UNIVERSITÀ DEGLI STUDI DI MILANO

INFN Istituto Nazionale di Fisica Nucleare

VII Topical Workshop on Modern Aspects in Nuclear Structure

The Many Facets of Nuclear Structure

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BOOK OF ABSTRACTS

Symposium
on Resonances and related topics

on the occasion of
Angela Bracco's farewell from Milano University

Particle-Vibration Coupling and Pairing Correlations

F. Barranco,
Departamento de Fìsica Aplicada III, Escuela Técnica Superior de Ingeniería,
Universidad de Sevilla, Spain

The interplay between the deformability of the nuclear surface (mainly quadrupole) and the pairing correlations constitutes one of the basic columns of the study of nuclear structure. The very discovery of nuclear superfluidity was based on the influence of the effects of BCS-like pairing correlations on the low-lying quadrupole vibrational states of even-even nuclei (Bohr, Mottelson, Pines 1958). But, as it usually happens, the influences are reciprocal, and, in fact, Bohr and Mottelson later proposed (Bohr,Mottelson 1975) that the exchange of quanta of surface vibrations between nucleons through particle-vibration coupling (Induced Pairing Interaction) should play a fundamental role, as large as, or even greater than, the bare nucleon-nucleon interaction, in determining pairing properties of nuclei, as modern ab initio calculations seems to confirm (Holt, 2013, and Palkanoglou, 2025). In this contribution we present the different facets of the Induced Pairing Interaction, analyzing both nuclei with BCS -type correlations (Idini(2013)) and pairing-vibrational nuclei, (Barranco(2025)) including the high-lying pairing resonances (known as Giant Pairing Vibrations), predicted by Broglia and Bes (1977) and recently discussed in connection with a series of experiments by Cappuzzello et al. (2015).

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Quasi-continuum M1 strength as function of nuclear deformation

Magne Guttormsen
Department of Physics, University of Oslo

The γ-ray strength function (γSF) is a fruitful concept in the quasi-continuum region describing the average reduced g-ray transition probability between groups of levels. The γSF reveals various resonances and structures below the neutron separation energy. Common structures are the pygmy resonances (PDR), scissors mode (SM) and the low-energy enhancement (LEE). In addition, these structures are superimposed on the low-energy tail of the giant dipole resonance (GDR).The shape of the γSF has impact on the radiative neutron capture and is important for constraining the reaction rates relevant for the r-and i-process nucleosynthesis.

The LEE seems to be most pronounced in lighter and medium heavy nuclei, whereas the SM is mostly observed in well-deformed heavier nuclei. The aim of this work is to investigate how these structures dependent on the nuclear deformation. Both structures are supposed to be of M1 character, and it is interesting to see if the summed M1 strength is constant with deformation.

We have chosen to study $^{142,144–151}$Nd for γ-ray energies up to the neutron separation energy using the Oslo method. This chain of stable neodymium isotopes covers nuclei from almost spherical to well-deformed shapes and gives a unique picture of the interplay between the LEE and SM structures.

Progress in the study of electric giant and pygmy resonances over the last five decades

Muhsin N. Harakeh
University of Groningen, Groningen, the Netherlands

To study the properties of nuclear matter we use nuclear reactions to excite the fundamental modes of the nucleus, which are also important for understanding nuclear structure aspects of nuclei. In the last five decades, the compression modes, the isoscalar giant monopole (ISGMR) and dipole resonances (ISGDR) were extensively studied because of their importance for the determination of the nuclear-matter incompressibility and consequently their implications for the equation of state (EOS) of nuclear matter. Though the nuclear matter incompressibility (K_∞) has been reasonably well determined (~ 240±20 MeV) through comparison of experimental results on several spherical nuclei with microscopic calculations, the asymmetry term was determined with much larger uncertainty. This has been addressed in measurements on a series of stable Sn and Cd isotopes, which resulted in a value of K_t = -550±100 MeV for the asymmetry term in the nuclear incompressibility.

In the last three decades, the pygmy dipole resonance (PDR) was studied as well with various probes, i.e. inelastic photon, proton and alpha scattering. The comparison between the results of the various reactions allow to disentangle the isospin character of the various components of the PDR, which turn to be in agreement with theoretical model calculations.

With the advent of radioactive ion-beam facilities, prospects for giant resonance studies in exotic nuclei become rich and promising. In pioneering experiments at GSI, the isovector giant dipole resonance (IVGDR) in neutron-rich oxygen and tin isotopes was investigated in Coulomb excitation by scattering off a Pb target at relativistic energies employing the invariant-mass method. More recently, the isoscalar giant resonances were studied in inelastic scattering off deuterium and helium targets in inverse-kinematics using two techniques: the active-target method and storage-ring method. This included investigation of the isoscalar giant quadrupole resonance (ISGQR) as well as the isoscalar giant monopole (ISGMR) and dipole (ISGDR) resonances, the so-called compression modes important for determining key parameters of the equation of state (EOS) of nuclear matter. The most recent results for the few cases studied will be presented and the advantages and disadvantages of both methods will be discussed.

The Pygmy Dipole Resonance

Edoardo G. Lanza
INFN - Sezione di Catania

The role of Angela in the nuclear structure field is overwhelming in quality and production. She has been involved
in the realisation of complex detection systems for gamma-ray built within European collaboration (EUROBALL, RISING and AGATA). Among her major achievement we can mention her relevant results on the giant dipole resonance at zero and finite temperature.
I had the privilege to collaborate with her and her group in the last ten years on the problem of the low-lying dipole states that are usually called Pygmy Dipole Resonances (PDR). She gave an important contribution with one of the first evidence of PDR on the exotic isotope 68Ni using relativistic Coulomb excitation (^{68}Ni + ^{A}Au at 600 MeV/u). Due to the isospin mixing of these dipole states, the investigation advanced in the direction of using isoscalar probes to excite the PDR. That was achieved at the INFN Legnaro Laboratory, where the use of the 17O projectile on several stable targets with neutron excess was of paramount importance in the understanding many aspect of the PDR states.
In my talk I will overview some of the main aspect regarding our collaboration on the PDR problem. Relevance will be given, in particular, to the calculation of the radial from factors which enter in the description of the inelastic cross section.
The results of our collaboration are summarised into two review paper [1,2] that are frequently cited in other work on the PDR.

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Theory updates on nuclear resonances: giant and pygmy, cold and hot, classical and quantum

Elena Litvinova

Western Michigan University, Kalamazoo MI, 49008-5252, USA

I will present selected results on nuclear giant and pygmy resonances at zero and finite temperatures based on the recent advancements of the nuclear many-body theory [1-6]. The theory will be compactly introduced in the most general quantum field theory formalism with only the bare fermionic interaction input. A special focus will be placed on the emergent scale of the quasiparticle-vibration coupling (qPVC) with the order parameter associated with the qPVC vertex. An efficient treatment of the nuclear many-body problem is thus organized around the qPVC hierarchy, which takes over the power counting, dominating the bare interaction and few-body systems [1-3].

Self-consistent solutions of the relativistic Bethe-Salpeter-Dyson equation for the nuclear response function in medium-heavy nuclei will be presented and discussed. Low-multipole neutral and charge-exchange resonances in calcium, nickel, and tin mass regions will be analysed in the context of the role of high-complexity configurations in reproducing spectral data [2,3,7]. Finite-temperature theory and implementations for astrophysically relevant low-energy dipole strength, beta decay rates, and electron capture rates will be compared to the respective zero-temperature quantities [4,5]. Finally, I will discuss the prospect of the quantum equation of motion to generate complex configurations for the response of strongly correlated fermionic systems on an example of the solvable Lipkin Hamiltonian [3].

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Electric Dipole Oscillations at Finite Temperature from the perspective of my long-standing collaboration with Angela

Adam Maj
IFJ PAN Krakow

The giant dipole resonance (GDR) corresponds to a back and forth sloshing of neutrons against protons. It was found that the photo-absorption cross-section for almost all target (cold) nuclei displayed a resonant behaviour. Typical values of the centroid and of the FWHM of giant resonances are 10-15 MeV and 3-5 MeV, respectively. In the case of quadrupole deformed nuclei, the absorption resonance cross section is generally reproduced by two Lorentzian functions, whose centroids and relative intensities can be used to infer the size and the type of nuclear deformation.

In two measurements, namely in the study of spontaneous fission of 252Cf [1] and especially in the fusion-evaporation experiment [2] shoulders in the spectra above 10 MeV were observed. They were interpreted as arising for the GDR built on nuclei possessing a finite temperature. This observation started the general interest to study the GDR in many hot rotating nuclei in fusion-evaporation reactions. It was realized that the study of collective motion in hot nuclei in general, and of giant resonances in particular, might provide a unique probe to study the evolution of the nuclear structure as a function of temperature. One of the leading laboratories which started, around mid-eighties, to pursue this subject was the Tandem Accelerator Laboratory of the Niels Bohr Institute in Risoe (Denmark).

I arrived to NBI-TAL as a postdoc in the beginning of 1989 and started the collaboration with Jens Joergen Gardhoeje, the local group leader, and Angela Bracco, the leader of the strongly collaborating Milano group. I was involved, together with them, in the first exclusive experiments of GDR in hot rotating nuclei. The extensive experimental and theoretical work done on the gamma decay of the GDR in hot rotating nuclei has allowed to investigate the properties of nuclear matter at finite temperature and how the damping mechanisms of this collective vibration evolve with temperature and angular momentum. In particular, we demonstrated that the nuclear shapes of hot and very fast rotating nuclei undergo a Jacobi shape transition: from oblate, via tri-axial, to very elongated prolate.

My collaboration with Angela on Electric Dipole Oscillation at finite temperature continued after the NBI period for many years in different European laboratories. In my presentation I will try to show the most important findings [3] of this long-standing collaboration.

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Experimental studies of the microscopic structure of the pygmy dipole resonance

Mark-Christoph Spieker,
Florida State University, Department of Physics

The pygmy dipole resonance (PDR) has been observed on the low-energy tail of the isovector giant dipole resonance (IVGDR) below and above the neutron-separation threshold. While the additional strength is recognized as a feature of the electric dipole response of many nuclei with neutron excess, its microscopic structure, which intimately determines its contribution to the overall strength, is still poorly understood making reliable predictions of the PDR in neutron-rich nuclei far off stability difficult. It has been shown that the coupling to complex configurations drives the strength fragmentation for both the IVGDR and the PDR, and that more strength gets fragmented to lower energies when including such configurations. The wavefunctions of $J\pi = 1^-$ states belonging to the PDR are, however, expected to be dominated by one-particle-one-hole (1p-1h) excitations of the excess neutrons. First experiments were performed to access these parts of the wavefunction via inelastic proton scattering through isobaric analog resonances and via one-neutron transfer (d, p) experiments [1–3]. The results, obtained from these experiments, will be presented in this contribution. I will also briefly present first results from a new experimental setup recently commissioned at the Super-Enge Split-Pole Spectrograph at Florida State University for particle-γ coincidence experiments, called CeBrA [4], and highlight the value other particle transfer reactions could add to studying the microscopic structure of the PDR. Given the special occasion and if time permits, I will comment on experimental studies of a possible pygmy quadrupole resonance(PQR) [5, 6].

The experimental program at the FSU John D. Fox Laboratory is supported by the U.S. National Science Foundation (PHY-2012522, PHY-2412808, and PHY-2405485) and by the U.S. National Nuclear Security Administration (DE-NA0004150) as part of CENTAUR. Support from Florida State University is gratefully acknowledged.

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Nuclear Photonics at ELI-NP

Călin Alexandru Ur

Extreme Light Infrastructure - Nuclear Physics, IFIN-HH, 077125 Măgurele, Romania

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) [1] is part of the pan-European Extreme Light Infrastructure project [2] and is mainly dedicated to the use of extreme electromagnetic fields for nuclear physics studies and related topics. The physics case of ELI-NP [2] was developed based on two state-of-the-art sources of extreme light: a high-power laser system and an intense gamma beam system. The main research area at ELI-NP is nuclear photonics.

Since 2020 ELI-NP hosts the world's most powerful high-power laser system, consisting of two 10 PW laser arms. The main research topics to be studied with this system are: understanding the fundamentals of the laser-matter interactions, new paradigms for electrons and ions acceleration driven by high-power lasers, astrophysical interest nuclear reactions in plasmas, generation of brilliant neutron sources, applications in medicine and industry. An overview of the laser experimental setups and first results will be presented. Extreme acceleration fields of hundreds of GV/m and gamma rays of several hundreds of MeV were generated in the first experiments. The ability to reach unprecedented laser intensities of the order of 10^{23} W/cm^2 has been demonstrated. A rich research program dedicated to the development of technologies with potential use in hadron therapy of cancer and high-sensitivity X-ray imaging driven by high-power lasers will be presented.

The intense gamma beam system is under implementation and promises to provide quasi-monochromatic gamma rays with high spectral densities specifically tailored for nuclear physics experiments covering a range of gamma-ray energies of up to Pygmy and giant dipole resonances. A set of complex experimental setups for high resolution and high efficiency detection of gamma rays, charged particles and neutrons has been developed at ELI-NP. Currently, some of these experimental setups are being used for complementary measurements, providing excellent tools for gamma-ray and particle spectroscopy studies of nuclear structure. Results obtained with these systems will be highlighted.

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Angela and the Electric Dipole Response – Giant and Pygmy, Hot and Cold

Peter von Neumann-Cosel
Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

A central theme of Angela Bracco's work has been the electric dipole response of nuclei. In my contribution I want to pick up a few aspects that impacted on my own research. First, a central problem addressed in her work are the mechanisms of damping of the GDR (and other giant resonances) at zero and finite temperature [1]. This has led us to develop a new approach to study the different contributions by analysing the fine structure of giant resonances using wavelet techniques [2]. Some applications to the GDR will be discussed [3,4]. Second, Angela has been a driving force of studies to understand the low-energy properties of the electric dipole response, where a resonance-like structure called pygmy dipole resonance (PDR) is observed in nuclei with neutron excess [5]. Two theoretical interpretations of the PDR are presently discussed: it might result from neutron skin oscillations (which would relate the PDR strength to properties of the symmetry energy [6]), or they represent the low-energy branch of the toroidal electric dipole resonance [7]. I will discuss the first experimental evidence of the toroidal mode in nuclei and its implications for the PDR [8]. Third, studies of the electric dipole strength at finite temperature - like Angela's pioneering work on the hot GDR in the γ decay of highly excited compound nuclei [9,10] - are based on the generalized Brink-Axel hypothesis stating that the γ strength function is independent of the energies of initial and final states. Its validity at low energies relevant to the statistical model approach in large-scale nucleosynthesis reaction network calculations is heavily debated. I present some experimental studies of the problem based on the comparison of γ strength functions obtained from g.s. photoabsorption and from the Oslo method [11,12].

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VII Topical Workshop on Modern Aspects in Nuclear Structure

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INVITED TALKS

Metastable States in Superheavy Nuclei

Dieter Ackermann
GANIL, CEA/DRF-CNRS/IN2P3, 14076 Caen, France

One of the most exciting features in nature are metastable states creating partly spectacular phenomena, often with beautiful optical manifestations and powerful properties like the aurora borealis or the very versatile tool of lasers. The basis is always quantum mechanics which hinders states with special quantum configurations from decaying. This holds as well for nuclear physics, and, in particular, for the heaviest nuclear species. The causes for these states are manifold, from large spin differences and parity change, shape degrees of freedom, or better: hindered freedom, to high values in the K quantum number of deformed nuclei.

In my presentation, I will summarize the many facets of isomeric states in superheavy nuclei (SHN) as we discussed in our recent review [1].

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DESPEC Experiment Highlights from FAIR Phase-0

Helena May Albers[1] for the HISPEC/DESPEC Collaboration

[1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

The HISPEC/DESPEC collaboration is a part of NUSTAR (NUclear STructure, Astrophysics and Reactions), which constitutes one of the four scientific pillars of the international FAIR facility currently under construction in Darmstadt, Germany. Experiments are divided into two main areas: high-resolution in-flight spectroscopy (HISPEC) and stopped-beam experiments (DESPEC).

In the future, both HISPEC and DESPEC experiments will be provided exotic secondary beams by the new Super-conducting FRagment Separator (Super-FRS), where the SIS-18 and SIS-100 synchrotrons will deliver high-energy beams to the Super-FRS production target. The DESPEC setup was successfully commissioned in 2020 in the so-called 'FAIR Phase-0' using exotic beams delivered by the SIS-18 and FRagment Separator (FRS) facilities of the existing GSI campus, with several campaigns running in 2021-2024.

In this talk I will show recent scientific highlights from the DESPEC Phase-0 campaigns [1], including investigations close to doubly-magic ^{100}Sn, insights into the prolate-oblate shape transition in heavy, neutron-rich nuclei south-west of ^{208}Pb, and preliminary results from the worlds first in-flight fragmentation of ^{170}Er ions, providing a wealth of information in the highly-deformed rare-earth nuclei with A~160-170. In addition, the medium- and long-term perspectives for DESPEC experiments at the Super-FRS in the coming years will be discussed.

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Deformation and isospin breaking effects in the A=71 mirror system

A. Algora IFIC (CSIC Univ. of Valencia)
for the NP1112-RIBF93 experiment collaboration

Studies of the beta decay of ^{71}Kr have not been free of controversy. The first study by Oinonenet al. [1] showed a relatively too small ground state to ground state feeding for a mirror pair and prompted an immediate alternative explanation by Urkedal and Hamamoto [2] invoking possible shape effects and isospin breaking in the mirror system. Some years later, a careful in-beam study [3] restored the earlier interpretation of Oinonen, that since then has prevailed [4].

New insights have been recently obtained based on a high-statistics experiment performed at RIKEN Nishina Center. In this talk, I will present these new results from the perspective of deformation and isospin effects in the A= 70 region. Our results indicate that this is the very first identified case of isospin breaking in the ground state of a T=1/2 case [5]. We also find evidence of a long-sought 0^+ state in ^{70}Se populated in the beta delayed proton process.

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Towards neutrino-nucleus scattering with coupled-cluster theory

Sonia Bacca
Mainz Univ., Germany

The past decade has witnessed tremendous progress in the theoretical and computational tools that produce our understanding of the nucleus as a compound object of interacting protons and neutrons. A number of ab initio calculations of nuclear electroweak properties that started from interactions and currents obtained from chiral effective field theory have successfully described key experimental observables. The level of accuracy and confidence reached by ab initio calculations opens up now the concrete possibility of using nuclear theory to help address open questions in other sub-fields of physics, such as neutrino physics.

In this talk, I will present our recent results for electron and neutrino-nucleus scattering based on coupled-cluster theory.

Precision mass measurements for nuclear structure and fundamental studies

K. Blaum
Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Precision mass measurements of ground and excited state properties of rare nuclides have a wealth of applications among others in atomic-, nuclear-, astro-, neutrino-and particle physics. Technical developments in the manipulation and detection of radionuclides and stable species in high-precision Penning-trap mass spectrometry like the phase-imaging and Fourier-transform ion cyclotron resonance detection methods have boosted the field and allow for relative mass uncertainties at the level of 10-11 and below. These technical advances as well as the opening of new fields of applications like the measurement of not only nuclear but also electron binding energies of exotic species as well as tests of physics beyond the Standard Model will be presented.

News and highlights from the ISOLDE Decay Station

James Cubiss

University of Edinburgh
On behalf of the IDS collaboration

The ISOLDE Decay Station (IDS) [1] is one of the permanent experiments at CERN's ISOLDE facility. The device aims to provide a versatile and flexible tool for low-energy studies of the wide range of radioactive beams available at the laboratory. The current system consists of a recently upgraded array of clover detectors surrounding a movable tape system. This core setup is augmented with ancillary detector arrays for charged particle (silicon, DSSDs, plastic scintillators), neutron (INDiE and OGS) and fast-timing (LaBr:Ce and plastic scintillators) measurements. In this presentation, an overview of the setup will be given along with recent highlights from the collaboration, and plans for future.

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Allowed and forbidden beta decays within the Realistic Shell Model

G. De Gregorio[1,2] , L. Coraggio[1,2] , N. Itaco[1,2], A. Gargano[2], R. Mancino[3], Z.H. Cheng[4] Y.Z. Ma[4] F.R. Xu[4], M. Viviani[5]

[1]*Dipartimento di Matematica e Fisica, Università degli Studi della Campania "Luigi Vanvitelli", viale Abramo Lincoln 5—I-81100 Caserta, Italy*

[2]*Istituto Nazionale di Fisica Nucleare, Complesso Universitario di Monte S. Angelo, Via Cintia—I-80126 Napoli, Italy*

[3]*Institute of Particle and Nuclear Physics, Faculty of Mathematics and Physics, Charles University,*
V Holešovickách 2, 180 00 Prague, Czech Republic

[4]*School of Physics and Key State Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*

[5]*Istituto Nazionale di Fisica Nucleare, Largo Bruno Pontecorvo 3, I-56127 Pisa, Italy*

In this talk I will discuss the renormalization of allowed and forbidden β decays within the framework of Realistic Shell Model. This approach, consists in the derivation of effective shell-model Hamiltonians and decay operators, using many-body perturbation theory starting from realistic NN, and eventually NNN, interactions.

Within this context, the "quenching puzzle" of the axial coupling constant g_A is therefore faced from a microscopic point of view, namely, without resorting to any phenomenological quenching factor. I will discuss the results obtained on allowed single- and double-β decay [1] as well as on forbidden β decays [2]. For allowed decays, we have studied the effect of two-body currents calculated within the contest of the EFT and found that it amounts to almost 20% of the total quenching. As regards the forbidden β decays, we have studied the electron energy spectra and half-lives of forbidden β decays for nuclear systems outside the ^{78}Ni core. In particular, we have examined how sensitive the calculated electron energy spectra and half-lives are to the renormalization of forbidden β-decay operators.

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Transfer reactions with ACTAR TPC: Complete study of neutron-rich oxygen isotopes : $^{19-20}O$

B. Fernández-Domínguez[1], J.Lois-Fuentes[1], M. Lozano-González[1], T. Roger[2]
C. for the ACTAR TPC collaboration
1) a IGFAE and Dpt. de Física de Partículas, Univ. of Santiago de Compostela, E-15758, Santiago de Compostela, Spain
2) GANIL, CEA/DRF-CNRS/IN2P3, Bd. Henri Becquerel, BP 55027, F-14076 Caen, France

Transfer reactions are essential tools for exploring the structure of exotic nuclei. Research on nuclei far from stability is typically conducted using secondary radioactive beams, which often have low intensities. To compensate for this limitation, experiments rely on thick targets and highly efficient detection systems to enhance luminosity. Active targets are essential tools that offer several advantages, including the ability to reconstruct reactions in three dimensions while maintaining resolution. The Active TArget and Time Projection Chamber (ACTAR TPC[1,2]) detector was developed at GANIL to support a wide range of physics research. The detector was commissioned in 2018 and has demonstrated excellent performance. Since then, several experiments have been performed at GANIL. In this talk, I will discuss the results of various transfer reactions performed with a ^{20}O secondary beam produced at the LISE spectrometer. From the single-proton removal reaction, the spin-orbit splitting and the size of the Z=6 shell gap has been deduced. From the single-neutron removal reaction, the neutron wave function of ^{20}O and the structure of ^{19}O were studied. The experimental results were compared to state-of-the-art shell model calculations using the SFO-tls interaction[3,4]

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Multi-proton emission in beta-decays along the proton drip-line

Hans Otto Uldall Fynbo

Department of Physics and Astronomy, Aarhus University, Denmark

13 beta-delayed two-proton (β2p) emitters are known today: ^{22}Al, ^{22,23}Si, ^{26}P, ^{27}S, ^{31}Ar, ^{35}Ca, ^{39}Ti, ^{43}Cr, ^{45,46}Fe, and ^{50,51}Ni. The Q-value (the energy released in the decay) is a major determining factor for what type of beta-delayed decays occur, and therefore two-proton emitters are found at or close to the dripline. Nuclear structure also plays a role as clustering in light nuclei evolves into competition between single particle and collective (rotational and vibrational) degrees of freedom. The cross-over happens in this interesting region of the chart of nuclei where the known β2p emitters are found. The relation between two-proton emission and many-body nuclear structure is still poorly understood.

Of the 13 known cases, only ^{31}Ar has been studied with sufficient statistics and beam quality to provide a deep study of the mechanism of the two-proton emission, this being the only case possible to produce at an ISOL facility (ISOLDE-CERN). Short-lived isotopes of the elements between Mg and Cl are difficult, or impossible, to produce at ISOL facilities due to the chemical properties of those elements.

With FRIB coming on-line and the Gas Stopping Area working excellently it is now possible to make low energy beams of most of these isotopes with unprecedented yields. With FRIB Experiment 21010 on the decays of ^{22}Al and ^{26}P we have initiated the exploration of this fertile region of nuclear structure and decay phenomena. The experiment is the first successful FRIB Experiment conducted in the Stopped Beam Area with yields of the two species of respectively 10 and 60 particles per second. The experiment provided much improved data both in quality and quantity not only for ^{22}Al and ^{26}P, but also for ^{21}Mg and ^{25}Si (beta-delayed one-proton emitters), which were present as contaminants and/or were used for calibration purposes.

In this contribution I will present results from FRIB Experiment 21010 including a clarification of the mechanism of two-proton emission in the decays of ^{22}Al and ^{26}P. Plans for future studies at FRIB to address more of the 13 known cases of beta-delayed two-proton emitters will also be presented.

The AGATA campaign at LNL: nuclear structure from high-resolution γ-ray spectroscopy

A.Gottardo for the AGATA collaboration

INFN-LNL, Viale dell'Università, 2 Legnaro 35020, Italy

The AGATA campaign at LNL has started in 2022 with stable beams from the Tandem-ALPI-PIAVE accelerator complex [1]. The AGATA γ-ray tracking array has been coupled to the magnetic spectrometer PRISMA as well as to other complementary detectors for heavy-ion and light particle measurement, like the silicon detectors OSCAR, SPIDER and SAURON. The physics campaign has encompassed a large variety of physics case, ranging from the sub-barrier Coulomb excitation of stable nuclei to the lifetime measurement of excited states in exotic nuclei. A new technique for lifetime measurement in heavy nuclei with the plunger technique was developed. Studies of γ-ray emission from near-barrier nucleon-pair transfer and sub-barrier fusion were also performed.

The performances of AGATA in the measurement of lifetimes in neutron-rich nuclei in the N=20, N=28 and N=40 and in the heavy Pt, Os nuclei towards N=126 will be discussed, as well as the use of the AGATA array to improve sensitivity and explore new observables in reaction studies. Selected physics results from recent experiments will be presented, discussing their implication on current research in nuclear structure.

Future AGATA physics campaigns at LNL will be outlined.

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Beta-delayed neutron decays of very neutron-rich nuclei

Robert Grzywacz

Department of Physics & Astronomy, University of Tennessee,

1408 Circle Drive, Knoxville TN 37996, USA

Beta-delayed (βn) neutron emission is a multi-step decay process for most neutron-rich nuclei. In the first step, beta-decay, the precursor and daughter nuclei shell structure dominate; in the second step, decays are expected to be statistical and determined only by the energy and angular momentum conservation rules. The current paradigm for βn-emission dates back to Bohr's paper developed to explain the decays of fission fragments. Multiple experiments performed on a broad range of isotopes from oxygen (Z=8) to cesium (Z=55) took advantage of the new-generation radioactive beam facilities, which enabled access to nuclei with a large energy window (Qβ-Sn) available for neutron emission. This enabled revisiting whether the assumptions formed in the days of discovery of the first neutron emission are also valid for the neutron-rich nuclei accessible now [Yok19, Yok23, Xu23, Hei23, Xu24, Sie24, Cox24, Neu24, Pel25]. The results of many experiments provided new insights into the beta-decay strength distribution to neutron unbound states. Most importantly, our studies revealed a more complex picture of how statistical model assumptions affect βn-decays. These results revealed an unexplored potential for multiple future experimental explorations and highlighted the need for renewed theoretical efforts to improve the modeling of this process. A new approach is needed to quantify the impact of propertied βn emitters on the r-process [Kis22, Pho22, Hal21] and improve the capabilities of nuclear models aiming to describe properties of very neutron-rich isotopes.

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Recent studies of resonant reactions of astrophysical interest using transfer reactions

Faïrouz Hammache
Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

Our understanding of stellar evolution has greatly advanced through the interplay of three fields: observation, stellar modelling, and nuclear physics. One of the most important ingredients in stellar models are nuclear reaction rates, making the study of nuclear reactions in various astrophysical environments essential to answer key questions in nuclear astrophysics. Two main experimental approaches are used to determine cross sections: direct measurements, where the reaction is reproduced (though often at different energy ranges), and indirect measurements, where a different reaction is coupled with theoretical modelling to derive the desired cross section or spectroscopic properties (e.g., Ex, Jπ, decay widths). Direct measurements at stellar energies are challenging due to low reaction cross-sections, especially when charged particles are involved, and/or the radioactive nature of many key nuclei present in explosive environments (e.g., novae, X-ray bursts). Indirect methods, such as transfer reactions [1] , provide a valuable alternative for studying both resonant and non-resonant reactions, whether involving stable or radioactive beams. In this context, recent studies of key resonant reactions, such as the $^{17}O(\alpha,n)^{20}Ne$ and $^{17}O(\alpha,\gamma)^{21}Ne$ reactions, which are important for the s-process in rotating metal-poor massive stars [2,3] as well as the $^{25}Al(p,\gamma)^{26}Si$ reaction which plays a crucial role in ^{26}Al nucleosynthesis in classical novae [4,5], will be discussed.

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Surrogate reactions in inverse kinematics at heavy-ion storage rings

B. Jurado[1], C. Berthelot[1], M. Sguazzin[1], B. Wloch[1], J. Pibernat[1], G. Leckenby[1], M. Grieser[2], J.Glorius[3], Y. Litvinov[3], and all the participants to the E146 and G0028 experiments of FAIR-Phase0

1 LP2I,Bordeaux, France
2Max-Planck Institute for Nuclear Physics,Heidelberg, Germany
3 GSI, Darmstadt, Germany

Neutron-induced reaction cross sections of short-lived nuclei are essential in nuclear astrophysics and for applications in nuclear technology. However, these cross sections are very difficult or impossible to measure due to the difficulty to produce and handle the necessary radioactive targets. We are developing a project that uses for the first time surrogate reactions in inverse kinematics at a heavy-ion storage ring. This allows one to measure all the de-excitation probabilities as a function of the excitation energy of the nuclei formed through the surrogate reaction with unrivalled precision and indirectly determine the aforementioned cross sections. In this talk, we will present our new methodology and the results of the two first surrogate-reaction experiments that we have successfully performed at the ESR storage ring of the GSI/FAIR facility in Darmstadt, Germany. In these experiments we have achieved a significant breakthrough by measuring for the first time the fission, γ -ray, neutron and even two- and three-neutron emission probabilities simultaneously. The measurement of all competing decay channels enables the precise determination of fundamental quantities, including fission barriers, particle transmission coefficients, γ-ray strength functions, and nuclear level densities. These quantities will be then employed to infer (n,f), (n, γ), (n,n'), (n,2n), and (n,3n) cross sections

Single-Neutron Strength Outside of ^{132}Sn

Ben Kay

Argonne National Laboratory

In a recent experiment at CERN's HIE-ISOLDE facility, the ^{132}Sn(d,p)^{133}Sn reaction was carried out at energies above the Coulomb barrier using the ISOLDE Solenoidal Spectrometer. The measurement revealed, for the first time, the energy and strengths of the $1f_{7/2}$, $2p3/2$, $2p_{1/2}$, $0h_{9/2}$, $1f_{5/2}$, and $0i_{13/2}$ valance neutron orbitals outside of ^{132}Sn, including a determination of the long-sought-after $13/2^{+}$ strength. The results suggest that the single-neutron strength for each orbital is carried in a single excitation, aﬃrming the notion that ^{132}Sn, the heaviest short-lived doubly magic nucleus, exhibits one of the strongest shell closures of all nuclei. The role of weak binding on spin-orbit partners will also be discussed in this context.

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Pygmy and giant resonances studied at CCB of IFJ PAN Krakow – highlights from the experimental campaign

Maria Kmiecik

IFJ PAN Kraków, Poland

A series of experiments have been conducted at the Cyclotron Centre Bronowice (CCB) of the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Kraków with the aim of studying the giant and pygmy resonances in the proton inelastic scattering reaction. The experimental setup, consisting of the KRATTA [1] array and HECTOR [2] or $LaBr_3$ detectors together with PARIS [3] phoswiches, allowed the measurement of gamma rays emitted by excited nuclei in coincidence with scattered protons.

As a result of performed experiments the gamma decay of excited ^{208}Pb, ^{120}Sn, ^{58}Ni and ^{62}Ni nuclei has been measured. The first result was measurement of gamma decay of Isoscalar Giant Quadrupole Resonance (ISGQR) from ^{208}Pb [4], which was the confirmation of the only previous observation [5]. ISGQR has been studied also in ^{120}Sn. The excitation of Ni isotopes has been used for study the pygmy strength as a function of neutron number.

In the talk the experimental system and measurement method will be presented. Some selected results will be discussed as well.

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New opportunities at the ISOL@MYRRHA facility

[1,2]Ágota Koszorús

[1]*KU Leuven*

[2]*SCK CEN*

The ISOL@MYRRHA facility will be constructed in the coming years, providing the nuclear physics community with a new laboratory for fundamental research and applications. The development of the first experimental setup, utilizing laser spectroscopy techniques, is already in progress at KU Leuven.

Laser spectroscopy experiments are indispensable tools at radioactive ion beam facilities. Collinear methods have found use in several areas of research including nuclear structure, atomic physics and materials science as well. The ISOL@MYRRHA facility will provide a unique opportunity to develop a laser spectroscopy apparatus which exploits the strengths of this new laboratory and allows for the implementation of novel techniques. In particular, the possibility for extended beamtimes opens the door to perform precision measurements which have so far been out of reach in radioactive ion beam laboratories. By combining the current state-of-the-art techniques, this new setup will aim to demonstrate the versatility of laser-based methods.

In this contribution, the plans and status of the ISOL@MYRRHA facility will briefly be discussed, highlighting the unique opportunities it offers. Plans for the first experimental setup will be presented, together with first scientific goals and long-term prospects.

Multiple shapes at low spin in nuclei close to the magic numbers

Nicolae Marginean

“Horia Hulubei” National Institute for Physics and Nuclear Engineering

Bucharest-Magurele, Romania

The nuclear deformation is associated in general with open shell nuclei, with high angular momentum states or with the weakening of shell closures far from stability line. However, the existence of deformed minima might be possible also in nuclei close to the stability line, even at the proton or neutron shell closures. Though not energetically favored, deformed zero or low-spin states are predicted by state-of-art models like Monte Carlo Shell Model to stabilize due to a delicate balance between interaction terms, with an important role played by the monopole interaction. Experimentally, is difficult to observe such states and identify their nature, and in many cases requires an almost complete spectroscopic investigation.

This contribution will try to make an overview of experimental campaigns dedicated to the identification of “shape isomer”-like 0^{+} states in nuclei close to the stability line, ranging from Si to Sn, with experiments performed using ROSPHERE array at IFIN-HH Bucharest and FIPPS clover array at ILL Grenoble.

Probing Heavy Element Nucleosynthesis Through Electromagnetic Observations

Gabriel Martínez-Pinedo
GSI Helmholtzzentrum für Schwerionenforschung and
Institut für Kernphysik (Theoriezentrum), Technische Universität
Darmstadt

Half of the elements heavier than iron are produced by a sequence of neutron captures, beta-decays and fission known as r-process. It requires an astrophysical site that ejects material with extreme neutron rich conditions. Once the r-process ends, the radioactive decay of the freshly synthesized material is able to power an electromagnetic transient with a typical intrinsic luminosity. Such kilonova was observed for the first time following the gravitational signal GW170817 originating from a merger of two neutron stars. This observation answered a long lasting question in nuclear astrophysics related to the astrophysical site of the r-process.

In this talk, I will summarize our current understanding of r-process nucleosynthesis. I will also illustrate the unique opportunities offered by kilonova observations to learn about the in-situ operation of the r-process and the properties of matter at extreme conditions. Achieving these objectives, requires to address fundamental challenges in astrophysical modelling, the physics of neutron-rich nuclei and high density matter, and the atomic opacities of r-process elements required for kilonova radiative transfer models.

Finally, I will introduce a new nucleosynthesis process, the r-process, that operates in ejecta subject to very strong neutrino fluxes producing p-nuclei starting from neutron-rich nuclei. It may solve a long standing problem related to the production of Mo and the presence of long-lived Nb in the early solar system.

Ab initio calculations of heavy nuclei

Takayuki Miyagi

Center for Computational Sciences, University of Tsukuba

One of the fundamental problems in nuclear physics is to predict the properties of nuclei based on underlying nuclear interactions. The applicability of nuclear ab initio calculation has been expanding in the past few decades, and systematic calculations can be performed up to mass number ~ 100 [1]. However, the applications for heavier systems are limited primarily due to the memory-expensive three-nucleon (3N) interaction matrix elements. Modern nuclear ab initio calculations begin with the nucleon-nucleon (NN) and 3N interactions, benefitting from chiral effective field theory. For medium- and heavy-mass nuclei, one can apply basis expansion methods such as the coupled-cluster method, self-consistent Green's function method, many-body perturbation theory, and in-medium similarity renormalization group, starting from the NN and 3N matrix elements expressed with the spherical harmonic-oscillator (HO) basis set, where a typical calculation is performed within 13 or 15 major-shell space. The memory requirement of the 3N matrix elements in such space will exceed 10 TB, and one needs another truncation for 3N matrix elements, known as E_{3max} defined by the sum of 3N HO quanta. It turned out that the current E_{3max} limit does not allow us to obtain converged results for nuclei heavier than A ~ 100. To overcome the limitation, we proposed a new storage scheme for the 3N matrix elements [2], where we exploit the feature of the normal-ordered two-body approximation widely used in the basis expansion methods. This new scheme enables us to compute the known heaviest doubly magic nucleus ^{208}Pb. In this presentation, I will show recent ab initio results for some heavy mass nuclei, including a prediction for the neutron-skin thickness of ^{208}Pb [3].

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Recent TAS results for fundamental nuclear physics and applications

E.Nácher[1], S.Parra[1], C.Fonseca[1], J.A. Briz[2], U. Köster[3]
for the IS570 and IS722collaborations

1Instituto de Física Corpuscular, CSIC -Univ. of Valencia, Spain
2Universidad Complutense de Madrid, Spain
3Institut Laue-Langevin, Grenoble, France

Total Absorption Spectroscopy (TAS) has proven to be an essential tool in the study of beta decay of exotic nuclei, providing accurate measurements of their decay properties. Its unique ability to detect the full energy of emitted gamma cascades addresses limitations in more extended high-resolution techniques. Recent measurements with the Lucrecia TAS at ISOLDE have yielded critical data of high relevance for two different topics: on one hand, nuclear structure models in the context of rp-process calculations in X-ray burst environments, and on the other hand, practical applications in the medical field such as dose calculations in theranostics.

As far as the astrophysical context is concerned, the N=Z 64Ge is considered the bottleneck of the rp-process path in type I X-ray bursts, followed by the heavier N=Z waiting points 68Se, 72Kr and 76Sr. Publications on TAS measurements of 72Kr and 76Sr show a very good agreement between different theoretical models(QRPA, shell model, beyond mean field)and experimental results [1][2]. Encouraged by the success of those results, both in the experimental and theoretical side, we proposed to perform the Total Absorption Spectroscopy of the beta decay of 64Ge at ISOLDE. Here we will present the results of such measurement, the decay of 64Ge measured with a TAS for the first time. Unexpectedly, and interestingly at the same time, these experimental results show clear discrepancies with the same theoretical models mentioned above.

In the medical field, theranostics, a combination of therapy and diagnostics, leverages nuclear instrumentation for personalized treatments, particularly in cancer care. Radiopharmaceuticals used in imaging and targeted radiation therapy are designed to both detect and treat tumours. In this regard, accurate knowledge of the decay properties of the radioisotope in use is essential for calculating the dose administered to the patient in different parts of the body. In the context of theranostics, Terbium presents a unique opportunity, with four isotopes (149Tb,152Tb, 155Tb, and 161Tb) covering a broad range of diagnostic and therapeutic applications. One of the four isotopes, namely 152Tb, was recently identified as a potential case with need for reassessment[3].We have performed Total Absorption Spectroscopy measurements at CERN to improve the accuracy of the nuclear beta-decay data of 152Tb. Here we will present preliminary results of such measurements and, additionally, Monté Carlo simulations to evaluate how these new results enhance dose calculations compared to the published data available in the ENSDF database.

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Nuclear Collective Vibrations: from Lab to Stars

Yifei Niu

Lanzhou University

Nuclear collective vibrations are not only important for nuclear structure studies in the laboratory, but also provide insight in understanding the origin of heavy elements in the universe. In this talk, I will talk about the study of nuclear collective vibrations from lab to stars. In the laboratory, novel ways to study nuclear collective vibrations are proposed using vortex photons [1] and vortex electrons [2]. In the stars, the rapid neutron capture process (r-process) is responsible for the synthesis of half of the heave elements, where neutron capture and beta decay are two basic ingredients in r-process. Gamma-ray strength function determines the neutron-capture cross sections, while Gamow-Teller transitions determine the beta-decay half-lives. I will explain the origin of the low-energy enhancement (LEE) of gamma-ray strength function by a new type of nuclear collective motion - scissors rotation [3], and show the improvements on beta-decay half-lives using the newly developed quasiparticle vibration coupling model based on relativistic PCF-PK1 interaction.

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Recent Progress and Achievements with the SAMURAI Spectrometer

Hideaki Otsu
(RIKEN Nishina Center)

The SAMURAI spectrometer is a powerful device for nuclear spectroscopy of unstable nuclei, using inverse kinematics technique, offering a large solid angle and broad momentum acceptance. Over the past decade, it has made significant contributions to our understanding of exotic nuclei. Notable achievements include the observation of tetra-neutron system and detailed analyses of oxygen isotopes up to 28. This talk will highlight these key results and demonstrate the spectrometer's unique capabilities for studying nuclear structure and reactions. It will also outline the future scope of SAMURAI over the next decade will be outlined, focusing on its potential to address unresolved questions in nuclear physics and its role in upcoming experiments.

Shapes, rotations and vibrations of heavy nuclei

Takaharu Otsuka
Tokyo University, Japan

I will overview recent findings about the shapes, rotations and vibrations of heavy nuclei, from formal and computational viewpoints. The example species include ^{148,154}Sm, ^{162,164}Dy and ^{166}Er. Prevailing triaxialities and emerging shape coexistence are the central agendas with illustrations of rotational and vibrational excitations in these nuclei, with different landscapes from traditional ones.

A unified view of the nuclear collective motion may be presented based on (i) fully restored relevant rotational symmetries, (ii) activation of main contributors of NN interactions besides apparent ones,

(iii) inclusion of Pauli's exclusion principle within collective degrees of freedom.

The PANDORA Project: a novel approach to investigate nuclear astrophysics phenomena in a magnetoplasma

D.Santonocito[1] and D. Mascali[1]

1) INFN – Laboratori Nazionali del Sud, Catania, Italy

The PANDORA (Plasmas for Astrophysics Nuclear Decays Observation and Radiation for Archaeometry) project aims to measure, for the first time, possible variations of in-plasma β-decay lifetimes in selected isotopes of astrophysical interest as a function of the thermodynamical conditions of a magnetized laboratory plasma. Theoretical predictions and past experiments on highly ionized atoms in Storage Rings have, in fact, already shown that the ionization state can dramatically modify the β-decay lifetime due to the opening of a new decay channel as the bound state β-decay [1,2].

The new experimental approach consists of creating and confining a plasma whose main features can mimic specific stellar-like conditions and mapping the evolution of the nuclear lifetime as a function of plasma density and temperature which affect the ions' charge state distribution [3]. In order to achieve this goal a dedicated plasma trap, based on a superconducting magnetic system where the radionuclides can be maintained in dynamical equilibrium for weeks, has been designed and is under construction. The β-decay events will be tagged by detecting the γ-ray emitted by the daughter nuclei populated in the decay process. An array of 14 HPGe detectors placed around the magnetic trap will be used for the γ-ray detection. Plasma parameters will be monitored online and measured through an innovative non-invasive multi-diagnostic system which will work synergically with a γ-rays detection system and will allow to correlate plasma thermodynamical properties with the in-plasma β-decays lifetime [3].

Three physics cases were selected for the first PANDORA experimental campaign: ^{134}Cs, ^{94}Nb, and ^{176}Lu. The observation of a β-decay rate variation in ^{176}Lu might help to solve the debated question on its role as a cosmo-thermometer or a cosmo-chronometer; β-decay rate changes in ^{134}Cs and ^{94}Nb might play an important role in the AGB stars modelling, varying the s-process nucleosynthesis backbone in several branching points

The sensitivity of the PANDORA setup to the expected variations of the nuclear lifetime of the isotope selected was evaluated through GEANT4 simulations taking into account array geometry, detection efficiency, plasma volume, in-plasma isotope concentration and also the intense plasma self-radiation which represents the main background-source.

The setup will also allow to measure plasma optical opacities that are relevant for the kilonovae scenarios [4].

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Search for a neutron dark decay in ^{6}He

M. Le Joubioux[1], H. Savajols[1], W. Mittig[2,3], X. Fléchard[4], L. Hayen[4,5], Yu.E. Penionzhkevich[6,7], D. Ackermann[1], C. Borcea[8], L. Caceres[1], P. Delahaye[1], F. Didierjean[9], S. Franchoo[10], A. Grillet[9], B. Jacquot[1], M. Lebois[10], X. Ledoux[1], N. Lecesne[1], E. Liénard[4], S. Lukyanov[6], O. Naviliat-Cuncic[2,3,4], J. Piot[1], A. Singh[1], V. Smirnov[6], C. Stodel[1], D. Testov[11,12], D. Thisse[10], J.C. Thomas[1]and D. Verney[10]

1Grand Accélérateur National d'Ions Lourds (GANIL),CEA/DRF-CNRS/IN2P3, Caen, France
2Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan, USA
3Department of Physics and Astronomy, Michigan State Univ. , East Lansing, Michigan, USA
4Universita de Caen Normandie, ENSICAEN,CNRS/IN2P3, LPC Caen, Caen, France
5Department of Physics, North Carolina State University, Raleigh, 27607 North Carolina, USA
6Flerov Laboratory of Nuclear Reactions,Joint Institute for Nuclear Research, Dubna, Russia
7National Research Nuclear University MEPHI, Moscow 115409, Russia
8Horia Hulubei National Institute for Physics and Nuclear Engineering, Bucharest, Romania
9Institut Pluridisciplinaire Hubert Curien,23 Rue du Loess, 67200 Strasbourg, France
10Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France
11Extreme Light Infrastructure-Nuclear Physics (ELI-NP)/Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania
12Joint Institute for Nuclear Research, Joliot-Curie 6, 141980 Dubna, Moscow region, Russia

Neutron dark decays have been suggested as a solution to the discrepancy between bottle and beam experiments, providing a dark matter candidate that can be searched for in halo nuclei. The free neutron in the final state following the decay of ^{6}He into ^{4}He + n + χ provides an exceptionally clean detection signature when combined with a high efficiency neutron detector. We will report on the results of an experiment performed at GANIL using the unique neutron detector TETRA and the high-intensity $^{6}He^{+}$ beam. A search for a coincident neutron signal resulted in an upper limit on a dark decay branching ratio of $Br\chi \leq 4.0 \times 10^{-10}$ (95% C.L.). Using the dark neutron decay model proposed originally by Fornal and Grinstein [1], we translate this into an upper bound on a dark neutron branching ratio of O(10−5), improving over global constraints by one to several orders of magnitude depending on mχ [2].

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Advancements in Decay Spectroscopy with GRIFFIN: Recent highlights and Future Directions

V. Vedia
TRIUMF, Vancouver, Canada

Large arrays of gamma-ray detectors coupled with auxiliary detection systems provide a powerful and versatile tool for studying exotic nuclei through nuclear spectroscopy at radioactive ion beam facilities. GRIFFIN (Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei) is a state-of-the-art facility dedicated to beta decay spectroscopy with rare-isotope beams, situated at the TRIUMF-ISAC-I facility in Vancouver, Canada [1]. GRIFFIN is composed of 16 Compton-Suppressed HPGe clover detectors complemented by a powerful suite of ancillary detector sub-systems that includes plastic-scintillators for beta tagging, LN_2-cooled Si(Li) detectors for conversion electron measurements and an array of eight $LaBr_3$(Ce) scintillators for fast-timing measurements. The spectrometer supports a variety of research in the areas of nuclear structure, nuclear astrophysics, and fundamental symmetries. Recent experiments using GRIFFIN will be discussed including: transition strengths in ^{50}Sc from lifetime measurements, using the half life of ^{34}Ar to guide the choice of theoretical radiative and isospin symmetry breaking corrections for Fermi super allowed beta emitters, probing cross-shell excitations on the border of the island of inversion using gamma-gamma angular correlations in ^{34}Si, and the nature of quasiparticle configurations in ^{160}Gd are explored using the high-statistics beta decay of ^{160}Eu.

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Recent achievements and future challenges in developing microscopic optical potentials for nuclear reactions

Matteo Vorabbi

University of Surrey

The optical potential is a well-known and successful tool that is widely used to describe nucleon-nucleus scattering processes. Within this approach it is possible to compute the scattering observables for elastic processes across wide regions of the nuclear landscape and extend its usage to inelastic scattering and other types of reactions. A phenomenological approach is usually preferred to achieve a good description of the data; however, it lacks predictive power due to the presence of free parameters contained in the model that need to be fixed. With the upcoming facilities for exotic nuclei, such as FRIB, we strongly believe that a microscopic approach, completely free from phenomenology, will be the preferred tool to make reliable predictions, assess the unavoidable approximations, and provide a clear physical interpretation of the process under consideration. The Watson multiple scattering theory [1] provides a successful framework to derive such optical potential for energies between 100 and 300 MeV. In its simplest formulation, derived at the first order, the optical potential is obtained as the folding integral of the nucleon-nucleon scattering t matrix and the target density, representing the two fundamental ingredients of the model. After many years of advances in theoretical nuclear physics, it is now possible to calculate these two quantities using the same inter-nucleon interaction that is the only input of our calculations [2]. Results obtained within this framework will be presented for light- and medium-mass nuclei [3-5], adopting different *ab initio* approaches to calculate the densities, such as No-Core Shell Model and Self-Consistent Green's Function. Future extensions of the model, such as the inclusion of medium effects and the calculation of the inelastic scattering, will be also discussed. Finally, we will present preliminary results for the extension of the formalism to compute a nucleus-nucleus optical potential for elastic scattering calculations.

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Microscopic Models of Induced Fission Dynamics

Dario Vretenar

University of Zagreb, Croatia

Nuclear fission presents an example of large-amplitude collective motion in self-bound mesoscopic systems, that exhibits both classical and quantal features. This process is relevant for the stability of superheavy elements, production of short-lived exotic nuclides far from stability, nuclear astrophysics, and the mechanism of nucleosynthesis.
Based on recent developments of time-dependent nuclear density functional theory (TD-DFT) [1,2,3] and the time-dependent generator coordinate method (TD-GCM) [4,5], significant advances in microscopic description of various aspects of induced fission dynamics have been reported. These include studies of the effect of fluctuations on fission observables [1], dynamics of neck formation and rupture [2], the energy dissipation mechanism and total kinetic energy distribution [3], fragment distributions and properties of fragments beyond scission [4,5,6]. Finite-temperature effects have been considered in TD-DFT [3,6], while the TD-GCM has been generalized to include time-dependent generator states [4,5]. With the coherent superposition of TD-DFT trajectories in the generalized TD-GCM, fission dynamics is described fully quantum mechanically in an approach that extends beyond the adiabatic approximation and includes quantum fluctuations [5].

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Fission studies with the nu-Ball2 array

Jonathan Wilson

IJC Lab, Orsay, France

A series of recent experiments to perform high resolution gamma ray spectroscopy of nuclear fission have been carried out with the ν-Ball2 spectrometer [1]. Nu-Ball2 is a state-of-the-art hybrid gamma-ray spectrometer that was developed and constructed at the ALTO facility of IJC Lab in Orsay. Several open questions are currently being addressed such as the evolution of evolution of fragment yield distributions in the sub-actinide region [2], the emission of high energy gamma rays in nuclear fission with potential population of collective excitations (PDR, GDR, etc.) in the emerging fragments [3]. The experiments have also explored other outstanding questions, such as the angular momentum carried away be neutron emission [4] and potential angular correlations between the spins of fission fragment partners [5]. Finally, the potential energy landscape before fission occurs can also be studied via gamma spectroscopy of fission shape isomers [6][7]. An overview of these new studies during the ν-Ball2 experimental campaign will be given and selected results will be presented along with future perspectives.

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CONTRIBUTED TALKS

Quantum Information Tools Applied to Nuclear Scission

Giacomo Accorto
CEA, DAM, DIF, F-91297 Arpajon, France

Fission is a remarkable event in nuclear physics, involving features of the quantum many-body problem and dynamic processes. Whether spontaneous or induced, fission generally results in the division of a nucleus into two fragments. To study this phenomenon, two primary microscopic approaches are employed: the Time-Dependent Hartree-Fock (TDHF) method and the Time-Dependent Generator Co-ordinate Method (TDGCM); both methods have unique advantages and limitations. A key aspect of fission is nuclear scission—the exact moment the nucleus splits into fragments. In the TDHF method, scission happens naturally and continuously, while in the framework TDGCM, scission appears as a physical discontinuity between the fission and fusion valleys. In such case, geometric criteria, such as the density of nucleons in the neck, are used to define the scission point and calculate observables of the fragments (yields, kinetic and excitation energies).Traditionally, nuclear scission has been understood through the lens of classical approaches, where the splitting of the nucleus is identified by the rupture of the neck region between two fragments. How-ever, recent quantum mechanical descriptions emphasize the need to consider the non-local properties of the wave function. Younes and Gogny [1] introduced a fully quantum mechanical framework, where disentanglement of fragment wave functions plays a crucial role. This approach uses localized quasiparticle (qp) orbitals to define scission, better reflecting the interaction between fragments and providing a deeper understanding of the energy partitioning during fission. To further understand scission, it is important to localize orbitals associated with quasiparticles, as done in molecular physics for defining "cores" and valence orbitals. By localizing qp-orbitals on fragments, we can accurately define observables like fission yields and fragment excitation energies. Additionally, with advancements in quantum computing, quantum information tools have begun to play a role in studying many-body problems across various fields of physics. In nuclear physics, recent studies [2-7] have explored quantum entanglement between distinguishable nucleons (protons and neutrons) and orbitals, revealing new insights. This research aims to analyse the quantum entanglement of nascent fission fragments using quantum information tools such as Von Neumann entropies. These entropies help identify the decoupling of degrees of freedom or the emergence of substructures. By introducing quantum criteria within the TDGC Mapproach, a more precise definition of nuclear scission can be achieved, improving understanding of the phenomenon and its impact on key observables.

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Further steps towards next generation of covariant energy density functionals

A.V. Afanasjev, B. Osei, A. Taninah, U. Perera
Department of Physics and Astronomy, Mississippi State University, MS 39762, USAV.
A.Dzuba, V. V. Flambaum
School of Physics, University of New South Wales, Sydney 2052, Australia

Covariant density functional theory (CDFT) describes the nucleus as a system of A nucleons(fermions)which interact via the exchange of different mesons. It is very successful in the description of phenomena related to nuclear structure, nuclear reactions and nuclear astrophysics[1]. However, at present absolute majority of covariant energy density functionals (CEDFs) are fitted to spherical nuclei. This does not permit the improvement of the global description of nuclear observables(for example, nuclear masses) and creates theoretical uncertainties.

Our group is working on the global improvement of covariant energy density functionals (CEDFs) towards more accurate description of binding energies, charge radii, deformations etc. across the nuclear chart. Some important steps in that directions will be discussed in this presentation. To overcome numerical problems connected with global fit of energy density functionals (EDFs), a new anchor-based optimization method has been proposed by us in [2]. In this approach, the optimization of the parameters of EDFs is carried out for a selected set of spherical anchor nuclei, the physical observables of which are modified by the correction function, which takes into account the global performance of EDFs. It is shown that the use of this approach leads to a substantial improvement in the global description of binding energies for several classes of covariant EDFs at moderate computational cost[2,3,4].This allows for the first time to take into account infinite basis corrections to binding energies in the fermionic and mesonic (bosonic) sectors of CDFT [4]. For the first time total electron binding energies for atoms of superheavy elements have been calculated within atomic relativistic Hartree-Fock approach and the dependence of these energies on the neutron excess has been investigated across the nuclear chart[4,5].In addition, it was shown that theoretical uncertainties in the calculations of the total electron binding energies are very small. This allows very accurate conversion of experimental atomic binding energies presented in Atomic Mass Evaluations into nuclear ones. The latter are used in global fits of CEDFs. The connection of the parameters of CEDFs defined via global fits of nuclear binding energies with nuclear matter properties generated by these functionals has been investigated. The remaining issues and in progress results will be discussed.

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Results on the multinucleon knockout reaction around ^{86}Mo using GRETINA and the S800 spectrometer at NSCL

P. Aguilera[1,2], F. Recchia[1,2], S. Carollo[1,2], J. Ha[1,2,7], S. M. Lenzi[1,2], A. Revel[3],J. Ash[3], D. Bazin[3], M. Bentley[4], S. Biswas[3], M. L. Cortes[5], G. de Angelis[5],R. Elder[3], R. Escudeiro[1,2], P. Farris[3], A. Gade[3], T. Ginter[3], M. Grinder[3], J.Li[3], A. Macchiavelli[6], D. Napoli[5], S. Noji[3], J. Pereira[3], S. Pigliapoco[1,2], A.Pompermaier[1], K. Rezynkina[2], A. Sanchez[3], R. Wadsworth[4], and D. Weisshaar[3]

1 Dipartimento di Fisica e Astronomia, Università degli Studi di Padova, I-35131 Padova, Italy
2 Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy
3 NSCL, Michigan State University, East Lansing, Michigan 48824, USA
4 Department of Physics, University of York, Heslington, York YO10 5DD, UK
5 Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy
6 Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA and
7 Institute for Nuclear and Radiation Physics, KU Leuven, Leuven, Belgium

Nuclear structure is a challenging topic as we deal with systems that are not small enough to use standard quantum methods, nor large enough for statistical mechanics. Nuclei with similar numbers of neutrons and protons (N≈Z) exhibit competition between different shapes, such as oblate and prolate, leading to phenomena like shape coexistence. These N≈Z nuclei are particularly interesting for studying proton and neutron interactions within specific orbitals.
The region around A≈80 near the N=Z line is not well explored due to the difficulty in reaching it with current facilities. A common approach to compare theoretical models and experiments is to measure transition probabilities between excited states. The reduced quadrupole transition probability $B(E\lambda;J_i \rightarrow J_f)$ is related to the lifetime of the excited state, which can be measured down to a few picoseconds using the Recoil Distance Doppler Shift (RDDS) method. This method relates the state lifetime to the energy splitting generated by a degrader placed at a known distance.
To study the region around ^{84}Mo,^{82}Nb and ^{82}Zr, the e19034 multinucleon knockout experiment was performed at NSCL. A ^{92}Mo primary beam was impinged on a beryllium target, and the produced nuclei were identified and separated by the A1800 spectrometer using TOF measurements before reaching a second beryllium target for the knockout reaction. The different channels produced, such as -2n and -1p-3n, were separated by the S800 spectrometer. Surrounding the secondary target, the GRETINA array provided high-resolution gamma-ray energy measurements. In this work we will present part of the results from this experiment and their implications for the N=Z vicinity.

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Search for a nuclear Josephson effect in ^{60}Ni+^{116}Sn sub-barrier transfer reactions with the PRISMA+AGATA set-up

G. Andreetta[1,2], L. Corradi[1], S. Szilner[3], E. Fioretto[1], A. Goasduff[1], A. Gottardo[1], A. M. Stefanini[1], J. J. Valiente-Dobón[1], F. Angelini[1,2], M. Balogh[1], D. Brugnara[1], G. de Angelis[1], A. Ertoprak[1], B. Gongora Servin[1], A. Gozzelino[1], T. Marchi[1], D.R. Napoli[1], J. Pellumaj[1], R.M. Pérez-Vidal[1], M. Sedlak[1], D. Stramaccioni[1,2], L. Zago[1,2], I. Zanon[1], P. Aguilera[4], J. Benito[4], S. Carollo[2,4], R. Escudeiro[2,4], F. Galtarossa[4], S.M. Lenzi[2], D. Mengoni[2,4], G. Montagnoli[2], R. Nicolás del Álamo[2,4], S. Pigliapoco[4], E. Pilotto[2,4], K. Rezynkina[4], M. del Fabbro[5], J. Diklić[3], I. Gasparić[3], D. Jelavić Malenica[3], I. Lihtar[3], T. Mijatović[3], L. Palada3, M. Sigmund[3], N. Soić[3], I. Tišma[3], G. Benzoni[6], S. Bottoni[6,7], A. Bracco[6,7], F. Camera[6,7], G. Corbari[6,7], F. Crespi[6,7], E.R, Gamba[6,7], A. Giaz[6,7], S. Leoni[6,7], B. Million[6], O. Wieland[6], L. Baldesi[8], N. Marchini[8], M. Rocchini[8], M. Caamaño[9] and the AGATA collaboration.

1 Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Legnaro (PD), Italy.
2 Dipartimento di Fisica, Universitá di Padova.
3 Ruder Bošković Institute, Croatia.
4 Istituto Nazionale di Fisica Nucleare, Padova, Italy.
5 Dipartimento di Fisica e Scienze della Terra, Universitá di Ferrara.
6 Istituto Nazionale di Fisica Nucleare, Milano, Italy.
7 Dipartimento di Fisica, Universitá degli Studi di Milano.
8 Istituto Nazionale di Fisica Nucleare, Firenze, Italy.
9 Universidade de Santiago de Compostela, Spain.

Sub-barrier transfer experiments have been recently carried out at LNL in the ^{60}Ni+^{116}Sn system [1,2,3], where the two neutron transfer channel is well Q-value matched. Reaction products have been detected in inverse kinematic and at forward angles with the large solid angle magnetic spectrometer PRISMA, providing high efficiency and resolution. In these studies one follows the behaviour of the transfer probabilities by varying the internuclear distance, a method which turned out to be fundamental to probe nucleon-nucleon correlation effects [4]. Indeed most of the cross section of the two neutron transfer channel has been shown to be in the ground-to-ground state transition, indicating the possibility to study into detail the effect of pair transfers. Very recently, the coupling of the AGATA gamma array to PRISMA offered a unique opportunity to study a nuclear (alternating current, AC) Josephson-like effect [5], with Cooper-pair tunnelling between superfluid nuclei, whose manifestation has been recently proposed [6] using the ^{60}Ni+^{116}Sn data as a stepping stone. Predictions have been made of a specific gamma strength function associated with the dipole oscillations generated by the, mainly successive, two neutron transfer process. We directly tested for the first time the possible manifestation of this important effect of Cooper pair behaviour, observed to date only in condensed matter physics. This talk focuses on the ongoing analysis of these new results.

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Studies of neutron-rich Tl-Bi isotopes at the ISOLDE Decay Station facilitated by in-source laser spectroscopy

Andrei Andreyev

on behalf of York-Leuven-Bratislava-Bucharest-IDS Collaboration
University of York, York, United Kingdom

The nuclear structure of the neutron-rich nuclides near the Z=82 and east of the N=126 shell closure is important for the astrophysical r-process. In particular, they can probe the competition between allowed and first forbidden beta decays in this region [1].

The talk will discuss the recent measurements for the neutron-rich Tl-Po isotopes, which are difficult to reach by traditional techniques. The experiments involved the usage of thein-source resonance ionisation technique, which when combined with the sensitivity of radiation detection systems such as the Isolde Decay Station (IDS)and mass spectrometry at the MR-ToF-MS of ISOLTRAP, allows access to exotic nuclides with extremely low production rates.

Highlights will be given of recent results from campaigns studying the charge radii and magnetic moments of $^{206\text{-}209}$Tl [2], and first detailed nuclear, mass and hyperfine studies of 208-211Hg [3]. The new data on the structure of 214-218Bi isotopes and their Po daughters will also be discussed [4,5].

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SPES Low Energy RIB's for nuclear physics and applications

A.Andrighetto[1], A. Monetti[1], A. Arzenton[1,3], M. Ballan[1], G. Bonomi[2],L. Centofante[1], S. Corradetti[1], A. Donzella[2], G.Lilli[1], M. Manzolaro[1],O.S. Khwairakpam[1],D. Scarpa[1],M. Lunardon[4], E. Mariotti[3], S. Moretto[4], A. Leso[1,5], D. Serafini[1,3], C. Sbarra[6], A. Margotti[6], Matteo Negrini[6] and T. Marchi[1]

1, INFN, Laboratori Nazionali di Legnaro, Viale dell'Università 2 –35030 Legnaro, Italy

2, Dipartmento di Ingegneria Meccanica e Industriale Università degli Studi di Brescia, Via Branze 38, 25123 Brescia Italy,

3, Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente and INFN Siena, Via Roma 56, 53100 Siena, Italy

4, Dipartmento di Fisica ed Astronomia, Università di Padova, Via Marzolo5, 35122 Padova Italy,

5, Dipartmento di Fisica e Scienza della terra dell'Università di Ferrara, Via Saragat 1, 44122 Ferrara Italy,

6, INFN Sezione di Bologna, Via Berti Pichat 6, 40126 Bologna Italy,

Radionuclides is a fundamental tool in Nuclear Physics and Medical Physics. At Legnaro National Laboratories (LNL), a second-generation ISOL facility named ''Selective Production of Exotic Species'' (SPES) is in the final stage of construction. In the SPES project, a multi-foil target system of uranium carbide will be used. When this target is irradiated by a proton beam with an energy of 40 MeV and a current intensity up to 200 μA, a fission rate of approximately 1013s−1 is expected inside the target. The formed RIB will be subsequently directed and focalized using different electromagnetic systems and purified in order to have a pure isotope beam without contaminants. The RIBs can be sent directly to the low energy experimental area and, afterwards, to the post-acceleration stage.

The main objective is to provide soon, in routine mode, the first low-energy radioactive beams for beta decay experiments using the b-DS (beta Decay Station) set-up and for medical applications by means of the IRIS (ISOLPHARM Radioactive Implantation Station) apparatus. The goal of the ISOLPHARM project is to provide a feasibility study for an innovative technology for the production of extremely high specific activity beta emitting radionuclides as radiopharmaceutical precursors.

In this presentation, all the specific issues related to the SPES RIB and the Low Energy beam lines will be appropriately presented and commented. The main RIB systems, such as the target material used, the ion source systems, target-handling devices and the installation of low energy transport beam line, activity concluded in the last months, will be presented in detail.

β-delayed fission of neutron-rich actinides

S. Bara[1], B. Andel[2], A. N. Andreyev[3], S. Antalic[2], A. Camaiani[4], T. E. Cocolios[1], J. G. Cubiss[3], H. De Witte[1], C. M. Fajardo[1], S. Goriely[5], M. Heines[1], J. D. Johnson[1], R. Lica[6], C. Page[3,7], R. Raabe[1], W. Ryssens[5], N. Thomas[1], P. Van Duppen[1], Z. Yue[3,7]

1 KU Leuven, Instituut voor Kern-en Stralingsfysica, Leuven, Belgium
2 Department of Nuclear Physics and Biophysics, Comenius University in Bratislava, Bratislava, Slovakia
3 School of Physics, Engineering and Technology, University of York, York, United Kingdom
4 INFN, Sezione di Firenze, Sesto Fiorentino, Italy
5 Institut d'Astronomie et d'Astrophysique, ULB-CP226, Brussels, Belgium
6 Horia Hulubei National Institute for Physics and Nuclear Engineering, Bucharest, Romania
7 CERN, Geneve, Switzerland

Beta-delayed fission (βDF) is a two-step process where a parent nucleus β-decays into a daughter nucleus that fissions from an excited state [1]. βDF may playa role in the termination of the r-process nucleosynthesis [2], and so it is of particular interest in the heavy, neutron-rich side of the nuclide chart. Experimentally measured βDF probability (PβDF) is often very small and has been studied mostly for neutron-deficient isotopes, while only a few cases have been reported on the neutron-rich side of the nuclide chart.

Aiming at expanding the limited information in this region, an experimental campaign was performed at the ISOLDE facility (CERN, Switzerland) to study the βDF in ^{230,232,234}Ac [3]. A new upper limit for the PβDF of ^{230}Ac was deduced to be two orders of magnitude lower than the previously measured value of 1.19(40) ·10-8[4]. PβDF upper limits were also deduced for 232,234Ac and updated values were found for ^{230,232}Fr. Moreover, at mass A = 230 five events were detected with the silicon detector in the energy range of 20-40 MeV. Given that these are too low in energy to be fission fragments, and too high in energy to be summing from multiple αparticles, they have been tentatively identified as clusters. Some hypotheses on the origin of these clusters have been formulated, and the branching ratio that would determine their emission has been calculated.

Theoretical calculations are ongoing, using the code PyNEB [5] to obtain fission paths based a microscopic input predicted from a single EDF-based model. All the needed ingredients are fed into TALYS[6] to calculate the final PβDF. The aim is to compare the theoretical results with reliable experimental values reported for the neutron-deficient isotopes [1],and then to extend the calculations to the neutron-rich side. The results obtained from the ISOLDE campaign will be discussed in this contribution, along with the prospects of this combined experimental and theoretical campaign to study βDF.

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Towards the synthesis of new heavy nuclei: a study of multinucleon transfer reactions with $^{136}Xe + ^{238}U$

Jonathan Bequet[1,2], Barbara Sulignano[1], Iulian Stefan[2] and collaborators
1 IRFU, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France
2 Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

Most of the heaviest nuclei synthesized in recent decades have been obtained using fusion-evaporation reactions. Due to neutron-evaporation, and the limited choice of beam-target combinations, this mechanism tends to produce mainly neutron-deficient nuclei. In addition, the cross-sections are often small, e.g. 0.5 pb at most for the discovery of ^{294}Og [1].Multi-Nucleon Transfer (MNT) reactions are therefore expected to be a complementary mechanism to fusion-evaporation. Indeed, according to the theory [2], this mechanism is well suited to produce neutron-rich heavy ions with relatively high cross sections at forward angles of the order of μbarns.

An experiment was carried out at Argonne National Laboratory in 2023 using a ^{136}Xe beam on a ^{238}U target with detection of the reaction products at forward angles. The setup consisted of the Gammasphere germanium array to perform prompt γ spectroscopy, the AGFA gas-filled separator (with He gas at 4 Torr) to separate the MNT products. A decay station for decay spectroscopy studies was installed at the focal plane, consisting of a DSSD, a PPAC and silicon detectors in a tunnel configuration surrounded by four Clover germanium detectors. The results of this analysis will be discussed in this talk.

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Setup and test of a beam profile monitor for coulomb excitation measurements at FAIR

Dennis Bittner[1], Gregor Kosir[2], Clemen Zagar[2], Jelena Vesic[2], Jan Jolie[1]
1 University of Cologne, Germany
2University of Ljubljana, Slovenia

At FAIR, radioactive single nuclei beams are available. To study Coulomb excitation reactions, the beam needs to be slowed down from 100 MeV/u to 5-10 MeV/u. During the slowing down process, the ions lose neutrons and protons, leading to a multi-nuclei beam. The goal is to reconstruct each ion's velocity, trajectory, and energy, enabling particle identification, which can serve as a trigger for a Germanium array like AGATA. Thin foils are mounted in the ion beam to produce secondary electrons, which are directed to the Microchannel Plates (MCP) through an electric and magnetic field. Two 15 cm diameter MCPs with Dual Delay Lines (DDL) are mounted behind to track the ion's velocity and trajectory. After the high-angular Coulomb excitation target, an array of Double-Sided Silicon Strip Detectors (DSSSDs) stops the ion and provides energy information. A Germanium and a LaBr detector are used to detect the de-excitation of the ions. The electronics for the MCPs and DDLs will be presented. In October 2024, the first test run of this setup will be conducted in Cologne to demonstrate that it meets the specifications for the separation of a radioactive ion beam.

[1] Michael Armstrong, PhD thesis

Study of the isospin mixing of the 2^+doublet in ^{8}Be populated in the β+/EC decay of ^{8}B

M.J.G. Borge, D. Fernández Ruiz, K. Riisager and O. Tengblad
for the IS633 collaboration

The 2^+ doublet in ^{8}Be is a well-known example of nearly equal isospin mixing in the nuclear chart. However, the degree of mixing has not been experimentally determined. The doublet was previously probed by reaction studies. A key contribution toits characterization was the study of the population of the excited states of 8Be through the ^{10}B(d,α)^{8}Be reaction at different energies [1, 2]. The observed feeding to both states remained similar independently of the deuteron energy, giving rise to the hypothesis that both states have some degree of isospin (T) mixing [1]. In addition, the results from the bombardments with 12 MeV deuterons exhibited a symmetric Gaussian line shapes, with the tails reducing between 16.6 and 16.9 MeV, while becoming more prominent outside the doublet, a behaviour characteristic of interfering levels of the same spin and parity (in this case, 2^+) [2]. This interference between the two levels is caused by the Coulomb interaction and the similar feeding for different projectiles leads to a mixture of isospin (already hinted at in [1]). Thus, the wave function (w.f.) of each level can be decomposed into a combination of "pure" isospin levels. However, in these reaction processes the feeding does not depend on the isospin.

On the other hand, beta decay studies are sensitive to the isospin value as the Fermi and Gamow-Teller strengths are heavily dependent of isospin. However, β^+/EC feeding to the doublet is very low. The IS633 experiment was conducted at the ISOLDE facility (CERN) with the aim of resolving the 2^+ doublet.

In this experiment the doublet was probed through the EC/β^+ feeding from ^{8}B. A four-particle telescope setup with a C-foil in the centre locus was employed to stop the ^{8}B beam, the implanted nucleus would β^+/EC decay populating the doublet that breaks up in two alpha particles detected in coincidence. The statistics achieved in this experiment were two orders of magnitude higher than that of any previous experiment [3], enabling the first experimental observation of both contributions to the doublet. By resolving the individual contribution to the two states at 16,6 and 16.9 MeV we were able to explore the isospin mixing through the study of the Gamow-Teller and Fermi population of these states. Two approaches have been followed to disentangle these contributions: an R-matrix analysis of the full beta decay feeding the excited states of ^{8}Be and a α-recoil study, the methodology is described in [3]. The obtained results will be presented in this contribution.

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Searching for Alpha-cluster Condensed State in ^{20}Ne

Alberto Camaiani
Dipartimento di Fisica, Università di Firenze, Sesto Fiorentino, Italy
Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Sesto Fiorentino, Italy

The search for Alpha-Cluster Condensate State (ACS) in always more heavy nuclei is one of the most intriguing puzzles of nuclear structure. In particular, in2021, Adachi et al. observed three states in ^{20}Ne at 21.2, 21.8, and 23.6 MeV [1]. Such states have been suggested to be realistic candidates, being their decay well correlated with the underlying ACSs in lighter nuclei [2].In this contribution, we attempt to shed light on this topic, populating the excitation energy window of interest via alpha-transfer ^{16}O(^{6}Li, d)^{20}Ne* at 13.5 MeV/nucleon in inverse kinematics. This exclusive measurement has been performed in summer 2024 and it consists in the detection of the target recoil deuteron with two OSCAR modules [3] placed backward in the laboratory frame, while the 20Ne decay products were collected thanks to the GARFIELD+RCo apparatus[4]. The large coverage of our apparatus and its identification capability permits to disentangle the different reaction channels involving the weakly bound Li-ions [5]. To confirm the ACS candidate states of ^{20}Ne, we will report on events selected by the presence of the transfer deuteron in coincidence with four (out of five)alpha particles from the excited20Ne detected, to fully reconstruct the kinematics of its decays for different excitation energy gates. Preliminary results of this experimental search will presented.

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Helium burning:
Addressing discrepancies and future approaches

Kevin Ching Wei Li
University of Oslo

Understanding stellar nucleosynthesis remains one of the forefront challenges in physics, requiring detailed knowledge of helium burning. This directly depends on the astrophysically pivotal triple-alpha and $^{12}C(\alpha,\gamma)^{16}O$ reactions. Recent measurements have cast doubt on our previous understanding of the triple-alpha reaction [1, 2]. This talk will explore recent and future approaches aimed at resolving these discrepancies.

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Probing the doubly magic shell closure at ^{132}Sn by Coulomb excitation of neutron-rich ^{130}Sn

M. Droste[1], P. Reiter[1], T. Kröll[2], L. Atar[2], A. Blazhev[1],F. Browne[3], R. Burggraf[1], J. Cederkall[4], G. Corbari[5], L. Gaffney[6], G. Georgi[7], G. Agnese[5], K. Gladnishki[8], A. Gottardo[9], C. Henrich[2],K. Ide[2], A. Illana[10], L. Iskra[12], H. Kleis[1], D. Kocheva[8], M. Komorowska[12], A. Korgul[12], M. Llanos-Expósito[10], R. Lozeva[7], M. Luciani[5], D. Luyken[1], S. Meyer[2], P. L. Napiorkowski[12], B. Olaizola[3], J. Pakarinen[13], I. Pietka[12], C. Porzio[3,14], G. Rainovski[8], C. Schladt[1], T. Stetz[2], K. Stoychev[7], T. Sültenfuss[1], N. Warr[1], K. Wrzosek-Lipska[13] and L. Zago[9]

1Institut für Kernphysik, Universität zu Köln, Germany
2Institut für Kernphysik, Technische Universität Darmstadt, Germany
3Physics Department, ISOLDE,CERN, Switzerland
4Department of Physics, Lund University, Sweden
5Università di Milano and INFN Sezione di Milano, Italy
6Department of Physics, University of Liverpool, United Kingdom
7IJCLab, Orsay, France
8Department of Atomic Physics, University of Sofia, Bulgaria
9Laboratori Nazionali di Legnaro INFN, Legnaro, Italy
10Grupo de Fisica Nuclear & IPARCOS, Complutense University of Madrid, Spain 11IFJ, Polish Academy of Sciences, Krakow, Poland
12UW HIL Warsaw, Poland
13University of Jyväskylä, Finland
14Nuclear Science Division, LBNL, US

Excited states of ^{130}Sn, the even-even neighbour of the doubly-magic isotope ^{132}Sn, were produced using the technique of safe Coulomb excitation and the recently commissioned, highly-efficient MINIBALL detector array. The ^{130}Sn ions were accelerated to an energy of 4.4 MeV/u at the HIE-ISOLDE facility at CERN and then collided with a ^{206}Pb target. The de-exciting ɣ rays emitted from the excited states of both the target and projectile nuclei were detected in coincidence with the scattered particles. In addition to the ɣ rays from the first 2^+ excited state, de-excitation from higher-lying states was observed, attributed to the presence of an isomeric ^{130}Sn 7^-beam component. The reduced transition strengths for the 0^+ g.s.→ 2^+_1 transition will provide valuable insights into the evolution of nuclear collectivity and structure around the doubly-magic shell closure in ^{132}Sn. Advanced shell model calculations using realistic interactions predict an enhanced degree of collectivity in the neighbouring isotopes of ^{132}Sn [1]. Furthermore, a discrepancy between previous experimental measurements of ^{130}Sn and recent theoretical results remains to be answered [2]. These Monte-Carlo shell-model calculations also suggest a transition from a slightly oblate to a prolate configuration of the first excited 2^+ state across doubly magic ^{132}Sn. The high-quality data obtained from the performed experiment will enable further experimental investigation of the quadrupole moment of the 2^+ state in ^{130}Sn.

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Octupole Collectivity in ^{96}Zr from Low-Energy Coulomb Excitation with the AGATA+SPIDER Setup

F. Ercolano[1], N. Marchini[2], D.T. Doherty[3], M. Zielińska[4], M. Rocchini[2], A. Nannini[2], P.E. Garrett[5], K. Hadyńska-Klęk[6], M. Balogh[7], P. Aguilera[7], F. Angelini[7], D.Bazzacco[7], J. Benito[7,8], G. Benzoni[9], D. Brugnara[7], S. Buck[5], F. Camera[9], R. Coleman[5], R. Escudeiro[7,8], A. Ertoprak[7], G. De Angelis[7], F. Galtarossa[7,8], N. Gelli[2], A. Goasduff[7], B. Gongora[7], A. Gottardo[7], A. Gozzelino[7], D. Kalaydjieva[4], W. Korten[4], Md. S.R. Laskar[9], M. Matejska-Minda[10], D. Mengoni[7,8], D. Napoli[7], M. Ottanelli[2], G. Pasqualato[11], J. Pellumaj[7], R.M. Pérez-Vidal[7], S. Pigliapoco[7,8], E. Pilotto[7], F. Recchia[7,8], K. Rezynkina[8], K. Stoychev[11], J. J. Valiente Dobón[7],K. Wrzosek-Lipska[6], L. Zago[7], G. Zhang[8], I. Zanon[7] and T. Zidar[5].

1Università degli studi di Napoli "Federico II", Dipartimento di Fisica "Ettore Pancini" and INFN Sezione di Napoli, Naples, Italy;
2INFN Sezione di Firenze, Florence, Italy;
3Department of Physics, University of Surrey, Guildford, UK;
4IRFU, CEA Saclay, Université Paris-Saclay, France;
5University of Guelph, Guelph, Canada;
6Heavy Ion Laboratory, University of Warsaw, Poland;
7INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy;
8Università degli Studi di Padova, Padova, Italy;
9INFN Sezione di Milano, Milano, Italy;
10IFJ-PAN, Kraków, Poland;
11IJCLab, Université Paris-Saclay, France.

Octupole correlations in the ^{96}Zr isotope isa topic of great interest, both from the experimental and theoretical points of view. In this regard, the structure of the first 3^-state has been widely debated in the literature. Previous measurements suggested that the $3_1^- \rightarrow 0_1^+$ γ-ray transition probability in ^{96}Zr is one of the largest across the nuclear chart [1] and the strongest in a supposed spherical nucleus. This observation has never been reproduced by any theoretical calculations, and it is puzzling as it does not correspond to a similar increase in the neighbour isotopic chains. A recent study, instead, provided a significantly reduced B(E3) value [2], which is in better agreement with state-of-the-art shell-model calculations. Nevertheless, these experimental values had been obtained indirectly from measured lifetimes and branching ratios. In this talk, I will present the preliminary results from a dedicated Coulomb-excitation study of the nucleus 96Zrusing the γ-ray tracking spectrometer AGATA coupled with the heavy-ion detector array SPIDER at INFN-LN. The yields extracted from the final γ–ray energy spectrum, in conjunction with other available spectroscopic data from complementary measurements, were used in the least-squares search code GOSIA. The target thickness, needed for the GOSIA analysis, has been investigated via a dedicated Rutherford backscattering spectroscopy experiment at the INFN LABEC laboratory in Florence. Its results will be also presented. From the present study, we directly extracted the $\langle 3_1^- || E3 || 0_1^+ \rangle$matrix element in ^{96}Zr. The obtained B(E3) value seems to confirm how this quantity is not as large as previously thought and is in agreement with the latest results, supporting the idea that it does not represent an outstanding value in the nuclide chart.

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Investigation of low-lying excited states in ^{214}Po and ^{214}Bi

A. Esmaylzadeh[1] ,M. Ley[1], A. Blazhev[1], C. Fransen[1], J. Jolie[1], V. Karayonchev[1,2], L.Knafla[1], C.-D. Lakenbrink[1,2], A. Pfeil[1] and F. von Spee[1]
1Universität zu Köln, Institut für Kernphysik, D-50937 Köln, Germany
2Argonne National Laboratory, Argonne, Illinois 60439, USA

The lifetimes of the 2_1^+, 4_1^+, 3_1^-, 2_2^+ and 0_2^+ states in ^{214}Po and the 1^- state at 295.2 keV in ^{214}Bi were determined using the fast-timing method in combination with the Cologne HORUS and Cologne CATHEDRAL spectrometers. Both spectrometers were equipped with high-purity germanium (HPGe) and lanthanum-bromide (LaBr3(Ce)) detectors. Furthermore, upper limits for the lifetimes of the 2_3^+, 2_5^+, and 1_1^+ states in ^{214}Po and of the (0_1^-, 1_1^-) state at 352 keV in ^{214}Bi were obtained. The excited states in ^{214}Po and ^{214}Bi were populated after the β decay of ^{214}Bi and ^{214}Pb, respectively. The lifetimes and upper limits were used to calculate transition strengths which are important observables to explain structural phenomena in these nuclei. The results are compared to other nuclei in the region around the doubly-magic nucleus of 208Pb and to shell model calculations using the KHPE interaction, and a general discussion is given. The results are already published in Ref. [1].

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Fast-timing@nu-Ball2 fission campaign: verification of the analysis and new results for the neutron-rich isotopes $^{134,136}Te$

J. Fischer[1], A. Blazhev[1], J. Jolie[1], N. Warr[1,2], C. Hiver[3], R. Lozeva[3], J.N. Wilson[3], A. Messingschlager[4], M. von Tresckow[4], S. Pascu[5], L.M. Fraile[6] and A. Korgul[7]
for the nu-Ball2 N-SI-120 Collaboration.
1 IKP, University of Cologne, Germany
2 Oliver Lodge Laboratory, University of Liverpool, UK
3 IJCLab, Orsay, France
4 TU Darmstadt, Germany
5 University of Surrey, UK
6 UCM, Madrid, Spain
7 University of Warsaw, Poland

Neutron-rich nuclei far away from the valley of stability contribute decisively to our understanding of nuclear characteristics. At the IJCLab in Orsay, a variety of nuclei were produced in a fast-neutron-induced fission reaction $^{238}U(n,f)$ as part of the nu-Ball2 fission campaign in 2022. The measurement was performed with the nu-Ball2 spectrometer, a hybrid γ-spectrometer equipped with HPGe and $LaBr_3(Ce)$ detectors, which provide excellent energy and timing resolution, respectively. In comparison to the first fission campaign in 2018, nu-Ball1, a number of improvements on the spectrometer and the beamline were made. An important gain was the tripling of the $LaBr_3(Ce)$ efficiency (from 0.7% to 2.1%). Together with the factor of 10 increased beam intensity, this led into almost two orders of magnitude more of HPGe-$LaBr_3(Ce)$-$LaBr_3(Ce)$ coincidences.

The excellent time resolution of the $LaBr_3(Ce)$ detectors allows lifetime measurements in the ps regime using the fast-timing technique. In order to reliably derive new results from the data, the time-walk of the $LaBr_3(Ce)$ detectors has to be calibrated and most importantly, the fast-timing technique has to be verified. Therefore, known lifetimes in low-lying excited states in $^{134,136}Te$ serve as benchmark cases. The fast-timing analysis improved significantly due to modifications on the spectrometer, especially to the $LaBr_3(Ce)$ detectors. This allowed the application of a more precise centroid shift method instead of relying on the convolution and slope method used for nu-Ball1 data analysis [1].

New results for the low-lying yrast states in $^{134,136}Te$ will be presented as well as compared with literature and theory. None of the previously published theoretical calculations can reproduce the new set of experimental B(E2) strengths for the low-lying yrast transitions in ^{136}Te.

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Nuclear Astrophysics With TPCs and Gamma-Beams

Moshe Gai

LNS at Avery Point, University of Connecticut, 1084 Shenecossetts Rd., Groton, CT06340, USA

Fifty years after the seminal work of Dyer and Barnes [1], Forty years after Willie Fowler declared the $^{12}C(\alpha,\gamma)$ Reaction "of paramount importance in nuclear astrophysics" [2] we still do not know with sufficient accuracy the rate of the $^{12}C(\alpha,\gamma)$ reaction at stellar conditions. Most disturbing is the disagreement of the measured E1-E2 interference phase angle (phi_2) with an elementary prediction of quantum mechanics (unitarity) [3,4].

We developed a new method for measuring the cross section of this reaction by measuring the reverse $^{16}O(\gamma,\alpha)$ reaction with TPCs operating in gamma-beams. It was measured initially with the UConn-TUNL-Weizmann-PTB optical readout TPC (O-TPC) [5] operating with 100 torr CO_2(80%) + N_2(20%) gas mixture, placed in the gamma beam of the HIgS/TUNL at Duke University. Most recently the O-TPC was decommissioned and replaced by the Warsaw electronic readout TPC (eTPC). Using the O-TPC we demonstrated [6] the validity of our new method and bench marked it against world data, with the measured total reaction cross section that agrees with the world data.

We will report on new results obtained using the Warsaw eTPC [7] and the O-TPC operating with N_2O gas [8]. We report angular distribution measured with unprecedented accuracy [7,8]. Specifically, we measured the E1-E2 mixing phase angle (phi_12) that for the first time agrees with the prediction of unitarity.

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Medium spin states in the ^{87}Se isotope produced in neutron induced fission of ^{233}U and ^{235}U targets

K. Gajewska[1], Ł. W. Iskra[1], B. Fornal[1], S. Leoni[2,3], C. Michelagnoli[4], S. Bottoni[2,3], N. Cieplicka-Oryńczak[1], G. Colombi[2,4], C. Costache[5], F. C. L. Crespi[2,3], J. Dudouet[6], M. Jentschel[4], F. Kandzia[4], Y.H. Kim[4], U. Köster[4], R. Lica[5], N. Mărginean[5], R. Mărginean[5], C. Mihai[5], R. E. Mihai[5], C. R. Nita[5], S. Pascu[5], E. Ruiz-Martinez[4], and A. Turturica[5]

[1] *Institute of Nuclear Physics, PAN, 31-342 Krakow, Poland*
[2] *INFN sezione di Milano via Celoria 16, 20133, Milano, Italy*
[3] *Dipartimento di Fisica, Università degli Studi di Milano, I-20133 Milano, Italy*
[4] *ILL, 71 Avenue des Martyrs, 38042 Grenoble CEDEX 9, France*
[5] *Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania*
[6] *Université Lyon 1, CNRS/IN2P3, IPN-Lyon, F-69622 Villeurbanne, France*

The exploration of the nuclear chart portion located northeast of the doubly magic ^{78}Ni isotope serves as a testing ground for various theoretical approaches based on the shell model. The study of those closed-shell nuclei has been a central activity of experimental and theoretical groups around the world for many years, however, only recently, R. Taniuchi et al. [1] confirmed the double-magic character of ^{78}Ni. The authors also indicated the breakdown of the N = 50 and Z = 28 magic numbers beyond ^{78}Ni, caused by competition with deformed structures, which aligns with recent large-scale shell-model calculations [2]. These results further strengthen the interest in studying the region in proximity to the ^{78}Ni isotope to seek a deeper understanding of the general properties of atomic nuclei.

In this context, the Se isotopic chain, located six protons away from the closed shell, shows a clear competition between configurations associated with different shapes. Moreover, in ^{86}Se, a possible 3^+ state has been suggested [3], pointing to an onset of γ collectivity. Our goal is to study the Se isotopic chain northeast of the doubly magic ^{78}Ni isotope. In this contribution, a new level scheme of ^{87}Se will be highlighted, in which up to now only three gamma transitions were known [4].

The neutron-rich ^{87}Se isotope has been produced in the fission of a ^{233}U and ^{235}U active targets induced by thermal neutrons from the reactor at Institut Laue-Langevin. The level scheme up to an excitation energy of 3.5 MeV has been established based on multi-fold gamma-ray coincidence relationships measured with the new highly efficient HPGe array - FIPPS [5]. The analysis, based on the cross-coincidence technique, revealed seven new gamma transitions together with their relative intensities. Additionally, spin assignments for low-lying states have been proposed based on the inspection of angular correlations between emitted gamma rays. The results indicate the presence of the E3 transition, $11/2^- \rightarrow 5/2^+$, encouraging the search for similar E3 excitations in neighbouring even Se isotopes.

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Study of beta-decay half-lives by relativistic quasiparticle-vibration coupling model with localized exchange terms

Liang Guo
School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, People's Republic of China

The nuclear beta-decay half-lives of Ni and Sn isotopes are studied using the Relativistic Quasiparticle Random Phase Approximation (QRPA) theory with quasiparticle-vibration coupling (QPVC), based on a covariant density functional with localized exchange terms. The density-dependent point-coupling effective interaction PCF-PK1 and a separable finite-range pairing force are employed in particle-hole and particle-particle residual interaction, respectively. Compared to the QRPA results, the calculated half-lives are significantly reduced by the inclusion of QPVC, leading to better agreement with experimental data, especially for double magic nuclei ^{68,78}Ni and ^{132}Sn. Furthermore, the effects of isoscalar pairing are also investigated. Increasing the isoscalar pairing strength further decreases the half-lives, particularly in the case of the Sn isotopes, which is crucial to obtain good agreement with the experiment data

Sensitivities of the r-process rare-earth peak abundances to nuclear masses and β-decay rates

Y. W. Hao[a] , Y. F. Niu[a], Z. M. Niu[b]

[a]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, People's Republic of China*
[b]*School of Physics and Optoelectronic Engineering, Anhui University, Hefei 230601, People's Republic of China*

The sensitivities of the r-process rare-earth peak abundances to nuclear masses and β-decay rates have been studied in different astrophysical scenarios. The most impactful nuclear masses lie along the r-process paths at r-process freeze-out and at the time when the neutron-capture timescale is approximately 3 times of the β-decay timescale, corresponding to the onset and completion of rare-earth peak formation, respectively. And the most impactful nuclear β-decay rates are those lying along the early r-process equilibrium path or r-process freeze-out path with even neutron number N, especially those with N = 100, 102, and 104. In astrophysical scenario with fission involved, the fission deposition can significantly reduce the sensitivities of the r-process rare-earth peak abundances to nuclear mass and β-decay rate variations. The effects of mass and β-decay rate variations on the final rare-earth peak abundance patterns for nuclei with high sensitivity also have been studied.

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Search for Double alpha decay

L. Heitz[1,2], E. Khan[2], M. Vandebrouck[1], D. Thisse[1], B. Sulignano[1] & Double alpha @CERN collaboration

1. CEA/IRFU/DPhN, 2.IJCLab Université Paris Saclay

Alpha decay is known for more than a century, however a global microscopic description of this process has only been successfully developed recently by *Mercier et al.* [1]. Within the framework of covariant energy density functional, using a least action principle, the half-life of medium and heavy nuclei agree within one order of magnitude with experimental value [2].

Moreover, a new type of decay was predicted: the double alpha decay, where two alpha particles are emitted simultaneously with a large relative angle. Their typical branching ratio (BR) of ($\sim 10^{-7}$) with respect to the single alpha decay, makes it experimentally accessible, these values of BR being those of well-known cluster decays already detected.

A dedicated experiment was held at Isolde in June 2023. A radioactive beam of $^{220-222}Ra$ has been used to probe for possible double alpha decay of $^{220-222}Ra$ as well as $^{216-218}Rn$. The setup consisted in 4 DSSD, which allows to make accurate spatial (and temporal) coincidences and therefore to drastically reduce the background due to single alpha decays. Preliminary results on this hunt will be shown.

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Development of a precise energy calibration method of Ge detectors for Θ^--Carbon atomic X-ray measurement at J-PARC

R. Imamoto[1], K. Ebata[3,4], M. Fujita[3], T. Gogami[4], T.K. Harada[3,4], A. Haratani[1], S.H. Hayakawa[1], Y. Ichikawa[1], S. Iwai[4], K. Kamada[1], R. Kurata[1], K. Miwa[1,2], T. Nagae[4,5], F. Oura[1], C Seong[1], T. Takahashi[2], H. Tamura[1,3], K. Tanida[3], M. Ukai[1,2], D. Watanabe[1], T.O. Yamamoto[3]

1 Department of Physics, Tohoku University, Sendai, Miyagi 980-8578, Japan
2 Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan
3 Advanced Science Research Center, Japan Atomic Energy Agency (JAEA), Tokai, Ibaraki 319-1195, Japan
4 Department of Physics, Kyoto University, Kyoto, Kyoto, 606-8502, Japan
5 Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka, 567-0047, Japan

Our understanding of hadronic systems with multiple strangeness, particularly the Ξ^- N system with S(strangeness)=-2, is quite limited. Our research group aims to gain insights into the Ξ-N interaction by utilizing Ξ atomic X-ray spectroscopy. In the Ξ atomic X-ray spectroscopy, Ξ-hyperons are captured at atomic orbitals, and X-rays emitted via deexcitation are precisely measured using Ge detectors. These X-ray energies are shifted from those calculated only with Coulomb interaction due to the strong interaction between a Ξ and nucleons. We aim to extract information on the Ξ -N interaction by precisely determining this energy shift.

In J-PARC E96 experiment, we will measure X-rays from Ξ carbon atoms at 55 keV (4F->3D) and 154 keV (3D->2P) by using a Ge detector array, Hyperball-X. This experiment will be performed at the J-PARC K1.8 beam line. Ξ-hyperons are produced via the p(K-, K+)Ξ-reaction, and then, Ξ stop events, in which Ξ atoms are formed, will be identified by using an Active Fiber Target (AFT). In this experiment, we need a high-precision energy calibration method to measure the energy shift of X-rays within an accuracy of 0.05 keV. We use “LSO pulsers” for the energy calibration.

The LSO pulser is a small LSO (Lu_2SiO_5) scintillation counter, in which natural radioactive nuclide of ^{176}Lu is contained. The LSO pulser provides a timing signal for gamma-ray emissions of the daughter nuclide ^{176}Hf by detecting a beta-ray from ^{176}Lu. Through a beta-gamma coincidence measurement between an LSO pulser and a Ge detector, we can discern gamma-rays (88 keV, 202 keV, 307 keV) from ^{176}Hf efficiently, even in in-beam conditions with huge background. Those gamma-ray peaks are used for in-beam energy calibration. Recently, we have observed significant X-rays peaks from materials around the Ge detector with the LSO-Ge coincidence trigger, in addition to the ^{176}Hf gamma-rays. By using these X-ray peaks and ^{176}Hf 202 keV gamma-rays, we have achieved an accuracy of the energy calibration less than 0.05 keV at 50 keV at the last J-PARC E96 commissioning experiment. In this contribution, the present status of the development of the calibration method will be presented.

Investigating the character of the pygmy dipole resonance in ^{96}Mo via (p,d) and(d,p).

Thuthukile Charmane Khumalo
iThemba LABS (NRF), Old Faure Rd, Eerste River, Cape Town, 7100

The total electric dipole (E1) strength of nuclei which can be related to the motion of the nucleons in the nuclear field, has been shown to be an important tool for nuclear structure studies. The energy-weighted sum rule (EWSR)is an observable that is related to this property of nuclei and most of the strength has been found in the isovector giant dipole resonance (IVGDR) [1]. In the past decades, the existence of a low-lying E1 strength which has been termed the pygmy dipole resonance (PDR) has been established. It manifests as a concentration of 1^- states below and around the neutron threshold. It has thus far been observed in neutron-rich nuclei and its study may have implications on the nuclear equation of state and nucleosynthesis. Since its discovery, there has been a great deal of work in an attempt to understand its nature, both theoretically and experimentally [2,3,4]. The degree to which the dipole states are collective is amongst the characteristics of the PDR under scrutiny. One-nucleon transfer reactions have been shown to be powerful probes of single-particle property of the nuclear structure [5]. In particular the (p,d) and (d,p) reactions have been successfully used in the past [5]. The ^{96}Mo nucleus is thus particularly attractive for such an investigation as it can be populated by both the (p,d) and (d,p)reactions using stable target nuclei [6]. In addition, recent measurements for the purpose of investigating the collectivity of the PDR states were conducted on ^{208}Pb [7] and ^{120}Sn [8] with a strong single-particle contribution observed, thus ^{96}Mo allows an investigation in a different mass region. ^{97}Mo(p,d)^{96}Mo and ^{95}Mo(d,p)^{96}Mo transfer reactions were performed in normal kinematics using the MAGNEX magnetic spectrometer at INFN-LNS. The 25 MeV/u proton beam and 5 MeV/u deuteron beam from the Tandem accelerator interacted with the ^{97}Mo and ^{95}Mo targets, respectively. The ejectiles were momentum-analysed by the MAGNEX spectrometer and detected by the focal-plane detection system which consists of a gas-tracker for final phase-space coordinates and a particle identification (PID) wall made up of 55 silicon detectors of 1000 μm thickness. Excitation energy spectra were obtained, and angular distributions were extracted for the bound states and the higher excitation energy region of interest (above Ex= 4 MeV). These were fitted, using the MDA with DWBA calculations considering different single-particle configurations from a simplistic shell model. In this talk the results will be presented along with theoretical interpretations within the QPM formalism.

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Microscopic Description of Low-Energy Nuclear Reactions Based on TDHF and GCM

Masaaki Kimura
RIKEN, Nishina Center

In this presentation, I will discuss a fully microscopic description of low-energy nuclear reactions based on the Time-Dependent Hartree-Fock (TDHF) and Generator Coordinate Method (GCM). While GCM is a powerful method commonly used to describe the collective motions of bound states, it can also be extended to describe scattering states by combining it with the Kohn-Hulten-Kato variational principle [1-3].

As an application, we demonstrate that phase shifts of nucleus-nucleus scattering can be described fully microscopically by generating the wave functions along the reaction path using TDHF and combining them with GCM. This method offers several advantages:

* Scattering can be described without any ad-hoc parameters from a single density functional.

* Unlike TDHF, the relative motion between nuclei is quantized (satisfying scattering boundary conditions).

* Multi-body quantum tunnelling below the Coulomb barrier can be described.

I will demonstrate these advantages with examples such as ^{4}He+^{16}O and ^{16}O+^{16}O description does not rely on phenomenological models or adjustable parameters.

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Bayesian inference on nuclear data and neutron star observations for the nuclear equation of state

P. Klausner [1,2,3], G. Colò [1,3], F. Gulminelli[2], and X. Roca-Maza[1,3,4]
[1]Dipartimento di Fisica "Aldo Pontremoli", Università degli Studi di Milano, 20133 Milano,Italy
[2]Laboratoire de Physique Corpusculaire, CNRS, ENSICAEN, UMR6534, Universitè de Caen Normandie, CEDEX, 14050 Caen, France
[3]INFN, Sezione di Milano, 20133 Milano, Italy
[4]Departament de Fìsica Quàntica i Astrofìsica, Martì i Franqués, 1, 08028 Barcelona, Spain

The Equation of State (EoS) of nuclear matter is related to many topics in nuclear physics. In particular, it is crucial for understanding the structure of compact objects such as neutron stars. In the conservative hypothesis of a purely nucleonic composition of neutron star matter, the EoS is fully determined in terms of the so-called nuclear matter parameters (NMPs), which, in principle, can be determined from nuclear theory and experiments, though with error bars. However, analyses that try to infer the NMPs from nuclear experiments often present one of the following limitations:

(i) the control over the quality of the simultaneous reproduction of different observables is limited.

(ii) independent inferences of single NMPs give poor knowledge of the correlations among parameters.

The main objective of our work is to address both limitations. Within the standard Skyrme functionals ansatz, we build a reliable probability distribution for a combination of nuclear matter parameters and Skyrme parameters (which are needed to constrain all the terms of the functional) by investigating the correlations between them using a combined Bayesian inference of a large set of EoS-sensitive nuclear structure data. In practice, we employ the hfbcs-qrpa [1] code to compute a wide selection of observables over the nuclear chart (binding energies, charge radii, spin-orbit splittings, giant resonance energies, dipole polarizability, parity-violating asymmetry). While ground state properties of nuclei require negligible computational time, observables linked to nuclear response, which are expected to be sensitive to specific nuclear bulk properties, are computationally more demanding. In Metropolis sampling, evaluating on the fly is time-consuming, so we resorted to the MADAI package [2] instead, an emulator software for Bayesian inference with slow models.

The result is a 10-dimensional multivariate probability distribution for the NMPs and Skyrme parameters. Marginalizing the distribution over all parameters but one allows to compare with previous simpler analyses in the literature. The talk will present such a critical comparison and the final predictions on some selected static properties of neutron stars, which can be computed from the distribution of NMP.

We will show that the constraints from nuclear experiments are well compatible with the theoretical predictions for infinite pure neutron matter from ab initio modelling, and those constraints additionally indicate the existence of interesting structures in the density dependence of the sound speed in neutron stars. Further attention will be devoted to the properties of the star crust, which is computed consistently with the star EoS.

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Beta Decay Spectroscopy of Neutron-rich Nuclei in the A=100 and 160 Regions and the validity of the Nilsson Model*

Filip G. Kondev
Argonne National Laboratory

Decay spectroscopy in combination with mass-spectrometry techniques is a powerful tool to elucidate properties of neutron-rich nuclei. These data are important to multi-disciplinary fields, including nuclear structure and nuclear astrophysics, as well as to energy and non-energy applications of nuclear science. This presentation will reflect on recent decay spectroscopy campaigns at the CARIBU facility at Argonne National Laboratory using the X-array and Gammasphere. New results in the deformed A=100 and 160 mass regions will be presented, and the experimental data will be compared with deformed shell-model calculations. Applicability of the Nilsson model in predicting the structure of the beta-decaying states and the associated beta-decay transition strengths will also be presented. In addition, specific configuration changes will be invoked to explain the half-life anomaly for the ground and isomeric states in the neutron-rich nucleus ^{104}Nb.

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Solving the ^{244,245}Md puzzle

S. Kumar[1-2], D. Ackermann[1], J. Piot[1], A. Bahini[1], B. Andel[3], S.Antalic[3], K. Bhatt[4], C. Burns[5], M. Carpenter[4], R. Chakma[4], A.Ertoprak[4], K. Hauschild[6], V. Karayonchev[4], F.G. Kondev[4], A.Korichi[4,6], T. Lauritsen[4], A. Lopez-Martens[6], A. McFarlane[7], J. Mist[4],C. Mueller Gatermann[4], D. Potterveld[4], S. Raeder[8], W. Reviol[4], H.Savajols[1], N. Sensharma[4], D. Sewerniak[4], R.S. Sidhu[8,9], M. Siliciano[4],Ch. Stodel[1], and B. Sulignano[10]

1Grand Accélérateur National d'Ions Lourds(GANIL), Caen, France ,
2Univ. of Caen Normandie, France ,
3Comenius Univ., Bratislava,Slovakia ,
4Argonne National Laboratory, Lemont, Illinois, USA ,
5UMass. Lowell, Lowell, Massachusetts, USA ,
6IJC Lab, Orsay,France ,
7Univ. of York, England ,
8GSI, Darmstadt, Germany ,
9Univ. of Edinburgh, UK ,
10IRFU/DPhN CEA Scalay, France

The exploration of neutron-deficient isotopes in the vicinity of the Z= 100 shell gap, offers valuable insights into nuclear structure and the boundaries of stability for nuclei with extreme proton numbers. This allows us to uncover the stability limits and also the effects of the single-particle states on the decay modes of these nuclei. To this effect the neutron-deficient mendelevium isotopes (^{244,245}Md) were the subject of study in two recent experiments at GSI[1]and Lawrence Berkeley National Laboratory (LBNL)[2,3]. The results of the two experiments raised a debate [4] on the mass assignment of these observed isotopes of mendelevium. The α-decay energies of the reported ^{244}Md events in the experiment at Berkeley were assigned to the neighbouring isotope ^{245}Md in a contemporaneous as well as an earlier experiment at GSI[5]. To resolve the discrepancy between the results from LBNL and GSI, a new experiment was conducted in the month of May-June, 2024 at the Fragment Mass Analyzer (FMA)[6] located at the Argonne Tandem Linear Accelerator System (ATLAS) facility of Argonne National Laboratory (ANL). In this experiment, instead of the two-step procedure applied at Berkeley[2,3], the mass(A) and α-decay energies (Eα) of the evaporation residues (ERs) were measured simultaneously. This was achieved using the mass-separation capability of FMA in conjunction with the focal plane decay station consisting of silicon detectors arranged in a box configuration surrounded by five germanium clover detectors. The aim of this experiment was not only to resolve the discrepancy and assign proper α-decay energies to the mass identified isotopes of Md, but also to establish a proper production cross section for the isotope of Md in question. The preliminary analysis of the experimental data revealed the existence of events that fit the alpha- decay energy of ^{245}Md at the beam energy used. In this contribution, the results of the analysis of the experimental data will be presented.

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Ground state properties of Chromium isotopes from stability to the N=40 Island of Inversion

L. Lalanne,[1, 2, 3], M. Athanasakis-Kaklamanakis,[1, 2], D.D. Dao,[3] ,A. Koszorus,[1] ,Y. C. Liu,[4],R.Mancheva[2,1], F. Nowacki[3], J. Reilly[5] C. Bernerd,[2], K. Chrysalidis,[2], T. E. Cocolios,[1], R. P. de Groote,[1], K. T. Flanagan,[5], R.F. Garcia Ruiz,[6], D. Hanstorp,[7], R. Heinke,[1], M. Heines,[1], P. Lassegues,[1], B. A. Marsh,[2], A.McGlone,[5], K. M. Lynch,[5], G. Neyens,[1], B. van den Borne,[1], R. Van Duyse,[1], X. F. Yang,[4] and J. Wessolek[5, 2]
1KU Leuven, Instituut voor Kern-en Stralingsfysica, B-3001 Leuven, Belgium
2CERN, CH-1211 Geneva 23, Switzerland
3Universitéde Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France
4School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China
5Department of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, United Kingdom
6Massachusetts Institute of Technology, Cambridge, MA 02139, USA
7Department of Physics, University of Gothenburg, SE-412 96 Gothenburg, Sweden

The Chromium isotopic chain sits half-way in between the magic Ca and Ni isotopic chains and displays the highest level of collectivity of the region [1]. Going from the N = 28 shell closure to the centre of the N = 40 Island of Inversion ^{64}Cr, drastic structural changes are observed along the Cr isotopic chain, driven by a complex interplay of single particle and collective behaviours that poses challenges to nuclear theories [2,3,4].In order to get a comprehensive picture of the evolution from spherical and single particle behaviour to deformed and collective structures, the CRIS collaboration performed the first measurement of the evolution of ground state properties of neutron rich Cr isotopes. The ground state spin, magnetic dipole moment and changes in charge radii of $^{50-63}$Cr have been measured using high resolution collinear resonance ionization laser spectroscopy and nine isotopes have been measured for the first time with this technique. The present ground-state spin measurement of ^{61}Cr, differing from literature, has significant consequences on the interpretation of existing beta decay. Its structure and shape reinterpreted with state-of-the-art Shell Model calculations, establishing the western border of the N = 40 Island Of Inversion (IoI)[5].The shape evolution along the Cr isotopic chains interpreted as a quantum phase transition at the entrance of the N=40 IoI. Discontinuities have been observed in the evolution of charge radii, entering the Island of Inversion. These results provide the first insight into the evolution of the ground state properties of even-Z isotopes from the magical N= 28 to the N = 40 island of inversion[6].In this talk, the CRIS experiment will be introduced. Preliminary results of the experiment will be presented and discussed in relation to the formation of the N = 40 island of inversion.

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Insights into the structure of neutron-rich rare-earth nuclei using the DESPEC setup in FAIR Phase-0

Johan Emil Linnestad Larsson[1,2,3], H. M. Albers[1], M. Górska[1], J. Bormans[1,2,3], T. Grahn[4], C. M. Petrache[5] and V. Werner[2,3] for the HISPEC/DESPEC Collaboration

[1]*GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany*
[2]*Technische Universität Darmstadt, Institut für Kernphysik, Darmstadt, Germany*
[3]*Helmholtz Forschungsakademie Hessen für FAIR (HFHF), D-64289 Darmstadt, Germany*
[4]*University of Jyväskylä, Jyväskylä, Finland and Helsinki Institute of Physics, Helsinki, Finland*
[5]*University Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France*

Nuclei close to the middle of the closed neutron and proton shells at N=82,126 and Z=50,82, respectively, exhibit some of the largest collectivity observed across the nuclear chart. Such isotopes have very large numbers of valence nucleons and provide an ideal probe of how collective behaviour and quasi-particle effects interact. Instead of the maximum deformation occurring in the dysprosium chain, which lies at the proton midshell, the lowest 2^+_1 energies are observed in the Nd isotopes. This effect is thought to be due to the appearance of a deformed shell closure at Z=60. Furthermore, the anomalous energies of the lowest-lying states in the even-even Z=66-70 nuclei have been attributed to the possible presence of a deformed shell closures at N=98 or 100 (e.g. [1, 2]). In addition, the region of interest here is rich in K-isomeric states, which provide stringent tests of contemporary nuclear models far from stability and are a crucial input to r-process network calculations.

In the framework of the FAIR Phase-0 program at the GSI Helmholtzzentrum für Schwerionenforschung, a high-energy primary beam of ^{170}Er ions was used to produce exotic nuclei in fragmentation reactions for the first time. The resulting cocktail beam of radioactive isotopes was transmitted by the GSI FRagment Separator (FRS), which provided an event-by-event particle identification, and implanted into AIDA (Advanced Implantation Detector Array) at the heart of the DESPEC (DEcay SPECtroscopy) setup [3]. Subsequent particle decays were detected by AIDA itself and surrounding fast plastic scintillators (βPlast), and γ rays emitted following either isomeric or beta decay were detected by a hybrid array comprising 36 FATIMA $LaBr_3$(Ce) modules and 12 DEGAS HPGe triple clusters. The combination of high-energy primary beam, clean particle identification and high-efficiency instrumentation allowed information regarding excited-state lifetimes, level structures and isomeric states to be obtained.

This contribution will present the first preliminary results on new structure information for neutron-rich rare-earth isotopes from Sm to Dy approaching N=104. The next steps in the analysis procedure and an outlook for future work will be discussed.

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Description of the γ decay and 0νββ decay with the (quasi)particle vibration coupling model

W. L. Lv[1,2], Y. F. Niu[1,2], and G. Colò [3,4]

[1]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*

[2]*Frontiers Science Center for Rare Isotope, Lanzhou University, Lanzhou 730000, China*

[3]*Dipartimento di Fisica, Universit`a degli Studi di Milano, via Celoria 16, 20133 Milano, Italy*

[4]*INFN sezione di Milano, via Celoria 16, 20133 Milano, Italy*

Giant resonances (GRs) and pygmy resonances (PRs) are two typical excitation modes. They can provide constraints on the equation of state of the nuclear matter. Besides, the latter play a crucial role in the (n, γ) reaction.

The low-lying states decay of giant and pygmy resonances can provide an insight to their microscopic structure. In the framework of nuclear field theory, we find the Feynman diagrams with particle vibration vertices contribute to γ-decay width a lot, which means the low-lying phonon component in the wavefunction of GRs and PRs. For the GRs, after excluding the isospin effects, a much larger weight of the low-lying phonon component in the GQR wave function of ^{208}Pb is deduced. For the PRs, after excluding the influence of collectivity, a smaller component of the first 2^+ state in the wave function of PDR than that of GDR is predicted by the majority of Skyrme functionals. Thus, we have shown that γ decay is a unique probe of the resonance wave functions.

Besides, our preliminary results about nuclear matrix elements of 0νββ decay are discussed. We find a very small QPVC effect, which could be caused by the cutoff on the single particle energies of the 2qp-phonon configurations.

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The PARTREC cyclotron: irradiation facilities, neutron spectroscopy, and remote access controls

Jacopo Magini[1], Peter Dendooven[1], Marc Jan van Goethem[1], Alex Gerbershagen[1], Julia Even[2], Francesco Romano[1], Thomas Kormoll[3]

[1]: UMCG PARTREC, [2]: University of Groningen, [3]: IKTP TUD

The PARticle Therapy REsearch Center (PARTREC) is a research facility at the University Medical Center Groningen (UMCG) in The Netherlands, which operates the superconducting cyclotron AGOR. AGOR is used for radiobiology and particle therapy research using the new IMPACT (IMage guided Proton/pArticle infrastructure for preClinical sTudies) setup, as well as experimental nuclear research.

A new experiment setup, called NEXT, aims to study the Neutron-rich, EXoTic, heavy nuclei produced in multinucleon transfer reactions around the neutron shell closure N=126 [1]. Transfer products are pre-separated by their magnetic rigidity, slowed down, bunched, and transferred into a Multi-Reflection Time-of-Flight Mass Spectrometer, which allows for precision mass measurements and provides isobaric separation, making background free spectroscopy feasible.

The recent Covid pandemic has shown the importance of providing accelerator users with tools to control their experiments remotely, minimising the number of people required to travel to the facility. However, giving users direct access to the control system constitutes a major security risk, and facilities irradiation control systems are often complex to use.

Work is ongoing to provide secure remote access to the accelerator, within the framework of the EURO-LABS project funded under the Horizon EU program. This is achieved via an interface PC reachable via VPN from external networks. Users can be given complete access to this interface PC, and they can interact with the control system PC by exchanging textual commands over a serial connection. These commands can be treated as a set of APIs that can control most aspects the irradiation setup, as well as beam controls. An optional GUI for sending and receiving commands is also provided, alongside a live video feed of the irradiation room and the operators' room. Users are also given the option of replacing the interface PC with their own computer, integrating the irradiation control commands into their own data acquisition setup.

Controls available to users will include, among others: beam on/off; dose/fluence specification; energy at sample via degrader; field size (collimator and/or scan magnet settings); positioning (control of XY-table, rotation stage); and flux/dose rate (beam intensity). For each setting, setter and getter commands are defined to control and receive feedback from equipment.

The server side of the setup involves a Python program that translates incoming commands strings into commands for the LabVIEW VIs that control individual hardware components. The code is designed for flexibility and will be open sourced. The LabVIEW components can be easily exchanged with a control system of choice.

In this presentation the status of PARTREC, IMPACT, and NEXT will be discussed, along with a brief demonstration of the current remote access implementation (subject to changes bases on feedback).

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Spherical-Oblate Shape Coexistence in ^{94}Zr from a Model-Independent Analysis

N. Marchini[1], M. Rocchini[1] , M. Zielinska[2] ,A. Nannini[1] , D.T. Doherty[3] , N. Gavrielov[4] , P.E. Garrett[5] et al.

1 INFN Florence section

2 IRFU, CEA, Universite Paris-Saclay, F-91191 Gif-sur-Yvette, France

3 School of Mathematics and Physics, University of Surrey, GU2 7XH Guildford, United Kingdom

4 Grand Accelerateur National d'Ions Lourds, CEA/DRF-CNRS/IN2P3, F-14076 Caen, France

5 Department of Physics, University of Guelph, N1G 2W1 Guelph, Canada

The study of shapes and collective properties of atomic nuclei is a vast area of research, and low-energy Coulomb-excitation is one of the most powerful experimental techniques for such studies. It provides information not only about the reduced transition probabilities, describing the collectivity of the transitions, but also about the spectroscopic quadrupole moments of excited states, as well as the relative signs of the extracted transitional and diagonal matrix elements.

Typically, following low-energy Coulomb-excitation experiments, a set of matrix elements is determined allowing for the use of the Kumar–Cline's sum rules that permit the determination of the deformation parameters together with their widths.

Coulomb excitation measurements have been performed to study structural changes and the presence of coexisting shapes in the zirconium isotopes, which are particularly interesting as, in recent years, evidence has come to light that they are excellent cases for exhibiting type II shape evolution.

In most cases, however, the nuclear matrix elements required to perform precision tests of state-of-the-art nuclear theory in this region are lacking.

These isotopes span a wide range of shapes from a mid-open-shell region ($^{80}Zr_{40}$), which is thought to be deformed, through a spherical shape at the closed neutron shell ($^{90}Zr_{50}$), to a closed neutron subshell ($^{96}Zr_{56}$), and then to a sudden reappearance of deformation ($^{100}Zr_{60}$), which has been shown to persist to another mid-open-shell region as far as $^{110}Zr_{70}$.

This variety of behaviour is unprecedented elsewhere on the nuclear mass surface.

It is, therefore, not surprising that the zirconium region has been the subject of intensive experimental and theoretical work in order to gather insight into a variety of different nuclear structure phenomena.

Of particular interest is how collectivity evolves in these isotopes and the coexistence observed between various configurations. For this reason we decided to perform Coulomb excitation measurement allowing for an in-depth comparison with theoretical predictions, shedding light on the structure of low-lying excitations in these nuclei.

In this talk, our experimental results will be presented focusing on the Coulomb-excitation measurement performed on the ^{94}Zr isotope.

From the measured γ-ray yields, reduced transition probabilities between low-spin states were determined, together with the spectroscopic quadrupole moments of the $2^+_{1,2}$ states. Based on this information, for the first time in the Zr isotopic chain, the shapes of the $0^+_{1,2}$ states including their deformation softness were inferred. The observed features of shape coexistence in ^{94}Zr will be compared with the Monte-Carlo shell-model and the IBM-CM predictions.

Prospects for the study of collective states and search for the exotic shapes using a modernized Recoil Filter Detector coupled with an EAGLE germanium array

M. Matejska-Minda[1], P. Bednarczyk[1], M. Ciemała[1], N. Cieplicka-Oryńczak[1], I. Dedes[1], D. Duda[1], B. Fornal[1], J. Grębosz[1], Ł. Iskra[1], M. Kmiecik[1], P. Kulessa[1], A. Maj[1], B. Sowicki[1], M. Ziębliński[1], M. Palacz[2], K. Hadyńska-Klęk[2], G. Jaworski[2], M. Komorowska[2], M. Kowalczyk[2], P.J. Napiorkowski[2], S. Panasenko[2], I. Piętka[2], J. Samorajczyk-Pyśk[2], P. Sekrecka[2], A.Spacek[2], A. Tucholski[2], K. Wrzosek-Lipska[2]

1 The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences, Kraków
2 Heavy Ion Laboratory University of Warsaw, Warsaw

In this presentation, we will outline the scientific objectives and prospects of the upcoming experimental campaign at the Heavy Ion Laboratory (HIL) in Warsaw using the Recoil Filter Detector (RFD) [1-5] combined with the EAGLE [6] germanium detector array, which is currently being configured. Together, these instruments will enable detailed gamma-ray spectroscopic studies focused on medium-light nuclei with mass numbers ranging from 40 to 70, as well as on the exploration of octupole-deformed actinide nuclei. During the presentation, we will also focus on the recent technical advancements made to the experimental setup, particularly the significant upgrade to the RFD detector. These improvements are expected to enhance the detector's performance, allowing for more precise measurements and expanding the range of possible experiments.

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Investigation of the Level Scheme in ^{107}Te

Guangxin Zhang, Andres Illana Sison, José Javier Valiente Dobón,

Daniele Mengoni,

Sun yat-sen UIniversity, Universidad Complutense de Madrid, LNL-INFN, University and INFN Padova

The level structure of the neutron-deficient nucleus 107Te has been reinvestigated utilizing a 58Ni beam on a 54Fe target at the Accelerator Laboratory of the University of Jyväskylä. 107Te nuclei were identified and correlated with prompt γ-rays detected by the JUROGAM III array, employing the recoil-decay tagging technique. A detailed γ-γ coincidence analysis enabled the construction of a level scheme up to ~8 MeV in excitation energy, revealing several new transitions and levels compared to earlier studies [1,2]. The experimental results are compared with large-scale Configuration-Interaction Shell Model calculations using the GCN50:82 effective interaction in the model space between the doubly-magic 100Sn and 132Sn cores. The calculations reproduce the low-lying levels well and provide new insights into the structure of the excited bands. Furthermore, the description of the ground-state wavefunction offers speculation on the single-particle energies in 103Sn and the suggested reordering of single-particle states between 103 and 101Sn [3].

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Weak interactions in nuclei and door-way states to many-particle many-hole configurations

Futoshi Minato

Kyushu University

Investigating nuclear structure is important for understanding unique phenomena appearing in quantum many-body systems. Neutron skin, halo, and change of magic number seen in unstable nuclei are typical examples. For stable nuclei, manifestations of cluster structure and giant resonance attract attention again recently. Valuable insights obtained in those studies are also essential for applications to nuclear astrophysics and nuclear engineering, etc. These kinds of activities still advance to fill out missing nuclear data.

Recently, some experiments reported that energy distributions of particle emission following muon captures and photo-absorptions are not reproduced well although integrated data such as cross sections are reproduced by conventional theoretical models [1,2]. To understand the origin of this problem, we develop a new theoretical model that calculates particle emissions after muon captures and giant dipole excitations. This model consists of a subtracted second random-phase-approximation (SSRPA) model [3] and a two-component exciton model [4]. We found that nuclei at high energies emit more particles than expected, before reaching a pre-equilibrium state, and its energy distributions strongly depend on many-body correlations of target nuclei. This result implies a possibility that one can reveal the mechanism how 1 particle-1 hole (1p-1h) states develop 2 particle-2 hole (2p-2h) states in finite systems like nuclei after nuclear reactions/decays more than ever.

In this talk, our recent works on the transitions from 1p-1h states to 2p-2h states in nuclei studied within the SSRPA model are introduced. We discuss the relation of energy distributions of emitted particles after muon captures and beta-decays with higher-order correlations like 2p-2h excitations.

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First study of the PDR via neutron inelastic scattering at GANIL-SPIRAL2/NFS

P. Miriot-Jaubert[1], M. Vandebrouck[1], I. Matea[2], D. Doré[1],
PARIS and MONSTER collaborations
1: DPhN, CEA Saclay
2: IJCLab, Orsay

The pygmy dipole resonance (PDR) refers to low-lying strength in the dipole response of nuclei, located around the neutron-separation energy[1]. This exotic excitation mode is associated with neutron excess in nuclei, and has possible implication on neutron capture rates and therefore abundances of elements produced via the r-process[2]. It may also be used as a tool to constrain the symmetry energy, one parameter of the nuclear equation of state[3]. As of today, available experimental data do not provide an accurate picture of the fine structure of the PDR, for the collectivity of the states or the isospin splitting in particular. There is consequently a clear interest in performing a "multi-messenger investigation" [4]of the PDR, via the use of different probes in the inelastic scattering experiments. The experiment I will present fits in this context, and offers a study of the PDR using a neutron probe for the first time. The experiment dedicated to the study of the PDR in the 140Ce nucleus via neutron inelastic scattering (n,n'γ) took place in 2022 at the Neutrons For Science facility at GANIL-SPIRAL2[5]. The facility can provide high intensity quasi-monoenergetic neutron beams of around 31 MeV. The PARIS array [6] and the MONSTER modules [7] were used respectively for the γ and scattered neutron detection. The detection setup offers very good timing properties, and a high γ efficiency in the PDR region. In the presentation, results of the study of the elastic scattering channel will first be communicated. Then, the analysis of the inelastic scattering on ^{12}C used as a benchmark will be presented. Finally, preliminary results on the PDR in ^{140}Ce will be shown.

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Two-neutrino double beta decay in the DFT-rooted No-Core Configuration Interaction model

J. Miśkiewicz[1], M. Konieczka[1] and W. Satuła[1]
1Faculty of Physics, University of Warsaw, Poland

Double beta decay is the rarest radioactive process — it occurs only between several neighbouring even-even nuclei that are close to valley of stability. A single-beta transition of an even-even nucleus into a neighbouring odd nucleus is energetically forbidden. However, if it's followed immediately with a secondary decay, a daughter even-even nucleus is lighter than the mother and thus, the whole process turns out as energetically convenient. This reaction, often denoted as 2vββ is a weak-interaction process of the second order, hence it's very rare [1]. Theoretical correspondence between measured half-life and quantum mechanical probability of the decay is given by [2, 3]:

$T_{1/2}^{-1}=G_{2v\beta\beta}\cdot|M_{2v\beta\beta}|^2$,

where $G_{2v\beta\beta}$ is a kinematic leptonic phase-space factor and $M_{2v\beta\beta}$ is a nuclear matrix element of 2vββ.The latter contains all information about transition rates between nuclear quantum states active in the process. Although the phenomenon itself is well known [3, 4], the main focus is currently put on the high precision of experimental and theoretical predictions of half-lives and nuclear matrix elements for various nuclear models. Such information is of a great value to perform comprehensive study of yet unmeasured neutrinoless double beta decay, forbidden by the Standard model. The Warsaw nuclear group at the Faculty of Physics has been developing so-called No-Core Configuration Interaction framework (NCCI) [5], which combines density functional approach enhanced with projection techniques and nuclear configuration mixing. Not only does this allow for restoration of good quantum numbers as isospin or angular momentum, but it also doesn't require any reference to the concept of nuclear core, simplifying tremendously construction of configuration space. The NCCI model has been implemented to evaluate for 3 nuclei confirmed of undergoing 2vββ: 48Ca, 76Ge, 136Xe [6]. Following the regime of Fermi golden rule for a second-order process [3] and assuming that Fermi transitions are suppressed on the favour of Gamow-Teller, we have constructed for each case NCCI-configuration space referring to mother $I^{\pi}=0^{+}$, virtual intermediate $I\pi=1^{+}$ and daughter $I^{\pi}=0^{+}$ nuclear states. During the conference we shall present the values of nuclear matrix elements obtained for the mentioned nuclei and discuss future prospects of the model for heavier nuclei.

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Status of the Fast Radioactive Ion Extraction and Neutralization Device for S3 (FRIENDS3)

E. Morin[1], W. Dong[1], S. Franchoo[1], T. Hourat[1], D. Lunney[1], V. Manea[1], and E. Minaya Ramirez[1]

1Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

The SPIRAL2 facility located at GANIL in Caen has recently been commissioned. Combined with the Super Separator Spectrometer (S3), which is currently being prepared for commissioning, it will be able to produce high intensity beams of neutron-deficient isotopes close to the proton dripline [1]. Ions produced by SPIRAL2/S3 will be studied with the experimental setup S3 Low Energy Branch (S3-LEB) [2, 3, 4] which has been installed at the focal plane of S3. The ions will be first thermalized in a gas stopping cell and then guided out by the gas ow, neutralized and extracted in a supersonic gas-jet. The extracted species will then be studied using laser spectroscopy, mass spectrometry and decay spectroscopy.

The current S3-LEB gas-cell extraction time is on the order of a few hundred milliseconds. Thus, the most short-lived isotopes will be lost before being extracted. In order to improve the S3-LEB gas-cell, a test and characterization setup was designed at IJCLab in Orsay within the scope of FRIENDS3 project [5]. This setup is dedicated to the development of a fast extraction gas-cell as well as an improvement of the neutralization techniques in order to enable nuclear structure studies on the most short-lived isotopes. It has been constructed and is now under commissioning in Orsay before being transferred to GANIL to be used with S3-LEB laser system.

This contribution will present results from the design and construction of the FRIENDS3 setup, including simulation work of an electrical gas-cell prototype and the ion transport from the gas-cell to a detection area. Results from the first commissioning tests will also be presented.

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Systematic investigation of *E1* strength below S_n in the tin isotopic chain using the $(\mathrm{d,p}\gamma)$ reaction

Markus Müllenmeister, Michael Weinert, Florian Kluwig, and Andreas Zilges

Institute for Nuclear Physics, University of Cologne - Cologne, Germany

The evolution of the electric dipole (*E1*) response in various nuclei has been the subject of intense study for decades [1]. The structure of the so-called Pygmy Dipole Response, which emerges around and below the neutron separation energy of most medium- to heavy-mass nuclei, is of particular interest [2]. New insights into its origin can be gained through the well-established method of neutron transfer [3,4]. When combined with state-of-the-art analysis techniques, theoretical calculations, and comparative studies using different probes, the evolution of dipole strength can be examined across different nuclides to obtain detailed structural information [5,6].

In this contribution, a comparison for the tin isotopes, accessible via a $(d,p\gamma)$-reaction, will be presented and compared to real photon scattering data. Together, these methods highlight the dominance of single-particle excitations at lower energies, while more complex phenomena become significant at higher energies.

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Isospin symmetry breaking energy density functional based on quantum chromodynamics

Tomoya Naito[1, 2], Gianluca Colò[3, 4], Tetsuo Hatsuda[1],Xavier Roca-Maza[3, 4, 5], and Hiroyuki Sagawa[6, 7]

1RIKEN Interdisciplinary Theoretical and Mathematical Sciences Program (iTHEMS), Japan
2Department of Physics, Graduate School of Science, The University of Tokyo, Japan
3Dipartimento di Fisica, Università degli Studi di Milano, Italy
4INFN, Sezione di Milano, Italy
5Departament de Física Quàntica i Astrofísica and Institut de Ciències del Cosmos, Universitat de Barcelona, Spain
6Center for Mathematics and Physics, University of Aizu, Japan
7RIKEN Nishina Center, Japan

The isospin symmetry of atomic nuclei is broken due to the Coulomb interaction and the isospin symmetry breaking part of the nuclear interaction. The former gives the dominant contribution to the isospin symmetry breaking of atomic nuclei, and the latter is a small part of the whole; however, it sometimes gives important contributions to nuclear properties, such as the mass difference of mirror nuclei and the isobaric analog states [1, 2]. Especially, it has been a long-standing problem that the Coulomb interaction is not enough to describe the mass difference of mirror nuclei, which is known as the Okamoto-Nolen-Schiffer anomaly [3, 4]. It also contributes to the slope parameter of the symmetry energy, which is known as the parameter, affecting the neutron-skin thickness non-negligibly [2]. The isospin symmetry breaking can be classified into two parts: the charge symmetry breaking and the charge independence breaking. Recently, we pinned down the effective interaction, i.e., the energy density functional, of charge symmetry breaking interaction using the effective mass in medium of nucleons calculated based on the quantum chromodynamics sum rule [5].We also estimated the energy density functional of the charge independence breaking based on the quantum electrodynamics effects in the one-pion exchange potential [6], where we can, in principle, consider the effective mass of pions in medium. In this talk, I will report our recent progress on the derivation of the isospin symmetry breaking energy density functional based on quantum chromodynamics.

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The $^{36}S(p,d)^{35}S$ reaction at 66 MeV

S. Jongile[1,2], M. Wiedeking[1, 3, 4], O. Sorlin[5], R. Neveling[1], N. Keeley[6], T. Duguet [7, 8], J.P. Ebran[9,10],F. Nowacki[11], V. Somà[7], C. Yuan[12], A. Lemasson[5], P.Papka[1,2] , P. Adsley[1,13], A.A. Avaa[1,3] , F. Azaiez[1], L.M. Donaldson[1], F. Flavigny[14], H. Jivan[1,3], P. Jones[1], D. Kenfack[1,2], N.Y. Kheswa[1], T.C. Khumalo[1,3], L. Makhathini[1,2], K.L. Malatji[1,2],S.H. Mthembu[1,15], F. Nemulodi[1], A.A. Netshiya[1,3,16], L. Pellegri[1 3], and F.D. Smit[1]

1 iThemba Laboratory for Accelerator Based Sciences, Somerset West, South Africa
2 Stellenbosch University, Stellenbosch, South Africa
3 University of the Witwatersrand, Johannesburg, South Africa
4 Lawrence Berkeley National Laboratory, Berkeley, California USA
5 Grand Accélérateur National d'Ions Lourds, Caen Cedex 5, France
6 National Centre for Nuclear Research, Otwock, Poland
7 IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
8 KU Leuven, Instituut voor Kern- en Stralingsfysica, Leuven, Belgium
9 CEA, DAM, DIF, 91297 Arpajon, France
10 Université Paris-Saclay, CEA, Bruyères-le-Châtel, France
11 Université de Strasbourg, CNRS, Strasbourg, France
12 Sino-French Institute of Nuclear Engineering and Technology, Sun Yat-Sen University, Guangdong, China
13 Texas A&M University, College Station, Texas, USA
14 Université de Caen Normandie, ENSICAEN, CNRS/IN2P3, Caen, France.
15 University of the Western Cape, Bellville, 7535 South Africa
16 Walter Sisulu University, Mthatha, South Africa

The neutron-removal reaction $^{36}S(p,d)^{35}S$ was investigated at iThemba LABS up to an excitation energy of E_x = 16 MeV. The study aimed to probe the effectiveness of the N = 20 shell closure and to examine the neutron $d_{5/2}$ - $d_{3/2}$ spin-orbit splitting in ^{36}S. Results show that the splitting between the reconstructed $d_{5/2}$ - $d_{3/2}$ single-particle spin-orbit partners increases from ^{36}S to ^{40}Ca, in contrast to the generally observed trend, which predicts a decrease of approximately ~450 keV. Since the central force is expected to play a minimal role in the splitting between two orbitals with the same *L* value, this atypical splitting could serve as a valuable test case for studying the role of the tensor force, especially because the neutron-proton tensor force counterbalances the effect of the spin-orbit force as protons are added to the $1d_{3/2}$ orbital. Thus, this data has the potential to provide a useful constraint for state-of-the-art theoretical models, particularly in assessing the role of the proton-neutron tensor component.

Spin entanglement in time-dependent two-proton emission

Tomohiro Oishi*
**RIKEN Nishina Center for Accelerator-Based Science, 2-1 Hirosawa Wako, 351-0198, Saitama, Japan*

In this contribution, I will present a theoretical evaluation of coupled-spin entanglement in the two-proton (2p) radioactive emission [1]. For this purpose, a time-dependent three-body model is utilized [2].Spin entanglement has been evaluated in terms of the coupled-spin correlation SCHSH for the two fermions. Here this SCHSH is so-called Clauser-Horne-Shimony-Holt (CHSH)indicator. For the two protons produced in the2H +p−→2He +n reaction by Sakaiet. al. [3], this quantity was measured as SCHSH∼=2.82. This is in agreement with the non-local quantum mechanics and beyond the local-hidden-variable (LHV) theory. After this experimental success, the spin entanglement can be one measurable quantity to probe the nuclear structures and interactions. In this work, the time-dependent calculation is performed to predict that SCHSH= 2.65in the6Be nucleus [1]: the 2p-spin entanglement beyond the LHV theory is suggested. This entanglement is sensitive to the proton-proton interaction: the short-lived, and thus, broad-width 2p-emitting state has the weaker spin entanglement. In parallel, the core-proton interactions do not harm this entanglement during the time-dependent decaying process. The sensitivity of SCHSH to the initial state, especially whether the diproton correlation exists or not, will be discussed in this contribution.

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Exploring Coexisting Structures in ^{178}Pt through the β-decay of isomerically pure beams

C.A. A. Page
University of York, UK
On behalf of the York-Leuven-Bratislava-Bucharest-IDS collaboration

The shape of a nucleus is a fundamental property with significant influence on other aspects of nuclear structure, such as state energies and the available decay modes. In the region around the Z= 82 shell closure and the N= 104 midshell, competition between spherical and deformed configurations leads to the phenomenon of shape coexistence due to the delicate balance between shell and collective effects [1,2]. Previous studies(e.g. [3, 4]) sought to understand the properties of such isotopes of platinum (Z=78) and gold (Z=79) to establish the extent to which this competition dictates their structures. These studies observed a striking trend in178–186Pt, where an inversion in the state ordering makes the strongly deformed intruder states the ground-state configuration [5]. This inversion coincides with a unique, large increase in the mean-square charge radii of the isobars 178-186Au that was found in a recent in-source laser spectroscopy study [6,7].During the laser-spectroscopy campaign, the deformed ground state,^{178}Au^{g},was found to coexist with a strongly-deformed isomer, ^{178A}u^{m},that was predicted in Ref. [3].

By exploiting the hyperfine structure of 178Au, laser-ionised, isomerically-pure beams of 178Augor 178Aumwere produced using RILIS and guided to the ISOLDE Decay Station (IDS) [8]. IDS was configured to perform γ-ray and conversion-electron spectroscopy allowing separate fine-structure decay schemes to be produced for each parent state. In this contribution, I will summarise the experimental technique used, and the results obtained which show significant differences in the β-decay feeding patterns between178Aug,m. The E0transitionsbetween states in two coexisting rotational bands were found to be significantly stronger than reported in Ref. [3] and were used to determine the difference in mean squared charge radius of the two bands' states. The experimental results will be presented alongside supporting relativistic mean-field and large-scale shell model calculations.

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Nuclear structure beyond the proton drip line

Robert Page

University of Liverpool

Elucidating the properties of nuclei at the edges of the nuclear landscape is a topical challenge in nuclear physics research [1]. Decay spectroscopy provides an important source of nuclear-structure information at the boundaries of known nuclei because information on decay energies, half-lives and branching ratios can be garnered even in cases where only a small sample of the nuclide of interest can be produced, providing that the levels of background are sufficiently low. These measurements can be used to test the validity of theoretical models in nuclei that are very far removed from the region of stable nuclei.

For nuclei between the N=82 and Z=82 shell closures, alpha-particle and proton emission are expected to determine the limits of observable nuclei. These decay modes are highly sensitive to decay Q-values and the structure of parent and daughter nuclei. This talk will focus on recent results obtained using the recoil mass separator MARA at Jyväskylä on proton, alpha and beta radioactivity of ground states and isomers in this region, and what they tell us about the limits of observable nuclei.

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Performances of SIRIUS for the decay spectroscopy of superheavy nuclei

J. Piot[1], A. Bahini[1], R. Chakma[2], D. Ackermann[1], V. Alaphilippe[3], J. Bequet[4], L. Caceres[1], O. Dorvaux[5], B. Gall[5], L. Gibelin[3], J. Goupil[1], K. Hauschild[3], S. Herlant[1], N. Karkour[3], K. Kessaci[5], X. Lafay[3], D. Linget[3], A. Lopez-Martens[3], C. Mathieu[5], J. Pancin[1], H. Savajols[1], Ch. Stodel[1], B. Sulignano[4], D. Thisse[4], G. Tocabens[4]

1 Grand Accélérateur National d'Ions Lourds, CEA/DRF-CNRS/IN2P3, Caen, France
2 Argonne National Laboratory, Lemont IL, USA
3 IJC Lab, CNRS, Université Paris-Saclay, Orsay France
4 IRFU/DPhN, CEA Saclay, Université Paris-Saclay, Gif-sur-Yvette, France
5 Institut Pluridisciplinaire Hubert Curien - IPHC, CNRS-Université de Strasbourg, Strasbourg, France

The stability of nuclei beyond the spherical double shell closure of 208Pb rapidly decreases because of the disappearance of the macroscopic fission barrier. This phenomenon is however compensated by quantum shell effects caused by alternating zones of high and low densities caused by deformation. The Island of Superheavy Stability is foreseen as a doubly spherical gap whose position varies depending on the model used [1,2].
Spectroscopy in the region of high masses is very close to the limits of the existing detection systems. The extension of the investigation on nuclear structure to heavier nuclei is governed by an improvement in the efficiency of the transport and selection of the nuclei of interest as well as in the detection systems. The very high intensity beams provided by the LINAC, combined with the high transmission and selection power of S^3 [3-5], will offer unprecedented production rates of nuclei in the nanobarn region.

SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S^3)[4,5] will be the detection system dedicated to spectroscopy experiments for superheavy nuclei with S^3. SIRIUS consists of five segmented silicon detectors optimized for precision spectroscopy of alpha, beta and fission decay, surrounded by five EXOGAM high-purity germanium detectors for gamma-rays. The conjunction of these detectors with the mass resolving power and the transmission of S^3 will make it a unique instrument for the study of superheavy nuclei.

In this contribution, after a brief review of the current status of S3, I will report on the offline tests of SIRIUS and the performances of its detectors.

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Spectroscopic Factor Investigation in the *N*=40 Island of Inversion

Carlotta Porzio[1] and Heather Crawford[2], for the E19019 collaboration

[1]*CERN*

[2]*Lawrence Berkeley National Laboratory*

This work focuses on neutron-rich Fe and Mn isotopes with *N*~40, which lie within one of the so-called Islands of Inversion. Here, a quenching of the *N*=40 shell gap allows deformation to develop in the ground-state configurations. Limited spectroscopic information has been collected so far in the region of *N*~40 below ^{68}Ni. For the even-even nuclei, the 2^+_1 and 4^+_1 state energy systematics has been explored and, for the Fe and Cr isotopes, of B(*E2*; $2^+_1 \rightarrow 0^+_1$) values have been measured up to ^{68}Fe and ^{64}Cr. Large-scale shell model calculations well reproduce the energy systematics of the observed low-lying states of the even-even Fe and Cr isotopes around *N*=40. However, spectroscopic factor predictions in the region have not yet been benchmarked by experimental results.

Therefore, proton knockout reactions on the neutron-rich *N*=38 and *N*=40 isotopes ^{64,66}Fe and ^{63,65}Mn have been performed to investigate the proton spectroscopic factors of the parent nuclei. The experiment took place at the NSCL laboratory in the US and exploited the γ-ray tracking array GRETINA coupled to the S800 spectrograph to perform an in-beam γ-ray spectroscopic study. Results of the data analysis will be presented.

Parity-violating asymmetry and dipole polarizabilities in atomic nuclei: how do they reconcile with each other?

Xavier Roca-Maza
Departament de Física Quàntica i Astrofísica, Martí i Franqués,1, Barcelona, Spain
Dipartimento di Fisica "Aldo Pontremoli," Università degli Studi di Milano, Milano, Italy
Institut de Ciències del Cosmos, Universitat de Barcelona, Martí i Franqués, 1, 08028 Barcelona, Spain
INFN, Sezione di Milano, 20133 Milano, Italy

In the recent years, attention has been paid to a careful measurement of the dipole polarizability and parity violating asymmetry in medium and heavy mass nuclei such as ^{48}Ca and ^{208}Pb [1-4]. These two observables, as it already happened for the neutron skin thickness, are thought to be particularly sensitive to the properties of the nuclear equation of state at densities around nuclear saturation [5]. Hence, the interest in the low energy nuclear physics community to foster the needed experimental and theoretical developments to accurately study these two observables. In this contribution I will briefly overview our recent theoretical analysis of the parity violating asymmetry and electric dipole polarizability [6,7].

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Novel microscopic approaches for Spin-Isospin excitations and Beta-decay with tensor force*

Hiroyuki Sagawa[1,2]
1RIKEN Nishina Center for Accelerator-based Science, Wako 351-0198, Japan
2Center for Mathematics and Physics, University of Aizu, Fukushima, Japan

The spin-isospin excitations including beta-decay may have strong impacts on the study of strong interactions in nuclear medium, and also the astrophysical phenomena such as the r-process nucleosynthesis together with the photonuclear cross sections, and the large-scale nucleosynthesis network calculations to create elements in the universe. . In addition, the Gamow-Teller (GT)and spin-dipole (SD) resonances are associated with double-beta decay processes, especially, for the zero-neutrino double-beta decay, which provides the information of neutrino-mass puzzle, and consequently the evidence beyond the standard model of elementary particles. We explore extensively new and old, but still unsolved, nuclear structure problems induced by the spin and the isospin degree of freedom by using microscopic models which accommodate realistic isoscalar and isovector pairing interactions and also tensor correlations [1]. We also adopt a self-consistent Hartree-Fock (HF)+random phase approximation (RPA) models embedded the tensor interactions [2], and a state-of-the-art beyond mean field model, Subtracted Second random phase approximation (SSRPA) [3] including the couplings to two-particle two-hole (2p-2h) states. Especially we study magnetic dipole (M1) [2,3], charge-exchange Gamow-Teller (GT) [1,3] and spin-dipole excitations. We mention also pigmy and giant resonances induced by the tensor interaction. Our results give a new insight on the quenching of GT sum rule strengths without introducing any external parameters in the self-consistent microscopic calculations. The SSRPA model is further applied to theβdecay half-lives of four semi-magic and magic nuclei,34Si,68,78Niand132Sn[3].We show the inclusion of the 2p-2h configurations in SSRPA model shifts low-lying Gamow-Teller(GT) states downwards, and leads to an increase of theβdecay phase space, and consequently reproduce theβdecay half-lives dramatically close to the experimental observations. The effect of tensor interaction on theβdecay half-life in SSRPA model is also pointed out to change largely the half-lives by about one to two orders of magnitude with respect to the ones obtained without tensor force.

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Practical use of scintillators in nuclear structure physics experiments

Paul Schotanus
SCIONIX

In nuclear structure experiments scintillators are commonly used to measure gamma ray energies up to around 30 MeV and it is often required to separate gammas from fast neutrons. The rates can be high and sub nanosecond time resolutions are important which requires bright scintillators with a short decay time (max tens of ns) . There are no scintillators that can fulfil all these requirements simultaneously so compromises need to be made.

In this presentation, an overview will be presented on currently available fast high resolution scintillators. Examples of Chlorine containing materials like CLLBC will be shown together with their merits and limitations. Combining several types of scintillators for cost reason is discussed.

SiPm readout of fast high resolution scintillators is well possible. It limits the detector size and allows sensor operation in high magnetic fields and low voltages.

Moreover scintillators are used as secondary detectors to act as Compton suppression shields around HPGe arrays which is much less demanding on the scintillator specifications. High density BGO remains often the material of choice.

Investigation of the low-lying dipole strength of ^{62}Ni via real photon scattering

Tanja Schüttler[1], Miriam Müscher[1], Florian Kluwig[1], Deniz Savran[2], Ronald Schwengner[3], and Andreas Zilges[1]

[1] *Institute for Nuclear Physics, University of Cologne, Cologne, Germany*

[2] *GSI, Research Division, Darmstadt, Germany*

[3] *Helmholtz-Zentrum Dresden-Rossendorf, Dresden-Rossendorf, Germany*

The low-lying dipole response of atomic nuclei was intensively studied both in theory and experiments in the last decades [1-3]. To improve the understanding of the underlying dipole excitation modes, investigations of one nucleus using different probes, the so-called multi-messenger approach [4], as well as studies along isotopic and isotonic chains are essential. Particularly the latter one can yield insights into the impact of e.g. the shell-structure or changing neutron excess on the low-lying dipole strength. Since photons transfer only small angular momenta, real-photon scattering, also denoted as Nuclear Resonance Fluorescence (NRF), is a powerful tool to study the dipole strength below the neutron separation threshold S_n of an atomic nucleus [5].
The semi-magic nickel (Z=28) isotopic chain is an excellent candidate for a systematic study, as it consists of four stable even-even isotopes covering a large range of N/Z ratios between 1.07 and 1.29. The isotopes ^{58}Ni,^{60}Ni and ^{64}Ni have already been measured using the NRF technique [6-9]. Furthermore, the unstable isotopes ^{68}Ni and ^{70}Ni have been studied using Coulomb excitation in inverse kinematics [10-12].
To complete the systematics, the dipole response of ^{62}Ni was investigated in an NRF experiment using energetically-continuous bremsstrahlung with a maximal photon energy of E_{max} = 8.7 MeV at the γ-ELBE facility at the Helmholtz-Zentrum Dresden-Rossendorf [13].
In this contribution, the NRF method will be briefly explained and first results of the bremsstrahlung experiment on ^{62}Ni will be presented.
This work has been supported by the BMBF (05P21PKEN9).

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Quantal and deformation effects in charge-asymmetric low-energy reactions

L. Shvedov,[1] S. Burrello,[1] M. Colonna,[1] and H. Zheng[2]

[1]*Laboratori Nazionali del Sud, INFN, I-95123 Catania, Italy*

[2]*School of Physics and Information Technology, Shaanxi Normal University, Xi'an, China*

We investigate the pre-equilibrium dipole response in the charge-asymmetric reaction ^{40}Ca + ^{152}Sm at E_{lab} = 11 MeV/A. The results obtained with the time-dependent Hartree-Fock (TDHF) approach and a semi-classical transport model that also includes two-body correlations, employing Skyrme effective interactions for the nuclear mean-field, are compared. The aim of this analysis is to disentangle the role of global deformation effects from the ones associated with structure details of genuine quantal nature in the ground state configuration of ^{152}Sm, for both central and peripheral collisions. Their impact on the reaction dynamics, as well as on the establishment of the dipole mode, is discussed. Moreover, we also investigate the impact of the occurrence of residual two-body collisions on the reaction dynamics. This study contributes to the understanding of the microscopic processes that determine the complex dynamics of low-energy heavy-ion collisions, also allowing to unravel some interesting connections with the characteristics of the nuclear effective interaction and the associated equation of state.

Influence of the intermediary nucleus continuum on pairing enhancement in a two-neutron transfer process

G. Singh
Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Germany

Two-neutron transfer reactions offer us a chance to understand the pairing dynamics in an easier way compared to other approaches. In the process, they help us understand the stability of Borromean nuclei near the drip lines. However, the inclusion of the continuum for such two-neutron transfers is a non-trivial task owing to the oscillatory nature of the continuum wave functions, even if obtained after discretisation. Nevertheless, since a majority of the spectrum for weakly bound nuclei is due to the continuum, its inclusion is indispensable. Ideally, one would want a coupled channels approach to study the possible interferences amongst the various states involved. On the other hand, pairing dynamics has been vastly analysed and studied for heavy magic nuclei, but the same for weakly bound nuclei lying away from the valley of stability have been few and far between. Curiously, the correlations in the initial and final state wave functions carrying the relevant microscopic structure information to compute the two-particle transfer amplitudes, lead to coherent interferences of the various paths in the intermediate nucleus, resulting in 'pairing enhancement' [1].In Ref. [2], it was recently quantified that the pairing interaction for a sequential two-neutron transfer process, via the continuum of the intermediate nucleus was in a big way responsible for the production of (A+2) nucleus even though the (A+1) nucleus can be unbound. In this contribution, I try to extend this study to explore the possibilities of such a transfer reaction when the bound state energy of the final (A+2) product nucleus is not fixed. Using a Transformed Harmonic Oscillator (THO) basis to generate the discretised spectrum of the intermediate 5He nucleus, I study the 18O(4He,6He)16O reaction to populate various hypothetical bound states in 6He depending on the strength of the pairing interaction used. To explore the results without the presence of a resonance in the continuum of the intermediate (A+1) system, and hence, try to paint a complete picture, the 18O(20C,22C)16O two-neutron transfer reaction would also be analysed from a similar perspective. Discussing the approximations used, I will show that the pairing enhancement plays the most important role when the intermediate nucleus in a two-neutron transfer is unbound.

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Increasing quenching of spectroscopic factors in neutron-deficient C isotopes: a signature of short-range correlations?

O.Sorlin
Grand Accélérateur National d'Ions Lourds, CEA/DRF-CNRS/IN2P3, Caen, France

Neutron-removal spectroscopic factors C2S of the 12C, 10C, 9C and 8B nuclei were obtained by means of (p,d) reactions at about 50~ MeV/nucleon in a liquid hydrogen target at the GANIL/LISE facility. The deuterons were detected in the highly-segmented MUST2 detector placed at forward angles and the excitation energies in the 11C, 9C, 8C and 7B nuclei were reconstructed by the missing mass method. Differential cross sections, which display an L=1 pattern for all nuclei, were fitted with 416 sets of uncertainty-quantified optical-model to derive C2S values [1].
The ratio between experimental and shell-model calculated C2S value, RS, is found to be slightly decreasing as a function of increasing proton to neutron separation energy asymmetry �S, with a slope of -0.0062(39)stat (15)sys. Such a precision has been reached for the first time by a careful minimization of all usual systematical experimental and theoretical uncertainties inherent to transfer, knockout or neutron-removal reactions [2]. This down sloping trend is in accordance with that predicted from results independently obtained from the study of short-range correlations at Jefferson laboratory with an electron probe on neutron-rich stable targets [3], but much lower than the one derived from one-nucleon removal reactions at intermediate energy [4].
Our study also shows that no sudden drop in C2S is observed in the neutron-removal of the 9C and 8B nuclei, leading to the final unbound nuclei of 8C and 7B, respectively. This is at variance with a very large quenching of C2S derived in [5] from neutron-removal reactions in a Be target, that pled for a strong coupling to the continuum [6].

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Nuclear Physics studies at the 5MV tandem in Madrid

O. Tengblad
EM – CSIC, Madrid, Spain

The Nuclear Physics beam line at the Madrid 5 MV tandem UAM-CMAM has been used to perform reaction studies at low energy to shed light in long standing problems in nuclear astrophysics. In this context we study the $^{19}F(p,\alpha\gamma)^{16}O$ to populate the states of ^{16}O near the alpha breakup threshold. For the case of the primordial abundance of ^{7}Li we study the $^{7}Li(^{3}He,p)^{9}Be$ to estimate the cross section of the reaction of $^{7}Li(^{3}H,n)^{9}Be$ much more difficult to determine accurately. Recently a new collaboration and research line was initiated.
Neutrons produced through α-induced reactions play important roles in fields such as nuclear astrophysics, neutron background in underground laboratories, fission and fusion reactors and non-destructive assays for non-proliferation and spent fuel management applications. However, most of the currently available data on such nuclear reactions were measured decades ago, and are incomplete or present large discrepancies.
The MANY (Measurement of Alpha Neutron Yields and spectra) collaboration is an effort by the Spanish nuclear research groups from Barcelona – Madrid -Valencia – Seville with the aim to carry out measurements of (α,xn)and (α,xnγ) reactions using the two existing low energy tandem accelerators CMAM (Madrid) and CNA (Seville), in combination with high performance novel neutron and gamma detectors:
+ MINIBELEN a 4π neutron counter with nearly flat response up to 10 MeV [1]
+ MONSTER based on BC501/EJ301 liquid scintillator modules, for ToF [2]
+ GARY array of fast gamma detectors. [3]
Commissioning of the beam-line has been achieved with well-known 27Al(α,n)30P reaction [4].
The ongoing and planned nuclear reactions studies at the CMAM accelerator will be discussed.

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Study of Giant Monopole Resonance in ^{58,68}Ni with ACTAR@GANIL

Damien Thisse, Marine Vandebrouck

Irfu, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France

Alex Arokia Raj, Riccardo Raabe

Instituut voor Kern- en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium

Thomas Roger

GANIL, CEA/DSM-CNRS/IN2P3, Bvd Henri Becquerel, 14076 Caen, France

A Giant Resonance corresponds to the collective motion of a large number of nucleons composing the nucleus. Specifically, the Isoscalar Giant Monopole Resonance (GMR) consists in a compression/dilatation mode of the nucleus, often called the "breathing mode", where all the nucleons move in phase. Its characteristics can be related to the nuclear matter incompressibility used in the equation of state, the latter used to describe the neutron stars for example. The systematic study of this type of resonance in exotic nuclei, using techniques like inelastic scattering reactions, allows to evaluate the dependence of neutron/proton asymmetric effects on the incompressibility and also to investigate the emergence of new mode, like the soft monopole mode at lower energy.

It has been shown that the use of active targets is well suited for the study of GMR in exotic nuclei [1-4]. In 2019, an experiment has been held at the GANIL facility to probe the GMR in both ^{58}Ni and ^{68}Ni with the active target ACTAR [5]. The ^{58}Ni(α, α')^{58}Ni* reaction has been used to validate the experimental method, comparing to the results obtained in direct kinematics [6]. The case of ^{68}Ni is particularly interesting as it will allow to validate the results obtained previously with the active target MAYA and investigate the soft monopole mode, as the energy and angular resolution of MAYA was not sufficient to characterize it.

Two years ago, preliminary results from the analysis, such as the effectiveness of the reconstruction methods, were presented during the previous Bormio workshop. Today, the analysis is almost completed. Properties of the GMR in both nuclei will be presented as well as a comparison to theoretical calculations using QRPA for the nuclear states predictions and DWBA for the differential cross-section distributions.

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Test of the charge symmetry hypothesis of NN interaction from the Coulomb-free p-p scattering cross section and its relation to universality

A. Tumino

Dipartimento di Ingegneria e Architettura, Università degli Studi di Enna "Kore", Enna,

Italy INFN-Laboratori Nazionali del Sud, Catania, Italy

The difference in scattering lengths between proton-proton and neutron-neutron interactions is crucial for understanding charge-symmetry breaking in nuclear forces. However, the Coulomb-free proton-proton scattering length (app) cannot be measured directly and depends significantly on various theoretical methods to account for the Coulomb contribution.

We determined the Coulomb-free proton-proton scattering length from the half-off-shell proton- proton scattering cross section, measured at centre-of-mass energies below 1 MeV, using the quasi- free reaction p + d ➔ p + p + n reaction [1]. The observed difference in scattering lengths between protons and neutrons indicates a lower degree of charge symmetry breaking in nuclear forces than previously predicted. To interpret this finding within the context of short-range physics, we developed a model based on universality concepts. We will present and discuss the results.

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Investigating the changes in nuclear structure below Z = 50 with Ag

B. van den Borne[1], S. Kujanpää[2], R.P. de Groote[1], G. Neyens[1], T.E. Cocolios[1], and members of the CRIS collaboration[1,3–9]

[1]Instituut voor Kern- en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium
[2]Department of Physics, University of Jyväskylä, FI-40014 Jyväskylä, Finland
[3]CERN, CH-1211 Geneva, Switzerland
[4]School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK
[5]Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[6]University of Gothenburg, 41296 Gothenburg, Sweden
[7]University of Nantes, 44035 Nantes Cedex 1, France
[8]IFIN-HH, Magurele, Ilfov, Romania
[9]Peking University, Beijing 100871, China

Exploring ground-state nuclear properties is a powerful tool for investigating our understanding of nuclear structure. Laser spectroscopy gives access to nuclear model independent measurements of the ground-state properties (spin, nuclear electromagnetic moments, changes in the charge radius) of short-lived (≥10 ms) nuclei, providing an excellent benchmark for theoretical predictions close to magic shell closures far from stability [1]. Moreover, combining laser spectroscopy and state-of-the-art quantum chemistry can provide insight into the Bohr-Weisskopf (BW) effect and thus into the nuclear magnetization distribution parameter [2]. One region of high interest is the region below closed proton shell tin (Z=50), a region with many competing nuclear configurations, and thus the subject of recent investigations: tin [3], indium [1], cadmium [4], palladium [5], and silver [6-8] studies have been successfully performed before, and neutron-rich silver has been studied recently at ISOLDE/CERN and IGISOL in Jyväskylä [8].

I will present the laser spectroscopy setup at IGISOL and the CRIS technique at ISOLDE. A new isomeric state was discovered, and the level ordering was unambiguously assigned. The nuclear spin and electromagnetic properties of the ground state and isomeric states are deduced. These data provide a benchmark for state-of-the-art nuclear models, further broadening our knowledge in this region of the nuclear chart. Further, I will present an outlook on BW effect studies in silver as a probe to the nuclear magnetization distribution.

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Understanding Scintillation Mechanisms: Theory, Limitations, and Future Research Directions

Weronika W. Wolszczak[1]

[1]Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, Berkeley, CA 94720, USA

Scintillators play a crucial role in particle detection, yet the fundamental mechanisms governing scintillation processes remain areas of active research. This talk will provide an in-depth look at the physics of scintillation, exploring how the material structure, energy transfer processes, and defect states affect light yield, timing, and energy resolution. We will examine the theoretical limitations of scintillators, including trade-offs imposed by intrinsic material properties, as well as the energy loss and non-proportionality effects that challenge the design of high-performance detectors.

Recent advances in our understanding of scintillation mechanisms have opened avenues for deliberate design of new materials, crucial for enhancing both energy resolution and timing accuracy. State-of-the-art developments will be discussed, with insights into how current research on radiation detection materials, defect engineering, and high excitation density processes are pushing these boundaries. Lastly, future directions will be proposed to guide the development of next-generation scintillators that can address unresolved challenges in applications requiring high stopping power, high timing precision, and efficient particle discrimination, such as those in nuclear physics and high-energy physics.

Shape coexistence of Zr and the neighbouring isotopes described by nuclear shell model

K. Yanase

RIKEN Nishina Center for Accelerator-Based

Science Coauthors: T. Otsuka, Y. Tsunoda, and N. Shimizu

The University of Tokyo and University of Tsukuba

Zr isotopes exhibit a sudden change of nuclear shape from spherical to deformed at N=60 as can be seen by the jump of the B(E2) transition strength from the lowest 2+ state to the ground state. This shape transition results from the shape coexistence of spherical and deformed bands at low energy. 100Zr (N=60) is deformed more easily than 98Zr, which is a subshell closure of N=58, so a deformed 0+ state comes down below the spherical 0+ state at N=60.

The detailed nuclear structure has been described particularly by Monte Carlo shell model (MCSM) calculations [1]. Comparing the results with recent gamma-ray spectroscopy, we can however find some discrepancies between the MCSM calculations and experiment for the energy spectra and B(E2) transition strengths.

In this talk, we present a recent study by using the Quasi-particle vacua shell model (QVSM) calculations. In the QVSM, a nuclear wave function is expressed with a superposition of quasi-particle vacua. The U and V matrices, which characterize each basis vector, are optimized to describe some low-lying states. The QVSM is a more sophisticated method than the MCSM as discussed in Ref. [2]. In addition, we developed a phenomenological effective interaction which can be applied to describe not only Zr (Z=40) isotopes, but also Kr (Z=36), Sr (Z=38), Mo (Z=42), and Ru (Z=44) for N=50-70. We are successful in systematically reproducing energy spectra and B(E2) strengths. We discuss the magnitude of deformation, triaxiality, and the mixing of different shapes based on the analysis of wave functions obtained by the QVSM calculations. In contrast to Zr isotopes, the Kr, Sr, Mo, and Ru isotopes exhibit more gradual shape transitions. Our calculations reproduce this trend and describe the detail of shape coexistence in those isotopes.

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Mixing between single particle and intruder states towards the N=20 island of inversion: lifetimes in ^{37}S

L. Zago[1,2], A. Gottardo[1], F. Galtarossa[3], J.J. Valiente Dobón[1], F. Angelini[1,2], M. Balogh[1], D. Brugnara[1], J. Collado Ruiz[4], G. de Angelis[1], A. Ertoprak[1], A. Goasduff[1], B. Gongora Servin[1,5], A. Gozzelino[1], T. Marchi[1], D. R. Napoli[1], J. Pellumaj[1], R. M. Perez-Vidal[1,4], M. Sedlák[1], I. Zanon[1], A. Gadea[4], N. Miani[2], P.A. Aguilera[3], D. Bazzacco[3], J. Benito Garcia[3], S. Carollo[2,3], Z. Huang[2,3], S. M. Lenzi[2,3], R. Menegazzo[3], D. Mengoni[2,3], S. Pigliapoco[2,3], E. Pilotto[2,3], M. Polettini[3], F. Recchia[2,3], K. Rezynkina[2,3], G. Zhang[3], G. Benzoni[6], S. Bottoni[6], G. Corbari[6], N. Marchini[7], A. Nannini[7], M. Rocchini[8], M. Beckers[9], F. Dunkel[9], C. Fransen[9], L. Kornwebel[9], C. Lakenbrink[9], F. von Spee[9], J. Diklic[10]

1) INFN-LNL
2) Università degli Studi di Padova
3) INFN sezione di Padova
4) IFIC Valencia
5) Università degli Studi di Ferrara
6) INFN sezione di Milano e Università di Milano "La Statale"
7) INFN sezione di Firenze
8) IKP Cologne
10) Ruđer Bošković Institute

The disappearance of the N=20 shell closure in the so-called "island of inversion" around ^{32}Mg is one of the most striking examples of the strength of nucleon-nucleon correlations. In this region, the quadrupole-deformed intruder configuration (based on a multi-particle multi-hole configuration) becomes the ground state, subverting the expected shell ordering predicted by a harmonic oscillator plus spin-orbit term. The odd N=21 isotonic chain provides the possibility to study the single-particle and intruder states as a function of decreasing Z. Available spectroscopic evidence points out the appearance of strong branching ratios among the single-particle and collective intruder configurations in ^{37}S [1], suggesting that they mix significantly, contrary to the notion of ^{37}S being well out the island of inversion. However, a precise quantification of this phenomenon in terms of transition strength is still lacking. The first excited state ($3/2^-$ state at 646 keV) is the only one with a measured lifetime [2], but no transition probability has been firmly determined for the intruder states, in particular those decaying to the *a priori* spherical single-particle states.

A combined DSAM+RDDS measurement has been performed to measure such transition probabilities, in particular for the 2p-1h $3/2^+$ state at 1397 keV and the 3p-2h $7/2^-$ at 2023 keV, exploiting the performance of the AGATA spectrometer in terms of energy and angular resolutions. The ^{37}S nucleus has been produced via the ^{36}S(d,p) reaction in inverse kinematics, detecting the recoiling protons in the silicon array SPIDER to obtain an accurate reconstruction of the excitation energy of ^{37}S. The short lifetimes measured point to large M1 and/or E2 strengths connecting the intruder and spherical states. This would imply a significant mixing between the configurations, arising questions about the determination of the neutron $p_{3/2}$-$p_{1/2}$ single-particle strength distribution in ^{37}S.

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The description of nuclear giant resonances in a self-consistent quasiparticle-vibration coupling approach

Zhengzheng Li

Peking University, China

Nuclear giant resonances play an important role in constraining the nuclear equation of state and other physical quantities. We present a self-consistent quasiparticle random-phase approximation plus quasiparticle-vibration coupling (QRPA+QPVC) approach base on the Skyrme Hartree-Fock-Bogoliubov within the spherical assumption. The isoscalar giant monopole resonance (ISGMR), isovector giant dipole resonance (IVGDR), and isoscalar giant quadrupole resonance (ISGQR) are studied by taking Ca, Sn, and Pb isotopes as examples. We demonstrate that the QRPA+QPVC approach is very powerful for the description of giant resonances. From the description of ISGMR, we show that the QPVC effects are important to achieve a consistent incompressibility value in Ca, Sn, and Pb isotopes. From the description of ISGQR, the QPVC effects on extraction of empirical value for the nucleon isoscalar effective mass are also discussed.

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The role of forbidden transitions on β-decay half-lives within Skyrme quasiparticle vibration coupling framework

Xuelin Zhi

School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China

The nuclear β-decay half-lives are crucial as they set the time scale of the rapid neutron capture process (r-process), which determines the production of heavy elements in the universe [1-3]. Several calculations of β-decay half-lives based on quasiparticle random phase approximation (QRPA), including first forbidden (FF) transitions, show that the FF transitions dominate in some nuclear mass regions [4-6]. However, QRPA always overestimates the β-decay half-lives [7-8].

The QRPA plus quasiparticle-vibration coupling (QRPA+QPVC) can systematically reduce the β-decay half-lives and bring them closer to the experimental results, compared with the QRPA model [9-10]. However, forbidden transitions are not taken into account in these QPVC calculations. Given that QPVC predicts β-decay half-lives so well, it would be interesting to include forbidden transitions and explore their contribution within QPVC framework.

By employing the β-decay formula derived by Walecka and Donnelly [11], the β-decay half-lives of Ni, Cd and Sn isotopes are investigated using QRPA plus QPVC with Skyrme non-relativistic density functional, based on the Hartree-Fock-Bogoliubov (HFB) theory, encompassing allowed and forbidden transitions. The effective interaction SkM* is used. We compare the ratio of allowed, first- forbidden and second-forbidden transition rates to the total transition rate in β-decay using the QRPA and QRPA+QPVC models respectively, and analyse the influence of QPVC effect on allowed and forbidden transitions.

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