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Contents

Decay spectroscopy studies of two new isotopes of astatine

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The two lightest known isotopes of astatine, ^{188}At and ^{190}At, have been identified at the Accelerator Laboratory of the University of Jyväskylä, Finland. The nuclei were produced in fusion–evaporation reactions, and those were subsequently separated from the primary beam using the RITU (Recoil Ion Transfer Unit) gas-filled recoil separator. A proton emission from ^{188}At was observed, resulting in the identification of the heaviest proton-emitting nucleus to date. The non-adiabatic quasiparticle model was expanded to interpret the experimental data, suggesting that the proton is emitted from a prolate deformed 2^- state with a dominant $s_{1/2}$ proton component in the wavefunction. The one-proton separation energy deviates from the systematics, and a possible source for this effect will be discussed in the this presentation. For the second-lightest known astatine isotope, ^{190}At, α-decay properties were measured and compared to the systematics. Additionally, the possibility of proton emission from this nucleus is discussed. In this presentation, the experimental details and the results concerning ^{188}At [1] and ^{190}At [2] will be discussed.

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References

[1] H. Kokkonen, K. Auranen *et al.*, *Nat. Commun.* **16**, 4985 (2025).
[2] H. Kokkonen, K. Auranen *et al.*, *Phys. Rev. C* **107**, 064312 (2023).

Nuclear structure studies with neutron-induced reactions

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I will review recent experimental results obtained at Institut Laue-Langevin using neutron-capture and neutron-induced fission reactions studied with the HPGe array FIPPS and the LOHENGRIN spectrometer. Different phenomena such as shape coexistence, onset of collectivity and particle-vibration coupling will be discussed in different regions of the nuclide chart including Ca, Ni, Se isotopes [1-3], and heavier systems like Rb and Sb nuclei [4,5]. Gamma-ray spectroscopy studies and lifetime measurements of excited states will be presented and interpreted with different theoretical models, such as shell-model calculations and EDF theories.

References

[1] S. Bottoni *et al.*, *Phys. Rev. C* **103**, 014320 (2021) - M. Luciani *et al.*, in preparation.
[2] N. Mărginean *et al.*, *Phys. Rev. Lett.* **125**, 102502 (2020).
[3] J. Pellumaj, submitted to *Phys. Lett. B* - F. Conca *et al.*, in preparation.
[4] E. Gamba *et al.*, *Phys. Rev. C* **108**, 064301 (2023).
[5] S. Bottoni *et al.*, *Phys. Rev. C* **107**, 014322 (2023).

Reflections upon reflection asymmetry in atomic nuclei

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For certain combinations of protons and neutrons it is expected that the shape of atomic nuclei can undergo octupole deformation, which would give rise to reflection asymmetry or a "pear shape". In this talk I will review the experimental evidence for octupole instability in heavy nuclei, including the results of experiments carried out at CERN using REX-ISOLDE [1] and HIE-ISOLDE [2,3,4]. The behaviour of the rotational levels and the E3 matrix elements suggests that only a few radium isotopes have stable pear shapes. I will also discuss the extension of these measurements to medium-mass nuclei such as ^{144}Ba and to odd-A nuclei important for EDM searches.

References

[1] L. P. Gaffney *et al.*, *Nature* **497**, 199 (2013).
[2] P. A. Butler *et al.*, *Phys. Rev. Lett.* **124**, 042503 (2020).
[3] P. A. Butler *et al.*, *Nat. Commun.* **10**, 2473 (2019); **11**, 3560 (2020).
[4] P. Spagnoletti *et al.*, *Phys. Rev. C* **105**, 024323 (2022).

Commissioning of the CRIS Decay Spectroscopy Station: combining ultra narrow-band laser and beta–gamma spectroscopy

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The Collinear Resonance Ionization Spectroscopy (CRIS) experiment at CERN ISOLDE is used to perform hyperfine-structure and isotope-shift measurements to the tens of MHz [1]. Narrow-band lasers in collinear geometry enable access to nuclear spins, electromagnetic moments, and changes in charge radii in a nuclear model-independent way [1]. Isomerically purified beams with $< 1\%$ contamination can be selected with ultra narrow-band resonance ionization and analysed at the Decay Spectroscopy Station (DSS) [2]. This dual-spectroscopy approach finds two key applications: isomer-selective decay studies, where excited nuclear states are separated from ground states (e.g. the α decay of isomers in francium isotopes [3,4]), even when the states overlap in energy [5]; and decay tagging, a technique previously used at CRIS to suppress background in hyperfine spectra resulting from a 10^4 excess of stable isobaric contaminants in the beam [6].

The current DSS setup features a tape system for removal of long-lived activity and a newly designed in-vacuum plastic scintillator that will be commissioned in September 2025 by performing decay-assisted laser spectroscopy of ^{99,100}In beams. For the same experiment, an array of High Purity Germanium detectors and scintillators will be integrated into the DSS, allowing us to perform laser-assisted decay spectroscopy of indium isomers in the region. In this contribution, the recent development of the DSS and the combined laser and decay spectroscopy approach will be discussed with preliminary results from the experiment.

References

[1] X. F. Yang, S. J. Wang, S. G. Wilkins, R. G. Ruiz, *Prog. Part. Nucl. Phys.* **129**, 104005 (2023).
[2] K. M. Lynch, T. E. Cocolios *et al.*, *Nucl. Instrum. Methods Phys. Res.* **844** (2017).
[3] K. M. Lynch *et al.*, *Phys. Rev. X* **4**, 011055 (2014).
[4] G. J. Farooq–Smith, *Phys. Rev. C* **94**, 054305 (2016).
[5] B. van den Borne *et al.*, *Phys. Rev. C* **111**, 014329 (2025).
[6] Á. Koszorús *et al.*, *Nat. Phys.* **17**, 439–443 (2021).

Shape evolution in neutron-deficient isotopes around $A = 170$ and first experiments with the recoil-distance Doppler-shift technique at ISOLDE

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Absolute transition strengths between excited states yield fundamental information on nuclear structure. These observables can be determined from level lifetimes. The recoil distance Doppler-shift (RDDS) technique employing so-called plunger devices provides a valuable method for the determination of lifetimes in the picosecond range and has been in the focus of our Cologne group since many years.

In the first part of this talk, new results from RDDS measurements of our group in neutron-deficient nuclei in the $A = 170$ region are discussed. In this region, we investigated the evolution of nuclear shapes with special respect to structural changes towards exotic nuclei. Furthermore, we studied an anomaly of the lowest yrast transition strengths that appears for decreasing neutron number in this region and cannot be understand with any simple collective approach but only with a very recent extension of the IBM.

In the second part of the presentation, the first campaign with the RDDS technique at ISOLDE with the MINIBALL spectrometer and a sophisticated plunger device developed by our group will be introduced. The focus will be a recent experiment on neutron-rich ^{144}Ba aiming for (i) the implementation of the RDDS technique at ISOLDE, especially employing incomplete fusion reactions in inverse kinematics and (ii) the search for octupole correlations in ^{144}Ba.

Shape transitions and coexistence in the $Z = 40$, $N = 60$ region

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The evolution of ground-state shapes usually proceeds smoothly, however for nuclei in the vicinity of $Z = 40$ and $N = 60$ there is an abrupt shape transition (see Refs. [1,2] for reviews). Some recent calculations, using the state-of-the-art Monte Carlo Shell Model (MCSM) [3,4] and the Interacting Boson Model employing the Intertwinded Quantum Phase Transition (IQPT) [5], have been able to reproduce this abrupt change for the Zr isotopes and predict that shape coexistence occurs both above and below the critical $N = 60$ point. The MCSM calculations also predict multiple shape coexistence in Zr. Moving away from $Z = 40$, the abruptness of the transition becomes tempered, with an overall smooth evolution observed in Ru, for example [2].

Recently, there has been a large number of experimental investigations, using a variety of probes, that are bringing new insights into nuclei in the $N = 60$ region. Deformed band structures have been revealed through detailed γ-ray spectroscopy following β-decay [6,7,8,9] and fission [10,11,12,13]. Coulomb excitation studies have provided important matrix elements and quadrupole moments [14,15,16,17] and have been complemented by lifetime measurements [18,19,20,21]. Single-nucleon transfer reactions have probed the single-particle degrees of freedom in the ^{94,96}Sr isotopes [22,23], and have mapped both the proton and neutron states in the nuclei around ^{100}Mo [24].

An overview of our understanding of the structure in the region of the $N = 60$ shape transition will be presented with a particular emphasis on shape coexistence.

References

[1] K. Heyde and J. L. Wood, *Rev. Mod. Phys.* **83**, 1467 (2011).
[2] P. E. Garrett, M. Zielińska, and E. Clément, *Prog. Part. Nucl. Phys.* **124**, 103931 (2022).
[3] T. Otsuka and Y. Tsunoda, *J. Phys. G: Nucl. Part. Phys.* **43**, 024009 (2016).
[4] T. Togashi, Y. Tsunoda, T. Otsuka, and N. Shimizu, *Phys. Rev. Lett.* **117**, 172502 (2016).
[5] N. Gavrielov, A. Leviatan, and F. Iachello, *Phys. Rev. C* **105**, 014305 (2022).
[6] A. Chakraborty *et al.*, *Phys. Rev. Lett.* **110**, 022504 (2013).
[7] K. Mashtakov *et al.*, *Acta Phys. Polon. Supp.* **18**(2), 2-A21 (2025).
[8] J. Wu *et al.*, *Phys. Rev. C* **109**, 024314 (2024).
[9] D. Kalaydjieva *et al.*, contribution to this meeting (2024).
[10] W. Urban *et al.*, *Phys. Rev. C* **96**, 044333 (2017).
[11] W. Urban *et al.*, *Phys. Rev. C* **99**, 064325 (2019).
[12] J. Wiśniewski *et al.*, *Phys. Rev. C* **108**, 024302 (2023).
[13] W. Urban *et al.*, *Phys. Rev. C* **100**, 014319 (2019).
[14] E. Clément *et al.*, *Phys. Rev. Lett.* **116**, 022701 (2016).
[15] N. Marchini *et al.*, *Phys. Lett. B*, submitted (2025).
[16] K. Wrzosek-Lipska *et al.*, *Phys. Rev. C* **86**, 064305 (2012).
[17] P. E. Garrett *et al.*, *Phys. Rev. C* **106**, 064307 (2022).
[18] P. Singh *et al.*, *Phys. Rev. Lett.* **121**, 192501 (2018).
[19] V. Karayonchev *et al.*, *Phys. Rev. C* **102**, 064314 (2020).
[20] G. Pasqualato *et al.*, *Eur. Phys. J. A* **59**, 276 (2023).
[21] J.-M. Regis *et al.*, *Phys. Rev. C* **95**, 054319 (2017).
[22] S. Cruz *et al.*, *Phys. Lett. B* **786**, 94 (2018).
[23] S. Cruz *et al.*, *Phys. Rev. C* **100**, 054321 (2019).
[24] S. Freeman *et al.*, *Phys. Rev. C* **96**, 054325 (2017).

High-Precision Mass Measurements with JYFLTRAP

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High-precision Penning-trap mass spectrometry is pivotal for advancing nuclear structure, fundamental symmetries, neutrino physics, and astrophysical processes. At the IGISOL facility, the JYFLTRAP double Penning trap [1] achieves sub-keV accuracy for short-lived isotopes, enabled by advances in ion production, preparation, detection, and measurement techniques.

We have implemented the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) method [2] coupled with laser-assisted in-source ionization, enabling efficient and selective production (up to 1 count/10 min) and rapid preparation and identification of exotic short-lived species for mass measurements [3]. PI-ICR has been combined with Ramsey cleaning, providing fast isomer separation and ultra-high precision; this approach was used to determine the Q value and mass of ^{136}Cs and is now routinely applied for low-Q-value decay measurements with high precision [4,5]. A novel scheme coupling PI-ICR with buffer-gas cleaning has been developed, improving purification efficiency and reducing preparation times. Additionally, a systematic study of PI-ICR performance has characterized frequency-ratio precision and systematic uncertainties [2]. These technical advances will be discussed. Moreover, selected measurements illustrating these capabilities will also be presented. They include the first direct mass of neutron-rich ^{95}Ag and precision masses of ^{96,97}Ag, with ^{96}Ag isomer separation and its high precision mass measurements demonstrating the ability to resolve close-lying states and constrain the $N = 50$ shell closure and empirical shell energies [2]. High-precision Q values for electron-capture transitions in ^{95,97}Tc, ^{111}In, ^{131}I, and ^{159}Dy [4,5,6,7,8] highlight candidates for sub-eV neutrino-mass studies. The mass of ^{136}Cs further demonstrates the capability of PI-ICR with Ramsey cleaning to probe low-Q-value transitions, study virtual β-γ transitions, and explore charged-current neutrino-capture processes [4].

These results refine empirical shell gaps, improve nuclear mass models, and constrain rp-process nucleosynthesis networks. They also underscore the potential for precision studies of rare weak decays relevant to neutrino physics, guiding the search for next-generation sub-eV neutrino-mass candidates. Finally, prospects for further upgrades will be discussed, which will extend high-precision mass spectrometry deeper into unexplored regions of the nuclear chart.

References

[1] T. Eronen, V. S. Kolhinen, V. V. Elomaa, D. Gorelov, U. Hager et al., *Eur. Phys. J. A* **48**, 46 (2012).
[2] D. A. Nesterenko, T. Eronen, A. Kankainen, Z. Ge, M. Vilen, *Eur. Phys. J. A* **57**, 302 (2021).
[3] Z. Ge, M. Reponen, T. Eronen, B. S. Hu, M. Kortelainen et al., *Phys. Rev. Lett.* **133**, 132503 (2024).
[4] Z. Ge, T. Eronen, A. de Roubin, M. Ramalho, J. Kostensalo et al., *Phys. Rev. C* **108**, 045502 (2023).
[5] Z. Ge, T. Eronen, V. A. Sevestrean, O. Niţescu, S.Stoica et al., *Phys. Lett. B* **859**, 139094 (2024).
[6] Z. Ge, T. Eronen, A. de Roubin, K. S. Tyrin, L. Canete et al., *Phys. Lett. B* **832**, 137226 (2022).
[7] Z. Ge, T. Eronen, K. S., Tyrin, J Kotila, J. Kostensalo et al., *Phys. Rev. Lett.* **127** 27 (2021).
[8] T. Eronen, Z. Ge, A. de Roubin, M. Ramalho, J. Kostensalo et al., *Phys. Lett. B* **830**, 137135 (2022).

Magnetic moments of short-lived isomeric states Recent experimental results and future ideas

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Magnetic moments provide a critical insight into the structure of the nuclei. They are very sensitive to the single-particle structure of the nuclear wave function and are of special interest in the vicinity of shell closure, where the extreme single-particle shell model approach is expected to be a valid approximation.

The application of different experimental techniques is strongly dependent on the lifetime and the production mechanism of the states of interest. The challenges of magnetic moment measurements of short-lives isomeric states for exotic, far from stability, isomers stem from the modest intensities with which they can be produced even at the last-generation radioactive beam facilities. In addition, the requirement for obtaining a spin-oriented ensemble, for most of the experimental techniques, imposes additional constraints on the experimental conditions.

Examples of TDPAD measurements, performed lately at projectile fragmentation facilities will be given. An illustration of the experimental difficulties will be demonstrated with some recent results in the region of the doubly magic ^{132}Sn, performed at RIKEN. The possibilities of performing TDPAC studies, both in fragmentation and in ISOL techniques will be discussed. This approach should allow accessing isomeric states with considerably shorter lifetimes, down to a few nanoseconds. An example will be given with recent studies at RIKEN (around ^{132}Sn) and at IFIN, Bucharest (around ^{208}Pb).

The AGATA Campaign at LNL: Recent Developments and Perspectives

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The Legnaro National Laboratories (LNL), one of the four national research centers of the Italian National Institute for Nuclear Physics (INFN), represent a cornerstone of European nuclear physics research. Located near Padua, Italy, LNL hosts a suite of advanced accelerators and experimental facilities, enabling cutting-edge investigations into nuclear structure and dynamics.

Among the most significant recent milestones at LNL is the installation and operation of the Advanced Gamma Tracking Array (AGATA), the state-of-the-art european gamma-ray spectrometer. AGATA marks a paradigm shift in gamma-ray detection, employing tracking techniques to achieve unprecedented resolution and efficiency. Since its reinstallation and commissioning at LNL in 2022, AGATA has been at the heart of a vibrant physics campaign, addressing fundamental questions in nuclear structure, reaction dynamics, and astrophysical processes.

This presentation offers an overview of LNL's infrastructure and ongoing research programs, with a particular focus on the AGATA campaign. The campaign is discussed in detail, highlighting its experimental configurations, scientific objectives, and initial results.

Nuclear structure of the ^{179}Pt isotope

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Experiment M20, carried out at the University of Jyväskylä (Finland), was dedicated to investigation of the isomeric states in ^{179}Au. As a by-product, γ rays produced during the β decay of the daughter nuclei were recorded with a BEGe-type HPGe detector, which provides excellent energy resolution. The aim is to identify known transitions in the spectrum and to search for previously unobserved radiation. Specifically for ^{179}Pt, three new transitions were found and assigned on the basis of coincidence analysis with the other germanium detectors at the focal plane.

Shape evolution of the Mo isotopes far from the valley of stability

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The ground-state shape of neutron and proton-rich molybdenum ($Z = 42$) isotopes draws attention as the theoretical prediction varies with the method of calculation. Phenomenologically, lowering of the energy of second 2^+ state observed in the neutron-rich Mo isotopes would indicate a small-amplitude gamma vibration, a gamma-soft rotor, or a rigid triaxial rotor. This feature is different from that of strontium ($Z = 38$) and zirconium ($Z = 40$) isotopes. Moreover, recent works opened a question of the interpretation of the second 2^+ band, showing a possibility of K-projected triaxial rotor for some neutron-rich nuclides [1].

We studied the neutron-rich even-A Mo isotopes $1^{106–114}$Mo using the EURICA HPGe array and the UK $LaBr_3$ array coupled to the WAS3ABi double-sided strip detector at RIBF, RIKEN. The level schemes of ^{110,112}Mo were extended for the second 2^+ and the third 4^+ bands. Moreover, we observed the first 2^+ and 4^+ states of ^{114}Mo for the first time. A small odd-even staggering of the second 2^+ band, and the experimental $B(E2;\, 2^+_1 \rightarrow 0^+_1)$ indicate that the ground-state shape of $^{106–110}$Mo would be prolate [2]. A similar odd-even staggering was observed in ^{112}Mo. In the case of ^{114}Mo, a comparison with the five-dimensional collective Hamiltonian calculation, employing a reduced pairing strength motivated from Ref. [3], implies that an oblate deformation would develop [4].

I will introduce the experimental work on even/A $^{106–114}$Mo and discuss the role of the triaxial degree of freedom in the neutron/rich Mo isotopes.

References

[1] T. Otsuka *et al.*, *Eur. Phys. J. A* **61**, 126 (2025).
[2] J. Ha *et al.*, *Phys. Rev. C* **101**, 044311 (2020).
[3] M. Yamagami, Y. R. Shimizu, T. Nakatsukasa, *Phys. Rev. C* **80**, 064301 (2009).
[4] T. Sumikama *et al.*, in preparation.

Probing nuclear deformation in the vicinity of ^{40}Ca and ^{56}Ni

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The concept of magic numbers constitutes a cornerstone of nuclear physics research. Over the past few decades, it has been well established that closed-shell nuclei exhibit spherical shapes in their ground states. However, as nucleons are added to or removed from complete shells, they tend to deform the microscopic mass distribution. Studies of deformed shapes are of key importance for the advancement of nuclear structure physics, especially the origin of the observed enhanced deformation in the vicinity of doubly-magic mass nuclei.

The observation of super-deformed structures (SD) at relatively low excitation energy in the mass $A\sim 40$ around doubly-magic Z=N=20 ^{40}Ca nucleus [1], is one of the most important discoveries of modern nuclear physics. Remarkably, the observed SD structures in these lighter nuclei are even less well understood than in heavier regions. Due to the vast reduction of nucleons involved and therefore complexity compared to heavy nuclei, $A \sim 40$ constitutes an ideal ground for investigating exotic structures within various theoretical frameworks. Recently, the electromagnetic structure of the nucleus ^{42}Ca with the advanced AGATA γ-ray tracking array was studied [2]. It was demonstrated for the first time that Coulomb excitation can probe SD structures. This work also provided the first direct experimental evidence for non-axially symmetric or triaxial SD shapes in the $A \sim 40$ neighborhood. The experimental studies of the deformation in this region are ongoing, aiming at investigating the origin of the emerging SD structures coexisting with the normally deformed bands in the Ar–Ca–Ti isotopes.

Going towards the medium mass region, the nickel isotopes offer a unique laboratory to investi gate shape evolution in the vicinity of another doubly-magic $N = Z$ nucleus, ^{56}Ni ($Z = N = 28$), which should exhibit similar structural properties to those observed in the $Z = N = 20$ region. Indeed, observation of the SD structures was also reported in ^{56}Ni, explained as the result of *mp–mh* excitations like in the case of ^{40}Ca [3]. However, recently, the questions on the validity of $Z/N = 28$ as a good magic number have been brought up, triggering the discussion on the deformation in the nickel region, including the signatures of shape coexistence. Microscopic and collective properties in the vicinity of ^{56}Ni shall be evaluated with the dedicated measurements of the deformation and the neighboring nuclei. To this end, the Coulomb excitation studies focused on the structure of ^{58,60,62}Ni isotopes are currently undertaken. These, together with the recent findings from the γ-ray and electron spectroscopy measurements reporting the unexpectedly large $E0$ transition strengths for the $2^+_2 \to 2^+_1$ transitions in ^{58,60,62}Ni [4], shall bring crucial information enabling the further discussion on the magical properties of Ni isotopes.

In this talk, I will present recent results from measurements designed to approach the well-deformed structures in Ca and Ni isotopes using the Coulomb excitation method, performed at the INFN LNL and IJC Lab, and compare them with state-of-the-art theoretical calculations.

References

[1] E. Ideguchi *et al.*, *Phys. Rev. Lett.* **87**, 222501 (2001).
[2] K. Hadyńska-Klęk *et al.*, *Phys. Rev. Lett.* **117**, 062501 (2016); *Phys. Rev. C* **97**, 024326 (2018).
[3] D. Rudolph *et al.*, *Phys. Rev. Lett.* **82**, 3763 (1999).
[4] L. J. Evitts *et al.*, *Phys. Lett. B* **779**, 396 (2018).

Applications of the charge plunger method

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The charge plunger method (CPM) is a technique that enables sub-nanosecond lifetime measurements in cases where the conventional recoil-distance Doppler-shift (RDDS) method is unfavourable due to large internal conversion coefficients for transitions depopulating the state of interest. This is especially relevant for highly collective states in heavy nuclei, where internal conversion dominates over γ-ray emission, e.g. $\alpha_{\mathrm{ICC}} = 1510$ in ^{254}No [1]. The CPM relies on the emission of several Auger electrons following an internal conversion, thus shifting the charge state to a higher value. Passing the ions through a recoil separator to determine their mass-to-charge ratio then allows one to determine the probability that a transition depopulates a state via internal conversion. By placing a charge-reset foil at a fixed distance after the target, similar to the role of a degrader or stopper foil in a conventional RDDS setup, the number of de-excitations before and after the reset foil can be determined, allowing for the state lifetime can be measured.

The CPM setup can be used in more applied studies for for determining emission multiplicities of Auger electrons following the creation of a vacancy in an inner-atomic orbital. This has relevance to Auger electron therapy, a form of radiotherapy that relies on the high multiplicity and short range of low-energy Auger electrons to provide precise targeting of cancerous cells [2]. For determining the impact of Auther electron emission, precise nuclear data measruements are required, not just for the energy of the emitted electrons but also the multiplicity, e.i. the average number of electrons emitted.

In this talk, the development of the CPM using the MARA recoil separator at the University of Jyväskylä Accelerator Laboratory is presented, including initial results from a recent experiment where the CPM has been applied to measure the lifetime of 2_1^+ states in the lighter mass rare-earth nuclei ^{128}Nd and ^{132}Sm. Alongside this, I will present results from an experiment using the GRETINA+FMA setup at Argonne National Laboratory, to measure Auger electron multiplicities in ^{197}Au, the daughter of ^{197}Hg, a candidate for targeted Auger electron therapy.

References

[1] T. Kibédi, T. W. Burrows, M. B. Trzhaskovskaya, P. M. Davidson, C. W. Nestor, *Nucl. Instrum. Methods Phys. Res. A* **589**, 202–229 (2008).

[2] A. Ku, V. J. Facca, Z. Cai, R. M. Reilly, *EJNMMI Radiopharmacy and Chemistry* **4**, 27 (2019).

Exploring the southwest corner with monopole transitions

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The structures of light even-even nuclei display a complex nature, featuring a-clustering, shape coexistence and super-deformations. In the mean-field approach a-like structures are emerging from the nuclear matter. Shape coexistence is a unique feature of self-bound, finite, quantum many-body systems in which two or more different shapes emerge at similar excitation energies. Super-deformation was discovered in medium to heavy nuclei, but they also present in lighter systems like ^{16}O, ^{40}Ca. With the improvement of the so-called no-core shell model calculations our understanding on nuclear structure can be challenged.

In even-even nuclei 0+ states are often associated with structures with different origin and/or different nuclear shapes. The formation region of *E0* transitions is inside the nucleus making them ideal tools to probe changes in the nuclear structure. In this talk we will review the recent results of *E0* transitions in ^{12}C [1], ^{24}Mg [2], ^{40}Ca [3] and more recently in ^{28}Si, using electron-positron pair spectroscopy.

References

[1] T.K. Eriksen, *et al.*, *Phys. Rev. C* **102** (2020) 024320
[2] J.T.H. Dowie, *et al.*, *Phys. Lett B* **811** (2020) 135855
[3] E. Ideguchi, *et al.*, *Phys. Rev. Lett* **128** (2022) 252501

Nuclear physics with muonic atom experiments

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Muonic atoms as laboratories for fundamental physics provide crucial input to quantum electrodynamics, the weak and the strong interaction. Muonic atom spectroscopy, i.e., the detection of the muonic X-rays emitted subsequently to the atomic capture of a negative muon, has been a very extensively used technique to determine the extent of the nuclear charge distribution. This method for determining nuclear charge radii complements the knowledge from electron scattering experiments and laser spectroscopy. Other properties such as the quadrupole moment of a nucleus can be extracted as well. In addition to the muonic X-rays, it is also possible to study the gamma rays emitted following the capture of the muon by the nucleus. This gives access to the nuclear excitation spectrum and is especially relevant for neutrinoless double beta decay as the momentum transfer in muon capture is high and thus very similar states can be probed.

This presentation will describe the basic techniques of muonic atom spectroscopy and its current applications that even include elemental analysis of historical artifacts and lithium batteries. Due to the improved muon beams nowadays, muonic atom spectroscopy has seen a revival in recent years and thus measurements that have so far been impossible are currently actively being pursued.

Reaction dynamics of exotic nuclei at Coulomb barrier energies

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As nuclear systems move away from stability, the binding energy of valence nucleons decreases, in some cases leading to extended matter distributions known as nuclear halos [1]. Two-neutron halo nuclei, such as ^{11}Li or ^{6}He, are Borromean systems: the three-body system (core+2n) is bound, yet none of its two-body sub-systems (core+n or 2n) are stable. Proton halos, such as those observed in ^{8}B and ^{17}Ne, are much less abundant due to the strong Coulomb repulsion between the valence proton(s) and the core. Interestingly, despite the low binding energy common to all halos, the reaction dynamics of proton and neutron haloes exhibit different features that are still not fully understood [2-5]. At high collision energies (above 100 MeV/A), where the reaction process is much faster than the typical nuclear motion, both systems exhibit well-known phenomena, such as broad transverse-momentum distributions and a large increase of total reaction cross sections. At energies around the Coulomb barrier, the collision time becomes comparable to the nucleons' internal motion, favouring the coupling between relative and collective degrees of freedom. Here, the intricate interplay between nuclear forces and nucleon correlations makes the reaction dynamics of neutron and proton haloes distinct [6-8]. Measurements of breakup, transfer, and fusion processes can be used to disentangle these effects. This contribution discusses the characteristic features of the low-energy dynamics of nuclear haloes, focusing on the latest experimental results and their interpretation through optical model and coupled channel calculations.

References

[1] I. Tanihata *et al.*, *Phys. Rev. Lett.* **55** (1985), 2676.
[2] K. Riisager *et al.*, *Phys. Scr.* T**152** (2013), 014001.
[3] A. M. Sánchez-Benítez *et al.*, *Nucl. Phys. A* **803** (2008), 30.
[4] R. Sparta *et al.*, *Phys. Lett. B* **820** (2021), 136477.
[5] L. Yang *et al.*, *Nat. Commun.* **13** (2022), 7193.
[6] J. Díaz-Ovejas *et al.*, *Phys. Lett. B* **843** (2023), 138007.
[7] V. G. Távora *et al.*, *Phys. Lett. B* **855** (2024), 138770.
[8] K. Palli *et al.*, *Phys. Rev. C* **111** (2025), 024615.

Shape coexistence in neutron-deficient Pb isotopes
Recent results from Jyväskylä

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Shape coexistence refers to a phenomenon where multiple shapes occur within the same nucleus. While this phenomenon has been proposed to exist in all nuclei[1], neutron-deficient Pb isotopes near the N=104 mid-shell have been a primary focus for detailed investigations for decades. In particular, neutron-deficient Pb isotopes, such as ^{184,186,188,190}Pb, are exhibiting evidence of three distinct shapes[2-4]. Within the shell-model framework, these three shapes are associated with $0p$-$0h$ (spherical), $2p$-$2h$ (oblate) and $4p$-$4h$ (prolate) configurations.

In the last few years, spectroscopic studies performed at the Accelerator Laboratory of Jyväskylä have advanced the understanding of the shape coexistence phenomenon in neutron-deficient Pb isotopes. These experiments allowed us to reassign states between different collective configurations and provided insight into the mixing between these configurations.

The ^{186,188,190}Pb nuclei have been investigated with two complementary in-beam experimental techniques[5-8]. One was by utilising a combined γ-ray and conversion electron spectrometer, SAGE, to be sensitive to E0 transitions and allowing us to assess the mixing between configurations. The other employing a plunger device for measuring lifetimes, which enabled assessment of the collectivity of different structures.

The most recent result at Jyväskylä focused on ^{184}Pb utilising recoil-decay-tagging method in conjunction with the JUROGAMII germanium detector array[9]. This experiment led to the identification of non-yrast structure for ^{184}Pb for the first time. Observing hints of non-yrast structures in this nucleus is currently at the limit of feasibility, as its production via fusion-evaporation reaction yields low cross-section.

This presentation will summarise the latest in-beam experiments around mid-shell Pb isotopes performed at the Accelerator Laboratory in Jyväskylä. The experimental results will hopefully generate new theoretical developments in this region.

References
[1] K. Heyde and J. L. Wood, *Phys. Scr.* **91**, 083008 (2016).
[2] J. F. C. Cocks *et al.*, *Eur. Phys. J. A* **3** (1998).
[3] A. N. Andreyev *et al.*, *Nature* **405**, 430–433 (2000).
[4] N. Bijnens *et al.*, *Z. Phys. A* **356**, 1 (1999).
[5] T. Grahn *et al.*, *Phys. Rev. Lett.* **97**, 062501 (2006).
[6] J. Ojala *et al.*, *Commun. Phys.* **5**, 213 (2022).
[7] P. Papadakis *et al.*, *Phys. Lett. B* **858**, 139048 (2024).
[8] A. Montes-Plaza *et al.*, *Commun. Phys.* **8**, 8 (2025).
[9] J. Ojala *et al.*, *Phys. Lett. B* **867**, 139601 (2025).

Effects of Kaonic condensates and neutron decay in compact objects

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The recent observation of the compact star XTE J1814–338 with a mass of $M = 1.2^{+0.05}_{-0.05}\,M_\odot$ and a radius of $R = 7^{+0.4}_{-0.4}\,\mathrm{km}$, together with HESS J1731–347, which has a mass of $M = 0.77^{+0.20}_{-0.17}\,M_\odot$ and a radius of $R = 10.4^{+0.86}_{-0.78}\,\mathrm{km}$, they provide evidence for the possible presence of exotic matter in the core of neutron stars and significantly enhance our understanding of the equation of state of dense nuclear matter. In our recent studies [1-2] we investigated the possible existence of negatively charged kaons and neutral antikaons in neutron stars by employing a relativistic mean-field model with first-order kaonic (K^- and $\bar{K}^0$) condensates. This represents a first alternative attempt aimed to explain the bulk properties of the XTE J1814–338 object and at the same time the HESS J1731–347 object, using a mixture of kaon condensation in dense nuclear matter. The kaon potential is further found to be compatible with values obtained using kaonic atoms. In addition, we compare our analysis approach with the recent observations of PSR J0437–4715 and PSR J1231–1411 pulsars, proposing that to simultaneously explain the current variety of astrophysical objects, it is essential to resurrect a scenario of two distinct branches, each corresponding to a different composition of nuclear matter.

In addition to this, we will explore the possibility originated from recent experimental observations, that neutron decay is always accompanied by emission of an electron while in 1% of cases, a proton is not emitted. We developed a scenario [3] kinematically compatible with the experimental observation, where neutron decay results in the production of two dark-matter particles of about half the mass of a neutron, and we test the properties of neutron stars with an admixture of such particles. Constraints on mass and coupling to vector dark boson are obtained. The structure of the compact object is modified to a dark star with a shell of nucleonic matter around nuclear saturation density.

References

[1] M. Veselský, P. S. Koliogiannis, V. Petousis, J. Leja, Ch. C. Moustakidis, *Phys. Lett. B* **860**, 139185 (2025).
[2] M. Veselský, V. Petousis, P. S. Koliogiannis, Ch. C. Moustakidis, J. Leja, *Phys. Rev. D* **111**, L061308 (2025).
[3] M. Veselský, V. Petousis, Ch. C. Moustakidis, M. Vikiaris, arXiv:2507.17340 (2025).

Exploring beta-delayed neutron emitters through spin-orientation experiments

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Beta-delayed neutron emission is the primary decay mode of very neutron-rich nuclei along the r-process nucleosynthesis path [1]. These exotic nuclei are extremely challenging to study experimentally, yet recent years have seen significant progress. Key advancements include the expansion of experimental data on ground-state properties of beta-delayed one- and multi-neutron emitters [2, 3], as well as the first detailed neutron spectroscopy studies of representative r-process nuclei [4, 5]. A recent milestone was the first detailed study of two-neutron emission in an r-process nucleus [5]— a crucial step towards understanding multi-neutron emission. Notably, recent results on strong beta-delayed neutron emitters show that long-standing assumptions about neutron emission must now be reconsidered [5-7].

Experiments with spin-oriented nuclei offer a powerful avenue for advancing the exploration of beta-delayed neutron precursors. The radiation anisotropy observed in the beta decay of polarised nuclei can be utilised for unambiguous spin-parity assignments for neutron-emitting states populated by allowed transitions [8]. A novel experimental approach [9] that combines nuclear-spin orientation with decay spectroscopy has recently been implemented at CERN ISOLDE. The VITO beamline [10], a state-of-the-art setup for laser-induced polarisation of radioactive beams, now features a dedicated end-station DeVITO [12] capable of measuring beta-particle emission asymmetries in coincidence with delayed neutrons and gamma rays. Preliminary results from the commissioning campaigns at VITO [11] demonstrate the strong potential of this method at ISOLDE and pave the way for future studies of beta-delayed neutron emitters through spin-orientation experiments.

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References

[1] M. Mumpower, R. Surman, G. McLaughlin, and A. Aprahamian, *Prog. Part. Nucl. Phys.* **86** (2016) 86.
[2] A. Tolosa-Delgado *et al.*, *Phys. Rev. Lett.* **134** (2025) 172701.
[3] V. H. Phong *et al.*, *Phys. Rev. Lett.* **129** (2022) 172701.
[4] Z. Y. Xu, M. Madurga, R. Grzywacz *et al.*, *Phys. Rev. Lett.* **131** (2023) 022501.
[5] P. Dyszel, R. Grzywacz, Z. Y. Xu *et al.*, *Phys. Rev. Lett.*, accepted (2025).
[6] Z. Y. Xu, R. Grzywacz *et al.*, *Phys. Rev. Lett.* **133** (2024) 042501.
[7] J. Heideman, R. Grzywacz *et al.*, *Phys. Rev. C* **108** (2023) 024311.
[8] K. S. Krane, in: H. Postma, N. J. Stone (eds.), *Low Temperature Nuclear Orientation*, North-Holland (1986).
[9] H. Miyatake *et al.*, *Phys. Rev. C* **67** (2003) 014306.
[10] M. Kowalska *et al.*, *J. Phys. G: Nucl. Part. Phys.* **44** (2017) 084005.
[11] M. Piersa-Siłkowska, M. Madurga, M. Kowalska *et al.*, CERN-INTC-2023-026 (2023).
[12] (DeVITO end-station) Commissioning details as cited in the source abstract.

Seniority scheme for $j = 9/2$ orbitals

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The seniority scheme assumes that the low lying states in a nucleus can be described considering one single orbital, and there is no seniority mixing. The aim of the present paper is to test the validity of this, by focusing on the reduced B($E2$) transition strengths, considered to provide more stringent test of the wave function than the excitation energies.

The largest amount of experimental data on seniority is related to $j = 9/2$ orbitals. The proton $g_{9/2}$ orbital between the $Z = 40$ sub-shell and the $Z = 50$ shell closures is isolated from other orbitals, therefore the $N = 50$ nuclei with $Z = 42$–48 provide a stringent test of seniority. Similarly, the proton $h_{9/2}$ orbital is the first one above the $Z = 82$ magic number, while the neutron $g_{9/2}$ is first above $N = 126$, making the $N = 126$ isotones and the neutron-rich $Z = 82$ Pb isotopes good test cases.

All available data, both on even- and odd-mass nuclei, were considered. The seniority scheme provides a good approximation for all these three regions, with the best fit given by the lead isotopes. In addition, shell model calculations using well established interactions were performed. In the $N = 50$ and $Z = 82$ considering all orbitals within a shell provide only a limited improvement in reproducing the data when compared to the seniority scheme. In contrast, the shell model provides much better agreement for $N = 126$ nuclei, where the proton $f_{7/2}$ orbital has increasing effect on the transition strengths as the $j = 9/2$ orbital is filled. In order to further test whether the lead isotopes provide the best example of the seniority scheme, and investigate the possible effect of the neutron $i_{11/2}$ orbital, more experimental information is required, especially for ^{214,215,216}Pb.

Quadrupole excitations within the self-consistent mean-field theory

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I present applications of the mean-field approach to some phenomena "beyond the mean-field", namely collective quadrupole excitations in even-even nuclei. First, I briefly recapitulate the most widely used effective nuclear interactions of both non-relativistic and relativistic types. Then I focus on the construction of the collective Hamiltonian and other operators in the deformation space and show some examples of the application of this approach to experimental spectroscopic data. I also mention other approaches based on the Generator Coordinate method and possible extensions to odd and odd-odd nuclei.

Structure of low-lying excited states in nuclei by Skyrme QRPA

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Density functionals (of Skyrme, Gogny or Relativistic-Mean-Field type) are commonly employed for the theoretical description of ground and excited states of atomic nuclei, mainly the even-even ones. They are based on phenomenological interactions, and provide a microscopic description along the whole nuclear chart, including deformation. The first step consists in the calculation of ground state by HFB (Hartree-Fock-Bogoliubov) or HF+BCS, and can be followed by GCM (Generator Coordinate Method) or QRPA (Quasiparticle Random Phase Approximation). The research of our team is focused on the implementation of QRPA on top of spherical and axially-deformed ground states computed by Skyrme HF+BCS. Traditionally, the QRPA method was primarily aimed to the calculation of giant resonances, which occur at higher excitation energies, such as 10 MeV and more. Nevertheless, QRPA treats collective and $2qp$ excitations on the same footing, so we have been employing it already for some time also for the description of certain individual low-energy excited states in nuclei. Once the excited state is well defined (as compared to the continuum of giant resonances), its structure may be further tested by certain experimental techniques. Recently, we showed that the results of inelastic electron scattering support the theoretical prediction of isoscalar vortical currents in low-lying 1^- states in ^{58}Ni [1]. In another study [2], we calculated the structure of low-lying excited states in nobelium, and we predict the pairing-vibrational character of the first excited 0^+ state in ^{254}No. Calculations of low-lying electric dipole (1^-) and in particular monopole (0^+) excitations greatly benefit from the corrections for spuriosity, which we developed for matrix-based QRPA in a form of projection-before-diagonalization [3].

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References

[1] P. von Neumann-Cosel *et al.*, *Phys. Rev. Lett.* **133**, 232502 (2024).
[2] V. O. Nesterenko *et al.*, *Phys. Rev. C* **111**, 064322 (2025).
[3] J. Kvasil, A. Repko, V. O. Nesterenko, *Eur. Phys. J. A* **55**, 213 (2019).

Accessing the immediate vicinity of ^{100}Sn with a hot-cavity laser ion source

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The different configurations of the atomic nucleus, a self-bound quantum mechanical mesoscopic system, form a landscape of over 3000 known isotopes. However, even more than 100 years since its discovery by Ernest Rutherford, the complexity of the nucleus continues to elude a global theoretical description. To drive theory development, new experimental data are required from unexplored reaches of the chart of nuclei. A key area for new data is the immediate region below the heaviest bound self-conjugate nucleus, tin-100. This proton-rich region past the shell closure has been and continues to be the subject of intense experimental and theoretical research [1]. However, only limited information is available for the ground-state properties in the region, mainly due to challenges in producing these isotopes with sufficiently high yields. Recently, new ultra-sensitive measurement techniques developed at the University of Jyväskylä Accelerator Laboratory opened the immediate vicinity of tin-100 to optical spectroscopy and mass spectrometry studies [2,3].

Here I will present our most recent result on mass and optical studies on silver [4] and palladium isotope chains, culminating on the masses of isotopes ^{94}Ag and ^{92}Pd which we recently accessed at the IGISOL facility at the Jyväskylä Accelerator Laboratory [4].

References

[1] M. Górska, *Physics* **4**(1), 364–382 (2022).
[2] M. Reponen *et al.*, *Rev. Sci. Instrum.* **86**(12), 123501 (2015).
[3] M. Reponen *et al.*, *Nat. Commun.* **12**, 4596 (2021).
[4] Z. Ge *et al.*, *Phys. Rev. Lett.* **133**, 132503 (2024).

MIRACLS — laser spectroscopy of radioactive nuclei in an MR-ToF device

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Over the last decade, remarkable advances have been made in the theoretical description of electromagnetic properties of atomic nuclei, stimulated by a wealth of high-quality experimental data on short-lived radionuclides (see references [1-6]). In particular, nuclear charge radii have proven to be highly sensitive probes of phenomena such as pairing, deformation, or shell closures, and thus represent intriguing experimental benchmarks for modern nuclear structure theory.

Collinear Laser Spectroscopy (CLS) is a highly effective, nuclear model-independent tool to experimentally access properties such as nuclear spin, electromagnetic moments, and charge radii with high accuracy and precision. In order to improve the sensitivity of conventional CLS, the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) exploits a new experimental approach by conducting CLS in a high-energy (> 10 keV) multi-reflection time-of-flight (MR-ToF) device [7, 8]. This is a type of ion trap which utilizes two electrostatic mirrors to reflect ion bunches back and forth for several thousands of revolutions. Hence, the ion bunches can be probed by the laser multiple times per measurement cycle to obtain higher statistics than with conventional CLS, which can study each ion bunch only once. In the most favourable spectroscopy schemes, offline measurements have demonstrated a sensitivity for yields as low as ~ 5 ions per second delivered to MIRACLS.

Building on these advances, a newly-built MIRACLS setup has been coupled to ISOLDE which has recently been exploited for the first time to determine nuclear charge radii of neutron-rich magnesium isotopes in the “island of inversion”, extending previous measurements by COLLAPS [9]. A second experimental campaign has also been conducted in August this year to measure neutron-poor cadmium isotopes, which will push our knowledge of cadmium charge radii down to the $N = 50$ shell closure.

In this contribution, I will describe the recent advances in the MIRACLS technique, present the results of the recent magnesium and cadmium campaigns, and discuss their physics implications.

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References

[1] R. F. Garcia Ruiz *et al.*, Nat. Phys. **12** (2016), 594–598.
[2] M. Hammen *et al.*, PRL **121**:102501 (2018).
[3] R. P. de Groote *et al.*, Nat. Phys. **16** (2020), 620–624.
[4] S. Malbrunot-Ettenauer *et al.*, PRL **128**:022502 (2022).
[5] A. Koszorus *et al.*, Nat. Phys. **17** (2021), 439–443.
[6] J. Karteim *et al.*, Nat. Phys. **20** (2024), 1719–1725.
[7] S. Sels *et al.*, NIMA B. **463** (2020), 310–314.
[8] F. M. Maier *et al.*, NIMA A. **1048** (2023).
[9] D. T. Yordanov *et al.*, PRL **108**:042504 (2012).

Lifetime measurements with reversed plunger at LNL INFN

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High-resolution gamma-ray spectroscopy plays a major role in the nuclear structure study, allowing for the measurement of physical observables related to the decay of the excited nuclear levels. From this precise measurement of the gamma rays emitted from excited nuclear levels one can obtain not only the excitation energy, but also the reduced transition probabilities and their associated quantum numbers, by measuring the lifetime of excited states, from which one can deduce the reduced transition matrix elements. The leading role in this field plays the state-of-the-art European project of AGATA (Advanced GAmma Tracking Array) spectrometer, which is currently installed in LNL INFN. Such a technology provides superior efficiency and energy and position resolution (continuous angle distribution). At present, AGATA is coupled to the large acceptance magnetic spectrometer PRISMA, which provides an unique opportunity to study neutron-rich isotopes via multi-nucleon transfer reaction. We have developed and successfully used a novel technique of lifetime measurements with a plunger device in its reversed configuration and analysis based on the reaction reconstruction of the target-like binary partner in the reaction of ^{136}Xe beam with ^{198}Pt target. Preliminary results of the experiment 22.76 performed with AGATA+PRISMA+Plunger at LNL INFN will be presented.

Study of isomerism in ^{179}Au

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Odd-mass neutron-deficient nuclei near the $Z = 82$ closed shell are currently the focus of extensive experimental research due to the frequent occurrence of shape coexistence and nuclear isomerism in this region. In 2022, a new isomeric state in ^{179}Au was discovered at $E = 1743(17)$ keV, with $I^{\pi} = 19/2^{+}$ and a half-life of $T_{1/2} = 2.16(8)\,\mu$s. However, limited statistics allowed the identification of only four decay paths [1]. Surprisingly, no analogous isomer had been observed in the neighbouring odd-mass Au isotopes. Therefore, a new dedicated experiment was carried out in Jyväskylä, employing the RITU separator and a non-standard focal-plane setup with two multiwire proportional counters. The aim of the experiment was to improve statistics and identify new, weaker decay branches. Preliminary results of this analysis will be presented in the contribution.

The previous experiment also revealed the existence of a low-lying $11/2^{-}$ isomer with $T_{1/2} = 196(15)$ ns and $E = 181(17)$ keV, associated with a $1h_{11/2}$ proton-hole configuration. One of its feeding transitions was deduced to have a mixed $E0 + M1(+E2)$ multipolarity, coming from a new $11/2^{-}$ band-head state. The presence of the $E0$ component was reinvestigated using the new dataset.

References

[1] M. Balogh *et al.*, *Phys. Rev. C* **106**, 064324 (2022).

Expanding the EAGLE Array at HIL: The FLASH Campaign for Fast-Timing Spectroscopy

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The EAGLE array (European Array for Gamma Levels Evaluations) [1] is a multi-configuration detector set-up for in-beam nuclear spectroscopy studies at the Heavy Ion Laboratory (HIL) of the University of Warsaw. It can accommodate up to 30 Compton suppressed HPGe detectors.

Building on this foundation, a new campaign, FLASH (Fast-Timing $LaBr_3$ Array for Spectroscopy at HIL), is planned to expand the experimental capabilities of the EAGLE array. By incorporating up to 15 $LaBr_3$(Ce) detectors, the setup will enable advanced fast-timing measurements, opening a possibility for precise lifetime measurements of excited nuclear states.

A first test experiment was carried out with six $LaBr_3$(Ce) detectors mounted in anti-Compton shields and combined with 16 Compton-suppressed HPGe detectors from the EAGLE array. Preliminary results will be presented, along with perspectives for future collaborative research within the FLASH campaign.

References

[1] A. Mierzejewski *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **659**, 84 (2011).

Marvels, myths and mysteries in nuclear moments

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Magnetic moments (μ) give unique insights into the nuclear quantum many body problem. Some of these insights will be discussed, along with cases where the magnetic moments question traditional interpretations of data, the consequential open questions, and possible directions to answer these questions.

The role of g factors ($g = \mu/I$) in revealing the pathway from seniority structures in semi-magic nuclei towards collectivity will be discussed, including their role and limitations in resolving the question of vibration versus multiple shape coexistence in the mid-shell Cd isotopes.

Pairing has long been held to play a role in nuclear moments of inertia, and hence collective g factors because for rotors $g_R \approx \mathcal{J}_p/(\mathcal{J}_p + \mathcal{J}_n)$, where $\mathcal{J}_p$ and $\mathcal{J}_n$ are the moments of inertia of the protons and neutrons, respectively; see e.g. Ref. [1]. The traditional view for odd-A rotational nuclei is that, due to the effect of blocking on the core moment(s) of inertia, g_R *increases* for odd-Z, whereas for odd-N it *decreases*, compared to that of the even-even neighbor [2].

This view is challenged by the E_γ versus I plots as shown in John Wood's contribution to this conference, as well as by the discussion of bands with near identical moments of inertia [3]. A comprehensive review of the experimental data on odd-A and neighboring even-A g-factor data is called for. It can be anticipated that, while ground-state moment data are extensive and precise, excited-state measurements in odd-A rotational bands are scarce. The challenge is that the ground-state moment is determined primarily by the single-particle g factor, g_K, whereas the excited-state g factors approach g_R only for $I \gg K$. On the theoretical side, a most recent comprehensive set of density functional theory (DFT) calculations for odd-N nuclei through the rare earth region, without invoking effective charges or effective g factors in the $E2$ and $M1$ operators, represents a considerable step forward and a solid theoretical basis for further investigation [4].

Aside from the recent DFT calculations such as in Ref. [4], it is customary to introduce effective operators in theoretical evaluation of magnetic dipole moments. Detailed calculations of the effective $M1$ operator have been made for nuclei with a single nucleon outside a doubly magic core. The fact that the $M1$ operator couples strongly to spin-orbit partners (core polarization) is key. However, it is not clear how these effective operators should be modified for open shell nuclei. Often the effective operator in shell model calculations is set via a global fit to data. It will be shown that the $M3$ magnetic octupole moment, in most of the cases that have been measured [5], can be estimated with considerable accuracy from the measured dipole moment. The level of agreement is a surprise, given that the core-polarization mechanism associated with the $M1$ operator is not expected to be applicable for the $M3$ operator. Implications and possible explanations, along with some strategies for further investigation, will be discussed.

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References

[1] A. E. Stuchbery, *Nucl. Phys. A* **589**, 222 (1995).
[2] A. Bohr and B. R. Mottelson, *Nuclear Structure* Vol. II, Benjamin, Reading (1975), p. 255.
[3] C. Baktash, B. Haas, W. Nazarewicz, *Annu. Rev. Nucl. Part. Sci.* **45**, 485 (1995).
[4] J. Dobaczewski, A. E. Stuchbery *et al.*, submitted to *Phys. Rev. C*; arXiv:2509.26549 (2025).
[5] S. Bofos, T. J. Mertzimekis, *At. Data Nucl. Data Tables* **159**, 101672 (2024).

Synthesis of heavy nuclei in multinucleon transfer reaction ^{136}Xe + ^{238}U close to $0°$

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Information on the heaviest elements have been obtained up to now via fusion-evaporation reactions. It is however well known that the only nuclei one can reach using fusion-evaporation reactions are neutron deficient and moreover in a very limited number (because of the limited number of beam-target combinations). An alternative to fusion-evaporation can be deep-inelastic collisions. Indeed, theoretical calculations [1] predict large cross-sections for neutron-rich heavy elements production close to zero degrees and recent experiments have been performed showing exciting results [2, 3, 4]. At the end of 2023, we have performed a first preliminary experiment at Argonne National Laboratory. The goal of the experiment was to investigate deep inelastic reactions mechanisms in the heavy elements region using the Gammasphere germanium array coupled to the AGFA (Argonne gas-filled analyzer) separator with the implantation-decay station (PPAC, DSSD and silicon tunnels) and germanium clover detectors XArray at the focal plane.

In this talk I will report on the result obtained in the experiments and I will give you some details about the further experiments and developments planned.

References

[1] V. I. Zagrebaev and W. Greiner, *Nucl. Phys. A* **944**, 257–307 (2015).
[2] S. Heinz *et al.*, *Eur. Phys. J. A* **52**, 278 (2016).
[3] A. Di Nitto *et al.*, *Phys. Lett. B* **784**, 199–205 (2018).
[4] J. S. Barrett *et al.*, *Phys. Rev. C* **91**, 064615 (2015).

The $^{55\text{-}58}$Co isotopes production in photonuclear reactions

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Data on photonuclear reactions are necessary for studying fundamental problems in various disciplines, e.g. astrophysics, theoretical description of the structure of the atomic nucleus, the mechanism of nuclear reactions, competition between statistical and direct reaction channels, etc. In addition, these data hold significant value for both medical and applied physics research, contributing to advancements in pharmaceutical development, the optimization of fast reactor designs, and the refinement of accelerator-driven subcritical systems. However, the lack of experimental data severely restricts both the general insight into the processes of γ-quantum interaction with nuclei and the model-approach testing capabilities. There is a particular lack of data for photonuclear reactions with the escape of charged particles.

The photonuclear production of the $^{55-58}$Co isotopes on natural nickel targets was investigated. The data were collected in a series of experiments carried out at the linac LUE-40 RDC "Accelerator" NSC "Kharkiv Institute of Physics and Technology", Ukraine at bremsstrahlung end-point energy in the range $E_{\gamma\max} = 35$–95 MeV. For this purpose, an activation method and off-line γ-ray spectrometric technique were used. Experimental flux-average cross-sections $\langle\sigma(E_{\gamma\max})\rangle$ were obtained for the studied reactions. The comparison result of the obtained cross-sections $\langle\sigma(E_{\gamma\max})\rangle$ and the literature ones will be shown.

In the talk, the comparison of the measured data with the theoretical model predictions from the TALYS code will be discussed. The experiment and theory agree in the case of the production of the ^{56,57,58}Co nuclei. However, a significant discrepancy is observed when the production of ^{55}Co is considered.

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In this talk, the new project called "Experimental investigation of reactions with importance for understanding the astrophysical p-process mechanism" will be briefly presented. This project has received funding through the MSCA4Ukraine project, which is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union, the European Research Executive Agency or the MSCA4Ukraine Consortium. Neither the European Union nor the European Research Executive Agency, nor the MSCA4Ukraine Consortium as a whole nor any individual member institutions of the MSCA4Ukraine Consortium can be held responsible for them.

RITU and MARA, three decades of spectroscopy

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For three decades Nuclear Spectroscopy Group (NSG) has performed nuclear spectroscopic studies utilizing the in-flight separators RITU [1] and MARA [2]. The gas-filled recoil separator RITU has been in operation since 1994 and the activity with the vacuum-mode double focusing MARA started 2016. To perform spectroscopic studies the separators, need various efficient detector setups alongside. Continuous development work is needed to stay in the front line of research. A short historical review with some milestones will be presented.

References

[1] M. Leino *et al.*, *Nuclear Instruments and Methods in Physics Research B* **99** (1995) 653.
[2] J. Uusitalo *et al.*, *Acta Physica Polonica B* **50** (2019) 319.

New energy formula for nuclear "rotations"

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A new energy formula for rotational bands in odd-mass nuclei is presented. This formula takes the form

$$E = E_0 + \mathcal{A}[I(I+1) - K^2] - {}^1\!/\!_2\mathcal{B}(I - K) \qquad (1)$$

where E_0 is related to the band-head energy, $\mathcal{A}$ and $\mathcal{B}$ are energy constants, I is the total spin of the nucleus, and K is the directional component of I on the nuclear symmetry axis (modelled as a symmetric top). The parameter $\mathcal{A}$ closely matches the rotational parameter for the ground-state bands of neighboring even-even nuclei. The parameter $\mathcal{B}$ is characteristic of a given Nilsson configuration and may vary with deformation. Details will be presented, and the formula will be shown to provide a new view of the backbending phenomenon in even-even nuclei (via its underlying band-crossing interpretation). Consequences for nuclei relating to the concepts of collective rotation, moments of inertia, and Coriolis effects will be discussed.

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Studying multiple shape coexistence in Cd isotopes through Coulomb excitation

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Mid-shell even-even Cd isotopes were traditionally considered to be the best examples of vibrational nuclei. Recent studies that combined detailed γ-ray spectroscopy with sophisticated beyond-mean-field calculations had suggested [1,2] that the low-lying 0^+ states in ^{110,112}Cd possessed prolate, triaxial, and oblate shapes with rotational-like bands built upon them. Soon afterwards a similar picture was suggested for ^{106}Cd [3,4]. Simultaneously, recent IBM configuration mixing calculation with a partial dynamical symmetry approach has successfully reconciled the discrepancies of the experimental B($E2$) values with the multi-phonon vibrational interpretation arguing that the latter can be maintained in $^{110-116}$Cd [5,6].

In order to distinguish between various interpretations and verify the the multiple-shape-coexistence hypothesis, a series of Coulomb-excitation experiments were performed. This experimental technique represents an ideal tool to study nuclear deformation. It enables a direct determination of electromagnetic transition matrix elements between low-lying excited states including spectroscopic quadrupole moments and signs. Those can be further analysed in terms of quadrupole invariants [7] yielding model-independent information on shape parameters of individual states. This requires, however, extensive sets of high-precision experimental data.

A multi-faceted experimental program to ascertain the deformation of low-energy states in ^{110}Cd has been initiated. We seek to firmly establish the shape of the $0^+_{1,2,3}$ states through the use of the rotation-invariant sum rules for $E2$ transitions. Coulomb-excitation measurements were performed using various reaction partners: ^{14}N and ^{32}S beams with EAGLE at HIL UW (Warsaw, Poland) [8,9], ^{60}Ni beam with AGATA at LNL (Legnaro, Italy) [9] and ^{110}Cd beam on a ^{208}Pb target with GRETINA at ANL (Argonne , USA). These measurements have been complemented by an experiment performed at TRIUMF-ISAC with the GRIFFIN spectrometer examining the decays of ^{110}Ag/^{110}In that will provide high-precision data on γ-ray branching ratios and transition mixing ratios. First results on quadrupole deformation parameters for the $0^+_{1,2}$ states, demonstrating non-axial character of the ground state in ^{110}Cd [10], will be presented. These experimental findings will be discussed in the context of: (i) Symmetry-Conserving Configuration-Mixing approach [1,2] and, (ii) the general quadrupole Bohr Hamiltonian involving various interactions: SLy4 and UNEDF0.

A brief overview of recent Coulomb-excitation studies addressing shape coexistence in the neighbouring ^{112}Cd and ^{116}Cd isotopes performed at Legnaro Nuclear Laboratory (Italy) and Argonne National Laboratory (USA) will be outlined.

References

[1] P. E. Garrett *et al.*, *Phys. Rev. Lett.* **123**, 142502 (2019).
[2] P. E. Garrett *et al.*, *Phys. Rev. C* **101**, 044302 (2020).
[3] M. Siciliano *et al.*, *Phys. Rev. C* **104**, 034320 (2021).
[4] D. Kalaydjieva, PhD thesis, Université Paris-Saclay (2023).
[5] A. Leviatan *et al.*, *Phys. Rev. C* **98**, 031302 (2018).
[6] N. Gavrielov *et al.*, *Phys. Rev. C* **108**, L031305 (2023).
[7] K. Kumar *et al.*, *Phys. Rev. Lett.* **28**, 249 (1972).
[8] K. Wrzosek–Lipska *et al.*, *Acta Phys. Pol. B* **51**, 789 (2020).
[9] I. Z. Piętka *et al.*, *Acta Phys. Pol. Supp.* **18**, A26 (2025).
[10] K. Wrzosek–Lipska *et al.*, *Phys. Lett. B* (2025), submitted.

Pairing in fission

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Usually fission is described in terms of the evolution of the nuclear shape from the ground state of the nucleus up to the pre-scission configuration. In the microscopic picture, the energy dependence of shape evolution can be studied within the Hartree- Fock-Bogoliubov (HFB) mean field theory. To do so, one needs to arbitrary choose constraints on deformation parameters, associated (most often) with the "geometrical" degrees of freedom, like various multipolar moments or necking. In order to determine fission observables like spontaneous fission lifetimes, one needs to perform dynamic calculations that involve the evaluation of the action integral. This quantity is governed by the interplay between the potential energy landscape and the behaviour of collective inertias. Similar approach, although in a slightly different framework can be applied to determine fission fragments mass yield. Since the HFB equations are numerically expensive, one needs to find a reasonable balance between a proper choice of the most relevant degrees of freedom and computational time. The choice of the right set of degrees of freedom in the theoretical description of fission still remains one of the major challenges for contemporary nuclear structure physics [1,2,3]. Obviously quadrupole and octupole degrees of freedom are essential to describe nuclear evolution towards fission. However one should remember also about the non-negligible role of pairing correlations in fission dynamics which is a well known fact since many decades. It has been shown that an increase in the pairing gap parameter (simple, realistic model), leads to an increase in the penetrability of the fission barrier [4]. The main message from those studies is that there is a strong interplay between the potential energy which increases as a square of the pairing gap and the collective inertia - decreasing as an inverse of the pairing gap squared. As a consequence the least action path leads through regions with a larger pairing gap than the least energy path. There are several ways of including constraints associated with pairing correlations into the fission picture. We will present three options based on considering a pairing gap, the particle number fluctuations and pairing strength. Their impact on the fission description will be discussed.

References

[1] A. Zdeb, M. Warda, L. M. Robledo, *Phys. Rev. C* **104**, 014610 (2021).
[2] N. Schunck, L. M. Robledo, *Rep. Prog. Phys.* **79**, 116301 (2016).
[3] H. J. Krappe and K. Pomorski, *Theory of Nuclear Fission*, Lecture Notes in Physics, Vol. 838 (Springer, Berlin, 2012), p. 207.
[4] L. G. Moretto and R. P. Babinet, *Phys. Lett. B* **49**, 147 (1974).

Shapes of neutron-rich Zn nuclei

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We explored shapes and collectivity of neutron-rich Zn nuclei by combining new branching ratios and spin assignments from β decay with transition probabilities and spectroscopic quadrupole moments obtained via low-energy Coulomb excitation. I will present our results on ^{74}Zn [1,2] as well as preliminary ones obtained for ^{79}Zn [3].

From our high-statistics β-decay study performed with the GRIFFIN γ-ray spectrometer at TRIUMF [1] we obtained firm spin-parity assignments for the 2_2^+, 3_1^+, 0_2^+ and 2_3^+ states in ^{74}Zn. The relative $B(E2)$ values deduced using the measured branching and $E2/M1$ mixing ratios for transitions de-exciting the 2_2^+, 3_1^+ and 2_3^+ states allowed organisation of the states into rotational-like structures, namely a $K = 2$ 'γ' band and a $K = 0$ band built on the 0_2^+ state. The appearance of a 'γ' band at low excitation energy suggests that the triaxial degree of freedom plays an important role in the structure of ^{74}Zn. This conclusion is further supported by the fact that the spectroscopic quadrupole moment of its first 2_1^+ state, deduced from the our complementary Coulomb-excitation experiment [2] at the HIE-ISOLDE facility, is close to zero. Our observations are consistent with the new results of Monte-Carlo and conventional shell-model calculations, which both predict non-axial shapes of the ground-state bands in neutron-rich Zn nuclei. The excited structure built on the 0_2^+ state is interpreted as having a similar shape as that of the ground state, but arising from fewer neutron excitations across the energy gap for $N = 40$. This suggests that ^{74}Zn belongs to the $N = 40$ island of inversion, which has previously been thought to be limited from the north by the $Z = 26$ Fe isotopes.

The first and most direct evidence for shape coexistence in the nearest vicinity of ^{78}Ni came from the observation of a large isomeric shift for the $1/2^+$ isomeric state in ^{79}Zn [4], which based on the measured g factor [4] was assigned a 2h–1p intruder configuration related to neutron excitation across the $N = 50$ shell gap. The ground-state β_2 deformation of ^{79}Zn, estimated from its measured spectroscopic quadrupole moment [4], is equal to 0.15(2). If the measured isomer shift is entirely attributed to an increase of deformation, it leads to an estimate of $\beta_2 \approx 0.22$ for the isomer.

In order to provide an independent verification of this scenario using a complementary experimental approach, we used a ^{79}Zn beam from HIE-ISOLDE, post-accelerated to 4.0 MeV/A, that consisted of a mixture of nuclei in the $9/2^+$ ground state and the $1/2^+$ isomeric state (amounting to about 7% of the total), to populate via Coulomb excitation the excited states built on these two different configurations.

References

[1] M. Rocchini, P. E. Garrett, M. Zielińska *et al.*, *Phys. Rev. Lett.* **130**, 122502 (2023).
[2] A. Illana, M. Zielińska, M. Huyse *et al.*, *Phys. Rev. C* **108**, 044305 (2023).
[3] F. Angelini, PhD thesis, University of Padova, 2025.
[4] X. F. Yang, C. Wraith, L. Xie *et al.*, *Phys. Rev. Lett.* **116**, 182502 (2016).