Sesto Incontro Nazionale di Fisica Nucleare

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Trento

Book of Abstracts

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Exploring the multidimensional structure of the nucleon (Invited)

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Protons and neutrons are among the basic building blocks of ordinary matter and account for more than 99% of the mass of the visible universe. They have been discovered about a century ago and, since then, their properties and composition have been studied both theoretically and experimentally with an increasing level of precision and accuracy. With the advent of the quark model and of QCD their structure in terms of elementary constituents became evident and was eventually established by the first DIS experiments in the late '60s. In more than fifty years of DIS experiments, performed with different beam particles and energies and covering complementary kinematic regions, we have learned a lot on the complex dynamical structure of nucleons. Today we have a rather precise knowledge of the longitudinal momentum and longitudinal spin distributions of quarks, encoded by the collinear *momentum* and *helicity* Parton Distribution Functions (PDFs). These objects, however, provide only a 1-dimensional description of the nucleon structure, in terms of the longitudinal momentum fraction carried by the partons. New fundamental insights and a rich phenomenology arise when we expand our studies by including the dependencies on the (originally neglected) parton transverse degrees of freedom: transverse polarization, transverse momentum, and transverse position across the nucleon. An immediate consequence of this novel approach is the appearance of two new families of partonic distributions: the Transverse-Momentum Dependent distribution functions (TMDs) and the Generalized Parton Distribution functions (GPDs). The former provide a 3-dimensional representation of the nucleon structure in momentum space, the latter in a space spanned by the parton longitudinal momentum and transverse coordinates. Together they thus allow for a complementary multi-dimensional description of the nucleon structure (nucleon tomography) and provide a new ground for studying the strong interaction in the non-perturbative regime of QCD. An overview of recent experimental highlights on both TMDs and GPDs is reported, along with some perspectives for future measurements at existing and future facilities.

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Mass spectra and electromagnetic decays of single bottom baryons

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The study of the mass spectra as well as the decay properties of single bottom baryons is relevant in hadron physics. Until now, only a few single bottom baryons have been discovered and many of them have to be discovered in the future. In this work, we computed the mass spectra of single bottom baryons within the quark model formalism up to D-wave states. Additionally, we calculated the

electromagnetic decay widths from P-wave to ground states. The electromagnetic decays become dominant in cases where the strong decays are suppressed.

The experimental uncertainties are propagated to the model parameters using a Monte Carlo bootstrap method. Our masses are in reasonable agreement with the available data at the moment. For this reason, our results will be able to guide the experimentalists in future searches for the undiscovered single bottom baryons at experiments like the LHCb, ATLAS, and CMS.

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Open heavy-flavour production from the high-mass dilepton spectrum in pp collisions with ALICE

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In hadronic collisions, charm and beauty quarks are mainly produced in hard partonic scatterings due to their large masses, m_c = 1.3 GeV/c^2 and m_b = 4.1 GeV/c^2. They are ideal tools to investigate various aspects of perturbative QCD.
In addition, measurements in pp collisions represent a baseline for cold nuclear matter studies in p–A collisions, and for the characterization of the hot and dense medium, the quark–gluon plasma (QGP), formed in A–A interactions. A detection technique that has received limited investigation until now at LHC energies to measure $c\bar{c}$ and $b\bar{b}$ cross sections consists in exploring the high-mass region of the lepton pairs invariant-mass spectrum. In ALICE, it is possible to reconstruct dileptons both in the electron channel at midrapidity (|\textit{y}| < 0.9) in the central barrel, and in the muon channel at forward rapidity (2.5 < \textit{y} < 4) with the muon spectrometer.
In particular, the two continuum regions between charmonium and bottomonium resonances ($4 < m_{\mu^+\mu^-} < 9$ GeV/c^2) and above the bottomonium states ($m_{\mu^+\mu^-} > 11$ GeV/c^2) are significantly populated by the semileptonic decays of hadron pairs containing charm or beauty quarks. In this presentation, a first measurement of heavy-flavour cross sections in pp collisions at $\sqrt{s}$ = 13 TeV and forward rapidity will be presented. This result is achieved using Monte Carlo templates from PYTHIA 8 simulations for the mass and p_T dependence of the dimuon yields, and it complements previous measurements obtained by ALICE in the dielectron channel at midrapidity. Both results are compared with FONLL predictions. Finally, the status of the charm and beauty cross section measurements using a Next-to-Leading Order Monte Carlo generator, POWHEG, will be presented, as well as the study of the contribution to the dimuon spectrum of the Drell-Yan process in the very high-mass region.

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AI application to hadron spectroscopy

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Generative models driven by artificial intelligence (AI) have been successfully used in several fields. In this contribution I will present the idea behind the A(i)DAPT (AI for Data Analysis and Data PreservaTion) working group. Our objective is to study how AI can be used to address the main challenges in Nuclear Physics and High Energy Physics measurements: unfolding detector effects and preserve information when working on large, multi-dimensional datasets.
I will present the closure test results based on MC simulations in CLAS g11 experiment kinematics,

where AI-supported generative models were able to reproduce highly correlated multi differential distributions in the presence of detector induced distortions. I will also show the current progress in expanding this study towards more complex processes, such as CLAS12 two pion electroproduction, and its use in data analysis.

Nuclear Astrophysics II / 155

Cosmological and stellar nuclear processes (Invited)

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I will discuss nuclear processes that are relevant for energy production in the Sun and solar-like stars and for the synthesis of light elements in the Early Universe. Special emphasis will be given to the relevance of nuclear reactions for understanding the Sun and for correct inference of solar properties from solar neutrino flux measurements.

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A new underground measurement of the $^{14}N(p,\gamma)^{15}O$ reaction at Bellotti Ion Beam Facility

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An accurate understanding of the slowest reaction of the CNO cycle, the $^{14}N(p,\gamma)^{15}O$, is essential for estimating the lifetimes of massive stars and globular clusters. Additionally, it plays a crucial role in determining the CNO neutrino flux emitted by the Sun. Despite the significant efforts over the years, including pioneering underground measurements made by the LUNA collaboration, this reaction remains the predominant source of uncertainty when assessing the solar chemical composition.

As a pilot project for the LNGS Bellotti Ion Beam Facility, the LUNA collaboration is conducting a $^{14}N(p,\gamma)^{15}O$ experiment focused on measuring the excitation function and angular distribution using improved solid targets, optimized to limit the beam-induced background contribution. An excellent sensitivity is achieved in synergy with the high beam current provided by the new 3.5 MV accelerator in its deep-underground location.

The aim of the measurement is to provide high-quality differential cross section data in the energy range from 0.3 to 1.5 MeV, which will give new insights and strengthen the knowledge of this key astrophysical reaction. Preliminary results of the $^{14}N(p,\gamma)^{15}O$ excitation function and angular distribution will be presented, including novel data for the least-known weaker transitions.

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Neutron capture and total cross-section measurements on 94,95,96Mo at n_TOF and GELINA

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Cross-sections for neutron-induced interactions with molybdenum, in particular for the neutron capture reaction, play a significant role in various fields ranging from nuclear astrophysics to safety assessment of conventional nuclear power plants and the development of innovative technologies. Molybdenum is found in pre-solar silicon carbide (SiC) grains and an accurate knowledge of its neutron capture cross section has a crucial role in stellar nucleosynthesis models, in particular in Asymptotic Giant Branch (AGB) stars. From the work of Liu et al. [1], a deviation on the model predictions has been observed when using Mo cross section data from the two main KADoNiS versions [2][3], with KADoNiS 1.0 providing the better agreement with the grains data. This deviation is particularly evident when extrapolating the data to lower energies. A new measurement of the capture cross section of the molybdenum isotopes is therefore needed to confirm this trend at low thermal energy. In addition to its astrophysical role, molybdenum isotopes can be found as a fission product in fission power plants and the use of this material is under study for future improved reactors [4][5]. This shows the importance of an accurate knowledge of the total and capture cross-section for molybdenum isotopes.

Experimental data in the literature for the capture cross-section of Mo isotopes suffer from large uncertainties. This is also reflected in the large uncertainties of the cross-sections recommended in the ENDF/B-VIII.0 library [6]. Below 1 eV the relative uncertainty of the capture cross-section is above 18% for 94Mo and around 40% for 96Mo, while above 2 keV the uncertainties are in the order of 10-20% for 94,95,96Mo. The uncertainty on the capture cross section data in the libraires is also reflected in the uncertainty of the MACS (Maxwellian Averaged Cross Section) found in the latest version of KADoNiS [3], which presents uncertainties on the level of 10% in the MACS at 30 keV for all the molybdenum isotopes. One of the reasons for these large uncertainties is related to the absence of transmission data for enriched samples.

In this contribution the first transmission and radiative capture measurements results obtained at n_TOF (CERN, Switzerland) and GELINA (EC-JRC Geel, Belgium) will be presented. Moreover, the updated values of the MACS for 94,95,96Mo will be shown. The effect of these new preliminary values of the cross section in stellar nucleosynthesis calculations for AGB stars will be presented.

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Effects of nuclear matter properties in neutron star mergers

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The properties of the nuclear equation of state (EOS) of dense matter have a dramatic impact on the dynamics in mergers of binary neutron stars (BNS), with profound implications on the emission of

gravitational waves (GWs) and the ejection of matter in the merger and post-merger phases. It is thus a topic of high interest for multi-messenger astronomy. A variety of nuclear EOSs are available with various underlying microphysical models. This calls for a study to focus on EOS effects from different physical nuclear matter properties and their influence on BNS mergers. We perform simulations of equal-mass BNS mergers with a set of 9 different EOSs based on Skyrme density functionals. In the models, we systematically vary the effective nucleon mass, incompressibility, and symmetry energy at saturation density. This allows us to investigate the influence of specific nuclear matter properties on the dynamics of BNS mergers, which we analyze in terms of the fate of the remnant, disk formation, ejection of matter, and gravitational wave emission. Our results indicate that some aspects of the merger are sensitive to the EOS around saturation density while others are sensitive to the behavior towards higher densities, e.g., characterized by the slope of the pressure as a function of density. The detailed density dependence of the EOS thus needs to be taken into account to describe its influence on BNS mergers.

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Results of 20 Ne (p, γ)21 Na and status of 21 Ne (p, γ)22 Na reaction at Laboratory for Underground Nuclear Astrophysics (LUNA) experiment

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The Gran Sasso massif provides a natural shield against cosmic rays, allowing several precision measurements of nuclear reactions of astrophysical interest at the LUNA accelerator facility. In the last years several key reactions of NeNa cycle in AGB (Asymptotic Giant Branch) stars, novae and supernovae, have been studied. The $^{20}Ne\,(p,\gamma)^{21}\,Na$ is the slowest reaction in the cycle and directly affects the abundances on Ne and Na isotopes. LUNA studied the $E_r = 386\,keV$ resonance and the direct capture below $E_p = 370\,keV$ using a gas target setup and two high purity germanium detectors. Same experimental setup has been recently used to study the $^{21}Ne\,(p,\gamma)^{22}\,Na$ reaction which have a significant role in the ^{22}Na radioactive isotope in novae and supernovae.

The experimental details, results on the $^{20}Ne\,(p,\gamma)^{21}\,Na$ and preliminary ones of the $^{21}Ne\,(p,\gamma)^{22}\,Na$ experimental campaign, together with Monte Carlo simulations, will be presented.

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Modification of 7Be β-Decay Rates in Laboratory Magnetoplasma and Perspectives for the PANDORA Facility

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PANDORA (Plasmas for Astrophysics, Nuclear Decay Observations and Radiation for Archaeometry) is an upcoming facility at INFN - LNS aiming to use an electron cyclotron resonance ion source (ECRIS) as a magnetoplasma trap to measure β-decay rates of radioisotopes in certain electron density and temperature ranges [1]. Decay rates λ are susceptible to changes in atomic configuration of the parent and daughter systems and are modified inside plasmas due to the ionic charge state distribution (CSD) and level population distribution (LPD). Measuring λ in energetic plasmas is crucial, for instance, for providing accurate inputs to nucleosynthesis models –s-process models in particular – where competition between β-decay and neutron capture dictates the elemental abundance.

Since the CSD and LPD are strongly non-uniform in ECRIS, so are the decay rates, and calculating them is a complex process involving sequential simulations of plasma electrons, ions and nuclei in order. Taking as example the test-case of ^{7}Be, we present here a detailed analysis of how its electron capture rates are modified in a realistic ECRIS, by starting from the Takahashi-Yokoi model and calculating plasma-induced λ variation for a grid of plasma density and temperatures [2]. The analysis is then extended to a realistic laboratory magnetoplasma, where, using a Particle-in-Cell Monte Carlo (PIC-MC) code [3, 4] to model ECR dynamics, we predict the expected spatial gradients of 7Be decay rates in the plasma chamber. The stepwise analysis results in a general model that covers both low-density plasmas in non-local thermodynamic equilibrium (NLTE) and high-density LTE plasmas as in the stellar interior. It also underlines the role of the plasma-decay model for extracting meaningful information from experimental data and the inherent technological challenges. These points offer useful perspectives for PANDORA which is expected to be operational by the end of 2024.

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Nucleosynthesis of light and iron group elements in the ejecta of binary neutron star mergers

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Binary neutron star (BNS) mergers are among the most intriguing events known in the universe, with impressive scientific potential spanning many different research fields in physics and astrophysics. On August 2017, the detection of the gravitational-wave GW170817 signal with the corresponding electromagnetic counterpart confirmed that heavy elements such as lanthanides and actinides can be generated in the aftermath of BNS mergers through r-process nucleosynthesis. Such elements are not the unique nucleosynthetic outcome in BNS mergers though, since the mass range of the yields strongly depends on the neutron richness of the matter expelled during the coalescence (ejecta), parametrized by the electron fraction (Ye). Specifically, the production of elements with mass number A < 80-90 is enhanced in the region of the ejecta with Ye >~0.25, at the expense of the heavier ones. Recent works featuring state-of-the-art BNS simulations showed that the Ye-range in the ejecta can extend up to ~ 0.4, complementing the distribution of heavy r-process elements with the presence of lighter nuclides among the final yields.
At the moment of writing, the production of elements with A < 80-90 has not been widely examined in the context of BNS mergers. Yet, understanding the details
behind their formation could help in better constraining the physics of compact binary mergers for different reasons, e.g.: I) the identification of individual
absoprtion features in the spectra of electromagnetic counterparts is in principle easier for light elements, II) the nucleosynthesis pattern at small atomic numbers exhibits a larger variability with respect to the binary properties.
In this work, we quantitatively investigate the nucleosynthesis of elements with atomic number Z <~ 38 in the ejecta of BNS mergers, combining an extensive set of nuclear reaction network calculations performed with SkyNet with datasets extracted from numerical BNS simulations modelling the ejecta of GW170817-like binaries. Among the various results, we find that a non-neglibible amount of iron-group elements is synthesized in the high-Ye tail of the ejecta, sometimes at a comparable

level with respect to the production of some of the most abundant r-process nuclides. We also investigate how the nucleosynthesis of light elements correlates with some binary properties, like the equation of state employed for the description of neutron-star (NS) matter or the ratio between the two NSs masses.
Our study also leads to astrophysically relavant implications regarding the chemical evolution of our Solar system. Contrarily to previous findings, we show that the recently observed signature of 60Fe and 244Pu isotopes in deep ocean sediments, dating back to the past 3-4 million of years, is compatible with a single nearby BNS event, occurred ∼ 100 pc away from the Earth.

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Flash Q&A

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From soft to hard observables: recent experimental results from ALICE (Invited)

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ALICE is a general-purpose, heavy-ion detector at the CERN LHC which focuses on quantum chromodynamics. It is designed to address the physics of strongly interacting matter and the quark-gluon plasma at extreme values of energy density and temperature in nucleus-nucleus collisions. In addition, it has a rich physics program for proton-proton and proton-nucleus collisions.

In this overview, a selection of recent ALICE results based on data collected during the LHC Run 3 and Run 2 will be presented. Prospects for the LHC Run 4 and beyond will also be briefly discussed.

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NA60+: an overview of the experiment at the CERN SPS

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The NA60+ experiment has been proposed as a fixed-target experiment for the study of quark-gluon plasma (QGP) in heavy-ion collisions.
Its aim is a precise of study hard and electromagnetic processes at high baryochemical potential from 200 to 550 MeV at the CERN SPS. The experiment plans to perform measurements of thermal dimuons, charmed hadrons, strange particles and hypernuclei production in Pb-Pb collisions at center of mass energies ranging from 6 to 17 GeV.
The proposed experimental apparatus incorporates a vertex telescope positioned near the target and a muon spectrometer located downstream of a hadron absorber. The vertex telescope will feature multiple ultra-thin, large-area Monolithic Active Pixel Sensors (MAPS) embedded within a dipole magnetic field, marking a significant advancement in detector technology. The innovative design of

the telescope enables precise tracking and identification of charged particles at the very core of the collision. The muon spectrometer, in turn, utilizes large-area gaseous detectors for muon tracking and a toroidal magnet based on a novel lightweight and general-purpose concept. This innovative combination of detection systems will enable NA60+ to make unprecedented measurements of rare and electromagnetic processes at high baryochemical potential, paving the way for a deeper understanding of the quark-gluon plasma.
A letter of intent was submitted at the end of 2022, with the goal of submitting a technical proposal by 2024 and start data taking in 2029.
In my talk, I will focus on the detailed description of the experimental apparatus and the ongoing R&D efforts associated. I will place particular emphasis to provide a comprehensive description of the vertex spectrometer. I will then give an overview on the physics program and the expected physics performances for hard and electromagnetic probes.

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New insights on strange quark hadronization measuring multiple strange hadron production in small collision systems with ALICE

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Among the most iconic results of Run 1 and Run 2 of the LHC is the observation of enhanced production of (multi-)strange to non-strange hadron yields, gradually rising from low-multiplicity to high-multiplicity pp or p–Pb collisions and reaching values close to those measured in peripheral Pb–Pb collisions. More insightful information about the production mechanism could be provided by measuring the full Probability Density Function (PDF) for the production of each strange particle species and investigating if any deviation from pure uncorrelated statistical behavior is observed. Using a novel method based on counting the number of strange particles event-by-event, it was possible to extend the study of strangeness production beyond the average of the distribution and to test the connection between charged and strange particle multiplicity production.
In this contribution, new ALICE preliminary results on the full PDF for the production of K^0_S, Λ, Ξ^- and Ω^- in pp collisions at $\sqrt{s}$ = 5.02 TeV as a function of the multiplicity together with the average probability for the production yield of more than one particle are presented. The results are compared to state-of-the-art phenomenological models implemented in commonly-used Monte Carlo event generators.

Nuclear Structure and Reactions I / 147

Nuclear response and decay processes within beyond mean-field methods (Invited)

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The nuclear response and decay processes, besides being intrinsic key-features of atomic nuclei, are intimately related to fundamental open questions such as the nuclear equation of state and in-medium nucleon-nucleon interaction, nucleosynthesis and properties of astrophysical objects, fundamental symmetries and physics beyond the Standard Model. From a theoretical point of view, the

nuclear response is typically described within the linear-response theory through the so-called Random Phase Approximation (RPA), relying on a mean-field description of the nucleus. This approximated description provides the general features of the nuclear response, such as the total strength and centroid distributions. However, a more refined description is required in many respects, which involves incorporating many-body correlations beyond the mean-field approximation. In the last decade, advanced beyond-mean-field methods have been developed and numerically implemented, showing their power and efficiency. In particular, the particle-vibration coupling model [1, 2, 3] and the second RPA [4,5] are able to describe properties and features that cannot be achieved within the standard RPA. In this talk, recent applications of these methods will be discussed, particularly those focused on the giant monopole resonance and nuclear incompressibility [6, 7], and on Gamow-Teller excitations and beta-decay [8–10].

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Nuclear Structure and Reactions I / 67

Nuclear fusion reaction cycles: new prospects

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Nuclear fusion reaction cycles involving solid room temperature lithium-6 deuteride (^{6}LiD) hit with beams of neutrons are revisited with new calculations of the time evolution of a network of differential equations for the abundances of various nuclear species. Modern-day compilations of nuclear cross-sections and non-thermal reaction rates are used to predict the full time evolution of the main thermonuclear reactions, namely the Jetter (n+^{6}Li) and Post cycles (p+^{6}Li), that offer great prospects for energy production in devices not based on plasma confinement. We investigate burning conditions and we find interesitingly high yields for the burning of the fuel material into alpha particles.

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Cluster Effective Field Reory calculation of electromagnetic breakup reactions with Lorentz Integral Transform method

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We present the study of the ^{9}Be photo-disintegration process, $\gamma + {}^{9}\mathrm{Be} \rightarrow \alpha + \alpha + n$, in the low-energy regime. This reaction is of astrophysical interest because the inverse process, including both sequential and direct reactions combining two α and a neutron into ^{9}Be, represents an alternative path to the formation of ^{12}C in a neutron-rich environment.
The ^{9}Be system shows a clear separation of scales: the shallow binding of ^{9}Be below the $\alpha\alpha n$ three-body energy threshold, and the deep binding of the α particle. As a consequence, at low energies, ^{9}Be nucleus can be studied as a three-body *clustering* system interacting through *effective* potentials. Unlike the calculations that can be found in the literature, where phenomenological potentials have been employed, we make an attempt to use potentials derived from an Halo Effective Field Theory (EFT) [1].
First we calculate the ^{9}Be three-body binding energy with the Non-Symmetrized Hyperspherical Harmonics (NSHH) method [2], including both two-body (α-α and α-n) and three-body *effective* potentials. We then study the ^{9}Be photo-disintegration reaction cross section via the Lorentz Integral Transform method [3]. Following the Siegert theorem, we compute the nuclear current matrix element using the dipole operator. This ensures that the contributions of the two- and three-body nuclear currents, due to the characteristics of the potentials employed (as momentum dependence and non-locality), are included in the calculation. We will discuss the results focusing on their dependence on the EFT parameters, and in connection with the experimental data.
The present formalism provides a starting point to study also other processes of astrophysical interest, such as the ^{12}C photo-disintegration reaction $\gamma + {}^{12}\mathrm{C} \rightarrow \alpha + \alpha + \alpha$.

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Evolution of the mixing between single-particle and intruder configurations approaching the island of inversion at N=20: lifetimes in 37S

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The disappearance of the N=20 shell closure in the so-called "island of inversion"around ^{32}Mg is one of the most striking examples of the strength of nucleon-nucleon correlations. In this region, the quadrupole-deformed intruder configuration (based on a multi-particle multi-hole configuration) becomes the ground state, subverting the expected shell ordering predicted by a harmonic oscillator plus spin-orbit term. The odd N=21 isotones therefore yield the possibility of a direct investigation of the mixing between single-particle and intruder states along the same chain, although experimental study of such nuclei becomes increasingly difficult with decreasing Z. Available spectroscopic evidence suggests that in ^{37}S the single-particle and collective intruder configurations are strongly connected, thus placing ^{37}S at the upper edge of the island of inversion. However, information on observables directly related to the wavefunction composition is rather scarce. The first excited state ($3/2^-$ state at 646 keV) is the only one with a measured lifetime, but no transition probability has been firmly determined for intruder states, in particular those connected with strong branching ratios to the a priori spherical single-particle states.
A combined DSAM+RDDS measurement has been performed at LNL to deduce such transition probabilities, in particular for the $3/2^+$ state at 1397 keV (2p-1h nature) and the $7/2^-$ at 2023 keV (3p-2h nature), exploiting the full performance of the AGATA spectrometer in terms of energy and angular resolutions. The ^{37}S nucleus has been produced via the ^{36}S(d,p) reaction in inverse kinematics, detecting the recoiling protons in the annular charged-particle silicon detector SPIDER to obtain an accurate reconstruction of the excitation energy of ^{37}S. This contribution will present preliminary results which provide new insights into the structure of this nucleus.

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LYSO calorimeters for searching ^{176}Lu electron capture decay

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The decay of ^{176}Lu to ^{176}Hf through β^- decay occurs naturally and has a half-life of 37.8 Gyr. This decay is a valuable isotopic clock (Lu/Hf) used for dating meteorites and minerals, and can also serve as an s-process thermometer in the study of stellar nucleosynthesis.
Apart from undergoing β^- decay to form ^{176}Hf, the radioisotope ^{176}Lu can also become unstable through electron capture decay, leading to the formation of 176Yb. The Q_{EC} value for this decay to the ^{176}Yb ground state is 106.2 keV. As a result, the decay can occur to both the $J^p = 0^+$ ground state and the $J^p = 2^+$ 82 keV first excited state of ^{176}Yb. These EC decay branches would be 7th and 5th forbidden transitions respectively, and, thus, are expected to be negligibly small. Previous searches of the 176Lu EC decay were performed using passive Lutetium sources and looking for the ^{176}Yb* 82 keV gamma or the characteristic Yb X-rays in an HP-Ge detector. We have developed a new method utilizing an LYSO crystal scintillator and PMT to act as an active Lutetium source. This is combined with an HP-Ge to significantly decrease the background from the known ^{176}Lu β^- decay branch. Our preliminary results from testing a detector prototype in the INFN-TIFPA laboratory have led to improved upper limits on the EC branching ratio of ^{176}Lu decay, surpassing previous measurements by a factor of 3-20 depending on the specific EC channel being considered.

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Flash Q&A

Applications of Nuclear Physics III / 149

Fundamental research and applications with the EuPRAXIA facility at LNF (Invited)

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In the next years, the Italian Laboratori Nazionali di Frascati of INFN will play a crucial role in the development of plasma-based acceleration techniques. In fact, it is involved in the EuPRAXIA initiative, that aims at realizing the first laser plasma user facility worldwide. The R&D activity ongoing in this field is hosted at SPARC LAB (Sources for Plasma Accelerators and Radiation Compton with Laser And Beam), that consists in a conventional high brightness RF photo-injector and a multi-hundred terawatt laser. While pushing forward the research in the field of plasma acceleration, the equipment installed in the infrastructure can as well provide different radiation sources that can be exploited to carry out measurements in the nuclear physics field and to develop applications in different sectors of interest, as cultural heritage and biophysics.

In particular, present and future laser facilities, that will reach intensity frontiers as high as 10^21 W/cm2, may represent an excellent environment where designing laser-based experiments relevant both for the field of nuclear astrophysics as well as for the general investigation of nuclear processes in plasma. Currently, the Frascati Laser for Acceleration and Multidisciplinary Experiments (FLAME) is installed in the SPARC LAB to study the laser-matter interaction with solids and gases at high laser intensities, up to 10^20 W/cm2. In a longer perspective, the laser will be upgraded to a Peta-Watt regime, opening the possibility to further extend the thermodynamic reach of the created plasmas. At SPARC LAB different experiments are being planned: for example, the deuterium fusion investigation (d + d → 3He + n) for the nuclear astrophysics measurements, but also studies of nuclear decays in plasma as a function of laser operation parameters such as beam spot size, intensity and pulse duration, that will eventually affect the thermodynamics properties of the created plasma. Beyond this, also other radiations that the facility will be able to produce (electrons, photons of different characteristics, neutrons, protons and positrons) can be exploited for the design of tools to be used, among the others, in the analysis of artworks, as well as for the study of biological compounds. Laser wakefield accelerator based light sources (LWFA) like betatron radiation sources, indeed, have many po-tential applications in different fields like X-ray phase contrast imaging (XPCI) and material science.
In this talk, the new facility will be presented, and the specific aspects of the different radiation sources that can be exploited for applications both in fundamental and applied research fields will be discussed.

Applications of Nuclear Physics III / 111

Primary particles tracking integrated with secondary radiation detectors for next generation of ion beam delivery system

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Introduction
Particle therapy relies on the peculiar depth dose deposition, featuring the Bragg peak to reduce the integral dose to healthy tissues. Technological improvements are needed to pursue new beam delivery modalities and develop an online verification system to ensure treatment quality. We propose an innovative beam monitor for particle therapy exploiting a silicon strip detector optimized for single particle tracking, integrated with prompt gamma detectors developed for a Range Verification System (RVS) employing Prompt Gamma Timing (PGT) technique.

Materials and Methods
A 2.7 x 2.7 cm2 silicon detector segmented in strips was developed within the INFN-MoVeIT project characterized by a frontend board named ESA-ABACUS to house six ABACUS chips wire bonded to the 144 consecutive strips featuring 180 um pitch. The ASIC channels identify the particle's crossing signal collected by each strip for a wide charge range (4-150 fC) and provide output digital pulses for each signal discriminated using a threshold.
The secondary radiation detector is based on a cylindrical monolithic Lanthanium Bromide LaBr3(Ce),

1.5 inches in diameter, from Saint Gobain, coupled to a 5x5 squared matrix of RGB Silicon Photo-Multipliers (SiPM) (total area of 24 x 24 mm2), made of microcells of 15 um size, from FBK. Optical grease is used, and the free crystal surfaces are covered by aluminum to increase the collected light. Read out of the 25 SiPM channels is made by a custom front-end board able to analogically sum the contribution of all channels. The analog signal is then amplified and converted into a digital signal using a Constant Fraction Discriminator (CFD) NIM module.
To perform the PGT measurement, the time of transit of each particle into the beam monitor and the time of arrival of each secondary prompt photon have to be precisely measured. Ideally, time resolutions of 50 ps and 100 ps are optimal for the beam monitor and the prompt photon detector, respectively.
The time measurement of each digital pulse from the beam monitor and the secondary particle detector is based on the time-to-digital conversion performed by picoTDC ASIC developed at CERN [Ref]. Moreover, the signal from the secondary radiation detector is used to trigger the acquisition and transfer to the computer only data belonging to the proper time interval, correlated to the trigger event.
The data acquisition and transfer are based on Virtex 7 FPGA and UDP protocol.

Results
The first tests of integration between the ESA_ABACUS and prompt gamma detector were performed first in the laboratory using a pulse generator to simulate the expected output from the strip detector and a radioactive source to generate a signal in the scintillator. Then a preliminary test with the CNAO carbon ion beam was done at a beam energy of 398 MeV/u and clinical intensity (10^8 carbon ions/sec).

Conclusions
A new beam delivery system for particle therapy is in progress within the INFN-SIG project to improve beam monitoring based on silicon detectors able to perform 4D particle tracking (fluence, position, shape, and energy). The timing information is also useful to boost the performance of the in-vivo range verification system based on the PGT technique. Preliminary tests were carried out at CNAO showing the feasibility of obtaining the PGT spectrum at the clinical rate.

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Re ARCADIA Depleted Monolithic Active Pixel: characterization and prospects for high precision tracking systems at future colliders

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In the last decades silicon detectors have had the leading role in the field of charged particles tracking. Although the mainstay for these devices is hybrid sensors, where a front-end die gets bonded to a silicon sensor, Monolithic Active Pixel Sensors (MAPS), which embeds the sensing volume and the processing electronics within the same silicon layer, have attracted interest for current and future applications thanks to their low power consumption, low material budget, and low production cost.

A further boost to the appeal of MAPS is their intrinsic lower noise, and the possibility to shrink the pixel pitch to 10 μm or less, depending on the required functionality, without incurring in the steep cost penalty of modern wafer-bonding processes.

The drawbacks of this approach, i.e reduced radiation tolerance and slower charge collection happening by diffusion, are partially overcome by recent Depleted MAPS (D-MAPS): MAPS where the depleted region is extended to the full silicon substrate, and charge collection happens by drift.

D-MAPS show larger and faster signal, and significantly improved radiation tolerance with respect to standard MAPS. These devices, therefore, represent an ideal option for trackers in future colliders and space experiments, and thanks to their competitive price and small pixel pitch, they are also of interest to many medical and industrial applications. In the field of high energy physics, next experiments to be built at operating or foreseen accelerators (HL-LHC, EIC, FCC, …) have stringent requirements in terms of material budget and granularity for their inner tracking systems.
Two key features of MAPS device, making larger than reticle size sensors through the stitching technique, and bending them in curved shapes thanks to their thinness (down to 50 μm or less), further increase their appeal to realize ultra low-mass, hermetic vertex trackers.

The INFN ARCADIA collaboration successfully designed and produced fully DMAPS, based on 110-nm CMOS technology and with deep active thicknesses (50-300 μm). The latest prototype produced has an active size of 1.28×1.28 mm^2, with a pixel pitch of 25 μm and has been succesfully characterized with several radioactive and laser sources.

This contribution will present the ARCADIA sensor characterization results in detail, together with discussion on their applications at future colliders trackers. Furthermore, an overview of commercial and medical applications currently under investigation will be given.

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Studies on MAPS devices for medical applications.

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The detection unity of the current Inner Tracking System of ALICE, called ITS2, is the ALPIDE sensor. This device is the result of an intensive R&D effort carried out in the last decade and has led to a quantum leap in the field of MAPS for single-particle detection, reaching unprecedented performance in terms of efficiency, spatial resolution, material budget and readout speed. The further upgrade of the inner tracking system, called ITS3, foresees the implementation of a new generation of large size, ultra-thin stitched MAPS, whose first prototype studies have shown promising results. The technological evolution of MAPS as commercial devices has extended their interest beyond the high-energy physics experiments. A varied range of medical applications can also benefit of the use of this innovative sensor technology. The feasibility of a system for computerised tomography with a proton beam, based on a large dimension high-segmentation hybrid calorimeter; the possible development of a Compton Camera based on a Pixel Chamber for on-line monitoring of hadrontherapy; and the potential usage of the ALPIDE chip as intraoperative probe for radio-guided surgery will be presented in this contribution.

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Measurements of the Birks-Onsager quenching parameters for the LYSO scintillator.

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Lutetium-yttrium oxyorthosilicate (LYSO) is a high density, rugged/radiation tolerant, fast scintillator. For this reason LYSO crystal scintillators are used or planned in many High Energy Particle experiments (as e.g., KLOE-2, srEDM, COMET, CMS Barrel Timing Layer) in medical diagnostic devices (PET, TAC, CT) and in current and planned astroparticle physics space calorimeters (as e.g., HEPD-01, HEPD-02, NUSES, Crystal-Eye, HERD, ALADInO, AMS-100).
On the other hand, a relatively strong light quenching phenomena was observed in LYSO scintillators when irradiated with highly ionizing particles. The current uncertainties in the modeling and in the measurement of quenching parameters for LYSO could affect the capability of a precise determination of shower energy in LYSO-based hadronic calorimeters planned for future space experiments.
In this work, the scintillation response of a Ce-doped LYSO crystal is investigated with ion beams and with gamma radioactive sources in the INFN-TIFPA laboratory. A non-proportionality of the light yield for sub-MeV gamma rays is measured. The effect of the scintillation quenching of relatively slow electron recoils produced by low-energy gamma rays in the LYSO scintillator is evaluated with an high resolution GEANT4 simulation to describe the measured light yield non-proportionality.
In the framework of the Birks-Onsager model, the quenching parameters for low-energy electron recoils are inferred. The comparison with the measurements of LYSO quenching parameters, using nuclei at particle beam from proton to Argon, is a powerful test for the underlying quenching theory, that appears to be valid for different particles in a wide kinetic energy range from several GeV nuclei down to few keV electrons.

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Flash (3+Q&A)

Quark Gluon Plasma I / 146

Recent theory developments on the physics of Quark-Gluon Plasma (Invited)

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Strongly interacting matter at high temperature and densities turns into a deconfined medium known as the Quark-Gluon Plasma. The combined effort of theory and experiment has helped shed light on its features, as well as on the phase structure of matter in such extreme conditions.
Heavy-ion collisions now routinely create short-lived Quark-Gluon Plasma droplets, and can explore the phase diagram of strongly interacting matter at low to moderate density.
Ever improving theoretical calculations can now provide a solid understanding of both dynamical and thermodynamical properties of this phase of matter, especially at low density.
In this talk I will provide an overview of theoretical developments in the study of strongly interacting matter at high energy, focusing on the mapping and characterization of the different phases.

Quark Gluon Plasma I / 50

Constraining the formation mechanisms of light (anti)nuclei with ALICE at the LHC and applications for cosmic ray physics

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The formation mechanism of light (anti)nuclei produced in high-energy hadronic collisions is an open question that is being addressed both theoretically and experimentally. Moreover, the study of (anti)nuclei production at particle accelerators is relevant to model the flux of antinuclei produced in cosmic ray interactions, which represents the dominant background for dark matter searches. In fact, according to the most accredited theoretical models, dark matter particles in the galactic halo could annihilate and produce ordinary matter-antimatter pairs.

At LHC energies, the same amount of matter and antimatter is produced, which makes this facility suited for detailed studies of (anti)nuclei production. ALICE, thanks to its excellent particle identification capabilities, measured (anti)nuclei in all the collision systems and energies provided by the LHC. Measurements of transverse momentum distributions, ratios of integrated yields, and coalescence probabilities are discussed in comparison with two phenomenological models used to describe the production of nuclei.

During the LHC long shutdown 2, the ALICE apparatus underwent a series of major upgrades to take advantage of the luminosity increase of the LHC Run 3. These upgrades will allow the collection of an unprecedented amount of data, opening new paths to probe the formation mechanisms of nuclei with A = 3 and A = 4 with very high precision. The performance of the upgraded ALICE detector during the Run 3 pp data taking will be discussed together with perspectives for new measurements with applications to searches for antinuclei in cosmic rays for indirect dark matter searches by the AMS and GAPS experiments.

Quark Gluon Plasma I / 62

Development of the ALICE Inner Tracking System 3

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The ALICE experiment at the Large Hadron Collider (LHC) at CERN has planned an upgrade of the Inner Tracking System (ITS), called ITS3, which will be installed during the LHC Long Shutdown 3 (2026-2028). The upgrade will implement a new 65 nm CMOS Monolithic Active Pixel Sensor (MAPS) employing the stitching technology to create wafer-scale chips up to 26 cm long. The produced chips will be bent around the beam pipe to replace the three innermost layers of the existing detector with new ultra-light, truly cylindrical layers. The ITS3 will improve the tracking performance of the detector especially at low transverse momentum, thanks to better track impact-parameter resolution, improved by a factor of two with respect to the present ITS in LHC Run 3. The detector will be closer to the interaction point and will have a lower material budget, of 0.05% X_0/layer. The presentation will show the final configuration and structure of the ITS3, the challenges related to its design and construction, and the results of the current R&D program on the sensor design and characterization.

Quark Gluon Plasma I / 57

A novel SiPM-based aerogel RICH detector for the future ALICE 3 apparatus at LHC

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The ALICE collaboration is proposing a new apparatus, ALICE 3, to investigate the Quark Gluon Plasma properties for the LHC Runs 5 and 6. The measurements planned to address ALICE 3 physics goals require to identify charged particles over eight units of pseudorapidity ($|\eta| < 4$) and to achieve a better than 3σ e/π, π/K and K/p separation up to above 2 GeV/c, 10 GeV/c and 16 GeV/c, respectively. In this context, studies for the development a Ring Imaging Cherenkov (RICH) detector are ongoing. The state of art detector concept for the ALICE 3 barrel ($|\eta| < 2$) RICH consists in a proximity-focusing layout, using aerogel (n = 1.03 at λ = 400 nm) as Cherenkov radiator and a layer of Silicon Photomultipliers (SiPMs) for the photon detection. A first small-scale prototype was successfully tested on beam in October 2022 and 2023. The barrel RICH specifications and expected performance, as well as beam test results will be presented.

Quark Gluon Plasma I / 52

SiPMs in direct detection of charged particles: response and timing performance for the future ALICE 3 at LHC

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Silicon PhotoMultipliers (SiPMs) are established photon detectors for a variety of applications because of their high efficiency, insensitivity to magnetic fields and low cost. In High Energy Physics (HEP) applications, SiPMs are usually coupled to scintillators or Cherenkov radiators. Nonetheless, it has been observed that SiPMs are able to directly detect charged particles: at the passage of a single charged particle, several SPADs (Single Photon Avalanche Diode), i.e. the SiPM unit microcell, are firing at the same time.

This effect has been explained through Cherenkov light emission in the protection layer normally placed above the sensor, as observed by comparing the response of SiPMs exposed to a beam of charged particles and with different, in thickness and material, protection layers and one SiPM without protection.

In this contribution, beam test results on SiPMs are reported. SiPMs with the protection layer feature an increased detection efficiency, if compared with a simple geometrical fill factor, reaching values >99%; moreover, the time resolution dramatically improves with increasing number of fired cells. An intrinsic time resolution around 20 ps has been measured considering the events when more than 5 SPADs are firing, corresponding to >80% of the total events.

These results pave the way for moving SiPMs from simple photosensors to combined charged particle detectors. This possibility would open to applications of SiPMs in many areas, from space experiments to colliders detectors, as for the TOF of ALICE 3 experiment, in which context this research is conducted.

Quark Gluon Plasma I / 93

Measurement of azimuthal anisotropy in coherent ρ0 photoproduction in ultra-peripheral Pb−Pb collisions with ALICE

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Ultra-peripheral heavy-ion collisions (UPCs) occur when the impact parameter of the collision is greater than the sum of the radii of the colliding nuclei. Given the short range of the strong force, these collisions allow one to study photoninduced reactions. Of particular interest is the photoproduction of a vector meson, that is a well-established tool to probe the gluon structure of the colliding nuclei. This talk will focus on the observation of spin interference in the ρ^0 meson photoproduction, in the form of angular anisotropy. Such an anisotropy appears due to two different factors: the first is that the photons involved in the process are linearly polarized along the impact parameter and the second is the quantum interference between the two amplitudes that contribute to the ρ^0 photoproduction cross section. Furthermore, the interference effect strongly depends on the impact parameter of the collision, which acts as the distance between the openings of a two-slit interferometer. In this talk, we present the first measurement of this anisotropy in coherent ρ^0 photoproduction from ultra-peripheral Pb–Pb collisions at a center-of-mass energy of 5.02 TeV per nucleon pair. This anisotropy is measured as a function of the impact parameter of the collision, estimated classifying the events in nuclearbreakup classes defined by neutron emission. The ρ^0 mesons are detected by the ALICE experiment through their decay into a pion pair. The anisotropy occurs as a function of ϕ, defined as the azimuthal angle between the two vectors formed by the sum, and the difference, of the four-momentum of the pions, respectively. It results in a $\cos(2\phi)$ modulation of the photoproduced ρ^0; the amplitude of the modulation is found to increase by about one order of magnitude from large to small impact parameters. This trend has been found to be compatible with the available theoretical predictions.

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First results on Timing Performance of Monolithic sensors with additional gain for the future ALICE 3 experiment

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The ALICE Collaboration has submitted a proposal for a next-generation heavy-ion experiment, named ALICE 3, to be installed during the LHC Long Shutdown 4. The key features of this new experimental apparatus will be an exceptional pointing resolution and an excellent Particle IDentification (PID) capability. A Time-Of-Flight system, made of silicon sensors, with an outstanding time resolution of 20 ps will, hence, play a crucial role.
To achieve this goal fully depleted CMOS sensors with an additional gain are under investigation. A vigorous R&D is needed as the time resolution of CMOS sensors needs to be pushed significantly beyond present state of-art to meet the demanding requirements of future-generation experiments. The results of the simulations performed to design the CMOS sensors with an additional gain will be presented. In addition, the experimental results obtained with the test of the first prototypes produced with a 110 nm technology will be shown.

Quark Gluon Plasma I / 24

Flash Q&A

Nuclear Structure and Reactions I / 153

Nuclear physics at LNS: recent results and future perspectives (Invited)

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The INFN-Laboratori Nazionali del Sud (INFN-LNS) represent a well-established international research reality of INFN.
The research activity is mainly devoted to basic nuclear physics and nuclear and particle astrophysics. Pivotal research activity is also in multidisciplinary fields such as accelerator physics, plasma physics, nuclear physics for medicine, biology, environmental and cultural heritage. In June 2020, the accelerators have been turned off to start the upgrade of the entire infrastructure, mainly aimed at the production of high intensity light ion beams (12<A<20, power up to 10 kW) accelerated with the Superconducting Cyclotron. The high intensity program, including the determination of the nuclear matrix elements (NME) of the double beta decay and the study of EOS for nuclear matter with large neutron content, is expected by 2025. New projects are under construction, such as PANDORA, BCT-iLUCE and large-scale expansion projects such as Km3NET. In this presentation, I will provide an overview of existing activities, focusing on some recent results in the field of nuclear physics, such as the one relating to the determination of the proton-proton scattering length deprived of the Coulomb interaction, functional to test the charge symmetry breaking in the nucleon-nucleon interaction.

Nuclear Structure and Reactions I / 112

Re AGATA campaign at LNL

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The Advanced GAmma Tracking Array (AGATA) is an European, state-of-the-art gamma-ray spectrometer used for nuclear structure studies, recently installed at Laboratori Nazionali di Legnaro. On behalf of the GAMMA collaboration of CSN3, I will present recent results obtained with stable TANDEM-ALPI-PIAVE beams in different regions of the nuclide chart. I will talk about the current experimental campaign with the PRISMA magnetic spectrometer and other ancillary detectors and I will briefly introduce the future zero-degree campaign.

Nuclear Structure and Reactions I / 114

Re three-nucleon correlation function

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In the past few years the femtoscopy technique has been applied in high-energy pp and p– Pb collisions at the Large Hadron Collider (LHC) to study the residual strong interaction between hadrons.

In such collisions, particles are produced and emitted at relative distances of the order of a femtometer, in the range of the nuclear force. The effect of the mutual interaction between hadrons is reflected as a correlation signal in the momentum distributions of the detected particles which can be studied using correlation functions. The latter incorporate information on the emission process as well as on the final state interaction of the emitted pairs at the femtoscopic scale. Therefore, by measuring correlated particle pairs at low relative energies and comparing the yields to theoretical predictions, it is possible to perform a new study of the hadron dynamics.

Recently, the *ppp* and *pd* correlation functions have been measured by the ALICE Collaboration. The interpretation of these measurements require a correct treatment of the three-nucleon scattering wave function which has to be used as input in the computation of the corresponding correlation functions. This observable reflects a complex structure when the three hadrons have low relative momenta mainly due to the contribution of the different partial waves. Traditional low-energy scattering experiments with three free hadrons in the ingoing channel are currently not yet available. Therefore, in the *ppp* case, the femtoscopic measurement gives a unique opportunity to study a $3 \to 3$ scattering process. In the *pd* case a very detailed discussion has been recently performed, showing that the description of the data is possible when a very sophisticated *pd* scattering wave function is used.

In the present contribution I will review the achievements in the description of the *ppp* and *pd* correlation functions and show preliminary results in the case of the *ppΛ* correlation function.

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Multi-channel analysis of the ^{18}O + ^{48}Ti reaction at 275 MeV within the NUMEN project

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In the last years, double charge exchange (DCE) nuclear reactions have gained an increasing interest due to their close analogies to neutrinoless double beta ($0\nu\beta\beta$) decay [1]. On this ground, the NUMEN project [2] proposed an innovative method to deduce data-driven information on the nuclear transition matrix elements for the candidate isotopes to $0\nu\beta\beta$ decay by measuring DCE cross sections. In this context, the ^{18}O + ^{48}Ti collision at 275 MeV incident energy was studied for the first time, with ^{48}Ti being the daughter nucleus of ^{48}Ca in the $0\nu\beta\beta$ process [3]. The measurements were performed at the INFN - Laboratori Nazionali del Sud in Catania, using the MAGNEX magnetic spectrometer [4]. A full understanding of DCE reactions is a complex task since different reaction mechanisms contribute to the measured DCE cross section. For this reason, a multi-channel approach is adopted, where DCE reactions are investigated not as stand-alone processes, but as a part of a network of nuclear transitions which includes elastic and inelastic scattering, one- and two-nucleon transfer reactions, and single charge exchange reactions [1,5]. The study of elastic and inelastic scattering gives access to the optical potential and nuclear deformations, respectively, which are key ingredients for the theoretical description of all the reaction channels [6]. The analysis of one-nucleon transfer reactions is fundamental to understand the degree of competition between the DCE process and successive nucleon transfer reactions, as well as to probe single-particle configurations in the nuclear many-body wave functions [7,8]. In this contribution, the status of the multi-channel study of the ^{18}O + ^{48}Ti system will be presented.

[1] F. Cappuzzello *et al.*, Prog. Part. Nucl. Phys. 128 (2023) 103999
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Recent results on clustering investigation from the CHIRONE collaboration

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The research on cluster states in neutron-rich nuclei has achieved recent developments within the CHIRONE collaboration of the Laboratori Nazionali del Sud of INFN (CSN3). Here, by means of the FRIBs facility [1], it was possible to produce radioactive beams of considerable scientific interest for the investigation of cluster physics, also obtaining notable results [2, 3]. In the next years, the new FRAISE facility [4], still under construction, will be completed, giving the possibility to produce radioactive ion beams (RIBs) of high purity and intensity, in order to study complex phenomena in unstable nuclei, almost at the limit of proton and neutron drip lines. New recent results on the CLIR experiment will be discussed, on the study of cluster break-up states in neutron-rich ions, using the CHIMERA [5] and FARCOS [6] detectors. Crucial for this measurement was the presence of FARCOS detectors with high angular and energy resolution, positioned at a small angle in order to increase the detection efficiency of possible cluster break-up products in radioactive ions of interest. Moreover, some preliminary results on 10Be spectroscopy will be discussed.

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Emergence of triaxiality in 74Se from electric monopole transition strengths

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The 2+2 state in non-doubly-magic, even-even nuclei is commonly interpreted as due to a collective excitation. In the vibrational and rotational limits, this state originates from vibrations around the ground-state shape. Even though these basic paradigms are known to represent only a first-order approximation of the nuclear structure, they are still used for classifying isotopes throughout the chart of the nuclides and as a basis for more complex theoretical approaches. Nevertheless, since the appearance of low-energy nuclear vibrations has been debated in the recent literature, the possible vibrational interpretation of the 2+2 state also needs to be carefully reanalysed.
Monopole transitions (E0) are an ideal tool to investigate nuclear structure because they are related to the radial distribution of the electric charge inside the nucleus. Therefore, monopole transition strengths ρ2(E0) are sensitive to changes in the shape of the nuclear states. In particular, this observable is zero if the shape of the two involved states is the same and/or if there is no configuration mixing between their wavefunctions. Noteworthy,
the ρ2(E0) value between the first two 2+ states is zero in both the vibrational and axially-symmetric rotational limits. A surprising result has been recently obtained in the Ni isotopic chain, where large ρ2(E0; 2+2 → 2+1) values have been measured. Apart from simple models, a more sophisticated method based on the shell model was also applied to explain these large ρ2(E0) values, unsuccessfully.
Selenium isotopes are thought to be collective in their low-lying structure. Which kind of collectivity, however, is still a matter of debate. A nearly spherical-vibrational scenario was suggested for 74Se in a recent β-decay study. The anomalous low energy of the 0+2 state, which is a member of the two-phonon multiplet in this case, was explained as due to the mixing between the 0+2 state and the intruder, strongly-deformed 03 state. While this interpretation explains several observables in 74Se, others are not reproduced. If this picture is correct, the ρ2(E0; 2 +2 → 2 1) value should be negligible and the ρ (E0; 0 3 → 0 2) value should be large. Noteworthy, former studies identified the 0+2 state as another shape-coexisting state, and the 2+ state as the band-head of a γ-band.
Given the most recent suggestions regarding the appearance of multiple-shape coexistence in the neighbouring Ni isotopes, and the emerging role of triaxiality in the nearby 76 Se and the close Ge and Zn isotopes, further investigation in 74Se is required.
This contribution presents new experimental results regarding internal conversion coefficients and monopole transition strengths in 74Se. A large ρ2(E0; 2+2 → 2+1) value has been measured, with a magnitude comparable to those in the close Ni isotopes, while the ρ2(E0; 0+3 → 0+2) value has been deduced to be small. Also, for the first time microscopic Beyond-Mean-Field (BMF) calculations for 74 Se will be present, and the role of triaxiality in this isotope discussed.

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Flash Q&A

Nuclear Astrophysics II / 156

Study of reactions of astrophysical interest with indirect methods (Invited)

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The understanding of stellar structure and evolution is strictly related to the possibility of energy production in a star. Indeed, nuclear processes generate the energy that makes stars shine. The same nuclear processes in stars are responsible for the synthesis of the elements. The theory of this building of elements is called nucleosynthesis and it is remarkably successful in predicting how these processes are based on the quantum mechanical properties of atomic nuclei. Nucleosynthesis, nuclear energy generation in stars, and other topics at the intersection of nuclear physics and astrophysics make up the science of nuclear astrophysics. The conditions under which the majority of astrophysical reactions proceed in stellar en- vironments make it difficult or impossible to measure

them under the same conditions in the laboratory. For example, the astrophysical reactions between charged nuclei occur at ener- gies much lower than the Coulomb barrier, therefore, the cross sections of these processes are very small (of the order of nano-picobarn) in the energy windows of astrophysical interest. It seems evident that the experimental determination of these cross sections is greatly hampered by the effects of penetration of the Coulomb barrier, which generally reduces the number of useful events for the experimental investigation. The behaviour of the direct cross sections is usually extrapolated from higher energies to the astrophysical interest region by using the definition of the astrophysical factor $S(E) = E\sigma(E)\exp(2\pi\mu)$ which varies smoothly with energies. Nevertheless this extrapolation procedure can introduce some uncertainties due, for example, to the presence of unexpected subthreshold resonances. In order to avoid the extrapolation procedure, a number of experimental solutions were proposed in direct mea- surements for enhancing the signal-to-noise ratio. However, the measurements in laboratory
at ultralow energies suffer from the complication due to the effects of electron screening.
To overcome the experimental difficulties, in the last decades many indirect techniques and alternative methods have been developed to determine reaction rates of astrophysical interest. A selection of these methods, mainly used among the INFN groups, will be presented.

Nuclear Astrophysics II / 69

Dark matter effects on the thermal properties of the neutron star

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Motivated by theoretical inquiries into the effective capture of dark matter by neutron stars, this study delves into the potential indirect impacts of captured dark matter on the cooling process of a neutron star. Utilizing the relativistic mean-field formalism with the IOPB-I parameter set, we derive the equation of states for various configurations of dark matter-admixed stars at finite temperatures. Our findings reveal significant alterations in neutrino emissivity, influenced by variations in dark matter momentum and specific neutrino-generating processes within the star. We also investigate the specific heat and thermal conductivity of dark matter-admixed stars to understand the propagation of cooling waves within the star's interior. The study explores the correlation between theoretical surface temperature cooling curves, equation of state, chemical composition of stellar matter, and observational thermal radiation data from diverse sources. Notably, we observe that dark matter-admixed canonical stars with dark matter momentum exceeding 0.04 adhere to a fast cooling scenario. Additionally, we calculate the metric for the internal thermal relaxation epoch with different dark matter momentum, concluding that an increase in the dark matter segment amplifies the cooling and internal relaxation rates of the star.

Nuclear Astrophysics II / 119

Direct and Indirect measurement of 22Ne(α,γ)26Mg

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The reaction 22Ne(α,γ)26Mg is associated with several open questions in nuclear astrophysics and plays a crucial role in constraining stellar models. Among other scenarios, it is pivotal in the creation

of elements heavier than iron. A reliable evaluation of the stellar reaction rate at the energy of astrophysical interest must consider all the possible excited states of the compound nucleus 26Mg. Due to very low stellar energies and therefore very low cross sections direct experiments in surface laboratories have so far only provided highly uncertain data.

As first step, an indirect measurement of 22Ne(α,γ)26Mg reaction will be held to probe the excited states of 26Mg in the astrophysically relevant energy range.
The 26Mg states will be selectively populated via the α-transfer reaction in inverse kinematics 7Li(22Ne, t)26Mg. The triple coincidence among the recoil mass separator EMMA, the highly segmented tracking gamma-ray spectrometer TIGRESS and silicon detectors for the light ejectile allows for the extraction of the properties of the populated excited level of 26Mg and hence the identification of potential α-cluster configurations around the particle threshold energy.

The measurements will be performed at the TRIUMF laboratory in Vancouver, Canada and represent a first step for the evaluation of the cross-section measurements for 22Ne(α,γ)26Mg, followed by a direct measurement in the reduced background environment provided by the Bellotti Ion Beam Facility at LNGS, Italy. A detailed simulation of the setup to be used underground is ongoing and first tests of the gamma-ray detectors will start this spring. We present the current status of the project and an overview of the planned TRIUMF experiment.

Nuclear Astrophysics II / 107

Glitches in rotating supersolids

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Glitches, spin-up events in neutron stars, are of prime interest as they reveal properties of nuclear matter at subnuclear densities. We numerically investigate the glitch mechanism due to vortex unpinning using analogies between neutron stars and dipolar supersolids. We explore the vortex and crystal dynamics during a glitch and its dependence on the supersolid quality, providing a tool to study glitches from different radial depths of a neutron star. Benchmarking our theory against neutron star observations, our work will open a new avenue for the quantum simulation of stellar objects from Earth.

Nuclear Astrophysics II / 89

Effect of thermal composition fluctuations in quark nucleation

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At the extreme densities reached in the core of neutron stars and related astrophysical phenomena, deconfined quark matter might take place. The formation of this new phase of strongly interacting matter is likely to occur via a first-order phase transition for the typical temperatures reached in astrophysical processes. The first seeds of quark matter would form through a process of nucleation

within the metastable hadronic phase.
I will discuss the role of the thermal fluctuations in the hadronic composition on the nucleation of three-flavours quark matter and its implication for the phenomenology of compact stars.

Nuclear Astrophysics II / 45

Flash Q&A

Hadronic Physics II / 148

Hadron spectroscopy in the light sector: the on-going experimental programs. (Invited)

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The study of baryonic excited states provides fundamental information on the internal structure of the nucleon and on the degrees of freedom that are relevant for QCD at low energies. N* are composite states and are sensitive to details about how quarks are confined. Meson photo-and electroproduction reactions have provided complementary information on light quark baryon spectroscopy for several decades, but a crucial step forward has been the advent of large solid angle detectors, together with polarized beam and targets, which gave access to single and double polarization observables. The Q2 dependence of excited baryons electro-couplings has also been measured, gaining insight into the internal structure of baryons and providing a signature in the search for hybrid hadrons, in which gluons appear as constituent components beyond the valence quarks.
An overview of the experimental program dedicated to light flavor hadron spectroscopy will be reported. In particular topics relevant for Jlab, MAMI, ELSA, and for future prospects at the Electron Ion Collider (EIC) will be presented, such as the emergence of the mass of the nucleon, the search for exotic states and the properties of dense systems of gluons.

Hadronic Physics II / 63

Overview and performance of the ePIC Silicon Vertex Tracker

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The Electron-Ion Collider (EIC) at the Brookhaven National Laboratory will allow to study the collisions of polarized electrons with polarized protons and ions. The measurement of scattered electrons and charged particles will provide the main ingredients to extract the physics information. The ePIC (electron-Proton/Ion Collider experiment) detector consists of barrel, forward, and backward detectors to achieve a precise tracking and particle identification over a wide pseudo-rapidity ($|\eta| < 3.5$) coverage. The central tracking detector relies on three innermost silicon layers with a very small material budget (~0.05% X0 per layer), two silicon barrel layers (with ~0.25 % and ~0.55 % X0, respectively), an inner micro-pattern gas detector (MPGD) layer (~0.50% X0) followed by a time-of-flight

(TOF) layer (∼1.0% X0) and an outer MPGD layer (∼1.50% X0). Forward and backward disks allow the reconstruction of particles at larger η. The three innermost silicon layers are based on a new MAPS generation in 65 nm CMOS imaging technology being developed by ALICE ITS3. Barrel layers and disks will use a variation of such sensor with

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Jefferson Labs secondary beams for nuclear physics

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Intense secondary beams of muons, neutrinos, and (hypothetical) dark scalar particles result from the interaction of the CEBAF 10 GeV high-current electron beam O(100 uA) and the Hall-A beam dump. While most radiation (gamma, electron/positron) is contained in the thick absorber, deep-penetrating particles (muons, neutrinos, and light-dark matter particles) propagate over a long distance, generating high-intensity secondary beams that can be used for several studies. High-intensity muon beams have applications in many research fields spanning from fundamental particle physics to materials science or inspection and imaging (e.g. elastic muon-proton scattering offers an alternative method to measure the proton charge radius). Decay at rest neutrinos are suitable for studying coherent elastic neutrino-nucleus scattering (CEvNS). Experiments designed to observe CEvNS events provide a unique opportunity to precisely measure the weak mixing angle as well as other nuclear properties (e.g. the neutron skin of heavy nuclei). Similarly, light-dark matter searches could take advantage of the large electron charge dumped on the Beam-Dump competing with leading experiments planned at CERN or FNAL.

Hadronic Physics II / 73

Silica aerogel characterization for the ePIC dRICH detector

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The ePIC detector is specifically designed to address the entire physics program at the Electron-Ion Collider (EIC). It consists of several sub-detectors, each tailored to address specific physics channels. One of the key sub-systems of ePIC is the dual-radiator Ring Imaging Cherenkov (dRICH) detector, which is a high-momentum particle-identification system located in the hadronic end-cap. For this purpose, silica aerogel has been chosen as a solid radiator.
The optical and geometrical characteristics of the aerogel tiles play a critical role in enhancing the Particle IDentification (PID) performance. Intensive R&D efforts are currently underway to optimize these properties. Ongoing studies are focused on defining and refining the aerogel tiles to ensure optimal performance. The measurement of the transmittance of 34 aerogel tiles with different refractive indices, including the setup and the measurement method, will be presented.

Hadronic Physics II / 61

A large-area prototype SiPM readout plane for the ePIC-dRICH detector at the EIC: realisation and beam test results

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Silicon photomultipliers (SiPM) are selected as the photodetector technology for the dual-radiator RICH (dRICH) detector of the ePIC experiment at the future Electron-Ion Collider (EIC). A large-area prototype readout surface consisting of a total of 1280 3 x 3 mm^2 SiPM sensors was recently built and installed on the dRICH prototype during a beam test in October 2023 at the CERN-PS. The SiPM prototype readout is based on a novel EIC-driven prototype photodetection unit (PDU) developed by INFN from a concept that integrates all SiPM services (cooling, front-end and readout electronics) in a ≈5 x 5 x 14 cm^3 volume. A few PDU detector prototypes have been realized featuring the full electronics chain for the readout of the SiPM sensors, based on the second version of the ALCOR chip developed by INFN Torino.

In this presentation I will discuss the features of the dRICH SiPM photodetector unit and the details that lead to the realization of a successful beam test at CERN-PS in October 2023. The results from the analysis of the beam test data will also be presented to highlight the performance of the new SiPM detector readout surface. An approach based on machine learning is also explored for Cherenkov image reconstruction and compared to classical ring reconstruction algorithms.

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Characterization of the photosensor and performance studies for the dRICH detector of the ePIC experiment at the future Electron-Ion Collider

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Silicon Photomultiplier (SiPMs) are solid-state photodetectors used for detecting light at the level of individual photons, employing avalanche multiplication as an internal gain mechanism. They have the advantage of high photon efficiency, excellent time resolution and are insensitive to the magnetic field. SiPMs are the baseline technology to equip the dual-radiator RICH detector (dRICH) of the ePIC experiment at the future Electron-Ion Collider (EIC).
We present the characterization of various types of SiPMs. Like many other detection devices, SiPMs are not immune to noise. One of the negative aspects of SiPMs is the presence of a Dark Count Rate (DCR), a phenomenon in which a SiPM generates electrical signals even in the absence of external interactions from particles or photons. This occurs due to the spontaneous thermal generation of electron-hole pairs in the semiconductor material of the detector. Such signals can be mistakenly interpreted as signals from incident light. Radiation damage is one of the main concerns when using these devices at accelerators. The effect of radiation on silicon detectors can be quite complex and depends on various factors, including the type of radiation, particle energy, radiation dose, exposure duration, as well as the specific characteristics of the detector itself. Irradiation can cause damage to the crystalline structure of the semiconductor material in the silicon photomultiplier (SiPM). These damages can increase the probability of generating free charge carriers, contributing to the increase in dark current and in DCR, as they can generate unwanted signals similar to those generated by incident light.
To estimate radiation damage in the sensors, they have been exposed to different radiation doses using the proton beam available at the Centro di Prontonterapia in Trento. These studies are essential to understand how to ensure optimal performance of the dRICH detector over an extended period, and consequently to confirm that SiPMs are the best sensors option for such detector. We will also discuss the separation of pions and kaons achievable with ePIC dRICH, exploring their dependence on particle momentum and selected pseudo-rapidity ranges. Finally, we will show how the resolution on the Cerenkov angle changes in the presence of noise.

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FLASH (Q&A)

Applications of Nuclear Physics III / 150

Quantum Computing for Nuclear Physics (Invited)

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With the recent experimental realization of quantum computing devices containing tens to hundreds of qubits and fully controllable operations, the theoretical effort in designing efficient quantum algorithms for a variety of problems has seen a tremendous growth worldwide. In this talk I will discuss the potential impact of quantum computing for application in nuclear physics and present some recent results of quantum simulations for simple nuclear models on current generation devices.

Applications of Nuclear Physics III / 56

Imaging methods for in-vivo Boron Neutron Capture Rerapy

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Boron Neutron Capture Therapy (BNCT) is an innovative and highly selective treatment against cancer. Nowadays in-vivo dose measurements and monitoring are important issues to carry out such therapy in clinical environments. In this work, different imaging methods were tested for dosimetry and tumor monitoring in BNCT based on a Compton camera detector. A dedicated data-set was generated through Monte Carlo tools to study the imaging capabilities. First, the Maximum Likelihood Expectation Maximization iterative method was applied to study dosimetry tomography. As well, two methods based on morphological filtering and Convolutional Neural Networks respectively, were studied for tumor monitoring. The results of each method and clinical aspects such as dependence by boron concentration ratio in the image reconstruction, and the stretching effect along the detector position axis will be discussed during this talk.

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A unique model to accurately describe low and high LET particle beam biological response

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Assessing the biological impact of radiation relies on understanding the fundamental interactions between radiation and matter. This is particularly essential in various fields, including radiotherapy cancer treatment. To link the physics of radiation to its biological effect, mathematical mechanistic models have been proven powerful tools. Consequently, developing an accurate and reliable model for predicting cell killing from specific irradiation patterns becomes imperative for improving our knowledge of the biological effectiveness of radiation.
Current mechanistic radiobiological models face limitations in offering a comprehensive description across a diverse spectrum of particle species and energies. Different ions with distinct energies yield various biological responses due to significant differences in the underlying radiation patterns. One of the most relevant situations is verified in the case of extremely high Linear Energy Transfer (LET), defined as energy deposited per unit length. In this regime, the overkill effect is observed, where there is a decrease in the biological effect as the LET increases. This contrasts with the conventional relationship where an increasing LET typically results in a higher biological response.
The Generalized Stochastic Microdosimetric Model (GSM2) [2,3] has been developed as a new mechanistic and probabilistic model, which describes the time-evolution of the DNA damages in a cell nucleus by considering the stochastic description of energy deposition. Among the most relevant strengths is the capability to efficiently treat several levels of spatiotemporal stochasticity in a broad range of particle species and energies [4].
In this study, we predict the Cell Surviving Fraction (SF) of an irradiated cell culture from the experimental work conducted by [1] using GSM2. First, an extensive study is conducted about the impact of the sensitive target volume size on the radiation-induced damage predicted by GSM2. This leads to a two-scale description of the radiation-induced damage. The experimental irradiation conditions have been accurately reproduced with Monte Carlo codes simulations, using TOPAS [5,6] as the MC toolkit. Then, the SF curves are predicted for two different cell-culture lines and three kinds of radiation quality: protons, Helium ions, and Carbon ions. The strength of the model is exploited with matching predictions for all three types of radiation fields in a completely general way and a very wide range of LET. This range covers two orders of magnitude: from 1 keV/μm to around 100 keV/μm (Figure 1). Moreover, the model's power is fully displayed with a natural mechanistic prediction of the overkill effect directly from radiation physics.
We show the complete generality and ability to successfully predict the SF considering the stochasticity inherently given by the nature of radiation fields interacting with matter.

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A model for particle beams response at Ultra-High Dose Rate including LET and oxygenation interplay effects

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FLASH radiotherapy is a novel technique based on Ultra-High Dose Rate (UHDR) irradiation (i.e., an overall dose rate > 40 Gy/s for a single dose > 10 Gy), which allows obtaining fewer side effects on healthy tissue and unchanged tumor effectiveness with respect to conventional delivery. In recent years, much experimental evidence [Schüler et al. Med. Phys. (2022)] confirmed this FLASH effect; however, the underlying mechanism remains largely unexplained.

Since the involvement of multiple scales of radiation damage has been suggested [Weber et al. Med. Phys. (2022)], in particular, the crucial role of the chemical environment has been underlined, and the development of multi-stage tools capable of investigating this radiobiological effect is crucial. Therefore, in this context, we developed the MultiScale Generalized Stochastic Microdosimetric Model (MS-GSM2) [Battestini et al. Front. Phys. (2023)], that is able to capture several possible effects on DNA damage at the UHDR regime. In particular, we extend the GSM2 [Cordoni et al. Phys. Rev. E (2021), Cordoni e .al. Rad. Res. (2022)], a probabilistic radiobiological model, coupling the slow time evolution of DNA damages in a cell nucleus to the fast chemical reaction kinetics [Labarbe et al. Radiother. Oncol. (2020)], with the possibility of describing different levels of spatiotemporal stochasticity, in physics, in chemistry and biology (Figure 1).

We study the combined effects of several chemical species and the formation and time evolution of DNA damage, for different dose delivery time structures, oxygenation conditions, and radiation qualities, including high Linear Energy Transfer (LET) beams. We assume that UHDR modifies the chemical environment, which implies a reduction in the indirect DNA damage yield only at UHDR. Further, this effect is more pronounced at high doses (Figure 2), reproducing experimental evidence (Figure 3), such as the larger sparing of healthy cells occurring at the FLASH regime observed, for example, with Carbon ions [Tinganelli et al. Int. J. Radiat. Oncol. Biol. Phys.(2021)].

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Bulk MgB2 superconductor for Nuclear Physics experiments

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In my talk I will illustrate the studies carried out at INFN-Ferrara on a novel idea of using bulk MgB_2 superconductor as replacement of conventional superconducting magnets in particle physics experiments.
The advantages of this technology are many: possibility to use almost arbitrary shape/size; no need of current leads (reduced heat-load and size); no power consumption (beyond cooling) once stable conditions are reached; high magnetic field (with preset setup we easily reached ~1 T with limited material budget, few mm of MgB_2 only, since the copper quench shield is not required).
Furthermore it can be used both as a magnet (i.e. to generate/trap a magnetic field, for example to hold the polarization of a target) and also as a shield from strong external fields.
I will present the studies initiated on a first tube of MgB_2 (actually a scrap, with irregular shape) and continued with new samples produced with different "recipes" and dimensions.
The results are promising in both configurations: with an external dipole field of ~ 1T, a trapped field of ~0.9T or a shielding of 90% (thus measuring a penetrating field of only ~0.1T) could be obtained despite the unconventional geometry (tube).

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FLASH (Q&A)

EPS / 65

Re European Physical Society and its Nuclear Physics Division (Invited)

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The European Physical Society (EPS) will be described.
Starting from its birth on 1968, the actual objectives, the organization and the governance will be illustrated, as well as the prizes, awards and distinctions recognized by the EPS for the excellence and contributions to the community.
Particular attention will be devoted to the Nuclear Physics Division (NPD), highlighting all aspects of general interest in the field of experimental, theoretical or applied nuclear science.

Symmetries and Fundamental Interactions / 90

Re X17 boson anomaly: overview and forthcoming experiments (Invited)

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Three significant anomalies have been observed in the emission of electron-positron pairs in the $^{7}Li(p,e^{+}e^{-})^{8}Be$, $^{3}H(p,e^{+}e^{-})^{4}He$ and $^{11}B(p,e^{+}e^{-})^{12}C$ nuclear reactions [1–3] that have been interpreted as the signature of a boson (referred to as X17) of mass $M_{X17} \simeq 17$ MeV/c^2 that could be the mediator of a fifth force, characterised by a strong suppression of the coupling to protons compared

to neutrons (protophobic force) [4]. Beyond the importance of such a discovery –if confirmed – this scenario could explain, at least partially, the long-standing (recent) anomaly on the muon (electron) magnetic moment [5]. More in general, the possible existence of this particle would be of paramount importance in particle physics and in cosmology (dark matter). For this reason, it has spurred various experiments addressed to verify the X17 boson claim and eventually to shed light on its properties. In this talk the present X17 boson scenario is summarised and new dedicated proposals are discussed.

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Symmetries and Fundamental Interactions / 151

Re CERN Antimatter Factory: testing the Equivalence Principle, the CPT symmetry, and beyond (Invited)

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The Antimatter Factory at CERN, comprising the AD and ELENA particle decelerators, is a unique facility for experimental research with low-energy antiprotons. During its 20 years of activity, its main goal has been to allow forming (in combination with cold positrons plasma techniques) and studying cold antihydrogen atoms, as well as to deepen the investigations started at LEAR of the antiproton properties (mass, magnetic momentum) and its exotic compounds with matter (e.g. antiprotonic helium). The main physics drives of the facility were to test the Charge, Parity, and Time (CPT) symmetry and, more recently, the Equivalence Principle with antimatter, both pillars of relativistic quantum field theories and metric theories of gravity, respectively.

An overview of the accurate tests of the CPT symmetry performed by the experiments in the Antimatter Factory over the years is presented. Among the several, the accurate determinations of the proton/antiproton charge-to-mass ratio with single particle techniques (ATRAP 1 and BASE 2 collaborations), the spectroscopic surveys of antihydrogen (ALPHA collaboration3), and antiprotonic helium (ASACUSA collaboration [4]), are the most sensitive to date.
The possibility to measure the gravitational coupling between matter and antimatter is, on the other hand, a novelty of the most recent years. Very recently, a first direct measurement of the sign of this coupling was obtained by releasing trapped antihydrogen atoms from a vertical magnetic trap and measuring the vertical anisotropy in their annihilation spatial (ALPHA-g collaboration [5]). This result came only a year later than the first model-independent (yet assuming perfect CPT invariance) test of the Equivalence Principle with antiprotons, obtained by searching for a yearly modulation in the cyclotron frequency of single trapped antiprotons as the Earth orbits elliptically in the Sun's gravitational potential (BASE collaboration 2).
Other techniques are also being investigated at the same time by other collaborations, from measuring the horizontal deflection of a pulsed free-falling antihydrogen beam in the absence of external fields (AEgIS collaboration [6]) to forming, sympathetically cooling and photo-ionizing positive antihydrogen ions to get an ultracold sample of free-falling antihydrogen atoms (GBAR collaboration [7]).
Beyond testing CPT and the EP with antimatter, several other activities are ongoing at the Antimatter Factory. These range from developing portable antimatter traps, such as those in the BASE-STEP and PUMA collaborations, to studying nuclear physics with antiprotonic atoms. Additionally, some collaborations are actively searching for dark matter candidates and developing the research field of positronium (Ps), a short-lived atomic bound state of an electron and a positron, originally introduced as an intermediate step to form antihydrogen. Ps is an alternative testing ground for CPT and

the EP, complementary to antihydrogen being purely leptonic and constituted by 50% antimatter mass on-shell. Active research is being conducted to first laser cool it (AEgIS collaboration), as well as produce unprecedented densities to form the positive antihydrogen ions (GBAR collaboration). These two techniques may lead, in the mid-term future, to the first Bose-Einstein condensation of antimatter.

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Symmetries and Fundamental Interactions / 84

Re status of the FAMU experiment

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The goal of the FAMU experiment is the measurement of the hyperfine splitting of the mounic hydrogen ground state. This measurement gives an accurate insight of the proton's magnetic structure, plays a key role in veryfing the most accurate QED calculations and tests the interaction between proton and muon. The hyperfine splitting transition is detected by exciting muonic hydrogen using a unique high enery mid-infrared laser developed on purpose by our collaboration. The FAMU experiment is installed at the Rutherford Appleton Laboratory in the United Kingdom. It has been taking data since October 2023 at the pulsed muon beam line of the proton syncroton accelerator. In this contribution, the status of the experiment, its capabilities, and its future development are presented.

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Kaonic atoms at the DAFNE Collider in Italy: a strangeness Odyssey

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The low-energy QCD, the theory within the Standard Model describing the strong interaction, is still missing fundamental experimental results in order to achieve a breakthrough in its understanding. Among these experimental results, the low-energy kaon-nucleon/nuclei interaction studies are playing a key-role, with important consequences going from particle and nuclear physics to astrophysics (neutron stars and their equation of state).

Combining the excellent quality of the low-energy kaon beam delivered by the DAΦNE collider in Frascati (Italy) with new experimental techniques, as fast and very precise X-ray detectors, like the Silicon Drift Detectors, we have performed unprecedented measurements in the low-energy strangeness sector in the framework of the SIDDHARTA Collaboration and are presently running the SIDDHARTA-2 experiment for the challenging kaonic atoms measurements, such as kaonic deuterium first measurement.
I shall introduce the physics of kaonic atoms, the experiment and the first results, and discuss future plans.
The experiments at the DAΦNE collider represents an unique opportunity in the world to, finally, unlock the secrets of the QCD in the strangeness sector and contribute to better understand the role of strangeness in the Universe, from nuclei to the stars.

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Momentum dependent nucleon-nucleon contact interactions and their effect on p-d scattering observables

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Starting from a complete set of relativistic nucleon-nucleon contact operators preserving parity and time reversal symmetries up to order $O(p^4)$ of the expansion in soft momenta p, we show that non-relativistic expansions of relativistic operators involve twenty-six independent combinations: two starting at $O(p^0)$, seven at order $O(p^2)$ and seventeen at order $O(p^4)$. This demonstrates the existence of two low-energy free constants that parameterize an interaction dependent on the total momentum of the pair of nucleons P. These, through the use of a unitary transformation, can be removed along with other redundant terms in the two-nucleon (2N) fourth-order contact interaction (N3LO) of the Chiral Effective Field Theory, generating a three-nucleon (3N) interaction at the same order. We express its short-range component in terms of five combinations of low-energy constants (LECs) that parameterize the N3LO 2N contact Lagrangian.
Within a hybrid approach in which this interaction is considered together with the phenomenological potential AV18, we show that the LECs involved can be used to fit very accurate data on the polarization observables of the low-energy p-d scattering, in particular the A_y asymmetry.

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Radionuclides: state of the art, INFN research and perspectives in production and medical applications (Invited)

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Radionuclides and radiopharmaceuticals are fundamental tools in nuclear medicine, by enabling imaging and treatment in tens of millions of procedures performed worldwide on a yearly basis. In Europe, 9 million patients benefit from nuclear medicine procedures per year, including 1.5 million patients requiring radionuclide therapy against cancer. The production of medical radionuclides is thus a key aspect and emerging radionuclides are being playing a key role in the development of innovative radiopharmaceuticals. The availability of new research infrastructures dedicated to this goal is thus crucial for Europe. For such a reason, in 2021 the PRISMAP consortium was established

as Horizon2020 call, to gather the European research community, first, working in this field. The INFN-LNL takes part in the PRISMAP consortium as an emerging facility, including both the direct activation method (LARAMED project, acronym for LAboratory of RAdioisotopes for MEDicine) and the ISOL (Isotope Separation On-Line) technique (ISOLPHARM project, acronym for ISOL technique for radioPHARMaceuticals), both based on the SPES infrastructure. The ongoing INFN research activities on medical radionuclides production using cyclotrons will be presented, as well as the future perspective of this interdisciplinary research field that presents a strong connection with the nuclear physics community.

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Nuclear fragmentation cross sections measurements: the FOOT experiment

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Nuclear inelastic interactions have an important role in particle therapy, radiation protection and in theoretical nuclear model studies. In particle therapy, the uncertainties on the evaluation of the nuclear inelastic interactions can lead to a miscalculation of the dose deposition evaluated by the treatment planning systems. In addition, a precise estimate of the fragmentation of 16O and 4He ion beams are essential to evaluate the possibility to include these new particles in the clinical practice. As far as radioprotection is concerned, space radiation is of particular interest: the knowledge on the nuclear inelastic interactions is fundamental to develop a proper shielding material for the future long-term and deep-space space missions.

The FOOT (FragmentatiOn Of Target) experiment aims to perform a set of double differential cross section measurements (d2σ/dΩdE) for the projectile fragmentation of 12C, 16O and 4He beams at 200-800 MeV/u on C and C2H4 targets and the differential cross sections (dσ/dE) in p-C and p-O collisions at 200 MeV/u, relevant for the target fragmentation process. The data will be used to benchmark the current Monte Carlo simulation models, which are in general affected by significant uncertainties. In addition, the FOOT experiment can be used also for other studies in nuclear physics. For example, the fragmentation reaction can be exploited in the investigation of the nuclear clustering phenomenon for different α-conjugated nuclei at intermediate energies. This has been a long-standing area of study with different experiments conducted, but mainly at the Coulomb barrier and Fermi energy range.
Two experimental setups have been developed to detect heavy (Z≥3) and light (Z≤3) fragments. The formers are measured by a set of electronic detectors composed of a high precision tracking system in a magnetic field, a time-of-flight measurement system and a calorimeter. Light ions are instead detected by an emulsion cloud chamber spectrometer. Both apparatuses have been employed in different experimental campaigns with beams of 4He, 12C and 16O at different kinetic energies (200-700 MeV/u) on target of graphite and polyethylene (C2H4).

An overview of the FOOT experiment will be given. The capability of the apparatus and the preliminary results on the cross-section measurements will be presented. In addition, we shall discuss some results about the capability of the FOOT experiment to investigate α-clustering phenomena in the fragmentation of 12C and 16O ion beams at 200 and 400 MeV/u, with particular attention to the identification of intermediate channels (e.g.: 12C→8Be+α→3α).

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A method to predict space radiation biological effectiveness for Galactic Cosmic Rays and intense Solar Particle Events

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Space research is object of a renewed interest, also considering that human missions to the Moon, and possibly Mars, are being planned. Astronauts'exposure to space radiation is one the highest-priority problems. In the framework of the ARES project funded by INFN, we developed and applied the BIANCA biophysical model to calculate absorbed, equivalent and effective doses following astronauts'exposure to Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) under different shielding conditions. More specifically, BIANCA allowed calculating the relative biological effectiveness (RBE) both for cell killing, which is related to non-cancer effects, and for chromosome aberrations, which are related to the induction of stochastic effects
including cancer. The calculations were performed first in a water phantom and then in the reference male and female computational phantoms recommended by ICRP.
The results were then compared with astronauts'dose limits for cancer and non-cancer effects. Concerning GCR exposure, the equivalent doses calculated multiplying the absorbed dose by the chromosome-aberration RBE were similar to those calculated using the Q-values recommended by ICRP. For a typical 650-day Mars mission at solar minimum, the obtained values were lower than the 1-Sv career limit recommended by ICRP, but higher than the 600-mSv limit recently adopted by NASA. More generally, both at solar minimum and at solar maximum, a 10 g/cm 2 Al
shielding resulted to be a better choice than 20 g/cm 2 . For the August 1972 SPE, a 10 g/cm 2 Al shield was sufficient to respect the 30-day limit for skin and blood forming organs (BFO). For the October 2003 SPE ("Halloween event"), a 5 g/cm 2 Al shield was sufficient to respect these limits. Smaller shielding values were sufficient for the January 2005 event, which had a harder spectrum (i.e., with higher-energy particles) but lower fluence and thus lower dose.
This work showed that BIANCA, interfaced with a radiation transport code, allows predicting GCR and SPE equivalent and effective doses based on the mechanisms underlying cell death and chromosome aberrations.

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XpCalib: a proton computed tomography system for proton treatment planning

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Introduction: The dose computation in the proton treatment planning system (TPS) is based on the proton relative stopping power normalized to liquid water (RSP) distribution in the target volume. Presently, the RSP maps are extracted from x-ray computed tomographies (xCT) of the patient. Namely, the photon attenuation coefficients (CT Hounsfield Units –HU), are translated into RSP values using empirical methods based on conversion tables. These methods introduce an uncertainty on the actual position of the Bragg peak inside the patient, which has to be mitigated by means of the use of safety margins around the target and organs at risk. To avoid this two-step process and to reduce the intrinsic errors, we propose a different approach based on the direct use of 3D RSP maps obtained with a proton computed tomography (pCT) system. Herein, we present the main results of the experiment XpCalib, funded by CSN5 INFN (2020-2023) and based on a pCT system previously developed 1.

Methods: The pCT system, tested at the Trento Proton Therapy Center, is made of four planes of silicon micro-strip trackers and a YAG:Ce scintillating calorimeter 1 (Fig1). A filtered backprojection algorithm, taking into account the protons'most likely path, allowed reconstructing the phantoms' RSP 3D maps. The imaging performances (i.e. spatial resolution, noise power spectrum, RSP accuracy) were assessed on a custom-made phantom, made of plastic materials with different densities (0.66-2.18 g/cm3), in two background conditions (liquid water or air) 2 . Then, moving towards more clinical scenarios, we designed the first clinical application for the INFN proton computed tomography (pCT) system through the realization of biological phantoms 3. Namely, the bio-phantom is made of biologic inserts of a bovine/porcine specimen, stabilized with a formalin solution and embedded in agar-agar gel in a plastic housing (Fig2). Both pCT and xCT images were acquired on these phantoms. The direct, voxel-by-voxel comparison of HU and RSP maps of the biological phantom provides a cross-calibrated xCT calibration curve, i.e. a RSP-HUs look-up table, improving the description provided by the existing calibration methods [4].

Results: Overall, the system results to have imaging performances comparable to the x-ray CT with standard imaging protocol for proton therapy. Moreover, the system is highly accurate, with a mean absolute percentage error on the measured RSP values well below 1% [2,5]. Comparing the bio-phantom data acquired with the pCT system with the one calculated with conventional xCT calibration curve, we obtained that the vast majority of pixel data, falling within regions of fat and muscles, shows differences within 2.46% on average. In the bone region, the conventional calibrations overestimate the pCT-measured SPR of the phantom, with a maximum discrepancy of 4% on average, corroborating previous results in literature. As a result, a new cross-calibration curve is directly extracted from the pCT data in the HU range ([-109, 1536]). Additionally, the associated uncertainty is below 3%, that is less than the standard error of conventional calibration curves adopted in clinics.

Conclusion: The obtained performances showed that the INFN pCT system provides a very accurate RSP estimation, and it can be used as a reference RSP measuring method for the verification of the xCT calibration in proton treatment planning, and, eventually, for the implementation of a new cross-calibration curve. This could allow reducing range uncertainty and margin size in proton therapy treatments.

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Reoretical simulations for innovative nuclear medicine applications: cyclotron production of the theranostic radionuclides ^{47}Sc and ^{155}Tb

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The novel approach of the precision nuclear medicine is tailoring the treatments on the patient instead of adapting the patient to standard therapies. The uniqueness of the patients'response to treatments is now the focus of the latest research. To achieve this goal the use of radiopharmaceuticals suitable for theranostic applications is a valid strategy. Theranostics conjugates diagnosis and therapy exploting the chemically identical composition of the drug used for both imaging and therapy.
Scandium-47 and Terbium-155 are both very promising and innovative radionuclides for precision nuclear medicine and the scientific community currently debates about feasible production routes in compliance with the clinical standards. In view of pre-clinical and clinical applications it is fundamental to produce the radionuclides of interest with high quality. The theoretical analysis is the first and crucial step to identify the optimal production parameters and irradiation conditions, limiting the co-production of those contaminants that could affect the purity of the final product. Nuclear-reaction theory for equilibrium and pre-equilibrium processes is well established and can be employed to simulate the cross sections production of both ^{47}Sc and ^{155}Tb and their main contaminants 1.
Currently, the ^{47}Sc production methods are not adequate to meet the medical standards required for a safe clinical practice. We have investigated the cyclotron routes ^{49}Ti(p,2pn), ^{49}Ti(d,α), and ^{50}Ti(p,α). The theoretical results of the cross sections have been compared with the the new preliminary REMIX data and few old datasets of the literature. To better reproduce the cross sections an optimization through genetic algorithms, inspired by Darwin's theory of natural selection, has been performed. The tuning of the models free parameters of the nuclear level densities allows to improve the theoretical cross sections and to be more precise in the prediction of the activities and radionuclidic purity derived form the cross sections evaluation. The results indicate the d-^{49}Ti channel a promising reaction, possibly also for a ^{47}Sc production by low-energy (hospital) cyclotrons. Similar outcomes are obtained for the reaction with protons on enriched ^{50}Ti targets, while the route p-^{49}Ti results unfeasible for clinics 2.
Regarding ^{155}Tb its interest is on the rise, however its availability in the market with sufficient purity to be adequate for actual applications is still an open issue. Focusing the attention on the level of enrichment of the enriched ^{155}Gd targets we found out that the major contribution to the contamination depends on the amount of ^{156}Gd impurity in the target. Thus, the target purity is the crucial issue and we identified the minimum enrichment necessary for the use of ^{155}Tb as safe imaging agent 3.

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Development of a β imaging detector tailored to Ag-111 for the ISOLPHARM project

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Targeted Radionuclide Therapy (TRT) is an emerging technique for cancer treatment. Radionuclides suitable for this technique could be produced at the Legnaro National Laboratories of the National Institute for Nuclear Physics (INFN-LNL), where a new facility for the production of Radioactive Ion Beams (RIB) called SPES is under construction. The production of radionuclides of medical interest through the ISOL technique is being studied by the ISOLPHARM project.
At the same time, the project is specifically researching Ag-111 as an innovative radionuclide for nuclear medicine. Ag-111 has an interesting theranostic potential because its half-life is about 7 days and it emits both low energy electrons and γ rays. Research on Ag-111 by the ISOLPHARM collaboration started six years ago and has continued with a series of experiments funded by the INFN.
A three-years CSN5 experiment called ADMIRAL is currently ongoing on this topic. One of its goals is to develop a β detector (sensitive to β radiation from Ag-111) that can be used in preclinical experiments. The core of this detector is the ALPIDE chip developed for the ALICE experiment at CERN LHC. This contribution will present a first performance study based on Geant4 simulations together with a preliminary experimental validation obtained with standard β sources.

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Cross-section measurements of different reactions leading to the production of 155Tb for medical applications

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Four of the terbium radioisotopes have great potential as theranostic radionuclides (^{149}Tb, ^{152}Tb, ^{155}Tb, and ^{161}Tb). This work mainly focuses on ^{155}Tb (I_{ec} = 100%, $T_{1/2}$ = 5.32 d). It emits gamma rays with energies suitable for SPECT studies (86 keV, 105 keV) and the absence of β^+/ β^- emissions reduces the radiotoxicity of this radionuclide. The effectiveness of ^{155}Tb for the diagnostic in nuclear medicine has been preclinically proved.
In the framework of the INFN REMIX project, our research involves the measurement of ^{nat}Eu(α,x)^{155}Tb

nuclear reaction cross-section, alongside with the ones of contaminants prevalent in the process. Moreover, we showcase the viability of indirect production through the generator method - ^{155}Dy/^{155}Tb. This entails the proton-induced nuclear reactions on terbium targets to produce ^{155}Dy, with the cross-section of the reaction ^{159}Tb(p,5n)^{155}Dy experimentally measured.
This presentation provides the results of the measurement of nuclear cross sections, offering a comprehensive comparison of the two production techniques with a keen focus on radionuclidic purity (RNP) and specific activity (A_S).
Our findings not only advance the knowledge about the production pathways of ^{155}Tb for theranostic applications but also contribute to the understanding of nuclear processes by enriching the nuclear libraries.

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Flash Q&A

POSTERS

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Detailed information on heavy-ion fusion provided by their sub-barrier slopes

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One of the yet unsettled problems in heavy-ion fusion near and below the barrier is the influence of nucleon transfer couplings with respect to couplings to collective modes on the cross sections. In this contribution, we present a new analysis of several systems, based on the combined observation of the energy-weighted excitation function Esigma in relation to the energy derivative d(Esigma)/dE (slope). We will see that this representation helps our understanding of the reaction dynamics, by complementing the information one obtains from the fusion barrier distribution and from coupled-channels calculations.
We show in the attached figure (left) the two-dimensional plot of d(Esigma)/dE vs Esigma for 48Ca,36S + 48Ca, obtained from Refs. [1, 2]. In this type of plot trivial Coulomb barrier differences between the two systems are eliminated to a large extent. The colliding nuclei are closed-shell or magic, and we see that, at sub-barrier energies, the two data sets are well overlapping. Indeed the Wong formula 3 implies that the slope and the excitation function are proportional to each other for fusion cross sections in that energy range. The proportionality constant is 2pi/hbaromega, i.e. inversely proportional to the second radial derivative of the barrier approximated by a parabola. In the figure (left), the two data sets essentially

coincide (i.e. the two barriers have approximately the same width).
This is not the case for the two other systems (and further ones) reported in the center and on the right panels of the figure. For 40Ca + 96Zr [4] and 58Ni + 64Ni [5] neutron transfer couplings are dominant, and this is reflected in the different behaviour with respect to 40Ca + 90Zr [6] and 64Ni + 64Ni [7], respectively. In either case, the system where transfer couplings are dominant, lies below the other case, meaning that the effective one-dimensional barrier is thinner. This mimics a wider barrier distribution produced by couplings, leading to a cross section enhancement as a function of energy, as it was observed.
A full systematics will be shown in the talk, with more detailed and quantitative considerations for the various cases.

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Heavy single baryons

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I will present a study of the spectra and strong decay widths of heavy baryons. The masses of single heavy baryons up to the D-wave have been calculated within a constituent quark model, employing both the three-quark and quark-diquark schemes. The decay widths of the ground and excited single heavy baryons into the heavy single baryon (vector/pseudoscalar) meson pairs and the (octet/decuplet) baryon- (pseudoscalar/vector) heavy meson pairs have been calculated. Moreover, I will discuss why the presence or absence of the ρ-mode excitations in the experimental spectrum is the key to distinguishing between the quark-diquark and three-quark behaviors. The quantum number assignments and predictions for mass spectra and strong-decay widths are in agreement with the available data. These findings provide valuable guidance for future measurements in experiments such as ATLAS, CMS, LHCb, Belle, and Belle II.

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Production of D-wave states of $\bar{b}c$ quarkonium at the LHC

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We study the hadronic production of D-wave states of $\bar{b}c$ quarkonium. The relative yield of such states is estimated for kinematic conditions of LHC experiments. The direct production is complemented by NRQCD contributions being the same order $calO(v^4)$. The NRQCD matrix elements are estimated within naive velocity scaling rule.

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Optimization of spin-coherence time for electric dipole moment measurements in a storage ring

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Electric dipole moments are very sensitive probes of physics beyond the Standard Model. The JEDI collaboration is dedicated to the search for the electric dipole moment (EDM) of charged particles making use of polarized beams in a storage ring. In order to reach the highest possible sensitivity, a fundamental parameter to be optimized is the Spin Coherence Time (SCT), i.e., the time interval within which the particles of the stored beam maintain a net polarization greater than 1/e. To identify the working conditions that maximize SCT, accurate spin-dynamics simulations have been performed using BMAD. In this study, lattices of a "prototype" storage ring, which uses combined electric and magnetic fields for bending, and a "hybrid" storage ring using only electric bending fields with magnets for focusing, are investigated. This talk presents a model of spin behaviour in frozen-spin lattices that has been verified in both situations, as well as a technique to optimize the second-order beam optics for maximum SCT at any given working point.

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Performance of Analog Pixel Test Structure of monolithic sensors with Operational Amplifier output buffer for ALICE ITS3 upgrade

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The ALICE ITS3 (Inner Tracking System 3) upgrade project together with CERN EP R&D on monolithic sensors are exploring the Tower Partner Semiconductor Co. (TPSCo) 65-nm ISC process. The ITS3 project aims to build the first fully cylindrical tracker by using wafer-scale, ultra-thin (≤ 50μm) bent MAPS. Four different pixel test structures, Circuit Exploratoire 65 (CE65), Digital Pixel Test Structure (DPTS), Analogue
Pixel Test Structure - Source Follower (APTS-SF), Analogue Pixel Test Structure - Operational Amplifier (APTS-OPAMP), were designed to validate the sensor technology through extensive characterization both
with laboratory and in-beam measurements.
Among these test structures, the Analog Pixel Test Structure (APTS) is a pixel matrix prototype equipped with an output buffer based on the high-speed individual operational amplifier (OPAMP) that allows to explore timing performance of this technology. The chip consists of a 4 x 4 square matrix of 10 μm x 10 μm pixels featuring small collection electrodes on a thin (∼ 10 μm) epitaxial layer.
This contribution will show the performance of the APTS OPAMP dedicated to timing measurements, with a focus on recent laboratory calibration (i.e., test pulses and noise measurements) and measurements using a
low-energy X-ray source (55Fe) to investigate the charge collection. Furthermore, the latest results from multiple in-beam measurements resulting in a time resolution of 77 ps will also be presented.

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Characterizing APTS-SF test devices for the ALICE ITS3 Upgrade

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During the upcoming Long Shutdown 3 (2026-2028), the ALICE Inner Tracking System is expected to undergo a second upgrade to ITS3. The sensors for ITS3 will be made of Monolithic Active Pixel Sensors that will be produced in the TPSCo65 technology, validated by studying small test chips from the first submission, called MLR1.
This contribution is focused on the results obtained in characterizing one of these test structures, the Analog Pixel Test Structure (APTS) with a Source Follower (SF) output driver. The APTS-SF consists of a 6x6 pixel matrix with a source follower, sub-unity gain, robust output buffer. However, to avoid edge effects, only the innermost 4x4 submatrix is actually read out. APTS-SF is available in different detector layout designs, doping profiles, geometries of collection diodes and pixel pitches, proving to be a versatile tool in ITS3 sensor technology. Nonetheless, it is slower than its unity-gain OpAmp (OA) output counterpart, the APTS-OA, fit for timing resolution studies.
The APTS-SF has been studied in all its versions, both in a laboratory setup, also with a Fe-55 source, and in a test beam setup under irradiation with proton beams. Extensive studies at a range of different temperatures and irradiation conditions have demonstrated that APTS-SF devices can meet ITS3 sensor technical requirements, reaching up to 99% detection efficiency at 15° C temperature and 1e+15 1 MeV neq/cm^2 irradiation.

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Resonance contributions to nucleon spin structure in Holographic QCD

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We study polarized inelastic electron-nucleon scattering at low momentum transfer in the Witten-Sakai-Sugimoto model of holographic QCD, focusing on resonance production contributions to the nucleon spin structure functions. Our analysis includes both spin 3/2 and spin 1/2 low-lying nucleon resonances with positive and negative parity. We determine, in turn, the helicity amplitudes for nucleon-resonance transitions and the resonance contributions to the neutron and proton generalized spin polarizabilities. Extrapolating the model parameters to realistic QCD data, our analysis, triggered by recent experimental results from Jefferson Lab, agrees with the observation that the Δ(1232) resonance gives the dominant contribution to the forward spin polarizabilities at low momentum transfer. The contribution is negative and tends to zero as the momentum transfer increases. As expected, the contribution of the Δ(1232) to the longitudinal-transverse polarizabilities is instead negligible. The latter, for both nucleons, turn out to be negative functions with zero asymptote. The holographic results, at least for the proton where enough data are available, are in qualitative agreement with the resonance contributions to the spin polarizabilities extracted from experimental data on the helicity amplitudes.

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Applications of the Interacting Boson Fermion Fermion Model

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I will present a new application of the Interacting Boson Fermion-Fermion Model (IBFFM) for describing double charge exchange reactions. The study of double charge exchange reactions induced by heavy ions involving candidate nuclei for neutrinoless double beta decay is a complex task carried out by the NUMEN collaboration, to which I belong. This investigation faces the intricacies of complex odd-odd intermediate nuclei in sequential double charge exchange processes. I will comprehensively describe heavy odd-odd nuclei using the (IBFFM). Additionally, I will outline the methodology for describing transfer operators within this framework. Finally, I will explore the potential applications of our results in future reaction codes for describing double-charge exchange reactions

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Coexisting Shapes and Precision Tests of Monte-Carlo Shell-Model Calculations in 96Zr

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We performed a dedicated Coulomb-excitation study of the nucleus 96Zr utilising the AGATA + SPIDER experimental setup at INFN-LNL. This investigation is extremely timely in order to provide new information on the structure of the 3− excited state, which is a source of debate in the literature.

In this talk, we will present the first results on the decay of this state to the ground state, essential to solve the puzzle of its interpretation and to allow for an in-depth comparison with state-of-the-art Monte Carlo shell-model calculations recently performed for the zirconium isotopic chain.

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Fusion dynamics far below the barrier for 12C + 28Si

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Heavy-ion fusion reactions are essential to investigate the fundamental problem of quantum tunnelling of many-body systems in the presence of intrinsic degrees of freedom. In addition, fusion of light systems is a base for the understanding of the astrophysics reaction networks responsible for the energy production and elemental synthesis in stellar environments 1. Large fusion enhancements are found near the Coulomb barrier, however, the hindrance phenomenon shows up 2 at lower energies. Fusion of light systems has Q > 0, and identifying hindrance requires challenging measurements, so the study of slightly heavier systems allows a reliable extrapolation towards the lighter cases. Here we present preliminary results of fusion cross section measurements for ^{12}C + ^{28}Si, performed at the INFN-Laboratori Nazionali di Legnaro, using 28Si beams from the XTU Tandem accelerator. We have used the combined set-up of the γ array AGATA 3 and two 4' annular DSSD Si detectors to identify and count the fusion evaporation events by coincidences between the prompt γ-rays and the light charged particles (p, α) evaporated from the compound nucleus. Five energies have been measured from 50 to 29.5 MeV. The left panel of the figure is the matrix of γ-energy vs particle energy above the barrier (50 MeV of ^{28}Si). Several evaporation channels are identified. At the lowest energy 29.5 MeV (right panel) we observe the $9/7^- \rightarrow 7/2^-$ transition of ^{39}K (1p), whose estimated cross section is $\sim$ 20 nb. The final experimental results will be presented.

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Two-Phonon Octupole excitation in 96Zr

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In this poster we present the preliminary analysis of an experiment performed at INFN LNL in November 2023 aimed at studying the two-octupole phonon collectivity in ^{96}Zr. The goal of the experiment was to perform a γ-decay branching ratio measurement from the 6^+ to the 3^- state, so as to extract the B(E3; $6^+ \rightarrow 3^-$) value. If large, this parameter would indicate for the 6^+ level to be a member of the $3^- \otimes 3^-$ multiplet. The 6^+ state was populated via the ^{96}Zr(p,p')^{96}Zr proton inelastic scattering and the scattered protons were measured in the SAURON Double-Sided Silicon Strip detector. These were used to select the reaction channel of interest, in coincidence with the γ rays in the AGATA array.

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Study of the 18O+12C nuclear reaction at 122 MeV with the GARFIELD-RCo multi-detector array

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In this poster presentation we will show the data analysis of the experiment "ISOLIGHT3"1 performed in 2021 at INFN-LNL with the GARFIELD array 2. The experiment was designed to investigate fusion-evaporation reactions where a Compound nucleus (CN) is created by the fusion of two light nuclei. During the decay of the short-living CN, α particles might be emitted together with other particles with even number of nucleons. In case of reactions where α-conjugated nuclei are involved some discrepancies between experimental and simulated data are observed in the decay channels with even residues, mainly when detected in coincidence with α particles. The research activity developed (up to now) mainly focused on the calibration of the detectors and on the preliminary analysis of mass and velocity distributions of evaporation residues emitted in the 18O+12C reaction, with particular emphasis to the coincidences between alpha particles and residues. Moreover, simulations with the HFl model 3 and the statistical code GEMINI++ [4] have been performed, and the results have been closely compared to the experimental data to search for possible deviations that could be ascribed to clustering effects in the decay of the hot fusion sources populated in the experiment.

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Measurement of the $^{12}C(\alpha,\gamma)^{16}O$ cross section with the ERNA recoil separator

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The uncertainty on the amount of carbon and oxygen produced in the helium burning phase of stars, is reflected in many aspects of the evolution of a star. The cross section of $^{12}C(\alpha,\gamma)^{16}O$ is one of the major contributors to such uncertainty, and because of this, it has been studied for more than 60 years. Despite all the efforts, the uncertainty on the astrophysical factor still sits above 10\%, which is the goal of the scientific community.
The cross section in the Gamow window (~0.3 MeV) is too low to make direct measurements, and we must rely on R-Matrix extrapolations to estimate it.
High-precision measurements focusing on different aspects of the complex reaction scheme of the $^{12}C(\alpha,\gamma)^{16}O$ reaction are needed for an accurate extrapolation.\\
Given the exceptional contribution to this scenario provided by the data of the ERNA collaboration in the E_{CM} 1.9 - 4.9 MeV in Bochum, the ERNA separator has been moved to the Tandem laboratory of the University of Campania, Caserta, with the objective of expanding this range and adding the capability to disentangle the E1, E2, and cascade transition contributions to the cross section.\\
The apparatus is now ready for such measurements, and the campaign has already started. In this contribution, I will summarize the improvements to the setup and show early results of the measurement campaign.

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A new positron system for fundamental experiments with positronium

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In the last decade, significant advances in positronium physics [1,2] and in the employment of positronium in fundamental experiments 3 have been made possible by the development of positron systems enabling efficient storing and bunching of large amounts of positrons [4] and by the synthesis of efficient positron/positronium converters [5,6].
A new positron system is currently under development at the AntiMatter Laboratory (AML) of the University of Trento [7] with the goal to perform inertial sensing measurements with long-lived positronium [8] and studies of the entanglement of the gamma rays emitted by positronium annihilation [9].
In this presentation, the novel characteristics of such a positron system will be described. A particular focus will be dedicated to the description of the methods employed to keep the positron/positronium converter in a free-field region. The absence of magnetic and electric fields is a fundamental requirement for the planned experiments. Finally, the scheme planned for measurements of inertial sensing with positronium and for studies of the entanglement of the gamma rays emitted by positronium annihilation with the present positron system will be described.

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Antiprotonic atoms and highly charged ions production in the AEgIS Experiment

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The AEgIS (Antimatter Experiment: Gravity, Interferometry, Spectroscopy) experiment, located at the Antimatter Factory at CERN, has as main goal the study of the asymmetry between matter and antimatter by measuring the deflection of a beam of antihydrogen. Recently, a new scientific avenue has been added, to study antiprotonic atoms and highly charged ions (HCI). They can enable multiple precision test of QED and QCD at low energy, and novel applications (e.g. qubits).
The methodology is as follows: a diluted gas is kept together with trapped antiprotons, and two physical processes can take place. One is collisional ionisation, where the antiprotons, while cooling on the buffer gas, can kick off, via Coulomb scattering, one electron from the atom's outer shell, gradually stripping the nucleus bare. The second process is antiproton capture, where an antiproton

can substitute the outermost electron of an atom, gradually eject all the electrons, finally leaving a two-body system (nucleus and antiproton), before annihilating onto a nucleon.
In this talk the technique developed to produce the HCI is presented, together with the first results obtained using Nitrogen and Oxygen as target gases.

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Remotely-operated On-board inSpections for SpecIal Nuclear materIal- the ROSSINI project

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This presentation introduces the ROSSINI system's innovative approach to illicit Special Nuclear Material detectionb. We aim at demonstrating how drones and robotic based methodologies can support and revolutionize container inspections. Our focus lies on the deployment of advanced radiation detectors for anomaly detection and internal assessment procedures. These techniques will be developed specifically to increase the safety standards in nuclear security and will be supported by custom designed AI algorithms which will enhance the system's detection capabilities. We explore the integration with RAISE network infrastructure, emphasizing improved data processing and communication capabilities. This method represents a significant advancement in nuclear physics applications, showcasing a blend of technology and safety in nuclear material handling.

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KM3NeT materials analysis with IBA at CIRCE-DMF

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KM3NeT (Cubic Kilometre Neutrino Telescope) is a deep underwater infrastructure installed in the Mediterranean Sea devoted to the detection of astrophysical and atmospheric neutrinos. The KM3NeT telescope operates in unconventional conditions characterised by salt water and pressure up to 350 bar. These unusual environmental conditions and the complexity of the experimental setup require a systematic investigation of all materials used in the construction of the underwater infrastructure of KM3NeT in order to assess the equipment lifetime. Nuclear physics provides useful tools to study the properties of the materials involved in innovative applications by exploiting Ion Beam Analysis methods. Among these methods, Nuclear Reaction Analysis represents an effective mean to investigate the concentration of isotopic species inside the materials by inducing nuclear reactions. In particular, at the CIRCE laboratory of the University of Campania Luigi Vanvitelli in Caserta, we have performed NRA (Nuclear Reaction Analysis) measurements on Low Density PolyEthylene (LDPE) samples that compose the VEOC (Vertical Electrical-Optical cable) in order to evaluate the diffusion of water in this material. During the last year, we have developed a new beam line devoted to material analysis. This development has included the installation and testing of the magnetic triplet quadrupole through the validation of beam transport simulations and the design of a scattering chamber in which will be installed a 5-axis manipulator suitable for high vacuum conditions. This manipulator will allow RBS (Rutherford Back Scattering) and ERDA (Elastic Recoil Detection Analysis) measurements on the surface with micrometric precision thanks to the combination of rotational and translational movements of the samples and will be operative during this year.

This contribution presents details of the implementation of the beam line and the results of the data analysis of the plastic samples exposed to deuterated water and bombarded with ^{15}N beam.

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Exploring the Beam Test Facility (BTF) at the Laboratori Nazionali di Frascati:

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This poster aims to offer a detailed examination of the Beam Test Facility (BTF) located at the Laboratori Nazionali di Frascati. The BTF functions as a vital experimental platform, providing distinctive capabilities for particle physics research and detector development, achieved through the production of primary and secondary electron and positron beams. The poster will describe the facility's key features, experimental setups, and recent advancements, offering insights into the cutting-edge research conducted at the BTF and its implications for advancing our understanding of fundamental physics and developing new detectors.

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Development and characterization of a new parallel-plate ionization chamber for FLASH dosimetry

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Background
FLASH radiotherapy (FLASH-RT) is a new promising approach in oncological treatments that involves the administration of the dose in less than 200 ms using ultra high dose rates (UHDRs) above 40 Gy/s. The great advantage deriving from FLASH-RT consists in an enhanced reduction in damage to healthy tissues while leaving the therapeutic efficacy on the tumour unchanged. So far, the most suitable radiations for FLASH applications are pulsed electron beams, in which very high doses per pulse (> 1 Gy) are needed to provide UHDRs. One of the most challenging issues limiting the clinical translation of FLASH-RT is the lack of a dosimetric protocol for UHDR beams, since the usage of conventional dosimeters for radiotherapy, the ionization chambers, is limited by an uncorrectable saturation and charge multiplication due to a perturbation of the bias electric field that the large amount of ionization charge produces inside the active volume. To overcome this problem, a new model of gas-based parallel-plate dosimeter, the ALLS chamber, has been proposed. The use of a noble filling gas as active medium eliminates the electron capture of oxygen, and both saturation and uncontrolled discharges are avoided by decreasing the density of the gas. The theory of the ALLS

chamber comprehends an analytical solution of the collection dynamic of the charges only for very low pressures of the gas (< 5 mbar). The practical realization of a device capable to contain a very low-pressure gas is very challenging since the material of the body must resist high mechanical efforts and the metallic components must minimize the collection of primary electrons and secondary emission. The aim of this work is the practical realization and the experimental characterization of a parallel-plate ionization chamber (PPIC) based on the conceptual design of the ALLS chamber capable to measure very high doses per pulse. This research is conducted as part of the INFN FRIDA experiment and in collaboration with the University of Santiago de Compostela.

Material and methods

A vectorized Python-coded numerical simulation of the charge transport in noble gases was implemented to study the response of a PPIC as a function of the filling gas and its pressure, the design, and the experimental parameters such the dose per pulse and the bias voltage. The aim is to explore the usage of different noble gases and ranges of needed pressures to measure very high doses per pulse by considering both the electric field perturbation and the charge multiplication in the active volume. Moreover, the variation of the charge collection efficiency (CCE) as a function of the dose per pulse is evaluated. In parallel, a first prototype of PPIC was realized with materials and structure suitable for low-pressure applications: the plastic material PEEK was used for the body, and the electrodes were realized by means of metallization. Such prototype was preliminary tested as an air-filled dosimeter with conventional beams to verify the goodness of the realized structure.

Results

Numerical simulations shows that it is possible to measure up to 12 and 10 Gy/pulse by filling the chamber with helium at a pressure of 50 mbar and nitrogen at 10 mbar respectively. Although a small fraction of proportional regime is present, the CCE is stable within 1% for a wide range of doses per pulse at fixed bias voltage of 30 V in helium and 40 V in nitrogen at the chosen pressures. The realized prototype shows a very good response in terms of collected charge as a function of the bias voltage. Moreover, a fraction of 0.3% of charge collected by the metallic components with respect to the ionization signal was obtained for a conventional clinical pulsed electron beam.

Conclusions

In view of an experimental validation, the implemented numerical simulation of the charge transport in gases represents a useful tool to study the response of a PPIC. To perform measurements with noble gases, the realized prototype must be adjusted to make it suitable to contain a low-pressure gas to obtain a first reliable version of the ALLS chamber that will be tested with FLASH pulsed electron beams produced by the ElectronFlash linac installed at the Centro Pisano FLASH Radiotherapy (CPFR) of the Santa Chiara hospital (Pisa, Italy).

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Radiation protection simulations for a BNCT facility of the ANTHEM project in Italy

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A Radiofrequency Quadrupole Accelerator (RFQ) delivering 5 MeV, 30 mA proton beam coupled with a Beryllium target has been designed and constructed by the Italian National Institute of Nuclear Physics (INFN). It is the neutron source of a BNCT facility that will be built at the University

of Campania L. Vanvitelli in Caserta, Italy in the frame of the PNC-PNRR project ANTHEM.
The building hosting the patients'irradiation room and the technology is being designed and optimized in view of the radioprotection prescriptions by means of simulations with the Monte Carlo transport code MCNP6. Radioprotection is a key aspect because the neutron flux at the beam port will be at least 10^9 cm^-2s^-1, obtained by moderation and collimation of the primary neutron source at the target whose intensity is 10^14 s^-1. A suitable neutron beam has been developed taking into account the quality of the BNCT treatment and treatment room radiation safety. Radiation protection simulations were performed with no phantom at the beam port. The geometry and materials of the facility walls were modified, and results were compared in terms of feasibility and spatial constraints. The effect of different materials for the walls of the facility have been analyzed. The dose distribution in uSv/h is shown in three representative areas of the facility: the treatment room, the maze, and the beam transport area. The results show that using borate baritic concrete offers a clear advantage compared to Portland concrete.
Dosimetry in the room also considers beam losses along the whole beam line, which have been lowered as much as possible. The beam transport along the accelerator room and the beam transport area towards the clinical room was simulated by MCNP6. A proton source was created to simulate the beam losses along the particle path in the vacuum tube; protons were extracted perpendicularly with an energy distribution depending on the position along the line.
Finally, the important issue of air activation has been studied, in fact, the activation of argon is a possible limitation in the use of the facility and requires detailed evaluation. The behavior of the activity of Ar-41 as a function of time also considering the air exchange in the room will be shown. Simulations have been produced with the beam designed in previous research, obtained by an ideal beam shaping assembly. The neutron flux, with the strategy employed, is well collimated, which helps in complying with the radioprotection prescriptions both in the room and for the out-of-field organs of the patient. Work is currently ongoing to design a Beam Shaping Assembly which ensures the same beam quality, but which also considers the construction criteria and the latest developments of the Be target design

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Proton-induced production of the theranostic 47Sc radionuclide: nuclear cross-section measurements and dosimetric analysis

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The research activities here presented have been conducted in the framework of the LARAMED (LAboratory of RADionuclides for MEDicine) project at the INFN-LNL, whose aim is to investigate new or alternative cyclotron-based production routes for standard or emerging medical radionuclides for innovative radiopharmaceuticals. 47Sc is a promising theranostic radionuclide thanks to its γ and β- decay emissions which can be employed in imaging and therapeutic medical applications, respectively. At present, the challenge is to find a valid production route which allows to obtain large and enough pure quantities. The first step to evaluate a possible innovative route is the measurement of the nuclear cross-sections. For this reason, the proton-induced reactions on enriched Ti targets are here presented, concerning not only the production of 47Sc but also of its contaminants, namely 43Sc, 44m,gSc, 48Sc, 48V, and 43K. In fact, co-produced contaminants play a key role in the assessment of the purity of the final product: their production has thus to be avoided to reduce the unuseful radiation dose to the patient. The quantification of the extra dose administered to human organs is possible thorough dosimetric simulations and, in this work, a dosimetric analysis for different production scenario will be presented, considering the DOTA-folate conjugate cm10 as an example of radiopharmaceutical. Limitation in the amount of the additional dose due to co-produced contaminants allows to individuate which are the optimal beam energy interval and irradiation time for a suitable 47Sc production.

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Optimization production of 61Cu by 59Co(α,2n) cross section measurements.

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Nuclear medicine is a field of medicine that uses radionuclides for diagnostic and therapy. Radionuclides for therapy must have a time of life long enough to damage the cancer by the emission of Auger electrons or α and β- particles. Radionuclide for diagnostic must have a half-life comparable with the physiological process investigated and they must emit gammas. The new frontier of nuclear medicine is the theranostic, that is a combination of diagnostic and therapy by using radionuclides which emit both massive particles and photons. In this way, it's possible to reduce dose at patient. Copper-61 (61Cu, T1/2=3,33 h), which emits auger and IC electrons, β+ particles and gammas at different energies, it's an optimum candidate. 61Cu can be product by different ways: through bombardment of natZn, highly enriched 64Zn (Rowshanfarzad, P. et al. (2006) Appl. Radiat. Isot. 64, 1563–1573, K. Abbas et al. / Applied Radiation and Isotopes 64 (2006) 1001–1005) or highly enriched 60,61,62Ni (F. Szelecsenyi, G. Blessing, S.M. Qaim, Appl. Radiat. Isot. 44 (1993) 575.) targets with protons beam in the energy range 20-70 MeV or through the Co(α,2n) reaction with α beam in the range 20-60 MeV. This reaction could be better because of using alphas instead of protons makes the radiochemical separation easier, thanks to the major different between the atomic number of product and target, and the production by cobalt doesn't require very expensive enriched targets, because cobalt is monoatomic. In this work, we measured the cross section of the reaction 59Co(α,2n)61Cu and of the contaminating radionuclides, as 60Cu, 54Mn, 56Co, 57Co, 58Co, 59Fe and 60Co, and we compared these with the literature and MC simulations Talys 1.9 and Empire 2.3. The irradiation occurred at IBA70 alpha cyclotron, located at ARRONAX in Nantes (FR), that can accelerate alpha particles at 70 MeV. The following measurements and data analysis were conducted at the Physics Measurement Laboratory at LASA in Segrate (MI), a structure of UNIMI and INFN.

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Lifetime measurements for the study of intruder states towards the island of inversion along the N = 20 shell closure

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Lifetime measurements are commonly used to unravel the nature and properties of nuclear states, as they are closely related to transition probabilities, which provide information on the nuclear wave functions. The aim of the experiment here presented was to study the interplay of spherical (0 $\hbar\omega$) and intruder (2 $\hbar\omega$) configurations in the low-lying states of isotopes on the edge of the N=20 island of inversion. In particular, the goal was to determine the lifetime of the first two 2+ states of ^{34}Si and the first 5/2+ state of ^{35}P using the Doppler Shift Attenuation Method. The experiment was conducted at the LNL facility in November 2022, employing the PRISMA magnetic spectrometer and the AGATA array. The lifetimes are extracted by comparing the experimental line shapes to those produced by a Monte Carlo GEANT4 simulation, which must be adapted to mimic the experimental conditions.

This presentation provides an overview of the first-step analysis of the experiment, which involved the AGATA and PRISMA data processing and the implementation of the AGATA GEANT4 simulation.

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Neutrino thermal properties evaluation by quantum imaginary time evolution

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Neutrino flavor oscillations are particularly relevant in core-collapse supernovae and binary neutron star mergers: the dynamics of these phenomena heavily depend on the properties of the many-particle system. We exploit quantum imaginary time evolution and related recent techniques to compute finite temperature expectation values of different observables on the typical thermal states of a small neutrino system.

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Investigations on η’photoproduction of near-free neutron at Graal

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An investigation on η’photoproduction of quasifree neutron (Deuterium target) is presented, by showing a preliminary estimation of Beam Asimmetry Σ as function of polar angle in the center-of-mass system near the threshold by analyzing the experimental data of GRAAL experiment. The etaprime fotoproduction channel is useful because it acts as a isospin filter, allowing to select only resonant contributions with one half isospin. The preliminary Σ measurements for the η’’ photoproduction off neutron was performed in the energy interval of the interacting γ photon [1447-1475] MeV for four bins in the θ. The present estimations have been compared with the data on the proton channel, published by Graal experiment, and are consistent.

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A new radiation source based on laser-plasma interaction: status and perspective with the upcoming I-LUCE facility at INFN-LNS

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The potential for developing compact, high-brightness particle and radiation sources have given a strong impetus to the development of the underpinning laser technology, including increasing the efficiency and repetition rate of the lasers. A result of this technological development can be seen in the new generation of ultrafast high-power laser systems working at a high repetition rate which have been built across Europe.
A new high-power laser facility called "I-LUCE"(INFN Laser indUced radiation acCEleration) will be realized at LNS-INFN (Laboratori Nazionali del Sud –Istituto Nazionale di Fisica Nucleare) in 2024. The facility realization is funded by three projects financed by the PNRR (Piano Nazionale ripresa resilienza) Italian program: EuAPS (EuPRAXIA Advanced Photon Sources), Samothrace (SiciliAn MicronanOTecH. Research And Innovation) and Anthem (AdvaNced Technologies for HumancentrEd Medicine). The Ti:Sapphire laser will have two outputs: the first one will be a 50 TW beam line (25 fs, 25-30 mJ, 10 Hz) while the main beam line will be a 350 TW laser (25 fs, 10 J, 2 Hz). I-LUCE will serve two distinct experimental areas known as E1 and E2. E1 will offer a globally unique combination of intense laser radiation with heavy ion beams, generated by the Superconductive Cyclotron and Tandem (already installed at LNS), thereby providing opportunities for intriguing experiments in the fields of plasma physics, nuclear physics, and atomic physics. For moderate laser beam intensities (up to 1 TW), the experimental room E1 will be dedicated to conducting experimental runs focused on nuclear fusion and studying stopping power in plasma.
Conversely, the E2 experimental room will be dedicated to both proton and electron acceleration. A specialized beamline designed to select, transport, and focus proton beams with energies between 5-60 MeV will be installed and optimized for radiobiological experiments. A corresponding beamline for selecting electron beams will also be implemented. Furthermore, stand-alone experiments involving intense laser beams will be conducted to explore various studies, including X-ray laser generation and neutron production. This presentation will provide an overview of the current status and future prospects of the I-LUCE facility.