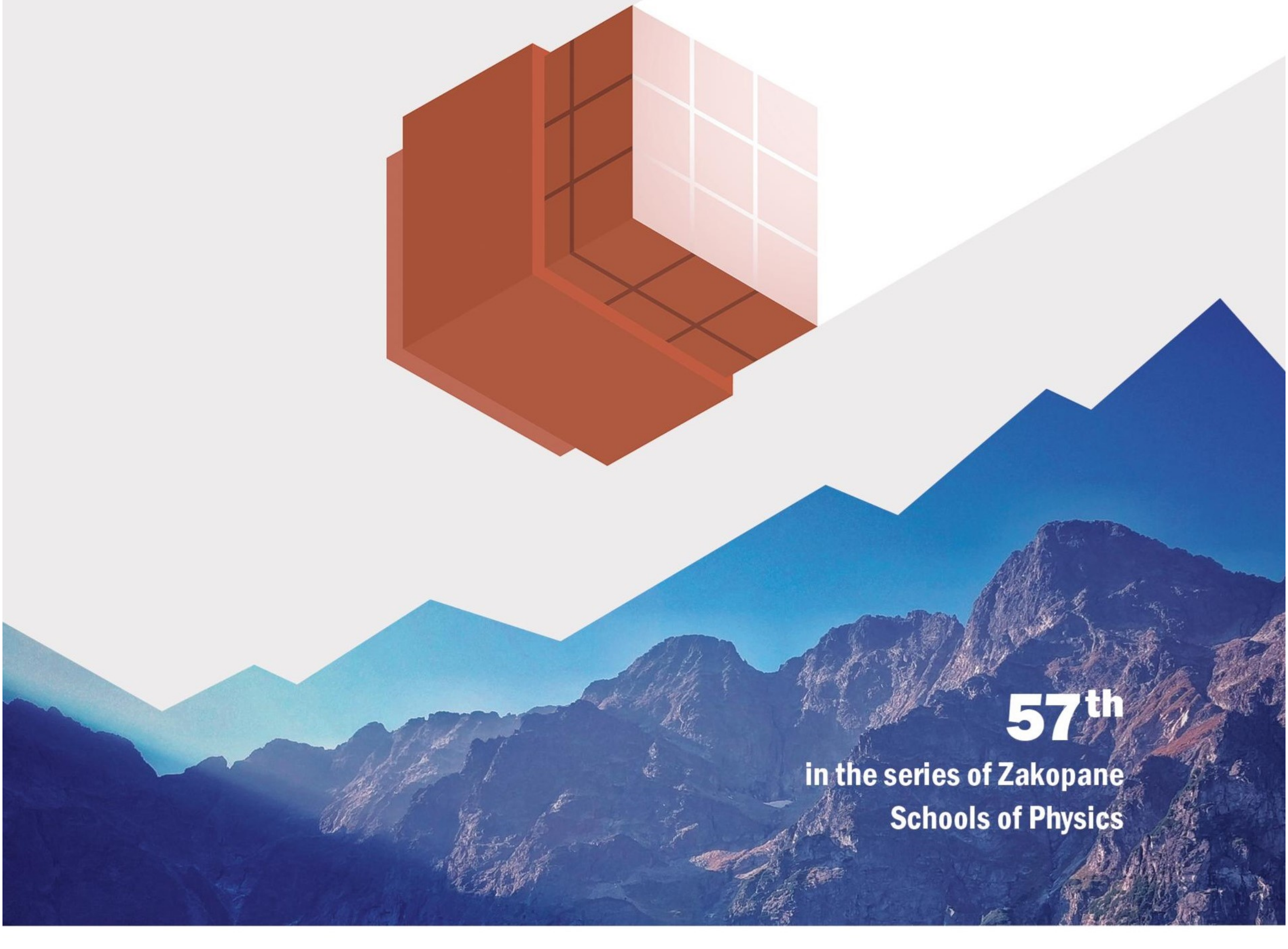
August 25 - September 1

ZAKOPANE CONFERENCE on Nuclear Physics 2024

Extremes of the Nuclear Landscape

Book of Abstracts



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BOOK OF ABSTRACTS

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ZAKOPANE CONFERENCE ON NUCLEAR PHYSICS 2024

"Extremes of the Nuclear Landscape"
August 25^{th} - September 1^{st}, 2024
Zakopane, Poland

Organized by:
The Henryk Niewodniczanski Institute of Nuclear Physics PAN

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About the Conference

The Zakopane Conference on Nuclear Physics, for historical reasons called School, has been organized since 1963 by the Henryk Niewodniczanski Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) and the Marian Smoluchowski Institute of Physics of the Jagiellonian University. Over the years the School became famous worldwide conference. Nowadays, the Zakopane Conference on Nuclear Physics has a character of a biennial international congress and is one of the major events in Poland, related to the low energy nuclear physics.

During the construction of the scientific program special attention has always been paid to offering the enthusiastic and pedagogical overviews of the most recent research subjects in nuclear physics from the both theoretical and experimental points of view. Young participants have also opportunity to present results of their research in short talks or on posters.

Currently, the conference theme is “Extremes of the Nuclear Landscape” and it is a forum for reviewing progress in theory and experiment at the forefront of nuclear research. This time a special attention will be given to the structure of exotic, unstable nuclei. We will also focus on collective excitations of the nuclear matter. Furthermore, the nuclear physics context of astrophysical processes will be widely discussed. An important part of the Conference will be devoted to presentations of newest achievements in the nuclear structure and reactions investigations and their influence on other disciplines. Noticeable discoveries in these areas are closely linked to the ongoing development of experimental facilities and detectors, which is among the conferences topics. The aim of the Conference is also to increase the mutual communication of physicists representing various areas of nuclear physics and to create opportunities for intense interaction between graduate students, young researchers and senior scientists.

The current 57th edition of the Zakopane Conference on Nuclear Physics is organized by IFJ PAN in cooperation with Coti Conference Time and is supported by NuPECC, Polish Academy of Sciences, and CAEN.

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PROGRAM

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Special lecture

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Monday, 26th of August

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Recent advances, applications, and ab initio derivations of nuclear DFT
11:00 – 13:00
Convener Jacek Dobaczewski

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14:00 – 18:00	**Hiking trip**		
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Recent advances, applications, and ab initio derivations of nuclear DFT
19:00 – 21:00
Convener Jacek Dobaczewski

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20:30 – 20:45	S	**Betania Backes** University of York	Accelerating nuclear DFT algorithms for finite-range interactions
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21:00 – 21:20	IT	**Manuela Rodríguez-Gallardo** University of Sevilla	Theo4Exp: a theory service for EURO-LABS community

Tuesday, 27th of August

Nuclear fission
08:30 – 10:00
Convener Jonathan Wilson

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09:00 – 09:30	IT	**Jorgen Randrup** Lawrence Berkeley National Laboratory	Generation of angular momentum in fission fragments
09:30 – 10:00	IT	**Dorthea Gjestvang** University of Oslo	Does neutron emission change the fission fragment angular momentum?
10:00 – 10:15	S	**Gilbert Bélier** CEA, DAM, DIF	Neutron and γ-ray emission in fast neutron induced fission
10:15 – 10:30	S	**Alex Cobo** GANIL, Caen	Isotopic fission fragments distributions in the Thorium region produced in inverse-kinematics with a ^{232}Th beam
10:30 – 11:00	**Coffee Break**		

Nuclear fission
11:00 – 13:00
Convener Jonathan Wilson

11:00 – 11:30	IT	**Laurent Gaudefroy** CEA, DAM, DIF	Deformation, angular momentum and excitation energy of fission fragments in the neutronless fission of ^{252}Cf(sf)
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12:15 – 12:30	IT	**Bogusław Włoch** University of Bordeaux, LP2I	Surrogate reactions at heavy-ion storage ring
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15:30 – 17:45

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16:30 – 16:45	S	**Bhoomika Maheshwari** GANIL, Caen	0_2^+ shape isomer in ^{44}S
16:45 – 17:00	S	**Marcell Begala** HUN-REN Atomki	Gamma-ray spectroscopy of ^{46}S and ^{47}S
17:00 – 17:15	S	**Massimiliano Luciani** University of Milan	Searching for the microscopic origin of shape coexistence in Ca isotopes
17:15 – 17:30	S	**Hemantika Sengar** GANIL, Caen	Exploring nuclear structures with fast neutrons at NFS
17:30 – 17:45	S	**Konstantin Stoychev** University of Guelph	Magnetic moments of isomeric states around ^{68}Ni
18:00 – 19:00	**Dinner**		

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15:30 – 17:45

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15:45 – 16:00	S	**Yuliia Hrabar** University of Lund	Deuteron evaporation and proton emission in the upper fp shell
16:00 – 16:15	S	**Konstantin Mashtakov** University of Guelph	Beta-decay study of the shape coexistence in ^{98}Zr
16:15 – 16:30	S	**Johannes Sørby Heines** University of Oslo	New lifetime measurements in the Ru chain: investigating the evolution of triaxiality
16:30 – 16:45	S	**Bram van den Borne** KU Leuven	Probing nuclear structure changes in odd-odd nuclei below Z = 50 with Ag
16:45 – 17:00	S	**Andrea Horvat** Ruder Boskovic Institute	Constraints on the symmetry energy from relativistic Coulomb excitation
17:00 – 17:15	S	**Adam McCarter** University of Liverpool	The study of proton-emitting nuclei near the N=82 shell closure
17:15 – 17:30	S	**Polytimos Vasileiou** National & Kapodistrian University of Athens	Investigating quadrupole bands in even-even Hf and W
17:30 – 17:45	S	**Gee Bartram** University of Surrey	Isomeric and beta decay transitions and lifetimes in the neutron-rich N=126 region
18:00 – 19:00	**Dinner**		

POSTER SESSION
19:00 – 21:30

Wednesday, 28th of August

Various facets of shape coexistence
08:30 – 10:30
Convener Silvia Leoni

08:30 – 09:00	IT	**Takaharu Otsuka** RIKEN and University of Tokyo	Prevailing triaxial shapes in atomic nuclei and a quantum theory of rotation of composite objects
09:00 – 09:30	IT	**Paul Garrett** University of Guelph	Shape transitions and coexistence in the Sr - Ru isotopes
09:30 – 10:00	IT	**Jonathan Wilson** IJCLab, Orsay	High-resolution studies of the back decay of fission shape isomers
10:00 – 10:15	S	**Cristian Costache** IFIN-HH, Magurele	Investigating the shape coexistence phenomena in ^{62}Ni
10:15 – 10:30	S	**Desislava Kalaydjieva** University of Guelph	β decay of ^{100}Y studied with GRIFFIN
10:30 – 11:00	**Coffee Break**		

Various facets of shape coexistence
11:00 – 13:00
Convener Silvia Leoni

11:00 – 11:30	IT	**Javier Menendez** University of Barcelona	^{28}Si: spherical, oblate, prolate and superdeformed states?
11:30 – 12:00	IT	**Franco Galtarossa** INFN, Padova	Shape coexistence probed via transfer reactions with AGATA at LNL
12:00 – 12:30	IT	**Katarzyna Wrzosek-Lipska** HIL UW, Warsaw	Shape coexistence in Cd isotopes studied with safe and un-safe Coulomb excitation
12:30 – 12:45	S	**Iwona Piętka** HIL UW, Warsaw	Coulomb excitation of ^{110}Cd studied with AGATA at LNL
12:45 – 13:00	S	**Giacomo Corbari** University of Milano and INFN	Study of shape coexistence in Sn isotopes around A=110
13:00 – 14:00	**Lunch**		

Afternoon Session
15:30-18:00

15:30 – 16:00	IT	**Krzysztof Rykaczewski** Oak Ridge National Laboratory	Towards solving the nuclear reactor antineutrinos puzzle
16:00 – 16:25	IT	**Faïçal Azaïez** LNL-INFN, Legnaro-Padova	The status and future plans of the SPES project
16:25 – 16:50	IT	**Kevin Insik Hahn** Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon	Research activities at CENS and status of RAON
16:50 – 17:05	S	**Karl Hauschild** IJCLab, Orsay	The SHEXI concept: superheavy element x-ray identification
17:05 – 17:20	S	**Istvan Kuti** HUN-REN Atomki	DIAMANT at HIL — the NEEDI setup
17:20 – 17:35	S	**Pavol Mosat** GSI, Darmstadt	Spectroscopy of superheavy nuclei with ANSWERS at TASCA
17:35 – 17:50	S	**Andrea Raggio** University of Jyväskylä,	Collinear laser spectroscopy of U isotopes at IGISOL
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18:00 – 19:00	**Dinner**		

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19:00 – 21:30

19:00 – 19:15	S	**Eugene Oks** Auburn University	Shedding light on neutron lifetime puzzle via the new unexpected result of the two-body decay of neutrons
19:15 – 19:30	S	**Adam Kozela** IFJ PAN, Kraków	Search for beyond standard model physics at the ESS in Lund
19:30 – 19:45	S	**Hervé Savajols** GANIL, Caen	Search for a neutron dark decay in ^{6}He
19:45 – 20:00	S	**Rehab Yajzey** Jazan University	Isospin symmetry breaking studied with nucleon knockout reactions
20:00 – 20:15	S	**Amiram Leviatan** The Hebrew University	Persistent vibrational structure and symmetry in $^{110-116}$Cd
20:15 – 20:30	S	**Joakim Cederkall** University of Lund	The quadrupole moment of the first 2^+ state and the B(E2) value of the 4^+ to 2^+ transition in ^{110}Sn from safe Coulomb excitation

20:30 – 20:45	S	**Heinrich Wilsenach** Tel Aviv University	Measurement of double alpha decay of ^{224}Ra at the FRS Ion Catcher
20:45 – 21:00	S	**Piotr Jachimowicz** University of Zielona Góra	Candidates for three-quasiparticle high-K isomers in even-odd Fm-Ds nuclei
21:00 – 21:15	S	**Jessica Warbinek** GSI/CERN	Probing the N=152 neutron shell gap by laser spectroscopy of fermium isotopes

Thursday, 29th of August

Superheavy nuclei overview

08:30 – 09:00	IT	**Dieter Ackermann** GANIL, Caen	Quo vadis SHE? Where do we go? - Where can we go?

Structure of exotic nuclei
09:00 – 11:00
Convener Alexandra Gade

09:00 – 09:30	IT	**Anna McCoy** Argonne National Laboratory	Collectivity from first principles
09:30 – 10:00	IT	**Remco Zegers** Michigan State University	Advances in charge-exchange reactions with rare isotope beams
10:00 – 10:30	IT	**Vladimir Manea** IJCLab, Orsay	News on masses of rare isotopes
10:30 – 10:45	S	**Christoph Fransen** University of Cologne	The recoil distance Doppler-shift technique: a valuable method for nuclear structure studies far from the valley of stability
10:45 – 11:00	S	**Michael Bentley** University of York	B(E2) measurements of heavy N = Z nuclei at FRIB
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11:30 – 19:00	**Excursion**		
19:00 – 23:00	**Regional Dinner**		

Friday, 30th of August

Collective properties of atomic nuclei 08:30 – 10:30 Convener Adam Maj

08:30 – 09:00	IT	**Angela Bracco** INFN and University of Milan	Nuclear structure at finite temperature and the electric dipole oscillations: overview and open problems
09:00 – 09:30	IT	**Peter von Neumann-Cosel** FAIR/GSI, Darmstadt	Evidence for a toroidal electric dipole mode in nuclei
09:30 – 10:00	IT	**Nils Paar** University of Zagreb	Properties of pygmy dipole strength from theoretical perspective
10:00 – 10:15	S	**Kamila Sieja** IPHC, Strasbourg	Electric dipole response of light nuclei within the CI-SM approach
10:15 – 10:30	S	**Frantisek Knapp** Charles University, Prague	Recent studies of nuclear collective excitations within the equation of motion phonon method
10:30 – 11:00	**Coffee Break**		

Collective properties of atomic nuclei 11:00 – 13:00 Convener Adam Maj

11:00 – 11:30	IT	**Andreas Zilges** University of Cologne	Pygmy or not Pygmy – an experimentalist's point of view
11:30 – 12:00	IT	**Mark Spieker** Florida State University	Accessing the single-particle structure of the PDR
12:00 – 12:30	IT	**Oliver Wieland** INFN, Milan	Extra yield below the Giant Dipole Resonance under extreme conditions
12:30 – 12:45	S	**Agnese Giaz** INFN and University of Milan	Search for PDR and ISGQR in $A \simeq 60$ and A = 120 mass regions
12:45 – 13:00	S	**Périne Miriot-Jaubert** CEA, IRFU, DPhN, Orsay	Study of the Pygmy Dipole Resonance using neutron inelastic scattering at GANIL-SPIRAL2/NFS
13:00 – 14:00	**Lunch**		
14:00 – 18:00	**Hiking trip**		
18:00 – 19:00	**Dinner**		

Collective properties of atomic nuclei
19:00 – 21:30
Convener Adam Maj

19:00 – 19:25	IT	**Par Anders Söderström** ELI-NP, IFIN-HH, Magurele	Gamma above the neutron threshold perspectives at ELI-NP
19:25 – 19:50	IT	**Antoni Szczurek** IFJ PAN, Kraków	Light-by-light scattering in ultraperipheral heavy ion collisions - new possibilities
19:50 – 20:15	IT	**Hiroyuki Sagawa** RIKEN, and University of Aizu	Effects of beyond mean field approximation and tensor forces on Gamow-Teller and β decay of magic nuclei
20:15 – 20:30	S	**Lauren Bell** University of Oslo	Nuclear level densities and γ-ray strength functions of ^{152,154}Sm
20:30 – 20:45	S	**Adrian Sanchez Fernandez** University of York	Two-center harmonic oscillator basis: alpha clustering and symmetric fission as Proof-of-Principle calculations
20:45 – 21:00	S	**Janusz Skalski** National Centre for Nuclear Research, Warsaw	Selfconsistent study of ternary fission of (super)heavy nuclei
21:00 – 21:30	IT	**Paweł Napiorkowski** HIL UW, Warsaw	30 years of ion beams from the Warsaw Cyclotron - a good beginning

High Spin States
08:30 – 11:00
Convener Piotr Bednarczyk

Saturday, 31st of August

08:30 – 09:00	IT	**Mark Riley** Florida State University	Physics opportunities at ultra-high spin
09:00 – 09:30	IT	**Bo Cederwall** KTH Royal Institute of Technology	The complex interplay between pairing modes and spin in deformed N $\approx$ Z nuclei
09:30 – 10:00	IT	**Costel Petrache** IJCLab, University Paris-Saclay and CNRS-IN2P3	Different manifestations of oblate rotation in nuclei
10:00 – 10:30	IT	**Katarzyna Hadyńska-Klęk** HIL UW, Warsaw	Probing nuclear deformation in the vicinity of ^{40}Ca and ^{56}Ni
10:30 – 10:45	S	**Irene Zanon** KTH Royal Institute of Technology	Anomalous $B_{4/2}$ ratio in the yrast band of ^{167}Os
10:45 – 11:00	S	**Attila Krakó** HUN-REN Atomki	Multiple chiral doublet bands in ^{104}Rh
11:00 – 11:30	**Coffee Break**		
11:30 – 11:55	IT	**Piotr Salabura** Jagiellonian University of Cracow	Poland in FAIR

Special lecture

11:55 – 12:40	IT	**Thomas Elias Cocolios** KU Leuven	From uNclear to Nuclear. How nuclear science contributes to our society
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14:00 – 19:00	**Hiking trip**		
19:00	**Conference BANQUET**		

Sunday, 1st of September

Bus departure to Kraków

Abstracts of talks

Sunday

August 25th

Special Lecture

NuPECC Long Range Plan 2024

M. Lewitowicz[1,2]

Invited talk

[1]NuPECC, [2]GANIL, BP 55027, 14076 Caen, France

The Nuclear Physics European Collaboration Committee (NuPECC) [1] hosted by the European Science Foundation represents today a large nuclear physics community from twenty three countries, three ESFRI (European Strategy Forum for Research Infrastructures) nuclear physics infrastructures and ECT* (European Centre for Theoretical Studies in Nuclear Physics and Related Areas), as well as from four associated members and ten observers. One of the major objectives of the Committee is: " ...on a regular basis, the Committee shall organise a consultation of the community leading to the definition and publication of a Long Range Plan (LRP) of European nuclear physics. " .
To this aim, NuPECC launched the preparation for the new LRP in May 2022 [2]. The bottom-up approach to the LRP, was strengthened by launching an open call for input. The received 159 contributions, submitted by more than 400 individual scientists, collaborations, research infrastructures, and institutions in Europe composed a solid basis for the further analysis and elaboration of the LRP by 11 Thematic Working Groups (TWG). The TWG covered a large set of topics relevant to the development of nuclear physics namely, Hadron Physics Properties of Strongly Interacting Matter at Extreme Conditions of Temperature and Baryon Number Density, Nuclear Structure and Reaction Dynamics, Nuclear Astrophysics, Symmetries and Fundamental Interactions, Applications and Societal Benefits, Research Infrastructures, Nuclear Physics Tools - Detectors and Experimental Techniques, Nuclear Physics Tools - Machine Learning, Artificial Intelligence, and Quantum Computing, Open Science and Data and Nuclear Science - People and Society. Two working meetings were held at GSI/FAIR in Darmstadt, Germany in October 2023 and in February 2024. The purpose of the first meeting was to draft the LRP recommendations, and the second meeting was dedicated to finalizing the LRP chapters. A draft of the full LRP2024 was presented and discussed with the nuclear physics community at a dedicated three-day Town Meeting in Bucharest, Romania in April 2024. The more than 300-page LRP 2024 document including recommendations of the LRP was approved by NuPECC at its meeting in June 2024 in Lund, Sweden.
The Executive Summary of the LRP2024 can be found at [3].
The presentation will focus on the findings and recommendations of the NuPECC LRP2024.

Acknowledgement: This work coordinated by NuPECC was accomplished by a large European nuclear physics community.

References

[1] `https://nupecc.org`
[2] `https://nupecc.org/?display=lrp2024/main`
[3] `https://www.nupecc.org/lrp2024/Draft_Executive_Summary_LRP2024.pdf`

Monday

August 26th

Old questions and new challenges in nuclear astrophysics

S. Palmerini[1,2,3]

Invited talk

[1] Dipartimento di Fisica e Geologia, Università degli Studi di Perugia, Perugia, Italy
[2] Istituto Nazionale di Fisica Nucleare, Sezione di Perugia, Perugia, Italy
[3] Istituto Nazionale di Astrofisica, Osservatorio Astronomico di Roma, Monte Porzio Catone (RM), Italy

Nuclear astrophysics was born in the 1957 by the publication of the B2FH paper [1]. In this famous work the nuclear processes and the astrophysical site responsible to synthetize each element were investigated to reproduce the element abundance distribution in the solar system. After decades of studies the main processes driving the stellar evolution are quite well known, but many questions are still open, particularly about the late stages of stellar evolution and the exotic nuclear processes they host. Will a star explode at the end its life? Will an evolved star produce heavy nuclei by neutron captures? These are 2 of the most common questions which astrophysics asks nuclear physics to address. Nowadays, ultimate technologies in both astronomy and the nuclear physics allow us to investigate exotic nucleosynthesis scenarios and pose new challenging questions. While so far, the main goal of nuclear astrophysics has been the study of fusion reactions, mainly between stable nuclei, now the study of reactions involved instable isotope and processes driven by the weak interaction, as beta decays and electron captures, in stellar plasma are becoming the new frontier to be explored I will illustrate, as examples, as the new cross section of ^{12}C $+$ ^{12}C reaction [2] may affect the final fate of stellar revolution [3] and as new estimates of beta decays in stellar plasma may modify the predicted yields of neutron capture nucleosynthesis in exotic galactic environments such as in the most common evolved stars [4].

References

[1] E. M. Burbidge *et al.*, Reviews of Modern Physics **29** (1957) 547.
[2] A. Tumino *et al.*, Nature **557** (2018) 687.
[3] A. Chieffi *et al.*, The Astrophysical Journal **916** (2021) 79.
[4] S. Palmerini *et al.*, The Astrophysical Journal **921** (2021) 7.

Nuclear reactions for Astrophysics and the opportunity of indirect methods

M. La Cognata[1]

Invited talk

[1] Laboratori Nazionali del Sud - Istituto Nazionale di Fisica Nucleare, Catania, Italy

Nuclear reactions among charged particles in stars take place at energies generally well below the Coulomb barrier, so its penetration factor exponentially suppresses the cross section down to values as small as few nanobarns or picobarns. Approaching astrophysical energies opens new challenges and calls for new approaches. I will introduce the mission of nuclear astrophysics and discuss how experiments are usually conducted. I will focus on the use of indirect methods as complementary approaches to direct measurements, discussing the asymptotic normalisation coefficient (ANC) and the Trojan Horse Method (THM), used to deduce the cross sections of reactions with photons and charged particles in the exit channel, respectively, with no need of extrapolation.
I will present recent results of the application of the two methods: the ^{6}Li(^{3}He,d)^{7}Be measurement used to deduced the ANC's of the ^{3}He + ^{4}He $\rightarrow$ ^{7}Be [1] and p + ^{6}Li $\rightarrow$ ^{7}Be [2] channels and the corresponding radiative capture cross sections. Then, I will discuss about the THM measurement of the ^{27}Al(p,α)^{24}Mg [3] cross section through the ^{2}H(^{27}Al,α^{24}Mg)n reaction and of the ^{12}C + ^{12}C [4] fusion reaction cross section measured down to astrophysical energies, using ^{14}N to transfer a deuteron and induce the reaction of astrophysical importance. The indirect measurements made it possible to assess the occurrence of several resonances that are responsible significant changes of the reaction rate at relevant temperatures.

References

[1] G. G. Kiss *et al.*, Physics Letters B **807** (2020) 135606.
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Pygmy Dipole Resonance in Sn Isotopes and its Astrophysical Impact

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The pygmy dipole resonance (PDR) is a feature commonly appearing in the low-lying electric dipole response of nuclei on top of the tail of the giant dipole resonance (GDR). Despite the ongoing debates regarding its origin, its emergence is commonly associated with the presence of the neutron excess and might potentially affect the neutron-capture rates and, thus, abundances of elements produced in heavy-element nucleosyntehsis [1]. A systematic investigation of the evolution of the PDR in different isotopic chains with different theoretical approaches and experimental methods is therefore of interest for both general nuclear structure studies and astrophysical calculations.
This work presents a consistent systematic study of the low-lying electric dipole strength and the potential PDR in eleven Sn isotopes, $^{111-113,116-122,124}$Sn, with the primary goal of investigating its evolution with increasing neutron number, comparing it with available theoretical approaches, and revealing a potential impact of this feature on the astrophysical radiative neutron-capture processes. The study is based on the combined analysis of the dipole γ-ray strength functions (GSF) below the neutron separation energy extracted from particle-γ coincidence data with the Oslo method [2] and the electric and magnetic dipole strengths from relativistic Coulomb excitation in forward-angle inelastic proton scattering [3]. The latter cover a wide energy range of both the PDR and the GDR and were used together with the Oslo data to extract the low-lying electric dipole strength in Sn isotopes in two different ways. It appears to exhaust $\approx 2 - 3\%$ of the classical Thomas-Reiche-Kuhn (TRK) sum rule and to be nearly constant throughout the whole chain of stable Sn isotopes. This is in contradiction with the majority of theoretical approaches, such as, e.g., relativistic quasiparticle random-phase and time-blocking approximations, which predict a steady increase in the PDR strength with neutron number. Moreover, a presumably isovector component of the PDR was extracted for $^{118-122,124}$Sn. Its strength was found to increase almost linearly with neutron number, reaching up to $\approx 0.5\%$ of the TRK sum rule in ^{124}Sn.
The GSFs and nuclear level densities, also extracted with the Oslo method, were further used as inputs to constrain the cross sections and Maxwellian-averaged cross sections of (n,γ) reactions in the Sn isotopic chain using the reaction code TALYS [4]. The obtained results agree well with other available experimental data and the recommended values from the libraries. Despite relatively small exhausted fractions of the TRK sum rule, the low-lying electric dipole strength makes a noticeable impact on the radiative neutron-capture cross sections in stable Sn isotopes, contributing up to 20% of the estimated total cross sections. Moreover, the presence of the PDR-like enhancement in the Oslo GSF was found to affect the production of Sb in the ^{121,123}Sn$(n,\gamma)^{122,124}$Sn reactions in the astrophysical i process, providing new constraints on the uncertainties of the resulting chemical abundances from multi-zone low-metallicity Asymptotic Giant Branch stellar models.

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New results on the proton capture on neon isotopes at LUNA

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The NeNa-MgAl cycles play a significant role in synthesising isotopes of neon, sodium, magnesium, and aluminum. The LUNA collaboration has intensively studied the reactions involved in this cycle during the last years. Recently new results on the proton capture on ^{20}Ne and ^{21}Ne have been obtained and the study of the ^{23}Na(p,alpha)^{20}Ne is starting. Meanwhile, at the National Laboratory of Gran Sasso, a new 3.5 MeV accelerator, Bellotti Ion Beam Facility, able to produce proton, helium and carbon beams has been installed. The machine is working since 2023 producing new results in nuclear astrophysics. The LUNA collaboration has already proposed a program of scientific cases to be studied at this new facility in the next years. In this contribution an overview of nuclear astrophysics at LUNA will be given with a detailed description of the new results obtained by the LUNA400 accelerator on the NeNa cycle. Additionally, a discussion on the new possibility achievable by the Bellotti IBF at LNGS will be present.

Probing finite-temperature effects on electromagnetic dipole transitions

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Nuclear temperature play a crucial role in diverse nuclear processes, including fusion reactions in stars, nucleosynthesis, and radioactive decay rates [1, 2]. A precise understanding of nuclear response under varying temperatures is essential for comprehensive understanding of its impact on nuclear processes. In this study, we developed a self-consistent finite temperature relativistic quasiparticle random phase approximation (FT-RQRPA), to investigate the behavior of electric dipole (E1) and magnetic dipole (M1) transitions at finite temperature in even-even nuclei [3, 4]. Our investigation focuses on the isotopic chains of $^{40-60}$Ca and $^{100-140}$Sn closed- and open-shell nuclei, exploring the behavior of E1 and M1 transitions within a temperature range of T $=$ 0 to 2 MeV. The analysis reveals that E1 giant resonance is moderately modified with temperature increase, and new low-energy transitions appear at higher temperatures, making a pronounced impact, particularly in neutron-rich nuclei. This emergence is attributed to the unblocking of transitions above the Fermi level due to thermal influences on single-particle states. Similarly, for M1 transitions, an interesting result is obtained for ^{40,60}Ca nuclei at higher temperatures, i.e., the appearance of M1 transitions, which are forbidden at zero temperature due to fully occupied (or fully vacant) spin-orbit partner states. Furthermore, we observe a shift in M1 strength peaks towards lower energies in Ca and Sn nuclei, primarily attributed to decreases in spin-orbit splitting energies and residual interactions, especially above critical temperatures (T_c). The significant temperature dependence observed in the E1 and M1 responses emphasizes their potential importance in the modeling of gamma strength functions and their application in nuclear reaction studies relevant to astrophysics. This work is supported by the Croatian Science Foundation under the project Relativistic Nuclear Many-Body Theory in the Multimessenger Observation Era (IP-2022-10-7773).

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High-energy reactor antineutrinos deduced from total absorption spectroscopy measurements

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In a recent study, F. P. An *et al.* [1] presented the first measurement of high-energy reactor antineutrinos at Daya Bay, with nearly 9000 inverse beta decay candidates in the prompt energy region of 8-12 MeV. Their findings corroborated the presence of reactor antineutrinos above 10 MeV while simultaneously unveiling a 29% deficit in antineutrino flux within the prompt energy range of 8-11 MeV when compared to model predictions. A comparable deviation between observed and predicted antineutrino in the lower energy spectrum amounts up to approximately 6%, as reported by G. Mention *et al.* [2].
The reference reactor antineutrino spectrum is computed as the sum of the contributions from all fission products. It requires thorough information about β decay of all fission products. However, β-decay schemes of fission products tend to underestimate the probability of β transitions feeding high-excited states, which artificially shifts the calculated antineutrino flux to higher energies. This causes an overestimation of the predicted number of detected antineutrinos. Studies of the β decay of fission fragments using total absorption detectors find a more accurate antineutrino distribution and, consequently, a better estimate of the number of predicted detectable antineutrinos [3,4].
F. P. An *et al.* point out that high-energy reactor antineutrinos are likely generated by only a handful of short-lived β-decay nuclei with high end-point energies Q_β, such as ^{88,90}Br and ^{94,96,98}Rb [1]. We will present the antineutrino spectra of ^{88,89,90,91}Br β decays, which Q_β values range from 8.2 MeV to 11 MeV. All bromine isotopes were measured by means of Modular Total Absorption Spectrometer (MTAS) [5]. The antineutrino spectra were derived from newly obtained MTAS decay schemes. We will discuss the impact of MTAS results on predicted high-energy antineutrino spectrum and observed antineutrino deficit.

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Towards nuclear energy density functionals from first principles

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Invited talk

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Nuclear energy density functionals successfully reproduce properties of nuclei across almost the entire nuclear chart. However, nearly all available functionals are phenomenological in nature. This issue might be solved with an energy density functional obtained from first principles. I briefly survey different ideas to reach this goal before focusing on our recent work [1] in which we construct the GUDE family of functionals. These functionals consist of long-range pion-exchange contributions derived from chiral effective field theory at the Hartree-Fock level and a phenomenological Skyrme part. When including pion contributions beyond next-to-leading order in the chiral expansion, we find significant improvements over a reference Skyrme functional. We identify which terms drive the observed improvements and conclude that these chiral contributions might constitute useful ingredients for true ab initio energy density functionals.

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Mean-field calculations with regularized pseudopotentials

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Invited talk

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Over the past decades, the Energy Density Functional (EDF) method has proven to be a tool of choice for the study of the entire chart of nuclei except the lightest ones. With the use of an effective interaction, a relatively simple ansatz for the wave function and the application of a variational principle, this method allows to account for a large set of properties of atomic nuclei such as their binding energies and shapes in their ground states, the energy levels of their rotational bands or their possible fission barriers [1].
Most of the effective interactions found in the literature contain a density-dependent term. This term is used because it is known that an effective interaction only containing two-body density-independent terms can not satisfactorily reproduce the properties of nuclei and infinite matter at the mean-field level [2,3]. Using a two-body density dependent term is a simple and very efficient way to cop with this problem.
It is known that beyond-mean-field calculations such as the Generator Coordinate Method (GCM) or symmetry restorations can only be implemented with EDFs which are strictly derived from an interaction [4]. But even with this constraint, it has been shown that the use of density-dependent terms leads to formal and technical problems for calculations beyond the mean-field approximation [5,6].
In order to have an interaction usable at the mean-field level and beyond, without facing such difficulties, we developed an interaction written as a sum of so-called "regularized finite-range pseudopotentials" [7,8]. In this approach, the EDF stems from a momentum expansion around a finite-range regulator (usually chosen as a Gaussian form factor) and thus have a form compatible with powerful effective-theory methods. The regularized two-body part of this interaction is complemented with a semi-regularized three-body term, i.e. a product of a Gaussian form factor multiplied with a Dirac delta-function.
Recently, such a regularized interaction was adjusted and tested with mean-field calculations for infinite nuclear matter and spherical nuclei. The results are very promising a represent a proof of concept that this approach is valid and may be used in beyond-mean-field calculations.

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Clustering in atomic nuclei

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Invited talk

Loosely bound nuclei are currently at the center of interest in low-energy nuclear physics. The deeper understanding of their properties provided by the shell model for open quantum systems changes the comprehension of many phenomena and offers new horizons for spectroscopic studies of nuclei from the driplines to the valley of β-stability, for states in the vicinity and above the first particle emission threshold [1,2]. Systematic studies in this broad region of masses and excitation energies will extend and complete our knowledge of atomic nuclei at the edge of stability. In this talk, I will review recent progress in the open quantum system shell model description of nuclear states. Firstly, I will discuss description of the proton-decaying 0_2^+ resonance of the α particle using the no-core Gamow shell model in the coupled-channel representation [3]. The recent precise experimental determination of the monopole transition form factor from the ground state of ^{4}He to its 0_2^+ resonance via electron scattering [4] has reinvigorated discussions about the nature of this first excited state of the α particle. Secondly, (i) the role of clustering in the spectra and elastic cross-sections for ^{7,8}Be,^{7}Li, (ii) the near-threshold evolution of reaction channel amplitudes, and (iii) the alignment of the many-body state with the decay channel which leads to the emergence of clustering, will be discussed for selected states [5]. Thirdly, salient generic features of open quantum systems will be illustrated on examples of (i) chameleon nature of near-threshold resonances, and (ii) resonances and low-energy reactions of astrophysical interest.

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Iterative solutions of the ATDHFB equations to determine the nuclear collective inertia

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An iterative adiabatic time-dependent Hartree-Fock-Bogoliubov (ATDHFB) method is developed within the framework of Skyrme and Gogny density functional theory to study nuclear collective motion. The ATDHFB equation is solved iteratively to avoid explicitly calculating the stability matrix. The contribution of the time-odd mean field to the ATDHFB moment of inertia is incorporated self-consistently, and the results are verified by comparing them with the dynamical cranking predictions. The method is applied to study the rotational moments of inertia in the even-even nuclei from gadolinium to osmium with two different Skyrme and one Gogny functional. It turns out that the calculated ratios of the ATDHFB and Inglis-Belyaev (IB) moments of inertia are functional-dependent and vary in function of the particle numbers, see the figure. Therefore, no fixed overall ratio between the ATDHFB and the IB moments of inertia can be expected to capture the effects generated by the inclusion of the time-odd mean fields.

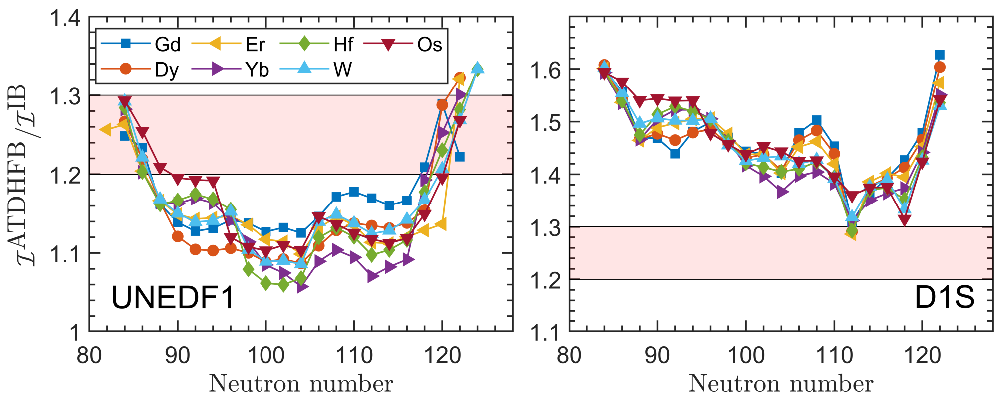

Figure 1: Ratios of the ATDHFB and Inglis-Belyaev moments of inertia determined for the even-even nuclei from gadolinium to osmium using the Skyrme UNEDF1 (left) and Gogny D1S (right) functionals compared with the empirical enhancement factor 1.2 to 1.3 (shaded areas).

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Demystifying the fusion mechanism in heavy ion collisions within six-dimensional Langevin dissipative dynamics

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We have thoroughly investigated the influence of entrance channel effects on the spin distribution and angular momentum in heavy ion collisions, employing six-dimensional dissipative dynamics. The microscopically derived Langevin equations were numerically solved using the distance, neck, asymmetry and the three angular macroscopic variables, which allow for an adequate description of the fusion process, as it was done in Ref. [1]. Our analysis showed that, unlike what was done in Ref. [1], a special handling of the boundary conditions is necessary to describe the correct asymptotic shape of the spin distributions. Moreover, by considering the full range of the asymmetry variable, rather than freezing it, we provide a comprehensive understanding of its impact on dissipative dynamics.
Different systems, involving various asymmetry entrance channels were studied using a Yukawa-plus-exponential folding + Coulomb potential. We will present results for the following heavy-ion reactions: ^{64}Ni + ^{92,96}Zr, and the asymmetric systems ^{16}O + ^{152}Sm and ^{48}Ca, ^{50}Ti, ^{54}Cr on ^{208}Pb.
Our analysis considers factors such as friction, mass tensor parameters, diffusion strength, potential energy, and stochasticity in a complete six-dimensional picture. We observe significant variations in the spin distribution by considering various target-projectile combinations with the same excitation energy and compound system. This underscores the crucial role of entrance channel asymmetry in shaping the spin distribution, as it strongly influences the hindrance mechanism and in turn, plays a vital role as a weight for subsequent processes such as splitting.
This investigation enhances our understanding of the intricate relationship between entrance channel effects and the resulting spin distribution, contributing to a broader understanding of dissipative dynamics in heavy ion collisions. Our ultimate aim is the inclusion of shell effects in the potential surface to give a fully microscopic-macroscopic description of the dissipative process.

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Electromagnetic Moments within Nuclear DFT

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Invited talk

The study of nuclear electromagnetic moments is essential for understanding nuclear structure. Electric quadrupole moments in atomic nuclei indicate nuclear deformation and collectivity whereas magnetic dipole moments are known to be sensitive to the single-particle properties of valence nucleons. The self-consistent calculations with broken spherical and time-reversal symmetries take into account the shape and spin polarization, with the latter crucially depending on the inclusion of the time-odd mean-field components. To determine the intrinsic moments, we align the intrinsic angular momenta along the axial-symmetry axis, which allows for building the spin polarization fully. Then, we determine the spectroscopic moments by evaluating them for the angular-momentum-projected wave functions. Since the full single-particle space is taken into account in nuclear DFT, there is no need to use any effective charges or effective g-factors. We have applied our methodology to systematic calculations of electric quadrupole and magnetic dipole moments in nearly spherical nuclei [1] and in heavy, deformed open-shell odd nuclei between tin and lead [2-3].
The meson-exchange interactions between nucleons and current conservation motivate the inclusion of the two-body currents to the magnetic dipole operator in terms of the intrinsic and Sachs terms. As shown in Ref. [4], the leading terms originating from the seagull and pion-in-flight diagrams are essential since they improve the global agreement between theoretical values and experimental data. We have incorporated these terms in our recent calculations for the odd near neighbours of 8 doubly magic nuclei (^{16}O, ^{40}Ca, ^{48}Ca, ^{56}Ni, ^{78}Ni, ^{100}Sn, ^{132}Sn, and ^{208}Pb).
Parity- and time-reversal-violating nuclear forces induce the P- and T-odd nuclear moments, particularly the nuclear Schiff moments. The Schiff moment calculations carried out by Dobaczewski *et al.* [5] have demonstrated a strong correlation between the octupole and Schiff moments in light actinides and that such correlation reduces the uncertainty of the calculated intrinsic Schiff moments. Following the method of Ref. [5], we determined the intrinsic Schiff moment of ^{227}Ac and found a similar correlation between the octupole and Schiff moments. By using the measured octupole moment of ^{226}Ra, we constrained the uncertainty of the intrinsic Schiff moment of ^{227}Ac.
In this talk, I will review the nuclear-DFT description of the nuclear electromagnetic moments and present recent results obtained for the electric quadrupole, magnetic dipole, and nuclear Schiff moments.
We acknowledge the support from a Leverhulme Trust Research Project Grant. This work was partially supported by the STFC Grant Nos. ST/P003885/1 and ST/V001035/1 and by the Polish National Science Centre under Contract No. 2018/31/B/ST2/02220. We acknowledge the CSC-IT Center for Science Ltd., Finland, for the allocation of computational resources. This project was partly undertaken on the Viking Cluster, which is a high performance compute facility provided by the University of York. We are grateful for computational support from the University of York High Performance Computing service, Viking and the Research Computing team.

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Multi-reference description of nuclear states

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Invited talk

Many quantal many-body methods that aim at the description of nuclear systems make use of auxiliary wave functions that break one or several of the symmetries of the Hamiltonian in order to include correlations associated with the geometrical arrangement of the system's constituents. The concept of symmetry breaking is central to self-consistent mean-field methods that use an energy density functional (EDF) for the effective in-medium interaction [1]. In these models, a single suitably optimized symmetry-breaking auxiliary product state provides the one-body density matrices from which the EDF and operator matrix elements are calculated. These approaches can be pushed to the point where they provide an excellent global description of global nuclear properties of even-even, odd, and odd-odd nuclei across the nuclear chart [2], albeit they often fail to systematically capture more local nuclear structure effects.
A fully quantal treatment of a self-bound many-body system like the atomic nucleus, however, requires the restoration of the broken symmetries through the projection of the many-body wave functions of interest onto good quantum numbers [1,3], and often also demands to account for fluctuations in the order parameters of the broken symmetries [1]. Both can be simultaneously achieved when calculating the EDF and operator matrix elements from a suitably chosen set of symmetry-breaking auxiliary product states. Phenomena for which such multi-reference (MR) calculations are relevant are the evolution of binding energies around shell closures [4], shape coexistence [5], excitation spectra as well as electromagnetic moments and transitions [6-9]. The systematic application of MR methods is presently limited by the non-availability of predictive nuclear EDFs for which the MR extension remains a well-defined object under all circumstances. Indeed, for reasons of flexibility in the parameter adjustment and low computational cost, most EDFs used in the literature use phenomenological density-dependences and often also disrespect the Pauli principle. When used in a MR application, such EDF can become the integral over a non-analytical multi-valued function in the complex plane [10,11], which then causes many conceptual and practical problems that have not been fully solved.
There are ongoing efforts to construct well-behaved EDFs for MR applications; their form is more complicated than the standard one, and the adjustment of their parameters more demanding. Still, already calculations using quite simple EDFs that are constructed along this line yield promising results for the spectroscopy of complex nuclei [6-9] that will be discussed in this presentation.

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Nuclear DFT: applications to single-particle and collective states and some open questions

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Invited talk

I will present a very short, personal overview of nuclear Density Functional Theory (DFT). Two specific aspects will be emphasised. Compared to so-called *ab initio* approaches, DFT is more phenomenological; however, it can access a lot of physics that *ab initio* cannot handle (mediumheavy and open-shell nuclei, highly excited states, reactions). Accordingly, I will focus on nuclear response calculations and discuss the status of collective and single-particle properties by using a few illustrative examples. Then, I will advocate the need of grounding DFT on *ab initio* as is done for Coulomb systems, and show some ongoing research.

Accelerating nuclear DFT algorithms for finite-range interactions

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The efficiency of high-performance computing in physics depends not only on the computers' ever-growing speed but also crucially relies on the algorithms used to solve fundamental equations. This is particularly important when solving equations that describe quantum systems of many particles and fields. Examples thereof are ubiquitous: from the Lüscher's algorithm [1] to solve the quantum chromodynamics (QCD) equations on the lattice to the Lanczos algorithm for diagonalising shell-model Hamiltonians of up to 10^{10} dimensions, progress has been driven by advanced ideas in constructing powerful numerical algorithms.

In this work, we report a new algorithm to solve the self-consistent nuclear density functional theory (DFT) equations [3] for finite-range interactions. In the Gaussian Separalisation Method (GSM) proposed here, we diagonalise the one-dimensional Gaussian matrix elements evaluated in the harmonic-oscillator basis and thus reduce the dimensionality by performing cut-offs of Gaussian eigenvalue spectra. Our new approach applies to two-body finite-range Gaussian-type interactions or so-called functional generators, such as energy density functionals coming from the Gogny pseudopotentials [4], the regularised pseudopotentials [5], or from the Gaussian expansions of the Coulomb [6] or Yukawa [6] potentials. We discuss the implementation of GSM in the nuclear DFT code HFODD [8], showing that a significant gain in CPU time can be achieved through this procedure.

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Multi-particle-hole configurations in description of double beta decay

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Double beta decay (DBD) is a phenomenon that provides us with a unique window to physics beyond the Standard Model and which lies at the intersection of particle, nuclear, and atomic physics. Determining whether DBD occurs solely in the two-neutrino mode or if there is also a neutrinoless variant is crucial. The discovery of neutrinoless or another exotic mode of DBD would significantly impact the further development of particle physics and cosmology. A challenge in the theoretical description of DBD is to provide accurate values of nuclear matrix elements (NMEs), which enter the calculation of DBD's half-life. In this contribution, we discuss selected methods that start and go beyond self-consistent mean-field by considering multi-particle-hole or multi-phonon configurations. Computational performance of these methods, namely Second Tamm Dancoff Approximation (STDA), Second Random Phase Approximation (SRPA), and Equation of Motion Phonon Method (EMPM), were recently studied in more detail [1]. While in [1], we described electromagnetic nuclear excitations, the subject of this contribution is the generalization of STDA and EMPM for particle-hole configurations that change the type of nucleon to make it suitable for calculations of DBD NMEs. In that context, the role of multi-particle-hole configurations in the computation of DBD NMEs is studied.

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Theo4Exp: a theory service for EURO-LABS community

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Invited talk

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In the last years, the nuclear scientific community has been moving towards open science: open access publications, accessibility to experimental data and codes, etc. In this context, the creation of user-friendly platforms, in which non-expert users can perform calculations using well-established theory codes, represents a significant and long-awaited advancement. The new virtual access facility Theo4Exp addresses this need, by providing a variety of computer codes for nuclear structure and reactions, made easily accessible to researchers worldwide. The use of these codes is made simple by the adoption of clear interfaces and the implementation of graphical tools. Results can be easily transmitted, exchanged and compared. It is expected that the new service will create a virtuous circle of increased collaboration between theorists and experimentalists, leading to innovative experiments and facilitating their interpretation. The EURO-LABS project https://web.infn.it/EURO-LABS/ , funded within the EC Horizon Europe program, has provided the appropriate framework and dedicated personnel to create this service. Open to users since February 1^{st} 2024, Theo4Exp is composed of three installations: one for reaction calculations, Reaction4Exp [1-3], and two dedicated to structure calculations, MeanField4Exp [4-6] and Structure4Exp [7-9]. The Theo4Exp portal can be found at the main web site https://institucional.us.es/theo4exp .

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Tuesday

August 27th

New insights into fission from recent experiments
What drives fission across the nuclear chart?

Ch. Schmitt

Invited talk

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Nuclear fission owes its name by it resemblance with the division of living cells. Though, hidden behind is the complex re-arrangement of a many-body quantum system involving two types of nucleons, the protons and the neutrons. As such, it is an ideal playground for studying fundamental nuclear properties, in general, and dynamical aspects of nuclear reactions, in particular.

While the importance of structural effects in the nascent fragments has been established through numerous studies over the past decades, the respective role of the proton and neutron sub-systems remains vividly debated. Discriminating between the latter is a challenge due to the experimental difficulty in precisely characterizing the fission-fragment products in mass and charge. Innovative approaches based on fission induced in inverse kinematics and employing state-of-the-art detection systems permitted to overcome the challenge recently, providing for the first time highly accurate and complete isotopic distributions for the entire fragment population. At GANIL, the method initiated with actinide fission was further applied to the pre-actinide region around Lead. It revealed that the protons - which importance was overlooked in the past, are key drivers of fission over the nuclear chart.

In parallel to their isotopic composition, accurate knowledge of the post-scission evolution of the fragments, and in particular their de-excitation, allows to deepen further the understanding of the dynamics of fission. Independent measurements of the neutrons and γ-rays emitted after scission so far do not allow drawing consistent and model-independent conclusions. Recent experimental advances succeeded in measuring neutrons and γ-rays simultaneously. In most elaborate setups, these particles could be detected in coincidence with the isotopically identified fragments, offering the possibility of high-fold correlations. Such measurements are currently exploited to unravel complex intricacies, and get a hand on the generation of excitation energy and angular momentum during the fission process and their sharing at scission.

Based on the results acquired today, a first step into the direction of a consistent, "universal" understanding of fission across the nuclear chart is proposed. "En route" experimental campaigns and projects are discussed.

Generation of Angular Momentum in Fission Fragments

Jørgen Randrup

Invited talk

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The primary fission fragments emerge with typically half a dozen units of angular momentum. While the average magnitudes of these can readily be understood on the basis of statistical considerations [1], the specific mechanism generating the angular momenta is not yet established. It is therefore important that the various theoretical treatments be developed to a level where quantitative confrontation with experiment can be made.

This presentation focusses on one candidate mechanism: *Nucleon Exchange*. In damped nuclear reactions [2], where the system remains binary throughout, this mechanism is responsible for the large energy dissipation and the correlated build-up of angular momenta in the two reaction partners [2,3]. Because the fissioning system develops a binary character as it approaches scission, the nucleon exchange mechanicsm may also play a role at the late pre-scission stage [4].

Generally, the angular momenta of a binary system, such as that consisting of the two fledging fission fragments, can be expressed in terms of six normal modes of rotation. These present a convenient reference because different models will populate those modes to different degrees, reflecting the various mechanisms being considered.

The nucleon exchange transport treatment is presented and the associated characteristic time scales [4] are discussed. Comparison of these with the expected saddle-to-scission times gives an indication of how large a role the various rotational modes may play. Such an analysis [5] leads to the expectation that the wriggling mode (in which the fragments have mutually parallel spins that are perpendicular to the fission direction) is fully populated, while twisting (where the fragments spins are opposite along the fission direction) is unlikely to play a major role, though it may grow more prominent at higher excitations; bending (where the fragments have mutually antiparallel spins that are perpendicular to the fission direction) probably has some presence which increases with mass asymmetry and with lower fragment kinetic energies.

These predicted features can be tested experimentally. In particular, the degree of twisting can be deduced from the Y(0°)/Y(90°) yield ratio in a modern experiment of the type pioneered by Wilhelmy [6] in which the angular distribution of identified rotational $E2$ photon transitions is measured relative to the fragment direction. Furthermore, with a view towards the future when the required technology has been developed, it is illustrated how the relative role of positive modes (wriggling) and negative modes (bending and twisting) can be determined by measuring the opening angle between two $E2$ photons whose helicities are also identified.

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Does neutron emission change the fission fragment angular momentum?

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Invited talk

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and the nuBall2 collaboration

The study of the nuclear fission process, where a heavy nucleus ruptures and creates two fission fragments, is interesting both from a basic science and application point of view. Lately, a heavily debated topic is how the angular momentum of the fission fragments are generated, and how differences in fissioning nucleus mass, fission fragment mass, and energy partition at scission impact this generation.
Since the angular momentum J of the fission fragments is not directly observable, experimental studies rely on measuring the γ rays resulting from fragment decay. The emission of neutrons from the fragments is known to generally precede γ decay. How much neutron emission changes the fragment angular momentum is therefore important to know in order to interpret the γ-ray measurements. Historically, it is assumed that neutron emission will have little impact on fragment J [1], however a recent study suggested that it could be significant [2], such that information about the initial fragment J is diluted through neutron emission.
Here, we propose an experimental approach to understand how the angular momentum of the fragments are impacted by neutron emission, using data collected during the ^{238}U(n,f) experiment in the nuBall2 campaign at the ALTO facility of IJC Laboratory in Orsay. A method using the γ-ray feeding intensities is employed to investigate how the fragment J changes when fission fragments result in pairs with an increasing number of prompt neutrons emitted. Preliminary results and interpretations will be shown.

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Neutron and γ-ray emission in fast neutron induced fission

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Fission modeling is still the subject of much work. The objective is to understand the structure and dynamic effects involved in this reaction. From the point of view of fission applications, the objective is to provide precise data on the fission fragments yields and kinetic energies, but also on the emission of neutrons and γ-rays. The work being carried out in numerous laboratories ultimately aims to enable the provision of such data based on theories or phenomenological models.
In this presentation I will describe the new results obtained with the large SCONE detector (Solid COunter for NEutrons), based on plastic scintillator bars. The detector design includes a significant amount of Gd, in order to carry out neutron counting with an efficiency of about 70 percent for fission neutrons. In addition, by design, SCONE is also a good γ-ray calorimeter, and in particular the granularity allows to determine the average γ-ray multiplicities.
I will present the experimental results of the fast neutron induced fission of uranium 238 campaign performed at the GANIL/NFS facility, for neutron energies ranging from 1 MeV to 30 MeV. The complete distributions of fission neutron multiplicities, the average total radiated γ-ray energy, and the average γ-ray multiplicity in the fast neutron induced fission of uranium 238 will be discussed. Furthermore, measuring the different observables continuously as a function of neutron energy makes it possible to study the effects of multi-chances which confer structures into those observables. For the first time the second chance fission probability on uranium 238 was measured experimentally. In a ddition, the re-analysis of old data on uranium 235 and plutonium 239 allowed us to obtain the aforementioned probability also for these two isotopes[1]. These measurements open a way to take into account the effects of multi-chance in fission, that overcomplicate the description of the neutron induced fission process. Unfolding these effects will simplify the achievement of more precise models.

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Isotopic fission fragments distributions in the Thorium region produced in inverse-kinematics with a ^{232}Th beam

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A general description of the fission mechanism considers both microscopical quantities, such as nuclear structure of the fission fragments, and macroscopic effects, like the Coulomb repulsion between the nuclei. The interplay between both quantities prevents a fully microscopical description of the interaction. Despite the development of different theoretical models [1] and simulation codes based on experimental data, such as GEF [2], the fission process fails to be systematically reproduced. A large set of experimental data is needed in order to constrain the models.
Using the inverse-kinematics technique and multi-nucleon transfer reactions, the fission process is studied at GANIL with the VAMOS++ spectrometer [3]. This enables the isotopic identification of complete fission fragment distributions [4]. Moreover, the coupling of this spectrometer to a highly stripped silicon detector (PISTA) allows the identification of the fissioning system and the reconstruction of its excitation energy with high resolution.
A new experiment was conducted at VAMOS++ with the newly accelerated ^{232}Th beam at coulomb energies. Transfer reactions performed with a ^{12}C target permitted to populate fissioning systems such as ^{234}U or ^{232}Th, among others. The experimental setup consisted on the VAMOS++ spectrometer, coupled to PISTA, and a set of detectors included for the simultaneous measurement of the velocity of both fission fragments on an event by event basis. In this work, the proton and neutron content of the fission fragments will be presented as a function of the excitation energy of the fissioning system. On top of this, neutron excess of the fragments will be shown, as well as some correlations between both fission fragments.

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Deformation, Angular Momentum and Excitation Energy of Fission Fragments in the Neutronless Fission of ^{252}Cf(sf)

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Invited talk

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Nuclear fission is a dynamic process by which a heavy nucleus, under the action of single particle and collective effects, is separated in two lighter, highly excited fragments. Excitation energy and angular momentum is released by the newly produced fragments through neutron and gamma-ray emission. The experimental study of fission is a real challenge, since the complete characterization of the process's exit channel requires identifying two heavy ions among the hundred of possible fragments, and to measure in coincidence the neutrons and gamma-rays emitted by these fragments. To the best of our knowledge there is no such comprehensive dataset.
Neutronless fission, i.e. fission where the fragments are produced below their neutron separation energy, offers a great simplification to this challenge. Indeed, because of conservation of energy and momentum, efficient and accurate fragment identification can be achieved. Moreover, in the absence of neutron emission, gamma rays are the only means by which the fragments can evacuate both excitation energy and angular momentum.
In this presentation, I will show how using a twin Frish-grid ionization chamber loaded with an ultra thin ^{252}Cf sample we were able to observe the rare events of neutronless fission (yield of the order of 10^{-3}). Combined with an array of 54 NaI detectors, we measured in coincidence the γ-rays emitted by the fragments. I will focus the discussion of the results on two particular cases.
The first one is the exceptional fragmentation ^{120}Cd/^{132}Sn, where the doubly magic nucleus is produced in its ground state. The measured gamma ray spectrum therefore solely reflects the properties of ^{120}Cd at scission. The reproduction of this spectrum allows us to deduce the spin distribution and the scission deformation of ^{120}Cd [1]. The nucleus appears to be more deformed than previously thought for a fragment produced via neutronless fission.
The second case to be discussed is the ^{118}Pd/^{134}Te fragmentation, only two protons away from the previous one. In this case, low lying transitions from both fragments are found in the measured gamma ray spectrum. The reproduction of the spectrum strongly depends on the excitation energy sharing between the two fragments, an information that is extracted for the first time using a genetic algorithm [2].

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Probing the fluctuation of fission observables

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Invited talk

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The nuclear energy-density-functional (EDF) is a successful theoretical tool to describe many properties of a fissioning nucleus up to the generation of primary fragments [1]. A core ingredient in the EDF-based many-body approaches is the Bogoliubov vacuum wavefunction. Expectation values of observables such as total binding energies or primary fragments mass are widely computed on Bogoliubov vacuua. They are either used directly to interpret the fission process or as an intermediate quantity in approaches such as the time-dependent generator coordinate method [2].
On the other hand, the whole distribution of probability of an observable resulting from the wavefunction of the system is less often studied. Recent studies attempting this include efforts toward the prediction of the primary fragments number of protons and neutrons [3] and their spin distribution [4]. It is yet a challenging task. Typically, determining the k'th moment of the distribution of a one-body observable amounts to computing the action of a k-body operator on a wavefunction. The associated numerical cost quickly becomes prohibitive.
In this presentation, we will present our recent efforts to develop a Monte-Carlo method to compute the whole probability distribution of some observables resulting from a Bogoliubov vacuaa. We will first show the algorithmic and numerical aspects of the method and then emphasize its first application to the fission of ^{252}Cf. We will finally discuss the current limitations and future prospects for this Monte-Carlo approach.

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Fission isomer studies at FRS and IGISOL

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Invited talk

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The 'island' of fission isomers identified in the actinide region (Z = 92 - 97, N = 141- 151) originates from multi-humped fission barriers, which can be described as the result of superimposing microscopic shell corrections to the macroscopic liquid drop barrier. For the first time, populating fission isomers by using the in-flight fragmentation and the electromagnetic dissociation methods were tried at GSI. With the fragment separator (FRS) at GSI, the fragmentation of 1 GeV/u ^{238}U projectiles gives access to isotopes that are hard or impossible to reach by light particle-induced reactions that are so far in use. In-flight separation with the FRS allows studying fission isomers with half-lives as short as 100 ns. Most importantly, it provides beams with high purity and enables event-by-event identification. Two detection methods were employed to study fission isomers with half-lives in the range of approximately 100 ns to 50 ms: beam implantation in a fast plastic scintillator, and beam thermalization in a cryogenic stopping cell at the FRS Ion Catcher followed by subsequent detection [1]. Additionally, the excitation energy measurement of the long-lived fission isomer ^{242f}Am was performed via mass spectrometry at IGISOL, Finland. Results from these experiments will be presented in this contribution.

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Surrogate reactions at heavy-ion storage ring

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Invited talk

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To fully understand the phenomena leading to the creation of heavy elements in stars, knowledge of the neutron induced cross-sections is essential [1]. In the case of the rapid neutron capture (r-process), the direct measurement of these cross sections is often impossible due to the short lifetimes of the nuclei of interest and their high radioactivity. A well-known approach to overcome these difficulties is the use of surrogate reactions, where the compound nucleus formed in the neutron-induced reaction is produced through an alternative, experimentally accessible reaction and the probabilities for the different decay modes are measured [2]. However, when used in direct kinematics, this approach also has its drawbacks, including significant background or difficulties in detecting low-energy neutrons.
To address these challenges, we proposed the NECTAR (NuclEar reaCTions At storage Rings) project [3], in which we intend to measure decay probabilities in inverse kinematics using a heavy-ion storage ring. One of its major advantages lies in the direct detection of heavy fragments produced after the de-excitation of the compound nucleus, which would normally be stopped in a target. This allows the NECTAR project to measure, in a completely unique way, simultaneously the gamma emission, the neutron emission and the fission probability of the nucleus with unprecedented precision and efficiency.
Following a successful experiment [4] at the ESR storage ring of GSI/FAIR in 2022, during which, among other achievements, the neutron-emission probability of Pb-208 was measured for the first time, preparations are being made for next measurement in June 2024, this time with a U-238 beam.
In this contribution I will present the methodology and technical developments of the NECTAR project with a particular emphasis on our new fission detectors, one of which is based on the innovative technology of solar cells. In addition, I will present the first preliminary results of our uranium beam experiment which will be conducted this year.

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Fission Dynamics Investigation using VAMOS and FALSTAFF Spectrometers

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The fission process is strongly determined by the both nuclear structure and the nuclear dynamics, which drives the system from its initial state to final break-up through various stages of extreme deformation. The resultant fission fragments, along with the neutron evaporation emerge as promising parameters for elucidating the underlying mechanisms governing the fission process. Currently, at GANIL two experimental setups are in operation for the precise identification of the fission fragments. The FALSTAFF [1-2] spectrometer, employing low-pressure gaseous detectors, is designed to provide constraining data from neutron-induced fission. This setup offers a novel opportunity to identify fission fragments. Conversely, the VAMOS++ spectrometer is a large solid-angle, ray-tracing magnetic spectrometer, that benefits from inverse kinematics to provide complete isotopic identification of the fission fragments. An experiment was conducted for the first time at GANIL with VAMOS++ spectrometer in conjunction with FALSTAFF [3-4] spectrometer – modified for inverse kinematics – to simultaneously measure both fission fragments in coincidence. In this experiment, a ^{238}U beam at coulomb energies was impinged on beryllium (Be) target to produce different fissioning systems via fusion and transfer reactions. In this work, the full isotopic identification of the fission fragments from ^{247}Cm was accomplished. The masses of the fragments before and after neutron evaporation, alongside their kinetic energy and proton content, will be presented. These results will be compared with the present-day fission models and will be discussed in terms of fission modes and nuclear structure.

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Efficient procedure for extracting isotopic (A, Z) fission yields with the VAMOS++ spectrometer

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The advent of elaborate heavy-ion electromagnetic spectrometers equipped with state-of-the-art detectors has permitted a crucial step forward in understanding nuclear structure and dynamics. In this context, nuclear fission was established as a particularly "profitable" reaction mechanism. For nuclear collisions around the Coulomb barrier, the VAMOS++ large acceptance magnetic spectrometer [1] installed at GANIL has played a pivotal role in these advancements in recent years. A unique feature of VAMOS++ is its capability to provide accurate mass and atomic number identification for heavy ions using software-based trajectory reconstruction [2]. This feature was successfully explored in studies dedicated to both the nuclear structure of exotic nuclei and reaction dynamics [3-6].
However, measurements with spectrometers like VAMOS++ come with challenges, due to the limited angular and momentum coverage by one setting of the instrument. The impact of acceptance can be crucial for nuclear dynamics studies as only part of the phase space spanned by the reaction products is measured, thereby possibly biasing the physics conclusions. The issue reaches a peak for fission, where hundreds of different isotopes, each with a wide velocity distribution, are populated [6]. One option to circumvent the problem is to perform measurements at various angles and with different magnetic field settings [7]. Unfortunately, this can imply prohibitive beam time.
In this contribution, a novel method will be presented to extract the entire fission fragment yield distribution from a single angular setting of VAMOS++, thereby avoiding multiple measurements. In addition to correcting for the limited acceptance, the procedure can address issues related to detection inefficiency. The method was validated through comparative analysis with measurements conducted at two different VAMOS++ angle settings for the same nuclear reaction at similar excitation energies. This method can be implemented with any other heavy-ion spectrometer of this type. Its potential for studies combining VAMOS++ with new-generation particle and γ-ray detectors will be illustrated with recent measurements from SPIDER, AGATA and PARIS@VAMOS.

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Searching for the Anomalous Internal Pair Creation in ^{8}Be

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In 2016, Krasznahorkay et al. published the breakthrough of an anomaly in the Internal Pair Creation (IPC) of ^{8}Be [1]. Unexpected angular correlation distributions in the emission of the pair $e^{+}e^{-}$ was found in the isoscalar magnetic dipole transition (18.15 MeV state ($J^{\pi}=1^{+}$, T=0) $\rightarrow$ ground state ($J^{\pi}=0^{+}$, T=0)). According to the model of Rose [2,3], the angular correlation distribution drops quickly with the relative emission angle of the leptons. In contrast, the Hungarian group reported a peak-like behavior at large angles [1]. This result has been interpreted as the signature of the emission of a previously unknown neutral isoscalar particle with a mass of 16.70$\pm$0.35(stat)$\pm$0.5(syst) MeV/c^2 and J^{π}=1^{+}.
At the Laboratori Nazionale di Legnaro (Istituto Nazionale di Fisica Nucleare, Italy), a dedicated array to study this anomaly has been designed and built [4]. The project aims to measure the angular correlation distribution of the emission of the pair $e^{+}e^{-}$ from the transition studied in ^{8}Be at the Atomki Laboratories. The detector unit is a telescope manufactured with the plastic scintillator EJ200. The in-beam commissioning of the setup demonstrated that the array is able to measure leptons in coincidence and reconstruct the energy of the electromagnetic transition in the IPC process. Furthermore, the ΔE layer consists of a system of bars able to detect the incident position of the particles. In addition, a Geant4 simulation has been development in order to correct by efficiency the angluar correlation distribution. The IPC of the transition $0^{+} \rightarrow 0^{+}$ in ^{16}O has been studied as a first case. This transition is used as a calibration point of the detectors, since the cross-section is order of magnitudes higher than the ones in ^{8}Be. During the end of November of 2023 and the end of April 2024 the former experiments has been carried out at the AN2000 Accelerator. LiF targets from 50-950 µm/cm^2 has been irradiated with a 1.06-1.09 MeV proton beam and a $\sim$500 nA current. The population of the state of interest and the integrity of the target was monitored with a 3$\times$3 in^2 $LaBr_3$ detector. In the present work the preliminary results in the study of the isovector and isoscalar magnetic dipole transitions in ^{8}Be are shown.

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Electron-positron pair spectrometers with high efficiency for angular correlation measurements

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Electron-positron pair spectrometers have been designed and constructed for the simultaneous measurement of energy- and angular correlations of e^+e^- pairs. Experimental results are obtained over a wide angular range for high-energy transitions in ^{16}O, and ^8Be. A comparison with GEANT simulations demonstrates that angular correlations between 40 and 180 degrees of the e^+e^- pairs in the energy range between 6 and 18 MeV can be determined with sufficient resolution and efficiency to study the anomalies in the e^+e^- angular correlations in different nuclear transitions.

Proton and neutron pick-up reactions with Be isotopes near the drip-line

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Proton-removal reactions along the Be-Li chain close to the drip line have been investigated to establish the role of the Geometrical Mismatch Factor (GMF) and NN effects [1] in lowering the cross sections, as observed previously in He-Li nuclei when compared to theoretical predictions [2].
The experiment E748 was performed at GANIL using ^{10}Be and ^{12}Be beams at 30 AMeV impinging a CD_2 target, with an intensity of 3×10^5 and 2×10^4 pps respectively. The light recoil's angle and energy were detected using 8 MUST2 telescopes [3], and a zero-degree detector consisting of an ionization chamber and a plastic scintillator that permitted the identification of the heavy recoil.
The missing-mass technique was used to reconstruct the excitation energy spectrum, from which cross-sections have been extracted. Particular attention has been paid to the ^{12}Be$(\mathrm{d},^3\mathrm{He})^{11}$Li transfer reaction, but also to the ^{12}Be$(\mathrm{d},\mathrm{t})^{11}$Be channel as it enables a further constrain to the GMF of ^{12}Be [4].
This work will present preliminary results of the angular distributions for all the interesting opened channels, alongside the corresponding J^π assignments and spectroscopic factors. The elastic channels will also be displayed as a validation mechanism of the normalization factors.

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Study of proton and neutron excitations along silicon isotopes between N=20 and N=28

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The main subject of this study is the experimental investigation of the nuclear structure of exotic neutron-rich nuclei in the vicinity of shell closures in order to constrain the description of the nucleon-nucleon interaction, and in particular its tensor term. Previous studies have shown that a deformation region develops along the N=28 isotonic chain between the doubly magical and spherical ^{48}Ca nucleus (20 protons/28 neutrons) and the ^{42}Si nucleus which is extremely deformed in spite of its semi-magical character (14 protons/28 neutrons). It has been shown that this deformation results from neutron excitations above N=28 and proton excitations above Z=14, both made possible by the reduction of these shell closures under the effect of the tensor component of the nuclear interaction. The goal is now to follow the evolution of the deformation along silicon isotopic chain, between ^{34}Si (N=20) and ^{42}Si (N=28).
To achieve this purpose, we performed an experiment to measure the two following quantities:
- The cross section of inelastic proton scattering of the 2^{+} state of $^{34-36-38}$Si nuclei.
- B(E2,$0^{+} \longrightarrow 2^{+}$) values of $^{34-36-38}$Si nuclei by coulomb excitation on a gold target.

The experiment has been set up during the 2022 campaign of LISE spectrometer (Line d'Ions Super Epluchés) at GANIL(Grand Accelerator National d'Ions Lourds). The spectrometer allowed to produce and select ^{34}Si, ^{36}Si and ^{38}Si nuclei. In order to measure the both quantities (inelastic proton scattering cross section and B(E2)), the experimental setup was composed of two independent setups on the same beamline with the same radioactive beam allowing us to save beam time and keep the same experimental conditions ("Brochette" mode experiment).
The first setup was ACTAR-TPC detector (ACtive TARget-Time Projection Chamber) to measure the inelastic scattering of ^{A}Si(p,p')^{A}Si* reactions, with $(A = 34, 36, 38)$. The second setup was the CoulEx part (Coulomb Excitation). The objective was to measure the effective cross section of coulomb excitation of the same silicon isotopes and deduce, from the cross section, B(E2) values. Several types of detectors composed the CoulEx setup like tracking detectors and gamma detectors from GANIL. Here we propose to present results from CoulEx part.

0_2^+ shape isomer in ^{44}S

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In lighter mass nuclei, the usual nuclear shell gaps are not very huge, leading to easy nucleonic excitations, resulting in the mixing of configurations from intruder space below core to normal valence space. The influence of such configuration mixing on the low-lying energy spectra of $N = 28$ isotones below and above ^{40}Ca will be presented using the configuration-mixed interacting boson model. A special focus will be made on the isomeric nature of 0_2^+ state in ^{44}S and the predictions in ^{42}Si and ^{46}Ar. These results are crucial to the generic understanding behind the $E0$ isomeric transitions throughout the nuclear landscape.

Gamma-ray spectroscopy of ^{46}S and ^{47}S

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Data on sulfur isotopes close to the neutron drip-line are rather scarce. Only one γ-ray has been found in ^{46}S and excited states in ^{47}S are unknown up to now. The very neutron-rich ^{46}S and ^{47}S nuclei have been investigated by in-beam gamma-ray spectroscopy at RIKEN RIBF via multinucleon knock out reactions. New excited states have been identified in ^{46}S and one gamma-ray has been assigned to ^{47}S. The experimental findings and their interpretation will be presented.

Searching for the microscopic origin of shape coexistence in Ca isotopes

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Nuclear shape coexistence plays a crucial role in understanding the microscopic origin of nuclear deformation. Supporting evidence has been found over the entire nuclear chart, with remarkable examples of shape isomerism in the very heavy actinides systems (*i.e.*, $^{236,238}U$) [1], while in lighter mass systems significant mixing between configurations characterized by different shapes is most often observed [2][3]. In this respect, the Ca isotopic chain between ^{40}Ca and ^{48}Ca is an optimal test area that can provide key information on shape coexistence when moving from the valley of stability towards the neutron-rich region of the Segrè chart.
This work aims to perform complete low-spin spectroscopy of $^{42,43,44,45}Ca$ isotopes, complementary to the already existing data of $^{41,47,49}Ca$ [4], and to look for evidence of shape coexistence in the $A \sim 40$ region. As a first step in this direction, we focused on ^{42}Ca, where the AGATA collaboration [5] has already highlighted the presence of a 0^+ excitation at $1837\ keV$ associated with a superdeformed shape. Moreover, previous particle spectroscopy experiments also indicated the existence of a few 0^+ states at higher energy [6] that could be associated with other deformed structures.
The ^{42}Ca nucleus of interest was populated with a (n_{th}, γ) reaction on a ^{41}Ca radioactive target. The γ cascades emitted from the neutron capture state were detected using a 32 HPGe crystals array called FIPPS [7] at ILL (Grenoble).
The result of the present work is a very complex set of excited levels and gamma-ray transitions that expanded Kikstra's work [8] to nearly 60 excited levels linked by more than 200 gamma-ray transitions, including more than 10 levels and 100 transitions never observed before. Preliminary angular correlation studies were also performed in order to establish spin and parities of several excited states of ^{42}Ca. First results on the $^{43}Ca(n_{th}, \gamma)$ reaction will also be presented to extend neutron-capture studies to ^{44}Ca and track shape changes towards mid-shell.

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Exploring nuclear structures with fast neutrons at NFS

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Shedding new light on the structure of ^{56}Ni using (n,3n) reaction at NFS Systematic studies of nuclear reactions are essential to the development of nuclear physics. Understanding and predicting the evolution of nuclear structure and the novel phenomena in atomic nuclei has long been a pursuit of scientific curiosity. Conventional methods such as charged particle probes, β-decay, Coulombic-excitation, and heavy-ion fusion evaporation reactions have been employed so far in the phase space of Shell structure, magic numbers, angular momentum, and excitation energy. However, the horizon of possibilities expands when we delve into the uncharted territories of fast-neutron probes. The (n,xn) reactions are a long-standing reaction mechanism used in the cross-section data evaluation, but rarely used in the framework of nuclear structure. This might unveil a treasure trove of reactions, particularly the (n,xn) reactions with high production thresholds, which, until now, have not been looked at from the eye of nuclear structures. As a result, we know very little about their reaction mechanisms.
While the structure of ^{56}Ni has been previously investigated using charged particle and heavy ions collisions as shown in Fig. 2, a pure neutron probe was never used. For the first time, using the unprecedented neutron flux at $\sim$20 – 40 MeV at the Neutrons for Science (NFS) facility of GANIL–Spiral2, ^{56}Ni can be populated from ^{58}Ni in a (n,3n) reaction which has a cross-section of 2 mb at $\sim$30 MeV, opening a new probe and possibly new aspects of the nuclear structure of this doubly magic nucleus. The TALYS cross-section calculation as a function of incident neutron energy is shown in Fig. 3. The maximum cross-section is predicted to be at 40 MeV, slightly higher than the end-point of NFS. p + Li/Be allows reaching the [20 – 30] MeV range, whereas d + Be allows up to a broader [25 – 40] MeV range. With ^{58}Ni target, studying pure neutron channels is the main interest alongside Co isotopes that are produced from (n,p/d/t) reaction.

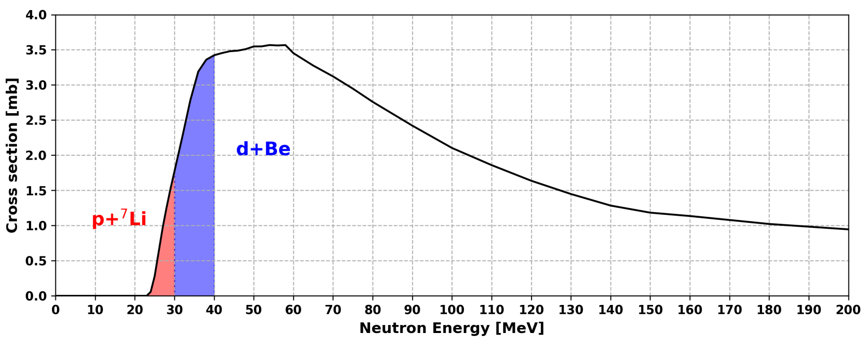

Figure 2: ^{56}Ni Yrast diagram

The nuclei near ^{56}Ni are of particular interest as they are amenable to different microscopic theoretical treatments while studying the competition between single-particle and collective excitations. The collective states in ^{56}Ni involve multiparticle multi-hole excitations across the $N = Z = 28$ shell gap from the 1f$_{7/2}$ shell to the 2p$_{3/2}$, 1f$_{5/2}$, and 2p$_{1/2}$ orbits. Excitation to the higher lying 1g$_{9/2}$ orbit are

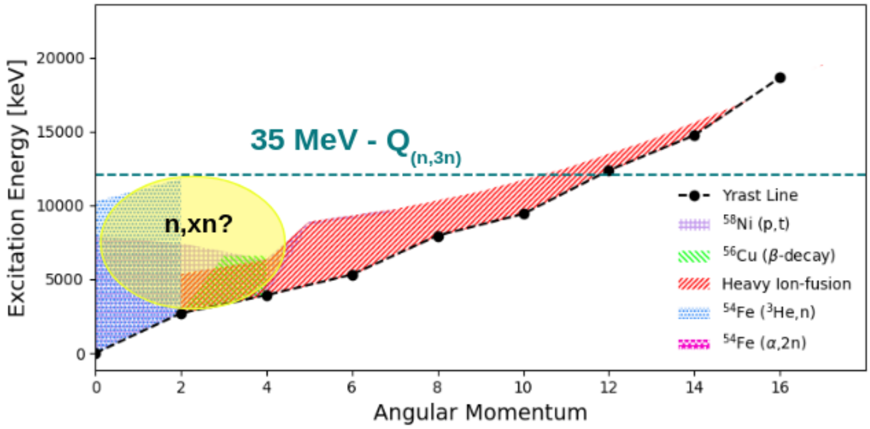

Figure 3: ^{58}Ni (n,3n) ^{56}Ni cross-section

necessary to explain the observed rotational bands in Cu and Zn. At high excitation energies, reaction studies have revealed evidence for hyper-deformed resonances in the ^{56}Ni compound.

In this project, we performed prompt-γ spectroscopy of ^{56}Ni using the EXOGAM array at NFS. From nuclear structure's point of view, the main motivation is the search for low spin (J $=$ 2 or 4) states from 3 to 10 MeV excitation energy possibly populating the 0^+ states at 3956 keV, 6654 keV and 7903 keV observed only in ^{58}Ni(p,t)^{56}Ni and ^{58}Ni(^{3}He,n)^{56}Ni reactions. New spectroscopic information that will be collected is also relevant for nuclear reaction mechanism formalism (like TALYS) and nuclear data evaluation libraries.

The experiment was carried out in October 2023. During an effective beam time of 11 days, a high energy neutron beam produced by a primary beam of 10 µAmps of ^{2}H, bombarded a 1 mm thick Ni target. The prompt gamma rays selected on the fastest neutron using the Time of Flight information have been detected by 12 EXOGAM clovers placed at 1 cm off the beam axis. About 1.6×10^{10} $\gamma\gamma$ coincidences have been sorted after the AddBack procedure. The ^{56}Ni decay was observed and a large number of $\gamma\gamma$ coincidences for ^{57}Ni and Co isotopes were sorted. The very preliminary analysis of the experiment, focusing mainly on the pure neutron channels, will be presented. The (n,2n) channel that produces ^{57}Ni has a much larger cross-section, reaching a maximum of $\sim$90 mb at around 23 MeV, making it easier to study. Additionally, ^{57}Ni is only one neutron away from the doubly magic ^{56}Ni, making spectroscopy of single particle, core-coupled, and collective states of great interest. The primary focus of the talk will be to provide a comprehensive description of its level scheme and excitation functions. This isotope has a half-life of 35.6 hours and undergoes β^+ decay to produce ^{57}Co in the system, which interestingly is also populated by the (n,d) and (n,n′p) channels. The question of whether large germanium volume detectors can be used for γ spectroscopy in a high flux high neutron energy environment will also be addressed.

This experiment is a pioneering work in the study of the nuclear structure studies using large gamma array and fast neutron and is only possible at GANIL-Spiral2 as of today. If successful, this program will open a new door for nuclear structure studies.

Magnetic moments of isomeric states around ^{68}Ni

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The presence of three doubly-magic nickel isotopes - ^{48}Ni, ^{56}Ni and ^{78} Ni, makes the nickel isotopic chain a fruitful testing ground for various theoretical models. Many phenomena that occur when moving from the neutron-deficient ^{48}Ni towards the neutron-rich ^{78}Ni can be investigated. Of particular interest are the evolution of the neutron effective single-particle energies and the magic numbers away from stability, and the interplay between single-particle structure and collectivity.

Magnetic moments of excited nuclear states provide sensitive probes to the contributions of single-particle configurations to the nuclear wave functions. This is especially true close to shell closures where the wave functions are expected to be quite pure. A peculiar case that was studied through the measurement of magnetic moments is that of ^{68}Ni which lies at the $N = 40$ sub-shell closure between the *fp* shell and the $g_{9/2}$ orbital. It exhibits some properties typically associated with doubly-magic nuclei, such as its first excited state being a 0^+ state [1] and a low $B(E2)$ value of its 2_1^+ state [2,3]. However, no sign of magicity at $N = 40$ was observed in the S_{2n} from mass measurements [4].

Further insight into the nuclear structure in the vicinity of ^{68}Ni could be obtained through measurements of the magnetic moments of $g_{9/2}$ isomeric states in the region. The magnetic moments of the $9/2^+$ isomeric states in ^{65}Ni [5] and ^{67}Ni [6] were determined in experiments at the ALTO and GANIL facilities, respectively, utilizing the Time-Dependent Perturbed Angular Distribution (TDPAD) method. A follow-up experiment to measure the magnetic moments of the $17/2^-$ isomer in ^{69}Ni and the 8^+ isomer in ^{70}Ni was performed at the NSCL facility at MSU, USA, together with a re-measurement of the magnetic moment of the $9/2^+$ state in ^{67}Ni. The nuclei of interest were produced following a projectile-fragmentation reaction of a ^{76}Ge primary beam (130 MeV/A) on a Be target. The fragments passed through the A1900 separator and were implanted at the center of a dedicated TDPAD detector setup to perform the measurement. The results obtained from this experiment will be presented and compared to state-of-the-art shell-model calculations. The implications on the robustness of the $Z = 28$ and $N = 40$ shell gaps will be discussed, as well as plans for future TDPAD measurements in exotic nuclei.

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New Exotic Geometrical Shape Predictions in the Range of Nuclei with $Z \approx N \sim 40$*

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In the recent years, the possible presence of exotic symmetries in atomic nuclei have been attracting both experimental and theoretical nuclear physicist, with an increase of the number of publications on this topic. Among these new symmetries, tetrahedral and octahedral symmetries are considered to be the most exotic, since they produce unprecedented 4-fold nucleonic level degeneracies, in contrast to the traditional or well studied Kramers (2-fold) degeneracies.
It is well known that the nuclear surface can be described with the help of spherical harmonics $\{Y_{\lambda,\mu}\}$. Following indications discussed in Ref. [1], suggesting the presence of tetrahedral symmetry is expected to occur in groups of nuclei throughout the nuclear chart, and Ref. [2], where the first spectroscopic identification of tetrahedral (T_d) and octahedral (O_h) symmetries was presented, we employ a phenomenological mean-field approach Hamiltonian with the parametric correlations removed, together with group and point group theories to show that the strongest shell effects around $Z \approx N \approx 40$ appear for the $\lambda = 7$ tetrahedral multipolarity, in contrast to the first order one with $\lambda = 3$. To our knowledge these are the first predictions of nuclear ground state shapes with so high deformation multipolarity.

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Deuteron Evaporation and Proton Emission in the Upper *fp* Shell

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An experimental campaign focusing on isospin-symmetry and proton emission in the upper *fp* shell was performed at Argonne National Laboratory (ANL) in 2020. The overarching goal was to perform in-beam high-resolution particle- and γ-ray coincidence spectroscopy along the $N = Z$ line beyond doubly-magic ^{56}Ni. The second experiment of the campaign, studied isobaric analog states in mass $A = 61$ nuclei, and in particular proton emission from low-lying states in ^{61}Ga.

The focus of the campaign on in-beam proton spectroscopy called for a new approach in charged-particle detection. The complex setup comprised two CD-type double-sided Si-strip detectors (DSSDs), the Microball CsI(Tl) array, the Gammasphere array, the Neutron Shell liquid scintillator array, and the Fragment Mass Analyzer (FMA). The novel combination of CD-DSSDs (pixelation 2×2048) with Microball allowed for proton tracking capabilities and optimized proton energy resolution while keeping high detection efficiency for evaporated charged particles.

For the experiment of interest, excited states in ^{61}Ga were populated via the fusion-evaporation reaction ^{24}Mg(^{40}Ca$, p2n)^{61}$Ga. Results from an earlier study concerning this $T_z = -1/2$ nucleus suggest a proton-emitting $g_{9/2}$ single-particle state at $E_x \approx 2400$ keV. As a result of the experiment, a proton emission line in ^{61}Ga has been identified.

During the offline analysis it was realized that the setup is also capable of unambiguously distinguish evaporated deuterons from evaporated protons. In combination with Gammasphere, this opens up for an unprecedented study of – possibly preferential – production cross sections along the $N = Z$ line involving deuterons for a series of compound and residual nuclei: for instance, ^{24}Mg(^{40}Ca$, 2pn)^{61}$Zn vs. ^{24}Mg(^{40}Ca$, dp)^{61}$Zn.

The analysis is ongoing. Results on deuteron evaporation and a proton emission line in ^{61}Ga will be presented.

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Beta-decay study of the shape coexistence in ^{98}Zr

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Anomalies in the systematics of nuclear properties challenge our understanding of the underlying nuclear structure. One such anomaly emerges in the Zr isotopic chain as a dramatic ground-state shape change, abruptly shifting from spherical into a deformed one at N=60. Only a few state-of-the-art theoretical models have successfully reproduced this deformation onset in ^{100}Zr and helped to establish the shape coexistence in lighter Zr isotopes [1, 2]. Of particular interest is ^{98}Zr, a transitional nucleus lying on the interface between spherical and deformed phases. Extensive experimental and theoretical research efforts have been made to study the shape coexistence phenomena in this isotope [3,4,5]. Although they provide an over-all understanding of ^{98}Zr's nuclear structure, uncertainties remain in interpreting its higher-lying bands. Specifically, two recent studies utilizing Monte Carlo Shell Model (MCSM) [6] and Interacting Boson Model with configuration mixing (IBM-CM) [7] calculations have presented conflicting interpretations. The MCSM predicts multiple shape coexistence with deformed band structures, whereas the IBM-CM favours a multiphonon-like structures with configuration mixing.
To address these uncertainties, a β-decay experiment was conducted at TRIUMF-ISAC facility utilizing the 8π spectrometer with β-particle detectors. The high-quality and high-statistics data obtained enabled the determination of branching ratios for weak transitions, which are crucial for assigning band structures. In particular, the key 155-keV $2_2^+ \rightarrow 0_3^+$ transition was observed, and its branching ratio measured, permitting the B(E2) value to be determined. Additionally, γ-γ angular correlation measurements enabled the determination of both spin assignments and mixing ratios. As a result, the 0^+, 2^+, and $I = 1$ natures for multiple newly observed and previously known (but not firmly assigned) states have been established. The new results revealed the collective character of certain key transitions, supporting the multiple shape coexistence interpretation provided by the MCSM framework. These results will be presented and discussed in relation to both MCSM and IBM-CM calculations.

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New lifetime measurements in the Ru chain: investigating the evolution of triaxiality

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In the neutron rich region around mass 100, nuclei undergo a variety of shape transitions. Theory and experiment have shown several cases of shape coexistence, notably in Zr and Sr isotopes [1,2]. Ru isotopes undergo a transition from prolate to oblate, passing through triaxial deformations [2,3]. The lifetimes of the exited states provide empirical information on the degree of deformation in these nuclei.
Experiment e706 conducted at ganil in 2017 used a $^{9}\mathrm{Be}(^{238}\mathrm{U},\mathrm{f})$ fusion-fission reaction to populate around one hundred nuclei in the mass 100 region, with the aim of determining lifetimes with the recoil distance Doppler shift method. The Advanced Gamma Tracking Array (AGATA) – covering about 1π at backwards angles – measured the energy of emitted γ-rays, and the Variable Mode Spectrometer (VAMOS++) identified the decaying nuclei event-by-event and measured their velocity.
Results from the Zr chain have been published by Pasqualato *et al.* [4]. This contribution will focus on the Ru chain, and present several new lifetimes in both odd neutron and even-even nuclei. For the latter, we have measured lifetimes in the gamma band as well as the ground-state band. This makes it possible to distinguish models with different degrees of triaxiality. Elements of improvement in the data analysis method will also be discussed. **References**

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Probing nuclear structure changes in odd-odd nuclei below *Z* = 50 with Ag

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Exploring ground-state nuclear properties is a powerful tool to investigate our understanding of the nuclear structure. Laser spectroscopy gives access to model-independent measurements of the ground-state properties (spin, nuclear electromagnetic moments, changes in the charge radius) of short-lived ($\geq$10 ms) nuclei, providing an excellent benchmark for theoretical predictions close to magic shell closures far from stability [1]. One region of high interest is the region below near-spherical Sn($Z = 50$), a region with many competing nuclear configurations, and thus the subject of recent investigations: tin [2], indium [1], cadmium [3], silver [4-6] and palladium [7] studies have been successfully performed before. Recently neutron-rich silver has been studied at ISOLDE/CERN [8] and IGISOL in Jyväskylä [7].
Though while the trends in ground-state properties in odd-even nuclei close to $Z = 50$ are relatively well studied [1-3,7], an explanation of the trends in odd-odd nuclei is not present. I will present the results obtained on radioactive odd-odd silver at CRIS in ISOLDE/CERN and compare them to the literature. The nuclear spin and electromagnetic properties of the ground state and several 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 for neutron-rich silver laser and decay spectroscopy studies at CRIS with the newly developed decay spectroscopy station.

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Constraints on the Symmetry Energy from Relativistic Coulomb Excitation

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The nuclear Equation of State (EoS) describes the energy per nucleon as a function of the density of infinite nuclear matter. The response of such a system to changes in isospin asymmetry is characterized by the symmetry energy term ($S_2(\rho)$), which determines the energy expense for turning symmetric nuclear matter into pure neutron matter as a function of density. Around the saturation density, $S_2(\rho)$ is parametrized by its value at saturation (J) and the slope (L), with the latter quantity still poorly constrained. Given its vital role in describing properties of exotic nuclei, neutron stars, and core-collapse supernovae, a worldwide effort to identify and measure observables containing the information necessary to constrain the density dependence of the symmetry energy is underway.

We aim to provide constraints on the symmetry energy by experimentally determining the values of the Coulomb excitation cross section (σ_C) for a range of tin isotopes $^{124-134}$Sn. The total Coulomb excitation cross section for neutron-rich medium heavy and heavy nuclei, when measured at high beam energies displays a strong correlation to the dipole polarizability (α_D) [1,2], a quantity known to display sensitivity to the isovector characteristics of the equation of state around and slightly below the saturation density. The advantage of measuring σ_C instead of α_D lies in a simpler experimental approach, where a precise determination of the excitation energy is not a requirement.

Measurements of the total Coulomb excitation cross sections have been performed on neutron-rich tin isotopes with the R3B-LAND setup at GSI, and more recently with the upgraded R^{3}B setup using the R3B-GLAD spectrometer and the NeuLAND neutron detector. The nuclei of interest have a large neutron excess, and can only be accessed in inverse kinematics due to their lifetimes. In this work, the theoretical investigations of the relationship between σ_C and α_D, and in turn L, based on density functional theory for nuclear structure and first-order perturbation and coupled-channels calculations for the cross sections, will be presented alongside preliminary experimental results and the status of the analysis.

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The study of proton-emitting nuclei near the N=82 shell closure

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Proton radioactivity provides a unique probe of nuclear structure far from stability and for odd-Z elements it is expected to be the decay mode that determines the limit of observability for neutron deficient nuclei. Establishing these boundaries of observability and identifying the nuclear structure at these limits is a long-standing challenge in nuclear physics. The nuclei in the region of the N=82 shell closure are expected to be the most nearly spherical proton emitters and therefore a benchmark for theoretical models of this decay mode [1,2]. These odd-Z nuclei are known to have low-lying isomeric states, which are often substantially longer-lived than the ground states in these nuclei, due to the strong increase of proton-decay half-lives with the orbital angular momentum of the emitted proton. In these cases the isomeric states all have a configuration involving a proton in the $\pi h_{11/2}$ orbital, while in the ground states the protons are in either a $\pi s_{1/2}$ or $\pi d_{3/2}$ orbital. This allows the observation of the isomeric states in proton-emitting nuclei where the ground state is too short-lived to be observed with current experimental techniques, for example ^{159}Re [3]. Additional interest in these nuclei comes from the possibility of microsecond multiparticle isomers that are analogous to those seen in their lighter isotones [4].

The aim of this work is to search for new, and clarify the nature of known proton radioactivities in the region of the N=82 shell closure, and to search for possible isomeric states in these nuclei. The searches were performed at the University of Jyväskylä in Finland. The nuclei of interest were produced by fusion-evaporation reactions induced by a ^{58}Ni beam bombarding isotopically enriched ^{102}Pd and ^{106}Cd targets. The evaporation residues were separated in flight using the Mass Analysing Recoil Apparatus (MARA) [6] and implanted into a double-sided silicon strip detector (DSSD), which was used to measure proton and alpha decays. The DSSD was surrounded by an array of germanium detectors to allow isomer gamma decays to be observed. The latest results from the analysis of these data will be presented.

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Investigating quadrupole bands in even-even Hf and W

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The structure of the low-lying quadrupole bands in the even-even Hf and W isotopes, with $N \approx 92 - 112$ is investigated with the use of a microscopically derived IBM-1 Hamiltonian. For each isotope, a potential energy curve is constructed from self-constrained mean-field calculations, employing a Skyrme energy density functional. The fermionic potential energy curve is subsequently mapped onto the corresponding bosonic one, thus leading to the derivation of the IBM-1 Hamiltonian parameters. These parameters are then used as inputs for the calculation of energy spectra and $B(E2)$ transition matrix elements for the ground state, β and γ bands in the examined isotopes. The results are compared to experimental data, where available, showing an overall good agreement. Potential future applications of this mapping method are also discussed.

Isomeric and Beta Decay Transitions and Lifetimes in the Neutron-Rich N=126 Region

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In May 2022 at GSI Darmstadt, Germany, a high-intensity, ^{208}Pb primary beam of 1 GeV/u was fired at a ^{9}Be target to populate neutron-rich fragmentation products at N$\approx$126. The study of such nuclei forms an important part of our understanding of nuclear structure and the testing of nuclear shell model predictions. In addition, investigating increasingly neutron rich N=126 nuclei brings us closer to important astrophysical isotopes, aiding in the refinement of current r-process path predictions. Fragmentation products from GSI's fragment separator were implanted in two 1 mm thick 24x8 cm^{2} AIDA active silicon stoppers and two scintillating beta plastic detectors. The implanted ions were surrounded by eight newly developed DEGAS and two well-established EUROBALL high-purity Ge detectors.
The primary aim of this experiment was to study the structure of N=126 nuclei through observing isomeric transitions and beta decays. In ^{203}Ir, a long-lived 11/2^{-} state is expected [1], however the decay of this was not previously observed. Furthermore, the beta-decay half-lives of many nuclei in this region are currently unknown, in addition to information on excited states in their daughter nuclei. To this aim, GSI's fragment separator was centered on the N=126 nuclei ^{203}Ir and ^{202}Os for one day and three days, respectively. The knowledge gained from level schemes in this region is valuable for understanding potential shell evolution at N=126, as well as filling current experimental gaps in ground state lifetimes. Preliminary analysis has identified all previously observed isomeric states in ^{203}Pt, ^{204}Pt, and ^{203}Ir [1]. In addition, known gamma transitions following the beta decays of Hg, Au and Pt isotopes were detected [2]. The collected statistics on neutron-rich nuclei are much greater than in previous experiments, revealing new internal decay channels. One such nucleus was ^{203}Ir, where the number of ions detected was 3 times larger than obtained previously in 2010 [1]; the updated ^{203}Ir level scheme of isomeric states will be compared with shell model calculations. Furthermore, additional isomeric decays detected in this experiment will be presented, alongside the observed beta-gamma correlations.

Wednesday

August 28th

Prevailing Triaxial Shapes in Atomic Nuclei and a Quantum Theory of Rotation of Composite Objects

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Invited talk

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Virtually any object can rotate: the rotation of a rod or a linear molecule appears evident, but a number of objects, including a simple example of H_2O molecule, are of complex shapes and their rotation is of great interest. For atomic nuclei, rotational bands have been observed in many nuclei, and their basic picture is considered to have been established in the 1950's. We, however, show that this traditional picture is superseded by a novel picture. In the traditional view, as stressed by Aage Bohr in his Nobel lecture with an example of ^{166}Er nucleus, most heavy nuclei are like axially-symmetric prolate ellipsoids (i.e., with two shorter axes of equal length), rotating about one of the short axes, like a rod. In the present picture, however, the lengths of these three axes are all different, called triaxial. The triaxial shape yields more complex rotations, which actually well reproduce experimental data, as confirmed by state-of-the-art Configuration Interaction calculations. Two origins are suggested for the triaxiality: (i) binding-energy gain by the symmetry restoration for triaxial shapes, and (ii) another gain by specific components of the nuclear force, like tensor force and high-multipole (e.g. hexadecupole) central force. While the origin (i) produces basic modest triaxiality for virtually all deformed nuclei, the origin (ii) produces more prominent triaxiality for a certain class of nuclei. An example of the former is ^{154}Sm, a typical showcase of axial symmetry but is now suggested to depict a modest yet finite triaxiality. The latter, prominent triaxiality, is discussed from various viewpoints for some exemplified nuclei including ^{166}Er, and experimental findings, for instance, those by multiple Coulomb excitations obtained decades ago, are re-evaluated to be supportive of the prominent triaxiality. Many-body structures of the γ band and the double-γ band are clarified, and the puzzles over them are resolved. Regarding the general features of rotational states of deformed many-body systems including triaxial ones, the well-known J(J+1) rule of rotational excitation energies is derived, within the quantum mechanical many-body theory, without resorting to the quantization of a rotating classical rigid body. This derivation is extended to the J(J+1)-K^2 rule for side bands with K$\neq$0. The present picture of the rotation is robust and can be applied to various shapes or configurations, including clusters and molecules. Thus, two long-standing open problems, (i) occurrence and origins of triaxiality and (ii) quantum many-body derivation of rotational energy, are resolved. Their possible relations to the Nambu-Goldstone mode for the symmetry restoration are mentioned, as well as those to Davydov's rigid-triaxial-rotor model. Substantial impacts on superheavy nuclei and fission due to the wide occurrence of triaxial shapes are mentioned.

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Shape transitions and coexistence in the Sr - Ru isotopes

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Invited talk

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, including the state-of-the-art Monte Carlo Shell Model (MCSM) calculations [3,4] and Interacting Boson Model calculations 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 $N = 60$ for Sr-Ru isotopes will be presented with a particular emphasis on shape coexistence.

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High-resolution studies of the back decay of fission shape isomers

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Invited talk

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Fission shape isomers (SI) are poorly understood metastable states characterized by a second superdeformed potential energy minimum co-existing with normal deformed states in the low- spin regime [1]. Although many such isomers have been observed in the actinide region, our understanding of excited states in the second minimum remains very limited. For most SIs, the only available information is their half life, determined via their exclusive decay mode - delayed fission. However, the interesting possibility of a competing branch of γ back-decay towards normally deformed states opens up as the number of protons decreases and the fission barrier becomes harder to penetrate. Characterisation of γ back decay provides a unique and precise way to determine the parameters of the inner barrier, which play an essential role in constraining the potential energy landscape on the path to fission calculated by theory. Improved knowledge of gamma back-decay and excited states in the second minimum is now feasible due to significant advances in the techniques of gamma ray spectroscopy since the first experiments which were carried out a few decades ago. Indeed, spectroscopy of several yet-to-be-discovered SI's in the light actinide region may now be possible. In this context two experiments were performed to study ^{236f}U and ^{233f}Th using the nu-Ball2/PARIS spectrometer at the ALTO facility of IJC Lab. nu-Ball2 consists of 24 High Purity Germanium (HPGe) Clovers and 64 phoswiches (LaBr3/NaI) from the PARIS collaboration [2] and covers more than 90% of the total solid angle. Additionally, a Double-sided Stripped Silicon Detector (DSSD) [3] was used to measure the energies of outgoing light charged particles. The state-of-the art fully digital FASTER electronics [4] allowed for triggerless data acquisition at high data rates. The exceptional selectivity of this setup allows us to probe rare decays with sub-microbarn cross sections. This was achieved by a combination of high efficiency HPGe detectors, charged particle selection, high quality beam pulsation, and calorimetry of prompt and delayed energy balances. Here, an overview of the physics of fission shape isomers will be given and results from the nu-Ball2/PARIS fission shape isomer experiments will be presented.

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Investigating the shape coexistence phenomena in ^{62}Ni

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We report the progress of our investigation of the excited states in ^{62}Ni in the search for the onset of shape coexistence in the neutron rich Ni isotopes, based on the predictions of state-of-the-art Monte Carlo shell model (MCSM) calculations [1]. Following our collaboration's discovery of spherical, oblate, and prolate states within ^{66}Ni [2] and ^{64}Ni [3] utilising the ROSPHERE HPGe array [4], the present investigation represents a natural progression.
The low-spin structure of the semimagic ^{62}Ni nucleus has been considerably expanded: ten 0^+ excited states were identified below 6.5 MeV, using the data taken with the FIPPS spectrometer [5] at ILL, in a neutron capture experiment. An extensive decay scheme of the identified 0^+ excited states was constructed from the same data. Additionally, at IFIN-HH, by employing the one-neutron transfer reaction induced by a ^{9}Be beam on a ^{61}Ni target, at the sub-Coulomb barrier energy of 18 MeV, the lifetimes of the first two excited 0^+ states were assessed with the plunger method, using the ROSPHERE and the SORCERER solar-cells arrays [6].
The extensive experimental information gathered on ^{62}Ni has been compared with MCSM calculations which turn out to remarkably describe the complex excitation and decay scheme of this nucleus. Particularly, in ^{62}Ni a shape coexistence scenario is expected to appear in the 3.5-6.5 MeV excitation-energy region, with 0^+ states of spherical, oblate and prolate nature, with different degrees of deformation.
This work contributes to shed light on the shape coexistence phenomenon and its evolution along the Ni isotopic chain.

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β decay of ^{100}Y studied with GRIFFIN

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A sudden shape transition is observed for the ground states of the nuclei with A ≈ 100, appearing sharply at $N = 60$ [1]. This unique feature is accompanied by equally dramatic changes in the low-energy spectra, further supporting the large increase in collectivity and suggesting a possible shape-coexistence scenario. Advances with the large-scale Monte-Carlo shell model (MCSM) allowed to successfully reproduce the energy systematics of the Zr isotopes around $N = 60$ and offered a possible explanation of the observed abrupt shape transition [2]. An inversion of configurations in ^{98}Zr and ^{100}Zr was suggested to appear with small to no mixing between them due to type-II shell evolution [3]. More precisely, the prolate configuration at ≈1 MeV in ^{98}Zr becomes the ground state in ^{100}Zr, while the spherical ground state of ^{98}Zr corresponds to a yet unobserved 0^+_4 level in ^{100}Zr expected at excitation energy of about 1.5 MeV. Furthermore, the calculations predicted the coexistence of an oblate-deformed 0^+_2 state and a prolate-deformed 0^+_3 state.

A β-decay study of ^{100}Y was performed at the TRIUMF-ISAC facility to investigate the possible coexistence of low-energy structures with distinct shapes in ^{100}Zr. Radioactive ion mixture of ^{100}Sr and ^{100}Rb was delivered onto a mylar tape in the center of the GRIFFIN spectrometer [4], comprising of 15 large-volume HPGe clover detectors. In addition, seven $LaBr_3$ detectors were used for fast-timing lifetime measurements. The large amount of gamma-ray coincidence data allowed to firmly assign the spins of several key states via gamma-gamma angular correlations, including a number of newly-observed low-energy excited 0^+ states. Selected results will be presented and discussed in the context of the MCSM predictions, including a first report of the 0^+_4 state and possible members of a collective structure built upon it.

Evidence, favoring the reinterpretation of the presumed gamma-band head at 1196 keV [5] as a member of the deformed structure built on the excited 0^+_3 state, will be presented. Furthermore, the lifetime of the 2^+_2 state, extracted from the present study via the fast-timing technique, will be reported, putting on firm ground the shape-coexistence scenario and revealing structural similarities between ^{100}Zr and ^{98}Sr, for which shape-coexistence has been previously established [6].

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^{28}Si: spherical, oblate, prolate and superdeformed states?

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Invited talk

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Even though in the original naive shell-model proposed 75 years ago [1,2] ^{28}Si would correspond to a spherical nucleus because of the $0d_{5/2}$ closure, it has been well established for decades that the ^{28}Si ground state is deformed with an oblate shape [3]. In addition, another deformed low-lying rotational bandhead appears at ~ 7 MeV excitation energy, in this case associated with a prolate shape. Furthermore, some theoretical calculations predict the appearance of superdeformed prolate states at low excitation energies about ~ 13 MeV [4].
In this talk I will present the main results of a study of the shape coexistence in ^{28}Si [5] with the nuclear shell model using numerical diagonalizations [6] complemented with variational calculations based on the projected generator-coordinate method [7]. The theoretical electric quadrupole moments and transitions as well as the collective wavefunctions indicate that the standard USDB interaction in the sd shell describes well the ground-state oblate rotational band, but misses the experimental prolate band. Guided by the quasi-SU(3) model, I will argue that the prolate band can be reproduced in the sd shell by reducing the energy of the $0d_{3/2}$ orbital, or, alternatively, in the extended $sdpf$ configuration space using the SDPF-NR interaction, which describes well other Si isotopes. Finally, I will address the possibility of superdeformation in ^{28}Si within the $sdpf$ configuration space.
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Shape coexistence probed via transfer reactions with AGATA at LNL

F. Galtarossa, on behalf of the AGATA collaboration

Invited talk

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The presence of shape coexistence and shape evolution in atomic nuclei is a direct consequence of their nature of finite many-body quantum systems [1]. The investigation of these phenomena, in particular the mechanisms allowing their occurrence in specific regions of the nuclear chart and their competition with other excitation modes, is fundamental for our understanding of the nuclear residual interaction. Among the many experimental techniques to probe the existence of such phenomena in nuclei [2], the high selectivity of transfer reactions can be employed to populate a specific set of states of interest in the final nucleus and study their properties to look for shape coexistence effects.
At the INFN Legnaro National Laboratories one-, two- and multi-nucleon transfer reactions at energies between 5 and 10 MeV/u have been recently employed to study shape coexistence and shape evolution along the whole nuclear chart, coupling the AGATA γ-ray tracking array to several ancillary detectors, including the PRISMA magnetic spectrometer and different Silicon detector arrays [3]. In the talk preliminary results of selected recent experiments will be presented, together with possible perspectives on the use of transfer reactions to pursue this kind of studies with the radioactive ion beams delivered in the near future by SPES at LNL [4].

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Shape coexistence in Cd isotopes studied with safe and un-safe Coulomb excitation†

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Invited talk

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on behalf of the E664 (GANIL), E22.41 (LNL), HIL094 collaborations.

Mid-shell Cd nuclei were traditionally considered as 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. If confirmed, this would have major implications on structural interpretations of nuclei in the Z $=$ 50 region, and perhaps beyond. Soon afterwards a similar picture was suggested for ^{106}Cd [3].
During the AGATA campaign at GANIL, Coulomb-excitation data were collected as a byproduct of experiments performed at near-barrier beam energies. Notably, the analysis of slightly “unsafe” Coulomb-excitation data on 106Cd, collected during an experiment aiming at lifetime measurements in ^{106,108}Sn [4], provides information on the collectivity of the presumably oblate structure built on the 0_3^+ state [5].
We also performed a campaign of low-energy Coulomb-excitation studies of ^{110}Cd. In combination with complementary measurements, 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. Measurements were performed using various reaction partners: ^{14}N and ^{32}S beams with EAGLE at HIL UW, ^{60}Ni beam with AGATA at LNL and ^{110}Cd beam on a ^{208}Pb target with GRETINA at ANL. First results on quadrupole deformation parameters for the 0_1^+ and 0_2^+ states including the non-axiality of the ground state in ^{110}Cd, will be discussed in the context of beyond mean-field and the General Bohr Hamiltonian approaches. Future perspectives will be outlined, including a brief overview of Coulomb-excitation studies addressing shape coexistence in the Z $\sim$ 40 – 50 mass region within the ongoing AGATA campaign at LNL.

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Coulomb excitation of ^{110}Cd studied with AGATA at LNL

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For several decades, stable even-mass Cd isotopes have been considered to be textbook examples of multiphonon spherical vibrators [1] based on the excitation energy pattern of their low-lying states. However, a detailed study of ^{110}In β decay and subsequent beyond-mean-field theoretical calculations [2-5] suggested instead the presence of multiple shape coexistence in ^{110}Cd and ^{112}Cd isotopes. To verify this hypothesis complete sets of transitional and diagonal E2 matrix elements, including their relative signs, are needed. This key experimental information can be obtained by applying the low-energy Coulomb-excitation technique [6].
Coulomb excitation of ^{110}Cd using a 187-MeV ^{60}Ni beam was performed at National Institute for Nuclear Physics – Legnaro National Laboratories, Italy [7]. This experiment was a part of a broader program focused on systematic Coulomb-excitation studies of ^{110}Cd initiated at Heavy Ion Laboratory, University of Warsaw, with light beams of ^{32}S [5] and ^{14}N ions [8]. The ^{60}Ni + ^{110}Cd experiment was carried out using 11 AGATA triple clusters [9,10] and the particle detection array SPIDER [11] to register back-scattered beam ions. SPIDER was placed at laboratory angles ranging from 128 to 160 degrees to enhance the probability of multistep Coulomb excitation. In total 20 states of both negative and positive parity were populated up to 3 MeV of excitation energy, including in particular the 0_3^+ state at 1731 keV. The on-going analysis focuses on the extraction of the γ-ray intensities from which a set of electromagnetic matrix elements in ^{110}Cd will be extracted, including quadrupole moments of excited states. This will yield quadrupole deformation parameters for the 0_2^+ and 0_3^+ states, including the non-axiality parameter γ. Details of the experiment performed with AGATA at LNL and selected aspects of the Coulomb-excitation data analysis will be presented along with the preliminary results.

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Study of shape coexistence in Sn isotopes around A=110

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In this contribution, we present our investigation of the shape coexistence phenomenon in Sn isotopes around A=110, by means of γ-ray spectroscopy and lifetime measurements of low-spin states. Recent observation of axially deformed 0^+ states in ^{64,66}Ni isotopes [1,2] suggested the possibility of having similar excitations in the stable Sn isotopes, across the $Z = 50$ shell gap, due to analogies in the orbital configuration. Such hypothesis is corroborated by Monte Carlo Shell Model (MCSM) calculations, performed with the interaction of Ref. [3], whose potential energy surfaces of $^{110-118}$Sn exhibit a well-separated prolate secondary minimum, as in the Ni case.
Experimentally, several excited 0^+ states have been observed in even-even $^{110-118}$Sn, mainly via particle spectroscopy (e.g. [4,5]), however limited information on their lifetimes is available. To address this issue, a series of complementary experiments was carried out by our collaboration between LNL and IFIN-HH, employing the ROSPHERE-SORCERER and the AGATA-PRISMA setup, respectively. In particular, ^{110,112,114}Sn were populated by low-energy multi-nucleon transfer reactions and the plunger method was applied to determine the lifetimes of excited states. Preliminary results will be compared with MCSM calculations, giving an insight into the microscopic mechanism leading to the onset of deformation in this region.

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Towards Solving the Nuclear Reactor Antineutrinos Puzzle

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Invited talk

The goal of our program is to provide a reliable reactor anti-neutrino flux determination with sufficient precision for studies of the fundamental aspects of lepton physics and to improve understanding of the operation of nuclear reactors and remote monitoring. Beta-decays of reactor fission products create anti-neutrinos emitted together with associated electrons. Our experiments at ORNL's High Flux Isotope Reactor (HFIR) will obtain the integral anti-neutrino flux through the measurement of integral electron spectra from neutron-irradiated ^{235}U, and later ^{239}Pu and ^{241}Pu. We are aiming in near 1% precision. Presently, two conflicting measurements of integral electron flux exist. Data from the Institute Laue-Langevin (ILL) 57 MW research reactor (Grenoble, France) were obtained at 4 MW and released in the 1980s [1,2] The results from the Kurchatov Institute (KI, Moscow, Russia), obtained with a neutron flux up to 7×10^6 n/s/cm^2, were released in 2021 [3]. These data sets are not consistent with each other and therefore do not allow for conclusion on the potential new sterile neutrinos that may cause the deficit of observed anti-neutrinos, the so-called Reactor Anti-neutrino Anomaly (RAA), see [4-6]. Our project will use the most powerful US research reactor, 85 MW HFIR and its neutron flux, which exceeds by an order of magnitude the ILL and KI studies. Our U/Pu materials have a purity near 99%, while ILL had 93% $^{235}UO_2$. The electron energy resolution of our Si-Ge telescopes discriminating gammas from electrons is 7 keV at 1 MeV [7]. This is nearly 17 times better than the KI scintillator and near the ILL detection resolution. Our electron spectra will be measured directly near the source over the entire energy range, while in the ILL experiments, the magnetic fields had to be adjusted and corrected for the different energy bins of electrons in the complex spectrometer. Digital data acquisition of Si-Ge signals is capable to process high rates (over 10 kHz) and will reduce dead time and pile-up effects present in previous studies. The energy range of measured electron spectra above 10 MeV will match the recent results of direct anti-neutrino counting at the Daya Bay experiment.

We will use HFIR fast pneumatic transfers, moving the samples irradiated near the reactor core to the adjacent detection laboratory, as well as the external neutron beam line CG-1A allowing for longer quasi-equilibrium measurements at 10^7 n/s/cm^2.

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The status and future plans of the SPES project

Faïçal Azaïez

Invited talk

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The SPES project (Selective Production of Exotic Species) at LNL (Laboratori Nazionali di Legnaro) aims at the realization of an accelerator facility for research in the fields of Fundamental Physics and Interdisciplinary Physics with a major part dedicated to Research and Development of innovative radioisotopes for medical diagnostics and therapies. The status of the project will be given as well as the plans for its completion.

Research activities at CENS and status of RAON

Kevin Insik Hahn

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Invited talk

The low energy accelerator part of the RI beam accelerator facility called RAON delivered a stable ^{40}Ar beam for users this summer. One of the experimental facilities called KoBRA is expected to carry out nuclear structure and nuclear astrophysics experiments in the early phase of RAON. The Center for Exotic Nuclear Studies (CENS) at IBS (Institute for Basic Science) was established about 5 years ago to carry out experiments using stable and RI beams at facilities abroad as well as RAON. Many detector systems and experimental devices are being developed by CENS. Research activities at CENS and status of RAON will be introduced.

The SHEXI Concept: SuperHeavy Element X-ray Identification

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In this talk, a concept for the next generation of efficient, large-area detection systems at the focal plane of heavy-ion separators such as SHELS [1,2,3] or S3 (Super Separator Spectrometer) [4] will be presented. The objective is to develop a state-of-the-art instrument sensitive to L X-rays (20 - 30 keV) of Superheavy elements. Characteristic X-rays are a fingerprint of the atomic number of a nucleus since the X-ray energy is proportional to the atomic charge Z. The proposed set-up will have sufficient energy resolution to distinguish neighbouring elements and thus unambiguously identify the atomic number of the newly discovered superheavy elements. The complete system is expected to offer ten times higher detection efficiency and a twentyfold improvement in intrinsic resolution compared to SIRIUS [5] at the energies of interest.

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DIAMANT at HIL — the NEEDI setup

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In order to enhance the efficiency of the identification of reaction channels produced via proton or alpha-particle emission the DIAMANT light-charged-particle detector [1-2] was connected to the EAGLE and NEDA [3-5] detector systems for the first time during its commissioning. The combination of the three detector arrays – NEEDI – has been already used in four experiments during two physics campaigns at HIL.

DIAMANT is a light-charged-particle detector system, designed partly and operated by the HUN-REN Institute for Nuclear Research (HUN-REN ATOMKI, Debrecen, Hungary). Over the past decades, DIAMANT has been effectively integrated with large γ-detector arrays, contributing to various physics projects [6-9]. Recently, the front-end electronics and the mechanical structure of DIAMANT was extensively redesigned, the latter allowing for partial- or full-geometry configurations, also employing a pass-through target loader.

DIAMANT at HIL includes sixty-four CsI scintillators which are mounted on a flexible PCB around the target, and eight detectors on a separate part located further downstream. The signal processing is entirely digital and carried out in NUMEXO2 units [10], using custom firmware. The particle discrimination process is carried out in the FPGA units of NUMEXO2.

Two experiments in 2023 and two in 2024 were performed successfully [11] with the NEEDI setup, and three more are scheduled. Performance of the setup during these experiments, also foresight of enhancements of the NEEDI array will be presented in this contribution.

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Spectroscopy of superheavy nuclei with ANSWERS at TASCA

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The stability of superheavy nuclei ($Z \geq 104$) depends strongly on the arrangement of their nucleons in the nuclear shells. The study of the radioactive decay of these nuclei is essential for exploring the underlying nuclear structure. Currently, superheavy nuclei can only be produced in heavy-ion-induced fusion reactions with small cross sections, which limits the use of various common experimental techniques for nuclear decay spectroscopy. The implantation/correlation technique is presently the main method used for performing nuclear decay spectroscopy experiments with superheavy nuclei [1]. However, despite being the state-of-the-art, this technique has certain disadvantages that limit comprehensive measurements of radioactive decays, such as a detailed study of alpha-decay fine structure and fission-fragment mass distributions.

A complementary experimental technique for nuclear spectroscopy, named Adsorption-based Nuclear Spectroscopy Without Evaporation Residue Signal (ANSWERS), was developed in the SHE Chemistry department at GSI Darmstadt, Germany, in 2020 [2]. The ANSWERS setup was commissioned offline with ^{219}Rn and its decay products. The results showed great potential of ANSWERS for measuring low-energy internal-conversion electrons originating from low-lying excited states, which are barely measurable in implantation-based setups.

The first online campaign with ANSWERS was focused on No isotopes, produced at the gas-filled recoil separator TASCA.

In this talk, ANSWERS will be presented with its commissioning results, including newly obtained spectroscopic data on the alpha-decay fine structure of ^{253}No.

We are grateful for GSI's the Experimental Electronics department and Target Lab for their continuous support of the experimental program at TASCA. We acknowledge the ion-source and UNILAC staff for providing the stable and high intensity ^{48}Ca beam. The results are based on the experiment U308, which was performed at the beam line X8/TASCA at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (Germany) in the frame of FAIR Phase-0.

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Collinear laser spectroscopy of U isotopes at IGISOL

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Actinide elements present a wide spectrum of nuclear structure phenomena, and have been the focus of several research programs aimed at developing a detailed picture of this region of the nuclear chart. For example, the region presents two unique low-lying isomeric states, ^{229}Th and ^{235}U, the former of which is considered in the development of a nuclear-based metrology time standard [1]. In addition, theoretical models have predicted the emergence of pronounced reflection-asymmetric (octupole deformed) shapes moving towards more neutron-deficient isotopes [2].

Within this context, laser spectroscopic techniques act as a bridge between nuclear and atomic physics, providing access to information including the evolution of mean-square charge radii through the measurement of isotopic shifts in atomic transitions, in addition to nuclear magnetic dipole and electric quadrupole moments via the measurement of hyperfine structure [3].

Within the LISA (Laser Ionization and Spectroscopy of Actinides) framework, a research program aimed towards the study of the nuclear structure of light actinide elements has been implemented at the IGISOL facility [4], at the University of Jyväskylä. High-resolution collinear laser spectroscopy on natural U isotopes has been performed on 10 transitions in the singly charged ion. New information on atomic hyperfine parameters in addition to high precision isotopic shifts has been produced. In parallel, the development of a gas-cell based production method of a ^{235m}U isomeric beam has been carried out, with the final aim of performing a collinear laser spectroscopy measurement of the low lying 76-eV isomer.

This contribution presents the results of these studies and the continuous development of the collinear spectroscopy setup at the IGISOL facility. The latter includes upgrades of the light collection region and the use of ultra-short time bunches to further increase the sensitivity of the technique.

This project has received funding from the EU Horizon 2020 research and innovation programme under grant agreement no. 861198-LISA-H2020-MSCA-ITN-2019 as well as from the Academy of Finland under project number 339245.

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Shedding Light on Neutron Lifetime Puzzle via the New Unexpected Result of the Two-Body Decay of Neutrons

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The discrepancy between the average measured lifetime of trapped ultracold neutrons $\tau_{trap} = (877.75 \pm 0.28_{stat} + 0.22/-0.16_{syst})$ s, this being the latest value from Gonzalez et al (2021), and the average beam measured lifetime of neutrons ($\tau_{beam} = 888.0 \pm 2.0$ s) remains unresolved up to now. In 1990 Green and Thomson brought up the two-body decay of neutrons (the decay into a hydrogen atom and antineutrino) into consideration. However, the Branching Ratio (BR) for this process, known at that time, was 4×10^{-6}, thus lacking over 3 orders of magnitude for the quantitative explanation of the neutron lifetime puzzle. In the present paper we bring to the attention of the research community that with the allowance for the second solution of Dirac equation for hydrogen atoms (whose existence is evidenced by four different types of atomic/molecular experiments and by astrophysical observations), the theoretical BR is increased by a factor of 3300: the theoretical BR becomes (1.3 $\pm$ 0.3)%. This is in the excellent agreement with "experimental" BR = (1.15 $\pm$ 0.27)% required for reconciling the above τ_{trap} and τ_{beam}. Thus, it seems that the above two-body decay of neutrons in the beam experiments (that count only the protons) solves the neutron lifetime puzzle completely. I also show that the two-body decay of neutrons has profound cosmological implications. Namely, it is the mechanism by which neutron stars are slowly but continuously producing baryonic dark matter – in the form of hydrogen atoms, corresponding to the second solution of Dirac equation (the atoms having only the s-states, so that due to the selection rules they practically do not couple to the electromagnetic radiation) – and this process goes on at the present time as well.

Search for Beyond Standard Model physics at the ESS in Lund

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Substantial progress in the quality of cold neutron beams, expected with approaching commissioning of European Spallation Source (ESS) in Lund, Sweden, creates a unique opportunity to set new limits on many beyond Standard Model processes, addressing the most basic questions of contemporary fundamental physics, like matter-antimatter asymmetry of the universe, or Dark Matter problem. A collection of measurements is proposed by international HIBEAM/NNBAR collaboration [1], with the ultimate goal to search for the first signature of Baryon Number Violation process or to improve the current limit of experimental sensitivity to neutron-antineutron oscillation by three orders of magnitude. As a first step towards large scale experimental facility, required to accomplish this goal, a small scale setup will be created and applied for the search of axion or axion-like-particles. The application of a new experimental principle should allow for an improvement for sensitivity to axion coupling strength to the neutron spin by more than three orders of magnitude, for a wide range of proposed axion masses.

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

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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 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 $\mathcal{O}(10^{-5})$, improving over global constraints by one to several orders of magnitude depending on m_χ [2].

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Isospin Symmetry Breaking Studied with Nucleon Knockout Reactions

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The concept of isospin symmetry in nuclear physics is rooted in the exchange symmetry that exists between protons and neutrons. This symmetry serves as a valuable method in comprehending the structure of nuclei on both sides of the $N = Z$ line. Moreover, it provides a means to extrapolate the behavior of nuclei near the proton-drip line. Examining Isobaric Analogue States (IASs) provides an avenue for investigating interactions that have the potential to break isospin symmetry [1]. The technique of mirrored one-nucleon knockout reactions was applied, in which the $T_z = \pm 2$ mirror pair, ^{48}Fe/^{48}Ti were populated via one-neutron/one-proton knockout from the secondary beams ^{49}Fe/^{49}V, respectively. Isospin symmetry is investigated by analyzing mirror energy differences (MED) within the $f_{7/2}$ shell, focusing on mirror nuclei with $T = 2$, $A = 48$. MED in this mass region are shown to be especially sensitive to excitations out of the shell, presenting a stringent test of the shell-model approach. Additionally, data obtained from analogous reactions have the potential to contribute to discussions regarding the suppression of spectroscopic strength in knockout reactions [2]. The experiment was conducted at the National Superconducting Cyclotron Facility (NSCL) using the A1900 separator and the S800 spectrograph to discover novel excited states in the exotic, proton-rich nucleus ^{48}Fe (T_z = -2) [3]. The mirror nuclei of interest were produced via mirrored one-nucleon knockout reactions, where the radioactive beams were selected by the A1900 fragment separator and then directed onto a ^{9}Be target. The resulting γ-rays were detected by the tracking array, GRETINA. The results from the analysis of $A = 48$ will be presented, including a new level scheme of the proton-rich nucleus ^{48}Fe, a mirror-energy difference analysis, and the latest theoretical predictions. In addition, the results of inclusive and exclusive one-nucleon removal cross sections for the populated states in the ^{48}Ti/^{48}Fe mirror pair will be discussed and compared with results from reaction-model calculations.

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Persistent vibrational structure and symmetry in $^{110-116}$Cd

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The cadmium isotopes ($Z = 48$) since long have been considered as textbook examples of spherical-vibrator nuclei and U(5) dynamical symmetry. On the other hand, detailed studies, using complementary spectroscopic methods, have provided evidence for marked deviations from such a structural paradigm [1,2]. Previous attempts to explain the observed discrepancies in $E2$ decays relied on strong mixing between vibrational and intruder states and ultimately proved unsuccessful. Two approaches have been proposed to address these unexpected findings. The first questions the spherical-vibrational character of the ^{110,112}Cd isotopes, replacing it with multiple shape coexistence of states in deformed bands, a view qualitatively supported by a beyond-mean-field calculation with the Gogny D1S energy density functional [3,4]. A second approach is based on the recognition that the reported deviations from a spherical-vibrator behavior show up in selected non-yrast states, while most states retain their vibrational character. In the terminology of symmetry, this implies that the symmetry in question is broken only in a subset of states, hence is partial [5]. Such a U(5) partial dynamical symmetry (PDS) approach was applied to ^{110}Cd [6].

In the present contribution, we show that the empirical data in $^{110-116}$Cd is consistent with a vibrational interpretation and good U(5) symmetry for the majority of low-lying normal states, coexisting with a single deformed γ-soft band of intruder states. The observed deviations from this paradigm are properly treated by an Hamiltonian with U(5) PDS acting in the sector of normal states, which are weakly coupled to SO(6)-like intruder states [7]. The results demonstrate the relevance of the U(5) PDS notion to this series of isotopes.

This work was done in collaboration with J.E. García-Ramos (Huelva), N. Gavrielov and P. Van Isacker (GANIL).

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The quadrupole moment of the first 2^+ state and the B(E2) value of the 4^+ to 2^+ transition in ^{110}Sn from safe Coulomb excitation

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The observed deviation between the experimental B(E2) values for the excitation of the first 2^+ -state in the light even-even Sn isotopes and the corresponding theoretical prediction has lacked a satisfactory explanation since the first B(E2) measurements were carried out for these isotopes now more than 10 years ago [1-3]. In relatively recent work [4] it has been suggested that additional experimental information regarding the quadrupole moment of the 2^+ - state may shed further light on this issue. Such measurements have, however, presented a significant experimental challenge, not least for the comparatively low-intensity radioactive beams of semi-magic nuclei that are of interest in this case.
In this presentation we will give the first results for the quadrupole moment, Q(2_1^+), including its sign and magnitude, in ^{110}Sn from a safe-energy Coulomb excitation experiment, using a ^{110}Sn beam at 4.4 MeV/u on a 4-mg/cm^2 ^{206}Pb target, at HIE-ISOLDE, CERN. The emitted gamma rays were detected using the Miniball HPGe spectrometer. In addition, the lifetimes of the 2_1^+ and 4_1^+ states were investigated using an independent method where the observed line shape is used in combination with a GEANT4 simulation. The method will be detailed, and the new results will be compared to theory.

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Measurement of double alpha decay of ^{224}Ra at the FRS Ion Catcher

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In nature, two particles of the same type are emitted together in various decays. Double beta decay, double gamma decay, and simultaneous emission of two protons or two neutrons have been observed. Double alpha decay has been predicted but never observed due to its expected small branching ratio. Recent work by F. Mercier *et al.* [1] and J. Zhao *et al.* [2] predicted that not only is the symmetrical double alpha decay more probable than the decay via the emission of ^{8}Be [3], but also that the branching ratio should be accessible by current measurement techniques ($BR \sim 3 \times 10^{-8}$ [2] for ^{224}Ra).
An experiment to measure this branching ratio was performed at the FRS Ion Catcher [4] at GSI, utilising the thermalisation of ^{228}Th alpha recoils in the cryogenic stopping cell (CSC). After extraction from the CSC, the $^{224}Ra^{2+}$ ions were transported and filtered using a system of radio-frequency quadrupoles (RFQs), resulting in a pure beam of $^{224}Ra^{2+}$. The ^{224}Ra beam was then implanted in a 10 µg/cm^2 carbon foil in the centre of a decay apparatus based on two double-sided silicon strip detectors (DSSD) that recorded the position, the time and the energy of each alpha particle. Since the experiment was done with a radioactive source instead of a nuclear reaction at an accelerator, data-taking over a long period was possible, and more than 10^9 ^{224}Ra decays were observed.
This talk will focus on the design and setup of the experiment, including Monte Carlo simulations, and will conclude with some preliminary results.

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Candidates for three-quasiparticle high-K isomers in even-odd Fm-Ds nuclei

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During my presentation, I will discuss our preliminary findings from the search for candidates for three-quasiparticle (3-q.p.) high-K isomers in the range of even-odd Fm-Ds nuclei with N=141-147. These investigations serve as a follow-up to our recent study, which focused on odd-even Md-Rg nuclei [1]. The significant axially symmetric deformation predicted in this region, both in the ground and excited states, establishes K as a "good quantum number." The experimental observation of isomers such as ^{253,255}No [2,3] and ^{255,257}Rf [4,5] offers the chance to compare our results with empirical data. Additionally, the progressively growing number of spectroscopic studies in this area gives hope for validating our predictions in the near future.
Our analysis is performed within the macroscopic-microscopic approach based on the Yukawa-plus-exponential macroscopic energy [6] and the deformed Woods-Saxon single-particle potential [7]. All parameters of the model, well-tested during many years in the region of the heaviest nuclei, are kept unchanged. Energies for ground-states and $2\pi 1\nu$ 3-q.p configurations are found by minimization with respect to four axially- and reflection-symmetric deformations. These are: β_2, β_4, β_6, and β_8 in the traditional expansion of the nuclear radius vector into a series of spherical harmonics. The criterion for selecting candidates is based on the search for exceptionally low-lying high-K 3-q.p configurations. The more precise determination of whether a candidate would be a true isomer in the context of hindered electromagnetic decay seems almost impossible at the current state of the theory.

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Probing the N=152 neutron shell gap by laser spectroscopy of fermium isotopes

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Understanding the extremes of nuclear structure and determining the limits of nuclear stability is a forefront topic in nuclear physics research [1]. The very existence of nuclei with proton numbers $Z \geq$100 is only due to quantum-mechanical shell effects, stabilizing them against spontaneous fission, and also impacting their shape and size. With recent mass measurements, the long-known shell gap at $N = 152$ [2] and the corresponding enhancement in nuclear stability in a region of strong prolate deformation could be confirmed [3,4]. Yet, the information on nuclear structure characteristics in the realm of the heaviest elements remains scarce due to limited production capabilities and challenging predictions by state-of-the-art nuclear models.

Laser spectroscopy constitutes a powerful tool to extract information on the nuclear shell structure, expressed in ground-state properties as the mean-square charge radius, the nuclear spin and moments [5,6]. The application of this method to the heaviest actinide elements and beyond however remains challenging, due to atom-at-a-time production yields, short half-lives and sparse to yet non-established information on atomic levels. The recent experimental identification of atomic states in nobelium ($Z = 102$) with the RADRIS method constitutes a gateway to new laser spectroscopy studies in this region [7].

Recent advancements towards new production schemes and an increased sensitivity of the RADRIS method allowed the first on-line laser spectroscopy investigations of fermium (Fm, $Z = 100$) isotopes. By combining on-line and off-line laser spectroscopy techniques and various production methods, isotope

shifts in an atomic transition were determined for eight isotopes ranging from the accelerator-produced ^{245}Fm to the reactor-bred ^{257}Fm. The investigated chain spanning over both sides of the weak deformed shell gap at $N = 152$ allowed probing its imprint on changes in the mean-square charge radii.
In this contribution, the experimental results, interpreted by several nuclear DFT models, will be discussed. A diminishing impact of the shell gap on this observable was identified, contrary to observations in lighter nuclei and to the clear imprint found in other observables as nuclear binding energies [3]. These observations will trigger new developments in theoretical models which will eventually improve their predictive power in the heavy elements for further and more sensitive nuclear structure effects.

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Thursday

August 29th

Quo vadis SHE?
Where do we go? – Where can we go?

D. Ackermann

Invited talk

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When Marie Skłodowska-Curie extracted, from uranium ore in pitchblende, the chemical elements polonium (Z $=$ 84) and radium (Z $=$ 88) at the end of the 19th century, the first elements in the gap between the heaviest stable isotopes ^{208}Pb (and the extremely long-lived ^{209}Bi) and the primordial nuclides ^{234}Th and ^{235,238}U, she started a race which is still now, after more than a century in the focus of scientific activities worldwide. Now the gaps between uranium and bismuth are filled and the Segré chart of nuclei has been extended up to Z $=$ 118 (oganesson). Beyond the sheer discovery or synthesis of new chemical elements, more and more details on the atomic and nuclear properties of those exotic nuclear matter objects are being revealed. We start to gather more and more information on properties like exotic deformations, metastability, single-particle configurations and decay mode competition at the edge of stability, prone to guide the scientific community towards the long sought-for "island of enhanced stability".

New experimental techniques, including atomic physics methods and successful developments of accelerator technology, providing highest beam intensities, nurture the hope to extend the experimental activities substantially, towards even higher atomic numbers as well as to the borders in terms of proton-neutron ratio. The promising prospects encouraged substantial efforts, financial and in man power, which are invested to upgrade existing facilities and to construct new installations all over the globe, in France, Russia, Japan, Germany, the USA and China. In my presentation I will follow the story of superheavy element research in its historical context starting from the very early days end of the 18-hundreds, through the 20$^{\mathrm{th}}$ century with the discovery and synthesis in the various phases [1] often connected with surprising stories, up the recent findings in the second millennium. I will try to illustrate those state-of-the-art findings of the last decades, providing a glimpse of the fascinating physics expected in the region of enhanced stability which we hope to finally reach in the decade(s) to come.

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Collectivity from first principles

Anna E. McCoy*[1], *Patrick J. Fasano*[1], *Mark A. Caprio

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Invited talk

The beryllium isotopic chain is a microcosm of collective phenomena including rotational dynamics, shape coexistence, parity inversion and intruder states. These phenomena emerge in ab initio no-core shell model (NCSM) calculations for which the only input is the inter-nucleon interaction [1,2,3]. With the NCSM predictions in reasonable agreement with experiment, we now have access to the underlying wave functions, which allows us to probe correlations and symmetries that give rise to collective behavior. In this talk, I highlight emergent rotational bands in $^{10-14}Be$ and delve into the emergence of an approximate Elliott SU(3) symmetry associated with nuclear rotations and deformations. I will also discuss the impact of collectivity on effective single particle structure.

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Advances in Charge-Exchange Reactions with Rare Isotope Beams

R.G.T. Zegers[1,2]

Invited talk

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Over the past two decades significant advances in the development of charge-exchange experiments with rare-isotope beams have been made. They include two types: i) experiments in which the rare-isotope beams contain the nuclei to be probed, such as in the (p,n) charge-exchange experiments in inverse kinematics, and ii) experiments in which the rare-isotope beams serve as the probe, such as the $(t,{}^3\mathrm{He})$ charge-exchange reaction in forward kinematics.

Very recently, the first type of charge-exchange experiments has been complemented by the $(d,{}^2\mathrm{He})$ reaction, which utilizes an active-target time-projection chamber, for detecting the two protons of the ^{2}He system, and a magnetic spectrograph, for collecting the residual particles from the reaction. At present, this new tool is the only one available for measuring β^+ Gamow-Teller strengths in neutron-rich unstable nuclei for the purpose of constraining electron-capture rates of importance for astrophysical scenarios. In the first successful experiment, the ${}^{14}\mathrm{O}(d,{}^2\mathrm{He})$ and ${}^{13}\mathrm{N}(d,{}^2\mathrm{He})$ reactions were studied.

For the second type of charge-exchange experiments, new heavy-ion probes can be utilized to isolate specific spin-isospin responses that are otherwise difficult to disentangle. For example, the $({}^{10}\mathrm{Be},{}^{10}\mathrm{B})$ reaction, in combination with in-beam γ-ray spectroscopy from photons emitted by the excited ^{10}B nucleus, can be utilized to isolate separately, in one experiment, the $\Delta S = 0$ and $\Delta S = 1$ responses. This is particularly useful for identifying isovector (spin-transfer) giant monopole resonances, which provide important insights into the bulk isovector properties of nuclear matter.

Both types of experiments benefit strongly from high-intensity rare-isotope beams available at current and future state-of-the-art rare-isotope beam facilities. In this presentation, an overview of recent advances of, and opportunities with charge-exchange reactions with rare-isotope beams will be provided.

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News on masses of rare isotopes

V. Manea[1]

Invited talk

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Masses of rare isotopes are among the primary observables driving the exploration of nuclear structure towards the limits of the nuclear chart [1]. Although providing a single experimental input for most nuclei, with the addition of only some isomeric states, the atomic mass represents via its trends with proton and neutron number a key benchmark of nuclear models and an important indicator of structural evolution. In recent years, mass-measurement techniques deployed at different radioactive ion-beam facilities have made enormous progress in sensitivity and resolution to cope with even lower production rates and larger contamination ratios. These developments have allowed new explorations of nuclear shell closures far from stability, with notable advances along $N = 50$ and $N = 82$. Combined efforts at different facilities have also closed in on ^{78}Ni and ^{100}Sn, while important progress has been made across the nuclear chart in the measurement of low lying isomeric states. This contribution will present recent advances in the mass measurement of rare isotopes, including some highlight results. Current directions of research and a few perspectives for studies with exotic isotopes will also be discussed.

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The recoil distance Doppler-shift technique: a valuable method for nuclear structure studies far from the valley of stability

Christoph Fransen[1], *Andrey Blazhev*[1], *Felix Dunkel*[1], *Jan Jolie*[1], *Casper-David Lakenbrink*[1], *Claus Müller-Gatermann*[2], *Richard Novak*[1], *Franziskus von Spee*[1]

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Besides the level schemes, absolute transition strengths between excited states yield fundamental information on nuclear structure. The determination of the latter from level lifetimes measured with the recoil distance Doppler-shift (RDDS) technique employing so-called plunger devices [1] has been in the focus of our Cologne group since many years. The RDDS technique provides a very valuable method for the determination of lifetimes in the picosecond range.

In this presentation, special emphasis is paid to the evolution of the shell structure and collectivity in exotic nuclei derived from investigations with the RDDS technique. We concentrate on the study of (i) shape coexistence in neutron deficient nuclei in the A=180 region and a structural change towards very neutron deficient nuclei that is not understood so far from theory, (ii) neutron rich nuclei in the A=40-50 region with respect to the evolution and possible weakening of the N=28 shell closure, (iii) search for shape coexistence in Te isotopes around neutron midshell (N=66).

We will also give a brief overview of the latest developments of the RDDS technique. This includes both the realization of the new sophisticated spectrometer CATHEDRAL at Cologne for lifetime measurements and the application of the RDDS technique for very different recoil velocities of the reaction products ranging from few percent of the speed of light up to relativistic conditions with $v/c \approx 60\%$. The related, newly developed plunger devices designed for the use at different facilities, including the state-of-the-art radioactive beam facility FRIB and at FAIR in the future, are also presented.

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B(E2) measurements of heavy $N = Z$ nuclei at FRIB

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The latest results on the measurement, at FRIB, of the $B(E2)$ for the decay of the first excited state in $N = Z$ ^{88}Ru will be presented. This is the heaviest $N = Z$ system for which such a measurement has been made.

Crucial questions remain unanswered in the heaviest accessible region of $N = Z$ nuclei, where both the neutron and proton Fermi levels are located well inside the $g_{\frac{9}{2}}$ region. The details of how collectivity varies for $N = Z$ nuclei between ^{56}Ni and ^{100}Sn, and the location, and extent, of the maximum collectivity presents a demanding test of our best nuclear-structure models - see e.g. [1]. The reduced transition probability $B(E2 : 2_1^+ \rightarrow 0_1^+)$ remains one of the most sensitive probes of quadrupole collectivity and can provide an indication of nuclear deformation. To date the heaviest $N = Z$ systems, for which $B(E2 : 2_1^+ \rightarrow 0_1^+)$ have been measured, are ^{78}Y (odd-odd) and ^{80}Zr (even-even) [2]. The results demonstrate the presence of rapidly changing nuclear collectivity with the addition of nucleons beyond mass 70. This work also highlighted an apparent staggering between the $B(E2 : 2_1^+ \rightarrow 0_1^+)$ values connecting $T = 0$ states in even-even $N = Z$ nuclei and $T = 1$ states in odd-odd $N = Z$ nuclei - the latter being systematically smaller than the former. A second issue of much contemporary significance in this region is whether $N = Z$ nuclei are likely to show clear evidence for isoscalar $(T = 0, J > 0)$ np-pairing correlations [3]. A measurement of the $B(E2 : 2_1^+ \rightarrow 0_1^+)$ can potentially shed light on these issues. For example, calculations [4] suggest that $T = 0$ np pairing plays an important role in both the evolution of the moments of inertia in the $N = Z$ nucleus ^{88}Ru and the absolute value of the predicted $B(E2 : 2_1^+ \rightarrow 0_1^+)$. Indeed, the structure of the ^{88}Ru yrast band exhibits a delayed rotational alignment [5] which has been interpreted in terms of the presence of such isoscalar np pairing.

The experiment was performed in April 2023 at FRIB. A 250 MeV/u ^{124}Xe beam was used to produce fragmentation beams of ^{88}Tc and ^{89}Ru, separated using the new ARIS spectrometer at FRIB. Final fragments were identified using the S800 spectrometer, with γ rays recorded using GRETINA. The TRIPLEX plunger device was utilised in order to determine the lifetimes, and hence $B(E2 : 2_1^+ \rightarrow 0_1^+)$ values, for the $N = Z$ nuclei ^{88}Ru and odd-odd ^{86}Tc. The first results for the measured $B(E2 : 2_1^+ \rightarrow 0_1^+)$s will be presented and compared with state-of-the-art shell-model and DFT calculations.

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Friday

August 30th

Nuclear Structure at Finite Temperature and the Electric Dipole Oscillations: overview and open problems

Angela Bracco

Invited talk

Dipartimento di Fisica Università di Milano, INFN sez. Milano and Centro Fermi (Roma)

Relevant aspects of the research concerning the Giant Dipole Resonances (GDR) built on excited states are reviewed. 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. The general finding is that the intrinsic width is not affected by the temperature. Another quantity found to be independent of temperature is the Coulomb mixing of states with different isospin values. This resulted in specific experiments in which the GDR decay was able to probe the isospin mixing, particularly in the mass region 60-80. Experiments presently being made and/or planned concern the search for the pygmy resonance at finite temperature and the gamma decay of the GDR of very heavy fissioning nuclei and in nuclei at extreme deformations (superdeformed, hyperdeformed and Jacobi types). These issues will be briefly discussed in view of the new experiments which are needed to pin down the effects of extreme deformations on the GDR response.

Evidence for a toroidal electric dipole mode in nuclei

P. von Neumann-Cosel

Invited talk

Institut für Kernphysik, Technische Universität Darmstadt, Germany

A toroidal electric dipole resonance has been predicted as generic feature of nuclei like the isovector and isoscalar giant dipole resonances. I present first experimental evidence for a low-energy toroidal electric dipole mode in the nucleus ^{58}Ni based on a combined analysis of high-resolution (p,p′), (γ, γ') and (e,e′) experiments [1]. Large transverse electron scattering form factors are identified as a unique signature of the toroidal nature of E1 transitions [2]. Although ^{58}Ni is a nucleus with $N \approx Z$, these results might bear important implications for the nature of the pygmy dipole resonance (PDR) in heavy nuclei with neutron excess [3]. The toroidal excitations carry the same experimental signatures as the states forming the PDR: large isovector response (on the scale of low-energy E1 strength), strong isoscalar response and large ground-state branching ratios. QRPA models successfully describing the toroidal mode in ^{58} Ni predict the PDR in heavy nuclei to be of toroidal nature [4] and also reproduce the specific form of transition densities of the PDR associated with neutron skin oscillations [5]. These findings challenge a neutron skin oscillation interpretation of the PDR.

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Properties of Pygmy Dipole Strength from Theoretical Perspective

N. Paar

Invited talk

Department of Physics, Faculty of Science, University of Zagreb, Croatia

The study of pygmy dipole strength (PDS) provides crucial insight into the nature of low-energy dipole excitations observed in neutron-rich nuclei and predicted in proton-rich nuclei [1]. Their properties have been extensively studied due to possibility for the formation of the pygmy dipole resonance (PDR), an excitation soft mode governed by dominant transitions from weakly bound neutrons. Over the past two decades, a variety of theoretical approaches have been developed and applied in analyses of the PDS (detailed list of references is given in [2]). In particular, these include macroscopic models, shell model, and various models based on nuclear energy density functional theory (EDF). Several variants of non-relativistic and relativistic EDFs have been employed in derivation of self-consistent quasiparticle random phase approximation (QRPA) that in addition to the effective nuclear interaction rooted in the EDF also includes pairing correlations. In addition, further theoretical developments included couplings to complex configurations, e.g., in the quasiparticle phonon model (QPM), multiphonom models, model using the quasiparticle time blocking approximation (QTBA), extended theory of finite Fermi systems (ETFFS), equation of motion phonon method (EMPM). In this way the insight into fragmenation of the PDS has been achieved, allowing more reliable comparison with the experimental data [3,4]. At the QRPA level, the nature of the PDS has been explored through the calculation of the transition strengths and more detailed analysis of the relevant two-quasiparticle contributions contributed to the discussions on the collective properties of the PDS. The studies of the isotopic and isotone dependence of the PDS allowed additional insight into the dependence of the PDS transition strength and energy with the neutron excess. The covariance analysis in the EDF framework identified relevant correlations between the observables on the PDS and various properties of finite nuclei and nuclear matter. Of particular interest are correlations with the parameters of the symmetry energy, providing potential constraints for neutron-rich nuclear matter properties and neutron-skin thickness in nuclei [5]. The comprehensive analyses underscore the importance of theoretical frameworks in elucidating the complex nature of pygmy dipole strength. A variety of theoretical approaches to the PDS contribute to a deeper understanding of the underlying nuclear structure mechanisms and offer valuable insights for the experimental studies [3,4].

This contribution is supported by the Croatian Science Foundation under the project Relativistic Nuclear Many-Body Theory in the Multimessenger Observation Era (IP-2022-10-7773).

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Electric dipole response of light nuclei within the CI-SM approach

Oscar Le Noan [1] **,** ***Kamila Sieja*** [1,*]

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[1] IPHC, *speaker

Photo-nuclear reaction rates provide key inputs to various applications of nuclear physics and consist fundamental probes of nuclear structure, from single particle to collective excitations, revealing the nature of complicated nucleonic correlations. Among the excitations of nuclei due to the external field, the E1 dipole response is of particular interest. It is dominated by the Isovector Giant Dipole Resonance (IVGDR) understood as a relative oscillation of protons against the neutrons. In neutron-rich nuclei the neutron-excess is believed to oscillate against the proton-neutron core, leading to low-lying E1 strength known as the Pygmy Dipole Resonance (PDR). The knowledge of the PDR serves to probe the neutron-skin thickness, constrain the nuclear symmetry energy and the properties of neutron stars.

In this contribution we will present systematic calculations of E1 dipole response of sd-shell nuclei within the Configuration-Interaction Shell Model approach, performed for the PANDORA project [1]. Further we will focus on the nature of the low-lying PDR strength as obtained in the present theoretical framework and answer the question about the collectivity of the PDR mode. Finally, the recently observed phenomenon of redistribution of the PDR strength with excitation energy of the initial state [2] will be examined.

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Recent studies of nuclear collective excitations within the Equation of motion phonon method

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The Equation of motion phonon method (EMPM) is a microscopic approach that is especially suitable for describing fine structures in nuclear spectra in spherical medium-heavy and heavy nuclei, in particular, its collective features such as giant and Pygmy dipole resonances.

Recently, we have addressed the issue of spurious states that arise in microscopic calculations that go beyond the one-phonon picture within methods like Second Random Phase Approximation (SRPA) [1,2]. We have suggested an orthogonalization procedure to cure this issue to eliminate spurious states within the EMPM. Furthermore, we have demonstrated the importance of such treatment for an accurate description of the low-energy part of strength functions of all multipolarities [3]. This method, adopted in EMPM, allows for spurious-free calculations of light systems, where spurious center-of-mass motion can spoil the calculations significantly. We have used the proposed orthogonalization method in a recent study of light nucleus ^{8}He, in the calculations of spectra and dipole response in the model space encompassing up to the three-phonon states employing modern nucleon-nucleon potentials [4].

In this contribution, we review the latest advancements in EMPM, showcasing its efficacy in portraying collective excitations in spherical medium-heavy and heavy nuclei, particularly when paired with chiral nucleon potentials commonly used in modern ab initio investigations.

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Pygmy or not Pygmy – an experimentalist's point of view‡

***Andreas Zilges*[1], *Katharina Haller*[1], *Florian Kluwig*[1], *Markus Müllenmeister*[1], *Miriam Müscher*[1], *Deniz Savran*[2], *Tanja Schüttler*[1], *Michael Weinert*[1]**

Invited talk

[1] University of Cologne, Germany
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All matter in the universe is constantly bombarded by photons from the lowest to the highest energies. Typically, photons with energies in the range of hundreds of keV to several MeV can induce photoexcitation and photodisintegration of atomic nuclei [1]. The interaction is governed by the nuclear electromagnetic dipole response. The highest cross sections are observed in the energy region of the isovector Giant Dipole Resonance (GDR) in the 10 MeV to 20 MeV range. However, since most of the photons come from a Planck photon bath, the reaction rate can be dominated by much smaller cross sections at lower energies.

A concentration of electric dipole strength commonly referred to as "Pygmy Dipole Resonance" (PDR) has been found in various nuclei [2,3]. Many models predict a correlation of the PDR with the neutron skin, i.e., one expects an increase of the low-lying E1 strength in exotic, neutron-rich systems. However, our knowledge about the structure of the low-lying electric dipole strength and its evolution is still rather limited. The key for to a better understanding is the combination of results from various complementary experiments.

The talk will present the advantages and limitations of different probes and show some recent results.

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Accessing the single-particle structure of the PDR§

M. Spieker[1], *A.L. Conley*[1], *D. Houlihan*[1], *B. Kelly*[1]

Invited talk

[1] Florida State University, Department of Physics, Tallahassee, Florida, United States of America

In atomic nuclei, the term pygmy dipole resonance (PDR) has been commonly used for the electric dipole (E1) strength around and below the neutron-separation energy. It has been shown that the PDR strength strongly impacts neutron-captures rates in the s- and r-process, which synthesize the majority of heavy elements in our universe. A precise understanding of the PDR's microscopic structure is essential to pin down how it contributes to the gamma-ray strength function (γSF) often used to calculate the neutron-capture rates. In fact, the different responses to isovector and isoscalar probes highlighted the complex structure of the PDR and emphasized that different underlying structures would indeed need to be disentangled experimentally if stringent comparisons to microscopic models wanted to be made.
Featuring our recent study of ^{208}Pb [1] and ^{62}Ni [2], I will present how the neutron one-particleone- hole structure of the PDR can be studied with high-resolution magnetic spectrographs. The data on ^{208}Pb were obtained from (d, p) one-neutron transfer and resonant proton scattering experiments performed at the Q3D spectrograph of the Maier-Leibnitz Laboratory in Garching, Germany, while the data on ^{62}Ni were measured at Florida State University with the Super-Enge Split-Pole Spectrograph. In this contribution, the new data will be briefly compared to the large suite of complementary, experimental data available for 208Pb highlighting how we established (d, p) as an additional, valuable, experimental probe to study the PDR and its collectivity. Besides the single-particle character of the states, different features of the (d, p) strength distributions will be discussed for ^{208}Pb and ^{62}Ni.
To highlight future possibilities, 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 [3] and highlight the value other particle transfer reactions could add to studying the microscopic structure of the PDR.

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Extra Yield below the Giant Dipole Resonance under extreme conditions

O. Wieland[1]

Invited talk

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After the discovery and first measurements of the pygmy dipole resonance state, especially in exotic nuclei, a new question rised up, if this kind of phenomena can also be built in a nucleous at finite temperature and high angular momentum. Theory predicted an increase of the PDR strength with increasing temperature and therefore also a substantial impact in hot nuclear astrophysical processes. Here first pioneering measurements, done at IFIN ELI-NP, in the Ni chain will be shown that reveald an extra Yield below the giant dipole resonance at finite temperature in the Ni isotopes with hight N/Z ratio.

Search for PDR and ISGQR in A$\simeq$60 and A = 120 mass regions

***A. Giaz*[1], *F.C.L. Crespi*[1,2], *O. Wieland*[1], *M. Kmiecik*[3], *M. Ciemała*[3], *A. Bracco*[1,2], *F. Camera*[1,2], *A. Maj*[3], *P. Bednarczyk*[3], *G. Benzoni*[1], *S. Bottoni*[1,2], *S. Brambilla*[1], *A. Dey*[4], *B. Fornal*[3], *J. Grębosz*[3], *K. Hadyńska-Klęk*[5], *M.N. Harakeh*[6], *C. Hiver*[4], *A. Krasznahorkay*[7], *S. Leoni*[1,2], *M. Lewitowicz*[8], *M. Luciani*[1,2], *J. Łukasik*[3], *I. Matea*[4], *M. Matejska-Minda*[3], *K. Mazurek*[3], *B. Million*[1], *P. Miriot*[9], *P. Napiorkowski*[5], *P. Pawłowski*[3], *B. Sowicki*[3], *G. Spina*[1,2], *D. Stramaccioni*[10,11], *A. Tamii*[12], *B. Wasilewska*[13], *J. Wilson*[4], *M. Ziębliński*[3], *A. Zilges*[13]**

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Measurements of the γ decay from states above the neutron threshold in ^{120}Sn, ^{62}Ni and ^{58}Ni were performed at the Cyclotron Centre Bronowice (CCB) in Krakow, Poland.
The experiment on ^{120}Sn aims to study the Iso-Scalar Giant Quadrupole Resonance (ISGQR). The experiment on ^{62}Ni and ^{58}Ni, instead, aims to investigate the low-energy part of the E1 response, denoted as Pygmy Dipole Resonance (PDR).
Little is known in the literature about gamma decay of the ISGQR. Indeed, up to now, measurements were carried out only for the ^{208}Pb nucleus [1-2]. To better understand this phenomenon, we choose and investigate another nucleus in different mass region, namely ^{120}Sn.
The PDR experiment aims to increase the systematic dependence on neutron excess in nickel isotopes. It is part of a campaign of PDR experiments including various complementary measurements carried out at different accelerators and setups. In another experiments [3], we are searching for the possible survival of pygmy states at finite temperature in ^{62}Ni and ^{58}Ni. PDR measurements in Ni isotopes at $\mathrm{T} = 0$ MeV become important to have a better insight into the evolution of the pygmy with nuclear temperature.
The setup installed at the CCB Krakow, used for both experiments, is composed of a large scattering chamber with the 30 KRATTA triple telescopes (with a segmented plastic scintillator in front for a better time resolution) [4], four large volume (3.5" × 8") $LaBr_3$: Ce detectors and 2 PARIS (9 single detectors) clusters. In the case of the PDR experiment, the setup also includes an extra 8 PARIS detectors around the two PARIS clusters.
The performances and characteristics of the experimental setup together with the first near-line results for both experiments will be described.

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Study of the Pygmy Dipole Resonance using neutron inelastic scattering at GANIL-SPIRAL2/NFS

Périne Miriot-Jaubert*[1], *Diane Doré*[1], *Iolanda Matea*[2], *Marine Vandebrouck*[1], *MONSTER collaboration and PARIS collaboration

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The Giant Dipole Resonance is a collective excitation mode of the nucleus that exhausts most of the dipole excitation strength. But additionnal low lying dipole strength has been observed in neutron-rich nuclei, called the Pygmy Dipole Resonance (PDR). Both experimental and theoretical studies [1,2,3] have been performed on the PDR, which is often described as the oscillation of a neutron skin against a symmetrical neutron-proton core. The study of the PDR is interesting in many ways: it allows to constrain the symmetry energy (a term in the nuclear equation of state that drives the neutron skin and the description of nuclear matter in neutron stars) [4], and predictions show that this mode can play a key role in the astrophysical r-process [5]. However no coherent description on the nature of the PDR has been achieved yet.

In this context, the study of the PDR using a new probe, the neutron inelastic scattering reaction (n,n′γ), has been proposed. The high-intensity proton beam of the SPIRAL2 accelerator at GANIL [6], and the NFS (Neutron For Science) facility [7] have made this study possible. The experiment to study the PDR in ^{140}Ce via the (n,n′γ) reaction was performed in Sept 2022. The new generation multi-detector PARIS [8,9] has been used for the detection of the γ from the deexcitation of the PDR, and MONSTER modules [10] were set for the scattered neutrons detection.

The characterization of the PARIS and MONSTER detectors and results on the elastic scattering will be presented, as well as preliminary results on the (n,n′γ) channel.

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Gamma above the neutron threshold perspectives at ELI-NP¶

***P.-A. Söderström*[1], *A. Kuşoğlu*[1,2], *A. Gavrilescu*[1], *M. Brezeanu*[1], *R.A. Guţoiu*[1], *D.L. Balabanski*[1]**

Invited talk

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The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) facility [1] is a major European nuclear physics infrastructure aiming at providing users with high-intensity laser beamlines delivering 100 TW, 1 PW, and 10 PW of laser power on target from the high-power laser system (HPLS), as well as high-brilliance γ-ray beams with energy up to 20 MeV and a very narrow bandwidth from the Variable Energy Gamma-ray (VEGA) system. The HPLS is operational, providing beam time for internal and external users, while the VEGA system is still under implementation.

The scientific focus of the VEGA system will cover a broad range of topics from nuclear astrophysics to applications to basic science. One of the exciting directions of the latter is the studies of the nuclear properties in the continuum and quasi-continuum that manifests as large amplitude resonances like the giant dipole-resonance (GDR) and the pygmy dipole resonance (PDR). For studies of the states in these regions, the ELI Gamma Above Neutron Threshold (ELIGANT) [2,3,4] instrumentation has been developed for high-efficiency detection of high-energy γ rays as well as neutron detectors with good efficiencies covering the entire energy range from thermal up to tens of MeV. The ELIGANT instrumentation is the perfect tool for the study of collective nuclear dipole excitations, including the γ-ray and neutron decay branchings from the GDR, the properties of the PDR around the neutron separation energy, and the γ-ray strength functions (γSFs), its functional form and universality, across the nuclear chart.

In this contribution, we will give an overview of the current status of the ELIGANT project within the context of the γ-ray beams foreseen to be provided by the VEGA system at ELI-NP.

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Light-by-light scattering in ultraperipheral heavy ion collisions – new possibilities

Antoni Szczurek

Invited talk

IFJ PAN Krakow, Krakow, Poland

We discuss possible future studies of photon-photon (light-by-light) scattering using planned FoCal and ALICE 3 detectors. We include different mechanisms of $\gamma\gamma \to \gamma\gamma$ scattering such as double-hadronic photon fluctuations, t/u-channel neutral pion exchange or resonance excitations ($\gamma\gamma \to R$) and de-excitation ($R \to \gamma\gamma$). The broad range of (pseudo)rapidities and lower cuts on transverse momenta open a necessity to consider not only dominant box contributions but also other subleading contributions. Here we include low mass resonant $R = \pi^0, \eta, \eta'$ contributions. The resonance contributions give intermediate photon transverse momenta. However, these contributions can be eliminated by imposing windows on di-photon invariant mass. We study and quantify individual box contributions (leptonic, quarkish). The electron/positron boxes dominate at low $M_{\gamma\gamma} < 1$ GeV di-photon invariant masses. The PbPb$\to$PbPb$\gamma\gamma$ cross section is calculated within equivalent photon approximation in the impact parameter space. Several differential distributions are presented and discussed. We consider four different kinematic regions. We predict cross section in the (mb-b) range for typical ALICE 3 cuts, a few orders of magnitude larger than for the current ATLAS or CMS experiments. We also consider the two-π^0 background which can, in principle, be eliminated at the new kinematical range of the ALICE 3 measurements by imposing dedicated cuts on di-photon transverse momentum and/or so-called vector asymmetry.

We discuss also possible new contributions due to exotic resonances and inelastic processes. In the second case we consider coupling of photons to constituents of nucleus - protons or neutrons. We include both elastic and inelastic transitions on the nucleon level. The inelastic contributions to the nuclear cross section are quantified for invariant mass and rapidity distance distributions.

The presentation will be partially based on:

P. Jucha, M. Kłusek-Gawenda and A. Szczurek, "Light-by-light scattering in ultraperipheral collisions of heavy ions at two future detectors", Phys. Rev. **D109** (2024) 014004.

Effects of beyond mean field approximation and tensor forces on Gamow-Teller and β decay of magic nuclei

***Hiroyuki Sagawa*[1,2], *M. J. Yang*[3], *C. L. Bai*[3], *H. Q. Zhang*[4]**

Invited talk

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The self-consistent Hartree-Fock (HF)+subtracted second random phase approximation (SSRPA) calculations based on the Skyrme energy density functions (EDFs) are pperformed for the Gamow-Teller (GT) excitations of four closed shell nuclei ^{48}Ca, ^{90}Zr, ^{132}Sn, and ^{208}Pb to study the systematic trend of SSRPA on the description of GT strength distributions with respect to the excitation energy and the width [1]. We apply also the SSRPA model including tensor force to the decay half-lives in magic and semi-magic nuclei, ^{34}Si, ^{68,78}Ni and ^{132}Sn with Skyrme EDFs. The inclusion of the two particle-two hole (2p-2h) configurations in the SSRPA model shifts low-lying GT states downwards. It leads to an increase of the β decay phase space, which ensures the half-lives of the four nuclei are finite and reduces the β decay half-lives dramatically. The effect of tensor interaction on the β decay 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 [2]. We further studt magnetic dipole (M1) transitions of magic nuclei to disentangle the role of triplet-even and triplet-odd tensor forces in the spin-isospin excitations [3].

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Nuclear level densities and γ-ray strength functions of ^{152,154}Sm

***L. Bell*[1], *S. Siem*[1], *A.C. Larsen*[1], *V.W. Ingeberg*[1]**

S

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The samarium isotopic chain is one of the best choices to study the evolution of the nuclear level density (NLD) and γ-ray strength function (γSF) as a function of deformation. This chain starts at the near spherical and stable ^{144}Sm, which has a magic number of 82 neutrons, to the well deformed isotope of ^{154}Sm. This isotopic chain has many stable isotopes which makes it one of the few isotopic chains which we can study at stable beam facilities, like the Oslo Cyclotron Laboratory. This gives us a unique opportunity to investigate how the NLD and γSF evolve with deformation and increasing mass.

In 2018, an experiment was carried out at the Oslo Cyclotron Laboratory in which 15 and 16 MeV proton beams were irradiated on targets of ^{152}Sm and ^{154}Sm, respectively. This allows for the study of the ^{152}Sm$(p,p'\gamma)^{152}$Sm and ^{154}Sm$(p,p'\gamma)^{154}$Sm reactions. In this work, the Oslo method is used to analyze the above mentioned data sets to simultaneously extract the NLD and γSF. The results from these experiments will be discussed with a specific focus on the scissors resonance.

Two-center harmonic oscillator basis: alpha clustering and symmetric fission as Proof-of-Principle calculations

Adrian Sanchez Fernandez[1]***, Jacek Dobaczewski***[1,2]***, Xuwei Sun***[1]***, Herlik Wibowo***[1]

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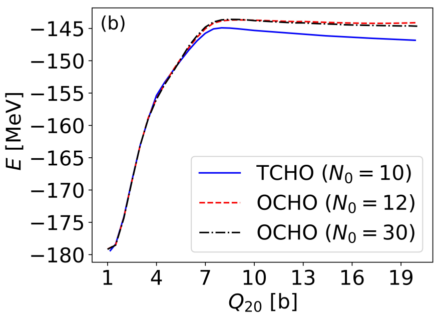
Fission is one of the most challenging processes to describe in nuclear physics. Contrary to most of the nuclear properties, which can be explained in terms of a small set of valence nucleons, in fission all the particles are involved. To link the properties of the nascent fragments with the structure of the initial compound nucleus, it seems adequate to consider the two-centre harmonic oscillator basis to build the many-body wave functions. Even though there are some existing results computed with that approach, in the self-consistent calculations the axial symmetry was so far preserved, which appears as a limitation for describing more complex phenomena (such as angular momentum generation in fission fragments).



Total energy of ^{24}Mg in function of the quadrupole moment, using two-center (TCHO) and one-center (OCHO) HO bases, with a different maximum num- ber of shells included.

In this work, we present the first results based on symmetry-unrestricted two-center harmonic oscillator (HO) bases implemented in the density functional solver HFODD within the Skyrme Hartree-Fock approach. Furthermore, the exact direct and exchange terms of the Coulomb interaction have been implemented and tested in the two-center setting. The separation between fragments and their deformations are explored in two Proof-of-Principle calculations: ^{8}Be as an alpha cluster and the symmetric fission of ^{24}Mg. In both cases, describing nuclei as molecular compounds made of smaller fragments captures the physics of the systems more easily than in the usual one-center HO methods, even when a small number of the HO shells are considered. An analysis of the fission path of ^{24}Mg sets the underpinning for future, more complex, calculations, where the asymmetric fission and odd-mass nuclei will be taken into account.

This work was partially supported by the STFC Grant No. ST/W005832/1, ST/P003885/1 and ST/V001035/1. We acknowledge the CSC-IT Center for Science Ltd., Finland, for the allocation of computational resources. This project was partly undertaken on the Viking Cluster, which is a high-performance computing facility provided by the University of York. We are grateful for computational support from the University of York

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Selfconsistent study of ternary fission of (super)heavy nuclei

Y. Jaganathen, J. Skalski*

S

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Tripartition is a rare outcome of actinide fission. Most frequently the additional fragment is alpha particle, but in rare cases it can be a heavier light fragment. For a long time a low-energy fission mode into three fragments of comparable size, called a genuine (or true) ternary fission, was speculated upon and searched for, but its existence still remains elusive. Recent experiments in Dubna suggested the genuine ternary fission mode in the spontaneous fission of ^{252}Cf and in the neutron-induced fission of ^{235}U, see reviews [1,2]. With two detected fragments close to ^{68,72}Ni and ^{132}Sn, the third, undetected one (supposedly due to its small velocity), should be Ca (or Si for ^{235}U). The unexpectedly large frequency of 2 – 5×10^{-4} per binary decay for this channel was deduced from data. A number of calculations using the microscopic-macroscopic (MM) method, mostly within a schematic three-cluster model, and some more advanced like the three-center MM model [3], suggest that these observations resulted from the collinear tripartition process. Apart from its experimental status in actinides, a possible ternary fission of superheavy nuclei is an open problem which deserves a study. Up to now, as in the actinides, it was studied within the more or less restricted MM models, see e.g. [4,5].

One usually assumes that ternary fission is a sequential process in which the secondary fission of the heavier primary fragment occurs thanks to a large elongation and two constrictions developed in the heavy parent nucleus prior to the first scission. Thus, one has to map energy landscapes for such configurations of heavy systems which are excited with respect to normal fission valleys. We present the approach based on the Hartree-Fock+BCS method with the Skyrme-type interaction. In application to tripartition it seems to present a few advantages over the MM method. In particular, it allows to find energy minima under relevant constraints without assuming a priori deformation parameters. However, a creation of minimally restrictive constraints in selfconsistent calculations is a nontrivial practical problem. We obtain energy surfaces for collinear configurations in actinides and for collinear and equatorial ones in some superheavy nuclei. We infer the secondary barriers for ternary fission which are by a few MeV higher than the standard barriers for binary fission. Then we consider an interplay of overdamped dynamics and barrier penetration to estimate the probability of ternary fission.

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30 years of ion beams from the Warsaw Cyclotron - a good beginning

Paweł Napiorkowski

Invited talk

University of Warsaw, Heavy Ion Laboratory

The „Nuclear Physics News" in 1994 reported: „New facility is born. It has been a good season for Polish heavy ion physicists and for Warsaw champagne dealers, as well. At the end of November 1993, the stocks of champagne were depleted after the first successful acceleration of 32 MeV 20Ne2+ beam in the Warsaw Heavy Ion Cyclotron[…]".

Since then, the world and the Heavy Ion Laboratory at the University of Warsaw have changed. Today, the Warsaw U-200P cyclotron delivers beams of heavy ions for experiments conducted by international experimental teams with the ICARE, EAGLE, and NEDA setups. Research opportunities offered by the HIL infrastructure are not limited to nuclear spectroscopy only, but also extend to radiobiology, materials studies and medical applications. A selection of results obtained in this European transnational access facility located in the centre of Poland and plans for the very near future will be presented.

Saturday

August 31st

Physics Opportunities at Ultra-High Spin

M. A. Riley

Department of Physics, Florida State University, Tallahassee, Florida 32306, USA

Invited talk

The next generation Ge γ-ray tracking arrays [1], GRETA [2,3,4] in the US and AGATA [5,6] in Europe, with their high efficiency, good peak-to-background ratio, and excellent energy and position resolution, offer extraordinary discovery potential for the future. They are also incredibly versatile devices ideally suited to a broad range of experiments at both radioactive beam (fast-fragmentation and reaccelerated) and stable beam facilities. One area of particular interest, as they approach their full 4π capability in the coming years, is the response of atomic nuclei at the limits of spin and deformation. Such studies deeply probe the competing modes of nuclear excitation and the rich variety of shapes that occur. Fascinating and often surprising new aspects of nuclei have been revealed through the decades, with many long standing mysteries still to be understood. This presentation will discuss some of the physics opportunities using these exciting new spectrometers at ultra-high spin.

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The complex interplay between pairing modes and spin in deformed $N \sim Z$ nuclei

B. Cederwall*[1], *AGATA collaboration

Invited talk

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The character of nuclear superfluidity and the isospin modes of nucleonic pair correlations is a long-standing problem of large interest in nuclear structure physics. The approximate isospin symmetry of nuclear forces implies the possible existence of a new and unique, *isoscalar* ($T = 0$), pairing mode in nuclei with equal or nearly equal numbers of neutrons and protons that remains unresolved. The presence of an isoscalar pairing condensate would lead to dramatic changes in the level energies and lifetimes of nuclear states and might even change the "textbook" ground-state properties we are used to for even-Z, even-N nuclides, such as the normal spin-parity 0^+. There are various experimental approaches to gauging whether this exotic pairing mode is embedded in the ground-state or excited-state nucleonic correlations or not [1]. In deformed $N \sim Z$ systems the differentiated influence of collective rotational angular momentum on the isovector and presumed isoscalar pairing modes may become accessible, albeit experimentally extremely challenging, in the heaviest self-conjugate nuclei where such correlations are expected to be most favored. Useful observables in this respect can be obtained from precision measurements of yrast level energies in order to search for perturbations in the normal isovector-pairing induced backbending patterns. Lifetime measurements for such states are also key to investigating possible effects of enhanced isoscalar np correlations the since increased $B(E2)$ strength is an expected result of such correlations. Intermediate-angular momentum states in heavy $N \sim Z$ nuclei such as ^{88}Ru are becoming accessible with advances in instrumentation, most notably the new generation of γ-ray tracking arrays. The spectrum of yrast states in the self-conjugate nucleus ^{88}Ru was measured up to angular momentum $I = 12\hbar$ [2] using the Advanced Gamma Tracking Array (AGATA) spectrometer [3] operated in conjunction with ancillary detectors for charged particles and neutrons. The observed γ-ray cascade established the sequence of low-lying excited states as a rotational-like band structure exhibiting a band crossing at a rotational frequency notably exceeding conventional theoretical projections involving isovector pairing. This deviation from standard theoretical predictions is further accentuated when compared with experimental observations in the neighboring odd-mass nuclides like ^{87}Tc [4]. In these systems the opposite trend in rotational alignments, i.e. a decrease in alignment frequency and interaction strength between the low-lying yrast band members and the aligned structure, has been observed [4]. The effect may result from the strong spin-aligned np pairing interaction favoring a triplet configuration based on the coupling between a rotation-aligned np pair and the odd valence nucleon of similar single-particle parentage. While an increased band crossing frequency and interaction strength between the g-band and S-band in deformed even-Z, even-N, $N = Z$ nuclei is in line with some predictions of theoretical calculations extended to include isoscalar pairing there are so far less clear predictions for odd-mass systems where isovector pair correlations are partially blocked.

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Different manifestations of oblate rotation in nuclei

Costel Petrache[1]

Invited talk

[1] University Paris-Saclay and IJClab, CNRS/IN2P3, 91405 Orsay, France

An extremely regular rotational band that extends to a spin of about 75/2 and an excitation energy of ≈4.5 MeV above yrast at the highest spins has been recently observed in ^{137}Nd, and interpreted to be built on oblate shape. A similar sequence was also identified in ^{136}Nd extending up to spin (39^-) and ≈2.5 MeV above yrast at the highest spins. In ^{126}Xe two bands were observed up to spin 56 and 4 MeV above yrast, reaching the terminating states at close to spherical shapes. Such bands are interesting because they are highly excited at very high spin, where the number of states per MeV are several orders of magnitude higher than close to the yrast line. They survive as long cascades of discrete transitions in a very hot $E^* - I$ region where the bands are expected to be completely damped, which is in contradiction with the present understanding of the nuclear structure at high temperature. Cranked mean-field calculations of the Nilsson-Strutinsky type suggests normal-deformed oblate shape for the band of ^{137}Nd and triaxial for the band of ^{136}Nd and ^{126}Xe. However, an alternative interpretation assuming much higher band-head spin ($+$ 13$\hbar$) and higher deformation (similar to that of the highly-deformed band) has been recently proposed for the band of ^{137}Nd. The pro and contra of the different interpretations will be presented. Solid evidence of a band consisting of two nearly degenerate rotational bands consisting on $E2$ transitions and inter-connected by $M1$ transitions was also identified in ^{119}Cs, and interpreted as built on oblate shape. These new experimental results and their interpretation in terms of oblate rotation will be discussed.

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

K. Hadyńska-Klęk[1]

Invited talk

[1] Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland

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$40 constitutes an ideal ground for investigating exotic structures within various theoretical frameworks. Recently, the electromagnetic structure of the nucleus ^{42}Ca with the advanced AGATA γ-ray tracking array was studied [2]. It was shown, for the first time, that it is possible to probe SD structures with Coulomb excitation. This work also provided the first direct experimental evidence for non-axially symmetric or triaxial SD shapes in the A$\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 more north-east from ^{40}Ca, the nickel isotopes offer a unique laboratory to investigate 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 reported also 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 $2^+_2 \rightarrow 2^+_1$ transitions of ^{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 the recent results from the 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 the comparison with the state-of-the-art theoretical calculations.

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Anomalous $B_{4/2}$ ratio in the yrast band of ^{167}Os

***Irene Zanon*[1,*], *Bo Cederwall*[2], *Maria Doncel*[1]**

S

[1] Stockholm University; [2] Royal Institute of Technology KTH; [*] speaker

Spectroscopic properties of exotic nuclei are powerful tools to obtain a better insight on the evolution of nuclear structure far from the stability. Mid-shell nuclei are expected to exhibit collective behaviour which is typically reflected in the observation of low excitation energies of the first excited states and high transition probabilities. Moreover, the collectivity is expected to increase with the spin, causing both the $R_{4/2} = E_X(4^+)/E_X(2^+)$ to be higher than 2 and the $B_{4/2} = B(E2; 4^+ \rightarrow 2^+)/B(E2; 2^+ \rightarrow 0^+)$ to be higher than the unit. However, an increasing number of mid-shell nuclei had been found to present a $B_{4/2} < 1$. This has already been observed in two neutron-deficient regions, one located close to the $Z = 50$ shell closure and one in the rare-earth region. In particular, the osmium isotopic chain presents cases both in even-even nuclei, such as ^{168,170}Os, and one in an even-odd nucleus, ^{169}Os, where the $B_{4/2}$ ratio has been redefined as $B(E2; 21/2^+ \rightarrow 17/2^+)/B(E2; 17/2^+ \rightarrow 13/2^+)$. According to theory, this anomaly could only be explained by a change from collective to seniority-like regimes or by phenomena such as shape coexistence. However, this change in structure has not been predicted by theory in the osmium isotopic chain, which remains an open question. In this context, lifetime measurements of the excited states of these nuclei can provide a meaningful insight on the structure of the low-lying bands. An experiment aimed at measuring lifetimes in ^{167}Os was performed at the Accelerator Laboratory of Jyväskylä (Finland), where the nucleus of interest was populated in a fusion-evaporation reaction. The selection of the channel was performed using the alpha-recoil tagging technique and the gamma rays emitted by the recoil were detected using the Jurogam3 array. The lifetimes were extracted using the Recoil Distance Doppler Shift method. From the measured lifetimes, it was possible to extract the reduced transition probabilities of the low-lying states and the $B_{4/2}$ ratio. The experimental results were then compared to potential energy surface calculations in order to shed light on the influence of the unpaired neutron. In this contribution, a summary of the performed experiment, the new results and the comparison with theory are presented.

Multiple chiral doublet bands in ^{104}Rh

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Chiral rotation has been found in many triaxial nuclei in the $A \sim$ 80, 100, 130, and 190 mass regions [1]. Observation of chiral bands also in odd-mass nuclei suggests that chiral geometry can be robust against the change of configuration. This raises the possibility of having multiple pairs of chiral doublet bands in a single nucleus with different configurations. During the last decade the phenomenon of multiple chiral bands has been observed in several odd-mass, odd-odd and even-even nuclei in the chirality regions. However, in the $A \sim 100$ mass region it has only been reported in odd-mass nuclei, for example in ^{103}Rh [2].
In order to search for multiple chiral structure in odd-odd nulcei with $A \sim 100$ we studied the medium- and high-spin negative parity bands in ^{104}Rh through the ^{96}Zr(^{11}B,3n) reaction at a beam energy of 40 MeV using the Gammasphere spectrometer. Beside the already known chiral doublet structure [3], two new negative-parity bands have been identified [4]. The observed properties of the four bands and their interpretation will be presented.

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Poland in FAIR

Piotr Salabura

Invited talk

Institute of Physics, Jagiellonian University of Cracow, Poland

FAIR- Facility for Antiproton and Ion Research- is one of the largest accelerator-driven research centers in Europe with an ambitious multidisciplinary scientific program. The first stage of FAIR, currently under construction with completion aimed in 2028, is focused on atomic physics and applications, nuclear physics with radioactive beams, studies of compressed baryon matter and hadron properties. It offers many world-leading research opportunities.

Polish physicists, led by Prof. Reinhard Kulessa and Prof. Zbigniew Majka, were one of the initiators of FAIR. Poland is currently a shareholder, making significant contributions to both experiments and accelerator devices. The presentation, dedicated to the memory of these distinguished FAIR mentors in Poland who passed away this year, will focus on Polish contributions to the FAIR infrastructure and research.

Special Lecture

From uNclear to Nuclear
How nuclear science contributes to our society

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Invited talk

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Nuclear science is a field of research addressing the properties of the constituents of matter at the heart of the atom. From the quarks to nuclear reactions in stars, nuclear science is driven by the passion of its communities and the research funding they secure, mostly from tax-payers. But some may wonder what returns does society gain from this investment.
Besides the evident developments related to the nuclear energy sector, nuclear science has direct impact in the medical sector, and in particular in the treatment of some of the most challenging forms of cancer, as well as in space exploration, in better understanding the climate, in heritage science, and many more fields. Some of these applications are directly driven by nuclear science while some other are serendipitous findings that have created domains of their own.
In this contribution, some examples of exciting applications of nuclear science will be presented, showing how nuclear scientists are actively contributing to answering challenges of our society as summarized by the United Nations with the Sustainable Development Goals.

Figure 4: Illustration of the 17 Sustainable Development Goals of the United Nations. Nuclear science contributes actively to improving our society by answering the call to all of these SDGs.

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P-01. Projctile fragmantation reactions properties and their applications

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P - 01

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During the last decades, projectile fragmentation and separation at high energies has become one of the most important methods for the production of exotic nuclei. Production and separation of such species can be performed for example at energies of around 500 to 1000 A MeV at the SIS/FRS facility [1] at GSI in Darmstadt, Germany. At RIKEN in Wako, Japan, operates the RIBF facility with the BigRIPS separator [2]. The main advantage of high-energy projectile fragmentation as a production method lies in the fact that very clean fragment beams can be produced. Also, the high energies allow unambiguous event-by-event isotope identification of the fragments. In principle, projectile fragmentation leads to all nuclei which can be generated by the removal of nucleons from the projectile, i.e., they can range from isotopes of the element of the projectile down to protons. However, the production cross-sections strongly decrease with the increasing number of removed nucleons. Therefore, all proposed and planned experiments should rely on good estimates of fragmentation cross sections. Choice of the appropriate primary beam and target are also important in order to increase the production rates of rare exotic nuclei. To predict fragmentation cross sections the universal analytical formula, called EPAX [3, 4], was used . This formula allows to calculate the yields from fragmenting in the range of projectile masses between about 40 to 209. In particular, the formula tries to take properly into account the influence of the projectile proton or neutron excess onto the neutron-to-proton ratio of the fragments. The cross sections are assumed to be energy independent, which seems to be supported by most of the measured data. To determine how to produce the isotope of interest, the behavior of the production cross section of fragments with proton and neutron numbers (Z, N) was calculated for the primary beams 124Xe, 209Bi, and 238U, with the target 9Be, which are commonly used in the SIS/FRS facility at GSI-FAIR. The behavior of the maximum cross section on the nuclear chart (Z, N) indicates that the individual paths for each projectile divide into two parts: the "asymptotic" line, which for lighter nuclei overlaps with the path of stability, and beyond. It is important that the "asymptotic" fragment path is common to all projectiles, with each fragment striving for it after losing approximately 4 protons and near 20 neutrons. Therefore, how a particular isotope is produced depends on its location relative to this "asymptotic" path. Those lying on the asymptotic can be produced in various ways using different projectiles. Those lying "beyond asymptotic" can be obtained using only a few projectiles. Hence, the selected projectile should be close in Z and N to the region of the isotope of interest. The calculations show that selecting the target can increase the cross-section by two to three times. When choosing the thickness and the target, it is also important to take into account the absorption and secondary reactions occurring within. The calculations allow for selecting the appropriate target thickness, which increases the production rate of the isotope of interest.

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P-02. Theo4Exp for EURO-LABS Live Demonstration

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Theo4Exp[1] is a virtual infrastructure which provides theoretical tools within the **EURO-LABS**[2] project. It is aimed mainly at experimental nuclear physicists to enable them standard but advanced calculations helpful in data interpretation, favouring collaboration between theorists and experimentalists. It is designed as an open access platform, where key computer codes, as well as results of calculations, have been made accessible to the community. It includes three different platforms:

- **MeanField4Exp**[3] hosted by IFJ PAN in Cracow,
- **Reaction4Exp**[4] hosted by University of Seville, and
- **Structure4Exp**[5] hosted by University of Milan.

During the poster session we will show how each of the three platforms works, offering assistance and discussions to the interested users.

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[1] https://institucional.us.es/theo4exp/
[2] https://web.infn.it/EURO-LABS/
[3] https://institucional.us.es/theo4exp/meanfield4exp.html
[4] https://institucional.us.es/theo4exp/reaction4exp.html
[5] https://institucional.us.es/theo4exp/structure4exp.html

P-03. Medium spin states in the ^{87}Se isotope produced in neutron induced fission of ^{233}U and ^{235}U targets

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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 γ 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 γ-ray coincidence relationships measured with the new highly efficient HPGe array - FIPPS [5]. The analysis, based on the cross-coincidence technique, revealed seven new γ 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 γ rays. The results indicate the presence of the E3 transition, $11/2^{-} \rightarrow 5/2^{+}$, encouraging the search for similar E3 excitations in neighboring even Se isotopes.

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P-04. Investigation of electron emission processes in light ion fusion reactions at extremely low energies using GEANT4 Monte-Carlo simulations

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P - 04

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The charged particle-induced nuclear reaction cross-sections decrease exponentially as the energy falls well below the Coulomb barrier. But, in contrast to reactions involving bare nuclei, studies conducted on nuclear reactions in metallic environments showed a strong enhancement of cross sections as the projectile energy decreased. This effect was first observed in the ^{2}H(d,p)^{3}H and ^{2}H(d,n)^{4}He [1] reactions and later confirmed with other reactions such as ^{6,7}Li(d,α)^{4,5}He and ^{6,7}Li(p,α)^{3,4}He [2] in various metallic environments. This experimentally observed enhancement of reaction cross-sections has primarily been attributed to the electron screening effect in metallic environments.
In addition to the electron screening effect, the presence of a 0^{+} threshold resonance at 23.85 MeV was suggested as another reason for the increased reaction cross-section in low-energy DD fusion reactions [3]. This resonance can potentially change the branching ratio of the DD reactions at extremely low deuteron energies. In this case, the total resonance width is dominated by the $e^{-}e^{+}$ internal pair creation partial width [4]. This was recently confirmed in the experiments conducted at the Ultra High Vacuum accelerator facility at the University of Szczecin [5].
This work presents the experimental techniques used for the detection of high-energy $e^{-}e^{+}$ pairs resulting from the decay of the 0^{+} threshold resonance. Thin Silicon Surface Barrier (SSB) detectors of varying thickness were used for this purpose. The detector response functions for fusion products, particularly high-energy electrons, were simulated using the GEANT4 Monte Carlo code. These simulations were then compared with the experimental spectrum obtained from silicon detectors. Contributions to the detector response function from different scattering processes involving experimental setup components were identified through simulations [6]. Additionally, probabilities of potentially competing electron conversion channels were also investigated. This methodology remains reliable for investigating potentially weak reaction branches in other light nuclear reactions as well, particularly where narrow resonances can significantly alter branching ratios at extremely low energies.
The study is part of the CleanHME project. This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 951974.

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P-05. Extracting isomeric yield ratios of fission fragments

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In nuclear fission, a heavy nucleus splits and the fission fragments emerge spinning [2]. The isomeric yield ratio (IYR) i.e. the population frequency of an isomer, is know to be sensitive to the angular momentum of the fragment. Measuring the IYR can therefore give information about the initial sate of the fission fragments.
This work uses a technique to reach short lived isomeric states where the IYR has not been measured before [1]. We study the IYR of the 52ns isomer in ^{130}Sn, extracted for the fissoning system ^{238}U(n,f) at two different energies, as well as the 511ns isomer in ^{135}Te extracted for the fissoning systems ^{232}Th(n,f) and ^{238}U(n,f) at two different energies. From looking at how the different fissoning systems affect the IYR, we get more knowledge about what impact the angular momentum generation. The fission code GEF is used in combination with the nuclear decay code TALYS to find the fragment angular momentum from the IYR.

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P-06. Effect of neutron transfer on the nuclear fusion using microscopic nuclear potential

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The effect of neutron transfer degrees of freedom on the heavy-ion fusion cross-sections has been investigated using the coupled channel (CC) code CCFULL [1,2]. The microscopic nuclear interaction potential and the densities of interacting nuclei used in the CC calculations are obtained for the relativistic mean-field approach using NL3* parameter set [3]. We have considered the ^{18}O-induced reactions, namely, ^{18}O + ^{148}Nd and ^{18}O + ^{150}Sm with positive Q-values and for which experimental fusion cross-section is available [4,5] around the Coulomb barrier. It is evident from the results that the microscopic R3Y nucleon-nucleon (NN) potential with intrinsic degrees of freedom is superior to the Woods-Saxon potential, particularly at energies below the barrier. Therefore in the next step, we employ relativistic mean-field formalism to provide the prediction for the unknown ^{18}O-induced reaction, i.e., ^{18}O + ^{150}Nd, ^{18}O + ^{154}Sm as well. The significant role of positive Q-value neutron transfer in enhancing the sub-barrier fusion cross-section is observed for the ^{18}O + ^{148}Nd reaction with R3Y NN potential. However, the effect of the corresponding transfer channel for the cases of other considered reactions is comparatively less pronounced.

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P-07. Exploring Ternary Decay of ^{252}Cf Nucleus: Charge and Mass Dispersion through Collective Clusterization

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P - 07

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The spontaneous disintegration of unstable nuclei, encompasses various decay modes, including binary and ternary fission. Heavy-mass nuclei often exhibit these decay processes, with binary fission being the most prevalent. In the past few decades, numerous attempts [1] have been made to explore the binary emission from the radioactive nuclei. Ternary fission, involving the simultaneous emission of three fragments is relatively rare phenomenon in comparison to binary decay. Ternary fission can occur as equatorial cluster tripartition (ECT) or collinear cluster tripartition (CCT) depending on the direction of the emitted third fragment with respect to the fission axis. The spontaneous emission of four fragments was observed experimentally for ^{252}Cf nucleus [2], where light charge particles (isotopes of hydrogen (H), helium (He), lithium (Li), boron (B), carbon (C), nitrogen (N), oxygen (O), fluorine (F), neon (Ne), sodium (Na), aluminum (Al), magnesium (Mg)) are detected. Many experimental and theoretical [3] studies emphasize the observation of alpha particles as the predominant third fragment in ternary fission. The main reason for this radioactive splitting is the shell closure effect associated with the daughter nucleus [4]. Hence, it will be of interest to explore the fragmentation behavior of such decay modes and make a comparative analysis of the probable fragmentation pattern.
Numerous theoretical models are introduced to explore fission dynamics based on different nuclear properties. The quantum mechanical fragmentation theory is successfully employed to address binary and other competing ground-state decay modes such as ternary fission, cluster radioactivity, quaternary fission etc. It works out in terms of the mass/charge asymmetry coordinates and relative separation. In the present work, an effort is made to understand the ternary fission of ^{252}Cf nucleus including a comparative analysis of charge and mass distribution.

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P-08. Study of collectivity and shape coexistence in A $\sim$ 120 nuclei close to the proton drip-line

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The phenomenon of shape-coexistence is established in several regions of the nuclear chart. It corresponds to the existence of more than two distinct geometrical shapes at similar excitation energies. Experimentally, one of the ways to study this phenomenon is through the gamma-spectroscopy, by identifying the structures built on coexisting minima with different shapes and study their properties. This method becomes challenging particularly when studying the neutron deficient isotopes due to the low cross-sections for the formation of these isotopes with the available stable beams. Also, even if these isotopes are formed, they can have very short half-lives. Thus, this requires an in-beam spectroscopy or the use of very fast separation techniques.
In the present work, our focus is on studying the collectivity and shape-coexistence in the neutron deficient isotopes of I, Cs, Ba, and La by in-beam gamma- spectroscopy and recoil decay tagging techniques. In an experiment performed with JUROGAM3 $+$ MARA at Jyvaskyla, Finland, using the ^{64}Zn beam on a thin ^{58}Ni target, we were able to identify new bands and transitions in ^{114}I, ^{117}Cs, ^{118,120}Ba and ^{120}La. In addition to intensity measurements, spins and parities of the states com- posing these structures have been obtained by measurements of angular distri- butions, angular correlations, and polarization of most of the intra- or inter- band gamma transitions. As well, the properties of these structures (transitions probabilities: B(M1)/B(E2), B(E2)$_{in}$/B(E2)$_{out}$, B(E1)$_{out}$/B(E2)$_{in}$; rotational properties: J$^{(1)}$ and J$^{(2)}$ moments of inertia, single-particle spin alignments) have been also extracted and interpreted within the framework of undergoing theoretical studies.
During this talk I will mainly present the new results obtained for the ^{117}Cs, ^{114}I and ^{120}La isotopes.

P-09. Photon-induced neutron, proton and alpha evaporation from heavy nucleus

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In ultraperipheral heavy-ion collisions (UPCs) at the Large Hadron Collider (LHC), Pb nuclei are excited through interactions induced by strong electromagnetic fields. The expected excitation energy could reach 140 MeV, which leads to the subsequent emission of various particles, including neutrons, protons, and alpha particles.

To accurately describe photon-induced deexcitation processes, we have developed two novel approaches. The first method utilizes the Heavy Ion Phase Space Exploration (HIPSE) model [1] to simulate pre-equilibrium emissions and to estimate the excitation energy of the remaining nucleus. Our second approach introduces a new technique for modeling the excitation energy of the nucleus. This method consists of a two-component function to represent the distribution in excitation energy more precisely, accounting for the energy loss due to the interaction between photon and quasi-deuteron. Both of these modeling techniques were integrated with the results produced by the GEMINI++ generator [2], which implements the Hauser-Feshbach formalism [3] to simulate the statistical decay of excited nuclei. Utilizing these approaches, we have calculated the cross sections for the emission of neutrons, protons, and alpha particles resulting from UPC events.

Our results were compared with experimental data from the ALICE group [4] and with results of the RELDIS model [5].

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P-10. ^{40}Ar Beam Commissioning of KoBRA for RI Beam Production at RAON*

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A multi-purpose experimental instrument, called KoBRA (Korea Broad acceptance Recoil spec- trometer and Apparatus), was constructed at the Institute for Rare Isotope Science (IRIS), as a part of the RAON facility in Korea [1-3]. Stable or rare isotope (RI) beams can be produced using Electron Cyclotron Resonance (ECR) ion sources or the Isotope Separation On-Line (ISOL) system at RAON, and these beams can be delivered to KoBRA at energies of 1 – 40 MeV/u via the SuperConducting Linear accelerator 3 (SCL3), respectively.
KoBRA has been in the beam commissioning phase since May 2023, and completed its beam commissioning using 16 MeV/u ^{40}Ar. The production target of graphite was used, and secondary RI beams were produced from the reaction ^{40}Ar + ^{12}C. The primary beam was found by energy straggling with target, and this beam was rejected from the detection system by tilting at about 50 mrad and stopping at a beam collimator.
The initial particle identification was performed by means of ΔE–ToF method, and the nuclei from $N = Z - 1$ to $N = Z + 3$ line were observed. The magnetic rigidity ($B\rho$) was set for the $N = Z$ nuclei of ^{10}B, and determined by B-field measurement of two dipole magnets with NMR probes. The momentum acceptance ($\Delta p/p$) was confined to 0.2% by a momentum slit. One silicon detector and two Parallel Plate Avalanche Counters (PPACs) [4] were used for ΔE and ToF measurement. The Z calibration and ToF offset were validated with $N = Z$ and $N = Z + 1$ nuclei up to $Z = 9$.
^{25}Ne and nearby nuclei up to $Z = 13$ was observed and identified by means of $B\rho - \Delta E -$ ToF method. The momentum acceptance was set to 8%, and the particle $B\rho$ was analyzed by position measurement with one large area PPACs at dispersive focal plane F1. The mass-to-charge ratio A/Q of the produced nuclei was deduced from the ToF and $B\rho$ measurements. The A/Q resolution was found to be 0.6% for ^{25}Ne, and an improvement is expected by using plastic scintillation detectors for ToF measurement.
KoBRA has plans for a series of nuclear physics experiments, including cross section measurement through RI beam production, as well as optical parameter measurements for ^{40}Ar at various low energies, utilizing the variable energy capabilities of the SCL3. A transport test of RI beam produced via the ISOL system is scheduled. These efforts are expected to enable comprehensive and distinct researches in RI physics at RAON in the near future.

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P-11. Negative-parity high-spin structure of ^{105}Pd

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Transitional nuclei in the $A \sim 100$ mass region are known to have triaxial shapes leading to the appearance of exotic phenomena such as the chiral twin bands, and the nuclear wobbling motion. Indeed, appearance of chiral twin bands has been observed in several odd-odd and odd-mass Rh and Ag nuclei around ^{105}Pd [1], and nuclear wobbling motion has been observed recently in ^{105}Pd [2], confirming the triaxially deformed shapes of these nuclei.
To search for the possible two-phonon wobbling band and chiral structures negative parity medium- and high-spin bands of ^{105}Pd have been studied via the ^{96}Zr(^{13}C,4n) reaction at incident energies of 51 and 58 MeV, using the Euroball IV γ-ray spectrometer coupled with the Diamant charged particle array. New bands have been observed and the previously reported bands have been extended to higher energies and spins. The obtained experimental results and their interpretation will be presented.

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P-12. Study of fusion and transfer reactions in ^{7}Li + ^{205}Tl system

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The complete fusion (CF), incomplete fusion (ICF), and neutron transfer (1n stripping, 2n stripping, and 1n pickup) cross sections for ^{7}Li + ^{205}Tl system were measured at energies around the coulomb barrier by online γ-ray detection technique. The experimental CF cross sections were found to be suppressed at above barrier energies compared to one dimensional barrier penetration model (1DBPM) as well as coupled channel calculations. The suppression observed in CF cross sections is found to be commensurate with the measured total ICF cross sections. Among ICF cross sections, t-capture is found to be dominant than α-capture at all the measured energies. Along with the present data, we have also considered the literature data with ^{7}Li projectile and a systematic of CF, ICF and TF is developed. Neutron transfer (1n stripping, 2n stripping, and 1n pickup) cross sections were also extracted from the data and compared with Coupled reaction channel (CRC) calculations. The cumulative sum of all measured observables CF, ICF, and one neutron transfer cross sections were found to match with the estimated reaction cross sections. Available data on neutron transfer with ^{7}Li projectile was also compared and an approximate universal trend of cross section was observed. Details of the measurement and results will be discussed in the conference.

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P-13. Ancillary detectors for the EAGLE array - new opportunities to study nuclear structure at HIL UW

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In-beam nuclear spectroscopy based on fusion evaporation reactions with light and heavy ions has been one of the major tools in nuclear structure research and is one of the richest resources of various data for nuclear structure investigations. At bombarding energies not too high above the Coulomb barrier, the fusion evaporation reactions are usually dominant, with a cross-section of about 0.1 - 1 barn. To perform detailed spectroscopic studies, it is necessary to make an identification and selection of γ-rays from the desired, often rarely occurring evaporation residues. Due to that, we have constructed the Recoil Filter Detector (RFD), which measures evaporation residues in coincidence with γ-rays detected in a germanium array, for details see [1]. The previous RFD campaigns at EUROBALL IV in Strasbourg and at GASP in LNL Legnaro demonstrated that the RFD in conjunction with those Ge-arrays was a powerful tool for spectroscopic studies both in light and heavy nuclei regions [1–5].
Thanks to European cooperation GAMMAPOOL, the HPGe gamma-ray detectors forming the EAGLE array [6] are available in Poland at HIL UW. Coupling the RFD with the EAGLE array on the Warsaw cyclotron U-200P beam-line at the HIL UW will open new possibilities for the laboratory, allowing for efficient in-beam spectroscopic investigations of nuclei in light, medium, and heavy mass regions. Furthermore, an additional advantage of the EAGLE+RFD setup is the possibility of coupling to other ancillary particle detectors such as NEDA [7-9] and DIAMANT [10-11] or the high energy γ-ray calorimeter PARIS [12].
In this contribution, we will present the scientific objectives of this experimental setup, possibilities to perform the experiments and prospects for new and innovative measurements using RFD coupled to the EAGLE spectrometer.

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P-14. Generator coordinate method with basis optimization

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The generator coordinate method (GCM) has been a well-known method to describe nuclear collective motions [1]. In GCM, one *a priori* specifies collective degrees of freedom (collective coordinates), such as nuclear deformations, and superposes many Slater determinants (SDs) within the selected collective subspace. However, there always exists arbitrariness in this approach in the choice of collective coordinates, for which one has to rely on empirical and phenomenological assumption. With such choice, it is not trivial whether the collective motion of interest can be optimally described (See e.g., [2-3]). Therefore, a description of the collective motion without pre-set collective coordinates is desirable in order not to miss important degrees of freedom.

In this contribution, we present a new extension of GCM in which both the basis SDs and the weight functions are optimized according to the variational principle [4]. With such simultaneous optimization of the basis states, one does not have to specify beforehand the relevant collective degrees of freedom covered by the set of basis SDs. In this presentation, we will show results for sd-shell nuclei with the Skyrme energy functional. We will show that the optimized bases correspond to excited states along a collective path, unlike the conventional GCM which superposes only the local ground states. This implies that a collective coordinate for large amplitude collective motions is determined in a much more complex way than what has been assumed so far.

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P-15. Investigation of ^{182}Pt via EC/β^+ decay of ^{182}Au

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Neutron-deficient nuclei in the lead region are excellent subjects for studying various interesting phenomena of nuclear structure and radioactive decay. One of them is the shape coexistence [1] which is well established for example in even-even mercury and platinum nuclei. This phenomenon occurs when two or more different types of deformation coexist at low excitation energy within the same nucleus. Exotic nuclei in this region have been extensively studied using various experimental techniques, including β-delayed γ-ray spectroscopy, which allows us to identify and study levels in the daughter nucleus up to relatively high excitation energy. Since β decay is sensitive to the change of nuclear structure between the mother nucleus and the populated state, this method can be used to determine properties of excited levels, such as nuclear spin.

In this contribution, we will report on the investigation of excited levels in ^{182}Pt, which is one of the nuclei from this part of the nuclear chart. The experiment was performed at the ISOLDE facility at CERN [2], where the states in ^{182}Pt were populated in the EC/β^+ decay of ^{182}Au. This isotope was produced in a proton-induced spallation of a thick uranium target. Gold atoms were selectively ionised using laser ionisation by RILIS [3] and mass separated to obtain a high-purity ^{182}Au ion beam. The measurement of its β decay was performed at the ISOLDE Decay Station (IDS) [4] with four HPGe Clover detectors for γ- and X-ray and detection.

Collected statistics was over an order of magnitude higher compared to the previous study [5], which allowed us to significantly expand the information on excited levels in ^{182}Pt using the prompt γ-γ coincidence technique. We confirmed the previously known level scheme [5] and added over 220 new γ-ray transitions and about 80 new levels, expanding it up to $\sim$3.7 MeV in the excitation energy. Moreover, we evaluated the β-decay feeding intensities into levels in ^{182}Pt and calculated corresponding log ft values for the first time for this β decay. Out of all observed direct β-decay feeding, about 35% leads to newly observed states, which reduces the influence of the Pandemonium effect for our extended level scheme. The log ft values for 2^+ and 3^+ states show a good agreement with the allowed β decay of the 2^+ ground state in ^{182}Au [6]. Additionally, log ft values will be used to estimate the spin and parity of levels, for which they are not known.

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P-16. Simulations and first tests for the new gSPEC setup @GSI/FAIR

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The gSPEC project [1] aims at measuring nuclear g-factors of isomeric states in nuclei produced after fission and fragmentation reactions at the GSI/FAIR accelerator facility and may cover nuclei over the entire nuclear chart. The phase gSPEC-0 is already started. Its is composed of the state-of-the-art HPGe detectors (DEGAS or a new gDEGAS type) for gamma-ray spectroscopy, set of ancillary detectors, and an electromagnet, delivering a static magnetic field for the g-factor measurements.
Monte-Carlo simulations of the entire setup are conducted using the Geant4 framework [2] for the setup preparation and tests. Details as the efficiency and feasibility of various DEGAS detector configurations for gSPEC-0 are thoroughly studied [3]. The simulation covers different aspects of the g-factor measurements for the different gSPEC configurations. These can be compared to first in beam tests to be conducted in 2024 at GSI, offering the possibility of testing detectors and their associated electronics under real experimental conditions. The presentation will focus on first results from these studies.

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P-17. Role of breakup-fusion of ^{9}Be in populating ^{95,96}Tc: The medically relevant radionuclides

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In addition to complete fusion (CF) of weakly bound heavy ions at low energies, incomplete fusion (ICF) may also occur, in which the projectile breaks apart and partially fuses with the target nucleus [1, 2]. Other direct reaction processes, such as the transfer of particles or a cluster, the collective excitation of the projectile and/or the target, etc., may also compete with and impact the fusion process. ^{9}Be is a weakly bound nucleus and may break up via different channels, viz. n + α + α (E$_{BU}$ = 1.57 MeV) or n + ^{8}Be (E$_{BU}$ = 1.67 MeV) or α + ^{5}He (E$_{BU}$ = 2.31 MeV). In order to understand the fusion dynamics of ^{9}Be, the ^{93}Nb targets of thickness (1.4 - 2.1 mg/cm^{2}) backed by Al foils (1.5 - 1.9 mg/cm^{2} thickness) were arranged in a stack and bombarded with ^{9}Be beam. The cross sections of the populated residues have been measured using the γ-spectrometry method. The measured cross sections of ^{99m}Rh produced through the $3n$ channel have been compared with the theoretical estimations from EMPIRE3.2.3 utilizing three different level density models: Gilbert-Cameron Model (GCM), Generalized Superfluid Model (GSM), and Enhanced Generalized Superfluid Model (EGSM). EMPIRE is based on the Hauser-Feshbach formalism for compound emission and the Exciton model for pre-compound emission. The EMPIRE calculations employing the GC level density model reproduced the data quite accurately for ^{99m}Rh, 3n channel residue. Therefore, EMPIRE(GC) was chosen for the analysis in other channels. An enhancement in the measured cross sections of αxn emission channels $(\Sigma\sigma_{\alpha xn})$ is observed compared to the theoretically calculated CF cross sections. It could be due to the possible contribution of ICF in producing ^{95}Tc and ^{96}Tc above CF through $\alpha 3n$ and $\alpha 2n$ channels, respectively.

It has been claimed that ^{95g}Tc and ^{96g}Tc could replace the popular medical radioisotope ^{99m}Tc, even though the γ-ray intensities and decay rates of ^{96g}Tc and ^{95g}Tc are lower than those of ^{99m}Tc [3]. In this work, we have also investigated the production yields of ^{95g}Tc and ^{96g}Tc within 21-46 MeV energy and the time evolution of yield compared to other concurrently produced nuclei, details of which will be discussed during the conference.

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P-18. Study of quasi-projectile properties at Fermi energies in ^{48}Ca projectile systems

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The emission of the pre-equilibrium particles during nuclear collisions at moderate beam energies is still an open question. This influences the properties of the compound nucleus but also changes the interpretation of the quasi-fission process.
A systematic analysis of the data obtained by the FAZIA collaboration [1] during a recent experiment with a neutron rich projectile is presented. The full range of charged particles detected in the experiment is within the limit of isotopic resolution of the FAZIA detector. Quasi-projectile (QP) fragments were detected in majority thanks to the forward angular acceptance of the experimental setup which was confirmed by introducing cuts based on the HIPSE event generator calculations.
The main goal was to compare the experimental results with the HIPSE simulations after introducing these cuts to investigate the influence of the n-rich entrance channel on the QP fragment properties. More specifically, the lowering of N/Z of QP fragments with beam energy was found to be present since the initial phase of the reaction. Thus, pre-equilibrium emissions might be a possible candidate to explain such an effect [2].
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P-19. Beam position monitoring system at HIL based on SiC detectors

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Fusion excitation function measurements require well defined and stable experimental geometry. It includes the beam position on the target changing during the beam energy adjustments. In fusion reactions, the angular distribution of the fusion products is centered around the beam axis at a very narrow angle [1]. To minimize the instabilities during our measurements at the Heavy Ion Laboratory (HIL), a system that enables the online monitoring of beam position at the target has been developed. The array consists of four Silicon Carbide (SiC) detectors placed at small forward angles downstream of the target. These SiC counters detect the elastically scattered projectiles (Rutherford scattering).
The radiation damage of the Si detector placed at a small angle is substantial, so we decided to use Silicon Carbide (SiC) detectors, owing to their extraordinary hardness to radiation damage [2, 3]. The detector support allows the monitors to be set at angles in the range of 8 - 15 degrees and the distance to the target from 10 to 15 cm. At this geometry, we are sensitive to $\sim$ 0.1 degree of beam position changes. This beam monitoring system has been successfully tested at HIL [4, 5] in experiments aimed at verifying the device's ability to precisely determine even small displacements in the beam position.
More details about the setup and the results of the test experiments will be presented in this contribution.

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P-20. Shell model based description of band-like structures in ^{63,65,67}Zn

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Various nuclear structure phenomena, such as magnetic rotational bands, super-deformed bands, band termination, and the evolution of shape and collectivity, have been observed in different isotopes of Ni [1], Zn [2], Ga [3] and Ge [4] in the vicinity of $A \approx 60$. This region corresponds to nuclei where the number of protons and neutrons is slightly above that of the closed shell (*N* = *Z* = 28) ^{56}Ni isotope. Here, the $1f_{5/2}$, $2p_{3/2}$ and $2p_{1/2}$ orbitals primarily contribute to the single-particle structure at low spin, while collectivity at intermediate and high spin emerges due to the involvement of the intruder $1g_{9/2}$ orbital. The energy systematics of the various states forming band-like structures in odd ^{63,65,67}Zn indicate a potential decrease in excitation energy as the number of neutrons increases. This might be attributed to an increase in paired neutrons with an increase in *A*. Theoretical calculations for positive-parity and positive-signature bands suggest a change in the shape from oblate to prolate (with considerable deformation, $\beta_2 \approx 0.2$) for ^{63,65}Zn from low to high rotational frequency. The observed decay scheme at intermediate and high spin suggests a competition between single-particle and collective modes of excitation [2]. However, the lack of lifetime data makes it more difficult to conclude about the nature adequately without ambiguity. Therefore, information regarding the B(E2) values is very crucial for understanding the intermediate and high spin yrast, as well as non-yrast band-like structures in the odd Zn isotopes. In this context, the shell-model, within an appropriate model space, proves effective in yielding promising outcomes. With the aid of model-based calculations, it is intriguing to delve into the precise structure of these isotopes in order to comprehend the microscopic structure and observe the effects of various orbitals on the structure.
Shell model calculations have been performed using *KSHELL* code [5] in $f_{5/2}pg_{9/2}$ model space, employing two different interactions, viz., *jun45pn* [6] and *jj44bpn* [7]. These calculations aim to investigate the observed band-like structures in the odd ^{63,65,67}Zn isotopes. Calculated energy values of the excited states are compared with the experimental data, showing good agreement at low and intermediate excitation energies. The probability of occupation for valence protons and neutrons has been computed within the *fpg* model space. Regarding the origin of angular momentum for individual states, detailed configurations have been calculated using both the interactions, and a comprehensive discussion on the findings will be presented. Furthermore, B(E2) values are calculated for different band-like structures, revealing a decrease in collectivity with increasing angular momentum, based on calculations with both the interactions.

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P-21. Thermonuclear reaction rate of $^{57}\mathrm{Cu}(p,\gamma)^{58}\mathrm{Zn}$ in rp-process

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The thermonuclear reaction rate of $^{57}\mathrm{Cu}(p,\gamma)^{58}\mathrm{Zn}$, which depends exponentially on the neutron-deficient nuclide ^{58}Zn mass, is of great importance to understand how the rp-process proceed beyond the ^{56}Ni waiting point in type-I X-ray bursts. So far the uncertainty of $^{57}\mathrm{Cu}(p,\gamma)^{58}\mathrm{Zn}$ reaction rate is dominated by the 50 keV uncertainty of the proton separation energy (S_p) of ^{58}Zn [1,2] propagated from its mass [3], which was determined indirectly by measuring the Q value of a double charge-exchange reaction ^{58}Ni$(\pi^+,\pi^-)^{58}$Zn nearly 40 years ago [4]. Recently, We directly measured the mass of ^{58}Zn by using $B\rho$-defined isochronous mass spectrometry [5], resulting in a more precise proton separation energy of $S_p(^{58}\mathrm{Zn}) = 2227(36)$ keV. With this new S_p value, the thermonuclear rate of the $^{57}\mathrm{Cu}(p,\gamma)^{58}\mathrm{Zn}$ reaction has been reevaluated to be higher than the most recently published rate [2] by a factor of up to 3 in the temperature range of 0.2 GK $\lesssim T \lesssim$ 1.5 GK. The new rate is used to investigate its astrophysical impact via one-zone post-processing type-I X-ray burst calculations. It shows that the updated rate and new $S_p(^{58}\mathrm{Zn})$ value result in noticeable abundance variations for nuclei with $A = 56$-59 and a reduction in $A = 57$ abundance by up to 20.7$\%$, compared with the results using the recently published rate.

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