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Book of abstracts

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Heavy ion experiments: latest results

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Heavy-ion experiments at RHIC and LHC are aimed at studying the properties of strongly interacting matter under extreme conditions. The temperatures and energy densities reached in these high-energy Nucleus-Nucleus collisions lead to a form of strongly interacting QCD matter in which quarks and gluons are no longer confined: the so-called quark–gluon plasma (QGP). A selection of recent results obtained in nucleus-nucleus collisions will be presented and discussed by keeping in mind the corresponding p-Nucleus and p-p results. Indeed, the latter turn out to be not only a reference for heavy-ion studies, but also a topic with intrinsic interest: similarities between "small systems" and heavy-ion collisions have been observed and will be highlighted in the talk.

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Probing dense matter at low energies with dileptons: prospects and challenges

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In this talk, I shall (i) review the results from almost 25 years of dilepton measurements, from the top RHIC energy of sqrt(s_NN)=200 GeV down to the lowest SPS energy of sqrt(s_NN)= 9 GeV, and their relation to chiral symmetry restoration, (ii) discuss the potential, challenges and prospects of extending the dilepton measurements at much lower energies, mainly at the NICA facility under construction at JINR.

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Exploring baryon rich QCD matter with electromagnetic probes

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Collisions of heavy atomic nuclei at (ultra-)relativistic energies provide a fascinating opportunity to produce in the laboratory, for a short moment (10⊠23 s), matter under extreme conditions of temperature (1012 K) and density (2⊠5 times ground state density). Such matter radiates photons, whose spectrum re
ects the temperature as well as possible critical behavior in the vicinity of
phase transitions. The spectra of dileptons o er the unique chance to investigate the microscopic properties of QCD matter. The key quantity is the in-medium electromagnetic spectral function, which encodes the e ects of the strong interaction on dilepton production in the hot and dense reball.
In this contribution I will rst discuss important experimental results on emissivity of matter obtained by HADES in Au+Au collisions at 2.42 GeV center of mass energy. Virtual photon spectra will be confronted with results of other experiments as well as with available model calculations. A deeper understanding of the microscopic origin of the excess radiation requires systematic investigation of di-electron radiation emitted from baryonic resonances produced o protons in pion-induced reactions. These are studied in HADES making use of pion beams. An important part of the future research program will be the high-precision measurement of the dilepton invariant mass distribution not only below 1 GeV/c2, but in particular between 1 and 2.5 GeV/c2 for di erent beam energies.
I will then give the prospects for intermediate mass measurements with STAR experiment at top RHIC energy and with upgraded HADES at SIS18. I will conclude presenting the potential of dilepton spectroscopy at future high ⊠B facilities.

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Parton dynamics and colour condensates

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A detailed, multidimensional imaging of protons and nuclei at high energy is one of the main goals of Quantum Chromodynamics. We review two complementary theories that study the dynamics of partons (quarks and gluons) in protons and nuclei when they are accelerated to large velocities: the factorization approach with multidimensional distribution functions and the Colour Glass Condensate theory. Both frameworks give independent information on the mixed, momentum and position structure of ultra-relativistic particles. Nevertheless, the complexity of the problem requires a consistent and inclusive description that will merge together and combine the advantages of the two approaches. We review recent progress along these lines and we present phenomenological results derived from the connection between the two theoretical frameworks.

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Breakthroughs in solar and neutrino physics from the Borexino experiment.

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Borexino, with its very low background, due to an unprecedented radio-purity, is a unique experiment in studying the solar neutrinos since more than 11 years, producing important results in the solar and neutrino physics.
The mechanism that produces 99% of solar energy, i.e. the pp cycle, has been entirely measured determining the rates of all its the reactions: pp, 7Be, pep, 8B. This measurement has led several findings: 1) the measured rates are in good agreement with the SSM; 2) the comparison between neutrino flux and photon luminosity tests the solar stability at 105 time scale; 3) the comparison of the 7Be and 8B rates with the SSM previsions for high and low metallicity gives a hint in favor of high metallicity.
The ⌧e survival probability, measured at the various pp reactions energies, shows a good agreement with the MSW model in the vacuum regime, where it has been measured for the first time, and confirms the MSW validity for the matter enhanced oscillation.
Evidence of the geo-neutrinos has been reached at 5.9 ⌧ confidence level.
Borexino is still taking data to try the nearly prohibitive measurement of the CNO cycle.

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KM3NeT and ANTARES status and results

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ANTARES is the largest and longest operated neutrino telescope in the Northern hemisphere. It is located 40 km off-shore Toulon, France, at a depth of 2475 m on the Mediterranean seabed and has been continuously taking data since 2006. Its primary goal is the search for astrophysical neutrinos in the TeV-PeV energy range. Its location and excellent angular resolution makes ANTARES sensitive to a large part of the Southern sky which contains many promising neutrino source candidates, including the Galactic Center region.
The latest results from ANTARES will be presented regarding the search for a diffuse high energy neutrino flux, the analysis to identify astrophysical neutrino point sources and the various searches for multi-messenger coincidences between neutrinos and other cosmic probes, like photons or gravitational waves.

KM3NeT, the new generation of underwater neutrino telescopes, is currently under construction in the Mediterranean sea. Thanks to its large size and improved detection capabilities, KM3NeT will open new perspectives in neutrino astronomy.
Results obtained with the first KM3NeT deployed lines, together with the current status and perspectives of the detector, will be reported.

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The PTOLEMY experiment

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The PTOLEMY project aims to develop a scalable design for a Cosmic Neutrino Telescope to detect the Big Bang relic neutrino. This will be the first of its kind and the only telescope conceived that can look directly at the image encoded in neutrino density fluctuations of the Universe in the first second after the Big Bang. The PTOLEMY prototype at Princeton has become the basis of a new world-wide collaboration consisting of seven countries and 29 institutions. The prototype will be setup in an underground site (proposal to LNGS is under review) and will validate many aspects of the technologies needed for the relic neutrino detection. It will also focus on the study of the background levels required in order to successfully detect events induced by Big Bang relic neutrino.

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: Results from the CUORE experiment

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The Cryogenic Underground Observatory for Rare Events (CUORE) is the first bolometric experiment searching for neutrinoless double beta decay that has been able to reach the 1-ton scale. The detector consists of an array of 988 TeO2 crystals arranged in a cylindrical compact structure of 19 towers. The construction of the experiment and, in particular, the installation of all towers in the cryostat was completed in August 2016 and data taking started in spring 2017. In this talk we present the neutrinoless doube beta decay results of CUORE from examining a total TeO2 exposure of 86.3 kg yr, characterized by an effective energy resolution of 7.7 keV FWHM and a background in the region of interest of 0.014 counts/(keV kg yr). In this physics run, CUORE placed a lower limit on the decay half-life of 130Te > 1.3 10^25 yr (90% C.L.). We then discuss the additional improvements in the detector performance achieved in 2018 and the latest update on the study of other rare processes in Tellurium and in the evaluation of the background budget.

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New Physics Searches with LUX and LZ

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The frontier of experimental particle physics research, and especially astroparticle physics research, frequently involves the detection of signals that are both rare, fewer than an event per year per kilogram of target, and small, with energy depositions at the keV scale. A prime example is the direct search for dark matter, although other signatures for new physics are also being sought, such as axions and various neutrino signals. The key technology that has evolved to meet this challenge is that of the ultra low background two-phase time projection chamber, typically deployed deep underground. The Large Underground Xenon (LUX) instrument was a leading such device. Now dismantled to make way for its successor, analysis of legacy data continues. Both the main scientific results of LUX and the novel approaches taken to calibration and characterisation of the detector will be presented.

With a 50 times larger fiducial mass, and an increased background rejection power due to the specially design veto systems, LUX-ZEPLIN (LZ) is presently under construction and is due to take first data in 2020. It will have a sensitivity at least two orders of magnitude beyond current best limits for the leading dark matter candidates. An overview of the LZ experiment will be presented, as well as sensitivity projections for a range of other candidates signals.

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Darkside status and prospects

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DarkSide uses a dual-phase Liquid Argon Time Projection Chamber to search for WIMP dark matter. The current detector, DarkSide-50, is running since mid 2015 with a target of 50 kg of argon from an underground source. The talk will present the latest results of searches of WIMP-nucleus interactions, with WIMP masses in the GeV-TeV range, and of WIMP-electron interactions, in the sub-GeV mass range. The future of DarkSide with a new generation experiment, involving a global collaboration from all the current Argon based experiments, will be also discussed.

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Results of the WIMP search with XENON1T

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Astronomical and cosmological observations indicate that a large amount of the energy content of the Universe is made of dark matter. The most promising dark matter candidates are the so-called WIMPs (Weakly Interacting Massive Particles).
The XENON project, at the Gran Sasso National Laboratory (LNGS), consists of a double-phase time projection chamber (TPCs) using ultra-pure liquid Xenon as both target and detection medium for dark matter particle interactions. The WIMPs can be indeed detected via their elastic scattering off Xenon nuclei.
The XENON Collaboration is now running the XENON1T experiment, the first ton scale liquid Xenon based TPC, with an active mass inside the TPC of about 2 ton. The first results were obtained in a run of 34.2 days acquired between November 2016 and January 2017. The detector achieved the lowest electronic recoil background in a dark matter experiment. Those data allowed to set the most stringent exclusion limits on the spin-independent WIMP-nucleon interaction cross section for WIMP masses above 10 GeV/c^2, with a minimum of 7.7 ×10^−47 cm2 for 35-GeV/c2 WIMPs at 90% confidence level. After the first run XENON1T continued the data taking with a scientific run ended in February 2018, for a live time of about 250 days of dark matter search. In this contribution we will present the results of the WIMP search with the XENON1T experiment.

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Dark matter search with the SABRE experiment

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The SABRE (Sodium Iodide with Active Background Rejection) experiment will search for an annually modulating signal from Dark Matter (DM) using an array of ultra-pure NaI(Tl) detectors surrounded by an active scintillator veto to further reduce the intrinsic background. The expected rate of interactions between DM particles and the detector in fact modulates due to Earth’s changing velocity relative to the DM halo.
The first phase of the experiment is the SABRE Proof of Principle (PoP), a single 5kg crystal detector operated in a liquid scintillator filled vessel at the Laboratori Nazionali del Gran Sasso (LNGS). The PoP installation is underway with the goal of running in 2018 and performing the first in situ measurement of the crystal background, testing the veto efficiency, and validating the SABRE concept. As part of this effort, GEANT4-based Monte Carlo simulations have been developed to estimate the background in the PoP based on radio-purity measurements of the detector components. The second phase of SABRE will be twin arrays of NaI(Tl) detectors operating at LNGS and at the Stawell Underground Physics Laboratory (SUPL) in Australia. By locating detectors in both hemispheres, SABRE will minimise seasonal systematic effects.
In this talk, the status report of the SABRE PoP activities at LNGS and of the full scale SABRE will be presented.

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Symmetry Energy at supra-saturation densities studied with neutron-proton elliptic flows

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P. Russotto for the ASY-EOS II collaboration

The symmetry energy contribution to the nuclear equation of state is of fundamental importance in both nuclear physics and astrophysics. In the last decades several works, based on different observable, have allowed to constrain the symmetry energy mainly below saturation density. Vice versa, few works have been able to study the behaviour of the symmetry energy above the saturation density.
In this talk we will present the results of the ASY-EOS experiment at GSI, where we measured neutron and light charged particle elliptic flows in Au+Au collision at 400 AMeV. The analysis, based on the comparison of the elliptic flows ratio with QMD calculations, has allowed to provide a stringent constraint
for the symmetry energy behaviour at supra-saturation densities. We will present also our future plans aiming to extend elliptic flows measurements at higher beam energies, in order to explore higher densities. The possibility to measure pions will be also discussed.

P. Russotto et al., Physics Letters B697, 471-476 (2011).
P. Russotto et al., Physical Review C94, 034608 (2016).

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Quarkonia in nuclear collisions

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Quarkonium has been regarded as one of the golden probes to identify the phase transition from confined hadronic matter to
the deconfined quark-gluon plasma (QGP) in heavy-ion collisions. Recent theoretical developments in the study of the J/ψ
and Υ families at the energies of Large Hadron Collider (LHC) are reviewed. In particular, the possible implications related to
the production and propagation of quarkonia in proton-proton, proton-nucleus and nucleus-nucleus collisions are discussed. A special
emphasis is put on the excited states such as the ψ', Y(2S) and Y(3S).

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Probing hot QCD matter in ultrarelativistic heavy-ion collisions

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In high-energy collisions of heavy nuclei, the resulting state of matter attains such high temperatures and energy densities that quarks and gluons are no longer confined into hadrons. Known as the quark-gluon plasma (QGP), this matter occupies the high-temperature and high-density regime of the phase diagram of quantum chromodynamics (QCD). By probing the properties of the QGP, we are able to study QCD and the strong nuclear force in the extreme high temperature limit. In this talk, a selection of measurements from the Large Hadron Collider (LHC) and the Relativistic Heavy Ion Collider (RHIC) will be presented which give insight into the space-time evolution of the QGP and its thermodynamical and hadrochemical properties.

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Study of quarkonium as an open quantum system using effective field theory techniques

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Heavy quarkonium related observables are very useful to obtain information about the medium created in relativistic heavy ion collisions. The interaction of charmonium or bottomonium with the hot QCD medium created in these collisions can be efficiently described with the use of non-relativistic Effective Field Theories. In this talk I will review recent progress in understanding quarkonium dynamics in a thermal medium with the use of potential non-relativistic QCD (pNRQCD). A non-perturbative master equation that describes the evolution of quarkonium in a medium can be obtained in the 1/r>>T regime. Furthermore, if the binding energy is the smallest of the energy scales this master equation takes the Lindblad form, which is well known the context of quantum physics. In this situation all the information needed from the medium can be encoded in two non-perturbative parameters. I will discuss the application of this formalism to obtain predictions of the nuclear modification factor that can be observed in experiments at different temperature regimes.

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Perspectives of QCD phase diagram studies with the CBM experiment at FAIR

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The future heavy ion experiment CBM at the FAIR facility will study the QCD phase diagram in the region of high baryon chemical potential at relatively moderate temperatures, where a complex structure is predicted by modern theories. In order to detect possible signatures of this structures, the physics program of the experiment includes a comprehensive study of the extremely rare probes like charmed particles, dileptons, multi-strange particles, hypernuclei and their antiparticles. The multi-differential analysis of spectra, flow, collective effects will be performed even for such rare particles with the unprecedented precision.

To achieve the goals the operation scenario assumes extremely high interaction rates of up to \$10^{7}\$ collisions per second. To cope with such conditions the beam will have no bunch structure and CBM will operate with self-triggered front end electronics and free streaming data. The detectors should be fast and efficient. Having no clear signatures for the hardware trigger, CBM will perform the full event reconstruction online including the stage of track and short-lived particle reconstruction. Fast and efficient reconstruction algorithms are being developed.

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Study of quarkonium production in p-A and AA collisions with ALICE at the LHC

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ALICE (A Large Ion Collider Experiment) is devoted to the study of heavy-ion collisions at the CERN Large Hadron Collider (LHC). It is predicted that a deconfined state of hadronic matter, the Quark-Gluon Plasma (QGP), is created at the large energy densities reached in such collisions. The production of heavy quarkonium (ccbar and bbar bound states) appears modified in the presence of a QGP, if compared to scaled production measurements performed in pp collisions.
Previous measurements at lower energy showed a suppression of quarkonium states, which could be explained by the dissociation of the bound state due to the colour screening in the medium (a phenomenon analogous to the Debye screening for QED). However, the measurements of charmonium (ccbar) production performed in Pb-Pb collisions at the LHC reveals the presence of regeneration phenomena occurring in the QGP or at the phase boundary.
The production of ccbar pairs is expected to be lower than the production of bbbar pairs, consequently regeneration phenomena are expected to be much smaller for bottomonia than for charmonia. Hence, the complementary studies of bottomonia and charmonia allow one to better understand the mechanisms affecting the quarkonium production in heavy-ion collisions at LHC energies.
In addition, production of quarkonium states is modified by Cold Nuclear Matter (CNM) effects, which can be estimated by studying p-A collisions.
In ALICE two rapidity ranges are accessible for quarkonium study, namely at mid rapidity (|yCMS| < 0.9) in the e+e- decay channel and at forward rapidity (2.5 < yCMS < 4) in the mu+mu- decay channel, down to zero transverse momentum.
An overview of the latest ALICE results on Y and J/psi production, in p-Pb and AA collisions, will be presented. A discussion of the results will be held, comparing the most recent results with previous measurements and theoretical predictions.

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Heavy-flavour production measurements in heavy-ion collisions with ALICE at the LHC

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Heavy quarks are effective probes of the properties of the Quark-Gluon Plasma (QGP) created in ultra-relativistic heavy-ion collisions. Charm and beauty quarks are produced in hard scattering processes on timescales shorter than the QGP formation time due to their large masses and, thus, they experience the entire evolution of the medium interacting with its constituents via in-medium gluon radiation and collisional processes. The measurement of the nuclear modification factor (R_AA) of D mesons and heavy-flavour decay leptons can provide important information about the microscopic interactions of heavy quarks with the medium constituents, in particular on the colour-charge and parton-mass dependence of heavy-quark energy loss. Azimuthal anisotropy measurements give insight into the participation of low-momentum heavy quarks in the collective expansion of the system and their possible thermalization in the medium. At high transverse momentum, the path-length dependence of parton energy loss mechanisms can be tested. The possible modifications of heavy-quark
hadronisation in the medium and, in particular, the role of the recombination mechanism can be studied for charm via the comparison of D mesons without strange-quark content, D_s and charm baryons.
The latest results on R_AA and v_2 of D mesons and heavy-flavour decay electrons and muons in Pb-Pb collisions at sqrt{s_NN}=5.02 TeV with ALICE will be presented. The first Lambda_c-production measurement in Pb-Pb collisions will be shown as well. In addition, the R_AA of heavy-flavour hadron decay leptons in Xe-Xe collisions will be presented. The comparison of the results with model predictions will be discussed.

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Results on quarkonia and its associated production with ATLAS

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The associated production of vector boson with quarkonia is a key observable for understanding the quarkonium production mechanisms, including the separation of single and double parton scattering components.
This talk will present the latest differential measurements from ATLAS of (associated) quarkonium production.

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Status and perspectives of the NUMEN project at INFN-LNS

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The presentation aims at describing the main achievements of the NUMEN project [1], together with an updated and detailed overview of the related R activities and theoretical developments. NUMEN proposes an innovative technique to access the nuclear matrix elements entering the expression of the lifetime of the double beta decay by cross section measurements of heavy-ion induced Double Charge Exchange (DCE) reactions. Despite the fact that the two processes, namely neutrinoless double beta decay and DCE reactions, are triggered by the weak and strong interaction respectively, important analogies are suggested. The basic point is the coincidence of the initial and final state many-body wave functions in the two types of processes and the formal similarity of the transition operators. First experimental results obtained at the INFN-LNS laboratory for the 40Ca(18O,18Ne)40Ar reaction at 270 MeV give an encouraging indication on the capability of the proposed technique to access relevant quantitative information [2]. The main experimental tools for this project are the K800 Superconducting Cyclotron and MAGNEX spectrometer [3]. The former is used for the acceleration of the required high resolution and low emittance heavy-ion beams and the latter is the large acceptance magnetic spectrometer for the detection of the ejectiles. The use of the high-order trajectory reconstruction technique, implemented in MAGNEX, allows to reach the experimental resolution and sensitivity required for the accurate measurement of the DCE cross sections at forward angles. However, the tiny values of such cross sections and the resolution requirements demand beam intensities much larger than those manageable with the present facility. The on-going upgrade of the INFN-LNS facilities in this perspective is part of the NUMEN project and will be discussed at the Conference.

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SiPMs for cryogenic temperature

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The DarkSide-20k collaboration is preparing to equip 20 m^2 of SiPMs working in liquid argon at 86 K for the direct search of WIMPs. The collaboration had to solve many technological aspects, such as the development of SiPM optimized for operation in liquid argon, the readout of large SiPM-based detectors, the reliable packaging of more than 200000 SiPMs using radiopure materials. The packaging solutions available for cryogenic applications and the performances of the newest cryogenic extended gain SiPMs from FBK will be discussed.

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Neutron/gamma discrimination by plastic scintillator (EJ299)

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Recently a new generation plastic scintillator (polyvinyltoluene PPO) has been developed and has shown an efficient pulse shape discrimination (PSD) neutron/gamma rays.
These techniques used to distinguish between the pulses from neutrons and the pulses from gamma rays on the differences in the pulse shapes produced.
The goal of this research effort was to test the ability of a polyvinyltoluene research sample to produce recordable, distinguishable signals in response to gamma rays and neutrons.
The results have been performed by using an Am-Be source and have been compared with different scintillators.
Pulse shape analysis allowed the definition of a new Factor of Merit (FoM) as an indicative parameter for the neutron/gamma discrimination.
The results of such separation are shown for EJ301 and EJ299.

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SiCILIA ,Silicon Carbide detectors for Intense Luminosity Investigations and Applications

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Silicon carbide (SiC) is one of the compound semiconductor which has been considered as a potential alternative to Silicon for the realization of charge particles detectors and dosimeters in high energy physics. The chemical and physical material properties are promising for high temperature and high radiation operation conditions [1]. The potential application of SiC as radiation hard material for detectors implementation and the possible use in several new INFN projects (NUMEN,NuReLP, ELIMED, FAZIA etc.) have led to the birth of a cooperation between INFN and IMM-CNR for a common R activity on Silicon Carbide technology named SiCILIA (Silicon Carbide detectors for Intense Luminosity Investigations and Applications) which has been totally funded by INFN.
SiC diodes are predicted to be radiation harder than Si due to the high displacement threshold and potentially used as detectors in high radiation conditions. The remarkable progresses in the material growth process [2] and device technology of the last years, allowed to realize high performances SiC devices based on p-n junction [4].
For nuclear community is very important the realization of detection system that can operate with high fluxes (107 pps/m2) and fluences (1014 cm-2) of heavy-ions in order to determine the cross sections of very rare phenomena (i.e. such as double charge exchange reactions). Silicon carbide technology offers today an ideal response to such challenges, since it gives the opportunity to cope the excellent properties of silicon detectors (resolution, efficiency, linearity, compactness) with a much larger radiation hardness (up to five orders of magnitude for heavy ions [5]), thermal stability and insensitivity to visible light.
In the framework of SiCILIA activities, several measurements have been performed on SiC prototypes, by using radioactive source and ions beams. In this contribution we discuss on the main results of these activities (material properties, fabrication processes, energy resolution, charge collection efficiency, radiation hardness, etc) comparing also the SiC performance with that of a standard Silicon detector.

References

[1] F. Nava, G. Bertuccio, A. Cavallini, E. Vittone Meas. Science Tech. 19, 102010 (2008)
[2] F. La Via, M. Camarda, A. La Magna, Appl. Phys. Rev., 1, 031301 (2014)
[3] M. Cutroneo et J. Material Res. 28, 87 (2012)
[4] F. Moscatelli, A. Scorzoni, et al. Nucl. Instr. Meth A 546, 218 (2005)
[5]M. De Napoli et al. Nucl. Instr. Meth in Physics Research A 608, (2009)

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Durability of actinide targets and metallic foils in experiments on synthesis of superheavy nuclei

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Durability of targets and window foils irradiated by intense heavy ion (HI) beams in the experiments on synthesis of superheavy nuclei (SHN) carried out in Dubna with Gas-Filled Recoil Separator (DGFRS) has been considered. High fluxes of HIs and heat generated within relatively small areas and thicknesses of the target and foil used in DGFRS are inherent in such experiments. The ability of these elements to withstand radiation damages, sputtering and evaporation of atoms is critical for these long-term experiments. All the processes are influenced by the target (foil) temperature and none of them is independent of the others, but they can be considered separately.

Sputtering of actinide targets and Ti window foils irradiated by HI beams has been considered on the grounds of available models and experimental data. At present the ~1 pμA 48^Ca beam allows obtaining several atoms/month of SHN at the production cross section of few pb. The detailed study of SHN with 112≤Z≤118 produced in the 48^Ca fusion-evaporation reactions implies the use of higher beam intensities than those used in the discovery experiments. The synthesis of SHN with Z>118 implies the use of heavier beam particles. Expected production cross sections for SHN in these reactions are ≤0.05 pb. It means that for the observation of two decay events of such SHN one should collect the beam dose ≥10^20 particles. This dose of particles passed through a stationary target may cause the disappearance of target material at the end of the experiment if the sputtering yield is estimated as 10^-2 atom/ion (TRIM). In the case of the rotating target the yield of sputtered atoms is reduced by increasing the irradiation area. The question arises whether this estimate is reliable to be taken into account in future experiments.

The temperature of the target (foil) is determined by the power generated inside it and by the conditions of heat removal from a HI beam spot on the target (foil) surface. The temperature is estimated in the conditions of pulse heating followed by subsequent cooling with radiation emitted from their surfaces. Such pulsing mode corresponds to the rotating target and window irradiated by a continuous HI beam in the DGFRS experiments. Estimates show that radiative cooling is the most effective way of heat transfer to the surroundings at the temperature of few hundred Celsius degrees.

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Time of flight identification with FAZIA

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FAZIA (Forward A and Z identification Array) is an array of three-stage Si-Si-CsI(Tl) telescopes. It was designed to operate with beams in the 20-100 MeV/u energy range and it provides charge and mass discrimination over a wide range of nuclei and energies. Indeed, in the last few years the FAZIA apparatus proved an excellent identification capability for charged particles emitted in nuclear collisions at Fermi energies. In particular, we achieved charge discrimination through Pulse Shape Analysis (PSA) for particles which penetrate at least 30-60 um (depending on their charge) in the first silicon layer. In the perspective of FAZIA experiments at lower energies (e.g. to be realized at the new ISOL facilities SPES and/or Spiral2), and in general to lower the identification thresholds, the time of flight (ToF) information could be used.

Usually, time of flight can be obtained in two ways: either two detectors (start and stop) are used at a certain well measured distance, or the start time mark is given by the accelerator RF signal. Considering the possibility to work also in the absence of pulsed beam, we are studying and implementing a new approach that works for those events where at least one ejectile is properly discriminated in mass. The identified fragments can be used to extract the event start time mark from their energy and mass. This algorithm needs a perfect synchronization among all the ADC clock signals and a precise tuning of all the possible clock skews.

This contribution reports on such recent FAZIA activity, focusing on the basic ideas of the method and on some first results from recent experiments at LNS.

Accelerators and Instrumentation / 8

A prototype detector array for measurements in laser accelerated charged particle beams

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In-beam dose measurements are paramount for any application seeking to harness the effects of the radiation beam, so all the future applications of the laser accelerated beams (as generated in the ELI and CETAL projects) will need such measurements. The gold standard in dose measurement remain the ion chambers, but for the beams we intend to measure they do present some limitations given be the large number of corrections to be applied in order to calculate a correct dose from the measured charge. The ELIDOSE project is addressing these problems by proposing an array detector that would allow the simultaneous measurement of the recombination and polarity corrections, as well as of the dose. The prototype detector consists of 4 identical ion chambers mounted together in a PMMA frame and the project analyses its response to various charged particle beams and the reciprocal influences of the chambers on each other.
This reciprocal influences of the four chambers have been studied in well characterised therapy electron beams and conclusions regarding further developments have been drawn. The paper presents the results of the initial measurements in the 3 MeV and 18 MeV proton beams at the Tandetron and TR19 Cyclotron accelerators of the IFIN-HH and the comparison between the experimental results and the FLUKA based simulations, as well as the results obtained in the 6 to 19 MeV electron beams generated by a Siemens radiotherapy LINAC and how these results will be used to further improve the design of the array detector.

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Design and test of an innovative static thin target for intense ion beams

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Current research in Nuclear physics often investigates rare reactions, which need intense beams to achieve a statistically sufficient amount of data. High beam intensities pose the problem of overheating the target, an issue, which becomes even more relevant when elements with low melting point are required. Currently, rotating targets are used, but such systems are cumbersome and complex. Moreover, the large ring-shaped target poses additive issues when target uniformity or cost cannot be neglected.
The proposed technique consists in the deposition of the target material on a substrate of pyrolytic graphite, whose superficial thermal conductivity is 2000 W/m/K. Heat is efficiently spread on the substrate, eliminating the need of a spinning support; this allows dissipating the heat via thermal contact with a cold sink instead of relying on thermal radiation.
Such target will be used in the NUMEN project, which uses targets of heavy isotopes and 18O and 20Ne beams with energy few tens of MeV/A, with intensity up to 60 uA. The target is few hundred nanometres thick and about 1 cm wide. The graphite substrate diameter is larger than that of the target and the exceeding part is pinched between two copper crowns at fixed cold temperature. The time evolution and the spatial distribution of the temperature have been numerically calculated. MatLab and Comsol programs have been used to evaluate the dependence of the maximum temperature on various parameters.
Concerning the deposition technique, the contact between target and substrate plays a major role in the heat transfer inside the system. In addition, the target homogeneity is a crucial requirement of the NUMEN experiment. In fact, the products of the nuclear reaction vary their energy by ionization and straggling, during the residual path inside the target and inhomogeneity in thickness affects the energy measurement. Therefore, the various deposition parameters have been carefully studied, to improve as much as possible the adhesion between target and substrate. Every deposited sample has been analysed by FESEM microscopy and a set of thickness measurements by proton back-scattering technique are planned in the next future, to test the thickness homogeneity of the deposition.
In the talk, the results of the calculations of the temperature distribution and of the thickness effects on the energy loss will be reported. The microscopy pictures of the deposition samples will be shown, together with the back-scattering measurements.

Nuclear Structure and Dynamics / 233

Investigation of nuclear cluster phenomenology with the relativistic EDF approach

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Relativistic energy density functionnal approaches are able to describe on a common ground quantum liquid and
cluster states in nuclei. We will first show how the experimental observables related to clusterisation are described with this approach.
The study of the localisation of the nucleonic wave-functions in nuclei will also be undertaken in order to provide a deep understanding
of the formation of alpha-like clusters over the nuclear chart.

Nuclear Structure and Dynamics / 124

Study of the IMFs production probability and dependence from the Isospin of the entrance channel in projectile-like break-up at Fermi energies

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The reactions 124Xe + 64Zn and 64Ni at 35 A.MeV beam incident energy (InKiIsSy, Inverse Kinemat-ic Isobaric System, experiment) were studied at INFN-LNS with the 4π CHIMERA detector and compared to results of previous studied reactions 124,112Sn + 64,58Ni [1]. We study the IMF produc-tion probability and emission mechanism in the projectile-like fission by using the kinematical recon-struction of the PLF* source and the break-up alignment angle as main observable. We show that prompt-dynamical emission is enhanced by increasing the projectile and target Isospin content in the entrance channel. Experimental results are compared with the Constrained Molecular Dynamic code CoMD. A new experiment [2] has been approved in order to expand our investigation at lower en-ergies of 20 A.MeV by using CHIMERA coupled with 10 telescopes of the new FARCOS correla-tor.

REFERENCES

[1] P. Russotto et al., Phys. Rev. C92, 014610 (2015).
[2] E.V. Pagano, E. De Filippo, P. Russotto and NewChim collaboration, CHIFAR LNS-PAC proposal.

Nuclear Structure and Dynamics / 365

Alpha clustering and condensation in nuclear systems

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Alpha clustering in nuclear systems has known an extraordinary growth in activity over the last 15 years or so. I have strongly participated in the theoretical developments of alpha clustering and with my collaborators I have for example proposed that the Hoyle state in 12C can be considered as an alpha particle condensate. This theory explains all known data of the Hoyle state, for instance the inelastic form factor without any adjustable paramter. The so-called THSR (Tohsaki, Horiuchi, Schuck, Roepke) wave function has now been generalized and most of the alpha-gas states of the family of Hoyle states are very well described. Predictions for alpha gas states in 16O are being made.
These alpha gas states are precursors of alpha condensation in low density nuclear matter. The critical temperature is calculated in symmetric and asymmetric matter. At zero temperature it is shown that alpha condensation is a Quantum Phase Transition with the density as control parameter (alpha condensation disappears above a critical (low) density). This is exemplified for nuclear matter but also for finite nuclei. Alpha decay of Actinides is a new subject treated with a THSR type of approach and, e.g., a pocket formation of the alpha on the surface of 208Pb in 212Po can explain the physics at work in alpha decay. The talk is intended to give an overview of alpha clustering in nuclear systems.

Nuclear Structure and Dynamics / 100

Evidence of non-statistical effects in the decay of 36,37Ar*

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The fusion-evaporation 24Mg+12,13C reaction at 162 and 142 MeV respectively has been investigated with the GARFIELD and RingCounter detectors, in operation at the LNL (Legnaro National Laboratories of INFN). Thanks to the large coverage (about 70% of the total solid angle) and to the good identification capability in terms of charge and energy, it is possible to obtain a very clean data set where the total charge of the 36,37Ar* compound nucleus is detected. The analysis of the Fusion-Evaporation or Fusion-Fission chains for those complete events can be compared with simulated events. In particular, a Hauser-Feshbach Monte-Carlo developed by the NUCL-EX collaboration and particularly optimized for light systems (HFl) and the GEMINI++ code, widely used to describe fusion-evaporation and fusion-fission reactions, will be used.
Following the previous analysis on light system as 12C+12C, 16O+12C performed with the same apparatus, LCP energy spectra, angular distribution and Branching Ratios(BR) of the different experimental channels will be studied in details and compared with simulations in order to disentangle possible effects due to clustering pre-formation in the CN. Moreover, the possible difference in the decay of 36,37Ar* created at the same excitation energy will be put in evidence.

Nuclear Structure and Dynamics / 114

Isospin dynamics and nuclear dipolar degree of freedom

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One of the most important and intriguing problems in studying Heavy Ion collisions at the Fermi energies is to recover information directly linked to the dynamical stage of the reaction without
the blurring effects of later stages associated the statistical decay of the hot source. In this case
the obtained results can give clear information on the effective interactions governing the dynamics
In the last decades [1-3] it has been shown that the time derivative of the average total dipole signal obtained by measuring the charges Zi and velocities of all the charged particles produced in an heavy ion collision does not depend on the statistical decay processes. It rather depends on the dynamics of the isospin equilibration processes between ions having large differences in the charge/mass ratios.
In this contribution we illustrate the results of a first attempt to perform these kind of studies on
the system 48Ca+27Al at 40 MeV/A performed with the multi-detector CHIMERA [4-5] at the LNS.
These investigations continue with a new campaign of measurements taking advantage of the improved performances of the CHIMERA detector.

Nuclear Structure and Dynamics / 24

Self-consistent single-particle approximation to nuclear state densities at high excitation energy

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We compute nuclear state densities in the frame of the grand-canonical formalism in an energy (or, equivalently, temperature) range where residual two-body interactions and collective effects can reasonably be neglected. The single-particle states used in the calculations are generated in a self-consistent relativistic mean field at finite temperature [1] based on the NL3* [2] and DD-ME1 [3] effective interactions. Resonant single-particle states of small width (Gamow states), which are expected to give a sizable contribution at high temperatures, are evaluated by means of the complex scaling method [4]. Nuclear state densities are then evaluated for a number of even-even nuclei in a large mass region by the Gamow state method and by the subtraction method, originally formulated by Bonche, Levit and Vautherin [5], where the grand-canonical potential of the excited nucleus is obtained by subtracting from the thermodynamic potential of the nucleus in equilibrium with its vapour the potential of the vapour alone at the same temperature. The results of the two approaches are compared and the limits of the adopted formalism discussed.

References
[1] R. Lisboa, M. Malheiro and B. V. Carlson, Phys. Rev. C 93 (2016) 024321.
[2] G. A. Lalazissis, S. Karatzikos, R. Fossion, D. P. Arteaga, A. V. Afanasjev and P. Ring, Phys. Lett. B 671 (2009) 36.
[3] T. Niksic, D. Vretenar, P. Finelli and P. Ring, Phys. Rev. C 66 (2002) 024306.
[4] J.-Y. Guo, M. Yu, J. Wang, B.-M. Yao and P. Jiao, Comput. Phys. Comm. 181 (2010) 550.
[5] P. Bonche, S. Levit and D. Vautherin, Nucl. Phys. A 427 (1984) 278, A 436 (1985) 265.

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Dynamical effects in Projectile like break-up, following a deep inelastic collision, in low energy 78,86Kr+40,48Ca reactions at 10 AMeV

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The reactions 78Kr+40Ca and 86Kr+48Ca realized at 10 AMeV, have been studied in Catania at LNS with the 4π multidetector CHIMERA.
For these systems, we have already studied the fusion-evaporation and fission-like processes [1][2][3].
Now we will present a study of the break-up of the Projectile-Like (PLF) into two fragments, following more violent deep-inelastic collision.
A selection method has been developed, in order to discriminate PLF break –up from events due to other mechanisms, fusion-fission like processes, which populate the same region of the phase-space. A preference for PLF aligned break-up, along the direction of the PLF-TLF separation axis with the light fragment emitted in the backward part, has been evidenced, suggesting dynamical-not equilibrium effects. The isospin is expected to play a crucial role in the onset of this process; a comparison between the neutron-rich 86Kr+48Ca system and neutron-poor 78Kr+40Ca one will be presented.

[1] B. G. Il Nuovo Cimento C39 (2016) 275
[2] S. Pirrone et al., EPJ Web of Conferences 122, (2016) 13001
[3] G. Politi et al., JPS Conf. Proc. Vol. 6 (2015) 030082

Future facilities in construction / 360

Setting the scene with the Nupecc long range plan on facilities

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Round Table

Plenary / 371

Beta-detected NMR: from nuclear structure to chemistry and biology

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Beta-NMR, in which the resonances are observed as changes in beta-decay anisotropy, is over 10 orders of magnitude more sensitive than conventional Nuclear Magnetic Resonance. The method has been used widely in nuclear physics and condensed matter, but not yet in soft matter. In the former it allows determining precisely the electromagnetic moments of exotic nuclei, thus providing information on their single-particle and collective properties, while in the latter it allows looking at the local properties of different host materials.
On the other hand, in chemistry and biochemistry classical NMR is currently the most versatile and powerful spectroscopic technique for characterization of molecular structure and dynamics in solution. However, the low sensitivity leads to relatively large amounts of sample, which poses constraints on the systems that may be explored. In addition, not all elements are easily accessible, as the most abundant isotopes display no or poor response. This is where ultra-sensitivity of beta-NMR can be of value.
Our project aims at applying beta-NMR for the 1st time to soft-matter biological samples, using the newly commissioned laser spin-polarization beamline at CERN-ISOLDE. We use optical pumping with lasers to polarize isotopes of different metallic elements. The anisotropic emission of beta radiation is them used to detect NMR response, leading to the above-mentioned 10 orders of magnitude increase in sensitivity.
The scientific goal is to investigate the interaction of essential metal ions, which are otherwise difficult to address, such as Na(I), K(I), Mg(II), Cu(I), and Zn(II), with nucleic acids and proteins. In 2016 we designed, built, and commissioned the experimental setup, in 2017 we recorded the first liquid-NMR spectra, and in 2018 we have performed the first studies of the interaction of DNA G-quadruplex structures with Na(I) ions that are crucial for the structures' formation, stability, and polymorphism.
My presentation will cover the principles of beta-NMR and will compare it to conventional NMR. I will describe the experimental setup and the challenges when applying it to liquid samples, will report on the first biological results, and will mention the future plans.

Plenary / 329

Nuclear Physics with an Effective Field Theory Around the Unitarity Limit

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Understanding the structure of nuclei from the underlying theory of strong interactions, QCD, has been a longstanding problem. Over the last quarter-century significant progress has been achieved with low-energy effective field theories (EFTs) of QCD and ab initio methods for the solution of the Schroedinger equation (and its many-body variants). Yet, this description remains highly complex. In particular, it does not explicitly incorporate the proximity of the unitarity limit, where the two-body system has S-wave bound states at zero energy and continuous scale invariance. Rich structures emerge in three- or more-nucleon systems from the anomalous breaking of scale invariance to a discrete subgroup, with the emergence of a dimensionful parameter. I show how this one three-body scale is sufficient to generate the spectra of light nuclei and quantum-liquid saturation in larger systems.

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Light Hypernuclei : a Testbed for Charge Symmetry Breaking

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Charge symmetry is broken in QCD by the up-down quark mass difference and electromagnetic interactions. In Λ hypernuclei, charge symmetry breaking (CSB) manifests itself in a charge dependence of Λ separation energies.
At the Mainz Microtron MAMI the novel method of high-resolution spectroscopy of decay-pions in strangeness electroproduction was established to measure Λ separation energies. A sizable CSB effect was reaffirmed for the A = 4 mirror pair and until recently it could not be reproduced in any ab initio 4-body calculation.
The full understanding of this large and spin-dependent effect remains one of the unresolved issues of hypernuclear physics.

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The Light Baryon Spectrum and QCD

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The spectrum of bound hadronic states is intimately connected with the behavious of QCD at low energies, where the theory in non-perturbative. An overview will be given of the progress in the study of baryon spectroscopy from recent experimental programmes. In particular, a range of photo-production measurements has been carried out, which include the extraction of several polarization observables for different reaction channels. The results so far show that these data are very useful in the search for evidence for new baryon resonances. A survey of the results will be presented, together with the latest phenomenological fits.

Plenary / 332

Uncovering carbon burning in stars

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C-burning plays a pivotal role in astrophysics to understand stellar burning scenarios in carbonrich environments [1-4]. The temperature for carbon burning to occur is greater than 0.4 GK, corresponding to center-of-mass energies exceeding 1 MeV. The dominant evaporation channels below 2 MeV are α and proton, leading to 20Ne and 23Na, respectively. In spite of the considerable efforts devoted to measure the 12C(12C,α)20Ne and 12C(12C,p)23Na cross sections at astrophysical energies, they have been measured only down to 2.14 MeV, still at the beginning of the astrophysical region [5]. As known, direct measurements at lower energies are extremely difficult. Moreover, in the present case the extrapolation procedure from current data to the ultra-low energies is complicated by the presence of possible resonant structures even in the low-energy part of the excitation function. For these reasons the Trojan Horse Method [6,7] can represent a unique way for an accurate investigation at the relevant energies. This has been done recently by measuring the 12C(14N,α20Ne)2H and 12C(14N,p23Na)2H three-body processes at 30 MeV of beam energy in the quasi-free (QF) kinematics regime, where 2H from the 14N Trojan Horse nucleus is spectator to the 12C+12C two-body processes. The cross section experiences a strong resonant behaviour with resonances associated to 24Mg levels. As a consequence, the reaction rate is enhanced at the relevant temperatures. Results, which have been recently published in Nature [8], will be presented and discussed.

[1] F. Kappeler et al., Ann. Rev. Nucl. Part. Sci. 48, 175 (1998).
[2] E. Garcia-Berro et al., Astrophys. J. 286, 765 (1997).
[3] L. Piersanti et al., Astrophys. J. 598, 1229 (2003).
[4] A. Cumming et al., Astrophys. J. 646, 429 (2006).
[5] T. Spillane et al., Phys. Rev. Lett. 98, 122501 (2007) and references therein
[6] C. Spitaleri et al. Phys. At. Nucl., 74, 1763 (2011).
[7] R.E. Tribble et al., Rep. Prog. Phys., 76, 106901 (2014).
[8] A. Tumino et al., Nature 557, 687 (2018).

Plenary / 333

Nuclear Astrophysics at LUNA: Status and Perspectives

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Except for primordial hydrogen, helium and few other light species, all chemical elements in the universe originate from nuclear reactions occurring in both quiescent and explosive stages of stellar evolution. Such reactions take place over a narrow energy region, typically well below the Coulomb barrier between the interacting nuclei [1]. As a result, their reaction cross sections are vanishingly small and difficult to measure at surface laboratories. In many cases, significant breakthroughs can be achieved underground, where the cosmic-ray induced background can be reduced by several orders of magnitude [2].

The Laboratory for Underground Nuclear Astrophysics (LUNA) of the INFN at Gran Sasso (Italy) has pioneered low-energy nuclear reaction studies for over 25 years now, allowing – often for the first time – the study of key reactions directly at the relevant astrophysical energies. In particular, experimental studies of hydrogen burning reactions in the pp-chain, the CNO cycles, and NeNa-MgAl cycles have led to major improvements in our understanding of nucleosynthesis processes in various environments, from the Big Bang, to our Sun, to Asymptotic Giant Branch stars and classical novae [3,4].

Here, I will review some of the most recent results and present future perspectives both at LUNA and elsewhere.

Plenary / 334

Nuclear physics with accelerator-produced neutron beams

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Neutron-induced nuclear reactions, a substantial part of the more generic notion of nuclear data, are important for a variety of research fields, going from stellar nucleosynthesis, basic nuclear physics, to nuclear technology to applications in dosimetry, medicine, and space science. Accelerator-based neutron sources play a major role in experimental studies for the determination of reaction cross sections spanning a wide energy range from sub-thermal to GeV energies. A number of present and upcoming neutron time-of-flight and mono-energetic facilities will be discussed and illustrated by examples of measurements for nuclear astrophysics and nuclear technology.

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NICA project: challenges for heavy ion collider

The global scientific goal of the NICA/MPD (Nuclotron-based Ion Collider fAcility / Multy Purpose Detector) project under realization at JINR is to explore the phase diagram of strongly interacting baryonic matter in the region of a high compression and temperature. The proposed program allows one to search for possible signs of the phase transitions and critical phenomena in heavy ion (up to Au+Au) collisions up to to energies of 11 GeV in nucleon- nucleon center-of-mass system.The collider experiment provides optimal conditions for efficient energy scan measurements. However, the accelerator task to reach required average luminosity of the order of 10^27 cm^-2*s^-1 is challenging: in contrast with a high energy collider the luminosity is limited by Lasslet tune shift, the beam-beam parameter is almost negligible. A flexible procedure of the beam storage and short bunch formation is to be applied to provide maximum peak luminosity in a wide energy range. The application of beam cooling methods is mandatory in order to suppress luminosity dilution due to the intra-beam scattering. A solution of these and other problems is demonstrated in the case of the NICA collider design.

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Gamma beam collimation and characterization system for ELI-NP-GBS

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The Gamma Beam System of ELI-Nuclear Physics is a high-brilliance monochromatic gamma source based on the inverse Compton interaction between a high-power laser and an accelerated electron beam. The source, currently being assembled in Magurele (Romania), is designed to provide photons with tunable average energy ranging from 0.2 to 19.5 MeV, energy bandwidth down to 0.5$\%$ and flux of about 10^8 photons/s.
The time structure of the gamma beam will consists of 32 ultra-short pulses of 10^5 photons separated by 16 ns and delivered at repetition rate of 100 Hz. Given the challenging characteristics of this gamma beam, dedicated devices and techniques have been developed to measure and monitor the beam parameters during the commissioning and the operational phase.
The characterization system includes four main elements: a Compton spectrometer, a sampling calorimeter, a nuclear resonant scattering spectrometer (NRSS) and a beam profile imager.
The Compton Spectrometer was designed to reconstruct the gamma energy spectrum, by measuring the energy and the scattering angle of electrons produced in Compton interactions on thin mylar targets. A new-concept sampling calorimeter, made of layers of silicon detectors and polyethylene absorbers, was developed to measure the average energy and beam intensity.
To obtain an accurate absolute measurement of the gamma beam energy the NRSS will use as calibration candles a few selected nuclear levels, whose fluorescence condition will be monitored by a scintillators system. To complete the characterization of the source, a gamma beam profile imager, based on a scintillator screen and a CCD camera, has been developed to evaluate the transverse spatial distribution of the beam.
Due to the nature of inverse Compton interaction, in order to obtain a monochromatic beam a collimation of the emitted photons is necessary. Depending on the energy, the angular aperture required for a relative bandwidth ΔE/E=0.5$\%$ is between 70 and 700 microrad. A collimation system to provide a continuously adjustable aperture having such a demanding positioning accuracy was designed and assembled.
In this talk an overview of these collimation and characterization system will be presented. We will focus on the working principles and technological solutions to realize such a challenging experimental apparatus. We will describe the expected performance, the result of tests carried out and the current status of the system assembly.

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The innovative Design of the PANDA Barrel DIRC

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The fixed target experiment PANDA at the High Energy Storage Ring (HESR) of the Facility for Antiproton and Ion Research in Europe (FAIR) in Darmstadt will open unique possibilities to solve fundamental questions of hadron physics by using a cooled high-intensity antiproton beam. Two fast and compact Ring Imaging Cherenkov detectors using the DIRC (Detection of Internally Reflected Cherenkov light) technology will provide excellent charged particle identification (PID) in the PANDA target spectrometer. The Barrel DIRC will cover the polar angle range from 22° to 144° and cleanly separate pions from kaons for momenta up to 3.5 GeV/c. It consists of 16 optically isolated sectors, each comprising three bars, flat mirrors and focusing lenses, a compact fused silica prism as expansion volume, and 11 Microchannel-Plate PMTs (MCP-PMTs) as photon sensors. The bars are made from synthetic fused silica, have a length of 2400 mm and a cross section of 17 mm x 53 mm, and are built to tight optical and mechanical specifications to preserve the photon angle during many internal reflections and to optimize the light transport efficiency. The spherical lens system is designed to efficiently focus the Cherenkov light on a flat image plane on the back wall of the prism where the photons are detected by the array of MCP-PMTs. Detailed Geant4 simulations were performed to optimize the design for performance and cost and two complementary reconstruction algorithms were developed, one primarily based on photon spatial coordinates, the other emphasizing the precise measurement of the photon propagation time. All the key elements of the PANDA Barrel DIRC design were implemented in several complex prototypes and tested in hadronic particle beams at GSI and CERN. The data obtained were used to tune the simulation, validate the reconstruction methods, and to evaluate the PID performance of the design. We will discuss the technical design of the PANDA Barrel DIRC and present results from the test beam campaigns at the CERN PS in 2017 and 2018.

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The new pulsed neutron beam facility at CNA (Spain)

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The neutron research activities with the Tandem Pelletron Accelerator at CNA in Seville (Spain) is based on the development of neutron sources with different energy and angular distributions, which could be generated by 7Li(p,n) and D(D,n) reactions. The neutron beam characterization is done using the Time of Flight technique (TOF). The TOF technique allows measuring neutron induced cross section as a function of the neutron energy, which can be obtained from the flight time that a neutron spends to travel over known path. To implement TOF technique one needs pulsed ion beams.
In order to provide pulsed beams, CNA team and NEC staff are currently working on a chopping/bunching system installation and commissioning, as well as the addition of new equipment to better monitor and control the beam in a new neutron line. The beam chopper consists of a pair of electrically deflecting plates, mounted in parallel to the initial ion beam. One plate is normally polarized with dc voltage deflecting the beam on an absorbing beam catcher. The second one is supplied with an electronic switch. Both work together producing an oscillation of the beam in the transverse direction, thus creating a beam pulse. The bunching unit, being made up involving a pair of tubular electrodes, is mounted coaxially to the ion beam, after the pulsing unit. The electrodes are supplied with radiofrequency voltage phase locked to the different frequencies of the chopping system. The entrance and the exit gaps of the tubular bunching electrodes are used for the time compression of the beam pulse. The other new devices are: a beam profile monitor (BPM), two magnetic steerers, two manual slits, a Faraday cup, and a Pick-Up.
The chopping/bunching system has been designed to deal with a primary beam of protons or deuterium. The first tests with protons show a pulsed beam with a FWHM of the order of ns and expected frequency.
These promising results will lead the way to various research lines in Seville, among them are nuclear energy production, radiation protection, cancer therapy by neutron irradiation, radio-biological and nuclear structure research.

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Status and perspectives of the neutron time-of-flight facility n_TOF at CERN

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In 2002 the neutron time-of-flight facility n_TOF started its operation at CERN using a 185-m beam line. After a series of successful measurement campaigns, a second beam line, at 18.5 m from the neutron-producing target, was built in 2014. The two lines provide an excellent combination of good energy resolution and high instantaneous neutron flux. The latter feature results in a much enhanced signal to background ratio for neutron-induced reactions on small mass radioactive isotopes and/or isotopes with very small cross sections.

Neutrons are created by spallation reactions induced by a pulsed 20 GeV/c proton beam impinging on a lead target. Two layers of water and borated water, respectively, surrounding the lead target, act as a coolant and at the same time as a moderator of the initially fast neutron spectrum, providing a wide neutron-energy spectrum ranging from the meV to the GeV region.

The innovative features of the facility have been complemented by a wealth of high-performance detection systems for fission, capture, and reactions involving charged particles in the exit channel. So far, a large number of experiments has been performed on a variety of isotopes of interest for nuclear astrophysics, advanced nuclear technologies, nuclear medicine, and for basic nuclear physics.

After the CERN long shutdown, a new phase of data taking is planned to start in 2021. The R of a new spallation target is ongoing and its upgrade will bring important improvements in both beam lines, eventually allowing the n_TOF Collaboration to perform new, challenging measurements.

In this talk, the status of the n_TOF facility will be presented together with an outlook on future opportunities.

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The Endcap Disc DIRC for PANDA at FAIR

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The PANDA detector at the future FAIR facility at GSI is planned as a fixed-target experiment for proton-antiproton collisions at momenta between 1.5 and 15 GeV/c. It will be used to address open questions in hadronic physics. In order to achieve a sufficient particle identification, two different DIRC detector concepts have been developed. This talk will cover the Endcap Disc DIRC detector which is placed at the forward endcap of the PANDA target spectrometer and will provide a separation of pions and kaons with a separation power of 3 standard deviations up to a momentum of 4 GeV/c for polar angles from 5° to 22°.

The most important component of the DIRC detector is a 2cm thin fused silica radiator plate that is divided into 4 identical quadrants. The surfaces are polished with high precision in order to guarantee little photon losses by total reflection and conserve the Cherenkov angle during propagation through the optical system. Intrinsic chromatic errors will be minimized by the implementation of an optical filter. The readout system consists of 96 readout elements with focusing optics and attached MCP-PMTs to focus the photons that are produced by the Cherenkov cone of the traversing particle and acquire their position and timing information.

This new detector concept requires the development of dedicated reconstruction and particle identification algorithms which permit an efficient analysis of the measured time-correlated photon patterns. Time and event based simulations with a Monte-Carlo simulation framework have been used to validate the PID requirements of the DIRC counter. Additionally, an online reconstruction algorithm prototype for the purpose of event-filtering has been designed and tested in combination with an FPGA board. For analyzing the detector performance, the decay of a glueball candidate into two kaons resp. pions has been studied.

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The upgrade of the ALICE Inner Tracking System at the CERN LHC

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ALICE is one of the experiment at the CERN Large Hadron Collider (LHC) studying the nuclear matter at extreme conditions of temperature and pressure. The third run of LHC will start in 2021 after a shutdown of two years to allow the upgrade of both the accelerator and the experiments. In Run 3 Pb-Pb collisions will be performed at a centre of mass energy per nucleon of 5.5 TeV, with a luminosity of 6 $\times$ 10^{27} cm^{-2}s^{-1}. The interaction rate will increase up to 50 kHz and 400 kHz for Pb-Pb and pp collisions, respectively.
To fulfil the requirements of the ALICE physics program for Run 3, a major upgrade of the experimental apparatus is planned for installation in 2019-2020. One of the key elements of the ALICE upgrade is the construction of a new, ultra-light, high-resolution Inner Tracking System (ITS) to significantly enhance the determination of the distance of closest approach to the primary vertex, the tracking efficiency at low transverse momenta, and the read-out rate capabilities, with respect to what can be achieved with the current detector. The setup will consist of seven layers, longitudinally segmented in Staves, equipped with silicon Monolithic Active Pixel Sensors with a pixel size of the order of 30x30 μm^{2} covering, for the first time, the large area of 10 m^{2}.
The main physics goal is to improve the reconstruction capabilities of heavy flavour (c and b quarks) mesons and baryons.
This contribution is dedicated to the description of the ITS upgrade project analysing the challenging aspects of the future detector showing how they have been implemented in the first Staves produced by the Collaboration. Finally, the expected physics performance with the new ITS will be outlined.

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Conceptual Design of Accelerator Driven Systems with Light Ion Beams

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The superior energy efficiency of light ion beams instead of proton beams for energy production in accelerator driven systems (ADS) is demonstrated. The energy efficiency is characterized by the energy gain calculated as the ratio of the energy released in the target to the energy spent for the beam acceleration. The energy deposited in the target is obtained via Geant4 simulation. The energy spent for the beam acceleration depends on the particle type and energy, beam intensity, and accelerator type (synchrotron, linac, cyclotron). A method to calculate the energy spent for the beam acceleration by scaling from the data for a reference beam is presented. For a given beam, the highest energy gain is obtained when the beam is accelerated in a synchrotron. A synchrotron, however, cannot ensure the beam intensities necessary for accelerator driven systems (ADS). Linacs are capable to produce the required beam intensities with good energy gain. For this reason, we consider the beams accelerated in a linac in the further analysis.
The influence of the target structure on the energy efficiency of 0.5-4 GeV proton beams and 0.25 − 0.5 AGeV light ion beams is studied. The target consists of rods with different composition (metal, oxide, carbide) and different levels of enrichment in order to implement the target with a criticality coefficient of 0.96 -0.97, which ensure safe operation. The influence of the rod diameter and the distance between rods was investigated. The cooling with different metals (lead, lead-bismuth eutectic-LBE, and sodium) is compared. The use of convertors from heavy metals (uranium, lead, tungsten) and very light materials (lithium, beryllium, carbon) and their influence on the neutron spectrum and energy released are analyzed.
Our studies yield the conclusion that the best solution for ADS from the point of view of the energy efficiency and miniaturization is as follows: beams of Li-7 and Be-9 with energies of 0.35 - 0.4 AGeV, cooling with lead or LBE, and the use of convertors from Be or Li.

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Final results from QWeak

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Experimental programs in the fields of nuclear and particle physics are searching for evidence of physics beyond that explained by current theories. The Standard Model cannot predict fundamental parameters such as the mass of the Higgs boson or account for dark matter/energy, gravity, and the matter–antimatter asymmetry in the Universe. These limitations have inspired direct searches for additional particles at high energy accelerators. Alternately, indirect searches using precise measurements of well predicted Standard Model observables allow highly targeted tests that can reach mass and energy scales beyond those directly accessible by today's high energy accelerators. Such indirect searches include the precise measurement of the weak charge of the proton. Because parity symmetry is violated only in the weak interaction, it provides a tool to isolate the weak interaction. With our precise measurement (-226 ±9 ppb) of the parity-violating asymmetry in the scattering of polarized electrons on protons, we extract the proton's weak charge and the weak mixing angle sin2�W at low Q2. This allows a mass reach for any parity violating semi-leptonic physics beyond the Standard Model at the multi-TeV scale. Implications for several specific models will be discussed. In conjunction with existing atomic parity violation results on 133Cs we also extract the vector weak quark couplings C1u and C1d and the weak charge of the neutron.

Hadron structure, spectroscopy and dynamics / 205

The 3D Structure of Nucleons

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A complete three-dimensional picture of the partonic structure of nucleons requires to step beyond the standard collinear approximation in high-energy processes, with the introduction of Transverse-Momentum Dependent (TMD) parton distribution and fragmentation functions. TMDs reveal precious information about spin-momentum correlations in the non-perturbative regime of QCD and help answering the question of the origin of the spin of the nucleon.

In the past twenty years, pioneering studies have opened up a broad vision of this multidimensional landscape. Recently, however, we have gone from the preliminary phase of explorative investigations to the stage in which precision mappings of the partonic structure in momentum space can be drawn.

I will summarize the most significant aspects of the phenomenological study of TMD physics and underly the most recent advances in the field.

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Quark-gluon correlations in the twist-3 TMDs using light-front wave functions

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Higher-twist transverse-momentum dependent parton distributions (TMDs) go beyond the parton model description of a proton as they describe correlations between quarks and gluons. In general, twist-3 distributions can be decomposed into different contributions: lower-twist (i.e. twist-2) contributions and pure twist-3 contributions. Most of the phenomenological parametrizations and models rely on the so called Wandzura-Wilczeck (WW) approximation, that set to zero the pure twist-3 contributions. However, the WW approximation removes the richness of the twist-3 distributions.
I will show how the quark-gluon correlations (pure twist-3 contributions) entering the T-even chiral-odd distribution $e(x,k_\perp)$ and in the T-even chiral-even distribution $f^\perp(x,k_\perp)$ can be calculated using the formalism of light-front wave functions (LFWFs). We consider LFWFs with non-vanishing parton's orbital angular momentum and an intrinsic, non-perturbative gluon contribution.
The LFWFs are modeled in terms of the nucleon distribution amplitudes, with parameters fitted to the MMHT2014 parametrization for both the valence-quark and gluon unpolarized parton distribution $f_1(x)$. With these fit parameters, I will show predictions of the pure twist-3 contributions, and I will compare the results for $e(x)$ to a recent extraction, obtained from the analysis of preliminary data of the beam asymmetry for di-hadron semi-inclusive deep inelastic scattering at CLAS 6 GeV.

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Generalized Parton Distributions at Jefferson Lab

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Exclusive processes at high momentum transfer, such as Deeply Virtual Compton Scattering (DVCS) access the Generalized Parton Distributions (GPDs) of the nucleon. GPDs offer the exciting possibility of mapping the 3-D internal structure of protons and neutrons by providing a transverse image of the constituents as a function of their longitudinal momentum.

A vigorous experimental program is currently pursued at Jefferson Lab (JLab) to study GPDs through DVCS and meson production. New results from Hall A will be shown and discussed. Special attention will be devoted to the applicability of the GPD formalism at the moderate values of momentum transfer.

We will conclude with a brief overview of additional DVCS experiments under analysis and planned with the future Upgrade of JLab to 12 GeV.

Hadron structure, spectroscopy and dynamics / 212

Electromagnetic transition form factors of light mesons

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Electromagnetic transition form factors are determined via meson decays into final states with dileptons. Form factors are evaluated as a function of the momentum transfer which is identical to the invariant mass of the dileptons. The results provide basic knowledge of the structure of hadrons and address the validity of vector meson dominance. Transition form factors are of renewed interest on account of the impact on the interpretation of the g-2 measurements. Here, light-by-light scattering is an important factor.
This talk will present experimental results from the concluded experiments WASA at COSY and CLAS6 at Jefferson Lab.

Nuclear Astrophysics / 181

Nuclear challenges for nucleosynthesis studies

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One of the major issues in modern astrophysics concerns the analysis and understanding of the present composition of the Universe and its various constituting objects. Nucleosynthesis models aim to explain the origin of the
different nuclei observed in nature by identifying the possible processes able to synthesize them. Though the origin of most of the nuclides lighter than iron through the various hydrostatic and explosive burning stages in stars is now quite well understood, the synthesis of the heavy elements (i.e. heavier than iron) remains obscure in many respects. The major mechanisms called for to explain the production of the heavy nuclei are i) the slow neutron-capture process (or s-process) occurring during specific hydrostatic stellar burning phases, ii) the rapid neutron-capture process (or r-process) believed to develop during the explosion
of a star as a type II supernova or during the merging of two compact objects, and iii) the photodisintegration process (or p-process) taking place in the high-temperature environment of type-Ia or type-II supernovae. The stellar nucleosynthesis requires a detailed knowledge not only of the astrophysical sites and physical conditions in which the processes take place, but also the nuclear structure and interaction properties for all the nuclei involved.

This seminar describes our present understanding of the stellar nucleosynthesis processes as well as the many experimental and theoretical efforts devoted to determine the related nuclear physics inputs of relevance. These include nuclear structure as well as decay and reaction properties of relevance in astrophysical environments. A special attention will be paid to the complex physics related to the r-process nucleosynthesis and the new developments in the light of the recent observation of the binary neutron star merger GW170817.

Nuclear Astrophysics / 23

Experimental studies of explosive heavy element nucleosynthesis

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About 50% of the chemical elements heavier than iron are synthesized in stellar explosions, in supernovas or in neutron star mergers. After tremendous experimental and theoretical efforts and significant progress in astrophysical modeling, the origin of neither the r nor the p isotopes is fully understood. One thing is certain: improved nuclear physics knowledge is needed to describe better the synthesis of these isotopes.

In recent years a large number of low energy alpha induced reactions relevant for the understanding the synthesis of the p isotopes have been studied at Atomki and worldwide. The measured cross sections are compared to theoretical calculations with the aim of improving the reliability of the calculated reaction rates used in the reaction networks.

In the so-called astrophysical r-process exotic isotopes, close to the drip line are formed via rapid neutron capture reactions. When the neutrons flux ceases these isotopes decay toward the valley of stability, therefore, to reproduce the observed abundance pattern, the properties of the β-decays have to be known. Last year the BRIKEN neutron detector has been built at the BigRIPS separator at RIKEN Nishina Center to study the decay properties of the most neutron-rich nuclei produced through the fragmentation of high intensity 238U primary beam.

In this talk, the cross section measurements performed at Atomki will be presented as well as the first results achieved using the BRIKEN neutron counter.

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Underground Measurement of Proton-Induced Reactions on 6Li at LUNA

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Proton-induced reactions on 6Li play an important role in nuclear astrophysics studies in relation to primordial lithium abundances. Whilst big bang nucleosynthesis theory excludes the existence of "primordial" 6Li, the 6Li/7Li abundance ratio observed in pre-main sequence (PMS) stars is ~ 0.5. The 6Li(p,a)3He and 6Li(p,g)7Be reactions are the main processes that contribute to 6Li destruction in stars. Both reactions were recently studied at LUNA via proton bombardment of 6Li-enriched targets, with complimentary target composition studies performed at HZDR. Improvements on the precision of the low-energy S-factor values are expected from this study. Notably, the low-background measurement at LUNA will assist the search for a recently observed 6Li(p,g)7Be low energy resonance proposed at Er ~ 195keV. In this talk I will introduce the LUNA experimental setup and present preliminary results of the ongoing analysis.

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Stellar Modelling for Nuclear Astrophysics: Constraining the astrophysical origin of the p-nuclei

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The production of the proton-rich stable isotopes beyond iron that we observe today in the solar system is still uncertain. Core collapse supernovae (ccSNe) and thermonuclear supernovae (SNe Ia) exploding within the single-degenerate scenario have been proposed to be a potential source for these isotopes. Recent works performing Galactic Chemical Evolution (GCE) calculations, showed that explaining the inventory of the p-nuclides in the Solar System by the contribution from ccSNe alone is really challenging, thus requiring a complementary contribution from SNe Ia, assuming in this last case an s-process rich pre-explosive seeds distribution, built by neutron captures in the external layers of the progenitor white dwarf (WD), during the accretion phase. Presently there are no complete stellar models calculating these abundances, covering the WD mass range up to the Chandrasekhar mass. We calculate accretion models for five WDs with different initial masses using the stellar code MESA. We then focus on the nucleosynthesis calculating the full abundance distribution. In our models the dominant neutron source are the 22Ne(α,n)25Mg, which is activated at the bottom of the convective thermal pulse driven by the Helium flashes along the accretion phase, for WD masses lower than 1.26 solar masses, and the 13C(α,n)16O for WD masses equal or higher than 1.26 solar masses. We found neutron densities up to few 10^15 cm^-3 in the most massive WDs. In particular, we obtain a strong production by neutron captures up to the Pb region, showing how the classic assumption of a pre-existing s-process rich pre-explosive seeds distribution is actually justified. Using these results, we compute the resulting explosive nucleosynthesis of proton rich heavy stable isotopes using a multi-D SNe Ia model, and discuss the uncertainties affecting our results, focusing in particular on the list of the main nuclear reaction-rates which provide the dominant contribution to the production uncertainty, highlighting which of the identified key reactions are realistic candidates for improved measurement by future experiments.

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Direct capture cross section and low-energy resonances in the 22Ne(p,gamma)23Na reaction

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The 22Ne(p,gamma)23Na reaction takes part in the neon-sodium cycle of hydrogen burning and may affect the observed anti-correlation between sodium and oxygen abundances in globular cluster stars. Its rate is controlled by a number of low-energy resonances and a slowly varying non-resonant component. Three new resonances at Ep = 156.2, 189.5, and 259.7 keV, respectively, have recently been observed and confirmed. However, significant uncertainty remains due to the off-resonant process and two hypothetical resonances at Ep = 71 and 105 keV, respectively. Here, new data with unprecedented high luminosity and low background on these aspects of the 22Ne(p,gamma)23Na reaction are reported. Stringent upper limits are placed on the two hypothetical resonances, ruling them out for astrophysical purposes. The off-resonant yield has been measured at unprecedented low energy, constraining the contributions from a sub-threshold resonance and the direct capture process. The 22Ne(p,gamma)23Na reaction rate, which used to be the most uncertain rate of the neon-sodium cycle, is now the best-known rate.

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Alpha particle induced reactions on Sr isotopes

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Preliminary alpha capture cross sections on Sr at energies close to the Gamow window will be presented. The cross sections were measured by means of the activation method using an alpha beam delivered by the Bucharest IFIN-HH 9MV tandem accelerator. The induced activities were measured with two large volume HPGe detectors in close geometry placed in a low background passive shielding. The experimental results are compared with theoretical predictions obtained in the framework of the statistical model, using the latest version of Talys1.8 and the alpha OMP potential by V. Avrigeanu et al [1].

Keywords: s, r and p nuclei, α particle induced reactions, p- nuclei nucleosynthesis, experimental cross sections

[1] V. Avrigeanu and M. Avrigeanu, Phys. Rev C 91, 064611 (2015).

Nuclear Astrophysics / 59

Activation cross section measurements of the 92,94,100Mo(a,n)95,97,103Ru reactions and optical potentials for modelling explosive nucleosynthesis scenarios

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Alpha-nucleus optical model potentials (OMP) are widely used in nuclear reaction network calculations aiming at the study of the gamma-process [1] and the weak r-process [2]. Considerable theoretical and experimental effort has been devoted in recent years to improve the knowledge of the OMP's in order to give correct predictions for the cross sections and reaction rates [3,4] (and references therein).
Recently, (a,n) cross section measurements on 92,94,100Mo are in progress at ATOMKI using the activation technique. The resulted cross sections have been used to test the predictions of global optical potential parameterizations used in modelling the gamma-process and the weak r-process. The experimental details and preliminary results will be presented.

[1] T. Rauscher et al., Reports on Progress in Physics 76 6201 (2013).
[2] Y. Qian et al., Phys. Rep. 442 237 (2007).
[3] T. Szücs et al., Phys. Lett. B 776 396 (2018).
[4] G. G. Kiss et al., Phys. Rev. C 88, 045804 (2013).

Nuclear Astrophysics / 82

A new measurements at LUNA of the 2H(p,gamma)3}He cross section at BBN energies

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The abundances of the primordial elements are sensitive to the physics of the early universe and are therefore a tool to test the Standard Cosmological Model.
The Big Bang Nucleosynthesis (BBN) theory is one of the pillars of standard cosmology: for a given baryon density it provides the abundance of the primordial elements.
Interestingly the abundance of deuterium deduced from observation of pristine gas at high redshift is more accurate with respect to the theoretical value [1,2], mainly because the BBN calculation is affected by the paucity of data for the deuterium burning reaction 2H(p,gamma)3He cross section at the relevant energies [3].
The concern for the 2H(p,gamma)3He cross section error is made worse by the fact that the theoretical and experimental values do not agree at the level of 20% [3,4,5].
A new measurement with a 3% accuracy would be very important to push down the BBN uncertainty on deuterium abundance to the same level of observations.

Deep underground in the Gran Sasso laboratory, Italy, the LUNA collaboration is pursuing a dedicated effort to measure the 2H(p,gamma)3He cross section directly at BBN energies (30 -300 keV). The campaign, started in 2016, is divided into two phases based on a BGO and a high-purity germanium (HPGe) detector, respectively.

In the present talk the LUNA measurement is described and results from both phases are discussed. The impact of this measurement in cosmology and particle physics is also highlighted: a precision measurement will allow to provide an independent cross-check of the determination of the universal baryon density Ωb from the cosmic microwave background and to constrain the existence of the so called dark radiation.

[1] R.J. Cooke, M. Pettini and C.C. Steidel, Astrophysical Journal 855 (2018) 102
[2] O. Pisanti et al., Comput. Phys. Commun. 178 (2008) 956.
[3] L. Ma et al., Phys. Rev. C 55 (1997) 558.
[4] L.E. Marcucci et al., Phys. Rev. Lett. 116 (2016) 102501.
[5] E.G. Adelberger et al., Rev. Mod. Phys. 83 (2011) 195.

Nuclear Structure and Dynamics / 245

Structure of neutron-rich nuclei around 208Pb

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Information gained on neutron-rich N~126 nuclei is essential for the understanding of nuclear structure in heavy nuclei. Studies around doubly magic systems allow direct tests of the purity of shell model wave functions. From a longer-term perspective, experiments in this region pave the way toward the proposed nuclear-astrophysical r-process waiting point nuclei along the N = 126 shell closure.
In the case of the beta decay of N~126 nuclei there is a competition between allowed and first-forbidden transitions. This is the mass region where first-forbidden (FF) transitions can be dominant, which can have profound implications on their half-lives and therefore on the r-process (A~195 abundance peak).
Recently several experiments were performed at ISOLDE with the aim to study neutron-rich nuclei around 208Pb.
(i) Structure of 208Tl from the beta decay of 208Hg. 208Tl being a one-proton-hole one-neutron-particle nucleus, its excited levels give direct information on the proton-neutron interaction in the Z<82, N>126 quadrant. In addition, the existence of both negative and positive parity states at low excitation energy makes this nucleus an ideal testing ground for the study of the competition between first-forbidden and allowed beta decay.
(ii) Structure of 207Tl from the beta decay of 207Hg. A large number of excited states, several of them of octupole character were observed and compared with calculations.
(iii) Coulomb excitation of 206Hg at safe energies. This gives information about both quadrupole and octupole collectivity.
The presentation will report on recent results and their relevance on the structure of neutron-rich nuclei around 208Pb.

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Light and Heavy Fragment Mass Correlation in the 197Au+130Te Transfer Reaction

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The production of neutron-rich nuclei in the mass region A ~ 200, in particular along the neutron closed shell N = 126, has recently received strong attention since these nuclei are fundamental to understand different physical aspects, from the shell evolution far from stability to the investigation of the path chosen by the r-process to synthesize the heavy elements.
Multinucleon transfer (MNT) reactions between neutron-rich projectile and target have been indicated as a promising tool to produce heavy neutron-rich nuclei but a complete understanding of the reaction mechanism and a precise measurement of the production cross sections are hindered by the difficulties in identifying nuclei with A ~ 200 in mass and nuclear charge with the present techniques.
In this context we performed an experiment to study MNT reactions at near-barrier energies in the 197Au+130Te system employing a method which consists of the simultaneous detection of light and heavy transfer products where one of the reaction partners (the light one) is identified with high resolution. We exploited the performance of the PRISMA spectrometer to identify isotopes in the tellurium region, while the coincident Au-like partners were detected with a dedicated set-up specifically built and coupled to PRISMA.
We reconstructed the mass and charge of the light reaction partner through an event-by-event trajectory reconstruction in PRISMA and compared the extracted cross sections for neutron transfer channels with the ones calculated with the GRAZING code. Thanks to the kinematic coincidence we determined the mass of the heavy partner assuming a binary character of the reaction. For each Te ion identified in PRISMA we obtained the coincident mass distribution of the heavy partner through a mass-mass correlation matrix. Comparing these mass distributions with those obtained with Monte Carlo simulations of the scattering process and the subsequent de-excitation, we could quantitatively infer about the behavior of the heavy partner and the contribution of evaporative effects on the population of neutron-rich heavy nuclei.
The analysis and main results of the experiment will be presented. The possibility to employ a similar method in forthcoming experiments with radioactive ion beams will be critically discussed.

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The effect of the temperature on the Gamow-Teller excitations in nuclei

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The nuclear weak interaction processes (beta decay, electron capture, neutrino-nucleus scattering etc.,) is known to play an important role in the supernovae evolution and formation of the chemical elements. The calculation of these processes necessitates accurate knowledge on the spin-isospin excitations as well as the ground state properties of nuclei [1,2]. In this framework, the proton-neutron quasiparticle random phase approximation (PNQRPA) based on the relativistic energy density functionals provides a consistent and reliable approach for the description of the spin-isospin excitations over the nuclide map [3-5]. In addition, it has been known that the nuclear weak interaction processes in stellar environments mainly take place at finite temperatures. Therefore, the current theoretical models should be extended to include the temperature and pairing effects simultaneously in order to obtain more reliable results.

In this work, the relativistic proton-neutron QRPA with density dependent meson-nucleon couplings is extended to include temperature effects. The pairing correlations are taken into account in the BCS scheme. We performed calculations using DD-ME2 functional for the Gamow-Teller excitations in open-shell nuclei. The effect of the temperature on the strength functions and excitation energies of the Gamow-Teller excitations is investigated for the selected nuclei. In addition, the interplay between the temperature and pairing effects is discussed at low temperatures, where both effects are relevant.

[1] F. Osterfeld, Rev. Mod. Phys. 64, 491 (1992).
[2] N. Paar et al., Rep. Prog. Phys. 70, 691 (2007).
[3] N. Paar, T. Nikšić, D. Vretenar, and P. Ring, Phys. Rev. C 69, 054303 (2004).
[4] Y. F. Niu, N. Paar, D. Vretenar, and J. Meng, Phys. Rev. C 83, 045807 (2011).
[5] T. Nikšić, T. Marketin, D. Vretenar, N. Paar, P. Ring, Phys. Rev. C 71, 014308 (2005).

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In-beam γ-ray spectroscopy of nuclei in the 132Sn region performed at RIKEN

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The nuclei around the doubly magic nucleus 132Sn (N=82 and Z=50) are of great interest both for nuclear structure investigations and nuclear astrophysics. Studying these systems, information about the evolution of nucleon-nucleon correlations, quadrupole collectivity and single-particle energies can be obtained. New experimental information allows to test different nuclear models and examine their validity in this region of the nuclear chart.

In April 2015, an experiment was performed at the Radioactive Isotope Beam Factory at RIKEN (Tokyo, Japan) to study neutron-rich nuclei in the 132Sn region using in-beam γ-ray spectroscopy. The exotic nuclei were produced via the projectile fission of a primary 238U beam at 345 MeV/u. The standard configuration of the BigRIPS and ZeroDegree spectrometers was used to select and identify the secondary beam [1]. After being identified in BigRIPS, the secondary beam impinged on C and Au targets to induce knockout reactions and Coulomb excitation. The γ rays emitted in the decay of excited states in several N=82-84, Z≥50 isotopes were detected using the DALI2 spectrometer, which consisted of 186 NaI(Tl) detectors.

In this contribution, I will discuss the new experimental information we obtained with respect to the γ decay of unbound states in 133Sn [2], the Coulomb excitation of 136Te [3] and other selected results.

[1] T. Kubo et al., Prog. Theor. Exp. Phys. 2012, 3C003 (2012).
[2] V. Vaquero, A. Jungclaus et al., Phys. Rev. Lett. 118, 202502 (2017).
[3] V. Vaquero, A. Jungclaus et al., in preparation.

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Nuclear structure of the neutron-deficient tin isotopes close to 100Sn

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In the last years the robustness of the proton shell closure Z=50 has been studied when N=50 is approached: the excitation energy together with the reduced transition probabilities of the low-lying states provides a clear evidence of the shell evolution along the whole Sn isotopic chain.
However, the presence of low-lying isomers has limited the investigation of the electromagnetic properties of the first excited states; for this reason the neutron-deficient Sn isotopes have been studied only via Coulomb excitation measurements, employing radioactive beams.

The excitation energy of the first 2+ and 4+ states is well known and it is rather constant along the whole Sn isotopic chain. On the other hand, for the neutron-deficient Sn isotopes the B(E2;2+⟶0+) values suffer from large experimental uncertainties and the information on B(E2;4+⟶2+) is completely absent, which make the interpretation of the shell evolution controversial.

In order to obtain a precise estimation of the reduce transition probabilities in the region close to 100Sn, a multi-nucleon transfer reaction was used together with the Recoil Distance Doppler-Shift method as an alternative and complementary solution to the previously-performed Coulomb excitation measurements. This allowed to directly measure the lifetime of 2+ and 4+ states in 106,108Sn for the very first time and then to extract the B(E2) values of the low-lying states.

Large-scale shell-model calculations have been performed by taking into account the new experimental results. In particular, the comparison of the B(E2;4+⟶2+) values with the theoretical predictions has shed light on the nuclear structure in the vicinity of the proton drip line.

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Relevance of neutron excess in nuclear matter to proton-induced composite-particle pre-equilibrium emission

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Studies of the surface of heavy nuclei provides information on the equation of state (EoS) at densities lower than the nuclear saturation density [1, 2]. At these low densities cluster correlations are predicted, with alpha clusters being of special interest. The isotopes of Sn are convenient examples for an experimental test of predictions from a generalized relativistic density functional theoretical approach [2]. In fact, a recent comparison between experimental alpha transfer cross sections on 112, 116, 118, 120, 124Sn and theoretical expectation provides consistent results [3]. In view of our current understanding of the reaction mechanism of proton-induced pre-equilibrium alpha-particle emission [4], it is expected that the extent of alpha-cluster correlations as a function of neutron excess should influence especially the analyzing power angular distribution in a characteristic way.
Recent insight into the mechanism of proton-induced composite-particle pre-equilibrium emission and its relevance to EoS results will be discussed.

[1] S. Typel EPJ Web of Conferences 88, 01016 (2015).
[2] S. Typel, Phys. Rev. C 89, 064321 (2014).
[3] A. A. Cowley, Phys. Rev. C 93, 054329 (2016).
[4] A. A. Cowley,S. S. Dimitrova, E. V. Zemlyanaya, K. V. Lukyanov,
and J. J. van Zyl, Phys. Rev. C 93, 034624 (2016).

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Shape Coexistence in the Neutron-Deficient 188 Hg Isotope

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Shape coexistence is a characteristic phenomenon of finite many-body quantum systems where different nuclear shapes coexist within the typical energy range of nuclear excitations. The principle behind this phenomenon is the contrast between two different forces: on one hand valence nucleons and np-nh excitations drive the nucleus to collective configurations; on the other hand, pair forces and shell effects lead to a spherical shape. Shape coexistence is significantly present in the neutron-deficient isotopes around Z = 82, in particular light isotopes of Hg. From the systematics of the mercury isotopes, 188Hg is expected to be the heaviest isotope where two different shapes coexist. However, information the electromagnetic properties of low-lying states is scarce or absent for 188Hg. For these reasons, an investigation of 188Hg states is of great interest for a better comprehension of shape coexistence in this region.
In order to shed light on the features of such phenomenon in the neutron-deficient Hg nuclei, an experiment was performed at the Laboratori Nazionali di Legnaro, employing GALILEO, a HPGe detectors array, coupled with Neutron Wall and with a dedicated plunger. The 188Hg nucleus was populated via fusion-evaporation reaction and the lifetime of its low-lying states was measured for the first time.
In the contribution, the preliminary results and their theoretical interpretation will be discussed.

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Perspectives on the Measurement of Competitive Double Gamma Decay with the AGATA Tracking Array

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The competitive double gamma decay is a process which can be explained by the second order QED theory together with the knowledge of the nuclear structure of the decaying nucleus, making its study interesting under many aspects. Aside from the theoretical interest on this rare process, it also holds an experimental appeal as its low branching ratio puts to test all current measuring devices.
This rare decay was first observed in 137Cs with an array of LaBr3 detectors in a data taking time period of 50 days [1]. The innovative setup took advantage of the good timing properties of these scintillators to suppress the Compton background by gating on a small time difference between the events, effectively eliminating Compton scattered gamma rays from one detector to another and allowed also measurement of the angular distribution in two points.
The measurement of the process with the AGATA array [2], if achievable, would not only return more detailed physical information, namely on the energy and angular distributions, but also test the capabilities of this advanced gamma ray spectrometer. The main challenge that the measurement faces is the suppression of Compton events without relying on timing properties due to the resolution limitations of germanium detectors. We discuss the outcome of the simulated response of the detector to this type of event and a proposal of optimization of the array's tracking properties to reject unwanted events and correctly reconstruct the double decays. We thus try to asses whether the good energy resolution and spacial reconstruction properties of the detector together with a strict event selection and optimization are able to overcome the shortcomings and difficulties of the measurement. We discuss the results of this simulation approach, the difficulties and future prospects, complementing the simulated data with measurements taken with a source of 137Cs.

[1] C. Walz et al., Nature vol. 526, (2015) p. 406;
[2] S. Akkoyun et al., Nucl. Instr. and Meth., A668 (2012) p. 26.

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Hidden-charm and bottom pentaquark states

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The LHCb pentaquark states have been shown to be described by several models: as compact or molecular states or even very recently as molecolar states with a core(1). A review of different models and different predictions will be given. Moreover new predictions for the most interesting channels where to look for new pentaquark states will be discussed.
(1) Y. Yamaguchi, A. Giachino, A. Hosaka, E. Santopinto, S. Tacheuchi, M. Takizawa, Phys.Rev. D96 (2017) no.11, 114031

Hadron structure, spectroscopy and dynamics / 358

XYZ states at BESIII

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A status report on XYZ states is shown and the last results by BESIII are reported.
The present data on the hidden charm candidate, the Y(4660), are discussed, in particular BESIII data close to the Λc-Λcbar threshold in comparison with Belle data.
Future BESIII plans are also reported.

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Probing XYZ meson structure in hadron and heavy ion collisions

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The spectroscopy of charmonium-like mesons with masses above the 2mD open charm threshold has been full of surprises and remains poorly understood. The currently most compelling theoretical descriptions of the mysterious XYZ mesons attribute them to hybrid structure with a tightly bound cc\bar diquark or cq(cq')\bar tetraquark core that strongly couples to S-wave DD*\bar molecular-like structures. In this picture, production of a XYZ particle in high energy hadron collisions and its decays into light hadron plus charmonium final states proceed via the core component of the meson, while decays to pairs of open charmed mesons proceed via the DD*\bar component. These ideas have been applied with some success to the X(3872), where a detailed calculation finds a cc\bar core component that is only above 5% of the time with the DD*\bar component accounting for the rest. In this picture, the X(3872) is compose of three rather disparate components: a small charmonium-like cc\bar core with r_rms < 1 fm, a larger D^+D^*- component with r_rms ≈ 1.5 fm and a dominant component D^0D^*0\bar with a huge, r_rms > 9 fm spatial extent. The experiments with pp and pA collisions (p ≤ 26 Gev/c and L ≤ 10^32 cm-2s-1) are well suited to test this picture for X(3872) and, possibly, other XYZ mesons. In near threshold production experiments (√SpN ≈ 8 GeV), X(3872) mesons can be produced with typical kinetic energies of a few hundred MeV. In the case of X(3872), its decay length will be greater than 50 fm while the distance scale for the cc\bar ⟶ D^0D^0*\bar transition would be 2 ~ 3 fm. Since the survival probability of an r_rms ~ 9 fm "molecular" inside nuclear matter should be very small, X(3872) meson production on a nuclear target with r_rms ~ 5 fm or more (A ~ 60 or larger) should be strongly quenched. Thus, if the hybrid picture is correct, the atomic number dependence of X(3872) production at fixed √SpN should have a dramatically different behavior than that of the ψ', which is long lived compact charmonium state.
The current experimental status of XYZ mesons together with hidden charm tetraquark candidates and present simulations what we might expect from A-dependence of X(3872) in pp and pA collisions are summarized.

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Baryon timelike Form Factors at BESIII

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A status report on Baryon Timelike Form Factors is shown and the last results by BESIII are reported. Unexpected features are enlightened, like: oscillations in the
e+ e- -> ppbar cross section energy behaviour, a jump in the e+ e- Lambda_c Lambda_cbar cross section at threshold, like in the case of e+ e- ->ppbar, as well as a jump in the
e+ e- ->Lambda Lambda_bar cross section close to threshold.
The first measurement of the e+ e- ->Lambda Lambda_bar GE/GM phase is also reported.

Fundamental Symmetries / 372

Nuclear structure solving problems of fundamental physics

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The atomic nuclei serve as fento-scale laboratories for a plethora of processes relevant for fundamental physics of neutrinos and dark matter. In my talk I touch some recent hot topics in this wide and interesting field of applications of nuclear-structure methods.

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Nuclear Structure with radioactive muonic atoms - The nuclear charge radius of radioactive isotopes by muonic X-rays measurements

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Muonic atoms as laboratories for fundamental physics provide crucial input to QED, the weak and strong interaction.
Muonic atom spectroscopy, i.e. the detection of the muonic X-rays emitted subsequently to the atomic capture of a negative muon, has been a very extensively used technique to determine the extent of the nuclear charge radii [1]. This method complements the knowledge from electron scattering experiments and laser spectroscopy [2].
For elements heavier than Z=83 only few nuclear charge radii have been measured. These measurements are of paramount importance to complement the measurements of relative differences in mean-square radii along the isotopic chain available from laser spectroscopy.
The precision of atomic structure calculation can be limited by the uncertainty on the knowledge of the nuclear charge radius. This is the case for the calculation of effects of atomic parity violation in radium-226 which requires the knowledge of the nuclear charge radius of radium at the level of 0.2% [3].
Till now, experiments with muonic atoms have been limited by low muon rates, poor beam quality and large muon stop volumes, but also by available detector technology. While beam intensities and quality have been improved in recent years, still no high-resolution spectroscopy of muonic cascades and muonic capture has been performed.
The muX project at the Paul Scherrer Institut aims to perform high-resolution muonic atom spectroscopy for the extraction of nuclear charge radii of radioactive isotopes that are available or can be handled only in micrograms quantities. To this end we are employing muon transfer reactions in a high-pressure hydrogen gas cell with a small admixture of deuterium. In 2017 we have shown the validity of this approach by performing a measurement with only 5 ug of gold. The muonic X-rays are detected by a large array of HPGE detectors. Currently we are getting ready for a measurement with radium-226 and curium-248 that will take place this summer. Details on the method developed to perform muonic atom spectroscopy with highly radioactive targets available only in microgram quantities and the first results on the muonic X-ray of radium-226 will be presented.

[0] R.Engfer et al., At. Data Nucl. Data Tables 14, 509 (1974)
[1] G.Fricke and K.Heilig, Nuclear Charge Radii, (Springer-Verlag, Berlin, Heidelberg, 2004)
[2] L.W. Wandenbeck et al. Phys. Rev. C 86, 015503 (2012)

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The FAMU experiment

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By using the RAL-RIKEN intense pulsed muon beam and an on-purpose developed high-energy mid infrared tunable laser the FAMU experiment will measure the hyperfine splitting in the ground state of muonic hydrogen ΔEhfs(μ-p)1S with a precision δλ/λ < 10-5 providing crucial information on proton structure and muon-nucleon interaction. Specifically FAMU will provide rZ, the Zemach radius of the proton with higher precision, than what was previously possible, disentangling discordant theoretical values and will quantify any level of discrepancy that may exist between values of rZ as extracted from hydrogen and muonic hydrogen. The aim is to sett a cornerstone result about not yet explained anomalies on the charge rch radius of the proton. The Zemach radius rZ and the charge radius rch are the only proton shape-related values that can be directly extracted from experimental data, and rZ is the only one that gives information about the proton's magnetic dipole moment distribution. The results of the preparatory phase and the present status of the experiment will be presented.

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Searching for the two γ -decay of the X(17)

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Serious efforts have been made to find particles related to dark matter. According to theoretical predictions, a (10 MeV-1 GeV) light particle is expected (hereinafter called X-boson), which mediates the interaction between dark particles.
Krasznahorkay et. al. have succesfully investigated the X⟶e−e+ mode [1]. They excited the EX = 17.6 MeV and EX = 18.15 MeV states of 8Be and measured the angular correlation between the e− and e+ particles emitted during the de-excitation of these states.
Signifcant peak-like enhancement of the internal pair creation was observed at large angles, which was interpreted as the creation and decay of an intermediate particle with the mass of m0c2 = 16.70±0.35 (stat)±0.5(sys).
The observed anomaly could not be described within conventional nuclear physics [2]. Feng et. al. suggested an explanation assuming a vector gauge boson with a mass of m 0c2 = 16.7 MeV, Jπ = 1+ mediateing a fifth force [3]. According to this interpretation, the X-boson decays with e −e +-pair emission. More recently, Ellwanger and Moretti gave another interpretation of these data [4]: a Jπ=0− pseudo scalar particle was observed.
According to the Landau-Yang theorem, the X ⟶γγ decay is allowed only if the X - particle is pseudo scalar. In the case of a vector boson, it is strictly forbidden. In order to be able to choose between the two different scenarios, it was decided to study the X⟶γγ
mode using the 3 He(n, γ)4 He reaction.
The γγ -decay of the X-boson might have been observed already by Subbert and Berthollet in the in this reaction [5]. We revisited their experiment and measured the angular correlation
of the γ -rays using 12 3"×3" LaBr3 detectors. If a new particle with a mass of 16.7 MeV is created in the decay of the 0− state, and also decays with two γ photons, their angular
correlation should peak at an angle of Θ=105o with equal energies.
In the talk, the first results of the ongoing X -boson experiments will be presented.

[1] A. J. Krasznahorkay et al. ; Phsy. Rev. Lett. 116 , 042501, (2016).
[2] X. Zhang, G. A. Miller ; Phys. Lett. B773, 159 , (2017).
[3] J. L. Feng et al. ; Phys. Rev. Lett. 117 , 071803, (2016).
[4] U. Ellwanger, S. Moretti ; arXiv: 1609.01669v2.
[5] M. Subbert , R. Berthollet , Nucl. Phys. A318, 54 (1979).

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The characterisation of the Quark Gluon Plasma

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New results on Coulomb interaction effects in relativistic heavy ion collisions

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In heavy-ion collisions, the differences in shape between the positive and negative pion transverse momentum spectra at low pT can be used to study the Coulomb final-state interaction. The produced charged particles are moving in a Coulomb field generated by the positive net-charge of the stopped participant protons. The charged pions, as the most abundantly produced and lightest species, are the particles most strongly influenced by this Coulomb field. Therefore, they are accelerated or decelerated and their final momentum is changed. The strength of the Coulomb field depends on the degree of baryon stopping produced in the collision.
The effects of the Coulomb interaction on charged pion production in Au+Au collisions at RHIC-BES energies are investigated. From the pion transverse momentum spectra measured with STAR experiment, the negative-to-positive pion ratios as a function of transverse momentum are obtained and used to analyze the Coulomb interaction. The "coulomb kick" (a momentum change due to Coulomb interaction) and initial pion ratio for three different collision energies (7.7, 11.5 and 19.6 GeV) and various centrality classes were obtained. The Coulomb kick shows a decrease with the increase of beam energy and a clear centrality dependence, with largest values for the most central collisions. These results are connected with the kinetic freeze-out dynamics.

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Light-Flavor Hadron Production from Small to Large Collision Systems at ALICE

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Light-flavor hadrons, which consist of up, down, and strange valence quarks, can be used to study many different properties of ion-ion collisions. An overview of light-flavor hadron measurements performed with the ALICE detector will be presented, including measurements in pp collisions from 0.9 to 13 TeV, p-Pb collisions at 5.02 and 8.16 TeV, Pb-Pb collisions at 2.76 and 5.02 TeV, and new results from Xe-Xe collisions at 5.44 TeV. The production of strange particles is enhanced from small to large collision systems, with the strength of the enhancement depending on the strangeness content. The production of some short-lived resonances, such as rho(770)0, K*(892)0, and Lambda(1520), is suppressed in larger collision systems, which may be attributable to scattering effects in the late hadronic phase. Hadron transverse-momentum spectra evolve with system multiplicity or centrality, becoming harder for larger collision systems. In nucleus-nucleus collisions, this is likely the result of radial flow; qualitatively similar behavior has also been observed in p-Pb and pp collisions. The ALICE collaboration's large set of light-flavor hadron measurements, including transverse momentum spectra, yields, and nuclear modification factors, will be presented for different collision systems. These will be compared to results from lower energy experiments and to theoretical models, including EPOS, DIPSY, PYTHIA, and statistical thermal models.

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Light (anti-)nuclei and (anti-)hypernuclei production with ALICE at the LHC

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The high energy pp, p-Pb, and Pb-Pb collisions at the LHC offer a unique opportunity to study the production mechanisms of light nuclei, their corresponding anti-nuclei and hyperon-baryon bound systems, called hypernuclei. Measurements at different energies and with various system sizes allow to constrain the models of the production mechanisms of light flavour baryon clusters, in particular those based on coalescence and on statistical hadronization approaches. Moreover, the study of the production yield of (anti-)(hyper-)nuclei in heavy-ion collisions at the LHC energy can help to probe the late stages of the evolution of the hot and dense nuclear matter created in the collision and serves as baseline for the search of exotic multi-baryon states. In addition, the measurements in smaller collision systems provide constraints to cosmological searches for segregated primordial anti-matter and dark matter.

Thanks to its excellent particle identification and tracking capabilities, the ALICE detector allows for the measurement of deuterons, tritons, 3He, 4He and their corresponding anti-nuclei. Furthermore, the Inner Tracking System is able to separate primary from secondary vertices allowing the measurement of (anti-)hypernuclei via their two and three body mesonic weak decays.

Results on the production yields of light nuclei and anti-nuclei in pp, p-Pb, and Pb-Pb collisions will be presented, together with the measurements of hypertriton lifetime and production rates in Pb-Pb collisions. The experimental results will be compared to the predictions of statistical (thermal) models and baryon coalescence models. Further constraints on the production mechanism of light nuclei are obtained from measurements of the elliptic flow of deuterons (and 3He) and their comparison to expectations from coalescence and hydrodynamic models.

Plans for the future LHC Run 3, scheduled to start in 2021, with the expected improvements in the statistics and precision will be also presented.

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LHCb Heavy-ion results in collider and fixed-target mode

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LHCb is a fully instrumented forward spectrometer at the LHC with a pseudorapidity coverage 2<eta<5 designed for the study of hadrons containing b and c-quarks in pp collisions. The forward acceptance and its instrumentation for high-precision vertex reconstruction, tracking and particle identification allow for unique studies in heavy-ion collisions. Furthermore, a system for noble gas injections into the beam vacuum at the nominal interaction point can be used for fixed target studies with the LHC beams. With these data sets, it is possible to constrain nuclear modification of heavy-flavour and quarkonium production with precision in proton-induced reactions. This is of particular interest as a baseline for deconfinement signature studies in ion-ion collisions. Furthermore, in the collider mode, the production of the charm and beauty quarks probe low Bjorken-x values in the initial state of the ions where gluon saturation may start to play a role. The fixed-target data cover a kinematic range which is particular interesting for the search of intrinsic charm at high Bjorken-x. Recent results on heavy-flavour and quarkonium production in proton-lead collisions in collider mode as well as in proton-Helium and proton-Argon collisions will be presented.

Nuclear Structure and Dynamics / 275

Decay spectroscopy exploration of nuclei around 132Sn

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A study on 4 reactions forming the 46Ti*

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The study of pre-equilibrium emitted particles is a useful tool to examine nuclear clustering; to study how possible cluster structures affect nuclear reactions, the NUCL-EX collaboration (INFN, Italy) is carrying out an extensive research campaign on pre-equilibrium emission of light charged particles from hot nuclei [1]. In this framework, the reactions $^{16}O+^{30}Si$, $^{18}O+^{28}Si$, $^{19}F+^{27}Al$ at 7 MeV/u and $^{16}O+^{30}Si$ at 8 MeV/u have been measured at the GARFIELD+RCo array [2] in Legnaro National Laboratories.
After a general introduction on the experimental campaign, this contribution will focus on the analysis results obtained so far; effects related to the entrance channel and to the colliding ions cluster nature are emphasized through differences between the theoretical predictions and the experimental data.

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[1] L. Morelli et al., Journ. of Phys. G 41 (2014) 075107; L. Morelli et al., Journ. of Phys. G 41 (2014) 075108; D. Fabris et al., PoS (X LASNPA), 2013, p. 061.D; V.L. Kravchuk, et al. EPJ WoCs, 2 (2010) 10006; O. V. Fotina et al., Int. Journ. Mod. Phys. E 19 (2010) 1134.
[2] F. Gramegna et al., Proc. of IEEE Nucl. Symposium, 2004, Roma, Italy, 0-7803-8701-5/04/; M. Bruno et al., M. Eur. Phys. Jour. A 49 (2013) 128.

Nuclear Structure and Dynamics / 370

Measurements of giant and pygmy resonances with the K600 spectrometer at iThemba LABS

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iThemba LABS, South Africa, is a suitable laboratory for the experimental study of giant and pygmy resonances. The K600 magnetic spectrometer is one of the few spectrometers in the region of 30-200 MeV with high-energy resolution and the ability to perform measurements at zero degrees. This capability enabled the study of the fines structure in giant resonances and the role of deformation in these collective modes. In addition, the recent developments of coincidence measurements of charged particle and γ-ray decays is a perfect combination to investigate the nature of the pygmy dipole resonance and in general broad excited structures in detail.
Results on the experiments conducted at iThemba LABS on giant and pygmy resonances will be shown.

Nuclear Structure and Dynamics / 25

Role of pair-vibrational correlations in forming the odd-even mass difference

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The RPA-amended Nilsson-Strutinskij theory, which successfully describes the pattern of binding energies of nuclei with approximately equal neutron number N and proton number Z and the energy differences between the lowest state with isospins T = 0 and 1, respectively, in the doubly odd N = Z nuclei [1,2], is applied to the Sn isotopic chain. In this theory, a pair-vibrational correlation energy calculated in the random phase approximation (RPA) is added to the independent-nucleon and Bardeen-Cooper-Schrieffer pairing energy terms of the Nilsson-Strutinskij theory. The pair-vibrational correlations are found to contribute about 10% of the total odd-even mass difference as the result of the blocking of the level of the unpaired nucleon to the pairing interaction. Evidence is given suggesting that this percentage is larger in lighter nuclei. The neutron-proton pair-vibrational correlation energy, which equals the neutron and proton ones in systems with equally many neutrons and protons and identical single-neutron and single-proton spectra, is found to remain large at the T = 16 of 132Sn. Reproducing the pattern of binding energies of the Sn isotopes around N = 82 requires an appreciable reduction with increasing T of the pair coupling constant as given by the (N+Z)-dependent expression emerging from the study of the N ~ Z region. The present study demonstrates that the RPA-amended Nilsson-Strutinskij theory is able of encompassing nuclei with N ~ Z and such with a large neutron excess by a unified description whose input consists of the stationary energy levels in a, possibly deformed, single-nucleon potential well and an isovector pairing interaction.

[1] Bentley, Neergård, Frauendorf, Phys. Rev. C 89, 034302 (2014)
[2] Neergård, Nucl. Theor. 36, 195 (2017)

Plenary / 335

Nuclear structure studies by measurements of nuclear spins, moments and charge radii via collinear laser spectroscopy at ISOLDE

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High-resolution laser spectroscopy at ISOLDE gives access to properties of nuclear ground states and long-lived (> 10 ms) isomeric states of radioactive nuclei far from stability, such as nuclear spins, nuclear magnetic and quadrupole moments and charge radii [1]. These fundamental properties of exotic nuclei provide important information for the investigation of the nuclear structure in different regions of the nuclear chart. Two complementary collinear laser spectroscopy set-ups are available at ISOLDE: one for optically detected Collinear Laser Spectroscopy (COLLAPS) [2] and one for Collinear Resonant Ionization Spectroscopy (CRIS) [3].
By combining these two techniques, the nuclear structure in several key regions of the nuclear chart is been studied, from the very neutron-deficient to the very neutron-rich side of the nuclear landscape. Recent results from studies in the Ca and Sn regions will be presented and an outlook to future opportunities will be presented.

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Isospin-symmetry breaking in nuclear structure

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The isospin symmetry is a useful symmetry in nuclear physics, which provides
important guidelines for the construction of the nucleon-nucleon interaction and
can largely simplify the formalism of some nuclear structure models.
However, it is an approximate symmetry, broken due to the up and down quark mass
difference and electromagnetic interactions between the quarks.
Experimental studies of proton-rich nuclei and precision measurements call for
an accurate theoretical description of isospin-symmetry breaking effects.

The talk will focus on recent achievements in the construction of precise
isospin-nonconserving Hamiltonians mainly in the framework of the nuclear shell model.
Phenomenological approaches will be compared with the first
charge-dependent microscopic effective interactions.
We will review recent applications to the structure and decay of nuclei near N=Z line
and proton-rich nuclei.
Then, we will show the importance of charge-dependent theoretical description of nuclear states
for the tests of the fundamental symmetries in nuclear weak decays
(such as superallowed Fermi beta decay),
as well as we will underline its relevance for some astrophysically important reaction rates.

Plenary / 337

Nuclear Structure studies with gamma-rays with AGATA@GANIL

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The AGATA campaign started in 2015 at the GANIL Facility - Caen, France. High resolution gamma -ray spectroscopy is since performed with unprecedent sensitivity using the heavy ions beams provided by the CSS cyclotron complex. The european tracking array was coupled to ancillaries such as the VAMOS magnetic spectrometer, the high efficiency PARIS LaBr3 array and several devices for nuclear lifetime measurement from the ns to fs scale. In 2018, the setup was modified and AGATA was coupled to the NEDA neutron array and Diamant charged particule. In-beam spectroscopy was performed from light to heavy element from the N=Z line to the very neutron rich isotopes covering therefore mainy of the current interrest in nuclear structure.

Results from 2015 and 2016 will detailled following the publication of the first results as preliminary spectra from the 2017 and 2018 beam time will be shown.

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Perspectives on Nuclear Structure Studies with Electromagnetic Probes

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Electromagnetic (EM) coupling is small compared to hadronic interaction. Reaction cross sections of EM probes with nuclei can be, therefore, calculated perturbatively and are in principle under control to any desired precision. EM probes are, thus, well appreciated for being best suited for precision studies of nuclear structure. They have signi cantly contributed to our understanding of nuclear structure physics through a vast amount of precision data in the past. Accelerator technology and instrumentation have been advanced in recent years. High duty-factor recirculating linear electron accelerators with very low energy spread as well as energy-tunable quasi-monochromatic -ray beams with large photon flux and high degrees of polarization open up new routes for precision studies of key questions of nuclear structure physics. We address advances in the relevant technology and discuss recent experimental progress in nuclear structure obtained from the usage of electromagnetic probes. Examples from the superconducting Darmstadt linear electron accelerator, S-DALINAC, [1, 2] and from the High-Intensity-ray Source (HIS) at Duke University will be provided [3, 4]. We will dare an outlook to future opportunities including those that will open up at the intense -ray beam at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) presently under construction at Magurele, Romania.

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Stiff symmetry energy from isovector aura in charge-exchange reactions

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On account of symmetry energy dropping with density, nuclear isovector density extends farther out than the isoscalar density, leading to an isovector aura surrounding a nucleus. The faster the drop of the symmetry energy and energy of neutron matter with density, the thicker the aura. The width and sharpness of the aura can be assessed by simultaneously analyzing elastic scattering and quasielastic charge-exchange data off the same target, with the two, respectively, testing primarily isoscalar and isovector densities. In the past (P. Danielewicz et al., Nucl. Phys. 958, 147 (2017)) we analyzed unpolarized nucleon elastic and quasielastic cross sections on 48Ca, 90Zr, 120Ca and 208Pb. We now augment the analyzed set with two more targets, 92Zr and 94Zr, and expand the data to include vector analyzing powers. The results consistently point to large widths, ~1fm, of the isovector aura, now for 6 nuclei. Such an aura implies stiff symmetry energy, with a slope parameter L>70MeV, and stiff energy of neutron matter. The neutron skins may be viewed as nucleus-dependent reflections of the aura.

Accelerators and Instrumentation / 175

The SPES Exotic Beam ISOL Facility: Status of the Project, Technical Challenges, Instrumentation, Scientific Program

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SPES (Selective Production of Exotic Species) is the INFN project aimed to build a facility for Nuclear Physics studies with Radioactive Ion Beam (RIB). The facility is under construction at the INFN Legnaro National Laboratories and it will provide mostly neutron-rich exotic beams originating by fission fragments produced by an intense proton beam on a direct UCx target. The RIB project is mainly related to the development of an ISOL facility for neutron-rich exotic beam production, by means of a quite intense proton beam (of the order of few hundreds of microA), which is sent onyo a direct and sliced UCx target, with the aim of producing up to 1013 fissions/s. The SPES project time schedule and perspectives will be presented, focusing on the main technological innovations and challenges foreseen. The expected SPES beam intensities, their quality and, eventually, their maximum energies (up to 11 MeV/A for A=130) will permit to perform forefront research in nuclear structure and nuclear dynamics, studying a region of the nuclear chart far from stability. This goal will be obtained coordinating the developments on the accelerator complex with those performed on the experimental apparatuses. Part of the instrumentation is already installed at the Legnaro National Laboratory and it is regularly upgraded. Some other efforts are devoted to the development of further instrumentation, very innovative and challenging, which is presently under development within international collaborations and will be available for the experimentation at SPES.
Several Letter of Intents have been submitted, containing proposals to study theoretical and experimental open questions in nuclear structure and dynamics, which represent up-to-date scientific themes of world wide interest.

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The Cryogenic Stopping Cell of the IGISOL facility at ELI-NP

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The upcoming advancement of the ELI-NP project into its operational phase will offer to the nuclear physics community access to two new photon installations: a high-power laser system and a high-brilliance gamma beam system, which can be used together or separately.
One of the experimental setups proposed at the gamma beam system is an IGISOL facility [1] which will generate a Radioactive Isotope Beam (RIB) via photofission in a stack of actinide targets placed at the center of a Cryogenic Stopping Cell (CSC) coupled to a radio-frequency quadrupole for beam formation [2,3]. The CSC will use DC and RF electric fields to extract a RIB orthogonal to the primary beamline [4]. The exotic neutron-rich nuclei will be separated, and their mass measured, by a high-resolution Multiple-Reflection Time-of-Flight mass spectrometer. The isomerically pure RIBs will be measured by a β-decay tape station and a collinear laser spectroscopy station.
The latest developments in the simulation and design of the gas cell are presented. We report benchmark calculations of the production rates and of the extraction time and efficiency from the CSC. Starting from these studies, we discuss the optimal design of the cell and its state-of-the-art technologies.

1. D.L. Balabanski et al., Rom. Rep. Phys. 68, S621 (2016).
2. P. Constantin et al., Nucl. Inst. Meth. B 372, 78 (2016).
3. P. Constantin et al., Nucl. Inst. Meth. B 397, 1 (2017).
4. T. Dickel et al., Nucl. Inst. Meth. B 376, 216 (2016).

Accelerators and Instrumentation / 139

Extracting signal's shape parameters using real-time interpolation: a possible way to enhance the performances of the GARFIELD+RCo apparatus at LNL

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In the last few decades, Pulse Shape Analysis techniques (PSA) has proven to be a very powerful tool to identify nuclear fragments that are stopped inside the active layer of a single detector. These techniques, as the name suggests, are based on the extraction of informations from the shape of the signal produced by the impinging fragment.

The NUCL_EX group of INFN has focused its recent work towards the development of highly performing detectors for studying nuclear collisions at energies around or below the Fermi Energy. In this field the capability to detect and identify nuclear fragments (both in Z and A) plays a crucial role, hence the group made great efforts in obtaining very good isotopic resolution. As of today, the FAZIA array, composed of several three-stage telescopes (Silicon-Silicon-Cesium) is the result of these efforts, granting the possibility to identify in mass the fragments up to Z=20 and even more, using both DeltaE-E techniques and PSA.

During the FAZIA R two main PSA techniques for Silicon detectors were considered, one techniques uses the correlation of the charge-signal rise time with the energy (amplitude) and the other uses the correlation of the current signal maximum value with the energy. Since the latter has shown better performances, the FAZIA apparatus has been designed in order to acquire also the current signal coming from the silicon detector, thus achieving better results concerning isotopic resolution.

However, the slightly older GARFIELD+RCo detector, which is also managed by the NUCL_EX group, does not have the possibility to acquire the current signal and uses the rise-time PSA to identify fragments.
To overcome this limit, hoping for better performances, we have implemented on the new FEE electronics of the apparatus a real-time algorithm that performs real-time Cubic Spline interpolation of the charge signal and then differentiates the interpolated signal to obtain the current signal, thus allowing for the current PSA to be exploited.

The algorithm has been tested in December 2015 at LNS during a campaign of the FAZIA apparatus and recently al LNL during the commissioning of the new electronic with the GARFIELD+RCo apparatus, showing encouraging results.

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Status report on the Legnaro NEPIR facility

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The NEPIR (Neutron and Proton Irradiation facility) project is a new irradiation facility at INFN Legnaro National Laboratories (LNL). This contribution focuses on the most recent progress of the project, which is in an advanced design phase and partially funded.
The facility will exploit the LNL 35-70 MeV, high current proton cyclotron to feed two different compact neutron sources in order to generate high flux neutron beams with different energy spectra.
The first will use a thin lithium target to produce a Quasi Mono-energetic Neutron beam (QMN), with controllable energy peak in the 35-70 MeV range; the calculated flux at maximum energy and maximum current (10 microA, limited by radioprotection regulations) is ~3*10^5 n cm^-2 s^-1, at a test point 3 m downstream. A carbon energy degrader will be used to further decrease the proton beam energy down at least to 20 MeV. This versatile tool will be an important addition to the park of research infrastructures for National and European research.
The second source will be used to study Single Event Effects in electronics induced by neutrons. The source will use 70 MeV protons to produce fast (E > 1 MeV) neutrons with a white energy distribution similar, in the 1-65 MeV energy range, to that of neutrons in high energy cosmic ray showers found at flight altitudes and sea level. At 4 m from the neutron production target, the maximum neutron flux will be ~7*10^6 n cm^-2 s^-1.
Using additional moderator panels, the same source can be used to further shape the white spectrum to resemble that of other environments (eg. surface of Mars).

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Photonuclear spectroscopy with the ELIADE array at ELI-NP: Status and perspectives

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The Extreme Light Infrastructure - Nuclear Physics in Bucharest-Magurele, Romania, is a major European undertaking with the aim of constructing a facility that can produce the worlds highest intensity laser beams as well as unique high-brilliance, narrow-bandwidth gamma-ray beams using laser-based inverse Compton scattering.

One of the main instruments being constructed for the nuclear physics and applications with high-brilliance gamma-beams research activity is the ELIADE detector array of eight highly segmented HPGe clover detectors and large-volume LaBr3 detectors, to be mainly used together with the gamma-beam system. Using the nuclear resonance fluorescence technique this setup will provide us with access to several nuclear observables like spins, parities, level widths, and branching ratios in the decay. From these observables we expect to draw conclusions about, for example, nuclear dipole response, properties of pygmy resonance and collective scissors mode excitations, parity violation in nuclear excitations, and matrix elements for neutrinoless double-beta decay, among other topics.

The uniqueness of the environment in which ELIADE will operate presents several challenges in the design and construction of the array. In this contribution we will present some of these challenges, the current status of implementation, and how these challenges are overcome. We will also present perspectives of the unique opportunities that the characteristics of the beam-lines of ELI-NP can provide and an outlook of the day-one experiments that we will be able to perform.

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Deuteron breakup in collision with proton - measurements at intermediate energies.

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Reactions in three-nucleon systems at intermediate energies, between 50 and 200 MeV/nucleon, attract attention due to theoretically predicted sensitivity of the observables to subtle effects of the dynamics beyond the pairwise nucleon-nucleon force, so-called three nucleon force (3NF). Precise measurements in the sector of elastic nucleon-deuteron scattering show importance of 3NF for correct description of the cross section data, though at energies above 100 MeV/nucleon the currently available models of 3NF do not produce effects sufficiently large to cure discrepancy between the data and calculations [1]. Complementary studies are conducted in the sector of 1H(d,pp)n and 2H(p,pp)n breakup reactions. The 3-body final state is rich in kinematic configurations differing in sensitivity to dynamical effects: Coulomb interaction between protons, 3NF and relativistic effects, while the state-of-the-art theoretical calculations either include 3NF and Coulomb effects [2] or are performed in relativistic regime [3]. Systematic (in beam energy) set of data collected in large phase space regions is necessary to single out the 3NF and relativistic effects and to pin down possible discrepancies.

So far the Coulomb effects have been confirmed in configurations close to FSI of proton-proton pairs at wide range of beam energies, while the 3NF shows its importance starting from energies as low as 65 MeV/nucleon [1,4]. There are also strong hints of discrepancies between data and theory at energies close to the pion production threshold. The results of measurements with SALAD and BINA detectors performed at KVI with beam energy below 100 MeV/nucleon will be presented together with recently analysed data taken with WASA detector at energies roughly two times higher. The prospects of acquiring new experimental data will be also discussed.

[1] N. Kalantar-Nayestanaki, E. Epelbaum, J. Meschendorp, A. Nogga, Rep. Prog. Phys. 75, 016301 (2012).
[2] A. Deltuva, A.C. Fonseca and P.U. Sauer, Phys. Rev. C 72, 054004 (2005);
A. Deltuva, A.C. Fonseca and P.U. Sauer, Phys. Rev. C 73, 057001 (2006);
A. Deltuva, Phys. Rev. C \textbf {80}, 064002 (2009).
[3] R.Skibinski, H. Witala and J. Golak, Eur.Phys.J. A 30, 369 (2006).
[4] St.Kistryn, E.Stephan, J. Phys. G: Nucl. Part. Phys. 40, 063101 (2013).

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First measurements of the analyzing powers of the proton-deuteron break-up reaction at large proton scattering angles

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Polarization observables in the proton-deuteron break-up reaction are sensitive probes to investigate the spin structure of the nucleon-nucleon and three-nucleon forces. A measurement of the analyzing powers for the 2H (p,pp)n break-up reaction was carried out at KVI exploiting a polarized-proton beam produced in an atomic-beam type polarized ion source [1] at a proton-beam energy of 135 MeV. The scattering angles and energies of the final-state protons were measured using the Big Instrument for Nuclear-polarization Analysis (BINA) [2] with a nearly 4π geometrical acceptance. In this work, we extended the earlier measurements [3] that were done for kinematical configurations at small proton scattering angles by analyzing configurations at which one of the final-state protons scatters towards the backward part of BINA. The results are compared with theoretical calculations based on NN potential alone or combined with the 3N potential, with or without the inclusion of the Coulomb effect. Discrepancies between polarization data and theoretical predictions are observed for configurations corresponding to small relative azimuthal angles between the two final-state protons. These configurations show a large sensitivity to 3N force effects. In this contribution, some of these configurations along with the analysismethod will be discussed.

References

[1] H. R. Kremers and A. G. Drentje, AIP Conf. Proc. 421, 502 (1997).
[2] A. Ramazani-Moghaddam-Arani, H. R. Amir-Ahmadi, A. D. Bacher, C. D. Bailey, A. Biegun, M. Eslami-Kalantari, I. Gapari, L. Joulaeizadeh, N. Kalantar-Nayestanaki, St. Kistryn, A. Kozela, H. Mardanpour, J. G. Messchendorp, A. M. Micherdzinska, H. Moeini, S. V. Shende, E. Stephan, E. J. Stephenson, and R. Sworst, Phys. Rev. C 78, 014006 (2008).
[3] N. Kalantar-Nayestanaki, E. Epelbaum, J. G. Messchendorp and A. Nogga, Rep. Prog. Phys. 75, 016301 (2012).

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Dynamics of three-nucleon systems in the deuteron-proton collisions at 100 MeV

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The dynamics of the three-nucleon system can be very extensively tested by means of the deuteron-proton breakup reaction. Experimental studies of the dp system exposes various dynamical ingredients, like three-nucleon force (3NF) and Coulomb force, which play an important role in correct description of observables (e.g. cross section). It is worth to underline that experiments with polarized beams (or targets) give opportunity to study a large number of observables sensitive to various dynamical components,which are hidden in the unpolarized case. All studied observables (e.g. vector and tensor analyzing powers [1]) are interesting for testing theoretical calculations based on various approaches [2 - 5] to model the interaction in three-nucleon systems. Moreover, studies of the dp breakup reaction at low energy are very crucial for testing The Chiral Perturbation Theory [6] (calculations for the nucleon-deuteron breakup reaction at low energies will be available soon).

The presentation will concentrate on testing the 3NF and the Coulomb force effects for the differential cross section of the 1H(d,pp)n reaction at beam energy of 100 MeV. The experiment was performed at KVI in Groningen, with the use of the BINA detector [1, 7].

[1] E. Stephan, et al., Eur. Phys. J. A 49 (2013) 36.
[2] H. Witała, et al., Phys. Rev. Lett. 81 (1998) 1183.
[3] A. Deltuva, et al., Phys. Rev. C 68 (2003) 024005.
[4] S.A. Coon, et al., Few-Body Syst. 30 (2001) 131.
[5] A. Deltuva, et al., Phys. Rev. C 80 (2009) 064002.
[6] E. Epelbaum, et al., Eur. Phys. J. A 19 (2004) 125; ibid. A 19 (2004) 405.
[7] N. Kalantar-Nayestanaki et al., Rep. Progr. Phys. 75 (2012) 016301.

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Precision measurements of differential cross section and analyzing powers in elastic deuteron-deuteron scattering at 65 MeV/nucleon

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We present measurements of differential cross sections and analyzing powers for the elastic 2H(~d, d)d scattering process. The data were obtained using a 130 MeV polarized deuteron beam impinging a liquid-deuterium target. The experiments were conducted at the AGOR facility at KVI using the BINA 4π-detection system. Our measurements are compared to results of previous studies and with independent data taken with the BBS at KVI. The data are found to be in excellent agreement with each other. A thorough systematic analysis has been carried out to provide the most accurate data in elastic deuteron-deuteron scattering at intermediate energies. The results can be used to confront upcoming state-of-the-art calculations in the four-nucleon scattering domain, and will, thereby, provide further insights in the dynamics of three- and four-nucleon forces in few-nucleon systems.

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Differential Cross Section for Proton Induced Deuteron Breakup at 108 MeV

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Research in the domain of few-nucleon systems is the basis for understanding of nuclear interactions and properties of nuclei.
The precision theoretical calculations for three nucleon systems should be confronted with a rich set of systematic experimental data. For this purpose a series of measurements of deuteron breakup in collision with proton was conducted in KVI Groningen and FZ-Jülich. These studies confirmed the important role of the Three-Nucleon Force (3NF) and huge influence of Coulomb interaction between protons [1, 2, 3]. However, some discrepancies persist, indicating that our present understanding of the problem is not yet perfect [4, 5, 6]. Continuation of the studies in a wide range of energies, at the regions of the maximum visibility of the certain effects are necessary. For this purpose, the BINA (Big Instrument for Nuclear-polarization Analysis) detection system has been installed at CCB (Cyclotron Center Bronowice). The BINA detection setup is especially dedicated to study various aspects of the dynamics in three nucleon system at intermediate energies. Moreover, allows to register coincidences of two-charged particles in nearly 4π solid angle, making it possible to study almost full phase-space of breakup and elastic reactions [4, 7].
The data analysis and preliminary results of the measurement of proton-induced deuteron breakup at beam energy of 108 MeV performed at Cyclotron Center Bronowice PAS in Cracow will be presented.

[1] I. Ciepał et al., Few-Body Syst. 56 665 (2015).
[2] St. Kistryn et al., Phys. Rev. C, 68 054004 (2003).
[3] St. Kistryn et al., Phys. Rev. C, 72 044006 (2005).
[4] St. Kistryn, E. Stephan, J. Phys. G: Nucl. Part. Phys. 40, 063101 (2013).
[5] K. Sagara, Few-Body Syst. 48, 59 (2010).
[6] N. Kalantar-Nayestanaki, E. Epelbaum, J.G. Meschendorp, A. Nogga, Rep. Prog. Phys. 75, 016301 (2012).
[7] A. Ramazani-Moghaddam-Arani, et al., Phys. Rev. C 78, 014006 (2008).

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Achievements and challenges in understanding nucleon-deuteron reactions

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Comparison of theoretical predictions based on a nucleon-nucleon potential with data for elastic nucleon-deuteron (Nd) scattering and nucleon
induced deuteron breakup reveals the importance of a three-nucleon
force (3NF). Inclusion of semi-phenomenological 3NF models, such as Tucson-Melbourne or Urbana IX, into calculations in many cases improves the data description. However, some serious discrepancies remain even when a 3NF is included.
At low energies the prominent examples of discrepancies between theory and data were found for the vector analyzing power in elastic Nd scattering and
for the neutron-deuteron (nd) breakup cross sections in neutron-neutron (nn) quasi-free-scattering (QFS) andsymmetric-space-star (SST) geometries. Since both these configurations depend predominantly on the S-wave nucleon-nucleon (NN) force components, these cross section discrepancies have serious consequences for the nn 1S0 force component.
At energies above about 100 MeV current 3NF's only partially improve the description of data for cross section and spin observables in elastic Nd scattering and breakup. The complex angular and energy behavior of analyzing powers, spin correlation and spin transfer coefficients fails to be explained by standard nucleon-nucleon interactions alone or combined with current models of 3NF's.
One of the reasons for the above disagreements could be a lack of consistency between 2N and 3N phenomenological potentials used or/and omission of important terms in the applied 3NF.
The Chiral Effective Field Theory approach provides consistent two- and three-nucleon forces. The 3NF occurs for the first time at next-to-next-to
leading order (N2LO) of chiral expansion. The N3LO and N4LO NN forces when used in 3N calculations provide description of NN data of the same quality as standard, realistic NN potentials.
Application of improved, semilocal coordinate-space regularized chiral NN nteractions up to N4LO order of chiral expansion combined with N2LO 3NF's supports conclusions obtained with standard forces. It can be expected that an application of consistent chiral NN and 3NF's up to N3LO will play an important role in understanding of elastic scattering and breakup reactions at higher energies.

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On the nature of the low-energy E1 strength in the unstable nucleus 68Ni

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The low-energy E1 strength, known as Pygmy Dipole Resonance (PDR) is an excitation mode connected to the neutron excess in nuclei. This mode is carrying few per cent of the isovector Energy Weighted Sum Rule (EWSR) and it is predicted to be present in all stable nuclei with neutron excess
and in particular for unstable nuclei [1,2]. The study of this mode and the knowledge about the structure are very important also due to the connection with the Equation of state of nuclear matter (EoS), indeed this mode is used as a further tool to constrain it [3,4]. Moreover, the PDR is connected also to the r- process, responsible for the nucleo-synthesis of the heavy elements [5]. Due to the properties of its transition densities this mode can be populated by both isoscalar and isovector probes [6]. Several experiments, with both the probes, have been performed on stable nuclei [1, 3] and on unstable nuclei by using Coulomb excitation [7]. Despite these different experimental studies the situation regarding the characterization of the PDR is not conclusive. At the LNS-INFN of Catania we have performed an experiment, using the unstable projectile 68Ni and an isoscalar 12C target, with the aim to study the PDR on the 68Ni by using an isoscalar probe. We produced the 68Ni by exploiting the projectile In Flight Fragmentation method in the dedicated FRIBs transport line. The CHIMERA multidetector [8] and the FARCOS array [9] were used to detect reaction products. We report on the results about the gamma-decay channel of the Pygmy Dipole Resonance [10] and the preliminary results about the study of the neutron decay channel.

References

[1] N. Paar et al., Rep. Prog. Phys. 70, 691 (2007).
[2] A. Bracco et al., Eur. Phys. J. A 51, (2015).
[3] A. Klimkiewicz et al., Phys. Rev. C 76, 051603(R) (2007).
[4] J. Piekarewicz et al., Phys. Rev. C 73, 044325 (2006).
[5] S. Goriely and E. Khan, Nucl. Phys. A 706, 217 (2002).
[6] E. G. Lanza et al., Phys. Rev. C 84, 064602 (2011).
[7] O. Wieland et al., Phys. Rev. Lett. 102, 092502 (2009).
[8] A. Pagano et al., Nucl. Phys. A 734, 504 (2004).
[9] E.V. Pagano et al., EPJ Web of Conf. 117, 10008 (2016).
[10] N.S. Martorana et al., in press to Phys. Lett. B

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Deviations from Hauser-Feshbach behaviour in evaporation chains in light heavy-ion collisions

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In the framework of the NUCL-EX activities, we extended the investigation on the decay of light nuclei at excitation energies above particle emission thresholds, by performing exclusive fusion-evaporation measurements. The 12O+12C reaction was investigated at three different bombarding energies, namely 90, 110 and 130 MeV.
For complete fusion, such reactions lead to a fused 28Si system respectively at 55, 63 and 72 MeV excitation energy. Therefore, we were able to explore the energy dependence of this autoconjugate system and to better put into evidence the role of non-statistical effects, clearly observed in our previous studies on other central ligh-ion collisions (i.e. 12C+12C, 14N+10B and 12C+13C)
The employed apparatus was composed by the coupling of GARFIELD and RingCounter detectors, in operation at the LNL (Legnaro National Laboratories of INFN). This apparatus has large coverage (about 75% of the total solid angle) and the capability to measure the charge, the energy and the emission angle of nearly all the charged reaction products, allowing for an excellent discrimination of the different reaction mechanisms.
Using the Hauser-Feshbach statistical theory of Compound Nucleus (CN) decay, the detailed output of a fusion-evaporation reaction is uniquely predicted under the knowledge of nuclear ground state properties and level densities. Two decay codes were used to compare the experimental data. The first one was a Hauser-Feshbach Monte-Carlo developed by the NUCL-EX collaboration and particularly optimized for light systems (HFl) by explicitly including the experimentally measured particle unstable levels from the archive NUDAT2. The second one was the GEMINI++ code, widely used to describe fusion-evaporation reactions.
One important result of the previously studied reactions was a clear deviation of the experimental Branching Ratio (BR) in the α-emission channels in coincidence with an even-Z evaporation residue with respect to the statistical decay model. These deviations were attributed to structure or pre-compound effects. Specifically, they were related to the α-cluster nature of the issued CN or of the reaction partners which persisted at high excitation energies.
The preliminary results obtained for the 12O+12C further confirm this behavior for even-Z evaporation chains and also highlight an energy dependence for the BR deviations which tend to grow with increasing bombarding energy. Moreover, an anomalous high BR was observed also for an odd-Z channel when compared to statistical code predictions at 130 MeV.

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Test of a 3He target to be used for transfer reactions in inverse kinematics

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In the last years, in the field of nuclear physics, there has been a large interest in the study of exotic nuclei far from stability. This new quest prompted the development of new research facilities that employ radioactive ion beams (RIBs). One example of these new endeavors is the SPES facility at Laboratori Nazionali di Legnaro in Legnaro (Italy). In order to make the best use of these new beams and to produce the nuclei of interest, new targets of light nuclei (such as d, 3 He, etc.) to be used for transfer reactions in inverse kinematics are of utmost importance. Between these targets, the 3He ones are some of the most interesting for neutron-deficient nuclei production, but also challenging to produce due to the fact that it is a gas at room temperature and the difficulty in the procurement of the material, which also makes them very expensive. Different techniques have been developed over the years, for example cryogenic targets or gaseous targets contained by thin walls, each with its own advantages and shortcomings.
The purpose of the experiment presented in this contribution was to test an innovative 3He target produced in collaboration with the CSIC-Materials Science Institute of Seville (Spain), where it was manufactured with a new technique (to be patented) that aims to reduce the costs while providing high quality targets. In particular, solid targets composed of W and 3He were deposited on a Au backing foil to allow lifetime measurements via Doppler-Shift Attenuation Method. The 3He target was tested by using the 64Zn(3He,n)66Ge reaction. The GALILEO HPGe detector array, coupled to the Neutron-Wall neutron detector array, was used to detect γ rays in coincidence with the emitted neutrons. The EUCLIDES Si ΔE-E detector array was used to detect 3He ejected from the target due to elastic scattering with the beam and to tag fusion evaporation channels with charged particle emission from the fusion of 64Zn with 3He or the contaminants present in the target. In this contribution, the results of this test experiment will be presented.

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Suppression of Weak Interaction in Nuclei

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About 40 years it was supposed that renormalization of weak interaction constants in nuclei is caused by the influence of Fermi and Gamow-Teller resonances, therefore, can be different for various nuclei due to strong distinction of Fermi surfaces in them. Our calculations of beta-decay more than 50 nuclei for $31 < A < 231$ have shown that in case of satisfactory description of the spectra and spectroscopic characteristics of the daughter nuclei good description of the probabilities of beta-transitions to their excited states with the same renormalization of weak interaction constants were received. Hence, it does not depend on Fermi surfaces of nuclei, by all means, from Fermi and Gamow-Teller resonances.

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Evaluation of the NEEC resonance window widths for 93mMo isomer in the case of electron capture into atomic shells for the assumed electronic excited configurations

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The main objective of this study is to determine the optimal conditions for a detailed knowledge of the nuclear excitation by electron capture (NEEC) process for selected nuclear isomers (i.e. metastable exited states of atomic nuclei) of a few elements. The part of these research focuses on the especially interesting and important case of NEEC process for the 93mMo isomer (T1/2 ~ 6.8 h), for which the NEEC process has been very recently registered for the first time [1, 2], on the world's most powerful Digital Gammasphere Spectrometer, installed in the linear accelerator (ATLAS) at Argonne National Laboratory in the USA [2].
The evaluation of the NEEC resonance window widths for 93mMo isomer will mean in practice determining the width of the atomic level for the state obtained after the electron capture to the unfilled shells, using the multiconfiguration Dirac-Fock (MCDF) method [3-8], because the contribution from the nuclear level width is only about 1.3 x 10-7 eV. Accordingly to this, it is worth to underline that the resonance should occur if the resonance window is sufficiently wide (i.e. in practice if enough large is the natural width of the atomic state obtained after the electron capture to particular subshells) in the comparison with amount of change of studied ion (of particular element) kinetic energy in single collision.
Obtained in this study knowledge allow to understand the processes occurring in the Universe, and in particular to provide a fundamental information concerning the survival of the nuclei of different isotopes of the elements in stellar environments. The results of this study will be a starting point for applied research, which aim will be to allow the controlled release of energy stored in the nuclear isomer of selected elements. Moreover, these studies will also contribute to the development of the concept of new, unconventional and ultraefficient nuclear batteries.

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Peculiar properties of the interaction of the 11Li nucleus with Be-isotopes.

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The present work aims to a report on the experimental and theoretical achievements obtained over the last decade in the study of (11Li+Be-isotopes) -reactions. We also carried out a comparative analysis of theoretical approaches in the study of scattering reaction and direct reaction (stripping, pick-up) of these systems, since they play a role in astrophysical processes. We have considered the theoretical approach to solving the non-stationary Schrödinger equation for determining dominant channels and theoretical predictions. We calculated the energy and wave functions of the states of single-particle levels for 9,11Li, 8-10Be within the framework of the shell model. The parameterization of the Woods-Saxon potential and the optimization of the spin-orbit part of the potential for 9,11Li, 8-10Be nuclei are discussed. In addition, the manifestation of the structure (9Li + 2n) in 11Li and the properties of valence neutrons in 10Be are discussed.

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How nuclear physics can be used against cancer and space radiation

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Charged particles are one of the elements that link innovations in cancer treatment with challenges related to space exploration.
The growing popularity of radiotherapy with protons and Carbon ions as well as the interest in finding additional candidate ions (as Helium or Oxygen) calls for nuclear and dosimetry measurements to develop and validate the delivery techniques.
The roadmap of space exploration foresees longer and further travels also outside the Earth orbit as well as the establishment of permanent outposts on other celestial bodies like Mars. It is now generally acknowledged that exposure to space radiation represents the main health risk for exploration-class missions.
Many challenges in radiotherapy with ions and in space radioprotection are related to the investigation of the same nuclear processes and require similar approaches to be tackled. To advance in both these fields experimental data have to be combined with predictions from theoretical and Monte Carlo codes to characterize the interactions of the primary particles with different media and, as a final step, to assess their biological effect and associated health risk.
One of the most important reactions is nuclear fragmentation.
In radiotherapy, it causes a loss of primary ions along their path towards the target volume and becomes especially relevant for the treatment of deep-seated tumors. Independently of the radiation type, the dose profile calculated with a Treatment Planning System (TPS) relies on the fragmentation cross sections for estimating the number of ions reaching the treatment site.
In space, fragmentation occurs when external radiation transverse the spacecraft walls and contents, including the astronauts' bodies, and plays a key role both in assessing the effectiveness of shielding materials and in predicting the radiation risks inside a habitat.
Different experimental approaches for characterizing nuclear reactions of interest in both fields (and in particular fragmentation) will be presented. Examples on the applications of the experimental data to tackle challenges in radiotherapy and space radioprotection will be also discussed.

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Characterisation of Nuclear Materials by using Neutron Resonance Analysis

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Neutron-induced reactions can be used to study the properties of nuclear materials in the field of nuclear safeguards and security. The elemental and isotopic composition of these materials can be determined by using the presence of resonance structures in the reaction cross sections as fingerprints. This idea is the basis of two non-destructive analytical techniques which have been developed at the GELINA neutron time-of-flight facility of the JRC-IRMM: Neutron Resonance Capture Analysis (NRCA) and Neutron Resonance Transmission Analysis (NRTA). In particular, NRTA is an absolute analysis method which does not require sample preparation or any calibration using representative reference materials.In this work, we present the results of transmission measurements performed on certified reference nuclear materials consisting of uranium and plutonium samples with different isotope abundances. The experiments were carried out in a GELINA station with a short flight path of about 10 m to validate the NRTA technique in small-scale facilities with poor energy resolution. The impact of reliable nuclear data on the NRTA accuracy is highlighted when discussing the results obtained for the plutonium samples.

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Nuclear Physics Applications in Astronaut Radiation Protection

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National space agencies and commercial companies continue to develop plans for long-term space missions outside the protection of the Earth's magnetosphere. An important concern for astronauts participating in these missions are the health effects from galactic cosmic rays (GCR). The GCR consist of protons, helium, and heavy ions with energy spectrum peaking at a few hundred MeV/nucleon, however with more than 50% of the heavy ion fluence inside tissues from ions with energies from 1000 to 10,000 MeV/nucleon. Secondary radiation including neutrons, protons, mesons and electrons increase in importance with shielding depth and can dominate astronaut risks for large shielding amounts (>50 g/cm2). We review nuclear absorption, fragmentation and particle production cross section data and the models used in GCR transport codes and risk assessment models. Recent data from the RAD experiment on the Mars surface and comparisons to models are described. NASA has implemented new radiation quality factors based on track structure concepts developed by the author (1-4). Also ancillary requirements using 95% confidence levels in risk projections
are used by NASA (1-4). Using state-of-the-art models of cancer risks, the impacts of cross section uncertainties and overall risk projection uncertainties are discussed.

(1) Cucinotta, F. A. 2014. Space radiation risks for astronauts on multiple
International Space Station missions. PLoS One 9(4), e96099 (2014).
(2) Cucinotta, F.A., To, K., and Cacao, E. Predictions of Space Radiation Fatality
Risk for Exploration Missions. Life Sci. Space Res. 13, 1-11 (2017).
(3) NRC, 2013. Technical evaluation of the NASA model for cancer risk to astronauts due to space radiation. National Research Council. The National Academies Press, Washington DC.
(4) NCRP. Radiation protection for space activities: supplement to previous recommendations. National Council on Radiation Protection and Measurements

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Nuclear cross section measurements of the theranostic radionuclide Sc-47: Preliminary results of the PASTA project

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In the framework of the SPES project at INFN-LNL, the LAboratory of RAdionuclide for MEDicine (LARAMED) program is focused on the production of innovative radionuclides of medical interest by exploiting the new 70 MeV proton cyclotron, installed in 2015. Among the various radionuclides of interest, the ones with theranostic application are in the spotlight, thanks to their potential use both in diagnostic and therapy by using the same radiopharmaceutical. The main advantage of theranostic isotopes, and consequently theranostic radiopharmaceuticals, is the selection of patients prior the treatment with a higher chance to positively respond to the specific therapy. The International Atomic Energy Agency (IAEA) has recently focused an international Coordinated Research Project (CRP) on the topic "Therapeutic Radiopharmaceuticals Labelled with New Emerging Radionuclides (67Cu, 186Re, 47Sc)". The INFN participates to this CRP through the LARAMED program and various satellite projects, focused on specific radionuclides, such as COME (COpper MEasurement, funded in 2016 by CSN3 Dotazioni LNL) and PASTA (Production with Accelerator of Sc-47 for Theranostic Applications, funded by CSN5 as Grant Giovani for the years 2017-2018). The aim of the PASTA project is answering to the following question:
is it possible to produce 47Sc for theranostic applications by using proton beams? Different nuclear reactions are explored in collaboration with the Arronax facility for the irradiation runs, with the University and INFN section of Ferrara for the radiochemical process to separate Sc from the irradiated material and with the INFN-PD and INFN-PV sections to compare various theoretical models (such as Fluka, Empire, Talys) with the experimental data. The first preliminary outcomes of the PASTA project will be presented in this work.

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Progress in nuclear Density Functional Theory calculations: isospin and spin-isospin excitations and the link with the nuclear Equation of State

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Atomic nuclei constitute a formidable intellectual challenge for scientists who are still striving to answer the fundamental question: how do the complex nuclear phenomena emerge from the interactions between the neutrons and protons?
In this contribution, I will first give a brief survey of the status of nuclear structure theory, and emphasise the role of Density Functional Theory (DFT). After showing some applications of the most recent DFT-based approaches to selected nuclear properties, I will focus on two specific aspects.
I will discuss nuclear giant resonances, and their importance to deduce from the experiment the so-called nuclear equation of state (EoS), that is, the relationship between pressure and density in nuclear matter. A link with neutron stars will be provided.
I will also discuss the recent progress in the field of spin and spin-isospin excitations and propose some new strategy to calibrate DFT models on ab initio calculations.

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Super-heavy elements, nuclear structure and related accelerators

Prof. OGANESSIAN, Yuri

A fundamental outcome of the microscopic theory is the prediction of an 'islands of stability' in the region of hypothetical super heavy elements (SHEs). In a heavy nucleus, going through the large-scale deformation on the way to fission, the motion of single nucleons is coupled with the collective degrees of freedom of the whole system. The most striking effect of this coupling is obtained for the case of fission of the heaviest nuclei, whose existence is defined entirely by the nuclear structure, i.e. by the shell effect.
From this point of view, the synthesis and study of properties of super heavy nuclei (SHN) is a direct way for checking the basic statements of the microscopic nuclear theory. On the nuclide map, SHN outline the border of the heaviest nuclear masses. SHN set the limits of the periodic system of chemical elements. The study of possible existence of SHN in nature offers a way for testing different scenarios of astrophysical nucleosynthesis.
The talk presents results concerning the synthesis and decay properties of the SH-nuclei from this 'stability islands' of SHEs obtained in cold and hot fusion reactions. The region of heavy nuclei have expanded and advanced up to mass of 294. New elements filled the 7th row of the Periodic Table of Elements. The results of the first chemical experiments and theoretical predictions about the influence of the "relativistic effect" on the electronic structure of the SH atom are presented. The prospects for research with the new facility - the SHE-Factory are discussed also

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Shape isomerism as a probe of microscopic origin of nuclear deformation

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The phenomenon of shape isomerism, being the best example of shape coexistence in nuclei, is related to the existence of a high barrier in the nuclear potential energy surface (PES), separating the primary energy minimum (the ground state) from a secondary energy minimum at large deformation. Shape isomers at spin zero have clearly been observed, so far, only in actinide nuclei - they decay mainly by fission, although in two cases, 236U and 238U, gamma-ray branches with very hindered transitions are known [1,2].
Inspired by various mean-field theoretical approaches [3-5] as well as by the state-of-the-art Monte Carlo Shell Model (MCSM) calculations [6], we have recently identified a shape-isomer-like structure at spin zero in a light nucleus 66Ni by using gamma-ray spectroscopy and employing the two-neutron transfer reaction induced by an 18O beam on a 64Ni target [7]. Being guided by the MCSM calculations, we have extended our studies to other Ni isotopes, making use of the two-neutron and one-proton sub-barrier transfer reactions. The new data should pin down, in great detail, evolution of the shape coexistence phenomenon in Ni isotopes.
Shape isomerism at spin zero might be a more common phenomenon. In fact, the mentioned mean-field theoretical models [3-5], as well as the recently published macroscopic-microscopic calculations [8], predict relatively deep secondary PES minima in nuclei in few other regions of the nuclear chart. For example, such minima associated with a sizeable deformation should exist in nuclei Pt, Hg and Pb with neutron number around N=110, and in Pd, Cd and Sn with N□66. A possibility for identifying gamma decay out of some of these minima, by using reactions induced by radioactive beams, will be discussed.
The experimental investigations aimed at searching for shape isomers, together with the development of the state-of-the-art microscopic theoretical approaches, should shed light on the microscopic origin of the appearance of deformed structures in nuclei.

[1] S.M. Polikanov, Sov. Phys. Uspekhi 15, 486 (1973).
[2] B. Singh, R. Zywina, and R. Firestone, Nuc. Data Sheet 97, 241 (2002).
[3] P. Bonche et al., Nuc. Phys. A 500, 308 (1989).
[4] M. Girod et al., Phys. Rev. Lett. 62, 2452 (1989).
[5] P. Moeller et al., Phys. Rev. Lett. 103, 212501 (2009).
[6] Y. Tsunoda et al., Phys. Rev. C 89, 031301(R) (2014).
[7] S. Leoni, B. Fornal, N. Mărginean, M. Sferrazza et al., Phys. Rev. Lett. 118, 162502 (2017).
[8] B. Nerlo-Pomorska et al., Eur. Phys. J. A 53, 67 (2017).

Plenary / 354

Nuclear structure far-off stability: Recent advances, surprises and future challenges in the region around doubly-magic 132Sn.

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In this talk the progress achieved in recent years in the understanding of the structure of nuclei in the vicinity of 132Sn, the heaviest doubly-magic nucleus far-off stability accessible for experimental studies, will be reviewed. It will be discussed how the results obtained using a variety of complementary experimental techniques employed in several leading laboratories in the field of nucler physics, in combination with state-of-the-art theoretical investigations, not only allowed to considerably advance our understanding of these exotic nuclei but also had a significant impact on nuclear astrophysics, in particular r-process calculations. Then we will report in more detail on the most surprising results of our studies which nicely illustrate the attraction of pushing the limits of knowledge to the extremes. The talk will close with a glance at the exciting future perspectives offered by the next-generation radioactive ion beam facilities which become operational during the next decade on one hand side and the new instrumentation which is currently under construction on the other.

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Fundamental Physics with neutrons and muons

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Precision experiments with high intensities of particles determine input parameters needed to describe the known interactions. They are also uniquely sensitive to physics beyond the highly successful Standard Model of particle physics, both, to very high and to very light new particles likely out of reach for direct production experiments. Last but not least they present the most sensitive tests of fundamental symmetries, such as parity, time reversal and matter-antimatter, CP, symmetry. Recent examples from experiments using the high intensity beams of muons and ultracold neutrons at the High Intensity Proton Accelerator HIPA at PSI will be presented.

Plenary / 356

Sterile neutrino searches at short distance from nuclear reactors

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The publication of the reactor antineutrino anomaly has revived the search for a sterile neutrino state at the 1 eV mass scale. A large experimental program is ongoing to search for a new oscillation pattern in the disappearance of electronic antineutrinos at short distance from nuclear cores. We will review the different measurements with emphasis on the complementary detection technologies and discuss the new limits already set on the sterile neutrino. In parallel to the experimental efforts, the prediction of the antineutrino spectra emitted by the reactors, at the origin of the reactor anomaly, is also under scrutiny in the community. A review of the uncertainties and potential biaises of the prediction will be presented.

Nuclear Astrophysics / 189

Fusion in massive stars: Pushing the 12C+12C cross-section to the limits with the STELLA experiment at IPN Orsay

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The 12C+12C fusion reaction is one of the key reactions governing the evolution of massive stars as well as being critical to the physics underpinning various explosive astrophysical scenarios [1]. Our understanding of the 12C+12C reaction rate in the Gamow window – the energy range relevant to the different astrophysical scenarios – is presently confused. This is due to the large number of resonances around the Coulomb barrier and persisting down to the lowest energies measured. In usual circumstances, where the fusion cross-section is smooth it can be readily extrapolated from the energy range measured in the laboratory down to the Gamow window but this is not possible for 12C+12C. Moreover, the existing data on this reaction obtained either through detection of evaporated charged particles or detection of gamma rays do not agree. This is a known problem which has been attributed to low-level contamination of targets with e.g. deuterium. In addition, there is considerable disagreement in the theoretical extrapolation of the data down to the Gamow window.

Jiang et al. have developed a new experimental approach to study of the 12C+12C reaction which can circumvent issues related to target contamination [2]. They used the Gammasphere array to detect fusion gamma rays in coincidence with detection of evaporated charged particles using annular silicon strip detectors [2]. This technique has shown considerable promise in essentially removing experimental background from the measurement [2]. However, very long running times and high beam currents are needed to push this technique to the lowest beam energies approaching the Gamow window.

The STELLA experiment has recently been commissioned at IPN Orsay. A intense 12C beam from the Andromede accelerator is incident on thin self-supporting 12C foils. A target rotation system can allow for cooling supporting μA beam currents. Evaporated charged particles are detected with a dedicated silicon array while gamma rays are detected in coincidence with an array of 30 LaBr3 detectors [3]. The design and status of STELLA will be presented along with initial results showing good agreement with earlier measurements of the 12C+12C system.

Nuclear Astrophysics / 21

Nuclear astrophysics at the n_TOF facility: some key cases in low mass stars evolution.

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Nuclear astrophysics is an interdisciplinary field at the crossing of various branches, from experimental and theoretical studies of nuclear cross sections to stellar evolutionary models of high complexity. The physics of stellar interiors can be constrained only if the adopted inputs in stellar modelling are known with high accuracy. For the nucleosynthesis of heavy elements, neutron capture cross sections are among the major sources of uncertainty and, thus, any improvement in their estimates represents a progress toward a better comprehension of stellar processes, as mixing and mass loss. Here I will present an astrophysicist perspective on some measurements carried out at the n_TOF facility (Guerrero et al. 2013), held at CERN. I will discuss some explicative cases related to the determination of neutron capture cross sections of interest for the slow neutron capture process (the so-called s-process). The latter is at work in low mass Asymptotic Giant Branch stars, which are among the most important chemical polluters of the Universe.

REFERENCES
C. Guerrero et al. , Eur. Phys. J. A 49 (2013) 27

Nuclear Astrophysics / 131

Nuclear Astrophysics with silicon strip detectors at ELI-NP

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Silicon strip detectors are popular and powerful instruments in nuclear astrophysics studies as they provide excellent energy and position resolution over a wide range of energies. The installation of resistive-strip silicon detectors in barrel-like experimental setups allows covering a large solid angle with a reduced number of electronic channels [1, 2].
Characterization of a large batch of X3 silicon detectors being considered for the ELISSA project was performed at ELI-NP [3]. The energy and position resolution, ballistic deficit, leakage currents, depletion voltage, as well as details of characterization of X3 detectors at LNS, Catania, Italy with charged particle beams will be presented.
The 7Li(γ,3H)4He reaction has been measured with gamma-ray beams between 4 and 10 MeV at the High-Intensity Gamma-Ray Source (HIGS) facility in 2017. Tritons and alpha particles were detected in coincidence using an array of silicon strip detectors. The results of the 7Li(γ,3H)4He experiment will be presented together with future measurements at ELI-NP.

1. C. Matei et al., Nuclear astrophysics measurements with ELISSA at ELI-NP, Il Nuovo Cim. C 39 360 (2016).
2. M. La Cognata et al., Gamma ray beams for Nuclear Astrophysics: first results of tests and simulations of the ELISSA array, JINST C03079 (2017).
3. S. Chesnevskaya et al., Performance studies of X3 silicon detectors for the future ELISSA array at ELI-NP, JINST 13 T05006 (2018).

Nuclear Astrophysics / 110

Recent THM investigation of the 7Be(n, alpha)4He reaction relevant for cosmology

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The role of the unstable 7Be during the early epoch of the Big Bang Nucleosynthesis is currently matter of study in view of the long-standing 7Li cosmological problem [1]. Recently, the Trojan Horse Method (THM) [2] have been applied for measuring the cross section of the (n,alpha) reaction channel on 7Be by means of charge-symmetry hypothesis applied to the previous 7Li(p, alpha)4He THM data corrected for Coulomb effects. The deduced 7Be(n,alpha)4He data overlap with the Big Bang nucleosynthesis energies and the deduced reaction rate allows us to evaluate the corresponding cosmological implications [3]. Beside this, a devoted experiment has been also performed in order to study the 7Be(n,alpha)4He via the THM application to the 7Be-deuteron quasi-free interaction with the aim of studying the 7Be-n cross section in a large energy range overlapping with the one of interest for BBN. The detailed analysis will be shown together with the preliminary results about the 7Be(n,alpha)4He cross section measurement.

[1] C. Bertulani & T. Kajino, Progress in Particle and Nuclear Physics 89, 56 (2016)
[2] R.E. Tribble et al., Report on Progress Physics 77, 106901 (2014)
[3] L. Lamia et al., The Astrophysical Journal 850, 175 (2017)

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Measurement of the 154Gd neutron capture cross-section at n_TOF (CERN), and its astrophysical implications

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Among the products of stellar nucleosynthesis heavier than Fe, 154Gd together with 152Gd have the peculiarity to be mainly produced by the slow capture process (the so-called s-process). Only a minor contribution may be produced in other processes. Their almost pure s-process origin makes them crucial for testing various models of the galactic chemical evolution (GCE). According to recent models, solar 154Gd and 152Gd abundances are expected to be 15-20% lower than the abundance of the s-only isotope 150Sm, which is discrepant to observations.
The close correlation between stellar abundances and neutron capture cross sections calls for an accurate measurement of 154Gd cross-section to reduce the uncertainty attributable to nuclear physics input and eventually rule out one of the possible causes of present discrepancies between observation and model predictions. To this end, the neutron capture cross section of 154Gd was measured in a wide energy range and with high resolution in the first experimental area of the neutron time-of-flight facility n_TOF at CERN.
In this talk, after a brief description of the motivation and of the experimental setup used in the measurement, the preliminary results of the 154Gd neutron capture reaction will be presented, together with their astrophysical implications.

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Exploring Neutron Channel Solutions for the Cosmological Lithium Problem at CERN/n_TOF

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Nuclear reactions responsible for the creation and destruction of Be-7 (the progenitor of Li-7), during Big Bang Nucleosynthesis (BBN), play the key role in the determination of the resulting primordial abundance of Li-7, the third chemical element formed during the very early phase of evolution of the Universe. Current standard BBN models predict a Li-7 abundance which is a factor of 2-3 larger than what is determined by astronomical observations. A neutron channel which could enhance the destruction rate of Be-7 during BBN has been recently investigated, amongst others, at the neutron time-of-flight facility, n_TOF a CERN, Geneva.

n_TOF (neutron time-of-flight) is the pulsed neutron source based on the spallation process induced by the 20 GeV/c proton beam of the CERN accelerator complex injected on a lead target. The source is coupled to two flight paths, one of 185 m and the other of 20 m length. The facility has been designed to study neutron-nucleus interactions for kinetic neutron energies ranging from a few meV to several GeV. The kinetic energy of the neutrons is determined by measuring the time of flight, hence the name n_TOF (www.cern.ch/ntof).

At n_TOF, the 7Be(n,a)4He reaction has been recently measured for the first time in a wide incident neutron energy range(*), allowing to put severe constrains on one of the Be-7 destruction mechanisms during BBN. A second reaction channel, the 7Be(n,p)7Li has been explored, again extending the reaction cross section data to a wider range and, therefore, allowing for an update of the related reaction rate to be used in standard BBN network calculations.

The new experimental results, theoretical interpretations and implications of these two reaction channels on the Cosmological Lithium Problem will be presented.

(*) M Barbagallo et al. (The n_TOF Collaboration), Phys. Rev. Lett. 117, 152701 (2016).

Nuclear Astrophysics / 98

Measurement of the 12C(p,γ)13N S-factor in inverse kinematics

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The 12C(p,γ)13N reaction is relevant in several astrophysical scenarios, such as the early stages of the Bethe-Weizsäcker cycle of hydrogen burning and the production of 13C in stars on the asymptotic giant branch of the Hertzsprung-Russell diagram. Here new data on the 12C(p,γ)13N astrophysical S-factor at low energy, 0.1-0.5 MeV in the center of mass system are reported from an experiment in inverse kinematics. Titanium hydride targets were irradiated with an intensive 12C ion beam from the HZDR 3 MV Tandetron accelerator. The emitted γ-rays were detected in a lead shielded high-purity germanium detector also equiped with a cosmic ray veto. For target characterization, Nuclear Resonant Reaction Analysis (NRRA) was used with a 6.4 MeV 15N beam. The new data will contribute to the understanding of the creation of chemical elements in the precursors of core-collapse supernovae.

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Equations of state of nuclear matter tested by simulating the merger of two neutron stars

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Binaries Neutron Stars (NSs) mergers can provide many constraints about stellar composition because the evolution and features of these processes strongly depends on the Equation Of State (EOS) of NSs. Indeed, the time of the collapse after the merger, for given masses, is determined by the softness of the EOS. Moreover, the process results in the ejection of matter, both during the merger due to tidal torques and/or shocks and after the merger from the disk formed around the remnant. This suggests NSs mergers to host r-processes. The decay of the produced nuclei has been directly detected as an EM signal (AT2017gfo kilonova), after the merger event observed on the 17th August 2017. The luminosity, frequency, time evolution and angle of the signal has been directly related to the features of the ejecta. We have performed hydrodynamical simulations of the NS merger in the general relativistic framework of the Einstein Toolkit code. We have compared two EOSs for different total masses of symmetric binaries; the first is the SFHo EOS which contains just ordinary matter while the second is an EOS which is characterized by the appearence in the high density regime of hyperons and delta particles. This feature leads to a softening, preventing this EOS to reach the two solar mass limit (in this scenario the more massive compact stars would be quark stars). The features of the two EOSs translate into different outcomes of the simulations: we have calculated the treshold mass for the hyperonic EOS, meaning the maximum mass for which the remnant does not make a promtp collapse to black hole. While the remnant in the case of SFHo survives for dozens of ms for a 1.3-1.3 solar masses binary, we found that already the 1.23-1.23 solar masses binary collapses promptly. In this scenario the event of August 2017 is interpreted as the merger of a quark star with a NS. We have also calculated the amount, the mean velocity and the angular distribution of the dynamical ejecta for a NS-NS merger. We found that, if a prompt collapse does not take place, the amount of matter ejected is from 4 times to an order of magnitude larger for the hyperonic with respect to the SFHo EOS case. This can be explained in terms of a greater contribution of the shock component for softer EOS.

Nuclear Structure and Dynamics / 261

Interplay of Nuclear Structure and Nuclear Reactions for exotic nuclei

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The study of the structure of normal, well bound nuclei, can be carried out by populating discrete excited states in a reaction, and studying their gamma decay. Here, the nuclear reaction is just a mechanism to populate excited states, whose properties such as energy and decay probabilities are independent of the reaction that produced it. Exotic nuclei, weakly bound, have few (if any) discrete excited states. The role of excited states is played by structures in the continuum (resonances and virtual states), which decay in fragments in a short time scale, comparable to the collision time. The properties of these continuum structures, such as the energy and angular distribution of the fragments, depend strongly on the nuclear interactions and the reaction mechanisms present in the nuclear reaction.
A key aspect of these nuclear reactions is the collision time. The properties of the exotic nucleus, inferred from its production of break-up in a nuclear reaction, will depend on whether the collision is fast or slow compared to the internal time. This dependence can be explored experimentally by reactions involving short time scales (relativistic beams, with short range interactions), and long time scales (few MeV per nucleon beams, in Coulomb dominated regimes). Both experiments are complementary. In this presentation, recent experimental measurements with their corresponding theoretical analysis will be presented. On one side, coulomb break-up of 11Li and 11Be on heavy targets at low energies will be analyzed, to extract the B(E1) distributions. On the other side, (p,pN) reactions at high energies will be discussed to obtain spectroscopic factors.

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Spectroscopy and Cross Sections of Near-Drip Line N=28 Aluminum and Island of Inversion Neon Produced by Nucleon Knockout Reactions

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The shell model lays an impressive foundation for broad understanding of nuclear systems. For the most exotic nuclei, universal mechanisms drive shell evolution from established structures, such as the disappearance of canonical magic numbers. The spin-isospin parts of the nucleon-nucleon interaction, and specifically, the monopole part of the tensor force between different orbits is a strong driver of these transformations.

Two areas of drastic shell evolution, the N=20 Island of Inversion and the N=28 neutron-rich region are studied through nucleon knockout reactions and in-beam gamma spectroscopy. The extension of systematic characteristics of collectivity and single-particle structures are investigated in near-drip line neon (32-Ne) and aluminum (39-Al, 40-Al and 41-Al) isotopes at the RIKEN Nishina Center Radioactive Isotope Beam Factory (RIBF). In-beam gamma spectroscopy is one of the few experimental techniques to comprehensively study these isotopes with unbound beta-decay parents. In addition, the measured inclusive and exclusive knockout reaction cross sections in combination with shell model calculations and reaction theory extends systematic trends of one and two-nucleon knockout reduction factors.

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Study of multi-neutron emission in the beta-decay of 11Li

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Beta-decay spectroscopy is one of the most useful tools for the study of nuclear structure. In exotic nuclei beta-decay is often followed by the emission of delayed particles, a process which becomes the dominant decay channel when approaching the driplines. In the most exotic species, the emission of two or more delayed particles can also occur with a significant probability.

Whereas the spectroscopy of two delayed proton emission has been explored in a number of cases, so far no such study has been performed for the emission of two delayed neutrons. We performed an experiment at CERN-ISOLDE to detect for the first time in coincidence two delayed neutrons following the decay of 11Li and measure their energies and angles, in order to investigate the sequential or direct character of the emission and the possible correlations between the neutrons. As 11Li offers one of the largest currently known two-neutron emission probabilities and can be produced with a sufficiently high yield, it was selected as the object of this first study. In addition, the experiment is expected to provide an improved picture of the very complex 11Li single neutron emission.

Detecting two neutrons in coincidence is particularly challenging. It requires the identification and rejection of random coincidences involving ambient gamma-rays and cosmic muons, as well as cross-talk events in which a single neutron fires two detectors. To overcome these issues, we used an array of liquid scintillator modules coupled to a digital electronics and signal processing system for the detection of neutrons. The use of a liquid scintillator allows to perform neutron-gamma discrimination to reject gamma-rays and muons, while the modular character of the array allows the application of kinematical cross-talk filters.

This talk will present the aim of the experiment and will focus on the selection of the two-neutron events.

Nuclear Structure and Dynamics / 123

New results on ^{13}C structure from α+^{9}Be low energy reactions

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Accurate studies on ^{13}C spectroscopy have great impact in the present understanding of the role played by extra-neutrons in stabilizing α-cluster structures formed in light nuclei. ^{13}C excited states are in fact the simplest systems that can be formed by adding a neutron to a triple-α molecular-like structure, and their spectroscopic properties are therefore a unique benchmark for theoretical cluster models aiming at describing light nuclei.
To investigate such aspects, we performed a comprehensive R-matrix fit of $\alpha+^{9}$Be elastic and inelastic scattering data in the energy range E$\simeq$ 3.5 – 10 MeV at several angles. To carefully determine the partial decay widths of states above the α decay threshold we included in the fit procedure also ^{9}Be(α,n_0)^{12}C$_{gs}$ and ^{9}Be(α,n_1)^{12}C$_{4.44}$ cross section data taken from the literature. This analysis allows to improve the (poorly known) spectroscopy of excited states in ^{13}C in the E$_x\simeq$12-17 MeV region, and tentatively suggests the presence of a large-deformation negative-parity molecular band.

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Experimental study of precisely selected evaporation chains in the decay of 25Mg. Results and perspective with light radioactive beams.

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Also in view of the availability of Radioactive Ion Beams at energies well above the Coulomb barrier, we present some results from an experiment on the fusion-evaporation reaction 12C+13C at 95MeV bombarding energy, performed with the GARFIELD+Ring Counter apparatus located at the INFN LaboratoriNazionali di Legnaro. We investigated the deexcitation of 25Mg compound nuclei aiming both at a further stringent test of the statistical description of nuclear decay and at a direct comparison with data on 24Mg,
previously measured in fusion reactions with the same apparatus. The key aspect of this study is the measurement of complete fusion events which allow to select and investigate the various decay chains and to evidence possible cluster or correlation effects for nuclear systems above the separation energies. This can be of particular interest on the way to experiments with light heavy-ion beams from 5 to 15MeV/u, as those obtainable with ISOL facilities using light atoms carbide as production targets.

Nuclear Structure and Dynamics / 39

Three-nucleon force contribution to the distorted-wave theory of (d,p) reactions

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In the last two decades rapid advances have been made in the implementation of the three-nucleon force (3NF) in nuclear structure calculations and its importance for various nuclear properties has been demonstrated. However, another large branch of nuclear physics – direct nuclear transfer reactions - is still based exclusively on Hamiltonians with two-body interactions only. These reactions are studied experimentally in many radioactive beam facilities, such as ISOLDE (CERN), RIKEN (Japan) or TRIUMF (Vancouver), to provide an important source of knowledge about single-particle nuclear structure and, more recently, to serve as a testing ground for ab-initio theories, in which the 3NF is often included.
In this talk I will present the first calculations of the 3NF contribution to the distorted-wave theory of (d,p) reactions [1]. I will discuss the qualitative difference between this contribution and the contribution from two-nucleon force only. This difference arises because of a new type of nuclear matrix elements which nuclear structure theory never dealt with before. I will discuss the challenges of the 3NF treatment in the distorted-wave theory and present a few (d,p) cross sections for double-magic nuclear targets calculated in the distorted-wave Born approximation using the contact 3NF whose strength has been fixed by the chiral effective field theory at the next-to-next-to-leading order. Introducing a 3NF into distorted-wave theories will pave the way to a consistent comparison of spectroscopic factors, calculated in ab-initio theories with 3NF, with those deduced from experiments with the help of reaction theory in which 3NF are included as well.

References:
[1] N.K. Timofeyuk, Phys. Rev. C, in press (2018)

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Dynamics of Nucleus-Nucleus Collisions and Neutron Rearrangement in Time-Dependent Approach

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The dynamical approach based on numeric solution of the time-dependent Schrödinger equation [1 ⊠ 3] was applied to the description of adiabatic and diabatic rearrangement of nucleons in reactions of light nuclei 3,6He, 9,11Li with heavy nuclei. For example, adiabatic and diabatic evolution of the probability density for the protons of the 3He nucleus in the collision with the 45Sc nucleus is shown in Figure. Experimental data on fusion, nucleon transfer and total reaction cross sections for reactions 3,6He + 197Au, 3He + 194Pt [4, 5], 3,6He + 45Sc [6, 7], 9Li + 28Si [8], and 11Li + 28Si were analyzed. The results of calculation of cross sections AXN(3,6He, …)A+1XN+1 and ZXN(3He, …)Z+1XN-1 taking into account neutron transfer and fusion-evaporation processes are in agreement with experimental data. The results of calculations of multinucleon transfer in reaction 40Ca + 128Sn are also in agreement with experimental data [9].

Figure. Evolution of the probability density for the protons of the 3He projectile nucleus in the collision with the 45Sc target nucleus at different values of the center-of-mass energy and the collision impact parameter b: adiabatic rearrangement of the probability density for the slow collision at = 6 MeV, b = 0 (a, b, c), diabatic rearrangement of the probability density for the fast collision at = 35 MeV, b = 7 fm (d, e, f). Radii of circumferences equal the effective radii of nuclei. The course of time corresponds to the panel locations from left to right (a-b-c), (d-e-f).

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References

1. V.V. Samarin, Phys. Atom. Nucl. 78, 128 (2015).
2. V.V. Samarin, Phys. Atom. Nucl. 78, 861 (2015).
3. V.V. Samarin, EPJ Web of Conf. 86, 00040 (2015).
4. Yu.E. Penionzhkevich et al., Eur. Phys. J. A 31, 185 (2007).
5. N.K. Skobelev et al., Phys. Part. Nucl. Lett. 11, 114 (2014).
6. N.K. Skobelev et al., Phys. Part. Nucl. Lett. 10, 410 (2013).
7. N.K. Skobelev et al., J. Phys. G: Nucl. Part. Phys. 38, 035106 (2011).
8. Yu.E. Penionzhkevich et al., Phys. Atom. Nucl. 80, 928 (2017).
9. L. Corradi et al., Phys. Rev. C 54, 201 (1996).

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IAEA activities in support of the accelerator-based research and applications

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Promotion of nuclear applications for peaceful purposes and related capacity building is among the missions of the IAEA. In this context, accelerator applications and nuclear instrumentation is one of the thematic areas, where the IAEA supports its Member States in strengthening their capabilities to adopt and benefit from the usage of accelerators. A number of activities are being implemented focusing on accelerator-based applications in multiple disciplines, such as materials characterization and modification, development of advanced moderators for cold neutron sources, forensics, cultural heritage and others.
This presentation aims at disseminating currently running and planned activities of the Physics Section of IAEA -especially those aiming at facilitating access to accelerator facilities for the countries without such capabilities- that are implemented through Collaborative Research Projects, Technical Cooperation projects and scientific-technical meetings organized by the IAEA.

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Applied nuclear physics for materials research and medicine

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Recent advances in detector developments, accelerator technology, and demands in medical treatments have driven intense knowledge transfer and applications of nuclear physics techniques towards societal relevant areas like particle tumor therapy, future energy production, astrophysical and materials research. In the contribution some selected examples will be presented regarding these areas. Superconducting RF-accelerator technology allows creating intense and high-repetition rate beams of direct and secondary beams. As one example, the ELBE facility at Dresden will be presented, where a superconducting electron linear accelerator is used to drive secondary photon beams (bremsstrahlung, monochromatic X-rays from laser-Compton backscattering) [1], fast neutrons from a photo-neutron source [2], coherent IR laser and THz light, and positron beams for materials research. Besides employing radioisotope sources in conventional positron annihilation spectroscopy, high-energy electron bremsstrahlung serves as an efficient source for pair-produced positrons.
Radiation safety issues, converter design, charged particle transport, and last-not-least high resolution detector designs highly benefit from nuclear physics expertise. Some examples of positron lifetime and Doppler-broadening measurements for defect spectroscopy, porosimetry, and positron chemistry will be presented [3-5]. As an example for the interplay between nuclear physics and medicine, developments for range verification and in-vivo dosimetry during proton tumor therapy at the Oncoray facility will be discussed. Proton-induced nuclear reactions enable new ways for spatially resolved dose delivery through prompt-gamma ray imaging [6] and single-plane Compton-imaging [7].
[1] R. Schwengner et al., Nucl. Instr. Meth. A 555(2005), 211
[2] R. Beyer et al., European Physical Journal A 54(2018), 58
[3] J. Ji et al., Scientific Reports 6(2016), 31238
[4] T. Kosub et al., Nature Communications 8(2017), 13985
[5] A. Uedono et al., Applied Surface Science 368(2016), 272
[6] C. Golnik et al., Physics in Medicine and Biology 59(2014), 5399
[7] G. Pausch et al., 2016 IEEE NSS/MIC Conference Record.

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The FOOT (FragmentatiOn Of Target) Experiment

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Particle therapy uses proton or 12-C beams for the treatment of deep-seated solid tumours. Due to the features of energy deposition of charged particles a small amount of dose is released to the healthy tissue in the beam entrance region, while the maximum of the dose is released to the tumour at the end of the beam range, in the Bragg peak region. Dose deposition is dominated by electromagnetic interactions but nuclear interactions between beam and patient tissues inducing fragmentation processes must be carefully taken into account. In proton treatment the target fragmentation produces low energy, short range fragments along all the beam range. In 12-C treatments the main concern are long range fragments due to projectile fragmentation that release dose in the healthy tissue after the tumor. The FOOT experiment (FragmentatiOn Of Target) is a funded project designed to study these processes. The detector includes a magnetic spectrometer based on silicon pixel and strip detectors, a TOF and ΔE scintillating detector and finally a scintillating crystal calorimeter for the fragment identification. In addition, a different setup with an emulsion spectrometer inserted before the target is foreseen to characterize the production of low Z fragments. The experiment is being planned as a 'table-top' experiment in order to cope with the small dimensions of the experimental halls of the CNAO, LNS, GSI and HIT treatment centers, where the data taking is foreseen in the near future (2020). The detector, the physical program and the timetable of the experiment will be presented as well as the results of a Monte Carlo study, which aims to evaluate the detector performance and the expected resolution on fragment identification and on the nuclear cross sections.

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Evidence of Oppenheimer-Phillips Reactions in Deuterated Materials Subjected to a Low MeV Photon Beam

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NASA Glenn Research Center (GRC) is investigating electron screened, enhanced nuclear reactions in deuterated materials exposed to photons with kinetic energie above and below the deuteron photo-dissociation energy in a stationary deuteron center-of-mass system using a repurposed medical linear accelerator (LINAC). The objective of the current work is to utilize a photon beam with energies around the deuterium photo-dissociation energy of 2.226MeV to induce possible reactions in deuterated materials and investigate the mechanisms producing these reactions.

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Impact of new results of the neutron capture cross section measurements for odd gadolinium isotopes on thermal-spectrum systems

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157Gd and 155Gd play a crucial role in the neutronics of thermal spectrum systems; this is due to their extremely high capture cross section at low neutron energies, so high that they can compete very efficiently with 235U and 239Pu in neutron absorption, even at very low atomic concentrations. Thanks to this characteristic, Gd odd isotopes can play either the role of parasitic neutron absorbers or that of desired neutron poisons, according to specific needs. In current Light Water Reactors (LWRs), Gd isotopes are used as neutron poisons to compensate Beginning-of-Life excess reactivity of nuclear fuels, necessary to increase the economic performances of these reactors; for Boiling Water Reactors, where Gadolinium poisoning is extensively used, a correct estimation of the depletion of odd isotopes is fundamental to ensure the desired safety margins for the storage of spent nuclear fuel in the reactor Spent Fuel Pools. Also in new, emerging LWR technologies, like the s.c. boron-free Pressurized Water Reactor cores, reactivity compensation relies heavily on Gd odd isotopes. In CANDU heavy water reactors, Gd liquid solutions are used as part of an emergency shutdown system to cut the chain reaction. Despite this very important physical role, it appears that the neutron capture cross sections of these isotopes at thermal energies is not known with the accuracy one would expect; many important experimental benchmarks containing Gd are not well reproduced by the currently available cross section evaluations. While for practical purposes the present knowledge might be felt adequate enough, the ever
demanding need for a very precise evaluation of safety margins in neutronics calculations suggests to improve as much as possible these cross sections, as well as their associated uncertainty. To this aim, a series of experimental campaigns at the n_TOF facility has been recently performed. This paper will show the impact of the new measurements on
neutronics calculations and, albeit preliminarily, will try to address qualitatively the issue if the new thermal values go in the desired direction of improving the reliability of the Gd evaluated cross sections.

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Measurement of 235U(n,f) cross section between 10 and 30 keV

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The 235U(n,f) cross section is established as a standard reference for measurements and evaluations at thermal neutron energy and in the range between 150 keV and 200 MeV. Thanks, amongst other considerations, to this wide energy interval the 235U fission is one of the most used standards, but recent experimental data suggest the presence of discrepancies in the 235U(n,f) reaction cross section between 10 and 30 keV. Although not considered as a standard in this energy range, it is often used as reference for the measurement of the neutron flux at various facilities. Any correction to the values adopted in evaluated libraries has an immediate impact over all the results of experiments that use the 235U fission as reference. In order to overcome this problem an accurate measurement of 235U(n,f) cross section in the energy range between 10 and 30 keV has recently been performed in the n_TOF facility at CERN, where is available a neutron beam with a remarkable energy resolution and high instantaneous flux. A new experimental setup has been used, consisting of a stack of single pad silicon detectors and 235U, 10B and 6Li targets
placed directly on the beam, the boron and lithium are used as standard reference. This measurement represents the first case of fission products measured using silicon detectors at n_TOF facility, proving the suitability of silicons even in this critical configuration. The customized experimental apparatus and the data analysis with definitive results will be presented.

Fundamental Symmetries / 118

Fundamental studies by laser spectroscopy of antiprotonic helium atoms

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The ASACUSA collaboration at CERN's Antiproton Decelerator has precisely measured the atomic transition frequencies of antiprotonic helium by laser spectroscopy. These three-body exotic atoms are each composed of a normal helium nucleus, and electron, and an antiproton. They constitute baryon-antibaryon bound states with the longest known lifetime. The experiments involved cooling 2 billion atoms to temperature 1.5-1.7 K by employing gas buffer cooling in a cryogenic helium gas target. By comparing the results with QED calculations, the antiproton-to-electron mass ratio was determined as 1836.1526734(15). This agreed with the proton-to-electron mass ratio with a precision of 8x10^-10. The spectroscopic data has also recently been used to set experimental limits on any hypothetical fifth force at the 1 Angstrom length range.

Fundamental Symmetries / 94

Study of the isospin symmetry in N=Z nuclei

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In Nature, symmetries help us to describe a complex physical system in a simple way and to better understand its behaviour. The search for symmetries is a fundamental goal in all fields in physics. At the same time, the possible breaking of a symmetry can open the gates for new and unexpected scenarios. In a nuclear system the isospin symmetry plays a key role in nuclear structure and nuclear reaction. In atomic nuclei, however, the presence of the Coulomb interaction between protons breaks this symmetry and induces a mixing between nuclear states with different isospin values. In this situation it is impossible to assign to a nuclear state a unique value of the isospin. This phenomenon is called isospin mixing.
The breaking of the isospin symmetry can be observed through decays which would be inhibited by isospin selection rules. This is the case of the electric dipole transition (E1 transition) from self-conjugate nuclei in a I = 0 configuration. To fully exploit this property, one should go in the region of the Giant Dipole Resonance (GDR), where most of the E1 strength is concentrated. This approach has been employed to measure the isospin mixing in nuclei formed in fusion-evaporation reactions. In this type of experiments the use of self-conjugate projectile and target nuclei ensures the population of a compound nucleus (CN) with I = 0. The hindrance of the GDR gamma decay can be measured and thus the isospin-mixing amplitude deduced. A partial restoration of the isospin symmetry is expected at high excitation energy because of the decrease of CN lifetime for particle decay.
The knowledge of the isospin mixing is important both to explain the properties of the isobaric analogue state (IAS) and for its connection with the test of the unitarity of the Cabibbo-Kobayashi- Maskawa matrix (CKM).
In the present case, I will present recent experimental results obtained in 80Zr (AGATA cam- paign at Laboratori Nazionali di Legnaro (LNL)) and preliminary results obtained in 60Zn during the GALILEO campaign at LNL. In particular, the study of the dependence of isospin-symmetry breaking with the nuclear excitation energy and how this affects the GDR gamma decay will be reported.

Fundamental Symmetries / 103

The AEGIS experiment at CERN: Probing antimatter gravity

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The AEGIS experiment at CERN's Antiproton Decelerator is being set up to precisely measure the gravitational interaction between matter and antimatter. For this purpose, antihydrogen will be formed from cold antiprotons and positronium, the hydrogen-like bound state of an electron and a positron. Subsequently, the free-fall acceleration of a cold horizontal beam of antihydrogen will be measured with a deflectometer. In this talk, the present status, recent experimental progress and the medium-term plan of the AEGIS experiment will be presented.

Fundamental Symmetries / 135

Constraints for fundamental short-range forces from the neutron whispering gallery, and extention of this method to atoms and antiatoms (updated)

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Extra fundamental short-range interactions mediated by new bosons are predicted in many extensions of the Standard Model of particle physics. They are also predicted in theories with large extra spatial dimensions and theories involving the light dark matter hypothesis. To search for such interactions at different characteristic distances, the experimentalists use
many methods including measurements of gravitational interaction at short distances, the search for extra interactions on top of the van der Waals/Casimir-Polder interaction, the search for rare processes in neutrino detectors, precision measurements with atoms, molecules and neutrons. Comparison of the sensitivities of different experiments to extra short-range forces in the standard Yukawa parametrization is published, for example, in ref. [1]. A competitive method of searching at characteristic distances of about 10 nm is the precision measurement of the neutron whispering gallery [2]. This phenomenon is analogous to the well-known phenomenon of the whispering gallery of electromagnetic waves of a broad frequency range, as well as the sound wave. However, a material wave, for example a neutron wave, provides an additional possibility due to the existence of a nonzero neutron mass: for a neutron, the energy values of the whispering-gallery quantum states depend on the mass of the neutron and the interactions of this mass with the surface. Moreover, the neutron in such quantum states is localized at a distance from the surface of the order of tens of nano-meters. Even a tiny extra force between the neutron and the surface at such distances would lead to a measurable shift in the energy of whispering-gallery quantum states. We present the results of experiments performed with cold neutrons and estimate their sensitivity to extra short-range forces. Calibration experiments and detailed analysis are going to be done in summer 2018. We affirm that this method can also be extended to experiments with atoms and antiatoms [3]. The sensitivity of atomic experiments may be even higher than thus providing a similar, or even higher than the sensitivity of neutron experiments. More details could
be found in [4].

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[1] I. Antoniadis et al., Compt. Rend. Phys. 12 (2011) 755.
[2] V.V. Nesvizhevsky et al., Nature Phys. 6 (2010) 114.
[3] A.Yu. Voronin et al., Phys. Rev. A 85 (2012) 014902.
[4] V.V. Nesvizhevsky and A.Yu. Voronin, Surprising Quantum Bounces (Imperial College Press, London, UK, 2015).

Fundamental Symmetries / 127

Production method for precision experiments with protonium

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Antimatter experiments conducted at CERN address the fundamental question of baryon asymmetry through comparison measurements of fundamental properties of matter and antimatter, such as tests of CPT symmetry and the weak equivalent principle (WEP).
The method of resonant-charge-exchange allows for the generation of H^{-} as well as for exotic antiprotonic systems such as p-p^{-} (Pn), μ-p^{-}, d-p^{-}, (and other novel systems) for subsequent comparison measurements sensitive to the strong force on threshold, the isospin or on the (anti)-proton charge radius.
We propose to generate cryogenic and long-lived pulses of Pn starting from a mixed H-/p^{-} ensemble in a Penning trap via photodetachment of H- and subsequent Rydberg excitation of H following the reaction: p^{-}+H*->Pn*+e-. Such a Pn source could be used for subsequent precision spectroscopy measurements or measurements of gravity in an atom interferometer, for e.g. testing charge neutrality.
In this presentation, the proposed production scheme of Pn is discussed using a semi-classical Monte Carlo approach and its implementation into an experiment at the antiproton decelerator (AD) at CERN.

Hadron structure, spectroscopy and dynamics / 214

Recent results on charmed meson decays at BESIII

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The BESIII experiment at BEPCII accumulated the world's largest e+e- collision samples at 3.773 and 4.178 GeV. In (semi-)leptonic decay aspect, we have studied the purely leptonic decays D+ -> tau+v and D_S+->mu+v, and the semi-leptonic decays of D0 to K(pi)- mu+v, D+ -> pi0 mu+v, D+(_S) -> eta(') ev and D_S+->K(*)0 e+v. We will report the improved measurements of the branching fractions of these decays and the CKM matrix elements |Vcs(d)|, the D(s)+ decay constants, the form factors of D(s) semi-leptonic decays. In hadronic decay aspect, we will report the measurements of the branching fractions of D0(+) -> PP (P=Peudecalor) decays, the observations of baryonic decay Ds+ -> pn-bar, the pure W-annhilation decay Ds+ -> omega pi+ and scs decay Ds+ -> omega K+. In rare decay aspect, we will report the upper limit of branching fractions of radiative decay D+ -> gamma e+v, c quark unchanged decay D+ -> D0e+v and FCNC process D -> h(h')e+e-.

Hadron structure, spectroscopy and dynamics / 216

Nucleon polarizabilities

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The scalar and spin electromagnetic polarisabilities of the proton and neutron are still not particularly well determined by Compton scattering experiments, with uncertainties ranging from somewhat less that 10% to over 100%. In the absence of free neutron targets, neutron properties must be extracted from light nuclei, particularly the deuteron and 3He, but that requires a good understanding of the contribution of nuclear e ects and two-body currents which substantially modify the cross sections.
Chiral e ective eld theory provides a uni ed framework for the analysis of the low-energy properties of both nucleons and light nuclei. World Compton scattering data has been used to give good constraints on the proton scalar polarisabilities and [1], with progress also being made on the spin polarisabilities [2] and prospects from a new generation of polarised scattering experiments [3, 4]. Progress is also being made on the theoretical and experimental front for Compton scattering from light nuclei [5, 6] and experiments are planned at both MAMI and HI
S. In this talk I will review progress in the eld, and
talk about future plans.

Hadron structure, spectroscopy and dynamics / 217

Measurement of the proton scalar polarizabilities at MAMI

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The electric (αE1) and magnetic (βM1) scalar polarizabilities describe the response of the nucleon to an applied electric or magnetic field. They are not only fundamental properties related to the internal structure and dynamics of the nucleon, but they are important also in other areas of physics, such as atomic structure. The values of αE1 and βM1 quoted by the Particle Data Group were determined using data on the unpolarized differential cross-section of the Compton scattering $\gamma p \longrightarrow \gamma p$. The measurement of the beam asymmetry Σ3, provides an alternative approach to the extraction of the scalar polarizabilities, with different sensitivity and systematics compared to the unpolarized cross-section. This asymmetry was measured recently for the first time below the pion photoproduction threshold by the A2 Collaboration with the Crystal Ball/TAPS experiment at MAMI (Mainz, Germany).
A linearly polarized photon beam impinged on a liquid hydrogen target and the scattered photons were detected with the Crystal Ball/TAPS setup, providing almost 4π coverage.
A new high precision measurement of both unpolarized cross-section and beam asymmetry Σ3 is ongoing at MAMI and the polarizabilities αE1 and βM1 will be extracted with unprecedented precision. The impact of the recently obtained and expected results on the extraction of the scalar polarizabilities will be discussed.
*On the behalf of A2 Collaboration.

Hadron structure, spectroscopy and dynamics / 218

Dipole Dynamical Polarizabilities from proton Real Compton Scattering data

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I will discuss the results of a recent work on the extraction of the dipole dynamic polarizabilities (DDPs) from proton Real Compton Scattering (RCS) data below pion production threshold. The dynamical polarizabilities are energy dependent functions which parametrize the response of the internal degrees of freedom of the proton to an external, real-photon field of arbitrary energy. As such, they contain enriched information with respect to the static polarizabilities defined in the limit of zero-frequency photon field. I will introduce the theoretical framework, which combines dispersion relations, the low-energy expansion and multipole decomposition of the scattering amplitude, focusing the attention on the electric and magnetic DDPs[1]. Furthermore, I will discuss the statistical analysis, based on the parametric bootstrap technique. These statistical tools have been applied for the first time to analyze RCS data, and have been crucial to overcome problems inherent to the analysis of the available data set. I will present the main advantages of this fitting method, including preliminary results about the statistical interpretation of the χ2 function when also systematical errors are taken into account. Finally, I will show new results for the extraction of the static polarizabilities αE1 and βM1, using subtracted dispersion relations and the bootstrap technique.

Nuclear Physics Applications / 273

The MINERVA facility within MYRRHA Phase 1

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MYRRHA is conceived as an Accelerator Driven System (ADS).It consists of a proton linear accelerator (linac) of 600 MeV, a spallation neutron source and a nuclear core cooled by liquid Lead-Bismuth (LBE). The 600 MeV accelerator of MYRRHA is a high intensity proton machine, delivering a proton beam on a spallation target. The high-energy protons are used in this target to create neutrons by spallation reactions. The produced neutrons in their turn feed the subcritical core of the MYRRHA reactor.
MYRRHA will strongly support the realisation of a European research and innovation framework by maintaining a high level of expertise in several crosscutting fields together with support to societal needs such as medical applications and high-level nuclear waste management.

According to the phased MYRRHA implementation strategy decided in 2015, the first facility that will be constructed at SCK•CEN, Mol (Belgium) will be the first part of the 600 MeV MYRRHA linac that will deliver intense proton beams up to 100 MeV. The 100 MeV accelerator will on the one hand demonstrate the required reliability of the 600 MeV linac for the MYRRHA ADS and on the other hand deliver protons to a target facility for the production of medical radio-isotopes and for fundamental or applied research in physics as well as for material research of interest to the fusion community. The 100 MeV accelerator together with the proton target facility is named MINERVA (MYRRHA Isotopes productioN coupling the linEar acceleRator to the Versatile proton target fAcility).
In this talk, the MINERVA facility will be described and the status of its implementation presented.

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155,157Gd neutron capture cross sections measured at n_TOF (CERN)

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Fuel assemblies (FAs) of current Thermal Reactors such as Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs) make extensive use of the so-called "burnable neutron poisons", i.e. isotopes characterized by a very high neutron capture cross section at thermal energy, so as to compete with the fissile 235U isotope in neutron absorption. One element that can be conveniently used as neutron poison is Gadolinium, thanks to the very large thermal neutron capture cross section of its odd isotopes 155Gd and 157Gd. For these properties, Gadolinium is also often used in neutron and, more recently, in neutrino detection, as well as in medical applications. The accurate knowledge of the neutron capture cross section of 155Gd and 157Gd is extremely important for assessing the performances and safety features of FAs and of the whole reactor core, as well as for reliable simulations of the neutron transport in the presence of Gd for other applications. Despite the importance of this cross section, only few experimental data are available on these two isotopes in the low energy region. For this purpose, a measurement of the neutron capture cross-sections of the two odd Gd isotopes was carried out at the experimental area (EAR1) of the n_TOF facility at CERN (Geneva). In this talk, the main results obtained in the thermal region as well as in the resolved resonance region (RRR), will be presented.

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Nuclear data program for NCT at the n_TOF Collaboration at CERN

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The n_TOF Collaboration, neutron time-of-flight, is the spallation neutron source facility located at the European Organization for Nuclear Research (CERN) based on a 20 GeV/c proton beam impinging on a lead target. n_TOF is a unique facility in the world due to the state-of-the-art of detectors, the data acquisition system and the characteristics of its neutron beam, i.e., high instantaneous flux in a wide energy range –from few meV to 1 GeV–, high energy resolution which allows resolving resonances and low repetition rate of the primary pulsed proton beam. The facility is in operation since 2001 and counts with two experimental rooms: n_TOF-EAR1, located at 185 m from the spallation target along the horizontal direction of the incoming proton beam, and n_TOF-EAR2, along the vertical direction at 20 m from the target was built in 2014. n_TOF is mainly dedicated to measure neutron-induced cross sections for nuclear technology, astrophysics, basic nuclear physics and medical physics. The nuclear data program for medical applications started in 2012 with the measurement of the 33S(n,a) cross section at the n_TOF-EAR1. This isotope is of interest in Boron Neutron Capture Therapy (BNCT) as a cooperative target to 10B because of its large cross section in the epithermal neutron energy range, the most suitable one for the accelerator based neutron sources. This measurement, in which the resonance region was successfully resolved, was completed in 2015 at n_TOF-EAR2, extending the cross section values from 10 keV down to the thermal point for the first time.

In 2017, two additional experiments were carried out at n_TOF-EAR2 with the aim of improving the dosimetry in BNCT treatments. In this case, the (n,p) cross section reaction on 14N and 35Cl were performed; the knowledge on the contribution to the total dose due to the proton emission is essential to preserve healthy tissues during the irradiation what has motivated this experiment. Continuing this program, in summer 2018 it is foreseen the measurement of the 35Cl(n,g) in order to increase the amount of data available on this reaction with the goal of enhancing the treatment planning in BNCT, in particular in case of brain cancer since it is in the brain where the higher concentration of 35Cl is found in the human body.

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Isomers Production in 238U Photofission

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The fission process induced by gamma quantas up to 25 MeV energy on 238U was analyzed. Experimental observables as cross sections, fragments mass distribution yields of some nuclides of interest and average prompt neutrons multiplicity characterizing 238U photofission were theoretically evaluated by using TALYS-1.9 software. Also results for the theoretical evaluations of isomer ratios using Talys possibilities supplied by own computer codes as well as experimental isomer ratios obtained at MT - 25 Microtron are presented. This study represents a research proposal for photofission investigations and isotopes production at the new neutron source IREN, from FLNP - JINR Dubna.

Nuclear Structure and Dynamics / 286

Recent progress on extended Skyrme functionals

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Any given finite-range two-body interaction can be developed by means of a simple Taylor series in momentum space.
This is the basic idea presented by Skyrme in its original paper. Truncating the Taylor series at second order in gradients, we obtain the standard Skyrme interaction (N1LO). In this talk I will discuss the truncation at 4th and 6th order in gradients and the new family of extended Skyrme interactions (N2LO/N3LO). The reason of considering the additional terms of the series is motivated by the lack of flexibility of current Skyrme functionals in reproducing nuclear observables at the desired level of accuracy.
Motivated by the previous work done by UNEDF collaboration, I will present the main new features of the extended Skyrme functionals and the new fitting strategy developed to avoid the appearance of spurious finite-size instabilities.

Nuclear Structure and Dynamics / 68

Charge Symmetry Breaking in strange nuclei

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The Charge Symmetry of the strong interaction requires that nn and
pp interaction strengths are equal. As a consequence, the energy levels of nuclear isospin multiplets are expected to be identical, after correcting for the Coulomb energy difference. The breaking of this symmetry manifests itself in experiments at a level of ~0.07 MeV for the NN interaction in normal, not strange, nuclei.

In Lambda hypernuclei, where the Lambda-N interaction acts, the breaking is predicted to be ~0.05 MeV by theoretical models which do not consider the effects of Lambda-N - Sigma-N coupling and of the three-body LambdaNN forces. However, from the experimental side, a large value of binding energy difference has been found for the A=4 isospin doublet, 4LambdaH - 4LambdaHe, in experiments based on emulsion techniques in the seventies. The same experiments gave also indications about the binding energy difference in A=7, 8, 10, 12 isomultiplets which did not show a substantial breaking effect.

In the last few years, several magnetic spectrometers provided high precision results in the field of Hypernuclear Physics. In particular, the accurate determination of the Lambda-binding energy for A=7, 10, 12, 16 systems contributed to stimulate considerably the discussion about the Charge Symmetry Breaking effect in Lambda-hypernuclei isomultiplets. Also for the A=4 isospin doublet, very precise measurements of 4LambdaH ground state binding energy and
of 4LambdaHe first excited state energy have been obtained.

This contribution aims at making an overview on Charge Symmetry
Breaking in s- and p-shell Lambda-hypernuclei, focusing on recent experimental results and analyses.

Nuclear Structure and Dynamics / 7

TOROIDAL MODE IN NUCLEI: FROM GIANT RESONANCE TO INDIVIDUAL STATES

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Last years the toroidal dipole resonance (TDR) attracts a high attention [1-4]. This mode is located at the energy of the pygmy dipole resonance and forms the low-energy part of the isoscalar giant dipole resonance. The TDR has many remarkable properties. This is the only known dipole vortical mode in the family of intrinsic electric excitations. The TDR is perhaps the origin of the pygmy dipole resonance [3]. Various TDR properties were explored by our group within the self-consistent Skyrme Quasiparticle Random-Phase Approximation (QRPA), see review [4]. Nevertheless, despite an impressive general theoretical and experimental effort, our knowledge on the TDR is still poor and even its experimental observation can
be disputed [5].
In this connection, we propose a new route to study the toroidal mode: to switch the effort from TDR (embracing many states and masked by other multipole modes) to individual well-separated low-energy toroidal states. As was recently shown [6], such states can exist in low-energy spectra of light nuclei with a strong axial prolate
deformation. For example, in 24Mg, this state appears as the lowest dipole K=1 excitation. These states can be easily discriminated and identified. They can serve as an excellent test cases to probe various reactions for vortical nuclear excitations. We briefly discuss the possibility to observe the toroidal individual states in inelastic electron scattering to back angles.

[1] N. Paar, D. Vretenar, E. Khan, and G. Colo, Rep. Prog. Phys. 70, 691 (2007).
[2] J. Kvasil, V.O. Nesterenko, W. Kleinig, P.-G. Reinhard, and P. Vesely, Phys. Rev. C84, 034303 (2011).
[3] A. Repko, P.-G. Reinhard, V.O. Nesterenko, and J. Kvasil, Phys. Rev. C87, 024305 (2013).
[4] V.O. Nesterenko, J. Kvasil, A. Repko, W. Kleinig, and P.-G. Reinhard, Phys. Atom. Nucl. 79, 842 (2016).
[5] A. Repko, J. Kvasil, V.O. Nesterenko, and P.-G. Reinhard, Eur. Phys. J. A53, 221 (2017).
[6] V.O. Nesterenko, A. Repko, J. Kvasil, and P.-G. Reinhard, arXiv:1711.08953[nucl-th], subm. to Phys. Rev. Lett.

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Isospin transport phenomena in semiperipheral heavy ion collisions at Fermi energies

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After a long R phase the FAZIA collaboration started its physics program in 2015 with a reduced setup consisting of four complete blocks. The results concerning isospin transport phenomena obtained in the first measurement run (ISOFAZIA experiment) on the system 80Kr+40,48Ca at 35AMeV are presented. An investigation of the isospin content of both fission fragments coming from the QuasiProjectile is also shown. An accurate comparison with the prediction of the AMD model is also presented.

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Symmetry Energy at supra-saturation densities studied with neutron-proton elliptic flows

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Symmetry Energy at supra-saturation densities studied with neutron-proton elliptic flows
Content
P. Russotto for the ASY-EOS II collaboration

The symmetry energy contribution to the nuclear equation of state is of fundamental importance in both nuclear physics and astrophysics. In the last decades several works, based on different observable, have allowed to constrain the symmetry energy mainly below saturation density. Vice versa, few works have been able to study the behaviour of the symmetry energy above the saturation density.
In this talk we will present the results of the ASY-EOS experiment at GSI, where we measured neutron and light charged particle elliptic flows in Au+Au collision at 400 AMeV. The analysis, based on the comparison of the elliptic flows ratio with QMD calculations, has allowed to provide a stringent constraint
for the symmetry energy behaviour at supra-saturation densities. We will present also our future plans aiming to extend elliptic flows measurements at higher beam energies, in order to explore higher densities. The possibility to measure pions will be also discussed.

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Achievements and challenges in understanding nucleon-deuteron reactions

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Comparison of theoretical predictions based on a nucleon-nucleon potential with data for elastic nucleon-deuteron (Nd) scattering and nucleon
induced deuteron breakup reveals the importance of a three-nucleon
force (3NF). Inclusion of semi-phenomenological 3NF models, such as Tucson-Melbourne or Urbana IX, into calculations in many cases improves the data description. However, some serious discrepancies remain even when a 3NF is included.
At low energies the prominent examples of discrepancies between theory and data were found for the vector analyzing power in elastic Nd scattering and
for the neutron-deuteron (nd) breakup cross sections in neutron-neutron (nn) quasi-free-scattering (QFS) andsymmetric-space-star (SST) geometries. Since both these configurations depend predominantly on the S-wave nucleon-nucleon (NN) force components, these cross section discrepancies have serious consequences for the nn 1S0 force component.
At energies above about 100 MeV current 3NF's only partially improve the description of data for cross section and spin observables in elastic Nd scattering and breakup. The complex angular and energy behavior of analyzing powers, spin correlation and spin transfer coefficients fails to be explained by standard nucleon-nucleon interactions alone or combined with current models of 3NF's.
One of the reasons for the above disagreements could be a lack of consistency between 2N and 3N phenomenological potentials used or/and omission of important terms in the applied 3NF.
The Chiral Effective Field Theory approach provides consistent two- and three-nucleon forces. The 3NF occurs for the first time at next-to-next-to
leading order (N2LO) of chiral expansion. The N3LO and N4LO NN forces when used in 3N calculations provide description of NN data of the same quality as standard, realistic NN potentials.
Application of improved, semilocal coordinate-space regularized chiral NN
interactions up to N4LO order of chiral expansion combined with N2LO 3NF's supports conclusions obtained with standard forces. It can be expected that an application of consistent chiral NN and 3NF's up to N3LO will play an important role in understanding of elastic scattering and breakup reactions at higher energies.

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Study of Few-Body Nuclei by Feynman's Continual Integrals and Hyperspherical Functions

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The probability densities for the ground states of 3H, 3,4,6He, 9Be nuclei were calculated in Refs. [1, 2] by Feynman's continual integrals method in imaginary (Euclidean) time [3, 4]. The present work is devoted to studying other light nuclei 6,7,9,11Li, 6,10Be using the same approach. For example, the probability density for the 6Li nucleus is shown in Figure. The correctness of calculations was checked by comparison with the results of the expansion in hyperspherical functions (K-harmonics) [5] using new effective method for the solution of the system of hyperradial equations using cubic splines [6].

Figure. The probability density for the 6Li nucleus and the vectors in the Jacobi coordinates; neutrons are denoted as small empty circles, protons and alpha-clusters are denoted as small filled circles and large filled circles, respectively. The only one possible configuration is alpha-cluster + deuteron-cluster.

References

[1] V.V. Samarin and M.A. Naumenko, Phys. Atom. Nucl. 80, 877 (2017).
[2] M.A. Naumenko and V.V. Samarin, EPJ Web of Conferences 173, 05011 (2018).
[3] R.P. Feynman and A.R. Hibbs, Quantum Mechanics and Path Integrals, McGraw-Hill, New York (1965).
[4] E.V. Shuryak and O.V. Zhirov, Nucl. Phys. B 242, 393 (1984).
[5] R.I. Dzhibuti and K.V. Shitikova, Metod gipersfericheskikh funktsiy v atomnoyi yadernoy fizike [Method of Hyperspherical Functions in Atomic and Nuclear Physics], Energoatomizdat, Moscow (1993).
[6] V.V. Samarin, Nuclear Theory, 36, 233 (2017), eds. M. Gaidarov, N. Minkov, Heron Press, Sofia.

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Nuclear force studies in the proton-deuteron break-up channel at 135 MeV

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A detailed description of nuclear forces is essential for understanding the properties of nuclei and the dynamics in few-nucleon scattering processes. The need for an additional three-nucleon potential became evident when comparing three-body scattering observables and light-nuclei binding energies with state-of-the-art calculations[1].
In this work, the analyzing powers (Ax and Ay) and differential cross sections are presented for the proton-deuteron break-up reaction studied with using a polarized-proton beam at 135 MeV impinging on a liquid-deuterium target. For the experiment we used the Big Instrument for Nuclear-polarization Analysis (BINA) at KVI, the Netherlands. BINA is composed two main parts, a forward wall to detect protons that scatter between 10-35 and a backward ball covering polar angles between 32-160. With this setup, we recently expanded our measurements of cross sections and analyzing powers from earlier presented result [1]. In particular, we measured for the first time A_x for a large range in the kinematical S-curve, polar and azimuthal angles of the two outgoing protons.

Cross section and analyzing power data are compared to predictions from Faddeev calculations that are based on modern two-nucleon and three-nucleon potentials. Our polarization data are reasonably well described by calculations for kinematical configurations at which the three-nucleon force effect is predicted to be small. However, striking discrepancies are observed at specific configurations, in particular in cases when the relative azimuthal angle between the two protons becomes small. The aim is to significantly extend the world's database in the three-nucleon scattering system as a benchmark to eventually confine the structure of the three-nucleon interaction. In this contribution, some of these configurations along with the analysis techniques will be discussed.

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The quest for new data on the Space Star Anomaly in pd breakup

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Even though the development of the theories providing a precise description of few-nucleon interactions is well advanced, certain inconsistencies between experimental data and theoretical predictions are still to be resolved. One of the most intriguing discrepancies observed in the proton-deuteron breakup reaction is known as the Space Star Anomaly [1]. It concerns a very special geometrical configuration, where the momentum vectors of the reaction products are of the same length. What is interesting, the experimental evidence shows that the effect marks its presence at low energies (7.5-13 MeV/nucleon) [2], to
the contrary to the inconsistencies attributed to the so-called three-nucleon force.

Unfortunately, the highest energies ever analysed with this respect were 19 MeV [3] and 65 MeV [4]. Therefore due to a poor coverage of the energy range over 19 MeV it was not possible to draw clear conclusions about the source of the effect. The measurement and the calculations at 65 MeV show lack of the Space Star Anomaly at this energy and, on the other hand, enhanced sensitivity to relativistic effects [5]. The systematic studies in the domain of energy and for various orientations of the star relatively to the beam direction are important for better understanding of the process dynamics. The Big Instrument for Nuclear-polarization Analysis (BINA) [6,7] is one of the detectors well suited for such measurements. The research programme of the experiment aims i.a. at providing additional data on the Space Star cross-sections.

In this contribution, a thorough description of the Space Star
Anomaly effect will be presented. The latest theoretical predictions based upon Refs. [8,9] will be compared with each other and with the preliminary data points for the star configuration obtained with the BINA experimental setup for beam energies >=50 MeV/nucleon, as the next step in the research programme started recently.

[1] J. Strate et al., Nucl. Phys. A501, 51 (1989).
[2] K. Ohnaka et al., Few-Body Syst. 55, 725 (2014).
[3] J. Ley et al., Phys. Rev. C73, 064001 (2006).
[4] J. Zejma et al., Phys. Rev. C55, 42 (1997).
[5] H. Wital a, et al., Phys. Lett. B634, 374 (2006).
[6] M. Eslami-Kalantari, Ph.D Thesis, RUG 2009.
[7] St. Kistryn, E. Stephan, J. Phys. D40, 063101 (2006).
[8] A. Deltuva, Phys. Rev. C 80, 064002 (2009).
[9] H. Witala, Phys. Rev. C 83, 044001 (2011).

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Measurement of the differential cross section of neutron scattering on deuterium in the neutron energy range from 400 keV to 2.5 MeV

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Accurate experimental data describing elastic scattering of neutrons on deuterium are of interest for both fundamental research, for understanding quantum-mechanical few-body systems, and nuclear applications, e.g. for the design and safe operation of heavy-water moderated critical systems. Below 3 MeV of incident energy, however, the available measurements of scattering angular distributions are scarce and partially inconsistent.

The differential cross section of neutron scattering on deuterium was measured using monoenergetic neutrons in the energy range from 400 keV to 2.5 MeV. A proportional counter filled with mixtures of deuterated gases was used as both neutron target and detector for the recoil deuterons. As the deuteron recoil energy is directly related to the neutron scattering angle, the experimental pulse-height can be analysed to reconstruct the neutron angular distributions over a large angular range.

Interferences due to photon-induced events were minimized by means of passive shielding and an active rise-time discrimination scheme. To account for the finite resolution of the detector, incomplete energy deposition (wall effect), and multiple scattering events, a dedicated Monte Carlo model was implemented simulating neutron and deuteron transport in the detector. The coefficients of the Legendre expansion of the differential cross section are obtained from the comparison of simulations to measurements using an iterative procedure.

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Few-body dissociation of relativistic light nuclei in nuclear track emulsion

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Events of dissociation of relativistic nuclei in nuclear track emulsion (NTE) allow a holistic investigation of "cold" ensembles of lightest nuclei. So far, with regard to fine structure dissociation of relativistic nuclei, the NTE technique remains the only means providing unique completeness of such observations at the best angular resolution and as well as a sufficient statistical provision. Moreover, full-bodied studies of light nuclear structure require reconstruction of relativistic decays of the unstable 8Be and 9B nuclei. Feasibility of such studies in electronic experiments is not visible at all. The cluster structure of light nuclei and the role of the unstable 8Be and 9B nuclei in them is studied in the BECQUEREL project (http://becquerel.jinr.ru/) on the basis of NTE layers longitudinally exposed at the JINR Nuclotron to relativistic Be, B, C and N nuclei, including radioactive isotopes. Recent advances are highlighted. On the practical side series of experiments with newly reproduced samples NTE has confirmed prospects of NTE in low and high energy nuclear studies.
Recently it is suggested to search in relativistic 12C dissociation for α-particle triples in the second excited state 0+2 of the 12C nucleus (the Hoyle state). The started study of the Hoyle-state (HS) in dissociation is setting new limit of NTE use. Being performed in contrast to relativistic energy of 3α-ensembles and minimum possible energy stored by them such observations would clearly demonstrated HS as a full-fledged and sufficiently long-lived nuclear-molecular object. Probably, not only single but also pair- and even triple-wise combinations of α-particles that are close to 8Be might be observed to reflecting the HS structure in less distorted way. It can be expected that 8Be and HS will become reference points to search for more complex states of dilute nuclear matter in dissociation of heavier relativistic nuclei. The current experiment task is to search for several hundreds of 3α-events in NTE pellicles and measure the angles of α-particles in the relevant ranges with a resolution allowing reconstructing decays of the unstable 8Be nucleus and HS. HS events are observed in dissociation 12C → 3α at 4.5 A GeV/c and 1 A GeV/c 12C nuclei with a contribution preliminary estimated to be of the order of 10%. Thus, the first data on relativistic HS are encouraging.

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Nuclear physics for cultural heritage

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There has been enormous progress in the use of nuclear physics techniques to study, characterize and preserve cultural heritage objects and artefacts. This expert review, published by the Nuclear Physics Division of the European Physical Society (EPS), seeks to provide the public with a popular and accessible account of the latest developments in this field. The contributions from a range of leading specialists explain how applied atomic and nuclear techniques can be used to obtain information that can help us understand the way of life in ancient times and how they can be used to conserve cultural heritage treasures. This topical review draws heavily on European work and is extensively illustrated with important discoveries and examples from archaeology, pre-history, history, geography, culture, religion and curation. It outlines key advances in a wide range of cross-disciplinary techniques and has been written with the minimum of technical detail so as to be accessible by as wide a possible audience as possible. The large number of groups and laboratories working in the study and preservation of cultural heritage using mainly nuclear physics methods across Europe indicate the enormous effort and importance attached by society to this activity.

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Nuclear masses for nuclear structure and astrophysics

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Nuclear masses reflect sensitively changes in nuclear structure, such as shell closures, pairing effects or onset of deformation. The masses are also one of the key inputs for nuclear astrophysics, and structural changes are reflected in the calculations. The recent observation of GW170817 [1] from a merger of two neutron stars and the associated kilonova manifested that a broad range of elements heavier than iron can be produced at least in this kind of mergers via rapid neutron capture process, the r process. It has been shown [2] that uncertainties in nuclear masses and fission properties need to be reduced in order to better constrain the role of neutron star mergers on the chemical evolution of r-process elements using LIGO/Virgo's detections. In this contribution, I will review the current status of nuclear mass measurements for nuclear structure and astrophysics with an emphasis on the r process.

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Fifty years of EPS

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