International Workshop on future research program with the high power Cyclotron of SPES-LNL

Report of Abstracts

https://agenda.infn.it/e/43877

Abstract ID : **5**

Development of novel radiotracers for climate change

Content

The purpose of this LOI is to study the production method of a new radiotracer, within the framework of the REMO/ ClimOcean project, dedicated to developing a novel methodology for monitoring the effects of climate change on marine species using radioisotopes. Radio tracer applications are essential instruments in evaluating the changes in some key biological processes, e.g. primary production, growth and calcification rates. This knowledge is also essential for the risk assessment of coastal ecosystems and the management of the stock of commercial species and to understand the responses of organisms to pH changes. Radiotracers are used to study the main changes of biological processes in selected marine organism (mollusks, crustaceans, seagrasses etc.), e.g. calcifications using 41,45Ca.
The REMO/ClimOcean project aims monitoring the adaptation of marine species to Climate Change. Goal is the study of the influence of the acidification of the seas and oceans on the growth of various species of coral, bivalves and echinoderms, as they are organisms that build their skeleton or their shell through the production of calcium carbonate. The uptake of isotopes of Ca (41Ca, 45Ca) into the exoskeleton is used to determine the growth of those species, exposed to present and time projected (50-100 years) climatic conditions. Isotopic composition is determined by direct determination of the emitted radiation (45Ca) or by the mass measurements performed with accelerator mass spectrometry (41Ca). In the first case (45Ca) self-absorption of the radiation in the exoskeleton represent a serious limitation for precise assessment of the growth rate. In the second case, since successive measurements on the same individuum are not possible, genetic variability is affecting the results.
A new radio tracer of potential interest is 85Sr, having a similar chemistry to Ca and with a half-life of 64.849 D, compatible with the animal growth. The complementarity here is that, being a gamma emitter, it allows a determination of the growth of the animal not affected by the uncertainties discussed above, potentially allowing measurements without removing the animal from water. 85Sr could be produced using the SPES cyclotron through the reaction 85Rb(p,n) 85Sr. The production cross section is relatively large, being at 11.5 MeV of 794.6 mb. The idea is to use the 40 MeV proton beam of SPES, degrade it to the required energy using an appropriate Pb foils (thicknesses 2mm), and direct it onto a target of pressed RbCl.
Therefore, with the starting of the operation/tests of the SPES cyclotron, we propose a short exploratory run in which we test the 85Sr production at energies close to the maximum production cross section (with the intention to minimize the contaminants).
Assuming an intensity of the proton beam of about 10 micrAmp, we estimate that about 2 day of irradiation would be sufficient.

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Status: ACCEPTED

Submitted by **ROCCA, Simone** on **Monday, 24 February 2025**

Abstract ID : **6**

Production at SPES of a 94Nb radioactive source for studying the quenching of the weak interaction axial-vector coupling constant

Content

The present proposal aims at the production of a solid state 94Nb beta-emitting radioactive source via the proton irradiation of a 94ZrO2 thin film (~200 µg/cm^2 areal density) evaporated onto a multilayer graphene (MLG) sheet, via 94Zr(p,n)94Nb reaction at 35 MeV incident energy. The source will be exposed to an array of silicon drift detectors (SDD) in order to study the shapes of the beta decay spectrum.
94Nb is an odd-odd nucleus with ground state spin-parity J^π (GS)=6^+. It decays by β^- emission, with an half-life T_(1/2)=2.03*10^4 y, to the J^π (E^x=1573.7 keV)=4^+ exc*ited state of 94Mo. This non-unique transition generates a spectrum with an endpoint set at 471.5 keV. No measurement of this spectrum has been performed so far, although this decay is suggested as one of the best cases to probe sensitivity of the axial-vector coupling constant g_A of the weak interaction to the nuclear medium, with major consequences in present and future search of neutrinoless double beta decay. A measurement of this spectrum is therefore highly desirable. Since no commercial sources of 94Nb is available, the custom production in a laboratory facility is mandatory. The sizable cross section for the (p,n) reaction (~30 mb at E_p=35 MeV) and the very high intensity for the proton beam of the LNL SPES facility offer a unique possibility to build by irradiation of 94ZrO2 targets a thin 94Nb source, thus less affected by self-absorption. Assuming an areal density of about 200 µg/cm^2 and a beam current of about 300 µA, the resulting activity will grow as about 6 Bq/day pointing to about 20 Bq after three days of irradiation. Challenging aspects connected with the removal of heat generated by the beam target interaction are considered. Indeed, an efficient heat dissipation is guaranteed by the high thermal conductivity of the MLG backing sheet.
Another issue is connected to the target isotopes different from the 94Zr. Although the 94ZrO2 target is based on isotopically enriched material, the 94Zr content is about 85-90% for affordable costs of the raw material. An insight on this problem shows that the main challenge comes from 91Nb, which decays by electron capture with an half-life *T_(1/2)=6.80*10^2 y, thus potentially generating a 91Nb activity comparable to the 94Nb one. Nevertheless, the decay products from 91Nb are Auger electrons with 2.02 keV and 13.4 keV, the latter of which may be visible just above the detector threshold (about 10 keV).
In conclusion, a promising technique to produce for the first time a 94Nb radioactive source is at reach, using the very intense proton beam from LNL SPES facility. For the study of the sensitivity of the axial-vector coupling constant gA of the weak interaction to the nuclear medium, which requires the measurement of the beta decay full spectrum with high energy resolution and very low systematic uncertainties, a source activity of more than 20 Bq would be ideal, which in turn means three days irradiation time.

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Submitted by **CAPPUZZELLO, Francesco** on **Monday, 3 March 2025**

Abstract ID : **7**

High-precision tests of the Pauli Exclusion Principle in proton-nucleus interactions using the SPES Cyclotron

Content

Introduction & Scientific Motivation: The Pauli Exclusion Principle (PEP) is one of the fundamental tenets of quantum mechanics, dictating the behavior of identical fermions within a system. While extensively tested (by us) for electrons within the VIP (VIolation of the Pauli exclusion principle) experiment using high-precision X-ray spectroscopy [1], its validity for nucleons remains an open question, with potential implications for beyond Standard Model (BSM) physics. Recently we put forward the study of possible PEP violations at similar precision level in nuclear reactions [2], leveraging proton beams to introduce protons into nuclear systems under controlled conditions. Building on these approaches, we propose an experimental study using the SPES Cyclotron at LNL-INFN to search for PEP-violating nuclear transitions. This experiment aims to refine existing limits and investigate whether non-Paulian nuclear states can be induced through controlled proton interactions, further probing quantum statistics and their foundational principles.

Experimental Setup & Feasibility: The proposed experiment plans to employ the high-intensity proton beam of the SPES Cyclotron. An optimized nuclear target, such as carbon-12, will be bombarded to induce potential non-Paulian (p, p') transitions, in analogy with pioneering studies conducted at LNL in '90s [3]. The experimental setup described in attached file.

By making use of the high-intensity proton beam of SPES, this experiment will significantly improve the sensitivity to possible PEP violations in nuclear reactions, far beyond previous limits.

Expected Outcomes & Impact: The results of this study will set new constraints on the possible violation of the Pauli Exclusion Principle for protons, providing a direct test of providing a direct test of quantum statistical laws in nuclei. If evidence of PEP violation is observed, it could signal new physics beyond the Standard Model, including scenarios related to quantum gravity, extra dimensions, and fundamental symmetry violations [4]. Additionally, the methodological advancements in high-precision nuclear spectroscopy could contribute to broader applications in nuclear physics and astrophysics.

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Submitted by **CURCEANU, Catalina Oana** on **Tuesday, 4 March 2025**

Abstract ID : **9**

Beryllium target for proton-induced neutron production: CoolGal

Content

Compact accelerator-driven neutron sources (CANS) provide excellent opportunities for generating intense neutron beams. As research nuclear reactors close, CANS provide a cost-effective alternative, supporting communities that rely on advanced neutron instrumentation; in addition, their distributed nature allows for broader accessibility, including use as training centers. The potential impact of these compact facilities has driven strong international collaboration, uniting representatives from nearly all developed countries every two years through UCANS (worldwide) and ELENA (European network). Within this framework, CoolGal is an innovative target system designed to generate fast neutrons with a continuous energy (white) spectrum using the SPES cyclotron. Funded by the Ministry of Research for 2023-2025 (PRIN_2022JCS2CN - CUP I53D23001180006), CoolGal incorporates a beryllium target cooled by liquid Galinstan, aiming to advance neutron science by enabling high-intensity neutron beam production at Compact Accelerator-driven Neutron Sources. A separation window will divide the target volume from the accelerator vacuum, thus preventing contamination of the beamline. Using the SPES 35-70 MeV proton cyclotron, the proposed experiment aims to test a simplified CoolGal prototype, without the Galinstan liquid. The study will assess the fundamental performance of the separation window and the target structure under real beam-induced thermal stresses, as well as address operational and decommissioning concerns. A key goal of this study is to measure the double-differential neutron yield of the Be(p,n) reaction, a crucial process for copious production of fast neutrons. Despite the importance of the Be(p,n) reaction, the data present in the literature at proton energies of 35-70 MeV comes from JENDL libraries. The lack of data in this range itself is a strong motivation to measure it. The produced neutron spectrum (spanning thermal to 70 MeV) is highly relevant for studying atmospheric neutron-induced effects in electronics; 65% of the atmospheric neutron spectrum at sea level above 1 MeV falls within the 1-70 MeV energy range. Two independent methods will be employed to measure the neutron energy spectrum and validate simulation results: the standard stack-activation foil technique and a plastic scintillator-based neutron detector. The latter was developed at the University of Cape Town (UCT) and is characterized at a number of fast and high energy neutron facilities, including at the UCT and iThemba LABS. These measurements will be conducted in collaboration with iThemba LABS. The HBS (High Brilliance Neutron Source, Jülich, Germany) is also proposing the study of the Ta(p,n) reaction as an alternative neutron production method using a heavy target instead of beryllium. These complementary proposals create a valuable opportunity for collaboration, promoting the exchange of manpower, instrumentation, and expertise.

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Status: ACCEPTED

Submitted by **MUSACCHIO GONZALEZ, Elizabeth** on **Thursday, 13 March 2025**

Abstract ID : **10**

Gamma-ray and conversion electron spectroscopy on irradiated targets

Content

We propose to irradiate different targets in the ISOL bunker 2 to then perform off-line γ-ray and conversion e^- spectroscopy on the long-living isotopes (at least 30 min) created by the 35-70 MeV protons. After irradiation, the targets can be placed in measurement setups like the b-DS tape station outside the bunker where detailed spectroscopy can be performed.
We highlight two possible physics cases:

1- Lifetime measurements with fast-timing techniques for octupole deformation in actinide nuclei. Nuclei with static octupole deformation in nuclei are considered the best systems in which a possible EDM (electric dipole moment) can be searched, since the octupole deformation enhances the sensitivity to EDM by orders of magnitudes [1]. The predicted octupole deformation in nuclei close to 229Pa, ^{229}Th can help to reach the sensitivity needed to detect the EDM value predicted by the Standard Model.
Protons of 30-50 MeV on ^{232}Th targets induce (p,xn) reactions which will populate $^{227-229}$Pa ($t_{1/2}$=30min-1.55 days) with cross sections of around 50-60 mbarn. The $^{227-22}$9Th nuclei will be populated by beta decay of $^{227-229}$Pa, enabling the measurement of their excited state lifetimes using LaBr3 crystals and fast-timing techniques [2]. Similarly, irradiation of ^{231}Pa target will produce ^{229}U with a 10 mbarn cross sections. The ^{229}U nucleus will in turn decay into ^{229}Pa ($t_{1/2}$=58 min), allowing to study dipole and octupole strengths in one of the best candidates for EDM studies. It will in turn decay into ^{229}Pa Complementary high-resolution γ-ray spectroscopy can be performed the b-DS tape station measurement point to detect weak E3 branches to probe the octupole deformation. This activity is linked to a future research program aiming at measuring the electric dipole moment using octupole-deformed radioactive nuclei from SPES
Requirements: 232Th, ^{231}Pa 2-10 mg/cm^2 targets, possibilities to move irradiated targets quickly outside of the bunker. Proton current: 100 nA.

2- Search for β+ decay in ^{56}Ni for cosmochronometer physics. Several nuclei produced in astrophysical process can act as cosmochronometers helping to measure the time scales of certain astrophysical process. One such case is ^{56}Ni: it mainly decays by EC, however in cosmic rays this nucleus is foreseen to be fully stripped, thereby inhibiting its decay. The fact that it is not detected in cosmic rays has been attributed to a small (around 10-6) β+ decay branch [3]. ^{56}Ni can be produced with 70 MeV protons on a ^{58}Ni target with a cross section of 80 mbarn. The irradiated target will then be moved to the b-DS setup and in particular to the electron conversion measuring point equipped with the SLICES setup [4]. The weak decay branch will be searched employing triple e^+-γ(511keV)-γ(811 keV) coincidences to enhance selectivity.

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Status: ACCEPTED

Submitted by **GOTTARDO, Andrea** on **Thursday, 13 March 2025**

Abstract ID : **12**

HBS Tantalum Target Development for Neutron Production at HiCANS

Content

Within the HBS (High Brilliance neutron Source) project, the Jülich Centre for neutron Science (JCNS) at Forschungszentrum Jülich has developed a new kind of HiCANS which shall serve as a competitive user facility. One of its key components is the neutron target designed to operate at a 70 MeV proton beam. It is designed as a stationary solid tantalum target consisting of three layers as shown in figure 1. The first layer is the neutron producing layer. It is made of tantalum with an integrated microchannel cooling structure for heat dissipation. The second layer is the beam stop. The approx. 98 % of the proton beam is stopped in this water layer. The third layer serves as an enclosure for the beam stop.

A particular focus of the target development was on minimising hydrogen embrittlement and the compactness of the target. Due to the parameters, the realisation of heat dissipation emerged as a particular engineering challenge. The heat is dissipated through a cooling structure eroded into the neutron-producing layer. The geometry of this cooling structure is optimised to minimise temperature transients to reduce stresses and to homogenise the proton range to reduce hydrogen implantation. The thermal efficiency and power limit of the cooling structure have already been successfully measured experimentally. The crucial performance tests in a proton beam is still pending:

a) Measurement of the ratio of stopped to penetrated protons behind the first layer at 70 MeV in order to verify the resistance against hydrogen embrittlement

b) Measurement of the neutron yield and neutron spectrum at 70 MeV to verify the performance

c) Measurement of the temperature distribution on the back side of the target to verify the coolant capability at real operation conditions

For the SPES-LNL experiment, we are planning to produce a target that only consists of the first layer. This allows a two-dimensional temperature field to be measured using a thermal camera on the back side of the target. In addition, the proton beam behind the target should be measured to determine the proportion of stopped protons inside the target. Finally, the neutron yield should be measured outside the proton beam using suitable measuring devices (e.g. Bonner sphere).
We apply for beam time at 70 MeV and at least 86.4 µA to focus these on an area of 6 cm² in order to achieve the design dimensioning of 1 kW/cm² and hence provides the best results for a reliable validation of the simulation results as well as the first experimental proof of the functionality of the HBS target.

More details regarding the HBS target are published:
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Submitted by **BAGGEMANN, Johannes** on **Thursday, 13 March 2025**

Abstract ID : **13**

Feasibility production of 67/64Cu mixture with SPES cyclotron for the first radiopharmaceutical in-vivo studies

Content

Copper-67 (67Cu, T1/2 61.9 h), as well as Copper-64 (64Cu, T1/2 12.7 h), are under the spotlight of the scientific community as single isotopes for targeted radionuclide therapy, and as a pair for theragnostic applications thanks to the, β- and γ emissions of 67Cu and β- and β+ emission of 64Cu . Their half-lives are suitable for tracking radiopharmaceuticals with slow pharmacokinetics. Although 64Cu is now commercially available from some suppliers and already on clinical evaluation in nuclear medicine for the PET diagnostic procedure, the use of 67Cu is limited by the lack of regular availability in sufficient quantities for preclinical/clinical studies worldwide. This challenge is one of the main goals of the LARAMED (LAboratory of RAdionuclides for MEDicine) project at INFN-LNL. Among the different production routes of 67Cu, there is the possibility of using proton beams and it is of particular importance since at LNL is present a 70 MeV proton cyclotron. In the energy range 35-70 MeV available in the SPES cyclotron, it is possible to produce 67Cu and 64Cu with two different nuclear reactions, 68Zn(p,x)64/67Cu and 70Zn(p,x)64/67Cu. Still, in the entire energy range, both isotopes are always co-produced. The production feasibility of the 64Cu/67Cu pair with thick targets will be performed at LNL when a suitable bunker is completed with a dedicated thick target station installed. However, with this proposal, we would like to start these studies by exploiting the target station already installed in a different bunker and designed specifically for cross section measurements. Despite this limitation, it has been theoretically ascertained that it is possible to use this target station to produce the minimum amount of activity that would allow us to start preclinical studies to evaluate the diagnostic efficacy and the therapeutic effect of the mixture of 67Cu and 64Cu. These studies will be conducted at the LARIM (Laboratory of Radionuclides and Molecular Imaging), situated within the LNL. This facility is equipped with the necessary apparatuses to facilitate the development and characterization of novel specific radiopharmaceuticals both in vitro and in vivo. Moreover, the quantitative analysis of nuclear images will be used to determine the radiopharmaceuticals kinetics and dosimetry. After the bombardment in the SPES building, the irradiated target will be transported to the LARIM where the radiochemical separation procedures will be performed. The obtained 67/64Cu mix will be used to radiolabel novel radiopharmaceuticals for the treatment of prostate cancer (PCa) and ductal pancreatic adenocarcinoma (PDAC). Their effectiveness and safety will then be tested by performing biodistribution studies in both healthy and xenograft mouse models, with the final aim of comparing the obtained data with those of 177Lu-radiopharmaceuticals, currently considered the gold standard for cancer treatment in nuclear medicine.

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Submitted by **MOU, Liliana** on **Thursday, 13 March 2025**

Abstract ID : **14**

Thick target yields measurements with natV targets for the production of the theranostic 47Sc

Content

47Sc is an emerging medical radionuclide with potential in the field of theranostic applications. Its favourable decay characteristics, namely β- particles of 162.0 keV mean energy, γ rays of about 159 keV energy, and a half-life of 3.3492 d, make it suitable for use in the radiolabelling of radiopharmaceuticals for cancer diagnosis using SPECT (Single Photon Emission Computed Tomography) cameras and for targeted radiation therapy of the same tumours. Furthermore, 47Sc can be used in combination with 43Sc or 44gSc, two β+ emitters that are useful for PET (Positron Emission Tomography) imaging, to constitute the true theranostic pairs 47Sc/44gSc or 47Sc/43Sc, needed in nuclear medicine. The scientific research concerning this radionuclide currently faces the challenge of identifying the optimal production route, corresponding to the best balance between the amount of 47Sc produced and the purity required for medical applications.
In the context of the LARAMED (LAboratory of RAdionuclides for MEDicine) program, within the PASTA (Production with Accelerator of Sc-47 for Theranostic Applications) project, funded by INFN (National Institute of Nuclear Physics) CSN5 for the years 2017-2018, the production with proton beams on natV and enriched 48Ti targets was investigated. Starting from cross section results, the radionuclidic purity (RNP) and the dose increase (DI) of the final product were assessed considering different energy intervals and irradiation times. For the natV targets, these calculations allowed to identify the energy interval 19-35 MeV as the one that best respects the allowed limits on RNP and DI. This interval is in the proton energy range that perfectly fits the SPES cyclotron of the INFN-LNL (Legnaro National Laboratories).
The objective of the present study is to validate, through experimental means, the energy interval highlighted by calculations. This objective can be achieved by bombarding thick targets of natV with a 35 MeV proton beam. It is estimated that a target with a thickness of 1.7 mm would suffice in covering the energy range down to 20 MeV. To test the RNP and the amount of 47Sc produced, it would be sufficient to have irradiation runs lasting 1 h and with a beam intensity of the order of 102 nA. A chemical dissolution process is required to collect an aliquot of the target and perform γ spectrometry measurements with HPGe detectors. The activity measured through γ spectrometry allows to evaluate the thick targets yields and corresponding RNP, and DI, to be compared to the values predicted in the PASTA project.

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Submitted by **DE DOMINICIS, Lucia** on **Thursday, 13 March 2025**

Abstract ID : **15**

Neutrino physics from gamma-ray spectroscopy

Content

Nuclear matrix elements (NMEs) are crucial for understanding weak interaction processes such as inverse beta decay (IBD) and neutrinoless double-beta decay ($0\nu\beta\beta$), which provide insights into neutrino properties and physics beyond the Standard Model. A novel experimental approach aims to extract NMEs using electromagnetic (EM) transitions from isobaric analog states (IAS). In this Expression of Interest, we propose to use the protons delivered by the SPES cyclotron to effectively populate IAS states and measure their gamma decay strengths.

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Status: ACCEPTED

Submitted by **STRAMACCIONI, Damiano** on **Thursday, 13 March 2025**

Abstract ID : **17**

AToMiQA –Young Researchers'Grant 5th Commission INFN (2025-2026)

Content

The new young researchers' grant AToMiQA has the aim of developing a microdosimetry system capable of measuring in high intensity beams. To this aim the newly commissioned LNL cyclotron offers a unique opportunity to test detectors starting with low beam currents to evaluate sensitivity and performance under minimal radiation exposure, then progressively increasing intensity to assess their limits under high currents. This allows for validation in conditions that mimic clinical dose rates, including those used in FLASH radiotherapy. The broad energy range (35–70 MeV) and adjustable current (30 nA to 500 µA) make it an ideal platform for systematically studying detector response, ensuring robustness and reliability in both standard and extreme irradiation scenarios. Currently, no other research facility offers these characteristics, as such tests can only be performed in clinical centers, where limited beam time, strict safety regulations, and restricted access pose significant challenges. The LNL cyclotron overcomes these limitations, providing an unprecedented opportunity for comprehensive detector assessment and development.

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Submitted by **BIANCHI, Anna** on **Friday, 14 March 2025**

Abstract ID : **18**

Miniaturized Microdosimeters for Hadron Therapy

Content

Microdosimetry is a spectrometric technique which measures energy imparted by ionizing radiation in sensitive volumes of micrometric dimensions. Starting from microdosimetric quantities it is possible to derive radiation quality descriptors of interest for the clinics, such as the Linear Energy Transfer (LET) or a physics-based estimation of the Relative Biological Effectiveness (RBE), using specific weighting functions or radiobiological models. Moreover, microdosimetry offers a cheap and fast characterization of the radiation field, which could be performed as a routine procedure. For this reason, its introduction in Quality Assurance procedures for hadron therapy is gaining increasing interest, and has been recently recommended by the International Commission of Radiation Units [1].

To integrate this methodology into standard clinical practice, commercially available detectors must be developed for use by medical physicists as quality assurance instruments. The 4MiCa project, part of the Research for Innovation (R4I) 2021 call from the Technological Transfer of INFN, had the aim of developing such engineered microdosimeters for clinical facilities. The engineered detectors are miniaturized Tissue Equivalent Proportional Counters (mini-TEPCs) constructed at LNL-INFN and integrated with custom-made low-noise electronics developed at PoliMI. Specific versions of these detectors loaded with boron-10 atoms can be applied in BNCT and will be used in the new facilities in Pavia (CNAO) and Caserta (ANTHEM project).

Each new detector needs to be tested in-field, and its response must be characterized, preferably under irradiation conditions comparable to those used for proton therapy. We propose to use the proton beam from the new SPES cyclotron for this purpose. Previous experiments at the clinical Proton Therapy center in Trento (Italy) have shown that the new mini-TEPCs can be operated in a pile-up free condition up to a proton fluence rate of $10^6 - 10^7\ cm^{-2}\ s^{-1}$ [2]. The high intensity of the cyclotron proton beam will allow for this characterization in a short time, even in the distal part of the Bragg peak and in the lateral out-of-field regions, which are very interesting under the clinical point of view, since the radiation quality in these regions is crucial to determine the normal tissue complication probability (NTCP) and the risk of secondary cancers [3].

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In collaboration with the Centre for Medical Radiation Physics, University of Wollongong (Australia) and the Belgian Nuclear Research Centre (SCK-CEN)

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Status: ACCEPTED

Submitted by **SELVA, Anna** on **Friday, 14 March 2025**

Abstract ID : **19**

Hybrid polysiloxanes and nanocomposite scintillators for high energy and medical physics applications

Content

Organic scintillators have found widespread use in several fields of physics as radiation sensors, owing to their peculiar chemical and physical properties. They are lightweight, easy to produce in different volumes and shapes, they commonly offer a fast response and are also tissue-equivalent in medical dosimetry. In high energy physics, these features are harnessed to collect and reveal the extremely low energy deposited by the incoming radiation by designing large volume, highly segmented calorimeters, based on organic scintillator tiles or cubes, boarding lightguides to deliver scintillation light to the far away photo-converter device. In medical physics, their classical use as X-, γ-, β- rays detectors, extensively adopted for real time delivered dose monitoring, has been recently widened to the field of proton therapy dosimetry, albeit the dependence of light output on the linear energy transfer (LET) in case of high energy protons needs to be accounted for, in order to preserve reproducibility, linearity with dose and proportionality with dose rate. Notwithstanding the assessed optimal features of commercial plastic scintillators, a lively research focused on new scintillators is ongoing to meet the requirements of future high energy experiments. In this scenario, polysiloxanes have been continuously producing new exciting shoots over the years. Their advantages over carbon based scintillators lie in the features of Si-O-Si chemical bond, which might be exploited to overcome the known limitations of plastics, such as Si-O bond strength, rotational freedom, partial ionic character. For several years we studied the properties of polysiloxane scintillator within INFN projects, probing the radiation hardness, the wavelength shifting, the neutron-gamma discrimination capabilities and the suitability for flexible dosimeters for hadrontherapy. Currently, we are working in collaboration with INFN Lecce, University of Salento and CNR Nanotec in the development of scintillators doped with perovskites and 3D printed by additive manufacturing. In the next future, different siloxanes formulations and doping methods with nanoparticles will be explored, according with the international strategy for improving the properties of timing and radiation hardness of scintillators for high energy physics. Therefore, the validation of nanostructured, dyes and/or perovskite loaded organic scintillators as for light yield, radiation resistance, dose-response correlation under high energy proton irradiation can be pursued exploiting the capabilities offered by the SPES facility. Protons with energy between 30 and 70 MeV could efficiently probe the sensing material manufactured in different shapes and volumes and their light response can be collected in situ by IBIL technique, Silicon based power meter and imaging sensors (CMOS or CCD cameras) for thorough investigation on the main features relevant for specific application in HEP and medical physics.

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Status: ACCEPTED

Submitted by **Dr CARTURAN, Sara Maria** on **Friday, 14 March 2025**

Abstract ID : **20**

γ-electron coincidence measurements with the BeGam set-up on the 70Zn(p,x) reaction products

Content

The Florence group is involved in a project (BeGam) aimed at the implementation of a portable device for the detection of β emitting contaminants in radiotracers used in medical diagnostics from Nuclear Medicine imaging. Its use is particular important when the radionuclide is produced in a nuclear reaction induced by medical cyclotrons. The BeGam project focuses on techniques for identifying contaminants in radiopharmaceuticals employing scintillator detectors. The approach involves coincidence and anti-coincidence measurements of γ and β radiations. A first prototype of the BeGam detector has been realized. In this design, four cylindrical slices of cesium iodide (CsI) surround a plastic scintillator. Each CsI sector measures 50 mm in height with a thickness of 133 mm. Two different plastic scintillators can be used, both of them with a height of 50 mm and an external diameter of 33 mm; however, one has a thickness of 4 mm, while the other is 13 mm thick.

The light produced by the scintillators is collected using silicon photon multipliers (SiPMs).
The energy spectra are acquired using a CAEN digitizer, which performs pulse height analysis (PHA), and a multiparametric DAQ software which allows time correlation between different channel to perform coincidence or anti-coincidence analyses.
Experimental measurements conducted using a ^{207}Bi radioactive source have validated the detector's capability for coincidence spectroscopy, thereby demonstrating the feasibility of the system for isolating and quantifying contaminants with this technique.

We propose to use the proton beam from the SPES Cyclotron to test BeGam in a more realistic situation. We plan to merge these measurements with an experimental campaign in the framework of the SPES_MED project, already approved by the INFN-CSN3 (2025-2027). Among all the proposed reactions to study the production of medical radioisotopes, the ^{70}Zn(p,x) will be measured with the SPES cyclotron in the energy range 30-50 MeV. This reaction is of particular interest to produce the ^{67}Cu isotope. We will perform a γ-electron coincidence measurement to identify it among the different isotopes produced in the reaction.

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Status: ACCEPTED

Submitted by **PERRI, Marco** on **Saturday, 15 March 2025**

Abstract ID : **21**

Development of beam monitors for Ultra High Dose Rate Radiotherapy

Content

The paradigm of radiation therapy is the optimization of the therapeutic ratio, i.e. striking a balance between effectively damaging malignant tissue and preserving surrounding healthy tissue. Among the most promising developments are the treatment modalities exploiting the FLASH effect, a normal tissue sparing effect demonstrated in electron and proton irradiations at ultra-high dose-rate (UHDR) regimes, exceeding 40 Gy/s mean dose-rate in single fractions and lasting less than 200 ms. A large world wide effort to fully characterize the parameters triggering the FLASH effect is being carried on, aiming at validating the optimal future beam delivery to the patients.
The implementation of FLASH treatments poses several technological challenges to the established dosimetry and beam monitoring equipment. Standard transmission ionization chambers are not suitable in UHDR as they suffer from large ion recombination rate and slow response time and new technologies, or the adaptation of the existing ones, are still to be identified.

The medical physics group of the INFN and the University of Torino is developing a complete simulation tool able to describe the charge transport inside ionization chambers with varying dose-rate conditions. In addition, the response of solid state thin silicon and diamond sensors and studied as a possible alternative to gas detectors for monitoring the FLASH beams.
Tests using the LNL proton facility are highly desired as they would offer the possibility to:
1. validate simulations of ionization chamber signal responses to high-current proton beams, ensuring
that numerical models accurately reflect the experimental data;
2. study the effects of signal distortion observed in silicon sensors in UHDR electron beams;
3. study the possibility to combine ionization chambers and solid-state detectors as an integrated technology, aiming at building a system able to cope with both electron and proton UHDR and conventional beams;
4. study the macroscopic effects of radiation damage on both solid state detectors and ionization chamber electrodes;
5. challenge all the electronic supply and readout chain at the high dose rates.

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Status: ACCEPTED

Submitted by **VIGNATI, Anna** on **Saturday, 15 March 2025**

Abstract ID : **22**

Extreme ultra-high dose rate proton conditions and insights in FLASH radiotherapy mechanism: validation of models on multiple spatio-temporal scales

Content

Despite an exponentially growing accumulation of experimental evidence, especially in in vivo irradiation for a plethora of different animals and organs, as well as varying radiation types, after 10 years from its discovery, FLASH radiotherapy is still eluding basic understanding of its underpinning mechanism. Indeed, the unexpected reduction of damaging effects when ultra-high dose rate (UHDR, typically larger than several tens of Gy/s) radiation is delivered to a normal tissue, as compared to conventional rates, with isoefficacy on tumors, remain unexplained, which limits a clinical exploitation of this highly promising new modality [1]. Massive research is moving worldwide in this direction, and while several initial candidate mechanisms has been disproven [2] and a number of facts have acquired consensus [3], there is still a lack of a comprehensive and consistent explanation. Indeed, even extremely simplified experimental configurations fail to return an agreement between experimental response at UHDR and the corresponding theoretical prediction. One example are radiation chemistry yeld, such as H2O2, used as an alias of intertrack recombinatiom, where most experiments provide opposite trend as all the the theoretical predictions (see e.g. [4].

In this context the Legnaro facility with the extreme high intensity and large dynamical range will offer a beam with unprecedented features for mechanistic investigations. In fact, all the experimental test of FLASH conditions to date were performed in clinical cyclotrons, limited to a maximum of 500 nA, corresponding to a dose rate hardly ecceeding 200 Gy/s, on small targets arouns 1 cm2, thus slightly above the typical threshold for FLASH effect observation. Attempts with laser driven accelerators, while producing larger intrapulse dose rate, were limited by the extremely low pulse repetition frequency, and the insufficient dose per pulse.
For this reason, we propose to use this beam on first instance for radiation chemical investigations at UHDR, We plan to measure H2O2 formation with AplexRed assay and O2 depletion with a custom sensor on a large range range of dose rate, allowing its comparison to electron beams of similar intensity (like those available at the CPFR facility in Pisa) allowing a pure particle type dependent effectiveness comparison. Morever, the range of energy will allow to evaluate also the impact of KLET in the observed response and compare with theoretical predictions [4]. Following this radiation chemistry campaign, we'll plan and perform in vitro (2D cell samples and spheroids) and quasi-in vivo (zebrafish) assays.

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Status: ACCEPTED

Submitted by SCIFONI, Emanuele on **Saturday, 15 March 2025**

Abstract ID : **23**

Radiation protection benchmark to test nuclear models between a nucleon within energy range 20 and 200 MeV and a light nucleus (C, N, O)

Content

EURADOS has established that there is a weakness [1] in the nuclear model concerning the interaction of a nucleon with an energy of between 20 and 200 MeV with light nuclei, primarily carbon, nitrogen and oxygen. However, this type of interaction is fundamental for describing the transport of nucleons in the human body as in secondary dose calculation in protontherapy for example. This type of model is also funda-mental for usual detectors simulation (as scintillators, Bonner sphere, etc.) and more generally in a wide range of simulations in the environment. A specific action has therefore been launched within the frame-work of Eurados [2] and the nuclear data community has been solicited for elementary interaction measurements within the High Priority Request List (HPRL) of the Nuclear Energy Agency (NEA). A request must also be made to theorists for build a coherent nuclear model.

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Status: ACCEPTED

Submitted by MARTIN, Silvia on **Monday, 17 March 2025**

Abstract ID : **24**

Exploiting the possibility to produce high flux proton minibeams

Content

One of the main challenges of radiotherapy is minimizing the damage to healthy tissues and organs at risk surrounding the tumor while maintaining high e[icacy in cancer killing. Among the innovative radiotherapy techniques aimed at improving treatment outcomes, spatial fractionation, particularly minibeam radiotherapy (MBRT), is recently emerging as a promising approach. This technique is based on the spatial modulation of the dose distribution, which enhances healthy tissue sparing while maintaining unaltered iso e[ectiveness on the tumor. In particular, the Minibeam RT (MBRT) makes use of sub-millimetric parallel beams (0.5-1 mm) spaced in 1-3 mm, typically obtained through passive collimation. This innovative irradiation modality has recently gained interest being an achievable good compromise between feasibility of the GRID (parallel beams with cm size) and e[icacy of the microbeam Radiotherapy approach (parallel beams with um size) [1-4]. Indeed, the first clinical trial on human patients recently started with minibeams to push the clinical translation of this innovative irradiation modality, although many challenges must be still addressed, both on the technological and clinical side. In this context, the MIRO (MInibeam RadiOtherapy) project, funded by CSN5 of INFN, aims to systematically investigate the biological e[ects of minibeam irradiation using di[erent particle sources: low-energy (7–10 MeV) electron beams and proton beams up to 230 MeV. The ultimate goal is to establish an clear correlation between the observed radiobiological e[ect (in vitro and in vivo) and key dosimetric parameters, such as the peak-to-valley dose ratio, center-to-centre distance of the beamlets, as well as the average dose and dose rate. Indeed, the combination of pulsed ultra-high dose rates (UHDR) and minibeam is attracting an increasing interest in the perspective of a possible synergistic effect.
To achieve this, the project will use pulsed UHDR electron beams accelerated at the Centro Pisano for FLASH Radiotherapy in Pisa and high-energy proton beams from the Trento Proton Therapy Center. Minibeam distributions are being generated using passive high-Z (tungsten) collimators with various geometrical configurations as reported in [5]. However, it is important to note that passive collimation inevitably results in a significant reduction of the final particle flux. Therefore, while for electron beams the possibility of combining FLASH and minibeam e[ect is achievable at CPFR combining UHDRs with passive collimation, thanks to the extremely high fluxes of the ElectronFLASH Linac, these studies cannot be performed so far with proton beams as the obtained dose rates are not enough to cope with the flux reduction caused by the passive collimation.
In this regard, the high-flux (up to 500 μA) 70 MeV proton beams that will be accelerated by the SPES cyclotron at the Laboratori Nazionali di Legnaro (LNL) presents a unique opportunity to produce high-flux proton minibeams using passive collimators. This would enable the generation of UHDR proton minibeams, never explored so far, and expand the experimental studies conducted within the MIRO project, exploring new configurations and beam parameters beyond those achievable with the currently available facilities in the world.
To this end, in the framework of the MIRO project, we propose the development of collimators, simulated, designed and realized at INFN Catania Division, with di[erent geometrical configurations to passively generate proton minibeams at LNL. These beams will be dosimetrically characterized using passive dosimeters (such as radiochromic films) to measure transverse and longitudinal dose distributions with high spatial resolution, as well as active dosimeters, such as large-area silicon carbide detectors, to measure the average dose.
The potential of the LNL proton beams would pave the way towards new approaches never explored so far, relevantly contributing to the investigation of these new irradiation modalities and to their clinical translation.

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Status: ACCEPTED

Submitted by **MILLUZZO, Giuliana Giuseppina** on **Monday, 17 March 2025**

Abstract ID : **25**

Design of a transport and dosimetric beam line for protontherapy and radiobiological experiments

Content

The availability of high-flux 35–70 MeV proton beams accelerated by the SPES cyclotron at LNL, opens exciting opportunities for multidisciplinary applications, including dosimetric studies and the further investigation of consolidated irradiation modalities, such as proton therapy, and also of newly developed ones.
To fulfill this scope and achieve highly reproducible, precisely controlled, and well-monitored proton beams with dosimetric parameters suitable for cell irradiation and detector characterization, it's certainly required the design and the realization of a dedicated transport beamline. Indeed, the beam parameters needed for accurate irradiations in the framework of radiotherapy related studies, require specifications that typically diUer from the ones characterizing the beams used for fundamental research. On this concern, passive or active systems are necessary to optimize the beam uniformity and the dose distribution at the irradiation point (in air), ensuring suitable conditions for multidisciplinary applications. At this purpose, we propose the design and subsequent realization of a dedicated beam line to perform multidisciplinary activities implying controlled and accurate dose delivery. In particular, we envisage two possible approaches: i) the first one more easily and rapidly achievable, but less versatile, based on incorporating in the beam line passive elements, such as scattering foils for spreading the beam and circular collimators to cut the beam tails; ii) the second one, more complex, and therefore to be designed for longer term activities, based on the installation of active elements (dipoles and/or quadrupoles), with the possibility to scan the proton pencil beams. This setup will optimize key beam parameters, including:
• Transversal dose profile, improving beam homogeneity and penumbra.
• Beam size, with the implementation of a final variable collimation system.
• Longitudinal dose distribution, focusing on parameters such as the distal fall-oU and the peak-to-entrance dose ratio to limit the beam energy spread.
This proposal focuses on the design and realization of the first, more feasible and cheaper, approach based on passive elements, in collaboration with the interdisciplinary group at INFN Legnaro Laboratories (LNL). The design process will rely on Monte Carlo Geant4 simulations, for which the medical physics group at INFN Catania Division has a recognized expertise, using as an input the beam characteristics at the exit of the first vacuum window. The passive elements will be simulated to compromise between the beam uniformity on one side and the loss of beam flux on the other side, performing also dedicated studies to limit radiation protection issues. Once the beam line will be finalized, experimental validations will be conducted at LNL using various dosimetric systems, including radiochromic films, ionization chambers, and a motorized water phantom, to verify the beam parameters and demonstrate the feasibility of delivering controlled beams for radiobiological studies and accurate detector characterizations at LNL.

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Status: ACCEPTED

Submitted by **ROMANO, Francesco** on **Monday, 17 March 2025**

Abstract ID : **26**

Characterization of new dosimeters with the high flux, high dose rate protons for FLASH radiotherapy

Content

The unique characteristics of the proton beams accelerated by the SPES Cyclotron, such as their extremely high beam current, make them highly attractive for medical applications such as FLASH radiotherapy. This innovative technique utilizes ultra-high dose rate (UHDR) beams for cancer treatment. Several preclinical in vivo studies worldwide have demonstrated that irradiating tumors with UHDR beams at an average dose rate exceeding 40 Gy/s achieves tumor control probability (TCP) comparable to conventional radiotherapy (CONV-RT), while significantly reducing toxicity and complications in surrounding healthy tissues [1]. Given these advantages, numerous research groups around the world are actively investigating FLASH radiotherapy to advance its clinical implementation.

In this context, several challenges are being addressed by the INFN CSN5 funded FRIDA project, particularly from a technological perspective, to identify suitable detectors and dosimeters capable of accurately measuring and monitoring the dose at these unconventional dose rates [2]. A significant effort has recently been dedicated to developing innovative dosimeters as alternatives to standard ones (mainly ionization chambers) used for conventional radiotherapy (CONV-RT), as gas-based dosimeters suffer non-negligible ion recombination effects. Several experimental campaigns have been conducted using UHDR low-energy pulsed electron beams (with average dose rates of up to several kGy/s) at the Centro Pisano for FLASH Radiotherapy (CPFR) in Pisa. UHDR proton beams were also used but at a lower average dose rate achievable of about 250 Gy/s at the Trento Proton Therapy Centre, still within the FLASH radiotherapy threshold but not comparable with the dose rates achieved with the electron Linac. Having a proton source able to deliver beams at much higher dose rates would be extremely beneficial to carry out fair comparisons between proton and electron beams at UHDRs at similar regimes.

Specifically, the following technologies have been extensively characterized by the medical physics group of the INFN Catania division over the past three years to assess their suitability for FLASH radiotherapy dosimetry: i)an innovative secondary standard and portable graphite calorimeter developed by the National Physical Laboratory (NPL) for accurate reference dosimetry; ii) silicon carbide (SiC) detectors realized by the STLab company for real time relative dosimetry and beam structure measurements (with 10 ns temporal resolution); iii) alanine dosimeters for absolute dose measurements, [3-5].

In this framework, the possibility of utilizing 35-70 MeV proton beams accelerated by the SPES cyclotron - capable of reaching an unprecedented beam current of up to 500 μA, corresponding to a never explored average dose rate for proton beams of at least 105 Gy/s—presents a unique opportunity to further extend the study of these innovative dosimeters to even higher dose rates. Therefore, we propose an experimental campaign dedicated to a systematic dosimetric characterization of the accelerated proton beams at LNL by means of the developed dosimeters, as described above. Our proposal is on one side characterizing these detectors at these never explored proton dose rates and, once consolidated, performing other dedicated campaigns to accurately characterize the beams at LNL in the perspective of possible radiobiological experiments, to investigate the FLASH effect with UHDR proton beams at these extreme regimes. These activities are of crucial importance as the first trials in human patients with proton and electron beams are already on-going.

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Status: ACCEPTED

Submitted by **OKPUWE, Chinonso** on **Monday, 17 March 2025**

Abstract ID : **27**

Higher Energy CROSSTEST

Content

We propose a test experiment on the EJ276 and EJ276G scintillators, to study their properties and peculiarities in order to realize a new challenging neutron and charge particle detector device.
The study and construction of such a detector has been recently approved and financed in the framework of the national PRIN2020 funding call. The name of this project is ANCHISE (Array for Neutron and Charged particles with HIgh linear momentum SElection), it is supported by the CSNIII - INFN and it involves many of the proposers of this test.
In particular, we want to extend at higher energy our investigations, already measured with 4.5 MeV neutrons at CN facility at LNL (CROSSTEST exp.), with further studies on the performance achievable in shape discrimination in gamma-neutron separation, on the energy calibration linearity, on the timing of the plastic scintillators and on the cross talk effect. We want also make a Time of Flight (ToF) neutron energy measurement test and a neutron efficiency measurement. We well use 6 clusters of NArCoS (Neutron Array for Correlation Studies), made by 24 elementary cubic cells of 3 cm sides. Four stacked cells compose one segmented single cluster having dimension of 3cm x 3cm x 12cm in order to test its preliminary version of the prototype of the detector. In CROSSTEST@LNL exp., performed in November 2023, we studied the crosstalk probability (same neutron detected in two different cells) at the energy of 4.5 MeV at CN facility, measuring a traverse crosstalk probability (to the respect of the beam direction) of about 0.1% and a parallel one of about 0.2%; both crosstalk probability resulted lower than the simulated value by means GEANT4 and MCNPX simulation toolkits (E. V. Pagano et al., NIM in preparation). With this proposal we request to use the proton beam from the new cyclotron at LNL at an energy of 35 MeV of about 200 enA of intensity, impinging on a LiF target in order to have neutrons in a range from 15 to 30 MeV to measure crosstalks as a function of energy (steps of 5 MeV), neutron detection efficiency (measuring the 7Be and the neutron in coincidence), n- PSD performances at higher energies, linearity of the energy calibration at high
energy, timing properties and Time of Flight (ToF) test of the neutron energy measurements. In order to perform the experiment we well need the experimental hall equipped of a flanged small thin walls vacuum scattering chamber to put inside the LiF target ad a Si detector in order to measure the 7Be in coincidence with the neutrons with NArCoS in air.

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Status: ACCEPTED

Submitted by PAGANO, Emanuele Vincenzo on **Monday, 31 March 2025**

Abstract ID : **55**

A medical and multi-disciplinary in-air transport beam line for the 70 MeV protons from the INFN-LNL cyclotron

Content

Thanks to the expertise coming from over twenty years of dosimetric and clinical experience gained from operating the CATANA and zero-degree proton therapy beamlines at INFN-LNS, we propose the establishment of a multidisciplinary in-air irradiation facility at the newly operating INFN-LNL cyclotron, which can deliver protons with energies up to 70 MeV and currents ranging between 20 nA and 50 µA. We propose the development of a dedicated in-air transport beamline. The beamline will incorporate systems for energy and fluence modulation, spatial distribution shaping, and extensive real-time, on-line monitoring systems for both relative and absolute dosimetry. A Geant4 simulation of the complete beamline will be also developed to be incorporated in the Geant4 official release and serving as an estimator of dose, fluence, LET and RBE in any experimental condition. Thanks to this beamline, the LNL facility will work as a sophisticated platform for conducting radiobiological experiments, medical physics research, and exploratory investigations into innovative FLASH radiation protocols. Through the establishment of this advanced infrastructure, INFN-LNL will enable pioneering multidisciplinary research, connecting fundamental science with clinical applications and fostering innovation in proton treatment techniques.

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Status: ACCEPTED

Submitted by **PETRINGA, Giada** on **Thursday, 17 April 2025**

Abstract ID : **56**

FlashDC, a fluorescence based beam monitor for ultra-high dose rates

Content

In recent years, there has been a significant focus on improving the effectiveness of radiotherapy (RT) and particle therapy in treating tumors while minimizing damage to healthy tissue. A promising development is offered by the observation of the so-called FLASH effect, where ultra-high dose rates delivered in a short time have shown to protect healthy tissues while maintaining anti-tumor efficacy. However, conventional detectors face challenges in monitoring charged beams at these ultra-high dose rates due to non-linear effects. To address this challenge, the FlashDC (Flash Detector beam Counter) has been developed. It uses air fluorescence to monitor beam fluence and spatial distribution in real-time with high accuracy and minimal impact on treatment delivery. This innovative detector offers a linear response for various charged beams, dose rates, and energies, making it a cost-effective solution. Multiple prototypes have been developed and optimized using Monte Carlo simulations. The analysis of data from recent test beam campaigns with electrons delivered at FLASH intensities has demonstrated a linear correlation between the detector signal and the delivered dose per pulse, confirming that fluorescence can be used for beam monitoring in FLASH-RT studies. This contribution introduces the FlashDC monitor, discusses its expected performance, and presents preliminary test beam results obtained with electron beams in FLASH mode.

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