, where applicable, in line with the gender equality plan. They must aim, to the extent possible, for a gender balance at all levels of personnel assigned to the action, including at supervisory and managerial level".*

Each organization participating in the project must have a Gender Equality Plan before signature of the contract.

Our community is already involved in this action, through the Diversity Charter of APPEC, ECFA, NuPECC and the participation of ENSAR2 in the GENERA network for Gender Equality in Physics in European Research Area.

The goal of this specific action within the project is to strengthen and develop activities concerning gender equality, diversity, including handicap, and inclusion. It will also communicate on these topics within the consortium and beyond. It is important to organize a contact point/person for European Commission and other partner institutions or organizations outside the consortium.

This action will mainly be advising and counselling for project and RI coordination teams, establishing annual statistics on indicators linked to these topics, communicating information to the consortium at large.

Some points to be addressed (as mentioned by female physicists of nu-Ball collaboration) and examples of solutions to be studied:

- Balance between work and private life:
    - Financial support for post-doc couples when they have to work in different countries in order to help them visiting each other.
- How to work in optimal conditions after a birth, even as a post-doc:
    - Extension of post-doc contracts in case of maternity or paternity leaves.
    - Financial support for young parents to go to conferences after maternity or paternity leave.

This list is non-exhaustive and could be enriched after a survey to be performed at the start of the project.

The aim is to ensure that user community as RI teams and groups working on RI developments reflect as much as possible the scientific community in all its human aspects. It is also crucial that this action takes into account the main points of Gender Equality Plans as defined by the European Commission (p. 9 of proposal template: https://sciencebusiness.net/sites/default/files/inline-files/5-Proposal-Template-v1.pdf)

Challenges:

Coordinating actions on Gender Equality, diversity and inclusion in several RIs and countries, with tailored solutions for each RI, in the aim to reach homogeneous improvement in the whole consortium.

Original aspects:

The original aspects of this action concerns RIs, being locations where scientists and non-scientists work daily and where scientific users spend some time of their career. This action has to address both populations.

Unique expertises:

Each institution participating in the project already has specific actions on these topics. There is no unique expertise but local solutions that can be used at larger scale if necessary.

Common expertises and collaborations:

Collaboration with GENERA network.

Synergies with other research/technical groups: none

Synergies with other communities:

- Physics in general with the GENERA network
- Women in STEM in North America

Main category of your contribution: Training, Education, Outreach, Social Impact

Connections with other categories:

- Improved Access

PhD for RIs

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PhD for RIs

Authors and affiliations: J. Wilson & K. Turzó, CNRS

General description (methodology, goals,..):

A consortium of RIs is a unique opportunity to provide outstanding education to young researchers in accelerator-based science. The aim is to educate a new generation of accelerator-based scientists, trained on different facilities already during their PhD time, in order to strengthen synergies between European RIs, much before possible post-doctoral experiences.

Such education programme may propose PhD between at least two RIs with synergies allowing PhD students to work 12 to 18 months in each RI, with secondments in other RIs of the consortium.

Common education workshops may be organised during the project to gather all RI PhD students, their supervisors and consortium members.

Challenges:

Centralized organisation of cotutelle PhD grants between RIs and associated universities.

Original aspects:

The main original aspect is the PhD time shared equally between at least 2 RIs for several PhD students at the same time. It is inspired by doctoral network with cotutelle aspect in addition.

Unique expertises:

RIs have unique expertises in accelerator-based science and are constantly training PhD students. The consortium will add a strong support to local scientific and administrative teams in order to centrally organize genuine European education for young researchers in this domain.

Common expertises and collaborations: /

Synergies with other research/technical groups:

Synergies are possible between all RIs of the consortium as each of them is working with at least an associated university.

Choices of RIs pairing for PhD offers will be done according to the topics to be chosen by the consortium.

Synergies with other communities:

Within this education programme, young accelerator-based scientists will be aware of needs of all other user communities and encouraged to work on topics related to these needs.

Main category of your contribution: Training, Education, Outreach, Social Impact

Connections with other categories:

- Improved Access
- Beams + Targets
- DMP + Data sharing
- New physics cases

EGDLabs (European Ge Detectors Laboratories)

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Proposal for a Training Activity in the framework of EURO-LABS

EGDLabs could provide training activities plus advice and support, in peer to peer basis, between local experts in the field of operation, maintenance and repair of HPGe detectors. This training activities will include online discussions, few presential activities in programmed visits and one Hands-on Workshop per year in the more advanced HPGe detectors labs in Europe.
The required resources are for covering the travelling costs for the few networking activities (travels for short stays of experts from each country) and the organization of one Hands-on Workshop each year, starting from the second year of the EURO-LABS contract.

Abstract
In spite of new materials and developments in gamma detectors technology, detectors based on Hyperpure Ge (HPGe) continue to be fundamental tools in nuclear gamma spectroscopy and applications when high gamma energy resolution is needed.
These detectors unfortunately are not only expensive resources but also are expensive in the repairs made by their manufacturer. For these reasons, a laboratory for the repair of HPGe detectors with a well-trained specialist is a strategic resource in the European nuclear facilities. Frequently these laboratories for HPGe germanium detectors give important advice, and many times support, to local institutes or companies that look for help when their HPGe detectors suffer severe failures.
Anyway, during the last decades, in spite of this drawback, important advances in nuclear structure studies have been possible due to continued improvements in high-resolution gamma-ray detector systems using HPGe diodes. For this reason, in the European transnational facilities, universities and institutes we can find HPGe detectors from simple single crystal for normal applications to expensive quite complex detectors systems.
It is complicate to give an economical value of the resources in HPGe detectors in the European scientific community, mainly because some of these detectors are not produced anymore and are priceless. But, in any case, it would be impossible to buy them again within the present financial situation.
In **Table 1** (in the **Tables ANNEX**) we present a picture, we have reported to the Scientific Committee of the ENSAR's network activity EGAN, of coaxial HPGe detectors in use in Europe in 2012.
In the report to the scientific committee of the EGAN, we have also included the summary of a survey organized by KU-Leuven (Belgium) with a picture, taken in 2012, of the detector maintenance and repair capabilities in the European Nuclear Structure community (see the Summary file in the attachment). This survey has been answered by 12 institutes: GANIL (France), GSI (Germany), IFIN-HH Bucharest (Romania), IKP-University of Koeln (Germany), IKS-Leuven (Belgium), IPN-Orsay (France), JYFL (Finland), LNL (Italy), T.U.Muenchen (Germany), Univ. of Liverpool (UK), HIL-University of Warsaw (Poland) and DL-Daresbury (UK).
The questions of the survey were:
• Which type of detectors is handled in your lab.
• Which maintenance and repair activities are carried out for the different detector types? (testing, pumping, warm electronics, cold electronics, HPGe crystal replacement, encapsulated HPGe replacement, electronics repair, cryostat heating, annealing).
• What equipment is available in your detector lab (not for loan).
• Number of people currently involved in the different maintenance and repair activities.
• Could technical support potentially be supplied on site?
• Are new people being trained for repair of detectors on a regular basis?
• Briefly describe the training strategy and capabilities in your lab.
We are showing in **Table 2** (in the **Tables ANNEX**) a summary of the type of maintenance and repair activities carried out in the 12 laboratories of this survey. As a conclusion of this detailed

survey, we can conclude that all of these 12 European institutes were performing since many years normal maintenance of HPGe detectors (test, detector pumping and warm electronic repairs) with one or two people of permanent staff and few of these institutes were also involving students in these activities. Many of them had a detector laboratory where it is possible also to perform other maintenances like cryostat heating, annealing and cold electronics substitution. Some of them could also replace encapsulated crystals. But if the failure of the Ge detector was due to the Germanium diode itself, e.g. high leakage current due to a damaged B-implanted contact or passivation layer, none of our laboratories were able to repair the detector, because as we affirm, the knowledge and the equipment for the full fabrication process is needed for this type of detector repairs.
More recently, in the framework of the ENSAR2's network activity NUSPIN (1) two Hands-on Workshop activities at IKP-Cologne in 2018 (2) and Liverpool in 2019 (3) have been organized to provide training in diagnostic, repair strategies and measurement techniques involving HPGe detector systems. The participants of the two workshops found the information exchange extremely useful and asked for a continuation of this type of activities.
As continuation of these very successful first meetings and exchange of experience we are proposing here in the framework of the EURO-LABS Transnational Access Facilities a Training Activity for both technical personnel and experimented specialists where to increase their skills in a peer to peer basis. This Training activity could be the first step for the creation of a network of specialists in this strategic field that could work as an effective extended European HPGe Detectors Lab by integrating the expertise of people who are actually working in this field.

Summarizing: EGDLabs could provide advice, support between local experts in peer to peer basis and special hands-on training once per year in some advanced laboratory as discussed above. The continuation of these training (and networking) activities have been asked by the community of experts that have participated to the NUSPIN Hands-on workshops mentioned above and both, the detailed proposal and the structure of this training activity, will be done with their contribution.

Synergies: EGDLabs will improve the quality in the operation, maintenance and repair of the HPGe detectors in the European Transnational Access facilities. **EGDLabs** will help in the creation of a network of specialists for the sharing of common knowledge in a peer to peer basis.
EGDLabs will have important synergies with any activity that will make use of HPGe detectors.

Social impact: If the European TNA facilities improve the capacity of their HPGe detector laboratories, they will give better advice and support to private or institutional (ie. universities or external small research groups) local activities that make use of high energy resolution gamma detectors.

References
(1) ENSAR2's WP4: Nuclear Spectroscopy Instrumentation Network: http://nuspin.pd.infn.it/index_events.html
(2) Hands-on Workshop on Operation, Test and Repairs of Ge Detectors: https://agenda.infn.it/event/15960/
(3) NuSPIN detector school: https://www.eventbrite.co.uk/e/nuspin-detector-school-tickets-61299937764

NOTE: See **Tables ANNEX** at the end of the EGDLabs.pdf attachment.

Master classes for training in Nuclear Physics

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Title: Master classes and students training
Authors and affiliations: J.Piot (GANIL) et al.

General description (methodology, goals,..):

The recruitment of new students for our field needs an increased visibility at the the undergraduate level. A good way to attract students to nuclear physics is to provide material and practical work directly from the data gathered at our facilities. This project aims to create the framework from our data and equipment and adapt it to different levels of education.

Three levels can be created :

1. Master classes for **high-school students** (1 to 3 days, by visioconference, handling pre-processed data sets and adapted analysis software or locally)
   The aim is to show the work of scientists, the techniques used and develop attraction of high school students for scientific careers and visibility for the RIs to the public.
2. Master classes for Licence level. The aim is to show the field and attract students to nuclear physics.
3. Summer/winter school for Master students (1 week, by visio or in attendance when permitted, handling data sets from experiments and machine developments)
   The aim is to show the technologies used to students, attract students to our facilities with a prior knowledge of our activities and techniques.

Level 1 could be expanded to an online platform for High-school Physics teachers that could be used as a resource for projects.
All these levels can either be thought as ressources for teachers or practical work performed with physicists from the facility. This will need to be determined.

Challenges:

Provide processed data sets for public use. This matches the challenges of the DMP and Open Science. Use the data produced by our experiments to generate attraction to our field and scientific careers in general.

Original aspects:

Provide three levels of training and use data from various fields using ion beams.

Unique expertises:

Each facility can tailor the three levels with its unique setups and developments.

Common expertises and collaborations:

Synergies with other research/technical groups:

The topics of all levels can be extracted from experiments from the Physicists' community as well as the accelerator, or ion source development community.

Synergies with other communities:

Topics from Atomic Physics, Material Science, Radiobiology, Radiation safety can be included in the program.
Specific actions about radiation safety could be expanded to wider public outreach. This would be a good way to improve the understanding of radioactivity for the public.

Main category of your contribution:

Training, Education, Outreach, Social Impact

Connections with other categories:

DMP + Data sharing

International schools on Monte Carlo codes (INFN-LNS)

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The medical Physics and Monte Carlo Group of the INFN-LNS has a long experience in the use of the Monte Carlo simulations and in new innovative computational approaches (deep learning and quantum simulations) mainly for applications related to medicine. Since 2003, INFN-LNS researchers have belonged to the Geant4 international collaboration contributing to the Geant4 code development. The INFN-LNS group is extremely active in the organisation of International school dedicated to Monte Carlo and high-performance computing. They organised more than twenty international schools on these topics.

Training of the next generation scientists in Nuclear Photonics

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Training of the next generation scientists in Nuclear Photonics

Dimiter L. Balabanski, IFIN-HH/ELI-NP (RO), Norbert Pietralla, TU Darmstadt (G)

Herewith, we suggest a training program for the next generation of scientists in Nuclear Photonics. ***Nuclear Photonics*** is a new research field which combines novel radiation sources based on ultra-high power lasers with methods from nuclear physics. Experiments in such environment require specific knowledge related to the beam diagnostics, the experimental techniques, the detector systems, etc., in comparison with experiments at particle accelerators. The training program will include hands-on training in experimental environment at the S-Dalinac facility at TU Darmstadt and the ELI-NP facility in Bucharest-Magurele. The goal of this training program is to allow the researcher to use in an optimal way the European research infrastructure. The training will cover three aspects:

1. Novel laser-based radiation sources and their application

This research training program aims at the development of methods for the establishment of innovative sources of photon and particle beams with unprecedented characteristics, such as intensity, emittance, brilliance, or time structure.

2. Scientific exploitation of photon beams

Photonuclear reactions will be applied in this research area at ELI-NP and at TU Darmstadt for fundamental research in contemporary nuclear science related to nuclear structure, dynamics and studies relevant to astrophysics and astroparticle physics.

3. ***Advanced instrumentation for Nuclear Photonics***

This research training program is devoted to the development of photonuclear instrumentation and charged-particle detectors capable of coping with the experimental conditions at and exploiting the extreme peak intensities of novel particle and laser beams.

Qualification of junior scientists on scientifically and technologically challenging projects for research in an international, collaborative environment will constitute the core of the proposed research training. The program will also be adequately reflected in collaborative supervising of the trainees for an efficient guidance of the junior researchers. In is worth noting that the European expertise in this quickly growing field is concentrated mainly in the laboratories proposing the hands-on training program. However, for achieving optimal results, also scientists from other European research institutes will be attracted as supervisors.

Annual training schools in experimental physics with particle accelerators

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Annual training schools in experimental physics with particle accelerators

Livius Trache

IFIN-HH, Romania

Modern nuclear physics at its best implies currently large research infrastructures. They are basically large accelerators to produce and deliver radioactive nuclear beams or large and sophisticated detectors looking for exotic decays. These are costly and in the last decades have become international endeavours, rather than national facilities. Only a few exist anywhere in the world, and fewer still are in Europe: at CERN, at FAIR or GANIL. Experiments are becoming more and more complex, built increasingly if not entirely by large collaborations, and it takes long time to be realized. The beamtime available is scarce and the competition for access is fierce. In this environment it is becoming rather difficult to train the new generations of researchers. Hands-on participation in experiments is difficult (and it may be further complicated by health crisis like the current pandemia).

Given the above conditions, we consider that smaller facilities, like those of IFIN-HH, can play an important role in the education and formation of young people. We propose a series of annual training schools in experimental nuclear physics using particle accelerators. We propose schools of 10-12 days, in June-July each year, open to 15-20 students, from master degrees, to PhD students or even post-docs who are up to 2 years after their degree. The schools will consist of a few lectures presented by invited and/or trainers and from hands-on work in our laboratories, including a full week of beam time at one of our tandem accelerators. The trainees will be given sufficient time to obtain and analyze the data taken and to present their results by the end of their stay.

IFIN-HH has 4 working accelerators that can deliver low or medium energies and are and could be used for different purposes. Three of them are tandem accelerators, of maximum voltages of 9, 3 and 1 MV, respectively. The Department of Nuclear Physics (DFN) has a target laboratory well equipped and manned by a few young chemists and physicists that can show various methods of producing targets for nuclear physics experiments. We have setups, detectors ans ACQs, of various complexities, from a single detector, to medium size detector arrays of 25-40 gamma-ray detectors or arrays of Si with dozens of channels. We will propose to the PAC of the tandems an experiment with this subject (most likely to be approved) and reserve a 7-day time slot to conduct it together with the trainees. Activities will consist in classes and hands-on activities:

1. In the target laboratory
2. Manning an experiment at the 9, or 3 MV tandetron (7 days around the clock)
3. Calibration of the accelerator and of detectors used
4. Prompt gamma-ray measurements with the RoSPHERE array, or another array.

De-activation measurements are possible in an ultra-low background underground laboratory we have in a salt mine, 125 km away from Bucharest.

The trainees will man the experiment round the clock, will make or change the experimental arrangement, will handle the DAQ system, will collect, store, and will analyze on/offline data.

We propose to have these schools an annual event, open to the young people of the Euro-Labs partners. They could become a tradition and an item in the education and formation program for their degree.

Training / 7

Small accelerators for supporting nuclear physics studies: the Catania DFA 3 MV Singletron

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Small accelerators offer the unique opportunity of low-energy beams acceleration for different kind of purposes, ranging from pure nuclear physics studies up to applied ones. The Department of Physics and Astronomy (DFA) "E. Majorana" belonging to University of Catania (UniCT) hosts the 3MV HVVE Singletron mostly used in these years for solid state physic studies. Thanks to the ion source, protons up to 3 MeV and He beams up to 6 MeV are now available with a maximum intensity of 100 μA (for protons). Thanks to its strategic position, close to the INFN-LNS (Laboratori Nazionali del Sud) of Catania where a 15MV Tandem and the K800 Superconducting Cyclotron are already available, the 3MV DFA-Singletron acts as an important ingredient for **complementing the INFN-LNS experimental activities** where no low-energy He beams are up to now available. This naturally favored (and continuously favors) the collaboration between INFN-LNS and DFA researchers taking also advantage from the **longstanding agreement between INFN and University of Catania**.
Further, the possibility of using a small-accelerator in an university department could be also used for the **training of new generation scientists**.
In more details, the 3MV DFA-Singletron will be used for the characterization of solid targets and detectors (efficiency measurements, detector response, noise studies….) to be used in the future experimental activities foreseen at INFN-LNS and other research infrastructures. Among these activities we could mention pure nuclear studies (cluster structure, low-energy scattering….), nuclear astrophysics studies (activation measurements, neutron induced reactions with RIB's,…), studies for the physics beyond the Standard Model (neutrino-less double beta decay, the search of candidates for dark matter…) and studies for applied physics (medical physics, cultural heritage,…). In order to perform such studies, devoted improvement and development need to be performed at the DFA-UniCT. Thus, we plan to install, in the already existing experimental hall at the DFA, a new beam line with a dedicated scattering chamber. Additionally, devoted simulations for radiation emission are already under study in order to develop in the near future the project of a devoted neutron-shielding system to be built and placed around the scattering chamber.
Summarizing the contents of this abstract we plan at:
- enforcing the already existing collaborations with INFN-LNS activities providing low-energy beams via the 3 MV HVEE Singletron;
- assembling a devoted beam line, equipped with a scattering chamber and its neutron-shield system, for performing the experimental activities ancillary to the future INFN experiments.

Main category of the contribution: The main category of our contribution is "Training, Education, Outreach, Social Impact" since the Singletron Accelerator is hosted in the UniCT Physics dept. where young researchers generation is continuously formed.

Connections with other categories: Due to the large interest to the DFA-Singletron, further connections can be also found with the "Beams+Targets" and "New physics cases" categories.

Small accelerators for supporting nuclear physics studies: the Catania DFA 3 MV Singletron

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2) INFN-LNS, Laboratori Nazionali del Sud di Catania, Italy
3) IMM-CNR, Catania, Italy

Small accelerators offer the unique opportunity of low-energy beams acceleration for different kind of purposes, ranging from pure nuclear physics studies up to applied ones. The Department of Physics and Astronomy (DFA) "E. Majorana" belonging to University of Catania (UniCT) hosts the 3MV HVVE Singletron mostly used in these years for solid state physic studies. Thanks to the ion source, protons up to 3 MeV and He beams up to 6 MeV are now available with a maximum intensity of 100 μA (for protons). Thanks to its strategic position, close to the INFN-LNS (Laboratori Nazionali del Sud) of Catania where a 15MV Tandem and the K800 Superconducting Cyclotron are already available, the 3MV DFA-Singletron acts as an important ingredient for **complementing the INFN-LNS experimental activities** where no low-energy He beams are up to now available. This naturally favored (and continuously favors) the collaboration between INFN-LNS and DFA researchers taking also advantage from the **longstanding agreement between INFN and University of Catania**.
Further, the possibility of using a small-accelerator in an university department could be also used for the **training of new generation scientists**.
In more details, the 3MV DFA-Singletron will be used for the characterization of solid targets and detectors (efficiency measurements, detector response, noise studies….) to be used in the future experimental activities foreseen at INFN-LNS and other research infrastructures. Among these activities we could mention pure nuclear studies (cluster structure, low-energy scattering….), nuclear astrophysics studies (activation measurements, neutron induced reactions with RIB's,…), studies for the physics beyond the Standard Model (neutrino-less double beta decay, the search of candidates for dark matter…) and studies for applied physics (medical physics, cultural heritage,…). In order to perform such studies, devoted improvement and development need to be performed at the DFA-UniCT. Thus, we plan to install, in the already existing experimental hall at the DFA, a new beam line with a dedicated scattering chamber. Additionally, devoted simulations for radiation emission are already under study in order to develop in the near future the project of a devoted neutron-shielding system to be built and placed around the scattering chamber.
Summarizing the contents of this abstract we plan at:

- enforcing the already existing collaborations with INFN-LNS activities providing low-energy beams via the 3 MV HVEE Singletron;
- assembling a devoted beam line, equipped with a scattering chamber and its neutron-shield system, for performing the experimental activities ancillary to the future INFN experiments.

Main category of the contribution: The main category of our contribution is "Training, Education, Outreach, Social Impact" since the Singletron Accelerator is hosted in the UniCT Physics dept. where young researchers generation is continuously formed.

Connections with other categories: Due to the large interest to the DFA-Singletron, further connections can be also found with the "Beams+Targets" and "New physics cases" categories.

Title: Summer (or winter) School on Radiation Instrumentation for Nuclear Physics and Synchrotron Radiation.

Authors and affiliations: Chiara Guazzoni, Politecnico di Milano and INFN, Sezione di Milano (principal Proponent). The idea and proposal is supported by many other colleagues around Europe, among them I can mention Martin Grossman, (PSI Switzerland) and Patrick Le Dû (CEA, France) who have a long experience in organizing Instrumentation Schools also in less technologically developed countries supported by the IEEE Nuclear and Plasma Science Society.

General description (methodology, goals,..): The era of 2.0 detectors is now a reality in many scientific fields, with particle physics and synchrotron and FEL radiation instrumentation leading the development, however even the full operation of these 2.0 detection system require advanced professional knowledge in electronics and related fields. On one side nuclear physics seems less permeable to these new technologies, on the other there is a need to bridge the gap in the educational system, not able to form professionals with cross/competence in the aforementioned fields.

The format I foresee is a well proven mixture of lectures and hands-on that has already proven effective in many previous events (ICFA Schools, NPSS Schools, etc.). In order to solve the issue arising from travel limitations and social distancing I am thinking of morning lessons being available also remotely and not only in live streaming, being a possible way to get a financial return, when used as Mooc. As for the hands-on training I think of low cost, well designed education test benches for given experiments (digital acquisition systems, simple detection systems, low noise frontend electronic…) that could be easily reproduced. Training hands-on sessions could be organized in parallel in different countries and also have one attendant per experiment equipped with an action camera to provide remotely connected attendees a feeling as much as possible similar to being in person.

Challenges: Given the present pandemic situation, we think that the best format for the school will be to follow a hybrid model that will have both a live and virtual component. In order to guarantee the same accessibility and best overall experience for all participants from the global community, and to encourage diversity and inclusion of underrepresented groups, new modalities must be developed for sharing and networking within this new environment.

Original aspects: The hybrid format proposed for the school is quite innovative, in addition the idea of cross-fertilization of knowledge can have a two-fold impact, on one side bring new blood to the nuclear physics community even from other fields, and on the other boost new larger initiatives towards novel Erasmus projects and joint degrees and PhD programs to train the upcoming detector designer and physicist and radiation instrumentation scientist.

Unique expertises: The proponent group has already excellent experience in the field that can be shared with the community and would be keen to be the driving force for this pillar.

Synergies with other communities: Synchrotron Radiation community, neutron imaging community, particle physics.

Main category of the contribution: Training, Education, Outreach, Social Impact

Connections with other categories: Detectors + Electronics, Data Acquisition + Analysis, Simulations

Training activity at the LNL target laboratory

The LNL target laboratory provides most of the isotopically enriched targets needed for nuclear physics experiments at the Tandem-ALPI-PIAVE accelerator complex of LNL as well as those for experiments carried out in other laboratories where local groups are involved. In addition, the laboratory also makes thin C depositions on samples of different nature for interdisciplinary activities at the AN2000 and CN Van de Graaff accelerators. In order to ensure good target quality (in terms of purity, composition, thickness and uniformity), the laboratory is equipped according to international standards required for this type of infrastructure.

The prepared targets cover a wide range of stable isotopes in different formats (self-supporting or backing deposited films, strip and sandwiched targets). Thin targets, with thicknesses ranging from few tens of $\mu g/cm^2$ to several hundreds of $\mu g/cm^2$, are produced by the deposition of the material via thermal and electron-gun evaporation or focused-ion sputtering. The production of thick targets (few mg/cm^2) is made by means of cold rolling in air or inside a glove box in an inert gas atmosphere for the materials that may oxidize very quickly.

Each target produced by the laboratory is characterized with regard to its thickness and is provided with the data sheet of the used material in which the contaminant level is indicated. Further characterizations, such as inspection of the film through Scanning Electron Microscopy (surface morphology) or elemental analysis by means Ion Beam Analysis (contaminant content) at the AN2000 accelerator, can be requested by the experimental group.

The target laboratory at LNL offers within the present call the possibility of training, at high scientific and technological level, researchers, engineers, technicians, and students.

We propose to build a network between the different laboratories where:

-target preparation procedures and knowledge can be shared

-target characterization procedures can be developed and standardized by creating official characterization protocols. This would provide to the users important pieces of information for subsequent analysis

-a pool of material scientists / technicians can be trained and consolidated for developing an EU-wide community of experts in target production and characterization

Title:

HONPHETYR: Hands-on nuclear physics – an entry training course for young researchers

Authors and affiliations:

P. J. Napiorkowski[1], U. Kaźmierczak[1], M. Palacz[1], A. Trzcińska[1]
M. Kmiecik[2], A. Kozela[2], M. Ciemała[2], M. Matejska-Minda[2]
[1]) HIL UW Warsaw, [2]) IFJ PAN Kraków

General description (methodology, goals,..):

The program is addressed to the young researchers starting preparation for their first diploma projects in nuclear physics. Participants will perform short experiments using research infrastructure HIL UW and CCB at IFJ PAN, and possibly other EURO-LABS facilities, to get acquainted with modern research technique: ion beams diagnostics, detection set-ups, vacuum systems controls, radioprotection, auxiliary laboratories for target, radiobiology, medical imaging, currently used experimental techniques, etc. Young researchers will work in small groups supervised by scientific staff members. Complementary lectures will present modern methods of nuclear physics.
Possible experimental tasks will depend on the equipment and expertise offered by the facilities. The possible subjects are:

- a selected experimental nuclear physics technique (gamma-ray spectroscopy, charged particle spectroscopy, X-ray fluorescence, fast-timing measurements with scintillators)
- methods to produce targets for nuclear physics experiments
- modern scientific equipment (HPGe detectors, modern scintillators, related electronics, vacuum systems, elements of ion optics)
- data acquisition systems and modern IT tools, dedicated for physics data analysis and preparation of experiments (Radware, ROOT, GEMINI++, GEANT)
- medical imaging techniques with gamma camera
- study of the biological response of cells to radiation
- good practice rules of laboratory work (sources handling, safe work with: ion beams, liquid nitrogen detector cooling systems, high voltage power supplies)

The course in each laboratory is foreseen for 7-10 days. Each team will take part in one laboratory exercise, which will include the following elements:

- defining the measurement's goal (the proposed experimental tasks usually have character of „open problems”), planning of the measurement
- construction or adaptation of the experimental set-up (most of the experimental tasks are performed with the use of complex multi-detector systems, used in on-going research projects at the facility; these devices have to be adapted for training's measurements, which includes choosing proper detectors, installing targets, setting up the measurement etc.)
- performing the measurement
- data analysis (a consistency check, error analysis, estimation of possible systematic errors and reliability of the results)
- preparation of the final presentation (aims of the measurement, the applied method, results, comparison with literature values, possible future improvements of the experimental method/set-up)

The lectures offer introduction to basic experimental techniques of nuclear physics, elements of ion optics, accelerator physics, physics of detectors of ionizing radiation, applications of nuclear physics in medicine and nuclear energy. Each lecture is given by a different specialist.
It is planned to organize one training a year per facility. The program of the course will be adapted to the specific needs of the participants. Collaboration of research groups working at EURO-LABS facilities is crucial to reach a high standard of the training course.

Challenges:
The training course groups will consist of participants with various skills, knowledge and educational background. To recognize their needs and prerequisites will be also our main task.

Original aspects:
The idea of the training program is based on the Students Workshop organized at the Heavy Ion Laboratory since 2005. The events are well recognized by participants and difficulty of the proposed program can be varied.

Unique expertise:
Usually university students have no chance to have a training in the nuclear physics facilities. Summer students' programs offered by the laboratories are more detailed and focused on specific research projects. They are obvious continuation of the proposed training course.

Common expertise and collaborations:
The lectures foreseen in the program can be given by experts working in the collaborating universities and laboratories. Also, laboratory exercisers will be supervised by in-house physicists and experienced facility users.
Each EUR-LABS facility can join the service and propose a specific programme of the course addressed to its future users.

Synergies with other research/technical groups:
Every EURO-LABS facility can present an additional offer within the framework of the service.

Synergies with other communities:
Other advanced training courses foreseen in other proposed services (e.g. INTRANS, Targets for Nuclear Physics) can be the continuation of the proposed basic training course for young researchers.

Main category of your contribution:
Training, Education, Outreach, Social Impact

Connections with other categories:
Beams +Targets
Detectors + Electronics
Data Acquisition + Analysis, Simulations

Abstract about outreach for next ENSAR2 program

INFN LNL infrastructure is involved in outreach activities mainly dedicated to students and teachers at Italian high school. Public engagement is based on accelerators and detectors. Experimental activities are more effective than classroom lessons or webinars. We propose a program for teachers with four measurements: identification of elements in lapis lazuli with Particle Induction X ray Emissions at AN2000 accelerator micro-beam setup, studies of thin film deposited with Rutherford Back Scattering at CN accelerator, radiobiology at CN accelerator, lifetime measurements of gamma sources with four germanium detectors. Four groups of six teachers perform all the experiments in a dedicated week, as a residential course. Accelerators, detectors, electronics modules, data acquisition systems, and logbook are like ones used by physicists. However, the equipment is dedicated to public engagement activities. Teachers can share the lab experiences with a lot of students in different classrooms: they keep a message for younger students (example: How we can measure fs?) about the concept of measurement as for the students approaching to university (example: How many different expertise are required to perform a physics experiment?). Teachers visit the infrastructure with the students. The most interested high school students participate during preparation and testing phases of nuclear or interdisciplinary experiments, as shadow of the researchers, technologists, and technicians. Each student selects the kind of experiment that he/she prefers. Finally, teachers and students write an internal report to document the experiences. In addition, researchers, technologists, and technicians can eventually go in the school for few conferences.

Title: EURO-LABS-Enabling Innovations

Authors and affiliations: Martina Bauer, Tobias Engert

General description (methodology, goals, …):

This project proposal is to be considered as an interdisciplinary and general measure within the framework of the EURO-LABS overall application.
This initiative aims to create an innovation mindset within the project EURO-LABS and ensure a cross-disciplinary exchange of information, knowledge and technologies. This should ensure the best possible use of synergies between the different research fields for innovative R&D projects and outreach activities.

Goals/Main categories:

- Training of new generation of researchers
- Cross-disciplinary fertilisations and a wider sharing of information, knowledge and technologies across scientific fields.

Task 1: Building up an innovation mindset (training of new generation of researchers)

The activities of this task include:

- Best Practice events of successful R&D projects (Lighthouse projects) of the partner labs.
- Offering training for the researchers in transfer skills as communication, how to speak to industry, negotiation skills, business modelling for R&D projects, validation funding opportunities, …
- Organisation of events in collaboration with design schools, entrepreneurship schools and business admin schools, with the aim of providing input for optimal continuation of R&D activities in order to optimise the potential for knowledge transfer

Task 2: Information, knowledge & technology overview/assessment

The activities of this task include:

- Building a complete picture of the innovations being developed in EURO-LABS.
- Evaluating the feasibility and optimal routes for knowledge & technology transfer.
- Identifying the key players in the corresponding scientific fields for the various knowledge & technologies.
- Providing a list of follow-up actions and recommendations both for an easy access sharing of information, knowledge & technologies across the different scientific fields to foster synergies between them and to reach the best outreach effect from the whole project.
- A dedicated EURO-LABS KT & TT Overview committee will allow to perform the work swiftly and efficiently, and to streamline the internal communication.

This committee should be composed of participants and the leaders of several WPs and it will meet twice a year and exchange regularly.

Task 3: Establishing of formats for cross-disciplinary fertilisations

The activities of this task include:

- Ideation-Workshops (or other suitable formats) with common topics in the framework established through the activities of Task 2.
- Identification of possible interdisciplinary cases.

Task 4: Technology/Knowledge matching

The activities in this task include:

- Follow-up of the cases & contacts established through the activities of Task 2 & 3.
- Set up of different scenarios/roadmaps for new R&D projects incl. business models.
- Conduct a market study for the relevant cases to identify future R&D partners in the industry.

Task 5: Technology/Knowledge promotion

The activities in this task include:

- Developing “Value propositions” promotional text and visual material highlighting the benefits of the technologies/knowledge cases established in Task 4 and the competitive advantage they have over what is already existing on the market.
- Proactively reaching out to the relevant industrial stakeholders identified in Task 4.

The marketing and promotion activities within this task will leverage on the instruments (newsletters, websites, events) provided by, inter alia, the TT Offices of the project partners and several networks in which the partners are already active.

The EURO-LABS technologies will also be promoted at selected industry events at relevant conferences.

➔ interacting with industrial partners will expand the job opportunities for PhD students in academic, health and industrial sectors after completion of the project.

Challenges:

Within the framework of EURO-LABS, an active exchange in the scientific field should take place. However, many scientists, especially young scientists, do not think outside the box. This means that often their thoughts are fully focused on science and do not think about how their research work can be transferred into a business model, for example. This proposed theme is intended to get scientists thinking about how to apply their scientific results outside of science.
Accordingly, the challenge lies in the respective basic research mentality.

Synergies with other communities:

There are synergies with the general HEP community as well as all other related application-related disciplines such as Life Science, Health Care, Renewable Energies, Materials and Nanosciences, ...

Main category of your contribution:

- Training, Education, Outreach, Social Impact

Connections with other categories:

This project proposal should be linked to all other categories of the overall EURO-LABS project, as it is to be considered as an interdisciplinary cross-cutting measure within the overall application.

Title: European Training Network for Young Researchers in Nuclear Science

Authors and affiliations: Prof. Dr. Henner Büsching (Goethe-Universität Frankfurt am Main and Helmholtz Graduate School for Hadron and Ion Research), Dr. Gerhard Burau (GSI Helmholtzzentrum für Schwerionenforschung GmbH and Helmholtz Graduate School for Hadron and Ion Research)

General description: As part of the Helmholtz Association of German Research Centers, the GSI Helmholtzzentrum für Schwerionenforschung GmbH and its new accelerator facility FAIR provides an excellent framework for conducting structured doctoral research and training in strong cooperation with its partner universities to optimally prepare young researchers for future careers inside and outside science. A key building block of this framework is the Helmholtz Graduate School for Hadron and Ion Research (HGS-HIRe) at GSI-FAIR. Based on this structured doctoral program, we suggest to create and establish a doctoral training network among the European partners of the EURO-LABS consortium in order to strengthen doctoral studies in the fields of fundamental and applied nuclear science.

It should be mentioned that – depending on available funding – similar activities can be considered, which can be beneficial for the training of next generation scientists, for instance „hands-on trainings" in (off-line or possibly on-line) experiments, joint seminars of the EURO-LABS access laboratories, joint colloquia of their user groups, or joint lecture weeks for graduate students.

Challenges: The new doctoral training network will put a strong emphasis on further internationalization of local programs with a strong emphasis on the strength and potentials of cooperation and exchange in the European context. The doctoral research and education within EURO-LABS will benefit from the existing and long-standing experience in structured doctoral training of HGS-HIRe at GSI-FAIR and its local partners. In addition to well-established measures like local lecture weeks, power weeks and transferable skills courses, the network will offer dedicated consortium-wide education events, which bring together experienced teachers and doctoral students working on related research topics. This will strengthen the scientific quality of the participating students, enhance the formation of networks among young researchers, attract excellent international students, and advertise the research facilities and institutions of the consortium worldwide. However, in order to reach these goals, additional funding as well as manpower for coordination and realization of the program will be necessary.

Possible training measures: Making use of existing research structures and cooperations within the consortium, we can extend the educational possibilities and generate a common learning experience for the doctoral students at the European partner institutions beyond their local groups by their active participation in topically well-defined and thoroughly designed educational measures as:

- Scientific cross-disciplinary Lecture Weeks and specialized Power Weeks including experimental, technical and/or theoretical hands-on training
- Transferable Skills Courses as an integrated series of three consecutive courses focusing on various transferable skills together and combining different aspects of professional, personal development
- Common doctoral seminars and lecture series making use of state-of-the-art online formats and tools

The scientific training and education measures within this training network will focus on the manifold fields of fundamental and applied nuclear science and their specific needs. The non-scientific ‘soft skills’ education cover a broad range of generic and transferable skills that are more generally essential for research students and their career development whether inside or outside science.

Unique expertises: HGS-HIRe offers structured doctoral training and education in all research fields at GSI and FAIR since many years:

- Structured doctoral education has been commonly established over the years.
- New innovative concepts such as cross-disciplinary lecture weeks, specialized power weeks and transferable skills trainings have been developed and are fully implemented.
- An active social and academic network within the local community of doctoral students has been established and has brought together students from the different participating institutions, and in particular from theoretical and experimental groups, emphasizing the strong multidisciplinarity of the GSI-FAIR research environment.
- Participating students are trained on a broader scientific basis and gain a comprehensive overview of their research field.
- Organizational structures have been established to conduct and sustain a structured doctoral training on a very high level.

Synergies with other research/technical groups: (not applicable)

Synergies with other communities: ? Improved Access (Easier procedures, increase of number of RI involved, opening to new communities) ?

(with reference to the categories described in the “Instructions for submission page”, https://agenda.infn.it/event/25373/page/5621-instructions-for-submission)

Main category of your contribution: Training of new generation of researchers / Training, Education, Outreach, Social Impact

Connections with other categories: (not applicable)

Training the next generation of researchers (ECT*)

Contact person: Gert Aarts (ECT* and Swansea University) -- g.aarts@ectstar.eu

General description

Nuclear physics, as all areas of science, is continuously adapting to new and developing methods and techniques, both experimentally and theoretically. For researchers in the field, it is essential to be exposed to and lead these developments, in order to remain at the forefront of scientific progress. ECT* has a long tradition of training the next generation of researchers in theoretical nuclear physics and related areas, e.g. via its annual Doctoral Training Programs (DTPs) and TALENT schools, both aimed at PhD students, as well as dedicated workshops, aimed at all researchers. It has dedicated lecture rooms and office space, to host participants and visitors for an extended period of time.

We propose to widen ECT*'s training program and reach out to the broader community. Of particular interest is training in computational and technical skills, applicable not only in nuclear physics but in fact across the sciences, from closely related areas such as particle and astro-particle physics, to areas superficially further removed such as the medical sciences and engineering.

Goals

Currently there is a large increase in activity worldwide in artificial intelligence (AI), machine learning, data science, and quantum technology, with many activities supported by high-performance computing. It is generally expected that these areas will keep developing rapidly over the coming years and make a drastic impact in the (physical) sciences and beyond. We propose to host and organise training programs in these areas at ECT*, with an emphasis on skills applicable across research areas, running besides the (more standard) training programs with a focus on a specific domain. This activity would positively impact the nuclear and the wider community, and increase the visibility of ECT*.

Training schools are planned to last one or two weeks each, with lectures in the morning and hands-on computational exercises in the afternoon. Topics could include:
- machine learning on large data sets
- classification and pattern recogniSition
- basics of quantum technology and quantum computing
- access to high-performance and quantum computing
- research software engineering:
    - reproducible environments and containers
    - automated testing and continuous integration
    - object-oriented programming in python
- data management
- ...

This list is by definition incomplete and should be further developed with input from the community, as is common practice at ECT*. Besides the lectures and exercises, time is reserved for short presentations by the participants, to enable interdisciplinary exchanges and networking.

Since training schools for PhD students and early-career researchers take place across Europe throughout the year, some coordination is required, to avoid overlap in topics and dates. ECT* proposes to coordinate this initiative on behalf of the community.

There is ample experience in running training and networking activities across Europe. In addition to schools hosted at ECT*, further coordination of PhD program activities would expose PhD students and early-career researchers to Europe-wide developments. It is possible to develop a multi-site doctoral training centre, bringing together a diverse set of research projects, linked e.g. through the use of AI, machine learning and advanced computing methods. An example of such activity is the UKRI Centre for Doctoral Training in Artificial Intelligence, Machine Learning & Advanced Computing (cdt-aimlac.org), combining activities at 5 universities in the United Kingdom (Aarts is Director of this CDT). The AIMLAC CDT could work as a template for an ambitious Europe-wide activity.

Impact

Training researchers interdisciplinary computational and technical skills has the additional benefit of further enabling mobility, knowledge exchange and employability. This includes transfer of knowledge from one scientific area to another, enhancing opportunities for researchers to move from one domain to another and make further progress outside their core area. Outside academia there is a large demand for highly skilled researchers in data science and AI, and hence the training received during e.g. the PhD program will increase prospects for employability and contribute to the economy at large, also after researchers leave academia.

Synergies

Clearly there are many links with other activities in this report and we are open to joint efforts for further development.