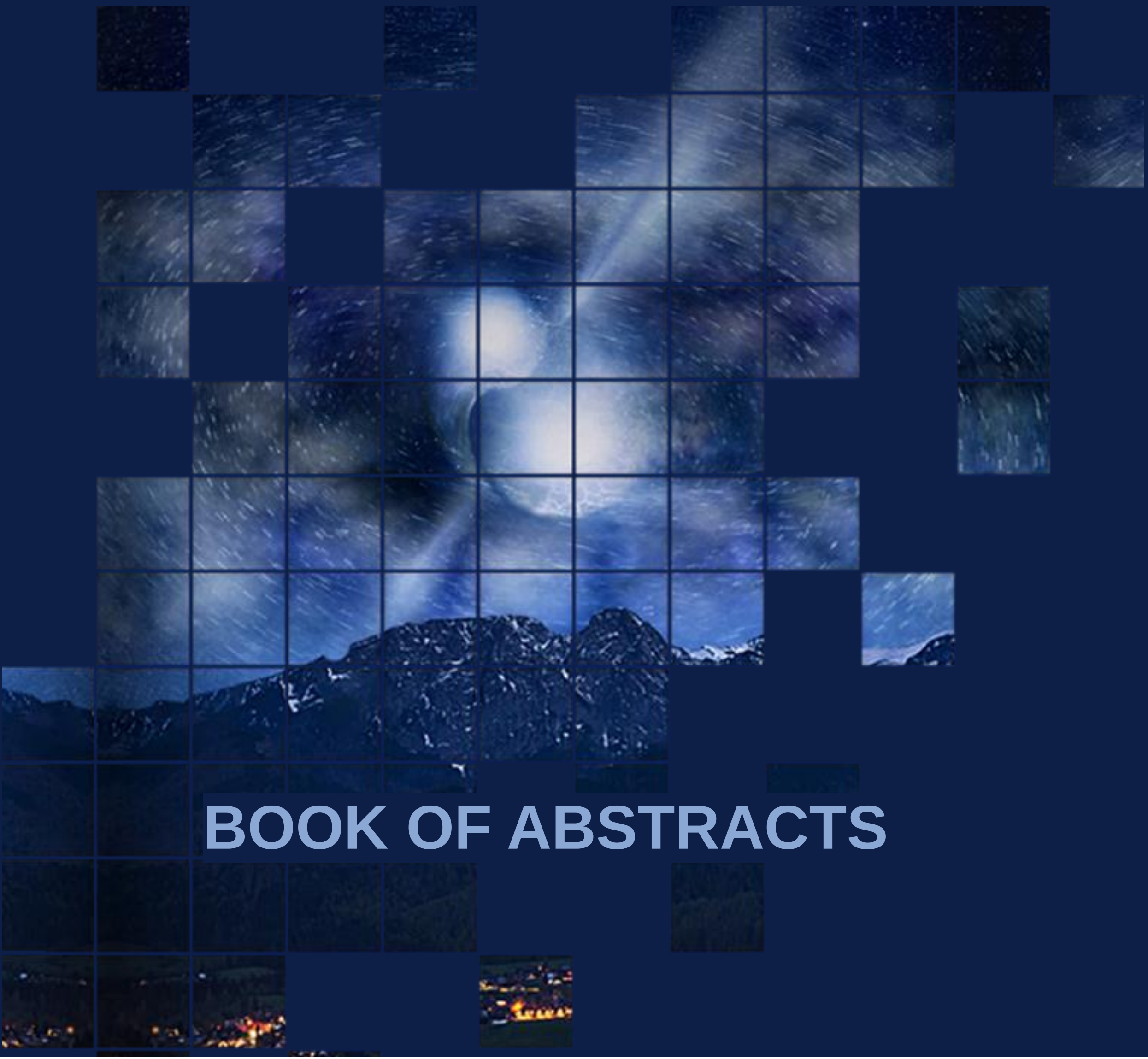
ZAKOPANE 2022
CONFERENCE
ON NUCLEAR PHYSICS

“Extremes of the Nuclear Landscape”

August 28th – September 4th, 2022, Zakopane, Poland



BOOK OF ABSTRACTS

ZAKOPANE CONFERENCE ON NUCLEAR PHYSICS 2022

"Extremes of the Nuclear Landscape"
August 28th - September 4th, 2022
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 a 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 low-energy nuclear physics.

During the construction of the scientific program special attention has always been paid to offering enthusiastic and pedagogical overviews of the most recent research subjects in nuclear physics from both theoretical and experimental points of view. Young participants have also the opportunity to present the 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 special attention will be given to the structure of exotic, unstable nuclei. We will also focus on collective excitations of 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 on the 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 conference 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 55th edition of the Zakopane Conference on Nuclear Physics is organized by IFJ PAN in cooperation with Coti Conference Time and is supported by NuPECC, CAEN, NAWA (The Polish National Agency For Academic Exchange).

BOOK OF ABSTRACTS

Editors:

Piotr Bednarczyk

Maria Kmiecik

Magdalena Matejska-Minda

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CAEN educational kit presentation
&
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08:30 – 13:15

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14:00 – 18:00	**Hiking trip**
18:00 – 19:00	**Dinner**

19:00 – 19:30	IT	**Fedir Ivanyuk** Institute for Nuclear Research, Kyiv; **Krzysztof Pomorski** Maria Curie Skłodowska University, Lublin	The fission observables of heavy and super-heavy nuclei
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20:30 – 21:00	IT	**Giacomo De Angelis** INFN Laboratori Nazionali di Legnaro	Shell Structure of the very n-rich Ni isotopes and the REMO project
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09:00 – 09:30	IT	**Marek Płoszajczak** GANIL, Caen	Nuclear physics at the edge of stability
09:30 – 10:00	IT	**Gaute Hagen** Oak Ridge National Laboratory	Recent progress in *ab-initio* computations of nuclei
10:00 – 10:30	IT	**Jacek Golak** Jagiellonian University	Few-nucleon Ssystems for nuclear physics
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19:00 – 23:00	**Regional Dinner**		

Friday, 2^{nd} of September

NUSTAR and APPA at FAIR Workshop
08:30 – 13:15

08:30 – 09:00	IT	**Paolo Giubellino** FAIR/GSI, Darmstadt	FAIR, the Universe in the Lab
09:00 – 09:30	IT	**Giovanna Benzoni** INFN Section of Milan	Recent results from the DESPEC campaign at GSI
09:30 – 10:00	IT	**Thomas Stöhlker** Helmholtz-Institut Jena	Physics program of the SPARC collaboration at FAIR: quantum dynamics in extreme electromagnetic fields
10:00 – 10:30	IT	**Yury Litvinov** GSI, Darmstadt	Precision experiments with heavy-ion storage rings
10:30 – 11:00	**Coffee Break**		
11:00 – 11:30	IT	**Yoshiki Tanaka** RIKEN Cluster for Pioneering Research	WASA-FRS experiments in FAIR Phase-0 at GSI
11:30 – 12:00	IT	**Haik Simon** GSI, Darmstadt	Experiments: from ALADIN-LAND to R^3B at GSI and FAIR
12:00 – 12:15	S	**Jianwei Zhao** GSI, Darmstadt	Studies of exotic nuclei with the FRS Ion Catcher at GSI
12:15 – 12:30	S	**Jose Luis Rodríguez-Sánchez** Universidad de Santiago de Compostela	Nuclear fission studies in inverse kinematics with the R^3B setup at the GSI-FAIR facility
12:30 – 12:45	S	**Marta Polettini** University of Milan	Search for octupole deformation in A$\sim$225 Po-Fr nuclei
12:45 – 13:00	S	**Aleksandrina Yaneva** GSI, Darmstadt	Lifetime measurement below the 14^+ isomer in ^{94}Pd
13:00 – 13:15	S	**Victor Guadilla** University of Warsaw	Results of DTAS campaign at IGISOL: overview

14:00 – 18:00	**Hiking trip**
18:00 – 19:00	**Dinner**

Parallel Sesion C
19:00 – 20:45

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19:30 – 19:45	S	**Ishtiaq Ahmed** IUAC, New Delhi	Probing quadrupole collectivity in N=38 ^{68}Zn isotope
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20:00 – 20:15	S	**Alejandro Ortiz-Cortes** GANIL, Caen	Collinear laser spectroscopy on the palladium isotopic chain
20:15 – 20:30	S	**Bram van den Borne** KU Leuven	Approaching N=82 through silver using laser spectroscopy
20:30 – 20:45	S	**Michail Athanasakis-Kaklamanakis** CERN, Geneva	Nuclear-structure studies with laser spectroscopy of radioactive molecules

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19:45 – 20:00	S	**Nikola Vukman** Ruđer Bošković Institute, Zagreb	Helium clustering in neutron-rich Be isotopes
20:00 – 20:15	S	**Irene Dedes** IFJ PAN, Kraków	Unprecedented geometrical shapes in the range of nuclei with $Z \approx N \sim 40$

20:15 – 20:30	S	**Monika Piersa-Siłkowska** CERN, Geneva	First β-decay spectroscopy of ^{135}In and new β-decay branches of ^{134}In
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09:00 – 09:30	IT	**Jose Javier Valiente-Dobón** INFN Laboratori Nazionali di Legnaro	The gamma-ray tracking array AGATA at LNL
09:30 – 10:00	IT	**Herve Savajols** GANIL, Caen	The Super Separator Spectrometer (S^3) for the very high intensity beams of SPIRAL2
10:00 – 10:30	IT	**Jonathan Wilson** IJC Lab, Orsay	Gamma-ray spectroscopy of nuclear fission
10:30 – 10:45	S	**Grzegorz Jaworski** Heavy Ion Laboratory, University of Warsaw	NEEDLE — fast neutron detection in the service of the gamma spectroscopy of neutron-deficient nuclei at HIL
10:45 – 11:15	**Coffee Break**		
11:15 – 11:45	IT	**Marek Pfützner** University of Warsaw	Exotic decays with emission of charged particles
11:45 – 12:00	S	**Konrad Czerski** University of Szczecin	Branching ratio of the deuteron-deuteron threshold resonance in ^{4}He
12:00 – 12:15	S	**Martin Venhart** Institute of Physics, SAS, Bratislava	Nuclear structure of ^{181,183}Au isotopes studied via β^+/EC decays of ^{181,183}Hg at ISOLDE
12:15 – 12:30	IT	**Krzysztof Rykaczewski** Oak Ridge National Laboratory	Beta-decay studies with the Modular Total Absorption Spectrometer

Closing Lecture

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13:15 – 13:30	**Closing**		
14:00 – 19:00	**Hiking trip**		
19:00	**Conference BANQUET**		

Sunday, 4th of September

7:30	**Breakfast**
9:00 – 10:00	**Departure to Kraków**

Abstracts of talks

Sunday

August 28th

Keynote Talk

Excitement and Challenges in Low-Energy Nuclear Physics

Witold Nazarewicz[1,2]

Invited talk

[1] Department of Physics and Astronomy and FRIB Laboratory, Michigan State University, East Lansing, Michigan 48824, USA
[2] Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warszawa, Poland

Understanding atomic nuclei is a quantum many-body problem of incredible richness and diversity and studies of nuclei address some of the great challenges that are common throughout modern science. Powerful nuclear facilities provide access to entirely new phenomena at different resolution scales. The microscopic nuclear theory has completely transformed our view of the nucleus and nuclear matter. In this talk, advances in low-energy nuclear physics will be reviewed in the context of the overarching scientific questions and opportunities.

Monday

August 29th

Prevailing Triaxiality in Nuclear Shapes

Takaharu Otsuka[1,2,3]

Invited talk

[1] University of Tokyo, Hongo, Tokyo, Japan
[2] RIKEN Nishina Center, Wako, Saitama, Japan
[3] Japan Atomic Energy Agency, Tokai, Ibaraki, Japan

It has been widely believed that the dominant majority of heavy deformed nuclei have axially-symmetric prolate ground states and gamma-vibrational second 2^+ states [1]. Namely, the prolate equilibrium is the decisive underlying mechanism, and oscillations on top of it give low-lying excitations. This is certainly what was stressed by Aage Bohr [2] in addition to the more general ellipsoidal deformation picture proposed also with Rainwater and Mottelson. Experimental data have been consistent with this picture, and the pairing + quadrupole-quadrupole (P+QQ) models supported it. However, the observed so-called double gamma-phonon states cast a clear challenge to it. Recently, the Monte Carlo Shell Model (MCSM) calculations with realistic nucleon-nucleon (NN) interactions showed that this hypothesis should be re-considered [3]: low-lying eigenstates (yrast, yrare and so-called double-gamma bands) are shown to be triaxially deformed in many nuclei, including ^{166}Er, a typical example suggested by A. Bohr. The MCSM calculations depict that the triaxial deformation is not rigid, and a certain fluctuation of the gamma value is observed. The fluctuation pattern is, however, very similar in the T-plot of the MCSM, in those states. The self-organization mechanism materialized by the monopole and quadrupole interactions of the NN interaction moves down triaxial states below prolate states in many nuclei [3,4]. The picture of Davydov [5,6] then appears to be relevant. Although the structure obtained by the MCSM is not really like the rigid triaxiality, some features of the Davydov model appear especially in the relations among physical quantities. I would like to mention that Davydov, a Ukrainian physicist, can/should be appreciated to a greater extent than in the past, because of his contribution to the fundamental understanding of atomic nuclei, unveiled now.

References

[1] A. Bohr and B. R. Mottelson, *Nuclear Structure* (Benjamin, New York, 1975), Vol. II.
[2] A. Bohr, in *Nobel Lectures, Physics 1971-1980*, edited by S. Lundqvist (World Scientific, Singapore, 1992); https://www.nobelprize.org/prizes/physics/1975/bohr/facts/.
[3] T. Otsuka *et al.*, Phys. Rev. Lett. **123** (2019) 222502, https://doi.org/10.1103/PhysRevLett.123.222502.
[4] T. Otsuka, Physics **4** (2022) 258, https://doi.org/10.3390/physics4010018. (Open access).
[5] A. S. Davydov and G. F. Filippov, Nucl. Phys. **8** (1958) 237; A. S. Davydov and V. S. Rostovsky, Nucl. Phys. **12** (1959) 58.
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Systematics of Band Termination at High-Spin in N$\sim$90 Nuclei

M. A. Riley[1], J. Simpson[2], E. S. Paul[3], J.S. Baron[1], D. J. Hartley[7], R. V. F. Janssens[4], X. Wang[1], A. D. Ayangeakaa[5], H. C. Boston[3], M. P. Carpenter[4], C. J. Chiara[4,6], U. Garg[5], , D. Judson[3], F. G. Kondev[8], T. Lauritsen[4], J. Matta[5], S. L. Miller[1], P. J. Nolan[3], J. Ollier[2], M. Petri[9], J. P. Revill[3], L. L. Riedinger[10], S. V. Rigby[3], C. Unsworth[3], K. Villafana[1], S. Zhu[4], and I. Ragnarsson[11]

Invited talk

[1] Department of Physics, Florida State University, Tallahassee, FL 32306, U.S.A.
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[3] Department of Physics, University of Liverpool, Liverpool, L69 7ZE, U.K.
[4] Physics Division, Argonne National Laboratory, Argonne, IL 60439, U.S.A.
[5] Physics Department, University of Notre Dame, Notre Dame, IN 46556, U.S.A.
[6] Dept. of Chemistry and Biochem., Univ. of Maryland, College Park, MD 20742, U.S.A.
[7] Department of Physics, United States Naval Academy, Annapolis, MD 21402, U.S.A.
[8] Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL 60439, U.S.A.
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[11] Div. of Mathematical Physics, LTH, Lund Univ., P.O. Box 118, S-221 00 Lund, Sweden

The light rare-earth nuclei near N = 90, are textbook examples of the evolution of nuclear structure with excitation energy and angular momentum. They display a variety of different phenomena, such as, multiple neutron and proton backbends, dramatic prolate to oblate shape changes associated with band termination plus a return to collective rotation at the highest spins which is most likely associated with highly deformed triaxial shapes, extending discrete gamma-ray spectroscopy above spin 60.

Band termination represents a clear manifestation of mesoscopic physics, since the underlying finite-particle basis of the nuclear angular momentum generation is revealed. Interesting features from the extensive systematics of the favored fully aligned band termination states in N = 90 and neighbouring nuclei will be discussed. The latter provide stringent tests of nuclear models since the wavefunctions for these special states are extremely pure.

Chirality, wobbling and oblate rotation

C. M. Petrache[1]

Invited talk

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The breaking of symmetries in quantum systems is one of the key issues in nuclear physics. In particular, the spontaneous symmetry breaking in rotating nuclei leads to exotic collective modes, like the chiral and wobbling motions, which have been intensively studied in recent years. Chiral bands in even-even nuclei, with complex configurations of at least four quasiparticles, which were thought to be unfavored energetically, unstable against 3D rotation and difficult to observe, have been instead identified at medium spins in ^{136}Nd. Multiple chiral bands in the neighboring odd-even Cs, Ba, Ce and Nd nuclei have been also identified, in the case of ^{131}Ba in the presence of octupole correlations, while in the case of ^{119}Cs involving only protons angular angular momentum revolving in 3D over the observed spin range. These new experimental results triggered many theoretical developments and extensions of the previous models, which are now able to describe complex band structures resulting from chirality-parity violation in triaxial nuclei with reflection asymmetry. The latest experimental results and theoretical developments will be emphasized.

The wobbling motion was also intensively studied in the last few years, mainly due to the introduction of the transverse wobbling concept, which enriched the diversity of collective modes exhibited by triaxial nuclei. Many experimental and theoretical groups intensively studied the low-spin wobbling in odd-even nuclei and medium-spin wobbling in even-even nuclei. While the experimental evidence and theoretical interpretation in terms of transverse or longitudinal wobbling of the low-spin non-yrast bands is seriously questioned in recent works, the transverse wobbling in two-quasiparticle bands observed at medium spin in even-even nuclei seems to be confirmed both experimentally and theoretically. Bands built on two-quasiparticle configurations interpreted as transverse wobbling have been recently identified first in ^{130}Ba, and shortly later in ^{136}Nd. Recent theoretical works revealed the inadequacy of the wobbling interpretation of these low-spin bands, which are naturally described by tilted precession (TiP).

Another topic of current interest is the existence of collective oblate shapes and their type of motion. Solid evidence of bands built on oblate shapes close to the ground state in ^{119}Cs, and at very high spin and temperature in ^{137}Nd has been recently published. The collective oblate band observed in ^{137}Nd up to 5 MeV above the yrast line offers the unique opportunity to investigate the decrease of decoherence with the increasingly dense background of quasiparticle excitations, while the strongly populated oblate band in ^{119}Cs offers the first example of prolate-oblate shape coexistence in the $A \approx 120$ mass region. These new experimental results and their interpretation will be discussed.

Reconciling collectivity, finite temperature and deformation in the relativistic nuclear field theory[*]

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Invited talk

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Challenges and recent progress of the nuclear many-body problem on the fermionic correlation functions (CFs) will be reviewed. Starting from the ab-initio Hamiltonian, a consistent equation of motion (EOM) framework is formulated for the low-rank CFs and adopted for nuclear applications by approximations with minimal truncations, which keep the leading effects of emergent collectivity. A mapping of the EOM formalism to the relativistic nuclear field theory (RNFT) allows for extending the RNFT to higher configuration complexity in a systematically improvable framework. The approach is implemented numerically for the nuclear response, on the basis of the relativistic effective meson-nucleon Lagrangian. The results obtained for medium-heavy nuclei show that the consistent inclusion of the emergent collective degrees of freedom refines the description of nuclear spectra, in both the high-energy and the low-energy sectors [1-3].

The approach confined by the leading ph$\otimes$phonon configurations beyond the standard random phase approximation has been extended to the case of finite temperature for both neutral and charge-exchange nuclear response [4-6]. The associated many-body correlations, which play a decisive role in the structural properties of atomic nuclei, are thus linked to the astrophysical processes occurring during star evolution. The r-process nucleosynthesis predominantly occurring in the neutron star mergers requires the precise knowledge of the radiative neutron capture and beta decay rates in neutron-rich nuclei, which can be extracted from the microscopic strength distributions in the neutral and charge-exchange, (p,n) Gamow-Teller and spin-dipole, channels [5]. The electron capture rates in the core collapse supernovae are related to the respective (n,p) spectra, which are also covered by the recent RNFT applications [6]. Perspectives of building a consistent nuclear many-body framework for generating astrophysical input will be outlined. The recent theoretical effort in reconciling superfluidity and deformation [7] will be introduced. The approach [1] is extended to superfluid systems with the quasiparticle-vibration coupling (QVC) unifying both the normal and pairing phonons. The QVC vertices are related to the variations of the Hamiltonian of the Bogoliubov quasiparticles, which can be obtained by the finite amplitude method. First beyond-mean-field QVC applications to axially deformed nuclei will be presented and discussed.

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Nuclear equation of state from nuclear collective excited state properties

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Invited talk

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This contribution reviews a selection of available constraints to the nuclear equation of state (EoS) around saturation density from nuclear structure calculations on collective excited state properties of atomic nuclei [1]. It concentrates on predictions based on self-consistent mean-field calculations, which can be considered as an approximate realization of an exact energy density functional (EDF). EDFs are derived from effective interactions commonly fitted to nuclear masses, charge radii and, in many cases, also to pseudo-data such as nuclear matter properties. Although in a model dependent way, EDFs constitute nowadays a unique tool to reliably and consistently access bulk ground state and collective excited state properties of atomic nuclei along the nuclear chart as well as the EoS. The impact on the EoS of the new CREx [2] and PREx [3] measurments of the parity violating asymmetry (ground state observable) in ^{48}Ca and ^{208}Pb, respectively, will be also discussed [4,5] and compared to previously presented results on collective excitations.
As the main conclusion, the isospin dependence of the nuclear EoS around saturation density and, to a lesser extent, the nuclear matter incompressibility remain to be accurately determined. Experimental and theoretical efforts in finding and measuring observables specially sensitive to the EoS properties are of paramount importance, not only for low-energy nuclear physics but also for nuclear astrophysics applications.

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Isoscalar Giant Resonances – experiments with radioactive beams and storage rings

Invited talk

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The study of isoscalar giant resonances and, in particular, the Isoscalar Giant Monopole (ISGMR) and Dipole (ISGDR) Resonances, has been pursued for several decades at a number of facilities worldwide. Since the discovery of the ISGMR in 1977 [1], many experiments were performed with inelastic scattering of isoscalar probes making use of magnetic spectrometers in order to measure at very forward angles where angular distributions of different multipolarities are quite distinct. Much has been learned from these experiments about the properties of the giant resonances, their microscopic structure as well as the incompressibility term of the Equation of State (EoS) of nuclear matter. With the advent of radioactive ion-beam facilities, prospects for giant resonance studies in exotic nuclei become rich and promising. Recently, the isoscalar giant resonances were studied in inelastic scattering off deuterium and helium targets in inverse-kinematics using two techniques: the active-target method [2-4] and storage-ring method [5]. This included investigation of the isoscalar giant quadrupole resonance (ISGQR) as well as the ISGMR and ISGDR, the so-called compression modes important for determining the key parameters of EOS of nuclear matter. The storage-ring method will be discussed and results for the only case studied until now will be presented. Future perspectives will be discussed.

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Nuclear Incompressibility: Does It Depend on Nuclear Structure?*

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Invited talk

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The nuclear incompressibility parameter has crucial bearing on diverse nuclear and astrophysical phenomena, including radii of neutron stars, and strength of supernova collapse.

The only direct experimental measurement of this quantity comes from the compression-mode giant resonances–the isoscalar giant monopole resonance (ISGMR) and the isoscalar giant dipole resonance (ISGDR). There have been some experimental results suggesting that nuclear structure effects may influence the energy of the isoscalar giant monopole resonance and, hence, the nuclear incompressibility. However, this being a bulk property of nuclear matter, one would generally expect no structure effects to play a role in it.

In this talk, I will review the current status of determination of nuclear incompressibility, and critically examine how, and if, nuclear structure effects play a role.

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Isospin Mixing in medium mass nuclei

Invited talk

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In this talk I will present the study of ”Isospin Mixing” in the mass region $60 < A < 80$ [1-3]. The measured values have been obtained using fusion-evaporation reactions and exploiting the selection rules for the emission of electric dipole radiation and the prediction reported in reference [4]. The measured data will be compared with the theory of reference [5]. It is important to stress that, using this technique, it is not possible to populate nuclei with N=Z with large mass of the compound nucleus using stable beams and targets. In addition, in the case of nuclei with mass number lower that 50, data based on an alternative and more precise techniques (using the super-allowed beta decay) are available. The Giant Dipole Resonance (GDR), where the maximum of electric dipole strength is concentrated, is the ideal probe for isospin mixing particularly with mass larger than 50. The GDR excitation state on a compound nucleus (CN) can be populated in a fusion-evaporation reaction. Using a combination of N=Z projectile and target it is possible to produce a CN in zero isospin channel. The electric dipole gamma decay from Isospin zero (I=0) to another Isospin zero state is forbidden and only the decay to states with isospin one is possible. The presence of isospin mixing, makes the initial state a superposition of I=0 and I=1 states and therefore the electric dipole gamma decay to I=0 states becomes possible. Therefore, the electric dipole of the GDR strength gives information on the value of the isospin mixing probability α^a. This quantity is expected to decrease, when the excitation energy increases, because the lifetime of the nucleus, becoming shorter as the excitation energy increases, limits the mixing and leads to an effective restoration of the isospin symmetry. In this talk I will present the measurement of isospin mixing in ^{80}Zr and ^{60}Zn and show some very preliminary data on the measurement of mixing in ^{72}Kr. In addition, as the value of the mixing enters as a correction of the first term of the CKM matrix, I will discuss, following the model of reference [6], how to deduce the values for δ_c . The latter parameter enters in the correction employed to evaluate the nuclear factor used to obtain the term of the CKM matrix dealing with the u and d quarks.

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The pre-equilibrium emission of light charged particles and the GDR strength functions

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Invited talk

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The heavy-ion collision is remarkable laboratory to investigate the interactions between nucleons but also conditions for various process such as fusion, fission, quasifission or particle and γ emission. Depending on the beam energy, impact parameter and few other parameters, the creation of the compound-like nucleus can be preceded by emission of the neutrons, protons or α. This action changes the temperature of produced nucleus, its angular momentum but also the mass and charge, which results totally different Giant Dipole Resonance strength function shape than expected.

The entrance channel physics is estimated by HIPSE model [1], which generates the set of nuclei, taking into account the distance between colliding nuclei and its parameters. This phenomenological approach produces not only compound-like nuclei but also the quasiprojectile and quasitarget events. The ensemble of hot collision products is de-exited by GEMINI++ statistical code. The final evaporation residues and fission fragments are accompanied by particle emitted before and after equilibration stage and the γ quanta. Apart of statistical photons, also the high energy γ are calculated, thus the GDR spectra are included. The reaction of ^{48}Ti(300, 600 MeV)+^{40}Ca [2,3] gives wonderful opportunity to investigate the dependence of the GDR shape on the pre-equilibrium emission.

Preliminary results [4] showed that this influence is quite substantial and further investigation concern the comparison with experimental spectra after application of experimental filter on theoretical data.

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Feeding of the isomers of different deformations via GDR gamma decay studied with nuBall + PARIS

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A study of the γ-decay of GDR formed in a hot ^{192}Pt compound nucleus was performed at IPN Orsay. The main goal of the experiment was to explore a link between characteristics of the compound and residual nuclei by investigating the GDR emission from the ^{192}Pt compound nucleus in its 4n decay channel leading to the ^{188}Pt residue. ^{188}Pt is a nucleus known for its ground state prolate shape and tri-axial band based on 12^+ state. The experimental method which can deliver information on feeding of states of different deformations was based on simultaneous measurement of GDR and low-energy γ rays.
The ^{192}Pt compound nuclei were created with fusion reaction using beam of ^{18}O at 90 MeV on ^{174}Yb target. The experimental set-up consisted of the PARIS + nuBall arrays. 32 PARIS detectors were employed to measure high-energy γ rays from the GDR decay, while low-energy discrete transitions were measured by 24 clover HPGe and 10 coaxial Ge detectors of nuBall. It is a very first experiment in which PARIS detectors were used for this type of measurement. To fully take advantage of these detectors, they were placed in a non-standard, wall geometry.
During the talk results of the data analysis will be shown, as well as plans for the PARIS + nuBall2 campaign. For the autumn 2022 there is being prepared experiment aiming to study the ^{80}Sr compound nucleus decay by measuring the gamma-ray emission from GDR, particularly the one which is associated with the 2p2n and α decay channel leading to ^{76}Kr evaporation residues. It was observed in the Kr isotopic chain coexistence of shapes built on the ground state band (prolate) and build on the excited states (oblate). By measuring high energy gamma rays in coincidence with low-spin discrete transitions of Kr residues, it will be possible to study the GDR built on states of certain deformation.

M4 resonances in light nuclei studied at CCB

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M4 resonances appear in light nuclei as high-lying excitations resulting from the $p_{3/2} \to d_{5/2}$ stretched transitions [1]. The structures of these stretched excitations are dominated by a single particle-hole component for which the excited particle (proton or neutron) and the residual hole couple to the maximal possible spin value available on their respective shells. Due to the expected low density of other one-particle-one-hole configurations of high angular momenta in the energy region where the stretched states appear, their configurations should be relatively simple. This feature makes them attractive as their theoretical analysis could provide clean information about the role of continuum couplings in stretched excitations. noindent The direct measurement of M4 states properties, poorly known thus far, should provide data which can be used as a very demanding test of state-of-the-art theory approaches, like for example, Gamow Shell Model [2] which is an adequate tool for the theoretical description of the stretched states. The stretched M4 resonances having high energies, relatively narrow widths, and possibly simple structure, thus provide an excellent testing ground for the GSM interaction. noindent The first experimental studies aiming at tracing the decay of the M4 stretched resonance in ^{13}C, located at 21.47 MeV, have been recently undertaken at the Cyclotron Centre Bronowice at IFJ PAN in Krakow. The data were obtained by measuring inelastically scattered protons (which excite the resonance) in coincidence with charged particles, from the resonance decay, and γ rays from daughter nuclei. The detection setup consisted of: i) the KRATTA telescope array for detection of scattered protons, ii) two clusters of the PARIS scintillator array and an array of four LaBr$_3$ detectors for gamma-ray measurement, and iii) a thick position-sensitive Si detector for light charged particles detection. In particular, the emitted γ rays give a precise knowledge of the feeding to specific states in daughter nuclei, even in the case of neutron decay from the resonance state. Thus, first experimental information on the proton and neutron decay channels of the 21.47-MeV resonance in ^{13}C, to ^{12}B and ^{12}C daughter nuclei, respectively, could be obtained. noindent The experimental results on the decay of the 21.47-MeV stretched state in ^{13}C were then compared with the theoretical calculations based on the Gamow Shell Model approach, in terms of energy, width, and in particular, the decay pattern.

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The systematic study of Pygmy Dipole States in ^{40,44,48}Ca induced in the (p, p'γ) reaction[*]

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The calcium nuclei form a unique isotopic chain. Calcium is the only element with two stable doubly-magic isotopes and the masses of stable isotopes spread over a wide range of N/Z ratios. The second feature is especially interesting for studies of the Pygmy Dipole Resonance (PDR). This additional E1 strength in the region of the neutron separation energy (S_n) has been shown to increase with the N/Z ratio, but its nature is a subject of discussion [1,2].
The recent progress in nuclear physics theory enabled *ab-initio* calculations in the medium-mass region [3], making calcium isotopes a perfect case to examine the states forming the PDR.nIn a series of experiments at the Institute for Nuclear Physics, University of Cologne, the isotopes ^{40}Ca, ^{44}Ca and ^{48}Ca were studied in the (p,p$'\gamma$) reaction at E_p = 12 and 15 MeV. Employment of the SONIC@HORUS set-up [4] allowed a high-precision measurement of the excitations near S_n.
In the talk, the experimental set-up and the analysis process will be briefly described. The obtained relative excitation cross-sections close to S_n will be shown and compared with other experiments. The attempt to assign spins of observed states based on the recorded p-γ angular correlations will also be discussed.

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Investigation of low-lying dipole excitations with real photon-scattering experiments*

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Real photon-scattering experiments are a very powerful tool for studying dipole excited states in atomic nuclei due to the low momentum transfer of the photons [1]. Because of this selectivity, they are a commonly-used probe to study the so-called Pygmy Dipole Resonance (PDR) in Nuclear Resonance Fluorescence (NRF) experiments. The PDR denotes the occurrence of an accumulation of electric dipole strength around and below the particle separation threshold.
nAlthough it exhausts only a few percent of the energy weighted sum rule it may have some influence on the reaction rates in nucleosynthesis processes, e.g., the rapid neutron-capture cross section [2,3], and could be important to constrain the nuclear equation of state [4]. Hence, the PDR has been a research topic of great interest in the last decades [5,6].
nPhotoabsorption cross sections as well as spin and parity quantum numbers of the excited states can be determined in a model-independent way via real photon-scattering experiments. The basic principles and first results of the analysis procedures of complementary (γ,γ') experiments performed with an energetically continuous bremsstrahlung beam at γELBE [7] and with quasi-monoenergetic γ rays at HIγS [8] will be presented using the example of ^{144}Nd.

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Evolution of the Pygmy Dipole Resonance in Sn Isotopes[*]

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The electric dipole response of neutron-rich nuclei below the neutron threshold often reveals the presence of the pygmy dipole resonance (PDR), superimposed on the low-energy tail of the giant dipole resonance (GDR). As the PDR is usually interpreted in relation to the neutron excess, a multifaceted experimental and theoretical study of this feature may have a significant impact on studying both the nuclear structure properties in general and the astrophysical r- and s-processes of element production.

This work presents a systematic study of the dipole γ-ray strength functions (GSF) below the neutron threshold in eleven Sn isotopes ($^{111-113}$Sn,$^{116-122}$Sn and ^{124}Sn) with a primary goal of investigating the evolution of the pygmy dipole strength with an increasing neutron number in the Sn isotopic chain. The experimental GSFs have been extracted from the particle$-\gamma$ coincidence data by applying the Oslo method [1], primarily used for the simultaneous extraction of statistical properties of nuclei, such as the GSF and nuclear level density. The most recent $(p, p'\gamma)$ experiments on ^{117,119,120,124}Sn have been performed at the Oslo Cyclotron Laboratory with a new array of 30 LaBr$_3$(Ce) scintillator detectors (OSCAR). This provides an improved energy resolution and timing properties for the selection of $p - \gamma$ events as compared to the earlier experiments with the NaI detector array CACTUS. The shapes of the strengths in these nuclei have been additionally constrained by applying the novel Shape Method to the coincidence data [2]. The previously published strengths in $^{116-119,121,122}$Sn [3] have been reanalyzed in order to provide a coherent analysis of the strengths in the studied nuclei.

All experimental strengths were compared to the GSFs extracted from relativistic Coulomb excitation in forward-angle inelastic proton scattering below the neutron separation energy [4] and were found to be in excellent agreement within the experimental error bands in the regions where the data overlap. The Oslo method strengths below the neutron threshold, combined with the inelastic proton scattering data above the neutron threshold provide an exhaustive picture of the nuclear response, covering the GDR, the PDR and the low-lying $M1$ strength. The evolution with an increasing neutron number of parameters characterizing the PDR as well as the fraction of the corresponding classical Thomas-Reiche-Kuhn sum rule will be presented together with the study of the effect of the pygmy dipole strength on the radiative neutron capture cross-sections is these nuclei. The increasing number of neutrons was found to lead to the increasing low-lying dipole strength towards the heaviest studied ^{124}Sn isotope. This trend may be expected to be the case for even heavier nuclei and play a noticeable role in various astrophysical scenarios.

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Measurements of γ-rays from ^{16}O (p, p′γ) ^{16}O reaction[*]

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Scattering of light particles such as protons, neutrons, α-particles, etc., can be utilised to get insight about the nuclear structure of the target nuclei. Such measurements are generally analysed using phenomenological optical model potential calculations for most of the projectile energies [1]. However, at energies below 30 MeV, incident projectile has enough time to interact with many nucleons in the target nucleus. Consequently, assumption of microscopic impulse approximation becomes invalid and nuclear physicists struggle to fit the experimental data for energy less than 30 MeV [2].

Very recently we have carried out detailed measurements to study the low lying states of ^{12}C using inelastic scattering of proton on ^{12}C nucleus. The measured production cross-section of the states have been analysed using both microscopic and phenomenological optical model calculations [3, 4]. In this regard, We have carried out one more measurement of inelastic scattering of proton on ^{16}O. Here we report about this very recent measurement. A large body of experiments have reported cross-section measurements of inelastically scattered protons from ^{16}O. However, only very few experiments have been carried out by detecting the γ-rays from the excited states of the ^{16}O target nucleus.

The measurement of γ-ray production cross-section from inelastic scattering of protons from ^{16}O is also useful for astrophysical studies. Gamma rays from sun during solar flare events, sites of star formation and supernova explosions are being detected for long time through satellite based observatories. These astrophysical γ-rays can provide crucial information about the isotopic composition of the sites of their generation. γ-ray production cross-section data is essential for the extraction of isotopic abundance data from the γ-ray lines.

Initial results of the γ-ray production cross-section measurements from ^{16}O nuclei using proton beam of energy 8 to 20 MeV will be presented.

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Tuesday

August 30th

The TRISR Project – A Storage Ring for Neutron Captures on Radioactive Nuclei

I. Dillmann[1]

Invited talk

[1]TRIUMF, Canada

Heavy-ion storage rings connected to radioactive beam facilities offer a unique environment for nuclear physics experiments. However, so far they have been only coupled to in-flight fragmentation facilities, for example the ESR and the CRYRING at GSI Darmstadt/ Germany, the CSR at HIRF in Lanzhou/ China, and the Rare RI Ring at RIKEN Nishina Center in Japan. Neutron capture reactions play a crucial role for the understanding of the synthesis of elements heavier than iron in stars and stellar explosions via the slow (s), intermediate (i), and rapid (r) neutron capture processes. Whereas most of the s-process neutron captures occur on stable or long-lived nuclei along the line of stability and have been experimentally constrained in the past decades, measuring directly the neutron capture cross sections of short-lived nuclides ($T_{1/2} << 1\ y$) has been so far out of reach and lead to large deviations between various Hauser-Feshbach predictions for very neutron-rich nuclei.

Recently, a new method to couple a neutron-producing "facility" to a RIB storage ring was outlined [1]. The initial proposal involved a storage ring running through a high flux fission reactor to achieve high enough neutron densities. Later, a facility with a spallation neutron source was suggested [2], a proposal that is presently investigated at Los Alamos National Laboratory [3].

Our storage ring project at TRIUMF proposes to use instead a compact neutron generator coupled to a low-energy storage ring ($E = 0.1 - 10MeV/u$) and the existing ISAC radioactive beam facility. The project is currently seeking funding in Canada for a feasibility study. The TRISR project is presented, and measurements are outlined that would become possible, especially with the availability of clean, intense radioisotope beams from the new ARIEL facility.

If this world-wide unique facility is funded and built, it could become a key player and lead within a decade of operation to a major reduction of uncertainties for neutron capture cross sections of radioactive nuclei.

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Constraints on neutron-star radii from laboratory experiments

Sakib Rahman*[1] *on behalf of the PREX/CREX collaboration

Invited talk

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The weak interaction is the only fundamental interaction in nature that violates the parity symmetry. High-precision asymmetry measurements, using an electron beam with rapidly flipping helicity, enhance our understanding of the structure of nuclei and neutron stars. PREX-2 and CREX (Lead/Calcium Radius Experiments) are two such recent experiments conducted at the state-of-the-art Thomas Jefferson National Accelerator Facility in Newport News, Virginia, USA. PREX-2 was conducted by scattering a longitudinally polarized 953 MeV electron beam elastically from ^{208}Pb at a ~ 5 degree scattering angle with a beam current of $\sim 70\ \mu$A. The measured asymmetry was $A_{PV} = 550 \pm 16$ [stat.] ± 8 [sys.] ppb at kinematics with mean $Q^2 \sim 0.00616$ GeV^2. Together with the predecessor experiment PREX-1, it imposed robust constraints on the neutron skin $(0.283 \pm 0.071$ fm$)$ of ^{208}Pb. Model correlations between the neutron skin and the nuclear symmetry pressure indicate a stiff symmetry energy near the nuclear saturation density. The constraint imposed by the PREX result and neutron star radii measurements from the NICER telescope on nuclear DFT models is in ~ 1 standard deviation tension with the constraint from LIGO measurements of tidal deformability of neutron stars. Using the same experimental technique, CREX was conducted at a beam energy of 2.2 GeV and a beam current of $150\ \mu$A with a ^{48}Ca target. The lab scattering angle and mean Q^2 were ~ 5 degrees and ~ 0.0297 GeV^2 respectively, resulting in an asymmetry measurement of $A_{PV} = 2668 \pm 106$ [stat.] ± 40 [sys.] ppb and neutron skin of 0.121 ± 0.026 [exp.] ± 0.024 [model] fm for ^{48}Ca. The CREX result is in agreement with coupled cluster predictions of a thin neutron skin for medium mass nuclei and provides confidence in the experimental technique. However, the CREX result still contrasts the PREX result predicting thick neutron skins for heavy nuclei and relatively large neutron star radii. Further experimental and theoretical studies are required to better understand these anomalies.

Isomer studies for r-process nucleosynthesis*

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To understand the exact path of the r-process and its link to the observed abundance pattern requires experimental discoveries combined with extensive network simulations. Structure and decay properties of thousands of neutron-rich nuclei are key determinants of the nuclear flow throughout the entire r-process. To date, multiple extensive sensitivity studies of nuclear masses, half-lives, β-decay branching ratios, neutron captures, and neutron emission probabilities, and more recently nuclear isomers [1-3], have been performed. This recent theoretical work highlights the importance of precise information on nuclear masses and careful treatment of isomeric states in network calculations. We have performed measurements to study the energy difference between the ground state and isomeric states of some potential important to astrophysics isomers for nuclei Sn and Sb isotopes in the vicinity of ^{132}Sn with the Canadian Penning Trap (CPT) using the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique [4] at Argonne National Laboratory's CAlifornium Rare Isotope Breeder Upgrade (CARIBU) facility. We will discuss our results and plans for future decay measurements of these key isotopes.

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Beta-decay properties of neutron-rich lanthanides and the formation of the rare-earth peak

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The solar r-process abundance distribution has a local maximum at A $\approx$ 160, known as the rare-earth peak (REP). The peak formation is sensitive to the β-decay parameters — such as the half-life and β-delayed neutron emission probabilities (P_{1n} values) — of very neutron-rich lanthanide isotopes [1,2].

The β-decay of the aforementioned neutron-rich isotopes were studied at RIKEN Nishina Center. The nuclei of interest were produced by fragmentation of a 30 pnA ^{238}U beam on a 3 mm Be target at 345MeV/nucleon. The fragments were identified using standard ΔE-$B\rho$-ToF method by BigRIPS, then implanted in the AIDA double-sided silicon strip detector (DSSSD) array. The implantation station is surrounded by the BRIKEN neutron counter, consists of 140 ^{3}He gas filled proportional counters with a nominal neutron detection efficiency of 66.8(20)%. Furthermore, the decay station was also equipped with two CLARION-type HPGe detectors and veto detectors [3,4].

Half-lives and P_{1n} values were measured for 28 isotopes, from which 9 half-lives and all of the P_n values were derived for the first time. Beta-delayed γ-spectroscopy was also performed for isotopes with sufficient statistics. Details of the experimental procedure and a selection of results, including the astrophysical interpretation, will be presented [5].

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NuPECC Long Range Plan 2024 for Nuclear Physics in Europe

Invited talk

M. Lewitowicz[1,2]

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[2] NuPECC

The Nuclear Physics European Collaboration Committee (NuPECC) [1] hosted by the European Science Foundation represents today a large nuclear physics community from 22 countries, 3 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 4 associated members and 9 observers.

The Committee, as one of its major activity, organises 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 has in the past produced five LRPs: in November 1991, December 1997, April 2004, December 2010 and November 2017 [2]. The LRP identifies opportunities and priorities for nuclear science in Europe and provides national funding agencies, ESFRI and the European Commission with a framework for coordinated advances in nuclear science in Europe. It serves also as a reference document for the strategic plans for nuclear physics in the European countries.

NuPECC published in February 2022 an assessment of the implementation of the LRP 2017 [1] which summarises achievements in nuclear science and techniques resulting from the LRP recommendations. At its recent meeting in May 2022, NuPECC took the decision to launch the process of creating a new Long Range Plan for Nuclear Physics in Europe, identifying opportunities and priorities for nuclear science in Europe, with the aim of publishing the document in 2024[3]. With the intention of strengthening the bottom-up approach that has always played an important role in its LRPs, NuPECC has opened recently a call for inputs to the next LRP in form of short (5 page) documents describing the view of collaborations, experiments, or communities on the key topics for the next 10 years to be included in the upcoming LRP. The committee also solicits new ideas going beyond the topics considered in the LRP2017 or/and exploring synergies with the particle physics and astroparticle physics communities and considering new developments such as gravitational waves and multi-messenger astronomy. Contributions related to novel applications in cross disciplinary fields are also welcome. Nuclear Physics is a cross-continent field of science and European scientists strongly participate in the research activities outside of Europe. Inputs reflecting these activities are warmly welcome, too. The call for inputs will be open until 1 October 2022. Details concerning the submission procedure and the format of inputs can be found at the submission Web page [4].

The Steering Committee of the LRP2024, supervising the whole process, and all NuPECC members encourage active participation of the whole community in the elaboration of an ambitious and achievable strategic plan for the future of European nuclear physics.

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Nuclear isomers in the heaviest nuclei and the odd nucleon as a sensitive probe of low-lying nuclear structure*

D. Ackermann[1]

Invited talk

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When the liquid drop fission barrier vanishes in the fermium-rutherfordium region, only the stabilization by quantum mechanics effects allows the existence of the observed heavier species. **Sigurd Hofmann** was one of the most prominent scientists working in the field of superheavy nuclei (SHN) which he reviewed in several overview papers like e.g. ref. [1]. He passed away in June 2022 and this presentation is dedicated to honor him, his scientific achievements and his memory.

Among the nuclear structure features to be studied [2], nuclear deformation and exotic shapes are the most intriguing, leading also to meta-stable states. In particular interesting are K-isomers, detected up the heaviest one ^{270m}Ds [3], which is located at the edge of the onset of the descent of deformation towards sphericity [2,4], following various theory predictions, see e.g. ref. [5]. Initially low statistics data had been extended in a second experiment showing an increasingly complex α decay spectrum for ^{270}Ds and surprising fission probabilities for the daughter ^{266}Hs, despite their even-even character.

The first K isomers found in the region of the heaviest nuclei were typically meta-stable states of even-even isotopes like e.g. ^{254}No [6] or the above mentioned ^{270}Ds. More recently, cases for even-odd and odd-even nuclei have been reported with e.g. ^{255}Rf [7], ^{255}No [8] and ^{249,251}Md [9], respectively. While for the even-even isotopes often 2-quasi-particle excitations across a shell gap lead to high K-numbers, the meta-stable states in odd-mass nuclei are formed as 3-quasi-particle states where high K values are produced by 2-quasi-particle excitation coupled to the odd un-paired particle. No high-K isomer has yet been assigned to odd-odd nuclei in this region, possibly providing interesting quasi-particle configurations. Nuclei in the vicinity of shell gaps like ^{254}Lr and ^{258}Db, lying close to Z=100 and N=152, would be interesting candidates. For the latter, two decay activities have been reported [10]. The observation of low excitation energies for single-particle states originating from orbitals which are supposed to define the shell gaps for spherical superheavy nuclei provide important input to validate theoretical predictions, like in the case of the ^{247}Md $\rightarrow$ ^{243}Es decay [11].

In this presentation I will take you to a journey along the coast of the mainland of atomic nuclei, looking out towards the so-called "island of stability" of spherical SHN, to reach the long searched for distant shores some day, following the path Sigurd and others had started to pave time ago.

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Facility upgrade for SHE research at RIKEN

***Hideyuki Sakai*[1], *Hiromitsu Haba*[1], *Kouji Morimoto*[1] *and Narruhiko Sakamoto*[1]**

Invited talk

[1] RIKEN Nishina Center, Wako, Saitama 351-0198, Japan

The RIKEN Nishina Center (RNC), established in 2006, inherits a long research tradition of nuclear science begun by Yoshio Nishina in 1931. The discovery of the superheavy element (SHE) nihonium (Nh: Z=113) was one of the recent epoch-making achievements. The nihonium was synthesized using the cold fusion reaction of ^{209}Bi$+^{70}$Zn$\rightarrow^{278}$Nh$+n$ with the ^{70}Zn beam of E=5.0 MeV/u and about 0.5 pμA.

In 2016, RNC commenced the new comprehensive superheavy element (SHE) research project. Aiming at the synthesis of a new superheavy element 119 in a hot fusion reaction, namely ^{51}V$+^{248}$Cm$\rightarrow$Z=119, the RNC carried out the accelerator upgrade project, constructing a superconducting linac (SRILAC) and a new superconducting electron cyclotron resonance (SC–ECR) ion source to boost the final beam energy and its intensity. The project included constructing a gas-filled recoil ion separator (GARIS-III) suitable for detecting hot-fusion reaction residues.

Commissioning of SRILAC finished in 2019 confirmed a ^{51}V beam accelerated up to 6.5 MeV/u that makes a hot fusion reaction of ^{51}V$+^{248}$Cm possible to synthesize a new element 119. Thus, the initial goal of the SHE project was successfully achieved. The commissioning experiment searching for the new element with the upgraded facility (SRILAC and GARIS-III) was started in 2020. The highly enriched ^{248}Cm$_2$O$_3$ material was provided to RNC under the Material Transfer Agreement between RNC and Oak Ridge National Laboratory.

After the commissioning, the new SHE search experiment started under an international collaboration called the nSHE (“n" could stand for ‘n"ew, ‘n"ishina, or ‘n"ihon.) research group. Unfortunately, the commissioning and searching for a new element were frequently interrupted during 2020 and 2022, mainly due to the COVID-19 pandemic.

In this talk, we present the upgrade project of SRILAC and GARIS-III, their commissioning, and the present status of the new element search experiment at RIKEN.

New possibilities for production of super-heavy nuclei

M. Kowal[*]

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I would like to present selected issues related to the physics studied by Sigurd Hofmann, which was the inspiration and motivation for the Warsaw group for many years. Our theoretical calculations as the evaluations of nuclear masses, fission barriers, or shapes of superheavy nuclei were done for systems around Z = 102-112 partially discovered already in GSI. Then, I will present the latest cross-section estimates based on these fundamental nuclear properties [1] paying attention to:

- the possibility of direct production of new superheavy isotopes [2,4];
- unexpected slow decline in the synthesis probabilities for high excitation energies in channels with the emission of many neutrons (1-9)n [3];
- the possibility of producing superheavy nuclei in channels with proton and alpha emission in the first step of the compound nucleus deexcitation cascade [2,5];
- fusion probabilities with a discussion of hindrance mechanisms for nuclear reactions done at GSI by Sigurd and colleagues [6].

Those may offer a new opportunity for the future synthesis of unknown superheavy isotopes.

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[*] I dedicate this lecture to the memory of Sigurd Hofmann.

Optimal energy for element 119 synthesis via ^{51}V + ^{248}Cm reaction probed by quasielastic barrier distribution measurement

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The periodic table is now completely filled up to the seventh period. The synthesis of elements 119 and 120 has been attempted in several cases using the combination of actinide targets and projectile beams heavier than ^{48}Ca. However, these new elements have not been discovered yet so far [1-4].
In the synthesis of superheavy elements, the reaction energy is the most important parameter that significantly affects the experimental efficiency. At RIKEN, element 119 is being searched using a ^{51}V + ^{248}Cm hot fusion reaction. The optimal reaction energy of this reaction system is unknown since theoretical predictions vary widely.
Under these circumstances, our group has developed a method to estimate the optimal energy from the quasielastic (QE) barrier distribution [5,6]. From the systematic studies of the relation between the QE barrier distribution and the fusion-evaporation cross section σ_{ER} for the hot- fusion reaction systems with an actinide target, the optimal reaction energy for maximizing σ_{ER} was found to be slightly larger than the average Coulomb barrier height B_0 obtained from the QE barrier distribution [6]. Furthermore, it was also pointed out that the side-collision energy B_{side}, which leads to a compact configuration of the colliding nuclei by touching along the short axis of the prolately-deformed target nucleus, deduced from the experimental B_0 value, is in good agreement with the optimal energy of the experimental σ_{ER} [6].
In our latest study [7], we measured the QE barrier distribution of ^{51}V + ^{248}Cm, using a gas-filled recoil ion separator GARIS-III at a recently upgraded Superconducting RIKEN Heavy Ion LINAC (SRILAC) facility. The energy corresponding to the B_{side} was derived from the B_0 value determined from the present experiment, and the optimal reaction energy was estimated based almost purely on experimental evidence. Using the optimal energy obtained in this study, an experiment to synthesize element 119 is currently in progress at RIKEN.

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High-K ground states & isomers in superheavy nuclei

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Isomeric states in superheavy nuclei (SHN) present a considerable interest not only regarding clues they provide about single-particle spectra but also because half-lives of some of them could be longer compared to those of other states in the domain of notoriously short-lived species [1]. Several high-K isomeric states are known in the $Z \geq 100$ region [2,3,4], mostly in even-even nuclei, with ^{255}Lr [5,6] and ^{249}Md, ^{251}Md [7] being the few known odd-even cases.

We studied some configurations in heavy and SH nuclei which could live longer owing to hindrance to fission and/or α-decay by using the Woods-Saxon microscopic-macroscopic model [8,9]. Recently, within the same model, we systematically studied candidates for the 3qp high-K isomers in odd-even Md-Rg nuclei.

Candidates for high-K isomers were searched by first selecting $\sim$2000 low-lying 1$\pi - 2\nu$ excitations in all isotopes, then determining the equilibrium shape for each of them, choosing those whose energies compared to the energy of collective rotation built on the 1π component they contain is sufficienly low, and finally, choosing the most favoured ones in the E vs K plot. Energies of nuclear configurations were calculated either within the BCS method with blocking or the quasiparticle approximation. We also performed additional calculations in which pairing was treated within the particle-number-conserving formalism (a variant of the minimization after particle-number projection). Optimal shapes for high-K configurations as well as for ground-states were found by the four-dimensional energy minimization over axially- and reflection-symmetric deformations. The results point to particular isotopes in which the presence of isomers is most likely according to the used Woods-Saxon model. One can also make some predictions regarding their stability with respect to fission/α-decay. The largest uncertainty is related to whether electromagnetic deexcitations of the candidate configuration would be sufficiently hindered; its resolution would require a precise prediction of the spectrum and transition probabilities below it.

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Diffusion as a possible mechanism controlling the production of superheavy nuclei in cold and hot fusion reactions

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Superheavy nuclides (SHN) are produced in fusion reactions with extremely low cross sections. This is mainly due to the rapid decrease of the fusion probability P_{fus} when the product of the projectile and target nuclei atomic numbers $Z_1 \times Z_2 \geq 1600$. The fusion probability for the production of SHN in cold fusion reactions ($1n$ channel) on ^{208}Pb and ^{209}Bi targets drops approximately five orders of magnitude from 10^{-1} to 10^{-6} with the change of projectile atomic number from 20 (Ca) to 30 (Zn). A different behaviour is observed in ^{48}Ca-induced hot fusion reactions on actinide targets (from ^{242}Pu to ^{249}Cf). The fusion probability for these reactions is independent of the projectile-target combination and increases from approximately 5×10^{-5} to 2×10^{-3} with the change of the reaction channel from 3n to 4n. The question of what is the mechanism preventing the synthesis of SHN is still under discussion.

Recent experimental results for reactions induced on a ^{208}Pb target by ^{48}Ca, ^{50}Ti, and ^{54}Cr projectiles show that the probability of compound nucleus formation at energies above the interaction barrier B_0 can be significantly higher (up to two orders of magnitude) than its value at the peak of the $1n$ channel and weakly depends on the bombarding energy. It therefore exhibits a similar effect to that observed in the evaporation residue cross section measurements for hot fusion reactions.

In this work, we present a possible explanation of the rapid growth and subsequent stabilization of the fusion probability at bombarding energies close to the interaction barrier B_0. Calculations were performed within the l-dependent fusion-by-diffusion model (FBD) using input data from new nuclear tables of SHN [1]. It is shown that the experimentally measured probabilities P_{fus} can be well reproduced within the framework of the FBD model. Below B_0 fusion probability growth is due to the reduction of the fusion barrier height with the increase of bombarding energy, while probability saturation above B_0 comes from suppression of the contributions of higher partial waves. The role of angular momentum in compound nucleus formation at energies above B_0 will be discussed in detail. The FBD model predictions of P_{fus} for various projectile-target combinations leading to the formation of SHN both in cold and hot fusion reactions will also be discussed. Some of the presented results were recently published in [2].

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Status of the SIRIUS detector array and investigation of the properties of ^{252}Fm[*]

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The superconducting LINAC (LINear ACcelerator) of SPIRAL2-GANIL will produce very intense heavy-ion beams up to uranium by virtue of the additional NEWGAIN (NEW GAnil INjector) with mass to charge state ratios (A/q = 7)[1]. The S^3 (Super Separator Spectrometer) of SPIRAL2 was designed to have high transmission, high beam rejection and high mass resolving power capabilities to study rare isotopes like superheavy and exotic nuclei far from the stability with very low production cross sections[2]. At the focal plane of S^3, a state-of-art detector array called SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S^3)[3] will be installed to perform decay spectroscopic studies in the region of very heavy and superheavy nuclei where very little spectroscopic data[4] is available. SIRIUS will be capable of detecting heavy ions and their subsequent decays products: alpha particles, internal conversion electrons, gamma rays, X-rays, beta particles and fission products. SIRIUS is composed of a SeD to track the transmitting ions and measure their times of flight, a DSSD (double-sided silicon strip detector) for implanting the ERs (evaporation residues) and establish position and time correlations between the implanted ions and their successive decays, a tunnel detector placed upstream to the DSSD and consisting of 4 stripy pad silicon detectors to detect the ionizing particles that escape the DSSD, five Germanium detectors placed in a close geometry around the silicon detectors for gamma spectroscopy. SIRIUS is in the commissioning phase now. In the first part of this talk, I will present the current status of the SIRIUS project.

In the second part of the talk, I will present some of the results obtained from the experimentnthat we have carried out at Argonne National Laboratory to investigate the yet unknown excited states of ^{252}Fm. Only the 2^+ state at 42.1(1.3) keV has been measured so far in the alpha decay of ^{256}No to ^{252}Fm[5]. ^{252}Fm being deformed and doubly-magic makes it a very interesting case to investigate the effects of shell closure on the nuclear structure. The ^{252}Fm nuclei were produced via the ^{238}U(^{18}O,4n) fusion-evaporation reaction. The prompt gamma rays emitted at the target position were detected by the GRETINA (Gamma-Ray Energy Tracking In-beam Nuclear Array)[6] gamma-ray detector array. The FMA (Fragment Mass Analyzer)[7] recoil mass spectrometer was used to isolate the ERs from the scattered beam and background of other reaction products and get the mass identification of ^{252}Fm from the neighboring evaporation channels. The ERs were implanted in a DSSD installed at the focal plane detector of the FMA. A clover detector was placed behind the DSSD to detect the X rays and gamma rays emitted during the isomeric decays.

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Multinucleon transfer reactions in the ^{238}U + ^{238}U system studied with the VAMOS + AGATA + ID-Fix

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Since the middle of the last century many efforts have been devoted to investigate the region of heaviest nuclei. Various models predict an existence of the island of stability of superheavy nuclei (SHN) with shell closures at a proton number between 114 and 126 and at a neutron number 172 or 184 [1]. However, the discovery of these nuclei is an experimental challenge. The fusion-evaporation reaction, being so far successful in synthesis of SHN, faces significant limitations caused by low production cross sections and the lack of sufficiently neutron-rich projectile-target combinations. Also, the region of neutron-rich light actinides (uranium region) in the vicinity of the N = 152 deformed shell gap, where important nuclear structure features are expected, is beyond reach. An alternative way to approach this region has been proposed via the employment of multinucleon transfer (MNT) reactions for which rather high cross sections were predicted in near-barrier deep-inelastic collisions of heavy ions [2,3]. Experimentally, the production of neutron-rich actinide nuclei up to Fm was observed via chemical separation techniques in cross section values ranging from mbarn to nbarn [4]. Within this context, an experiment aiming to investigate the MNT cross sections of exotic neutron-rich light actinides in the reaction of ^{238}U+^{238}U was carried out at GANIL in May 2021. The measurement was performed employing the VAMOS++ magnetic spectrometer [5] for the atomic mass identification, the AGATA γ-ray spectrometer [6] and the x-ray detection array ID-Fix for the identification of the atomic number through x-ray spectroscopy. In the talk, I will focus on the work done for preparation of the detection setup, in terms of absorber studies for a photon background from the ^{238}U+^{238}U reaction and optimization of the digital pulse processing for an efficient x-ray spectroscopy, and will report on results on the ^{238}U+^{238}U experiment at VAMOS + AGATA + ID-Fix.

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Spectroscopic studies of the neutron-rich $^{255/256}$No

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Nuclei around ^{254}No (Z=102) have been widely studied by means of cold fusion reactions using projectile and targets around the doubly magic ^{48}Ca and ^{208}Pb in order to study the evolution of the single-particle structure both below and above Z=100 and N=152 deformed gaps. Numerous rotational structures and high-K isomers were observed giving valuable information on the single particle orbitals ordering around the Fermi level in theses nuclei (see [1-2] and references therein). Indeed, decay-spectroscopy techniques are very powerful to pin down high-K isomers and to study their decay path to the ground state as well as to subsequent states fed by radioactive decay of the nucleus of interest and its daughters.

The experiments were performed in 2019 and 2020 with the GABRIELA [3] array, at the focal plane of the SHELS [4] separator of the FLNR in Dubna. The first part of this talk will be dedicated to the presentation of this spectroscopic setup and to the genetic correlation analysis method developed to detect and to characterize the isomeric states discovered in these Nobelia.

Although E. D. Donets and his team studied the ^{256}No alpha decay in the sixties [5], this "hard-to-reach" nucleus has never been successfully studied in detailed spectroscopy up to our experiment. Since it cannot be produced in cold fusion reactions, the ^{256}No were synthetized through the fusion-evaporation reaction ^{238}U(^{22}Ne, 4n)^{256}No, with a special care for the separation efficiency because of the slowness of the recoils induced by this hot fusion reaction. We performed an alpha-beta-gamma spectroscopic study which allows us to discover a new high-K isomer which gave us a first idea of the level scheme of this nucleus. This low-statistic study will be presented in the second part of this talk, and was already published in Phys. Rev. C [6]. The third part of this talk will focus on a second experiment performed using a cold fusion-evaporation reaction ^{208}Pb(^{48}Ca, n)^{255}No, with the same setup optimized for a ^{48}Ca beam. Thanks to a higher transmission of the separator, this latter reaction allowed the discovery of four isomeric states in ^{255}No. The lifetime measurements and excitation energies will be presented and a tentative interpretation in terms of high-K isomers and underlying single particles content will then be discussed.

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Multidimensional PES in spontaneous fission*

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The potential energy surface (PES) is the basic ingredient for fission studies. Typically fission is described in terms of the evolution of the nuclear shape from the equilibrium state of the nucleus up to the pre-scission configuration. In the microscopic picture, the energy dependence on shape evolution can be studied within the Hartree-Fock-Bogoliubov (HFB) mean field theory with constraints on the arbitrary chosen deformation parameters. In order to determine fission observables like spontaneous fission lifetimes or mass yields, one needs to perform dynamic calculations that involve the evaluation of the action integral, a quantity that is governed by the interplay between the potential energy landscape and the behavior of collective inertias. Since the HFB equations are numerically expensive, one needs to find a reasonable balance between a proper choice of the most relevant degrees of freedom and computational time. The choice of the right set of degrees of freedom in the theoretical description of fission still remains one of the major challenges for contemporary nuclear structure physics [1,2,3].

In this work we present detailed studies of 3-dimensional PES of heavy nuclei. We show the complicated internal structure of the PES that cannot be fully described in two-dimensional picture, where some fission paths are not visible. The problems, that appear when multidimensional energy is projected into a finite dimension plane based on standard deformation parameters, are also discussed and the ways how one can resolve them are proposed. On this background, we study the competing fission channels responsible for the observed bimodal mass yield in fission of ^{258}No. The aspect of the so-called scission cliff has been raised as well. It has been shown that one can obtain a continuous PES in the scission region when the neck parameter is considered as a collective degree of freedom. Additionally, we provide a microscopic definition of the scission point, based on the limit number of nucleons in the neck [4].

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Experimental study of high-energy fission and quasi-fission dynamics with fusion-induced fission reactions at VAMOS++

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During the last ten years, the use of inverse kinematics in the experimental study of fission is bringing a wealth of new observables obtained in single measurements, which allows their analysis and, also importantly, of their correlations [1,2]. An ongoing application of this technique the basis of a series of experiments performed with the variable-mode, large-acceptance VAMOS++ spectrometer at GANIL (France) [3,4]. In these experiments, fission reactions are induced by fusion and transfer reactions between a ^{238}U beam and a set of different light targets. The kinematics of the transfer and fusion reactions allows us to identify the fissioning system and determine its initial excitation energy [5], while the data from the VAMOS spectrometer gives us the isotopic identification for the full fragments distribution, and their velocity vectors. These measurements result in an accurate determination of the fragments mass before and after post-scission neutron evaporation, their neutron multiplicity, the total kinetic and excitation energy, and their emission angle in the centre of mass [1,6,7]. In addition, these characteristics can be studied as a function of the initial excitation energy of the fissioning system [9]. The correlation between these magnitudes also permits to determine, for instance, the scission configuration and the sharing of excitation energy between the fragments [8, 9], and even to obtain information about the balance between intrinsic and collective excitation energy [10].

In a recent experiment, we have focused on the survival of nuclear structure effects in high excitation energy and the frontier between fission and quasi-fission. The main objective is to build and to study observables that would allow us to estimate the fission and quasi-fission components of the production and to identify relevant shells, such as newly highlighted octupolar-deformed closed shells [11], and their role on the fission dynamics at high energy.

The results of our analysis show that the ratio between neutrons and protons at scission as a function of the fragment split, together with the total kinetic and excitation energies, and the isotopic yields, reveal the presence of structure effects related at high energy, even if pre-scission evaporation is taken into account.

Concerning the quasi-fission component, the classical mass-angular distribution is completed in our case with the fragment identification, the ratio between neutrons and protons, and more importantly, the ratio between the production of fragments with an even and odd number of protons, the so-called even-odd effect [12, 13]. The latter shows a clear different mechanism for fission and quasi-fission that can be used to address, not only the separation between fission and quasi-fission, but also to study the energy dissipated in each of these processes.

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Nuclear Reaction Studies at MARA focusing on prospects for the new MARA-LEB facility

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The Low Energy Branch (LEB) [1] for the Mass Analysing Recoil Apparatus (MARA) separator [2] is a facility under construction in the Accelerator Laboratory of the University of Jyväskylä. The MARA-LEB facility will make use of MARAś high mass selectivity [3] to study the ground-state properties of exotic isotopes far from stability via both laser spectroscopy and decay studies. The main region of interest for MARA-LEB is the proton drip line near the N=Z=50 doubly-magic shell closure. This region, which includes the heaviest self-conjugate nuclides, such as ^{80}Zr, ^{94}Ag and ^{100}Sn, is optimal for the testing of nuclear models and their predictions [4,5] and for astrophysical nucleosynthesis models involving the rapid proton capture process in stars [6].

Mass-selected recoils from MARA enter the first part of the facility, the gas cell, through a thin window that separates a buffer gas region from MARAś high-vacuum environment. Incoming recoils will be stopped and neutralised by a buffer gas within the cell. The neutralisation of the recoils allows for subsequent in-gas-cell or in-gas-jet laser ionisation and spectroscopy via a state-of-the-art Ti:Sapphire laser system. Ionised recoils are subsequently accelerated to 30 keV and transported to a dipole magnet and an electrostatic deflector for further mass separation before arriving at a detector station [1].

An experiment was performed using the MARA separator to investigate the charge distribution of produced recoils at the focal plane of MARA, where the MARA-LEB buffer gas cell will be located. Results from this analysis informed final design decisions for the gas cell and the window dimensions.

Additionally, a recent experiment carried out using the MARA separator to study the reaction dynamics of the quasi-fission (QF) process has opened the possibility of studying actinide isotopes using laser spectroscopy in the MARA-LEB facility. Production yields of actinide species produced via QF reactions are being extracted from this experimental data using alpha-decay spectroscopy. These will be of importance in the design and proposal of experiments at the MARA-LEB facility.nThe outcomes of these studies at MARA relating to the feasability of future experiments in MARA-LEB will be presented and discussed alongside the status of the facility.

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Discovery of ^{160}Os & ^{156}W, and increasingly sensitive spectroscopy of the most neutron-deficient N=84 isotones

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Alpha (α) radioactivity is the principal decay mode of the most neutron deficient isotopes of even-Z elements from plutonium (Z=94) down to osmium (Z=76). Q_α values increase steadily with increasing neutron deficiency down to N=84 and consequently half-lives decrease rapidly. Beyond N=84 a sudden drop in Q_α-values is observed as a result of the neutron shell closure at N=82. For this reason the previously unobserved nucleus ^{160}Os$_{84}$ is expected to be the lightest osmium isotope for which α emission is the dominant ground-state decay mode.

The yrast 8^+ states in the neighbouring even-even N=84 isotones ^{156}Hf and ^{158}W are at lower excitation energies than their respective 6^+ states and as a result they are isomeric [1, 2]. With an E2 cascade no longer allowed, decays from these state proceed via α emissions that carry large amounts of orbital angular momentum. This isomerism is attributed to the attractive monopole interaction between $h_{11/2}$ protons and $h_{9/2}$ neutrons. The decays of ^{160}Os allow for this interaction to be further investigated as the $h_{11/2}$ proton orbital is filled. This behaviour is not restricted only to the even-even members of the N=84 isotones. At Z=71 (lutetium), the yrast seniority inverted $\pi h^3_{11/2} \otimes \nu f_{7/2} h_{9/2}$ (25/2-) state is found at lower energy than the respective $\pi h_{11/2} \otimes \nu f^2_{7/2}$(23/2-) state [3]. Novel features of the decay of the spin-gap isomer may be elucidated by observing very weak partial electromagnetic ($M3/E4$) branches that compete with the established dominant α decay.

Producing nuclei so far from stability is challenging due to very small production cross-sections and weak partial decay-branches. As a result of this, previous attempts to study the aforementioned decays of these nuclei have proved ineffective. Our recent study took advantage of the MARA recoil separator [4], which due to unparalleled selectivity provides the ability to successfully study nuclei that were hitherto not within reach. Results of the decays of ^{160}Os, the daughter of its α decay, ^{156}W, and delayed conversion electrons from ^{155}Lu will be presented and discussed alongside state of the art theoretical interpretations [5, 6].

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Lifetime measurements for nuclei in the f$_{7/2}$ shell using the AGATA spectrometer

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Very interesting phenomena of the nuclear structure appear in nuclei in the 1f$_{7/2}$ shell (the nuclei between ^{40}Ca and ^{56}Ni), like shape co-existence, backbending, collective and single-particle behavior. These features motivated theoretical and experimental research work aiming to understand the nuclear structure in this region [1]. Typically the nuclei in the 1f$_{7/2}$ shell show a large prolate deformation in the low energy excited states which decrease soon at high angular momentum and in particular towards the band termination. Theoretical calculation based on the shell model predicts high B(E2) values in low excited states, translated into high collectivity and short lifetimes of the excited energy levels [2]. The experimental investigation of such a phenomenon has been carried out in this work.

Transition probabilities are essential in understanding collectivity. Such information can be extracted from precise lifetime measurements of the nuclear excited states. In this work, the lifetimes of excited states of the cross conjugate pair of nuclei ^{46}Ti and ^{50}Cr have been measured by using the Doppler Shift Attenuation Method (DSAM). High spin states of these two nuclei were populated by the fusion-evaporation reaction ^{16}O(^{36}Ar, αn). The experiment was performed in Ganil laboratory in 2018. A beam of ^{36}Ar with energy 115 MeV and intensity 5 pnA was sent in a target which consisted of a thin foil of CaO (550 μg/cm^2 thick) with a gold backing of 10 mg/cm^2 for slowing down the recoil nuclei. The state of the art of gamma spectroscopy, the Advanced GAmma Tracking Array (AGATA), has been placed in the close-up configuration in the backward direction with respect to the beamline to detect the γ-rays emitted from the de-excitation of the reaction products. AGATA array has been coupled to NEDA and Neutron Wall (NEutron Detector Array) and Diamant (light charge particle detector array) to obtain the needed channel selectivity event by event.

The transition probabilities obtained from the experimental lifetimes will be discussed in the framework of theoretical calculations obtained from shell model using the KB3G and the GXPF1A interaction and compared with literature data from previous experiments. Rotational collectivity decreasing by the yrast termination of the band has been confirmed in both nuclei.

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Gamma-ray spectroscopy of the neutron rich Sc isotopes ^{55,57} and ^{59}Sc*

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Experimental data have shown that far from the valley of stability new magic numbers can emerge and the traditional ones can disappear. In particular, two new magic numbers at N=32 and N=34 have been suggested in the vicinity of Z=20 based on gamma-ray spectroscopy and mass measurements. In order to assess the impact of a single valence proton outside of the Z=20 shell on the shell-evolution mechanism in this region, it is necessary to study the neutron-rich Sc isotopes around, and even beyond, neutron number N=34. Investigation of exotic nuclei in this region was the goal of the third SEASTAR campaign at RIKEN-RIBF. Neutron-rich isotopes in the vicinity of ^{53}K were produced by fragmentation of a primary ^{70}Zn beam on a ^{9}Be target. Known and new γ-ray transitions of the isotope ^{55}Sc were observed and new γ-ray from ^{57,59}Sc identified for the first time. Observed γ spectra from ^{55,57,59}Sc will be presented together with preliminary level schemes. They will be discussed in the framework of the tensor-driven shell evolution.

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First spectroscopy of neutron rich odd-odd ^{74,76,78}Cu

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Spectroscopy of odd-odd ^{74,76,78}Cu has been performed in an experiment with the EURICA setup [1][2] at the Radioactive Isotope Beam Factory at RIKEN Nishina Center. Excited states were populated following β decay of ^{74,76,78}Ni, produced by in-flight fission and separated by the BigRIPS separator. Based on the analysis of $\beta-\gamma$ correlations and $\gamma-\gamma$ coincidences, level schemes were obtained for the three odd-odd Cu isotopes for the first time, comprising 12, 25, and 8 excited states for the three nuclei, respectively. For ^{78}Cu there is clear evidence for an isomeric state with a half-life of 3.8(4) ms.
The experimental results are compared to state-of-the-art Monte Carlo Shell Model calculations using the A3DA-m interaction [3] and a valence space comprising the full fp shell and the $1g_{9/2}$ and $2d_{5/2}$ orbitals for both protons and neutrons.nThe low-lying states are interpreted in terms of spin multiplets arising from the coupling of an odd proton in either the $\pi 1f_{5/2}$ or $\pi 2p_{3/2}$ orbital with an odd neutron in the $\nu 1g_{9/2}$, $\nu 2p_{1/2}$, or $\nu 2d_{5/2}$ orbital.nThe results confirm the previously observed crossing between the $\pi 2p_{3/2}$ and $\pi 1f_{5/2}$ orbitals [4][5], which are near degenerate in ^{74}Cu, and provide quantitative information on their increased energy separation toward ^{78}Cu.nFor the case of ^{78}Cu with one proton and one neutron hole outside doubly-magic ^{78}Ni, where configurations are relatively pure, it was possible to extract experimental two-body matrix elements for the $\pi 1f_{5/2} - \nu 1g_{9/2}^{-1}$ interaction, which represent important input for future shell-model calculations in the ^{78}Ni region.

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Structure of ^{83}As, ^{85}As and ^{87}As: from semi-magicity to γ-softness

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The neutron-rich nuclei beyond Z=28 and N=50 shell closures present a rich variety of collective effects, such as shape coexistence found in ^{78}Ni [1,2]. In germanium isotopes, an onset of triaxial deformation with filling of the $s_{1/2}$ and $d_{5/2}$ neutron orbitals has been reported [3-5]. One proton heavier, the arsenic (Z=33) nuclei are expected to manifest a similar structure, with the onset of collectivity beyond N=50. The quantification of deformation over the region of Ge, As and Se chains may be an important feature to connect with r-process nucleosynthesis scenarios, as these nuclei lie in the path of the r-process flow. The exotic arsenic isotopes between ^{83}As and ^{87}As (N=50 to 54) were populated in the inverse-kinematic fusion-fission reaction ^{238}U+^{9}Be (6.2 MeV/u) in the experiment performed in GANIL. The AGATA array composed of 24 HPGe crystals was coupled to the VAMOS spectrometer placed at 28^{circ} to detect the most exotic light fragments, in order to study the isotopes beyond N=50 in the ^{78}Ni region. The previously existing information about the level schemes of these exotic species is scares. In this talk the extended level schemes of ^{83}As and ^{85}As will be presented, along with the first suggested level scheme of ^{87}As. The data are interpreted in terms of the state-of-the-art LSSM calculations, pseudo-SU3 symmetries and the beyond-mean-field calculations with the novel DNO-SM method. The comparison points to the prolate deformation of the ^{85}As and ^{87}As ground states and confirms the presence of triaxiality and γ-softness in this region.

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Lifetime measurements in ^{105}Sn: nuclear structure studies close to the N=Z=50 shell closure

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One of the main goal of nuclear physics is to investigate the evolution of the conventional shell closures when moving far from the valley of stability, toward the more exotic and unexplored regions of the nuclear chart. Nuclei close to the doubly-magic and self-conjugated nucleus ^{100}Sn [1] have been intensively studied in the last decades in order to prove the robustness of the double-shell closure at Z=N=50. The spectroscopy of the Sn isotopic chain down to ^{101}Sn, including the measurement of electromagnetic properties of low-lying excited states, provides a stringent test for theoretical calculations and improves our understanding on nuclear phenomena in this region.

In this contribution I will present the results of lifetime measurements in ^{105}Sn with the Recoil Distance Doppler Shift technique (RDDS) [2]. The experiment was performed at Legnaro National Laboratories (Italy) using the Compton-suppressed γ-ray spectrometer GALILEO [3] in coincidence with the Si-detector array for light, charged particle EUCLIDES [4]. This setup enables the performance of γ-γ and γ-particles coincidences to select the channel of interest. Lifetimes of nuclear excited states in the order of the picosecond can be measured with the RDDS technique by using a plunger device [5].

The obtained lifetime values, in particular for the 7/2+ and the 11/2+ excited states, help to shed light on nuclear structure in this region thanks to the comparison with different theoretical approaches. Our results support the important contribution of proton and neutron particle-hole excitations from the ^{100}Sn core in the definition of the wave function of these states. Moreover, they point out a significant structural difference between the core-coupled state 11/2+ in ^{105}Sn and the 2+ excited states in the even-mass neighbouring nuclei.

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Neutron-deficient exotic decays in the ^{48}Ni region with ACTAR TPC

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The doubly-magic ^{48}Ni nucleus, the only known $T_z = 4$ isotope, was discovered in a projectile fragmentation experiment at GANIL [1]. A first indication of its ground state 2-proton radioactivity could be observed few years later [2] at GANIL, and this decay mode was established in a tracking experiment performed at NSCL [3]. Theoretical descriptions were able to reproduce the measured half-life for the few known ground-state 2-proton emitters (^{45}Fe, ^{48}Ni and ^{54}Zn), but not anymore when the 2-proton radioactivity was established for ^{67}Kr, at RIKEN [4] with a half-life in the order of 20 times lower than expected.

Two hypothesis have been proposed to explain this discrepancy for ^{67}Kr: either a transitional situation between a direct and a sequential emission of the protons [5] or the influence of the nuclear deformation [6]. This latter hypothesis is based on a Gamow coupled channel approach, that is benchmarked with ^{48}Ni that is expected to be spherical (doubly-magic). Both theoretical frameworks can predict angular distributions of the protons, that need to be confirmed experimentally.

An experiment at GANIL/LISE3 facility has been performed in May 2021 aiming at producing this ^{48}Ni nuclei and measure the angular distribution of their emitted protons. We used the ACtive TARget Time Projection Chamber detector to implant the ions and perform the tracking of their proton decays. Due to a production rate ^{48}Ni significantly lower than expected, the data will not be sufficient to extract an accurate angular distribution. Nevertheless, we may be able to combine them with the information of previous experiments [3].

In addition, we produced other exotic nuclei in the ^{48}Ni region. For several of them, we have found a first evidence of exotic decays such as $beta$-2p (^{40}Ti, ^{46}Mn, ^{47}Fe) and $beta$-3p (^{49}Ni). For some decays already seen, such as $beta$-3p (^{43}Cr) [7] and $beta$-2p (^{46}Fe)[8] we also aim to compare and complete some missing information (i.e, energies of emitted protons). Moreover, $beta$-p low energy emissions (of special interest in astrophysics) (^{40}Ti, ^{46}Mn) have been observed for the first time. The analysis of these decays (proton energies and partial branching ratios) will provide many experimental information about the structure and decay scheme of these very unstable nuclei.

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Active target TPC for study of photonuclear reactions at astrophysical energies

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One of the main interests in nuclear astrophysics are (p,γ) and (α,γ) reactions. In particular, those that regulate the ratio of C and O and those that burn ^{18}O and, therefore, regulate the ratio between ^{16}O and ^{18}O in the Universe. Such reactions in the stars happen at energies well below the Coulomb barrier and the respective cross-sections are incredibly small, often below the experimental reach. Therefore, the available experimental results on cross-sections for low energies are very sparse, and existing theoretical extrapolations are burdened with large uncertainties.

An opportunity to elude a part of the experimental limitations is to study the time-reversal reaction, i.e. photo-disintegration. For this purpose, a novel active gas target Time Projection Chamber (TPC) optimised for experiments with high-intensity γ-ray beams was developed and built at the University of Warsaw [1]. The TPC operates with pure CO$_2$, as a reaction target and charge transport medium, in a broad gas pressure range offering great flexibility for the studied reactions. The detector uses a 3-coordinate planar electronic readout acting as virtual pixels, read-out by GET electronics with negligible dead-time for the trigger rates expected. The very first experiments were carried out at the Van der Graaff accelerator and IGN14 neutron generator at IFJ-PAN in Kraków in summer 2021. The first experiment employed the ^{15}N(p, γ)^{16}O reaction at E$_{CM}$=1.05 MeV on a solid ^{15}N target to produce γ-rays, which interacted with the gas in the detector. In the second experiment the flux of 14.1 MeV neutrons produced in the d+T reaction was used to induce ^{16}O(n, α)^{13}C and ^{12}C(n, α)^{9}Be. The charged reaction products, namely α particles and ions, were detected, and their momenta reconstructed in 3D. The principles of the experiments will be illustrated, together with preliminary results. An outlook on other ongoing studies and plans will be given

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Neutron deficient Zn isotopes studied with the Optical TPC detector

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Two proton radioactivity is the most recently discovered decay mode which occurs only in a few nuclei beyond the proton drip line. It is still not fully understood since such exotic nuclei that undergo 2p decay are difficult to produce in numbers sufficient for statistically significant analysis.

In April 2019, we made an attempt to produce and study ^{54}Zn, the most neutron deficient isotope of zinc known to undergo two proton decay. Using BigRIPS separator at RIKEN facility, we produced ^{54}Zn and two other zinc isotopes, ^{55}Zn and ^{56}Zn, in the projectile fragmentation of ^{78}Kr on a beryllium target. We measured the production cross section for those nuclei. In this experiment, we registered several two proton decays of ^{54}Zn and beta-delayed proton decays of ^{55}Zn using the Warsaw OTPC detector. The OTPC allows for a full 3D reconstruction of decay kinematics. This information can give a unique insight into the structure of the exotic nucleus.

In this contribution, we present and discuss the results of the RIKEN experiment. We show the results of cross section measurement and compare them with theoretical predictions and other production methods in hope for finding the best production method for two proton emitters. We also show the preliminary results for ^{55}Zn beta delayed decays and for ^{54}Zn two proton decays.

Wednesday

August 31st

Gamma-ray spectroscopy of bound and unbound states in B, C, N and O isotopes as a test-bench of nuclear structure theory

Invited talk

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The structure of light nuclei can be predicted by state-of-the-art *ab initio* and shell model calculations, which aim at probing nuclear interactions and describing nuclear properties in a wide range of nuclei, including exotic systems. With the advent of powerful modern detection instrumentation for γ rays and particles, high-precision spectroscopy measurements become feasible, yielding strong constrains on such theory approaches. This talk will give examples of recent results from experiments performed at GANIL and Argonne National Laboratory with the AGATA and GRETINA tracking arrays, and at Legnaro Laboratory of INFN with the GALILEO array. At GANIL, the main aim of the measurement was the spectroscopy of neutron rich C to O isotopes, with special emphasis on the lifetimes of the second 2^+ states of ^{16}C and ^{20}O. *ab-initio* calculations predict, in fact, a strong sensitivity of the lifetime of such states to the details of the nucleon-nucleon interactions, in particular to the three-body term. The nuclei of interest were populated by deep-inelastic collisions between an ^{18}O beam and a ^{181}Ta target, and the nuclear state lifetimes were determined via a novel approach which allows to access nuclear state lifetimes in the tens-to-hundreds femtoseconds range, in reaction with complex structure of the product velocity distribution [1,2]. The results on transition probabilities clearly point to the importance of the three-body term of the nuclear force for an accurate description of electromagnetic observables in neutron-rich nuclei. High-resolution γ-ray spectroscopy of ^{18}N was also performed, leading to the complete identification of all negative parity excited states below the neutron threshold. The comparison with large-scale shell model calculations in the *p-sd* space provides strong constrains on cross *p-sd* shell matrix elements based on realistic interactions [3].

The Argonne and LNL experiments aimed instead at the detection of γ emission from near-threshold states in ^{11}B and ^{14}C, with expected decay branches of the order of 10^{-3} and 10^{-5}, respectively. In the case of ^{11}B, the existence of a narrow resonance 152-keV above the proton-threshold state (located at 11.229 MeV) was postulated on the basis of an unexpectedly high branch for β-delayed proton emission from ^{11}Be. This follows from experiments performed at ISOLDE and TRIUMF, using indirect and direct techniques for the β-delayed proton channel determination. The existence of a resonance state, with a sizable single-proton content, just above the proton separation energy in ^{11}B, is a manifestation of the universal phenomenon of near-threshold collectivity of the nuclear open quantum system, predicted by the Shell Model Embedded in the Continuum (SMEC). With the GALILEO array, at LNL, an independent search for this near-threshold state in ^{11}B was performed by using its γ decay as a probe [4]. Similarly, the γ-decay from the 2^+_2 narrow resonance, located at 8318 keV (i.e., only 142 keV above the neutron threshold) in ^{14}C has been searched for with the GRETINA array, as a test of SMEC predictions [5]. In both ^{11}B and ^{14}C experiments, the narrow resonance states are populated by direct proton emission from compound nuclei produced in fusion evaporation reactions with ^{6}Li beams. Preliminary results from both experiments will be discussed, together with perspectives for investigations in other systems, with further enhanced sensitivity.

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Recent highlights from high-resolution laser spectroscopy studies at ISOLDE

G. Neyens[1]

Invited talk

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High-resolution laser spectroscopy provides in a single experiment nuclear-model independent information about 4 fundamental properties of exotic nuclei: their spin, charge radius, magnetic dipole and electric quadrupole moments. At ISOLDE, CERN's radioactive beam facility, high-resolution measurement can be performed using 3 experimental set-ups: COLLAPS, CRIS and very recently also the PI-LIST laser ion source.

This talk will briefly introduce the 3 experiments and their complementarity, followed by very recent results not covered in other contributions to this meeting. Physics questions in the Mg, Ca, Sn, Pb and trans-lead region have been addressed in recent measurements, which were building further on previous studies [1,2,3,4,5].

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Experiments on light nα nuclei ^{8}Be, ^{12}C and ^{16}O

H.O.U. Fynbo[1]

on behalf of collaborations around experiments at ISOLDE and IGISOL

Invited talk

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I will discuss results mainly from experiments at ISOLDE-CERN and IGISOL-JYFL on the nα nuclei ^{8}Be, ^{12}C and ^{16}O.
The focus of the talk will be on the existence of broad resonances in these nuclei and on the relation between observables and the their nuclear structure.

E0 transitions in ^{188}Hg and evidence of multiple shape coexistence

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The neutron-deficient Pb isotopes have been suggested to possess multiple shape coexistence, i.e., more than two distinct shapes, since the discovery of the 0_2^+ and 0_3^+ states as the first two excited states in ^{186}Pb [1]. These states were interpreted as prolate and oblate configurations coexisting with a spherical ground state. Subsequent studies have provided candidates for multiple shape coexisting structures in ^{188,190}Pb (for a review of the current status of the data, see Ref. [2]). In the neighbouring Hg isotopes, no evidence has been found, to date, for the existence of multiple shape coexisting structures despite the (generally) better spectroscopic data that are available.

In order to probe for the existence of such coexisting structures in the Hg isotopes, we have studied the β-decay of ^{188,188m}Tl using the GRIFFIN spectrometer and its associated auxilliary devices at the TRIUMF-ISAC facility. Definitive spins assignments for many of the observed levels were made from the results of γ-γ angular correlations, as well as $E2/M1$ mixing ratios for a large number of $\Delta J = 0$ transitions. These results were critical for the extraction of the $E0$ contributions to the conversion electrons that were measured with the PACES array of Si(Li) detectors. Spins for a previously suggested "$K = 2$" band were definitively assigned for the $J^\pi = 2 - 6^+$ members. Newly observed structures, including a "$K = 4$" band and a "$K = 0$" band based on an unobserved 0_3^+ state, are proposed in ^{188}Hg. Large $E0$ components in the $J^\pi \to J^\pi$ transitions between the observed band members are interpreted as indicating significant configuration mixing and a deviation from axial symmetry. Comparisons of the experimental data are made with self-consistent beyond-mean-field calculations using the five-dimensional collective Hamiltonian and the Gogny D1M interaction. It is suggested that the proposed "$K = 0_3^+$" band represents a third distinct shape, thus extending multiple shape coexistence into the Hg isotopes [3].

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Beta-decay spectroscopy studies - a bridge between nuclear structure and nuclear astrophysics

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In this contribution I will present recent results of β-delayed γ emission and β-delayed proton emission measurements of the β decay of proton-rich exotic nuclides with A $\sim$ 60 performed at NSCL, Michigan. In the measurements, a double-sided silicon strip detector was used as the implantation detector together with the Clovershare Array to describe the decay process. A detailed analysis of the β-decay scheme of exotic ^{56}Cu [1] and ^{57}Zn [2] isotope will be presented. For ^{56}Cu β-decay, 8 new γ-ray transitions were identified and the half-life was derived from time correlations of the β's = (78.9$\pm$0.7) ms. In ^{57}Zn decay, the second occurrence of the rare and exotic $\beta - \gamma - p$ decay mode was observed. Astrophysical implications relevant to the rp-process in Type-1 X-ray bursts will be discussed. With our new and precise β-delayed proton emission branching ratio of (84.7$\pm$ 1.4)$\%$, we conclusively demonstrated the existence of the ^{56}Ni bypass, with 14-17$\%$ of the rp process flow taking this route [1,2].

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Transfer Reactions with Solenoidal Spectrometers[*]

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Invited talk

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Solenoidal spectrometers are designed for stuides of two-body reactions induced in inverse kinematics particularly with radioactive ion beams. Light ejectile ions emitted in the reaction at the target site are returned to the beam axis by a solenoidal magnetic field, where they are detected by an on-axis silicon array and can be identified by their time of flight. The energy in the centre-of-mass reference frame can be constructed in a simple fashion from measurements of the ejectile energy and position along the axis. Detection of the heavier recoil often improves cleanliness, allows selectivity, and can provide a time reference.

Kinematics in a solenoidal field have many advantageous features. The acceptance is large, without necessarily introducing large granularity and its associated complexity. It enables the use of thin targets with weak beams, providing good Q-value resolution without deleterious effects of kinematic compression or requirement for γ-ray coincidence due to the linear relationship between energy in the laboratory and centre of mass frames as a function of position. The approach allows studies of isomeric states with long lifetimes or unbound states with vanishing γ-ray widths.

The solenoidal method will be introduced and the development of this class of magnetic spectrometer will be discussed. Some recent measurements will be reviewed that have used the three operational solenoidal spectrometers: HELIOS at Argonne National Laboratory, SOLARIS at FRIB and ISS at ISOLDE, CERN.

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A Crack in Nuclear Mirror Symmetry

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Invited talk

Symmetries are ubiquitous in nature, and the observation of symmetry breaking often leads to new insights in physics. Within nuclear physics, it is possible to consider neutrons and protons as isospin projections of a single fermion. Nuclear states can then be characterized by a total isospin (or isobaric spin T) and this quantity is largely conserved in reactions and decays. A mirror symmetry emerges from this formalism; nuclei with exchanged numbers of neutrons and protons, or mirror nuclei, should have an identical set of states, including their ground state. Despite knowing that isospin symmetry is not perfect, it has proved to be rather robust across the chart of nuclides. In this talk, I will show evidence for mirror-symmetry violation in bound nuclear ground states between the mirror partners ^{73}Sr and ^{73}Br. By analyzing the β-delayed proton emission of ^{73}Sr, a spin assignment of $J^{\pi} = 5/2^{-}$ is needed to explain the proton-emission pattern observed from the $T = 3/2$ isobaric-analog state in ^{73}Rb, which is identical to the ground state of ^{73}Sr. Therefore, the ground state of ^{73}Sr must dffer from its $J^{\pi} = 1/2^{-}$ mirror ^{73}Br [1].

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Location of the Neutron Dripline at F, Ne, and Na[*]

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Invited talk

A search for the heaviest new isotopes of fluorine, neon and sodium was conducted by fragmentation of an intense ^{48}Ca beam at 345 MeV/nucleon and identification of isotopes in the large-acceptance separator BigRIPS [1-2] at RIKEN Nishina Center RI Beam Factory (RIBF). No events were observed for ^{32,33}F, ^{35,36}Ne and ^{38}Na and only one event for ^{39}Na after extensive running. Comparison with predicted yields excludes the existence of these unobserved isotopes with high confidence levels, which indicates that ^{31}F and ^{34}Ne are the heaviest isotopes of fluorine and neon, respectively [3]. Thus the neutron dripline has been confirmed up to neon for the first time since ^{24}O was confirmed to be the dripline nucleus nearly 20 years ago. In addition, the results of a follow-up experiment, which was conducted to confirm the ^{39}Na event, will be also introduced. Nine ^{39}Na events have been observed in this work and clearly establish the particle stability of ^{39}Na.

In this talk, the determination of neutron driplines for fluorine, neon, and sodium will be presented along with comparisons with nuclear mass and structure models. These results provide new keys to understanding the nuclear stability at extremely neutron-rich conditions.

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First beta-delayed neutron spectroscopy of ^{24}O

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The doubly-magic nucleus ^{24}O is located at the neutron drip line, making it the heaviest system along the oxygen isotopic chain. Spectroscopy of such a drip-line nucleus provides us with valuable information on the roles of nuclear interactions and many-body correlations approaching the limits of nuclear stability. A high-statistics measurement of beta-gamma and beta-delayed neutrons associated with the decays of ^{24}O was performed at the National Superconducting Cyclotron Laboratory at Michigan State University with VANDLE [1] and NEXT [2] neutron arrays. The beta-decay strength distribution populating both bound and unbound states in ^{24}F was extracted from the experimental data, providing tests for nuclear models at the drip line. Preliminary experimental results and comparisons with shell-model calculations will be presented.

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First trap-assisted decay spectroscopy of the ^{81}Ge ground state[*]

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The ^{78}Ni ($Z = 28$, $N = 50$) region has been one of the main focus points in nuclear structure studies during the last decades. The recently measured 2_1^+ excitation energy of ^{78}Ni $E_x(2_1^+) = 2.6$ MeV has been interpreted as the proof of its doubly magic nature [1]. Despite this remarkable result, the nuclear structure in the region is far from fully understood. Shape coexistence phenomena observed in the $N = 40$ region seems to extend to the $N = 50$ region and result in a new island of inversion. Coexisting shapes can also lead to isomeric states which complicate the studies of these nuclei.

In this work [2], we re-investigate the ^{81}As level scheme populated in the decay of ^{81}Ge in a systematic attempt to improve spectroscopy knowledge in the region of suspected shape coexistence. Up to now, the β-decay studies of the $N = 49$ isotones for $Z \leq 32$ have not been performed with an unambiguous ground state and isomer separation. In this work, we have utilized the JYFLTRAP Penning trap at IGISOL, Jyväskylä and selected the $(9/2^+)$ ground state of ^{81}Ge ($Z = 32$) for detailed studies at a post-trap decay spectroscopy setup. This is a clear improvement compared to the previous spectroscopy study of the decay of ^{81}Ge [3] which utilized a mass-separated $A = 81$ beam consisting mainly of ^{81}Ga.

The intrinsic half-life of the ^{81}Ge ground state has been determined as $T_{1/2} = 6.4(2)$ s, which is significantly shorter than the literature value. A new level scheme of ^{81}As has been built and is compared to shell-model calculations leading to suggest another hint of shape coexistence in the region.

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First observation of the radiative decay of ^{229}Th low-lying isomer: recent results from ISOLDE

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Owing to its very low excitation energy the isomer of thorium-229 has been proposed as a candidate for a possible future frequency standard, a nuclear clock and is expected to outperform the current atomic clocks [1,2]. Currently, the best values of the excitation energy are 8.28(17) eV and 8.10(17) eV [3,4]. These were measured using two different techniques where the population of the isomer was achieved via the α-decay of uranium-229. However, a precise knowledge of the isomer excitation energy is a necessary for the development of an optical clock.

Recently, spectroscopy measurement has been possible using an alternative approach of populating the isomer via the beta decay of actinium-229 [5]. The laser ionized actinium-229 ions produced online at CERN's ISOLDE facility were implanted onto a large bandgap crystal at specific lattice positions. A favourable feeding fraction of the isomer from the beta decay of actinium-229 compared to that via the $\alpha-$decay of uranium-229 and a low beta energy compared to alpha decay leads to a significantly reduced radioluminescence. This allowed us to study the VUV-photons stemming from the radiative decay of the isomer for the first time resulting in a much precise determination of the energy and lifetime of the isomer. In this contribution, a dedicated setup developed at KU Leuven for the implantation of francium/radium/actinium-229 beam into large-bandgap crystals and the vacuum-ultraviolet spectroscopic study of the emitted photons will be presented

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The fission observables of heavy and super-heavy nuclei

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Invited talk

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The nuclear fission process is described by the four-dimensional set of the Langevin equations for the shape degrees of freedom given by the two-center shell model (TCSM) parametrization [1]. For comparison, a parallel calculations are performed using the Yukawa-folded potential and a new, rapidly convergent, Fourier over Spheroid (FoS) shape parametrization [2].

The 4D Potential Energy Surfaces (PES) of even-even actinide nuclei are evaluated within the macroscopic-microscopic model. The collective mass, M, and friction, γ, tensors are defined both in macroscopic (Werner-Wheller and wall-and-window formula) and microscopic (linear response theory) approaches. For the diffusion tensor we use the modified Einstein relation, $D = \gamma T^*$, where T^* is the effective temperature.

We start calculations from the ground state shape with zero collective velocities and solve equations until the neck radius of nucleus turns into zero (scission point). At the scission point the solutions of Langevin equations supply the complete information about system, its shape, excitation energy, collective velocities. The knowledge of the shape at the scission point make it possible to calculate the mass distribution of fission fragments. The results of numerous calculations for the actinide nuclei are in a reasonable agreement with the available experimental data [3]. We show also the present results on the mass distributions and TKE for the chain of Thorium isotopes.

The mass distributions for super-heavy nuclei were considered in [4]. Here we tried to clarify which of the two double magic nuclei, ^{132}Sn and ^{208}Pb, is more important for the formation of the most probable fragment. It turned out, that both are important. In fission process of super-heavy nuclei one would observe both, the fragment with the mass number close to ^{132}Sn, $A_F \approx 140$ plus the rest, and almost spherical fragment with the mass number $A_F \approx 208$ plus the rest. Similar results are obtained using the PES evaluated using the Yukawa-folded single-particle and the Fourier shape parametrization of fissioning nuclei [5,6].

In the recent work [7] we have calculated the fission width Γ_f within a one-dimensional Langevin approach with the potential energy given by simple two-parabolic (Kramers) potential and found out that for excitation energies slightly above the fission barrier the $\Gamma_f(E)$ calculated in constant energy regime is substantially smaller than $\Gamma_f(T)$ calculated in constant temperature regime, and popular Bohr-Wheeler or Kramers approximations.

We have also investigated the impact of memory effects on the fission width Γ_f of heavy nuclei. It turned out that Γ_f is very sensitive to the damping parameter η. In the low viscosity region the fission width Γ_f grows as function of η and decreases as function the relaxation time τ. In high viscosity region the tendency is opposite. Such dependence is common both for small and large excitation energies.

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Near-barrier elastic scattering of ^{17}Ne from ^{208}Pb

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Invited talk

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New data taken at the SPIRAL facility, GANIL will be presented for the elastic scattering of the two-proton halo candidate ^{17}Ne from a ^{208}Pb target at an incident energy of 136 MeV, close to the Coulomb barrier. The data look remarkably similar to those for the two-neutron halo nucleus ^{6}He scattered from a ^{208}Pb target at similar energies with respect to the Coulomb barrier, see e.g. Ref. [1]. Since the two-proton separation energy of ^{17}Ne (933 keV) is very close to the two-neutron separation energy of ^{6}He (975 keV) it is tempting to ascribe the behaviour of the ^{17}Ne +^{208}Pb elastic scattering to the same cause, viz. strong dipole coupling to the low-lying continuum. A comparison of the single-proton and single-neutron separation energies of ^{17}Ne and ^{6}He, 1469 keV and 1710 keV respectively, would seem further to support this conjecture. However, the charge on the protons complicates matters, as pointed out by Kumar and Bonaccorso [2], leading to a larger “effective” binding energy compared to the equivalent neutron halo, at least as regards the breakup cross section.

The ^{17}Ne + ^{208}Pb elastic scattering data also bear a striking similarity to those measured for the stable ^{20}Ne scattered from a ^{208}Pb target at 131 MeV [3], where Coulomb excitation of the strongly coupled (bound) 2_1^+ level of ^{20}Ne plays the crucial rôle. The new data therefore provide an interesting addition to the available information on the scattering of halo nuclei, providing the first unambiguous evidence of strong coupling effects for a proton halo nucleus. In this talk various analyses will be presented, beginning with simple optical model fits through coupled channels calculations to a coupled discretised continuum channels calculation based on a simplified ^{2}He + ^{15}O two-body cluster model, and some preliminary conclusions will be drawn.

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Experimental investigations of octupole collectivity in atomic nuclei

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Invited talk

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Atomic nuclei which exhibit a reflection-asymmetric shape are of considerable interest for the understanding of nuclear structure. These "pear-shaped" nuclei are expected to occur in the regions of the nuclear chart where the octupole degree of freedom is enhanced. Strong octupole correlations manifest when the Fermi surface lies close to single-particle orbitals with quantum numbers [l,j] and [l-3,j-3] giving rise to the octupole magic numbers N,Z=34,56,88 and 134. Atomic nuclei in these regions can exhibit enhanced particle-hole interactions from the octupole component of the nucleon-nucleon interaction driving this reflection asymmetry which gives rise to the nuclear pear shape [1]. This phenomenon is important for experimental studies of atomic electric dipole moments (EDMs) in odd-mass isotopes exhibiting octupole deformation due to their enhancement of the Schiff moment [2].

Several experimental studies to measure the magnitude of octupole collectivity in nuclei have been performed via Coulomb excitation. This technique has been exploited to study nuclei for over 50 years and has undergone a renaissance with the development of post-accelerated radioactive ion beams (RIBs) from ISOL (Isotope Separator On-Line) facilities. A recent experiment performed at HIE-ISOLDE, which can now produce post-accelerated beams up to 10 MeV / u, to study E3 moments in ^{222,228}Ra [3] and ^{222,224,226}Rn [4,5] was performed in 2018. The results suggest that ^{222}Ra exhibits a significant enhancement of the octupole moment similar to previous studies of ^{224}Ra [6] and ^{226}Ra while ^{228}Ra is classifies as having an octupole-vibrational character based on observed vanishing E3 matrix elements. For the Rn isotopes, analysis of level energies in these nuclei indicate that no Rn nuclei will exhibit static octupole deformation in their ground state and are subsequently not ideal candidates for studies of atomic EDMs.

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Shell Structure of the very n-rich Ni isotopes and the REMO project

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Invited talk

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The study of neutron rich nuclei with unusually large neutron/proton ratio is challenging the conventional description of the structure of nuclei. The Ni isotopes are in this regard a benchmark of nuclear studies, as they correspond to a proton shell closure (Z = 28), while also exhibiting neutron shell or subshell closures at N = 28, 40 and 50. An intriguing interplay among spherical, prolate and γ-unstable shapes has been predicted in such isotopes driven by the combined effect of the tensor force and different particle configurations [1]. Such configuration-dependent shell structure translates into the coexistence of spherical and strongly deformed shapes with shape fluctuations and with a spectrum approaching the symmetry group E(5) with a behavior which has been interpreted as a striking example of phase transitions in dual quantum liquids [1,2]. Nickel isotopes are also an interesting example of partial conservation of the seniority quantum number. Seniority remains a good quantum number for any two-body interaction acting within j shell when j $\leq$7/2, but it needs not be conserved for j $\leq$ 9/2. Partial conservation of the seniority quantum number - most eigenstates are mixed in seniority but some remain pure - has been recently predicted in the neutron rich Ni isotopes, filling the $g_{9/2}$ shell [3]. Reduced transition probabilities have been recently measured for the most exotic ^{73,74,75}Ni nuclei with relativistic Coulomb excitation performed at the RIKEN Nishina Center [4]. Deformation lengths for n-rich Ni isotopes have been determined from proton inelastic scattering at NSCL using Gretina [5] and neutron/proton matrix elements have been extracted. In this presentation I will discuss the results obtained (^{75}Ni is the most exotic neutron reach Ni isotope presently reachable for such kind of studies) together with future programs on the use of radiotracers for monitoring the adaptation of marine species to the change of the climate [6]. The REMO project, in a collaboration composed by the IFIC (CSIC) Valencia (E), LNL (INFN) (I) and the Oceanografic of Valencia (E), has been recently approved in the spanish recovery plan program with the aim of investigating the effects of ocean acidification on molluscs [7].

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Charge-dependent DFT: formalism and selected applications*

Wojciech Satuła

S

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I shall start by briefly introducing the charge-dependent nuclear Density Functional Theory (CD-DFT) which, apart of the Coulomb interaction, includes isospin-symmetry-breaking (ISB) contact terms up to next-to-leading (NLO) order and the proton-neutron mixing in particle-hole channel [1]. Next, I shall demonstrate that such formalism, with an aid of six new low-energy coupling constants, is capable to account globally (irrespectively on atomic number) for the ISB in nuclear masses of $N \approx Z$ nuclei reproducing well both the isovector as well as the isotensor coefficients of the Isobaric Multiplet Mass Equation (IMME), see [2].

In the second part of my talk, I shall focus myself on multi-reference DFT (MR-DFT) calculations of ISB corrections to the ground-state beta decay of $T = 1/2$ mirror nuclei (more precisely to the Fermi branch) that involve, for the first time, both the Coulomb interaction as well as the local isovector interaction at LO and NLO fitted to reproduce mirror energy displacements [3]. I shall demonstrate that, rather counterintuitively, the local isovector potential surprisingly strongly influences the calculated Coulomb impurities and ISB corrections. This study is important in the context of the future high-precision testing of the electroweak sector of the Standard Model. At the moment the accuracy of $T = 1/2$ β-decay experiments is too low for such tests but fast progress in β-decay correlation techniques makes such experimentation very promising and keeps the field vibrant see, for example, Ref. [4] for the β-asymmetry measurement in ^{37}K decay.

Eventually, I shall demonstrate that after including (no-core) configuration-interaction (NCCI), our model can be also applied to compute the so called mirror energy differences (MEDs) i.e. changes in ISB effects in function of angular momentum along the rotational bands of mirror nuclei, see [5,6,7]. It allows us to conclude that, in particular, the MR-DFT and DFT-NCCI variants of our model are reliable theoretical tools allowing to assess quantitatively diverse isospin-sensitive observables in $N \approx Z$ nuclei without a need for local tuning of model's LECs.

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New developments in the description of four-nucleon continuum

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S

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Four-nucleon reactions are described in the framework of exact Faddeev-Yakubovsky-type integral equations that are solved numerically using momentum-space partial-wave basis. The technique is able to include not only the Coulomb and realistic nuclear potentials, but also the virtual excitation of the Δ isobar. The calculations were performed for (p, n) charge-exchange and (d, p) and (d, n) transfer reactions in proton-triton and deuteron-deuteron collisions, respectively [1]. Differential cross sections, analyzing powers, and polarization transfer coefficients are calculated. After demonstrating the reliability of the developed solution methodology in the four-nucleon continuum, it will be applied to the study of the tetraneutron resonance.

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Quadrupole and octupole collectivity in ^{96}Zr from Coulomb-excitation studies with the Q3D magnetic spectrograph

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S

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Quadrupole and octupole deformation of low-lying excited states in ^{96}Zr has attracted considerable attention in the last years. In particular, the $B(E2;2^+_2 \rightarrow 0^+_1)$ value was recently measured using electron scattering [1]. The deduced $B(E2;2^+_2 \rightarrow 0^+_2)$ value of 36(11) W.u., compared to the $B(E2;2^+_1 \rightarrow 0^+_1)$ value of 2.3(3) W.u., demonstrates that an excited deformed configuration coexists with a nearly spherical ground state. This has been linked to the type-II shell evolution mechanism [2], i.e. reorganization of nuclear shells due to specific proton and neutron occupations. Moreover, numerous theoretical studies attempted to address the unusually large $B(E3;3^-_1 \rightarrow 0^+_1)$ transition strength in ^{96}Zr, being at 57(4) W.u. the strongest known $E3$ transition in a spherical nucleus. Very recently, the $E3/E1$ γ-ray branching in the decay of the 3^-_1 state in ^{96}Zr has been remeasured following deep-inelastic reactions [3], yielding a $B(E3;3^-_1 \rightarrow 0^+_1)$ value almost 30% lower than those resulting from previous measurements and raising doubt about the exceptional character of octupole correlations in ^{96}Zr.

We performed a high-precision study of $B(E2;2^+_2 \rightarrow 0^+_1)$ and $B(E3;3^-_1 \rightarrow 0^+_1)$ transition strengths in ^{96}Zr using low-energy Coulomb excitation. The experiment was performed at the Maier-Leibnitz Laboratory of the Technische Universität and Ludwig-Maximilians Universität München. Beams of 45-MeV ^{12}C and 56-MeV ^{16}O with up to 0.2 μA current bombarded an isotopically enriched target of ^{96}ZrO$_2$ 27 μg/cm^2 thick. The ^{12}C and ^{16}O ejectiles were momentum analyzed using the Q3D magnetic spectrograph. Under the experimental conditions, the probability of multi-step excitation process was negligible and thus the transition strengths could be easily and accurately determined from the measured relative population of the excited states.

The resulting $B(E2;2^+_2 \rightarrow 0^+_1)$ and $B(E3;3^-_1 \rightarrow 0^+_1)$ values, obtained with a precision better than 10%, will be discussed in the context of shape coexistence and evolution of the octupole collectivity across the Zr isotopic chain.

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Thursday

September 1st

Insights into the structure of light nuclei

Martin Freer[1]

Invited talk

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The structure of nuclei is a dynamic interplay between microscopic and macroscopic properties guided by the nature of the strong interaction. Though fundamentally a system whose properties are governed by the nature of these inter-nucleon forces, with the influence of many-body components, the nuclear structure is guided by emergent symmetries. A recent study using quantum many-body simulations formulated from first principles [1] has explored the emergence of α-particles which reproduce the densities of the nuclei ^{8,10}Be and ^{12}C. Lattice based Chiral Effective Field Theory calculations, where nucleons are free to move between the lattice sites under the influence of the strong interaction also demonstrates the emergence of α-clustering [2]. These correlated 4 nucleon systems are evident in experimental observations across the nuclear chart, but an interesting question is how these correlations then imprint onto the mean-field/shell-model interpretation of nuclei. There is some guidance from very simple mean-field type approaches such as the deformed harmonic oscillator, which reveals symmetries and magic numbers which are imprinted onto more complex models and more importantly experimental properties. This presentation will expose some of the simple patterns which infect more complex approaches to our understanding of light nuclei and that are not diluted through the complex nature of the nucleon-nucleon interaction [3].

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Nuclear physics at the edge of stability

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Invited talk

Loosely bound nuclei are currently at the centre 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 from the driplines to the well-bounded nuclei for states in the vicinity and above the first particle emission threshold [1]. 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 the recent progress in the open quantum system shell model description of nuclear states, in particular, the understanding of (i) near-threshold collectivity and clustering, (ii) modification of effective NN interactions and shell occupancies in weakly bound/unbound states, and (iii) low-energy reactions of astrophysical interest.

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Recent progress in *ab-initio* computations of nuclei

G. Hagen[1,2,3]

Invited talk

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High performance computing, many-body methods with polynomial scaling, and ideas from effective-field-theory is pushing the frontier of ab-initio computations of nuclei.

Here I report on advances in coupled-cluster computations of nuclei starting chiral Hamiltonians with two- and three-nucleon forces. Global surveys of bulk properties of medium-mass and neutron-rich nuclei from ab-initio approaches are now becoming possible by using reference states that break rotational symmetry and keeping axial symmetry [1,2]. These calculations have revealed systematic trends of charge radii in various isotopic chains [3,4], questioned the existence of certain magic shell closures in neutron-rich nuclei [1,5], and confrontation with data have exposed challenges for ab-initio theory [5,6]. The restoration of broken rotational symmetry in coupled-cluster calculations [1] allow us to address rotational structure of nuclei. With this approach we have made predictions for excited state in neutron-rich neon isotopes including ^{32,34}Ne, and finding that ^{34}Ne is as rotational as ^{32}Ne and ^{34}Mg.

In addition to entire regions of the nuclear chart now being targeted by ab-initio computations, entirely new ways to make quantified predictions are becoming possible by the development of accurate emulators of ab-initio calculations [7]. These emulators reduce the computational cost by many orders of magnitude allowing for billions of simulations of nuclei using modest computing resources. This allows us to perform global sensititvity analysis, quantify uncertainties, and use novel statistical tools in predicting properties of nuclei. Very recently we used these tools together with delta-full chiral interactions at next-to-next-to leading order to identify regions of the parameter space of low-energy constants of the nuclear interaction that give results consistent with data including nucleon-nucleon scattering phase-shifts, $A = 2, 3, 4$ observables, and the binding energy and charge radius of ^{16}O. The resulting 34 parametrizations where then used to compute the properties of the heavy nucleus ^{208}Pb [8]. We accurately reproduced bulk properties of ^{208}Pb and made predictions for the neutron-skin which is smaller and more precise than a recent extraction from parity-violating electron scattering but in agreement with other experimental probes. These developments demonstrates how realistic two- and three-nucleon forces act in atomic nuclei and allow us to make quantitative predictions across the nuclear landscape.

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Few-Nucleon Systems for Nuclear Physics

***J. Golak*[1], *R. Skibiński*[1], *H. Witała*[1], *D. Ramirez*[1], *V. Urbanevych*[1], *V. Chahar*[1]**

for the LENPIC collaboration

Invited talk

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Chiral effective field theory (EFT) and ab initio few- and many-body methods play a very important role in precision nuclear theory. In this contribution the current status of the chiral nuclear forces [1–4] derived by the Low Energy Nuclear Physics International Collaboration (LENPIC) [5] will be presented. These forces were very recently employed in a comprehensive investigation of few-nucleon systems as well as light and medium-mass nuclei up to $A = 48$ [6]. To this end Hamiltonians comprising higher-order nucleon-nucleon potentials in combination with the three-nucleon force at N^{2}LO were first determined using the $A = 3$ binding energies and selected nucleon-deuteron cross sections as input. They were then used to calculate other nucleon-deuteron scattering observables, spectra of light p-shell nuclei and ground state energies of nuclei in the oxygen isotopic chain from ^{14}O to ^{26}O as well as ^{40}Ca and ^{48}Ca. We will discuss these new results, which give insights into the convergence pattern of chiral EFT for light and medium-mass nuclei.

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Friday

September 2nd

FAIR, the Universe in the Lab

Paolo Giubellino[1]

Invited talk

[1] FAIR/GSI, Germany

The construction of FAIR is proceeding rapidly. The tunnel for the SIS 100 accelerator is complete, and the realization of the experimental halls advances. The installation of the technical infrastructure is in full swing. The components of the accelerators of the future facility are in production and are arriving progressively on the campus of the GSI Helmholtzzentrum for Heavy-Ion Research in Darmstadt, Germany. While the full science potential of FAIR can only be harvested once the new suite of accelerators and storage rings is completed and operational, some of the detectors and instrumentation are already available and are used for a precursor science program called FAIR Phase-0, exploiting also the significantly upgraded GSI accelerator chain. The program has started in the summer of 2019 and continues with a few months of beam time per year. The progress of the FAIR realization and the status as well as prospects of science at FAIR and in the precursor Phase-0 program will be presented.

Recent Results from the DESPEC campaign at GSI

G. Benzoni[1]

Invited talk

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The HISPEC-DESPEC collaboration aims at studying the evolution of the shell structure and exotic nuclear shapes in uncharted nuclear territory, providing spectroscopic information for the nucleosynthesis of medium to heavy nuclei, exploiting the uniqueness of the GSI-FAIR laboratory.
In this first years after the restart of GSI, starting from early commissioning in 2019 to real experiments in 2020-2022, the collaboration focused on stopped-beams experiments, with the aim of providing a complete picture of the β-decay process [1,2]. The use of the FATIMA array coupled to HPGe detectors provides, in fact, a detailed reconstruction of the decay scheme with a particular focus on specific observables, such as levels lifetimes.
In this contribution a detailed description of the detection equipment and first results of the campaigns, together with an outlook onto the future experimental program will be given.

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Physics Program of the SPARC Collaboration at FAIR: Quantum Dynamics in Extreme Electromagnetic Fields

Th. Stöhlker[1,2,3]

Invited talk

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Relativistic interactions with matter involving heavy high-Z ions provide a unique testing ground for our understanding of quantum electrodynamics and correlation in the non-perturbative regime as well as of elementary atomic processes mediated by ultrafast electromagnetic interactions. For this realm of physics, the future international accelerator Facility for Antiproton and Ion Research (FAIR) has key features that offer a range of novel challenging research opportunities [1,2]. The facility currently under construction will provide the highest intensities for relativistic beams of both stable and unstable heavy nuclei at high nuclear charge, in combination with the strongest possible electromagnetic fields, thus allowing to extend atomic spectroscopy virtually up to the limits of atomic matter. At the same time, experiments at relativistic beam energies are complemented by experiments at low beam energies (< 10 MeV/u) or even at rest but still at high charge state (see Figure). This scenario is worldwide unique and will deliver high-accuracy data for bound state QED (avoiding Doppler shifts) as well as the determination of fundamental constants. In addition, atomic collisions can be studied in the nonperturbative, adiabatic regime, and even super-critical fields will get accessible.

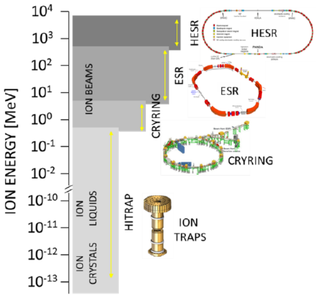

Figure: Portfolio of storage and trapping facilities at FAIR. Note, HITRAP, CRYRING, and ESR are already in operation or under commissioning.

In this talk, I will also review recent experimental results for atomic, quantum and fundamental research obtained at the already existing ion storage and trapping facilities [3,4]. Examples include e.g. laser spectroscopy exploiting the large Doppler boost associated with relativistic ions as well as precision x-ray, laser and di-electronic recombination spectroscopy. Finally, experiments at the border between atomic and nuclear physics will be addressed in addition with emphasis on rare nuclear decay modes only possible at high atomic charge states.

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Precision Experiments with Heavy-Ion Storage Rings

Yu. A. Litvinov[1]

Invited talk

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The storage of freshly produced secondary particles in a dedicated storage ring is a straightforward way to achieve the most efficient use of the rare species as it allows for using the same secondary ion multiple times. Employing storage rings for precision physics experiments with highly-charged ions (HCI) at the intersection of atomic, nuclear, plasma and astrophysics is a rapidly developing field of research. The number of physics cases is enormous [1].

Until very recently, there were only two accelerator laboratories, GSI Helmholtz Center in Darmstadt, Germany (GSI), and Institute of Modern Physics in Lanzhou, China (IMP), operating heavy-ion storage rings coupled to radioactive-ion production facilities. The experimental storage ring ESR at GSI and the experimental cooler-storage ring CSRe at IMP offer beams at energies of several hundred A MeV. The ESR is capable to slow down ion beams to as low as 4 A MeV. Beam manipulations like deceleration, bunching, accumulation, and especially the efficient beam cooling as well as the sophisticated experimental equipment make rings versatile instruments [2]. The focus here will be on the most recent highlight results achieved within FAIR-Phase 0 research program at the ESR.

The ESR is presently the only instrument enabling precision studies of decays of HCIs [3]. Radioactive decays of HCIs can be very different as known in neutral atoms. Some decay channels can be blocked while new ones can become open. Such decays reflect atom-nucleus interactions and are relevant for atomic physics and nuclear structure as well as for nucleosynthesis in stellar objects. Especially the two-body weak decays of HCIs will be discussed.

The efficient deceleration of beams to low energies enabled studies of proton-induced reactions in the vicinity of the Gamow window of the p-process nucleosynthesis [4]. Proton capture reaction on short-lived ^{118}Te was successfully measured in 2021 in the ESR. Here, the well-known atomic charge exchange cross-sections are used to constrain poorly known nuclear reaction rates.

The performed experiments will be put in the context of the present research programs at GSI/FAIR and in a broader, worldwide context, where, thanks to fascinating results obtained at the presently operating storage rings, a number of new exciting projects is planned. Experimental opportunities are being now dramatically enhanced through construction of dedicated low-energy storage rings, which enable stored and cooled secondary HCIs in previously inaccessible low-energy range. The first such facility, CRYRING, has just been constructed at GSI to receive decelerated beams of HCIs from ESR. A new era of precision experiments will start once the Collector Ring (CR) and the High-Energy Storage Ring (HESR) of FAIR will be taken in operation. In this presentation the emphasis will be made on scientific programs of the SPARC [5] and NUSTAR/ILIMA [6] collaborations at these rings.

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WASA-FRS experiments in FAIR Phase-0 at GSI

Y. K. Tanaka*[1] *for the WASA-FRS and Super-FRS Experiment Collaborations

Invited talk

[1] RIKEN Cluster for Pioneering Research, RIKEN, Wako, Japan

We have developed and constructed a new unique experimental setup which combines Fragment Separator (FRS) at GSI [1] and the central part of Wide Angle Shower Apparatus (WASA) [2]. The WASA detector system has been installed at the central focal plane of the FRS. Proton or heavy-ion beams accelerated by the synchrotron SIS-18 at GSI impinge on a production target located inside or in front of the WASA detectors. Exotic hadronic systems can be then produced in nuclear reactions. Forward emitted particles are separated and momentum-analyzed by the FRS operated as a high-resolution spectrometer, while light decay particles are detected by the WASA central detectors with a large solid-angle acceptance.
We have recently carried out two pioneering experiments with the WASA-FRS experimental setup from January to March 2022 in the framework of the FAIR Phase-0 program at GSI. The first experiment S490 was conducted to search for η' meson bound states in carbon nuclei (η'-mesic nuclei) [3]. While existence of η'-mesic nuclei is theoretically predicted for various cases of η'-nucleus potentials [4], no experimental observation was reported so far due to small signal-to-background ratio in the previous experiment [5]. The second experiment S447 aims at studying light hypernuclei in heavy-ion induced reactions [6], where the main goals are set to give answers to the two puzzles raised by the previous HypHI experiments at GSI: indication of a neutral $nn\Lambda$ bound system [7] and a short lifetime of $^3_\Lambda$H [8].
In this talk, we introduce the two experiments performed in 2022 including various developments for realizing the new experimental setup. Reports from the beam times and preliminary status of the data analysis will be presented. Future prospects with Super-FRS at FAIR will be discussed as well.

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Experiments: From ALADIN-LAND to R^{3}B at GSI and FAIR[*]

Invited talk

H. Simon[1] *for the R^{3}B collaboration*[#]

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In my talk i'd like to show you the evolution of our setup and experiments, being initiated and used at GSI, towards a dedicated experiment for various experiments with secondary beams at relativistic velocities for FAIR. Intermediate steps in the commissioning of the novel devices, together with the addressed physics questions, in the frame of Phase-0 beam times will be presented. Prototype studies at the SAMURA setup in RIKEN will also be shown.
The general time line for the Super-FRS facility at FAIR with intense SIS-18 and SIS-100 beams will be discussed and prospects for associated physics studies will be presented.

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[*] The research presented here is based on results from several experiments at the R3B setup as part of FAIR Phase-0, supported by the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt (Germany). This work is supported by the German Federal Ministry for Education and Research (BMBF) under contract numbers 05P15RDFN1, 05P19RDFN1, 05P2015PKFNA, 05P19PKFNA, 05P2018, 05P2015 and 06FY711051, HIC for FAIR funded by the state of Hesse, Germany, and the GSI-TU Darmstadt cooperation, Germany contract. Further support was provided by GSI, Germany (KZILGE1416) and the Swedish Research Council under grant numbers 2011-5324 and 2017-03839.

Studies of exotic nuclei with the FRS Ion Catcher at GSI

J. Zhao[1], ***D. Amanbayev***[2], ***S. Ayet San Andrés***[1,2], ***D. Balabanski***[3], ***S. Beck***[1,2], ***J. Bergmann***[2], ***Z. Brencic***[4], ***P. Constantin***[3], ***T. Dickel***[1,2], ***T. Fowler-Davis***[5], ***Z. Ge***[1], ***H. Geissel***[1,2], ***C. Hornung***[1,2], ***N. Kalantar-Nayestanaki***[6], ***A. Kankainen***[7], ***Y. Kehat***[8], ***G. Kripkó-Koncz***[2], ***I. Mardor***[8], ***A. Mollaebrahimi***[1,2,6], ***W.R. Plaß***[1,2], ***I. Pohjalainen***[1,7], ***M.P. Reiter***[5], ***C. Scheidenberger***[1,2], ***A. Spataru***[3], ***A. State***[3], ***P. Thirolf***[9], ***N. Tortorelli***[9,1], ***M. Vencelj***[4], ***J. Yu***[1], ***A. Zadvornaya***[2]

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At GSI, exotic nuclei have been produced at relativistic velocities by projectile fragmentation or fission at the entrance of the fragment separator FRS [1], separated in flight, identified and transported to the FRS Ion Catcher [2,3], where they were slowed down and thermalized in a Cryogenic Stopping Cell (CSC). Subsequently, their masses were measured by using a Multiple-Reflection Time-Of-Flight Mass-Spectrometer (MR-TOF-MS). Masses of nuclides with production cross sections down to a few nb and rates down to two counts per hour have been measured with the FRS Ion Catcher. The MR-TOF-MS features mass resolving powers of up to one million and relative mass measurement accuracies of down to 2x10^{-8} with measurement times of merely a few tens of milliseconds [4]. Broadband mass measurements covering more than 20 mass units can be performed in a measurement time of about 10 ms, and nuclides with half-lives of a few milliseconds are accessible with mass resolving powers of a few 10^5. Moreover, the device can also be employed as an isobar and isomer separator [5].

Mass measurements of neutron-deficient light lanthanides close to the proton drip line and neutron-rich nuclei around the N = 126 shell closure have been performed [4,6,7]. Newly measured masses of ground and isomeric states of nuclei close to the N = Z line and below ^{100}Sn shed light on nuclear structure and the proton-neutron interaction. Furthermore, a search for fission isomers produced via the projectile fragmentation has been performed with the FRS Ion Catcher.

An overview of the setup, recent experimental highlights, upcoming technical advances and experiments will be given in this contribution.

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Nuclear fission studies in inverse kinematics with the R^3B setup at the GSI-FAIR facility

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Despite the recent experimental and theoretical progress in the investigation of the nuclear fission process, a complete description still represents a challenge in nuclear physics because it is a very complex dynamical process, whose description involves the coupling between intrinsic and collective degrees of freedom as well as different quantum-mechanical phenomena. Due to this complexity and the use of different reaction mechanisms to induce the fission process, as well as the definition of different fission observables which were often biased by the experimental conditions, many contradictory results and conclusions exist in literature [1]. In the last decade, unprecedented fission experiments have been carried out at the GSI facility using the inverse kinematics technique in combination with state-of-the-art detectors especially designed to measure the fission products with high detection efficiency and acceptance [2,3]. For the first time in the long-standing history of fission, it was possible to simultaneously measure and identify both fission fragments in mass and atomic numbers and obtain many correlations among them sensitive to the fission dynamics [2,4] and the nuclear structure at the scission point [5,6]. Recently, these measurements have been improved by combining the previous experimental setup with the calorimeter CALIFA (CALorimeter for In-Flight detection of γ-rays and high energy charged pArticles) [7] and the neutron detector NeuLAND (New LArge Neutron Detector) [8] developed by the R3B collaboration, which allow us to measure the γ-rays and light particles in coincidence with the fission fragments. In this talk I will show the results obtained in all these experiments, summarizing as well the new ideas for the future fission experiments at the GSI-FAIR facility.

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Search for octupole deformation in A$\sim$225 Po-Fr nuclei

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In the landscape of nuclear shapes the occurrence of asymmetric pear-like nuclei has long been searched for. Evidence of static octupole deformation has been found only in selected regions of the nuclear chart (A$\sim$146 and A$\sim$222), where orbitals which differ by $\Delta j, \Delta l = 3$ approach the Fermi level for both protons and neutrons [1]. A$\sim$225 Rn-Th nuclei are expected to show the largest static octupole deformations, as highlighted both by recent experimental measurements and by theoretical calculations [2,3]. This region is characterised by a dearth of experimental information and very few direct measurements of E3 transitions were performed in recent years in ^{220}Rn, ^{224}Ra [4] and ^{228}Th [5], highlighting also a typical de-excitation pattern. Atoms where nuclei display static octupole deformation are an ideal playground for measurements of electric dipole moments (EDM) [6].

We performed an experiment at GSI-FAIR (Darmstadt, Germany) in April 2021 within the HISPEC-DESPEC collaboration experimental campaign, with the aim to search for evidence of octupole deformation in 220$<$A$<$230 Po-Fr nuclei via beta decay measurements. The primary ions were produced in in-flight fragmentation reactions, selected and identified using the FRagment Separator (FRS) [7] and implanted in the DEcay SPECtroscopy (DESPEC) station [8]. The DESPEC station is composed of a stack of Double Sided Silicon-Strip Detectors (DSSD) sandwiched between two plastic scintillator detectors and a hybrid γ-detection array consisting of HPGe and LaBr$_3$(Ce). The ions are let decay in the DSSDs and the internal structure of the daughter nuclei is performed with ion-beta-gamma correlation and fast timing techniques. Recent results of the data analysis will be reported on.

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Lifetime measurement below the 14^{+} isomer in ^{94}Pd

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In March 2020 the first formally approved DESPEC experiment as part of the FAIR phase-0 campaign was performed at GSI Helmholtzzentrium f"ur Schwerionenforschung. This experiment was focused on the measurement of electromagnetic transition rates between yrast excited states below the 14^{+}, $T_{1/2} = 499(13)$ ns isomer in ^{94}Pd [1]. The main goal was to measure the lifetimes of the yrast $I^{pi} = 6^{+}$ and 8^{+} states in this $N = Z + 2$ isotope, which would provide insight into the structural evolution in the ^{100}Sn region. The isomeric state in the nucleus of interest was produced by the fragmentation of ^{124}Xe primary beam on a ^{9}Be target [2]. The secondary cocktail beam was separated and identified by FRS (FRagment Separator) detectors on an event-by-event basis [3]. In the final focal plane of the FRS, the nuclei of interest were implanted in the AIDA (Advanced Implantation Detector Array) active stopper, which consisted of 3 Double Sided Silicon Strip Detectors [4]. Thirty six LaBr$_3$ detectors (FATIMA) [5] and six tripple cluster HPGe detectors (GALILEO) [6] surrounding AIDA were used to detect the depopulating gamma rays. The FATIMA array was used for fast-timing spectroscopy, while GALILEO provided precise energy information. Data obtained in this measurement are currently being analysed by checking correlations between ion implantation in AIDA and isomeric decays in FATIMA. In order to measure isomeric lifetimes in FATIMA the prompt response of the detectors has been determined. Similarly precise energy and timing information are being extracted after proper calibration and drift corrections. Preliminary results of the lifetime of the 8^{+} state in ^{94}Pd will be presented in comparison to the shell model calculations.

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Results of DTAS campaign at IGISOL: overview*

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The Decay Total Absorption γ-ray Spectrometer (DTAS) is a segmented NaI(Tl) detector designed for the DESPEC experiment at FAIR [1]. It was employed for the first time in a campaign of experiments at IGISOL [2], where the β decays of around 20 fission fragments were measured using the Total Absorption γ-ray Spectroscopy (TAGS) technique. It allows one to determine the β intensity distributions free from the Pandemonium effect [3] that impairs the results of high-resolution γ-spectroscopy approaches based on HPGe detectors.nnIn this contribution we will summarize and highlight the main results obtained so far from this experimental campaign, which represent the state-of-the-art of our analysis methodology for segmented spectrometers. They cover: **1)** cases that were observed to impact significantly antineutrino and decay heat reactor summation calculations, such as ^{100,102}Nb [4,5], **2)** β-delayed neutron emitters, such as ^{137}I and ^{95}Rb, in which we found a large γ-neutron competition above the neutron separation energy [6], **3)** decays of importance for shape evolution studies, such as ^{100,102}Zr [7] and ^{103,108}Mo [8], where comparisons of the experimental β strength and theoretical calculations allowed us to shed light on the oblate or prolate character of the ground state of the parent nucleus, **4)** β decays with a large ground state to ground state feeding probability, studied by using a revisited β-γ counting method [9] that confirms and complements the results obtained with the TAGS technique, **5)** nuclei with β-decaying isomeric states, such as ^{96}Y and ^{98,100,102}Nb [10,4,7], for which we could study separately the decays of the ground state and the isomeric state thanks to the purification capabilities of the JYFLTRAP double Penning trap system [11] and to different experimental strategies, **6)** cases with important E0 transitions, such as ^{96}Y [8] and ^{98}Nb, whose effect, overlooked in earlier studies, was carefully treated in our analyses and **7)** the advantageous use of the segmentation of our spectrometer to cross-check our results by looking at the TAGS spectra gated on the number of modules involved in each event (multiplicity) [4,6,7,10], including a newly developed method to directly analyse these multiplicity gated spectra [10].

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Multiple shape coexistence in ^{100}Zr

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The rapid onset of deformation observed at $N = 60$ in the Zr isotopic chain has been a subject of numerous experimental and theoretical studies. A microscopic explanation of this effect has been provided thanks to advances with the large-scale Monte Carlo shell model (MCSM) calculations, which attribute the appearance of deformed states in Zr isotopes to the type-II shell evolution, i.e. reorganisation of nuclear shells due to specific proton and neutron occupations [1]. Within this approach, the prolate-deformed configuration appearing at about 1 MeV excitation energy in ^{98}Zr becomes the ground state in ^{100}Zr, while the spherical ground state of ^{98}Zr corresponds to the 0_4^+ state in ^{100}Zr. Additionally, oblate and prolate deformed structures built on the 0_2^+ and 0_3^+ states, respectively, are predicted. The prolate-oblate shape coexistence in ^{100}Zr is supported by the observation of a low-lying 0_2^+ state and an associated band, and by an enhanced $\rho^2(E0; 0_2^+ \to 0_1^+)$ value [2] that implies a change in the $|\beta|$ values and mixing of the configurations. Recently, a γ band based on the 1196-keV state, tentatively assigned as a 2^+ level, has been proposed [3] suggesting a certain triaxiality of the ground-state configuration.
To investigate further the structures present at low excitation energy in ^{100}Zr, a β decay experiment was performed at the TRIUMF-ISAC facility in November 2021. A radioactive ion beam containing a mixture of ^{100}Sr and ^{100}Rb was used to populate ^{100}Y and subsequently ^{100}Zr through a series of β decays. The beam was deposited onto a tape in the center of the GRIFFIN spectrometer, consisting of 15 large-volume HPGe clover detectors equipped with BGO anti-Compton shielding. To allow for detailed investigation of the nuclei of interest, ancillary detectors were employed, including Si(Li) detectors for internal conversion electrons and LaBr$_3$ detectors for fast-timing lifetime measurements. The high-statistics data obtained in this study show that the presumed band head of the γ band at 1196 keV is linked to the 0_3^+ state by an enhanced transition, which implies its reinterpretation as a member of a deformed structure built on 0_3^+. The collectivity of this structure can be deduced from the lifetime of the 1196-keV state measured via fast timing. Together, these new results suggest that, in line with the MCSM calculations, a new deformed configuration is present at low excitation energy in ^{100}Zr, coexisting with the prolate ground state and the oblate 0_2^+ state.

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Coulomb excitation of ^{142}Xe[*]

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The isotope ^{142}Xe is located in the neutron-rich area north-east of the doubly-magic ^{132}Sn, in a region through which the astrophysical r-process is expected to pass. This nucleus is of particular interest as it allows to follow the onset of octupole collectivity, which is expected to peak for the nearby ^{144}Ba, and the evolution of quadrupole collectivity.

A perfect tool to investigate the low-lying structure and collectivity of ^{142}Xe is “safe” Coulomb excitation as it gives access to reduced transition strengths as well as spectroscopic quadrupole moments.

The experimental campaign was carried out at HIE-ISOLDE (CERN). After the excitation of the post-accelerated beam with 90 % purity and impinging at 4.5 MeV/u on a ^{206}Pb target, the deexcitation gamma rays are detected using the MINIBALL spectrometer, consisting of 24 six-fold segmented HPGe crystals, in coincidence with the corresponding particles. The latter are detected utilizing the silicon detector array C-REX, covering a large range of scattering angles, i.e., $22\,^\circ < \vartheta_{\mathrm{lab}} < 62\,^\circ$ and $102\,^\circ < \vartheta_{\mathrm{lab}} < 172\,^\circ$. Several B(E2) values of low-lying transitions, along with the spectroscopic quadrupole moments of the respective states, and the B(E3; $0^+_{\mathrm{g.s.}} \rightarrow 3^-_1$) value could be determined for the first time. Additionally, new low-spin low-energy states, interpreted as part of a γ band, observed for the first time in this isotope, could be identified, and the location of the 3^- state supported.

Experimental results are presented and compared to SCCM and LSSM calculations.

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Probing quadrupole collectivity in N = 38 ^{68}Zn isotope[*]

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The existence of a possible harmonic subshell closure at $N = 40$ is still an open question in the regime of large neutron excess. An alternate sub-shell closure for N=38 has also been suggested lately. The underlying shell structure changes rapidly while adding or removing a few neutrons in this region. Precise determination of B($E2$) serves as an ideal tool to investigate the evolution of nuclear structure across the N=40 region. Previous attempts to study the stable even-even Zn isotopes have yielded large discrepancies in the values of B(E2; $2^+_1 \rightarrow 0^+_1$) & B(E2; $4^+_1 \rightarrow 2^+_1$) [1-3]. We performed a multi-step Coulomb excitation experiment to study the low-lying electromagnetic structure of ^{68}Zn ($N = 38$) by bombarding a ^{32}S beam on an enriched ^{68}Zn-target at Inter University Accelerator Centre, India. Particle-γ coincidences were recorded identifying the scattering and recoiling ions by using a parallel plate avalanche counter subtending an angular range of 15° - 45° in lab frame and four germanium clover detectors in the backward angles with respect to the beam direction. A rich low-lying states of ^{68}Zn isotope upto 3.8 MeV were populated. The reduced electromagnetic strength of several low-lying transitions (like $4^+_1 \rightarrow 2^+_1$, $0^+_2 \rightarrow 2^+_1$, $2^+_2 \rightarrow 0^+_1$, etc.) were extracted using least square search code GOSIA.

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The first charge radii measurements of ^{33,34}Al transitioning into the N = 20 island of inversion

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The CRIS collaboration recently measured $^{26-34}$Al using laser spectroscopy, crossing the $N = 20$ shell closure and entering the island of inversion. The neutron-rich aluminium isotopes provide an excellent opportunity to investigate the evolution of nuclear structure crossing the $N = 20$ shell closure, where current results are limited to isotopes close to the line of stability. In particular, the change in mean square charge radius of ^{33}Al charts the transition into the island of inversion, from spherical silicon [1] ($Z = 14, N = 19$) to deformed magnesium [2] ($Z = 12, N = 21$). This work builds on the previous laser spectroscopy measurements of $^{27-32}$Al [3] that were conducted at ISOLDE, CERN.

In this talk, a brief overview of CRIS will be introduced before presenting measurements of the change in charge radii and magnetic dipole moments along the isotopic chain of Al. In particular, the first charge radii measurements of ^{33,34}Al will be highlighted. These results will then be discussed in relation to the $N = 20$ shell closure and the implications when entering the island of inversion.

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Collinear laser spectroscopy on the palladium isotopic chain

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The use of high resolution optical measurements of the atomic structure is at the forefront of modern subatomic physics. Laser spectroscopy provides model-independent nuclear data of nuclear spins, moments and charge radii across long chains of isotopes [1]. This allows the study of the evolution of nuclear observables versus particle number to probe shape deformation, configuration mixing and structural evolution effects. The collinear laser spectroscopy setup [2] at the IGISOL facility [3] in the Accelerator Laboratory of the University of Jyväskylä, has been used to perform measurements on palladium isotopes (Z=46) in the mass range A=98-118. Thanks to the chemically insensitive IGISOL ion-guide production method [4], it has been possible to reduce the existing gap in optical spectroscopy data below Z=50, created by the refractory character of these elements.
This contribution will present the latest results on laser spectroscopy measurements on the Pd isotopic chain. Special attention will be paid to the magnetic dipole and electric quadrupole moments. The main results of trends in the mean-square charge radii have recently been accepted for publication [5], nevertheless, new complementary results regarding the odd isotopes will be presented. These observables will be compared to state of the art theoretical calculations. Three different models for the interpretation of our data will be confronted, Large Scale Shell Model (LSSM), Fayans Energy Density Functionals (EDF) and Beyond-mean field calculations.

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Approaching N=82 through silver using laser spectroscopy

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Challenging our understanding of nuclear structure goes via the exploration of nuclear properties far from stability. Laser spectroscopy gives access to many ground-state properties (spin, nuclear electromagnetic moments, changes in the charge radius) upon which the structure of these nuclei is based. Furthermore, it can give access to the same properties for long-lived states (>10ms). The region from the strongly deformed zirconium (Z=40) to the nearly spherical tin (Z=50) is very rich with multiple competing nuclear configurations and thus the subject of recent investigations: tin [1], indium [2], cadmium [3], palladium [4], and neutron-deficient silver [5-6] have been successfully performed. Neutron-rich silver have been studied recently at ISOLDE/CERN [7] and at IGISOL in Jyväskylä [8].
I will present the results from both experiments. The nuclear spin and electromagnetic properties of the ground state and several newly-observed 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.

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Nuclear-structure studies with laser spectroscopy of radioactive molecules

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The optical spectra of diatomic molecules can be sensitive to properties of the constituent nuclei, such as the nuclear electromagnetic moments [1], the nuclear charge radius [2,3], and even signatures of nuclear and hadronic symmetry-violating properties, such as the nuclear Schiff moment [4]. Combined with the possibility to enhance the chemical release [5] and simplify the valence electronic structure [6] of complex and refractory species by placing them within a chemical bond, molecular spectroscopy at radioactive ion beam (RIB) facilities is a promising pathway to surpassing the limitations of atomic spectroscopy in many species.

Recently, molecular laser spectroscopy of short-lived radioactive molecules was performed for the first time at an RIB facility with low-resolution experiments on RaF at the collinear resonance ionization spectroscopy (CRIS) beamline at ISOLDE [7]. High-resolution spectra of RaF were further obtained in 2021 [8], and in 2022 we plan the first laser spectroscopy of AcF [9], a promising candidate for the first measurement of a nuclear Schiff moment (^{227}Ac) [10]. Besides the importance of these molecules for proposed tests of physics beyond the Standard Model, radioactive molecules can also be used for nuclear-structure studies [11,12].

This contribution will present an overview of recent advances at the intersection of nuclear and molecular physics, including our work on extending the King-plot analysis to extract the nuclear charge radii from isotope shifts in diatomic molecules [12], with an emphasis on cases where molecular spectroscopy could assist to bypass limitations of atomic laser spectroscopy.

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Study of the ^{20}Ne(p, γ)^{21}Na reaction at LUNA

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The NeNa-MgAl cycles are involved in the synthesis of Ne, Na, Mg, and Al isotopes. The $^{20}Ne(p,\gamma)^{21}Na$ ($Q = 2431.68$ keV) reaction is the first and slowest reaction of the NeNa cycle and it controls the speed at which the entire cycle proceeds. At the state of the art, the uncertainty on the $^{20}Ne(p,\gamma)^{21}Na$ reaction rate affects the production of the elements in the NeNa cycle. In particular, in the temperature range from 0.1 GK to 1 GK, the rate is dominated by the 366 keV resonance corresponding to the excited state of E_X = 2797.5 keV and by the direct capture component. The present study focus on the study of the 366 keV resonance and the direct capture below 400 keV.

At LUNA (Laboratory for Underground Nuclear Astrophysics) the $^{20}Ne(p,\gamma)^{21}Na$ reaction has been measured using the intense proton beam delivered by the LUNA 400 kV accelerator and a windowless differential-pumping gas target. The products of the reaction are detected with two high-purity germanium detectors located at two different positions along the beam path.

The experimental details and preliminary results on the 366 keV resonance and the direct capture below 400 keV will be shown.

Cluster states in ^{14}C and ^{15}C studied with the ^{10}Be + ^{9}Be reactions*

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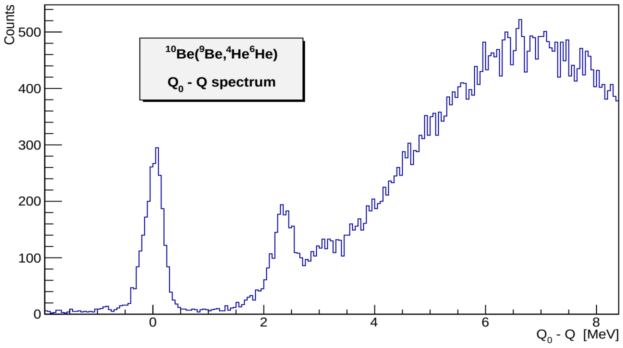
In this contribution, a brief analysis will be given of an experiment performed at LNS-INFN with a 54 MeV ^{10}Be beam and a ^{9}Be target. The ^{10}Be+^{9}Be reactions are measured to get information on different types of structures of several light nuclei. Special attention is given to a search for cluster states in ^{14}C and ^{15}C. The ^{9}Be isotope has been chosen as the reaction target because of the existence of a cluster structure ^{5}He+^{4}He inside its ground state. Such target structure, alongside the choice of the ^{10}Be radioactive beam with a suitable energy of 54 MeV, means that the transfer of one of the aforementioned clusters from the target to the beam should result in the creation of the sought ^{14}C or ^{15}C isotopes. This should be followed by sequential decay into several channels, some of which are ^{4}He + ^{10}Be for ^{14}C and ^{4}He + ^{11}Be or ^{6}He + ^{9}Be for ^{15}C. If we manage to see the experimental signature of these processes, this would be the first indication of the existence of cluster states inside the ^{15}C nucleus, while a positive result for the ^{14}C isotope would help to clear up the contradicting findings of other authors.

The experimental setup consists of four highly segmented telescopes covering polar angles from 20° to 90° which enable particle identification using traditional ΔE-E techniques. E part of the telescope is a double-sided silicon strip detector divided into 16 strips at each side, while the ΔE part is one-sided with 16 strips.

Preliminary results for the reaction channels of interest will be shown. For example, from coincident alpha particle detections ^{4}He+^{4}He, we clearly see at least 6 excited states of ^{11}Be. Also, from coincident ^{4}He+^{6}He detections we see at least 2 states of ^{9}Be (0 and 2.43 MeV) and several excited ^{13}C states (between 13 and 15.5 MeV). In both of these reaction channels we continue to look for other signatures, like ^{10}Be and ^{15}C. Plans for the remaining analysis will also be included.



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Gamma decay from the near-neutron-threshold 2$^+$ state in ^{14}C: a probe of collectivization phenomena in light nuclei

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Light nuclei, with mass A$<$20, are among the best probes of most advanced nuclear theory models. Of particular interest are near-threshold states, i.e., narrow resonances lying in proximity of particle-emission thresholds. According to advanced theory approaches, such as the Shell Model Embedded in the Continuum (SMEC) [1] (a recent realization of the real-energy Continuum Shell Model), the existence of near-threshold states is a universal phenomenon, and the structure of these states is expected to provide relevant information on the microscopic mechanism leading to the onset of collectivization and clusterization phenomena in molecular-like nuclei, as, for example, C, O, Ne … The adequate description of the nuclear structure near threshold states is also of primary importance for the precise modeling of nucleosynthesis involving fusion processes.

So far, the decay properties of near-threshold states in neutron-rich systems have been poorly explored, and almost uniquely via particle spectroscopy. The γ-decay branch from these states is, in fact, at the level of 10^{-3}-10^{-5} of the dominant particle-decay mode, i.e., below the detection capabilities of conventional γ-ray spectrometers.

In this contribution we will present preliminary results from an experiment performed at Argonne National Laboratory (USA) employing a very powerful setup, namely the GRETINA γ-tracking array coupled to the ORRUBA highly segmented Si array, for light charged particles detection. The experiment aims at the investigation, for the first time, of the γ decay of the second 2$^+$ in ^{14}C, located at the excitation energy of 8318 keV, i.e., 142 keV above the neutron-decay threshold. Experimental results will be compared with predictions from the SMEC model which is able to estimate the γ-decay branch, as a function of the continuum coupling constant [2].

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Helium clustering in neutron-rich Be isotopes

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A promising way to study the clustering and molecular like structures, even in neutron-rich light nuclei, is to explore the sensitivity of transfer reactions to the structure of the nuclei in the reaction entrance channel. Evolution of the clustering phenomena with the addition of neutrons in beryllium isotopes, from the α-α two-center clustering in ^{8}Be to the molecular like α-Xn-α structures in ^{10}Be and ^{12}Be $[1,2]$, is an important benchmark to our understanding of the nuclear structure $[3]$. With the aim to study these structures experiment S1620 was performed at the ISAC-II facility at TRIUMF, using the ^{9}Li beam and LiF target. Large solid angle array, comprised of six wedge shaped telescopes, each having 65 μm thick ΔE and 1.5 mm thick E detector, both SSSSD, arranged in "lampshade" geometry, was used and the reaction products were identified using the standard ΔE-E method. Many interesting cluster decay channels of the neutron-rich light nuclei were populated in reactions on both elements of the LiF target, where the ^{10}Be and ^{12}Be nuclei could have been produced by either proton or triton transfer to the ^{9}Li beam. The observed helium cluster decays of the ^{10}Be excited states to the ^{4}He+^{6}He and ^{4}He+^{6}He* pairs and the ^{12}Be decays to the ^{4}He+^{8}He, ^{6}He+^{6}He and ^{6}He+^{6}He* pairs will be presented and discussed. Results confirm known molecular and cluster states in these nuclei and provide strong indications for previously unobserved decay channels and cluster states, strongly supporting the existance of exotic clustering in these nuclei.

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Unprecedented Geometrical Shapes in the Range of Nuclei with $Z \approx N \sim 40$[*]

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Following indications discussed in Ref. [1], 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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First β-decay spectroscopy of ^{135}In and new β-decay branches of ^{134}In[*]

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The β decay of the neutron-rich ^{134}In and ^{135}In was investigated experimentally with the aim of providing new insights into the nuclear structure of the tin isotopes above N = 82. Better understanding of exotic nuclides from the ^{132}Sn region is required for accurate modeling of the rapid neutron capture nucleosynthesis process (*r* process), due to the A $\approx$ 130 peak in the *r*-process abundance pattern being linked to the N = 82 shell closure [1, 2]. Because a vast number of nuclei involved in the *r* process are β-delayed neutron (βn) emitters, new experimental data that can verify and guide theoretical models describing βn emission are of particular interest. Neutron-rich isotopes ^{134}In and ^{135}In – being rare instances of experimentally accessible nuclides for which the β3n decay is energetically allowed [3] – constitute representative nuclei to investigate the competition between βn and multiple-neutron emission as well as the γ-ray contribution to the decay of neutron-unbound states.

The β-delayed γ-ray spectroscopy measurement was performed at the ISOLDE Decay Station. Three β-decay branches of ^{134}In were established, two of which were observed for the first time [4]. Population of neutron-unbound states decaying via γ rays was identified in the two daughter nuclei of ^{134}In, ^{134}Sn and ^{133}Sn, at excitation energies exceeding the neutron separation energy by 1 MeV. The βn- and β2n-emission branching ratios of ^{134}In were determined and compared with theoretical calculations. The βn decay was observed to be dominant β-decay branch of ^{134}In even though the Gamow-Teller resonance is located substantially above the two-neutron separation energy of ^{134}Sn. Transitions following the β decay of ^{135}In are reported for the first time, including γ rays tentatively attributed to ^{135}Sn [4]. A transition that might be a candidate for deexciting the missing neutron single-particle $\nu 1 i_{13/2}$ state in ^{133}Sn was observed in both β decays and its assignment is discussed. Experimental level schemes of ^{134}Sn and ^{135}Sn are compared with shell-model predictions, including calculations considering particle-hole excitations across the N=82 shell gap [5].

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Beta decays of ^{82,83}Ga studied at the ALTO facility

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and the NRI15 Experiment Collaboration

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Most of the heavy elements in our universe are created via the rapid (r) and the slow (s) neutroncapture processes. Modeling the r-process information on the properties of neutron-rich nuclei, such as their masses, β-decay half-lives, and β-delayed neutron emission probabilities, which provide essential inputs for the astrophysical r-process calculations [1]. The first r-process abundance peak is located at A$\approx$80, and therefore this region is of special interest for the r-process. The recent observation of Sr lines in GW170817 shows that these nuclei are abundantly created via the r-process in neutron-star mergers [2]. The neutron-capture rates are also crucial for the r-process modeling, and a good understanding of the γ-strength function is needed [3]. The Pygmy Dipole Resonance (PDR) interpreted as the oscillation of a neutron skin against an isospin saturated core, brings a non-negligible dipole strength at excitation energies that can be populated by β-decay in neutron rich-nuclei. The way β-decay connects with PDR states in daughters nuclei is an open question and only scarcely investigated [4]. These states are usually above the neutron separation energy and compete with delayed neutron emission.In this contribution, I will discuss a recent experiment performed at the ALTO facility on β-decays of ^{82,83}Ga. Photofission of uranium, using a 50-MeV electron beam on a UCx target, together with laser ionization was employed to produce the neutron-rich Ga beams. The experimental setup was composed of 3 PARIS clusters (Photon Array for studies with Radioactive Ions and Stable beams) [5] for high-energy γ detection, combined with a plastic detector for betas used for tagging the decay events, a segmented Clover detector and a HPGe detector for the measurement of low excited states in coincidence with the high-energy γ-transitions. Several new γ-ray transitions in the β-decay of ^{82}Ga have been observed and a new Pn value is determined for ^{83}Ga. In this contribution, the experiment together with preliminary results will be presented.

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Saturday

September 3rd

In-beam gamma-ray spectroscopy with HiCARI[*]

K. Wimmer*[1] *for the HiCARI collaboration

Invited talk

[1] GSI Helmholtzzentrum für Schwerionenforschung

At the Radioactive Isotope Beam Factory at the RIKEN Nishina Center in-beam gamma-ray spectroscopy experiments take advantage of the wide range of radioactive ion beams produced by the projectile fragmentation and fission. The HiCARI project (High-resolution Cluster Array at RIBF) combined several germanium based detectors from around the world for in-beam spectroscopy. In 2020/21, an experimental campaign was launched studying neutron-rich nuclei from Ca to Te isotopes. The high resolution offered by the HiCARI array combined with the high selectivity of the BigRIPS and ZeroDegree spectrometers enabled experiments aiming at detailed spectroscopy and excited state lifetime measurements.

The physics program includes a wide range of topics in nuclear structure addressing collective and single-particle structure of nuclei very far from stability. In this talk, I will some selected recent results on the spectroscopy of very exotic nuclei.

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[*] JSPS Kakenhi 19H00679, ERC COG 101001561

The gamma-ray tracking array AGATA at LNL

J.J. Valiente-Dobón[1] ***for the AGATA collaboration***

Invited talk

[1] Laboratori Nazionali di Legnaro (INFN), viale dell'Università 2, 35020 Legnaro, Italy

Gamma-ray spectroscopy represents one of the most powerful methods to study nuclear structure since a large fraction of the de-excitation of the nuclear levels goes via gamma emission. The precise measurement of the γ rays emitted from nuclear levels can provide a large amount of structural information on the nucleus under study. The continuous improvement in germanium gamma-array performances and in their associated instrumentation has allowed a significant increase of the experimental sensitivity. The current state-of-the-art Ge gamma-array in Europe is AGATA [1]. Based on the concept of gamma-ray tracking, it can identify the gamma interaction points (via pulse-shape analysis) and reconstruct the trajectories of the individual photons. The tracking array AGATA had its first implementation at the Laboratori Nazionali di Legnaro (LNL) in 2009 with 5 AGATA triple Clusters: the AGATA demonstrator [2]. The AGATA gamma spectrometer has now returned to LNL in the new 2π solid angular coverage configuration. The first physics campaign will start in spring 2022 with AGATA coupled to the magnetic spectrometer PRISMA [3] and other compatible ancillary detectors. In this talk, a review on the achievements in nuclear structure physics and future physics campaigns with the gamma-ray tracking AGATA will be presented.

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The Super Separator Spectrometer (S^3) for the very high intensity beams of SPIRAL2*

H. Savajols[1] ***and the*** S^3 ***collaboration***[2]

Invited talk

[1] GANIL, B.P.55027 14076 Cane Cedex 5, France
[2] https://www.ganil-spiral2.eu/scientists/ganil-spiral-2-facilities/experimental-areas/s3/

The Super Separator Spectrometer S^3 [1] is, with the NFS (Neutrons For Science) facility, a major experimental system developed for SPIRAL2. It is designed for very low cross section experiments at low (<15MeV/u) energy. It will receive the very high intensity (more than 1pμA) stable ion beams accelerated by the superconducting LINAG accelerator of SPIRAL2. S^3 will be notably used for the study of rare nuclei produced by fusion evaporation reactions, such as superheavy elements and neutron-deficient isotopes. Such experiments require a high transmission of the products of interest but also a separation of these nuclei from unwanted species. Hence S^3 must have a large acceptance but also a high selection power including physical mass resolution. These properties are reached with the use of seven large aperture superconducting quadrupole triplets which include sextupolar and octupolar corrections in a two-stage separator (momentum achromat followed by a mass spectrometer) that can be coupled to the SIRIUS implantation-decay spectroscopy station [2] or to a gas cell with laser ionization to provide very pure beams for low energy experiments [3]. S^3 is now in the installation and tests phases. We will present the scientific objectives of S^3 as well as the current status of the facility and its different elements: target station, magnets, electric dipole, detection set-up, and the low energy branch.

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Gamma-ray spectroscopy of nuclear fission

J.N. Wilson[1]**, *D. Gjestvang***[2]**, *C. Hiver***[1]**, *M. Lebois***[1]

Invited talk

[1] IJC Lab, Orsay, France
[2] University of Oslo, Oslo, Norway

Gamma-ray spectroscopy is a versatile tool which can be used to study the decay of the excited fragments produced in the complex process of nuclear fission. Gamma ray coincidence and relative time information can give important information on both the nuclear structure of exotic neutron-rich nuclei and the fission process itself. Recent results from the nu-Ball hybrid gamma-ray spectrometer at the ALTO facility of IJC Lab will be presented. In particular, studies of short-lived states in neutron-rich nuclei will be highlighted [1][2][3] along with recent advances in the understanding on the generation of angular momentum in the fission process [4][5][6][7][8]. The prospects for new and innovative measurements using gamma spectroscopy of fission will also be presented.

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NEEDLE — fast neutron detection in the service of the gamma spectroscopy of neutron-deficient nuclei at HIL[*]

G. Jaworski and M. Palacz on behalf of the NEDA and EAGLE collaborations

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Heavy Ion Laboratory, University of Warsaw, Poland

Contemporary studies of nuclear structure concentrate in regions far from the valley of β stability. Experimentally such regions are accessible via, inter alia, fusion-evaporation reactions in which the nuclei of interest are produced by the emission of a few particles from the compound nucleus. The arrays of HPGe detectors, used for these studies, have to be complemented with ancillary devices, which make possible accurate identification of the reaction products, and thus of the reaction channel. In particular, when approaching very neutron-deficient nuclei the channels with neutron emission lead to the most exotic nuclear structures, which are produced with very small cross-sections. With the purpose of identifying neutron-evaporating reaction channels, large arrays of liquid scintillator detectors like the Neutron Wall [1,2] and the Neutron Shell [3] were constructed in the past and successfully used in many experiments, aiming at the study of more and more neutron deficient nuclei, especially along and close to the $N = Z$ line, up to the region of the doubly magic ^{100}Sn. Building up on the decades on experience with the above-mentioned arrays, following the extensive R&D phase, a new neutron multiplicity filter NEDA [4] has been constructed. The new array is optimized to have high efficiency, excellent capabilities to distinguish the detected neutrons and gamma rays and to properly determine the multiplicity of neutrons. It should also work at high counting rates. Thanks to these features NEDA is apt to work as an ancillary device to the modern γ-ray spectrometers. Indeed, within its first physics campaign in 2018 [5–7] NEDA was connected to AGATA at GANIL [8] presenting excellent performance. Currently, the installation of the neutron multiplicity filter NEDA is in progress at the Heavy Ion Laboratory, University of Warsaw, where the device will work in conjunction with the EAGLE γ-ray spectrometer [9]. The new aggregate of the detectors, nicknamed NEEDLE, will be an ideal tool to investigate the structure of exotic neutron-deficient nuclei. Following the discussions at the dedicated workshop, a number of experiments were proposed at the PAC and the first experimental campaign of NEEDLE will start in the late autumn this year. Later on, NEEDLE will be also equipped with the charged particle detector DIAMANT [10], which will further enhance the selectivity of the setup.

Within this contribution to the Zakopane Conference the current status of NEEDLE will be presented and the possibilities to perform the experiments on this setup will be discussed and advertised.

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Exotic decays with emission of charged particles

Marek Pfützner[1]

Invited talk

[1] University of Warsaw, Warsaw, Poland

Nuclei far from stability with a large difference between the number of protons and neutrons undergo decay modes which do not appear close to stability. These decays include direct emission of a proton (or two protons) from the nuclear ground state or processes like emission of β-delayed charged particles. The latter decays are typical for nuclei close to the proton drip-line but have been observed also for neutron-rich nuclei. All these processes provide us with precious information on exotic nuclei which are in general difficult to access experimentally.

Investigations of exotic and rare decay channels require special instrumentation offering efficiency and sensitivity. An example of such an approach is the Optical Time Projection Chamber (OTPC) developed at the University of Warsaw. Originally, it was designed to study two-proton radioactivity (*2p*), but it proved to be an excellent tool for studies of other decay channels accompanied by emission of charged particles. Among interesting results obtained with help of the OTPC, in addition to *2p* spectroscopy [1,2], are the first observation of the β-3*p* decay mode in four nuclei [3,4,5,6] or a study of ^{6}He decay into the $\alpha + d$ continuum [7]. Recently, we undertook an ambitious search for the β-*p* channel in the decay of ^{11}Be. The collected data are still under analysis so only preliminary results are available.

In the talk I will present a selection of experiments performed with help of the OTPC with focus on recent results and on-going projects.

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Branching ratio of the deuteron-deuteron threshold resonance in ^{4}He[*]

K. Czerski[1], **R. Dubey**[1], **M. Kaczmarski**[1], **A. Kowalska**[2], **N. Targosz-Sleczka**[1], **M. Valat**[1]

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[2] Institute of Mathematics, Physics and Chemistry, Maritime University of Szczecin, Szczecin, Poland

The ^{4}He level structure at excitation energies below 30 MeV seemed to be very well known for last decades and could be successfully applied for description of nuclear reaction by means of the multichannel R-matrix parametrization and ab-initio structure calculations of the four-nucleon system applying realistic nucleon-nucleon interactions and the microscopic cluster approach [1].

For the first time, the deuteron-deuteron (DD) threshold resonance was observed in the experimental study of the ^{2}H(d,p)^{3}H reaction in the Zr target performed under ultra-high vacuum conditions [2]. The experimental data supported the single particle structure of this resonance, its total width less than 1 eV and the $J^\pi=0^+$ alignment, which could explain very strong increase of the electron screening effect at deuteron energies below 10 keV. A similar resonance contribution was also recognized [3] in the older data of the gas target experiment [4], which enabled to estimate the partial proton resonance width at several tens meV.

On the other hand, it has been recently predicted that this resonance should decay predominantly by the internal electron-positron pair creation [3] due to the weak coupling of the 2+2 and 1+3 clustering states in ^{4}He. Here, both theoretical calculations of the DD threshold resonance width and the first experimental results confirming electron-positron pair emission from this resonance will be presented. Based on these data, the DD reaction rates and the corresponding branching ratios will be determined down to the thermal energies. Particular attention will be paid to study the interplay between the electron screening effect and threshold resonance excitation.

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Nuclear structure of ^{181,183}Au isotopes studied via β^{+}/EC decays of ^{181,183}Hg at ISOLDE

***M. Venhart*[1]*, J. L. Wood*[2]*, M. Sedlák*[1]*, M. Balogh*[1]*, M. Bírová*[1]*, A. J. Boston*[3]*, T. E. Cocolios*[4]*, L. J. Harkness-Brennan*[3]*, R.-D. Herzberg*[3]*, D. T. Joss*[3]*, D. S. Judson*[3]*, J. Kliman*[1]*, L. Makhathini*[5]*, V. Matoušek*[1]*, R. D. Page*[3]*, A. Špaček*[1]*, C. Unsworth*[3] *and M. Veselský*[1]**

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[2] Department of Physics, Georgia Institute of Technology, Atlanta, GA 30332, US
[3] Department of Physics, Oliver Lodge Laboratory, University of Liverpool, Liverpool, L69 7ZE, UK
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A recently developed portable, on-line capability for high resolution γ-ray and conversion-electron spectroscopy, TATRA [1] is demonstrated with its application to the studies of ^{181,183}Hg to ^{181,183}Au decays [2,3] at ISOLDE. TATRA is a compact and versatile tape transport system for the collection and counting of radioactive samples from radioactive ion beam facilities. It uses an amorphous metallic tape for transportation of the activity. Because of this material, the system can hold very good vacuum, typically below 10^{-7} mbar.

Key details of the low-energy level scheme of the neutron-deficient nuclide ^{183}Au will be presented. A Broad Energy Germanium detector (BEGe) [4] was employed to achieve this (the first-ever use of such a device in decay-scheme spectroscopy), by way of a combination of high-gain γ-ray singles spectroscopy [5] and γ-γ coincidence spectroscopy. Rydberg-Ritz combinations were used at the $\pm$ 30 eV level of precision. Further, by combining the γ-ray detectors with a liquid-nitrogen-cooled Si(Li) detector operated under high vacuum, conversion-electron singles and e-γ coincidences are obtained. These data lead to the determination of transition multipolarities and the location of a highly converted ($E0 + M1 + E2$) transition in the ^{183}Au decay scheme, suggesting a possible new shape coexisting structure in this nucleus. Identification of new intruder and normal states fixes their relative energies in ^{183}Au for the first time.

A decay scheme for the ^{181}Hg β decay was constructed for the first time. The first-excited $3/2^{-}$ state has the excitation energy of 1.79 keV. New systematic features, based on the above data, in the odd-Au isotopes will be presented.

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Beta-decay studies with the Modular Total Absorption Spectrometer*

T.T. King*[1]*, A. Laminack*[1]*, B.C. Rasco*[1]*, K. P. Rykaczewski*[1] *and P. Shuai*[1]*,

on behalf of the MTAS Collaboration

Oak Ridge National Laboratory, Oak Ridge, USA

Invited talk

The studies of beta-decays of fission products using the Modular Total Absorption Spectrometer (MTAS) were initiated in 2012 at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL). From 2018, MTAS was used to study the beta-decays of the isotopes of refractory elements at the CARIBU facility at Argonne National Laboratory, and in 2022 was adapted to the beams at the Facility for Rare Isotopes Beams (FRIB).

MTAS is a one metric ton array of 19 NaI(Tl) segments and auxiliary beta detectors including segmented silicon counters [1-3], high energy resolution Silicon Drift Detector [4] and most recently the pixelized scintillator ion implantation-beta decay array for the fragmentation studies [5]. MTAS was funded to perform the measurements of the decay heat released from fission products abundant during the nuclear fuel cycle, via the reliable determination of the complete beta-decay pattern [6]. The latter information can be used for the determination of the corresponding anti-neutrino energy spectrum and use to help to conclude on the reactor anti-neutrino anomaly and related concepts of sterile neutrino.

Selected earlier results [7,8] to the most recent ones [9,10], including an attempt to measure ^{55}Ca decay with MTAS at FRIB, will be presented and their impact discussed.

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Closing Lecture

Qantum Computing

Philippe Chomaz

Invited talk

Scientific Director of CEA Basic Science Division, France

Theorized in the 1980’s, quantum computing became a first laboratory reality with the first devices allowing demonstrations of principle about fifteen years ago. Since then, the academic world but also startups and even digital giants have launched themselves in the race to the quantum computer. The recent technical progress is breathtaking, allowing us to foresee important possibilities of a new type of calculation.

However, there are still many technological challenges to be met and even if quantum machines have been available on the cloud for a few years, they are only first toy models that are useless in terms of computing power. The major challenge is to fight quantum decoherence and to correct the induced quantum errors. It is therefore difficult to predict when and if quantum computing will become operational. However, if this challenge is overcome, which could happen in the next decade, the power of quantum computers would be such that they would revolutionize many sectors of digital technology. This would be the case for scientific research. Given the change of computing paradigm that quantum computers require, this revolution is already being prepared today and many communities have launched research programs to be ready in time. This is the case, for example, of CERN which is coordinating an ambitious international program.

This talk will review quantum computing and quantum computers and will explore some initiatives in nuclear and particle physics to start working with these new kinds of computers.

List of Posters

P - 1 **Giacomo Accorto, University of Zagreb**
Smoothing discuntinuities: effect on nuclear fission properties

P - 2 **Betania Backes, University of York, United Kingdom**
Mirror mirror on the wall: is isospin broken at all?

P - 3 **Matus Balogh, INFN Laboratori Nazionali di Legnaro**
New collective structures in ^{179}Au

P - 4 **Marcel Beckers, University of Cologne**
Lifetime measurement of excited states in ^{144}Ce: Enhanced $E1$ strengths in a candidate for octupole

P - 5 **Saikat Bhattacharjee, Saha Institute of Nuclear Physics**
Influence of entrance channel mass asymmetry on the degree of fusion hindrance

P - 6 **Anna Bohn, University of Cologne**
Extension of the level scheme of ^{104}Ru and lifetime determination using the Doppler-shift attenuation

P - 7 **Vaibhav Chahar, Jagiellonian University**
Chiral truncation errors in the p(d,pp)n cross section at E$_d = 100$ MeV

P - 8 **Xiangcheng Chen, University of Groningen**
The NEXT step towards neutron-rich exotic nuclides

P - 9 **Priyanka Choudhary, Indian Institute of Technology Roorkee**
Ab initio no-core shell model study of carbon isotopes

P - 10 **Michał Ciemała, IFJ PAN Kraków, Poland**
Investigation of rare nuclear decays - double gamma decay in ^{137}Ba nucleus

P - 11 **Navjot Dhillon, Panjab University, Chandigarh**
System size effects on the energy of onset of vaporization

P - 12 **Artur Dobrowolski, UMCS Lublin**
Collective bands in ^{156}Dy

P - 13 **Rakesh Dubey, University of Szczecin**
Development of the eLBRUS UHV accelerator system for studying nuclear reactions at very low energies

P - 14 **Baptiste Fraisse, CEA DAM DIF, Bruyéres-le-Châtel**
Study of fast-neutron-induced fission for ^{238}U with SCONE at NFS

P - 15 **Alexis Francheteau, CEA DAM DIF, Bruyéres-le-Châtel**
Study of the radiative decay of $^{252}\mathrm{Cf}$ fission fragments

P - 16 **Miki Fukutome, Osaka University**
One-neutron removal cross sections for the $^{16}\mathrm{N}$ isomeric state

P - 17 **Andrzej Góźdź, UMCS Lublin**
Algebraic Generator Coordinate Method for mixed states

P - 18 **Victor Guadilla, University of Warsaw**
Supervised event classification in an Optical Time Projection Chamber

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Poster abstracts

Smoothing discuntinuities: effect on nuclear fission properties[*]

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P - 1

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Many quantities, either related to nuclear collective degrees of freedom or characterizing individual nucleons, play an active role in the fission process. Most approaches rely on the adiabatic approximation, that allows to map the nuclear many-body problem [1] into a collective Schroedinger-like equation governed by only a few variables [2]. Multipole moments (*e.g.*, quadrupole, octupole) of the nucleus are routinely used as constraints in the HFB equations. Using them as parameters to navigate potential energy surfaces (PES) and find minimum energy paths (MEP) leading nuclei towards fission is justified by the experimental observations of low-energy vibrational modes, that usually display multipole character. PES are computed through an HFB solver, a routine that returns the minimum energy of a the nuclear configuaration with a given number of costrained variables. A numerical routine is devised, based on the HFBTHO solver [3], to deal with the appeareance of discontinuities along the nuclear MEP [4]. A discontinuity on the fission path precludes the calculation of any physical property, and it has therefore to be dealt with. One possibility is to brute-force recalculate the PES by including the degree of freedom in which the nuclear path jumped. Unfortunately, computational resources generally hinder the addition of extra variables. In [2], a different set of variables, based on geometrical properties of the nuclei, is used in place of multipole moments. To patch a 1D-PES discontinuity with a small 2D-PES, and to find a stitching continuous path across it, may be a more economic option. To this purpose, the Dynamic Programming Method (DPM) [6], an optimized breadth-first tree search (BFS), has been implemented on the mesh that discretises the intruding 2D PES. It improves the BFS algorithm by calculating only a maximum number of MEP at each step of the search, removing exponential memory and time requirements. With respect to [6], we implemented a robust calculation of the overlaps [7,8] between adjacent points on the PES. Overlaps are crucial in the method, as they are used to quantify the path smoothness. A comparison of results obtained by using different overlap formulas for the nucleus $^{252}\mathrm{Cf}$ [9] is presented. To quantify the actual usefulness of the method, fission lifetimes on top of the smoothed MEP are calculated, and compared to the results obtained with the more common choice of least action paths, in a similar philosophy to [10]. Finally, we plan to extend the code functionality to discontinuities on 2D PES, with the aim of designing a tool of wide usage in the static and dynamic studies of the fission process.

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Mirror mirror on the wall: is isospin broken at all?*

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The study of $T = 1$ triplets plays an important role in our understanding of isospin physics. A linear dependence of the proton matrix elements (M_p) with respect to T_Z indicates the isospin purity of states, an effect that has been studied and observed for triplets of 22 $\leq A \leq$ 50 [1]. As reduced electromagnetic transition probabilities are being measured for heavier $T = 1$ triplets, some studies suggest that beyond-Coulomb isospin symmetry breaking effects take place in mirror nuclei [2]. The goal of the present (and ongoing) work is to investigate all even-even $T = 1$ mirrors with 42 $\leq A \leq$ 98 within the Density Functional Theory approach, and analyze systematic properties of the obtained $B(E2 : 0^+ \rightarrow 2^+)$ values. For this purpose, we use the numerical software HFODD with full angular momentum restoration [3]. The results obtained are compared with the experimental data available. Our preliminary results show significant differences between the mirror pairs without beyond-Coulomb isospin symmetry breaking effects.

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New collective structures in ^{179}Au

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P - 3

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The odd-mass Au isotopes offer a broad systematic view of nuclear structure in a region of near-degenerate, multiple coexisting shapes [1]. The most neutron-deficient Au isotopes have been the subject of an extensive program of experimental investigation in the past. In comparison to the heavier Tl and Au isotopes, where multiple shape coexistence has been established [1-4], a rich variety of structures remains to be discovered. Indeed, already it is evident that there are new structures in ^{177}Au [5] and ^{179}Au [6] that have no counterpart in the heavier Au isotopes, as far as current spectroscopy has revealed. In this contribution, the results from the in-beam γ-ray and isomeric-decay spectroscopy of the extremely neutron-deficient isotope ^{179}Au will be presented. This high-statistics study was performed at the Accelerator Laboratory of the University of Jyväskylä utilizing the JUROGAM II array, the RITU separator and the GREAT focal-plane spectrometer. A previously unknown, high-spin isomeric state with an excitation energy of 1743(17) keV and $T_{1/2}$ = 2.16(8) µs was discovered. Five decay paths were identified, some of them feeding previously unknown non-yrast excited states associated with proton-intruder configuration. No such isomer was previously observed in heavier Au isotopes. Additionally, a new rotational band, associated with the unfavoured signature band of the $1h_{9/2} \oplus 2f_{7/2}$ proton-intruder configuration was revealed.

Calculations based on the particle-plus-triaxial-rotor model [7] were performed to interpret these newly observed structures in ^{179}Au.

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Lifetime measurement of excited states in ^{144}Ce: Enhanced $E1$ strengths in a candidate for octupole deformation[*]

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P - 4

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The $^{144}_{58}$Ce$_{86}$ nucleus is located on the neutron-rich side of the valley of stability, close to N=88, a nucleon number that is related to interesting phenomena throughout the nuclear chart. On the one hand a shape phase transition is expected at N=88-90 for nuclei in the Ba-Dy region [1]. Such transitions have been of major interest in nuclear physics research for a long time. Especially, a phase transition from spherical to deformed is expected between ^{146}Ce and ^{148}Ce , which has been the object of extensive studies in recent work [2]. The investigation of neighboring 144Ce is essential to learn about the onset of deformation in that region. On the other hand also the phenomenon of octupole deformation plays an important role in the N≈88, Z≈56 region. At these nucleon numbers nuclei are especially prone to octupole correlations [3]. This is explained with a strong octupole coupling between the $h_{11/2} \leftrightarrow d_{5/2}$ and the $i_{13/2} \leftrightarrow f_{7/2}$ single-particle orbitals, respectively [4]. Experimentally, octupole deformation has been related to alternating parity bands and low-lying negative-parity band heads. Such bands are reported in several lanthanide nuclei, including ^{144}Ce [5]. Experimental indications for such a deformation apart from the band structure are enhanced $E1$ and $E3$ transition strengths. Direct evidence for octupole deformation was obtained for ^{144}Ba by measuring $E3$ transition strengths [6].
Aside from the $2_1^+ \rightarrow 0_{gs}^+$ transition, no transition strengths were experimentally known for ^{144}Ce prior to this work. Therefore, a lifetime measurement of excited states in ^{144}Ce using the ^{142}Ce(^{18}O,^{16}O) reaction with a beam energy of 67 MeV and the Recoil Distance Doppler-Shift (RDDS) method has been performed at the Cologne FN Tandem accelerator. Lifetimes of the three lowest yrast states in ^{144}Ce have been measured as well as for the 3_1^- state and an effective lifetime of the 4_2^+ state. Reduced $E2$ transition strengths, determined using these results, have been compared to predictions from recent shell-model calculations. From the interband transitions, reduced $E1$ strengths could be determined, which are strongly enhanced. This may indeed hint at the possibility of octupole correlations.

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Influence of Entrance Channel Mass Asymmetry on the Degree of Fusion Hindrance

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The fusion hindrance is characterized by the deviation of experimental fusion excitation function compared to the Coupled Channel (CC) calculations. The phenomena was first observed in symmetric ^{64}Ni+^{64}Ni system [1]. Thereafter, different symmetric and asymmetric systems have exhibited the fusion hindrance [2,3]. Studies on the energy onset (E_s) of hindrance for different target-projectile systems covering a wide mass region exist in literature. However, the extent of the deviation in the experimental fusion excitation function compared to the CC calculation, once the hindrance occurs, has not been comprehensively studied. In this work, the extent or degree of fusion hindrance has been studied by implementing a two-potential fit of the experimental fusion excitation function, as prescribed in Ref. [4]. Several systems covering different mass region have been selected for this study, from symmetric to far-asymmetric target-projectile combinations. The E_s for each system has been identified as the point where the change in slope of the experimental fusion excitation function occurs. It has been observed that the shallow potential is required to reproduce the hindrance in fusion at energies below E_s. However, multiple theories based on different physical significance exist to explain the transition from a deeper to shallower potential. In this work, the idea of two potentials - one deeper and the other one shallower, has been implemented. For each system, cross-sections above the E_s have been fitted with a deeper potential of Woods-Saxon form in the one-dimensional barrier penetration model (1DBPM) framework. The points below E_s have also been fitted with a shallower potential. Difference between the potentials $\triangle$V is a representation of the degree of fusion hindrance. Increasing $\triangle$V corresponds to more rapid change in slope of experimental fusion cross-section below E_s. The value of $\triangle$V has been further normalized with the Coulomb barrier for each system. When the reduced potential difference $\frac{\Delta V}{V_b}$ (V_b is the Coulomb barrier) has been plotted with the entrance channel mass asymmetry, it was observed that the more symmetric systems have a higher degree of fusion hindrance compared to the far-asymmetric systems. The dependency of fusion hindrance on entrance channel mass asymmetry might have significance from the astrophysical perspective as well. As of yet, the nature of the non-resonant fusion excitation function for symmetric systems of astrophysical relevance such as ^{16}O+^{16}O, ^{12}C+^{12}C could not be determined from direct measurement. The importance of entrance channel mass asymmetry on the fusion hindrance could be significant for such systems with astrophysical importance.

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Extension of the level scheme of ^{104}Ru and lifetime determination using the Doppler-shift attenuation method[*]

P - 6

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The (p,p'γ) Doppler-shift attenuation method (DSAM) is a powerful tool to determine nuclear level lifetimes in the sub-picosecond range and was established at the Institute for Nuclear Physics at the University of Cologne in recent years [1,2]. The combined particle-γ detector array SONIC@HORUS [3] enables the measurement of p-γ and p-γ-γ coincidences. Hence, knowledge of the complete reaction kinematics is provided and feeding contributions from energetically higher-lying states can be eliminated [4].

Recently, a ^{104}Ru(p,p'γ) DSAM experiment was performed to continue the effort on this isotopic chain up to the most deformed stable ruthenium isotope. More than 60 nuclear level lifetimes could be determined from a single data set. Additionally, the level scheme of ^{104}Ru could be extended by 70 previously unknown excited states and over 100 decaying transitions by investigating the p-γ-γ coincidence data. The profound analysis procedure as well as the extensive results will be presented in this contribution.

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Chiral truncation errors in the p(d,pp)n cross section at E$_d$ = 100 MeV

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The nucleon-deuteron breakup reaction allows us to study details of nuclear dynamics in its whole complexity. From theoretical point of view, the models of nuclear potential arising from the Chiral Effective Field Theory are currently the most sophisticated tools to study nuclear phenomena. Among its various advantages the chiral approach delivers not only the nucleon-nucleon interaction but also a consistent three-nucleon force. However, working with chiral models brings also some disadvantages, like need of additional regularization or working in a perturbative expansion. In practice one neglects contributions from higher orders of such expansion, what introduces additional uncertainty, known as the truncation errors, to theoretical predictions.

In this work we present the Bayesian estimation of the truncation errors for the differential cross section in the deuteron-proton breakup reaction at incident deuteron beam of lab kinetic energy E$_d = 100$ MeV. The choice of the energy and the studied final kinematical configurations is dictated by the ongoing experimental efforts [1].Our predictions are obtained within the Faddeev approach [2].We use the two-nucleon chiral SMS interaction [3] augmented by the three-nucleon force [4] up to the third order of the chiral expansion (N^{2}LO).

In this contribution we investigate 90 kinematical configurations. In Fig.1 we give an example of our predictions for one of configurations defined by directions of momenta of two outgoing protons, and the position on the S-curve which is equivalent to the knowledge of the kinetic energy of one of protons. In general, we find nice convergence of predictions with chiral order with the LO potential overestimating results obtained for the NLO and N^{2}LO. The truncation errors remain below 15%. More detailed discussion of dependence of the magnitude of the cross sections and truncation errors on the outgoing protons' momenta directions will be presented.

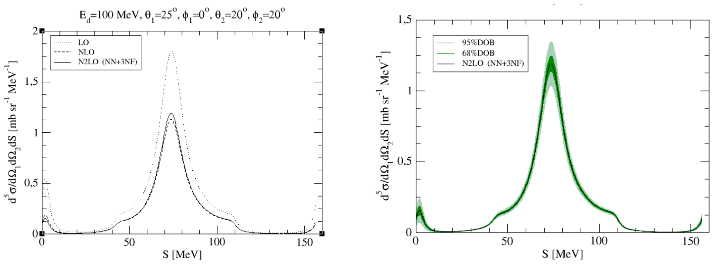

Figure 1: The differential cross section for the p(d,pp)n cross section (left) and its truncation error (right) at $\theta_1 = 15^o, \theta_2 = 0^o, \phi_{12} = 60^o$. Dark (light) green band (in the right panel) represents the truncation errors at 68% (95%) DoB.

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The NEXT Step Towards Neutron-Rich Exotic Nuclides[*]

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P - 8

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At the University of Groningen, we have launched the NEXT project to access Neutron-rich EXotic nuclei through multi-nucleon Transfer reactions and to investigate their properties [1]. Our focus lies on nuclides around $N = 126$ neutron shell closure and in the $Z > 100$ transfermium region, of which we want to study masses and decay properties.

The experimental setup, which will be coupled to the superconducting AGOR cyclotron in Groningen, consists of a solenoid separator, a gas catcher, an ion guide, and a Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS). The primary beam delivered from AGOR will impinge on a rotating target wheel at an energy around the Coulomb barrier. The transfer reaction products will be separated by the solenoid separator according to their magnetic rigidities. The nuclei of interest will be focused into the gas catcher for slowing down and later be transferred to the ion guide for cooling and bunching [2]. Afterwards, the ion bunches will be injected into the MR-ToF MS for the mass measurements [3].

In this contribution, we will present the current status of the NEXT setup and the planned experiment program.

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Ab initio no-core shell model study of carbon isotopes[*]

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The *ab initio* no-core shell-model approach (NCSM) [1], which is a powerful microscopic many-body technique, has opened a new path for understanding the structure of atomic nuclei from the first principles. In the NCSM method, all nucleons are considered active, which means there is no concept of inert core, unlike in the standard shell model. We have studied the nuclear structure properties of $^{10-14}$C, which are known to pose challenges to the *ab initio* methods. To check the predictive power of this *ab initio* nuclear method, we have calculated nuclear observables including proton radii of carbon isotopes corresponding to the recently measured experimental data [2]. The charge-dependent Bonn 2000 (CDB2K), the chiral next-to-next-to-next-to-leading order (N3LO), and optimized next-to-next-to-leading order (N^{2}LO$_{opt}$) NN interactions are employed in our work. Typically, the three-body forces are required to correctly reproduce the experimental ground state (g.s.) spin 3^+ of ^{10}B with the NCSM calculations [3]. In our recent work [4], we have reproduced the spin of the aforementioned state using the inside non-local outside Yukawa (INOY) *NN* interaction only. Success of this interaction encourages us to implement it for the study of carbon isotopes. We have reached basis sizes up to $N_{\max} = 10$ for ^{10}C and $N_{\max} = 8$ for $^{11-14}$C with m-scheme dimensions up to 1.3 billion.

Energy of excited states for carbon isotopes approach the experimental value with increasing basis size. The 0_2^+ state (Hoyle state) of ^{12}C is predicted at high excitation energy even for the $N_{\max} = 8$ basis space calculation, which indicates that optimal frequency for convergence of this state could be different from the optimal frequency of g.s. The energy of $1^+; T = 0$ and $1^+; T = 1$ states of ^{12}C from *ab initio* calculations are in remarkable agreement with the experimental data. In these NCSM calculations, two-body OLS transformation method has been used that renormalizes the short-range correlations of the CDB2K, INOY and N^{3}LO interactions and short-range operators, while long-range operators are weakly renormalized. Hence, to account for long-range correlations in the two-body cluster approximation, one needs to enlarge the model space. E2 operator has r^2 dependence, *i.e.* it is a long range operator, and M1 is independent of r, so, we have studied the behavior of these effective operators on NCSM parameters (basis size N$_{\max}$ and harmonic oscillator frequency $\hbar\Omega$). We found that B(E2) curves converge slowly in an oscillator basis expansion, while the B(M1) converges quickly and accurately. Furthermore, point-proton radii is also a long-range operator which is also sensitive to the tail of the nuclear wave function. We obtained the converged radii for INOY and N^{3}LO interactions as 2.11 and 2.34 fm, respectively, for ^{12}C from the variation of r_p curves with the NCSM parameters. We have noted that radii obtained from the N^{3}LO interaction is close to the experimental data. We also observe that optimal frequency corresponding to radii could be different from that obtained from minima of g.s. energy. The INOY interaction gives a reasonable description of energy for g.s. and excited states, and B(M1) transition strengths and magnetic moments. We have also predicted quadrupole and magnetic moments for some states of $^{10-14}$C using the NCSM calculations, where the experimental data are not available. Our theoretical study will be helpful for future experiments.

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Investigation of rare nuclear decays - double gamma decay in ^{137}Ba nucleus

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Double-gamma decay is a rare nuclear decay process, firstly investigated in 1930 by Maria Goeppert in her doctoral thesis [1]. In the double-gamma decay, an excited nuclear state decays over an intermediate virtual state to a lower-lying state and emits two photons in coincidence. Sum energy of the two photons is equal to the transition energy. So far this mode of decay was observed in nuclei such as ^{90}Zr [2], ^{40}Ca [2] and ^{16}O [3], for which single photon decay is forbidden and just in one case when it is competitive to single gamma decay for ^{137}Ba [4,5,6]. This unsatisfactory situation is due to experimental problems with measuring the two-photon decay if a single-photon decay is allowed (as in ^{137}Ba case). For $0_2^+ \rightarrow 0^+$ transition, a single-photon decay is forbidden by angular momentum conservation. In addition, the nuclei ^{16}O, ^{90}Zr and ^{40}Ca have it in common that the 0_2^+ state is also the first excited state. One can excite this state selectively and therefore it is not necessary to deal with the one-photon decays of other excited states.

We will introduce the setup designed for studying double γ-decay process at IFJ PAN, with use of PARIS CeBr$_3$-NaI phoswiches. Then we will show GEANT4 simulations which characterize experimental setup, and confirm their relevance with comparison with collected data. Finally, we will present measured energy spectrum for the case of ^{137}Ba $11/2^- \rightarrow 3/2^+$ double γ transition for various conditions used to suppress background. Deduced $\gamma\gamma/\gamma$ branching ratio will be compared with the ones from Refs. [4,5,6].

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System size effects on the energy of onset of vaporization

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We have investigated the energy of onset of vaporization. For this we have studied the ^{16}O + Br and ^{16}O + Ag collisions at various energies ranging from 10 to 220 MeV/nucleon as emulsion data is available for these collisions. Jakobsson *et al.*, [1] have studied the average charge of fragments in this emulsion data. We have used Quantum Molecular dynamics (QMD) [2] model to study the phenomenon of vaporization. The QMD model generates the phase space of nucleons and next clusterization of nucleons is required to identify the fragments. At first, we used minimum spanning tree (MST) method to produce fragments. This method didn't reproduced the data very well at lower energies, so next we used Simulated Annealing Clusterization Algorithm (SACA) [3] for making fragments. Using SACA a good agreement between available data and calculated results is obtained which shows model is good enough to study the phenomenon of vaporization. For examining the phenomenon of vaporization we looked into the average charge of the fragments and it is inferred that when average charge approaches unity then nuclear vaporization has started. Further, we investigated the system mass effects on the energy of onset of vaporization. For this we have chosen four systems which are ^{40}Ca + ^{40}Ca, ^{84}Kr + ^{84}Kr, ^{132}Xe + ^{132}Xe and ^{197}Au + ^{197}Au i.e, from lighter to heavier. It is noted that average charge as observable do not give clear picture of system size effects on the energy of onset of vaporization. However, it can be said that for all systems nuclear vaporization starts above or near 150 MeV/nucleon. This work is still in progress and we are searching for more observables which can give clear picture.

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Collective bands in ^{156}Dy

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A collective band of positive as well as negative parity in ^{156}Dy are composed of vibrational and rotational collective modes. The octupole vibrational configurations can be based either on axial or nonaxial octupole phonon excitations. A consistent approach applied to the quadrupole and octupole collective vibrations coupled with the rotational motion enables us to distinguish between various scenarios of disappearance of the E2 transitions in negative-parity bands observed till now in several nuclei. The theoretical estimates which are going to be presented are compared with the very recent experimental energies and transition probabilities in and between the ground-state and low-energy negative-parity bands in ^{156}Dy nucleus. A realistic collective Hamiltonian contains the potential-energy term obtained through the macroscopic-microscopic Strutinsky-like method with a particle-number-projected BCS approach and a deformation-dependent 'cranking' mass tensor. The potential energy and the inertia parameters are defined in the vibrational-rotational, 9-dimensional collective space of the multipole-deformation parameters and Euler angles. The so called symmetrization procedure, based on the group-theory considerations, applied to the eigenstates of the collective Hamiltonian ensures their uniqueness with respect to the laboratory coordinate system. This quadrupole-octupole collective approach may also allow us to find and/or verify some fingerprints of possible high-rank symmetries in nuclear collective bands.

Development of the eLBRUS UHV accelerator system for studying nuclear reactions at very low energies*

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Nuclear reactions at very low energy (i.e in the energy range of a few keV) are difficult to comprehend due to the interplay of multiple physics processes related to solid-state, atomic, molecular and nuclear physics. Since 2015, dedicated research studies have been carried out at the 20 keV Ultra High Vacuum (UHV) Accelerator Facility in the laboratories of the University of Szczecin, Poland [1].

Recently, a new deceleration lens and beam transport system was installed to increase the beam current on the target at energies even lower than 1 keV. The upgraded system will allow to operate the Electron Cyclotron Resonance ion source at higher voltages and reduce the energy of accelerated ions immediately before the target chamber to decrease the beam contribution of neutral particles and supress the defocusing effects resulted from the beam volume charge.

The main focus of this one-of-a-kind UHV facility will be devoted to study proton and deuteron induced reactions on light nuclei and an enhancement of the corresponding cross sections due to the electron screening effect resulting in part from the crystal lattice defects of the target materials. Both phenomena could be previously demonstrated for the deuteron-deuteron (DD) reactions taking place in metallic environments [2] and have a large impact for construction of new energy sources based on the nuclear fusion [3]. The new experiments also show that the DD reactions at very low energies are dominated by the 0^+ threshold resonance in the compound nucleus He^4. For the first time, the decay of this resonance by the electron-positron pair creation has been lately observed [4]. However, it is expected that the experiments at the deuteron energies below 5 keV could deliver much more precise information about the resonance branching ratios and its partial widths.

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Study of fast-neutron-induced fission for ^{238}U with SCONE at NFS

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Much remains to be discovered about fission, a complex process involving extreme deformations. Within this scope, neutron-γ competition is highly informative. Notably, it is related to angular momentum generation in fission, a phenomenon brought to light exactly fifty years ago [1] but for which there is still no consensus on the underlying mechanisms [2]. While recent works focus on γ-spectroscopy [3] and isomeric ratio [4], few γ-calorimetry data are available for fast-neutron-induced fission. As far as we know, merely ^{232}Th, ^{235}U and ^{237}Np were explored up to 15 MeV [5].

In November 2021, an experiment was carried out on ^{238}U target with NFS (*Neutrons For Science*), a new neutron research facility at GANIL. The experiment involved for the first time SCONE (*Solid Counter Of NEutrons*), a large modular gadolinium-loaded plastic scintillator. The interest of this set up lies in the unique NFS neutron beam flux, extremely intense from 1 MeV to 40 MeV, and the high neutron detection efficiency of SCONE together with its ability to be a γ-calorimeter.

In this presentation, an overview of the experiment as well as the preliminary results are shared. Prompt neutron multiplicity distributions are fully unfolded by a Tikhonov-inspired regularization. Thereby, the results go beyond the first moments [6] or predefined skew normal distributions [7]. Moreover, the total γ-energy released by fission is plotted against the incident neutron energy. Together, these observables might be innovative inputs for neutron-γ competition models.

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Study of the radiative decay of ^{252}Cf fission fragments

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This work focuses on measuring the prompt γ-spectra emitted by $^{252}\mathrm{Cf}$ spontaneous fission fragments to gain insights on the γ strength function (γSF) and nuclear level density (NLD) in the neutron-rich region. The experiment was performed for 6 months with a 4π-NaI array and a Frisch-gridded twin ionization chamber[1]. The FGTIC is used as a fission trigger and measure both fragments kinetic energies, hence their masses. To get the best of the FGTIC an ultra-thin ($5\ \mu\mathrm{g/cm}^2$) $^{252}\mathrm{Cf}$ source was prepared by self-transfer for a two-year period resulting in a resolution of 0.7 (FWHM) on the fragments masses for events without neutron emission. The charge indetermination of the primary fragments was partially lifted by selecting one of the two primary fragments by long-lived isomeric transitions (from tens of nanoseconds to several microseconds). The measured prompt γ-spectrum selected by an isomeric transtion represent the decay to the isomer and the 3-4 possible complementary primary fragments cascades.

29 isomers have been identified, mainly distributed in two regions: around $\mathrm{A} = 96$ (prolate deformation) and the double shell closure of $\mathrm{Z} = 50$ and $\mathrm{N} = 82$. The first preliminary results presented here will focus on the evolution of the prompt γ-spectra through the isomers, isotopic and isotonic chains as well as multiple kinetic selections. First comparisons with simulated spectra from FIFRELIN [2] using different models for the γSF and NLDs will be shown.

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One-neutron removal cross sections for the ^{16}N isomeric state

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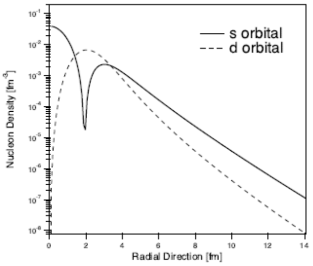

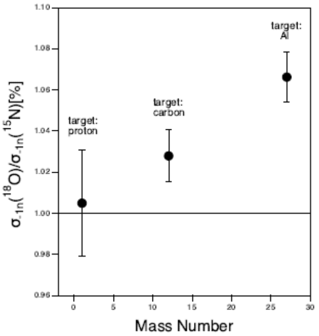

The enhancement of halo neutron removal cross sections in neutron halo nuclei is well known and is one of the evidences for the neutron halo structure. We have measured neutron removal cross sections for several exotic light nuclei to reveal their characteristic neutron-halo-like structures [1]. The difference in the nuclear structure between the ground and the isomeric state of $^{16}\mathrm{N}$ can be explained by the orbitals in which the valence neutron is sitting. Considering the spin and parity, the valence neutron is considered to be mainly occupying the $1\mathrm{d}_{5/2}$ orbital in the ground state and the $2\mathrm{s}_{1/2}$ orbital in the isomeric state. Therefore, the valence neutron in the $^{16}\mathrm{N}$ isomeric state, with effects of $2\mathrm{s}_{1/2}$ orbital and its relatively small neutron-separation energy of 2 MeV, can be distributed more broadly in the radial direction. Upper figure shows the calculated nucleon density distributions of $^{16}\mathrm{N}$ valence neutrons using the single-particle model. The spread of the density distribution depends on which orbital the valence neutron resides in. Therefore, the $^{16}\mathrm{N}$ isomeric state is a candidate for neutron halo nucleus. The halo nucleus in the excited state has not been observed directly with experimental evidences.

In the present study, we measured one-neutron removal cross sections using secondary beams of $^{16}\mathrm{N}$ with a mixture of ground and isomeric states. We used two types of primary beams, $^{15}\mathrm{N}$ and $^{18}\mathrm{O}$, to produce $^{16}\mathrm{N}$ beams with different isomeric ratios, and compared the one-neutron removal cross sections measured with each secondary beam. The experiments were carried out at the HIMAC heavy ion synchrotron facility at National Institute for Radiological Sciences (NIRS), Japan. The experimental results (lower figure) show that the neutron removal cross section obtained from a $^{16}\mathrm{N}$ beam with a large isomeric ratio, which was produced from $^{18}\mathrm{O}$, is large compared to that obtained with a $^{16}\mathrm{N}$ beam with a small isomeric ratio produced from $^{15}\mathrm{N}$. This results suggest that the $^{16}\mathrm{N}$ isomeric state is considered to have a neutron-halo-like structure.

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Algebraic Generator Coordinate Method for mixed states

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In the standard Generator Coordinate Method (GCM) the main ansatz is that the trial functions are continuous superpositions of some generating functions $|\psi(\alpha)>$, which are labeled by the parameters $\{\alpha\}$ called the generator coordinates. In this way one generates the space of states from a family of pure staqtes.
However, the hot nuclei, to describe them microscopically, the state space should be generated from the quantum density operator dependent on temperature.
The Algebraic Generator Coordinate Method (AGCM) seems to be the appropriate tool for this purpose. We derive generalization of the Griffin-Hill-Wheeler equation widely exploited in nuclear physics for the temperature $T = 0$.

Supervised event classification in an Optical Time Projection Chamber*

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Time Projection Chambers (TPC) provide a wide range of applications in nuclear physics. One of them is the study of the radioactive decay of exotic nuclei emitting charged particles. A powerful technique for such studies was developed at the University of Warsaw based on the use of a TPC with optical read-out (OTPC) [1,2]. The light produced in the amplification stage of the detector, composed of several gas electron multipliers, is registered by a CCD camera and a photomultiplier tube. This information allows the full 3D reconstruction of the tracks of the charged particles emitted by the nuclei [3].

The search for rare events in decay experiments with a TPC is many times constrained by the difficulties in classifying the registered signals. On the one side, the identification of a rare decay branch among the huge amount of data typically recorded, may be like looking for a needle in a haystack. On the other hand, sometimes the fingerprint of such an exotic branch happens to be very similar to some background or to other decay branches.

In this contribution we will present the application of Machine Learning (ML) algorithms to classify events registered with the OTPC detector. Such techniques are increasingly used in nuclear and particle physics and they have already proved their applicability to other TPC set-ups [4,5]. In our case, supervised algorithms based on Monte Carlo (MC) simulations are used to classify the events. The OTPC signals used for training the ML models are simulated by means of the GEANT4 simulation package [6], including realistic noise and resolution effects.

We have applied these new methods for the study of the decay of ^{11}Be, the most promising candidate to observe the rare $beta^-$-delayed proton emission [7]. The charged-particle decay of ^{11}Be is dominated by the emission of alphas [8] and the possible proton branch is expected to be several orders of magnitude weaker [9,10]. In addition, there is also a $beta^-$-delayed tritium channel open. In this work, we will show how ML models allowed us to successfully classify the signals from these three channels. Finally, these trained models have been applied to real data from an experiment performed with the OTPC at ISOLDE that searched for the $beta^-$-delayed proton branch [11,12].

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Signature of hexadecapole deformation in the synthesis of superheavy elements via hot and cold fusion processes

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The heavy-ion induced reactions are used as a probe to study the fusion-fission related nuclear phenomena. The fusion dynamics is influenced by many factors such as entrance channel mass-asymmetry parameter, excitation energy, angular momentum, deformations, and orientations. In the present work, we are focused on the deformations and orientations of the colliding nuclei. These degrees of freedom play an important role in the synthesis of superheavy elements (Z = 104-120) through two processes viz. cold and hot fusion, occurs at different scale of excitation energy, i.e. E^*_{CN} = 10-20 MeV and 35-45 MeV, respectively. These ranges of E^*_{CN} correspond to the incident energy $E_{c.m.}$, which may spread across the Coulomb barrier [1]. For the production of new elements at these energy ranges, ^{48}Ca (nearby nuclei)-induced and ^{208}Pb (or ^{209}Bi)-based reactions have been considered. In former works [2], the significant effect of quadrupole deformed nuclei has been investigated in synthesizing superheavy elements. In the present work, we explore the importance of higher-order deformation (up to hexadecupole deformation β_4) for the above mentioned reactions, at the below and above barrier energies. Also, the effect of signs and magnitude of β_4-deformation is examined, by considering $\beta_2^+\beta_4^+$, $\beta_2^+\beta_4^-$, $\beta_2^-\beta_4^+$ and $\beta_2^-\beta_4^-$ shapes of hexadecupole deformed nuclei. The involvement of β_4^+ and β_4^--deformations in $\beta_2^\pm$ expands and compresses the hexadecupole deformed shapes, respectively. Subsequently, in reference to the β_2-deformation, one can find the enhancement and hindrance in the capture cross-sections ($\sigma_{cap.}$), respectively, due to + and - signs of β_4-deformation. Also, the calculation of $\sigma_{cap.}$ using extended ℓ-summed Wong model [3] gives better agreement with the available experimental data of ^{30}Si, ^{34}S and ^{48}Ca+^{238}U reactions [4-6] at the below- and above-barrier energies, respectively, due to the cold and hot optimum orientations of β_4-deformation of target nuclei.

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Exploring entrance channel effects in the interaction of ^{16}O with ^{93}Nb

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The heavy-ion induced reactions in intermediate mass target regions are complex in nature, even at low energies [1-2]. Thus more experimental data are required to bring out a clear understanding of these reactions. In view of this, the present work manifests the experimental study of ^{16}O projectile with ^{93}Nb target at energies $\approx$ 4-7 MeV/nucleon using the offline γ-ray spectroscopy. A systematic analysis of the complete and incomplete fusion (CF-ICF) dynamics has been carried out by comparing the measured excitation functions with the statistical model code PACE4. The entrance channel mass asymmetry, α-Qvalue, projectile energy, coulomb interaction and neutron excess of projectile are some important entrance channel parameters, which play significance role in ICF dynamics. In order to study the incomplete-fusion behavior with various entrance channel parameters, the incomplete-fusion fraction (F_{ICF}) has also been deduced and compared with those obtained for the systems available in the literature. The present work explores the role of Coulomb interaction on ICF dynamics more effectively. Moreover, the projectile α-Q value is found to be a suitable parameter which explains effectively the role of projectile structure on ICF. The existence of ICF below critical angular momentum is also anticipated for the present work.

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Fingerprints of different fission modes in sub-lead Au-nuclei*

P - 21

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Interaction of a heavy projectile (A$>$4) with a heavy target (A$>$120) leads to several nuclear processes, namely, quasi-fission, fusion, fast-fission, etc., depending on the projectile's energy and entrance channel parameters. The fusion of a large number of nucleons results in a massive equilibrated compound nucleus (CN) which undergoes de-excitation through evaporation of neutrons, protons, alphas, etc., in competition with fission. Fission fragment mass distribution (FFMD) is a tool to understand fission observable for a better understanding of the fission dynamics. Recently, the unexpected observation of asymmetric splits for ^{180}Hg [1] developed a great interest in investigating the fission dynamics of sub-lead region (new island of asymmetric fission) nuclei. Several studies revealed the existence of different fission modes (symmetric and asymmetric) through the distributions.

In this work, the study of mass distributions of the fission fragments, obtained through the de-excitation of neutron-deficient (N/Z = 1.44) ^{193}Au CN, has been studied. We have performed an experiment at the 14UD BARC-TIFR Pelletron Accelerator facility, Mumbai, India, bombarding ^{12}C projectile on ^{181}Ta target within excitation energies 39-53 MeV. A total of 12 fission fragments having mass numbers within the range of 71-135 u have been verified by estimating their half-lives. The Gamma-spectrometry method was utilized to extract the cross section information of the fission fragments. A single Gaussian fit of the mass distribution at each excitation energy gave an impression of only symmetric (super long) fission mode. A similar kind of situation was encountered while fitting mass distribution for ^{191}Au [2], but considering the fluctuations at the middle of the mass distribution revealed the appearance of asymmetric fission modes. By considering this fact, for the present study, theoretical estimations for the mass widths' determination, based on the Liquid drop model (LDM) [3], have been performed. Theoretical mass width depends on several parameters, which mainly include the mass number of the CN, effective temperature of the nucleus at the saddle point, and mean square angular momentum $< \ell^2 >$ which was evaluated by CCFULL calculations considering the rotational couplings of ^{181}Ta target. Consequently, the enhancement registered in the experimental mass widths compared to the theoretical outcomes hinted at the presence of both asymmetric modes and symmetric modes. However, the signature of persistent asymmetric fission modes along with symmetric mode is seen throughout the measured excitation energy range.

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Designing a BGO active shield for DEGAS

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The new DEspec Germanium Array Spectrometer (DEGAS) is among the most advanced gamma-ray spectrometers to date and is being used for nuclear spectroscopy experiments at GSI/FAIR [1]. DEGAS includes BGO scintillation detectors for active shielding in order to improve the sensitivity of its high-purity germanium (HPGe) detectors.

Compton-scattered photons present a major source of spectral noise in most gamma-ray spectrometers, because only a part of the energy from an incident photon is measured. The BGO detectors have a very high gamma-ray detection efficiency and can suppress such background by operating in an anti-coincidence veto mode with the germanium spectrometer. Thus, incomplete energy measurements are discarded from the HPGe energy spectra, making detection of rare isomer decays less challenging. Simulations suggest it could be possible to achieve a background suppression of up to 40% for all of the 28 modules of the DEGAS array (84 germanium and 84 BGO crystals) [2].

Our work started with simulations to determine the positions and the optimal number of silicon photomultipliers (SiPMs) to be used with each BGO crystal. This was followed by the circuit board design process with several iterations of readout electronics. The completed system now achieves the desired energy ($< 30\%$ FWHM@511keV) and timing resolutions (~ 30ns @511keV) needed for the operation in the DEGAS spectrometer, with just eight 6×6 mm^2 SiPMs on each BGO crystal. In order to maintain the flexibility and modularity of DEGAS, we designed the readout electronics for the SiPMs to be compact and energy efficient with a very low power consumption.

Recently (in May 2022) the DEGAS array was used in a decay spectroscopy experiment as part of the FAIR-0 experimental campaign, with one detector cluster equipped with three BGO prototypes. The results are still preliminary, but early analysis shows a promising background suppression of up to $\sim 8\%$ in the raw HPGe spectrum.

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Neutron emission in low-energy nuclear fission in framework of the Fourier shape parameterization

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In this work, the study of neutron evaporation from a compound nucleus and primary fission fragments for cases of low and medium excitation energy (E^* up to 30 MeV) fission of actinide nuclei were performed. The main task was the calculation of the excitation energy, release of which can be transferred to fission collective motion. The description of the process of fission of compound nucleus were provided within the framework of the statistical approach, specifically the multidimensional system of Langevin equations, where the geometry of the nucleus was specified by Fourier parametrization [1]. The potential energy surfaces of the studied system were calculated within the framework of the Lublin-Strasbourg Drop model [2] and the folded-Yukawa single-particle potential [3]. It is assumed that in cases of fission, when the excitation energy of the compound nucleus with $T \lesssim 1$ MeV, the probability of neutron emission is small and, therefore, excited fission fragments are the main source of neutrons. For this, the excitation energy was determined for the case of the process of fission of a compound nucleus, which, after decay, was distributed among the primary fragments. Their deformations were determined by the so-called general deformation parameters first introduced in [4], and the energy carried away by neutrons was associated with a Monte Carlo-type procedure, where Master equation for the energy were calculated using the Weisskopf-type formula [5]. In the case when the temperature of the composite fissile system reached the threshold value, a similar calculation procedure was carried out, but for the compound nucleus.

The obtained results made possible to improve the mass (FMD) and total kinetic energy (TKE) distributions of fission fragments for the studied fission types, which demonstrates closeness to analogous empirical values.

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XRD and PAS investigations of deuteron irradiated zirconium samples

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LENR phenomena are known to be extremely dependent on the local crystal structure and crystal defects of the deuterated samples. This has a strong influence on both hydrogen diffusion and the effective electron mass. The latter determines the strength of the local electron screening effect [1]. The latter determines the strength of the local electron screening effect [1] and can change the deuteron-deuteron reaction rates at thermal energies by many orders of magnitude [2].
In the present study, Zirconium samples were exposed to various conditions and energies of deuteron beams using the unique accelerator system with ultra-high vacuum, installed in the eLBRUS laboratory at the University of Szczecin [3]. Irradiated and virgin samples were investigated by means of the X-ray diffraction (XRD) and positron annihilation spectroscopy (PAS) [4]. Whereas the first method delivers information about changes of crystal lattice parameters and possible production of hydrides [5,6] accompanying the formation of dislocations that are produced during irradiation of the samples, the second one can determine the depth distribution of crystal defects, being especially sensitive for vacancies. Both investigation methods show structural changes of the Zr samples. The number of vacancies produced by deuterons are comparable to that observed by carbon or oxygen irradiations. The target structure modifications at the surface of the samples could be also confirmed by the scanning electron microscopy (SEM). The presented diagnostic methods will be applied in the future studies to correlate the number of crystal defects and changes of crystallographic parameters with the increase of the deuteron-deuteron nuclear reaction rates.

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Competing incomplete fusion and transfer processes in ^{6}Li + ^{181}Ta reaction[*]

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The study of the fusion mechanism with weakly bound projectiles (WBP) helps to gauge the underlying physics of reactions with RIBs. As a matter of fact, the WBPs such as ^{6,7}Li and ^{9}Be have been pervasively used in the last two decades to establish a firm understanding of different reaction processes involved in the reactions with these beams[1]. Researchers around the globe have observed processes like complete fusion, non-capture break-up, incomplete fusion (ICF), transfer, transfer followed by break-up, etc., with such beams on different mass targets. Transfer processes have been found competing with ICF at energies around the Coulomb barrier [2,3]. In our study of ^{6}Li reaction on ^{181}Ta, we try to look at these two competing processes around the coulomb barrier. The experiment was performed using ^{6}Li beams upto 43 MeV delivered by the 14UD BARC-TIFR Pelletron facility, Mumbai, India, which were bombarded onto the foils of ^{181}Ta (backed by ^{27}Al) with 1.4-2.4 mg/cm^{2} (1.6-1.9 mg/cm^{2}) thickness stacked up and facing the beam. The γ-ray spectroscopy method was used to identify ERs, and the residual cross-sections were measured.

The measured excitation functions of the residues ^{183g,183m,182}Os (via xn), ^{183}Re (pxn), and ^{183,182m2,180}Ta (αpxn) were compared with the theoretical estimations from EMPIRE 3.2.2 code. EMPIRE uses the Hauser-Feshbach formalism for compound nucleus (CN) cross-section evaluation and the Exciton model for the pre-equilibrium part. It caters various level density options, viz. Gilbert-Cameron, generalized superfluid model (GSM), and enhanced genralized superfluid model. We observe a satisfactory agreement between the experimental cross-sections and EMPIRE (with GSM level density) computed ones for residues populated via xn and pxn channels. However, a copious enhancement in experimental cross-sections over the theoretical calculations has been noted for residues obtained via the αpxn channel. The first explanation for this enhancement could be the incomplete fusion of remnant fragment after the break-up of ^{6}Li projectile into α+d (breakup threshold: 1.47 MeV). The fusion of d into the ^{181}Ta target will form ^{183}W CN which can subsequently decay through proton emission to form Ta residues. The variation of ICF fraction (F_{ICF}) reveals that F_{ICF} has a parabolic shape, and it varies between 1-7% in the whole energy range. It has been learned from the literature that the ICF fraction increases with incident energy [4], but for the present case, we observe that F_{ICF} increases with decreasing energy below 34 MeV. The presence of another process is demanded to explain the observed peculiarity, and the most suited candidate turns out to be the neutron transfer process. One neutron transfer may lead to formation of ^{182m2}Ta (Q_{gg}= -0.34 MeV)and ^{180}Ta (Q_{gg}= 0.4 MeV) residues since one-neutron transfer has been found to be a competing process in reactions with Li beams around the barrier. The production of ^{183}Ta via the transfer process is quite not expected due to the very large negative Q-value. So, it is more likely to be produced via the ICF process. Thus, the study demonstrates that incomplete fusion and transfer are two dominant competing processes in the ^{6}Li+^{181}Ta reaction.

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Incomplete fusion dynamics studies for ^{14}N + ^{169}Tm[*]

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The study of incomplete fusion dynamics remain elusive around the Coulomb barrier energies due to their complexity below 10 MeV/nucleon [1]. In order to probe the incomplete fusion dynamics, the spin-distribution of evaporation residue populated in the system ^{14}N + ^{169}Tm at energy 5.86 MeV/nucleon have been measured using particle-γ coincidence technique [2-4]. The spin-distribution of evaporation residues (direct-α/2αxn-channels) populated through the incomplete fusion reaction mode are found entirely different than that observed for complete fusion (fusion-evaporation xn/αxn-channels). In case of complete fusion, spin-distribution of evaporation residue shows normal de-excitation (transition yield falls exponentially with the higher spin states) pattern of compound nucleus, however, in the case of incomplete fusion the yield is constant up to certain spin states and falls sharply with the higher spin that indicates lower spin states are hindered in incomplete fusion. Moreover, the input angular momentum associated with direct-α/2αxn-channels are found to be slightly higher than the fusion-evaporation xn/αxn-channels and increases with the direct α-multiplicity. The spin-distribution results in the system ^{14}N + ^{169}Tm at energy 5.86 MeV/nucleon will be presented in detail.

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Collectivity in Erbium[*]

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P - 27

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The nature of low-lying excitations, K$^{\pi} = 0^{+}$ bands in deformed nuclei remain enigmatic in the field, especially in relationship to quadrupole vibrations. One method of characterizing these states is by reduced transition probabilities, B($E2$) values, a measure of the collectivity. These values can be measured directly by Coulomb excitation or calculated from measured lifetime values. Within the deformed region, there are five stable Er isotopes, one of which has been studied intensely in search of quadrupole vibrations (^{166}Er). The neighboring isotope, ^{168}Er is the focus of this work. We have examined ^{168}Er with the $(n, n'\gamma)$ reaction and neutron energies up to 3.0 MeV to confirm known 0^{+} states. Angular distributions at three different neutron energies were performed to determine their lifetimes through DSAM measurements. Gamma-ray excitation functions, angular distribution, and lifetime measurements will be presented and compared with the other Er isotopes

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Transfer reactions with the active target ACTAR TPC

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Transfer reactions are selective tools to identify single-particle orbits and have been extensively used to study the underlying nuclear structure. Traditionally, transfer reaction experiments were performed with solid targets combined with complex devices that suffer from limited luminosity for radioactive beams. Active targets, where the gas works both as target and detection medium, are exceptional devices that allow to overcome the experimental limitations without losing resolution.

In 2022 we performed the first transfer experiment with ACTAR TPC [1,2] at GANIL to study the spin-orbit splitting in neutron-rich Oxygen isotopes. Additionally the goal of this experiment was to test the feasibility of transfer experiments with ACTAR TPC.

The GANIL facility provided a pure ^{20}O beam that was selected with the LISE3 spectrometer. The gas consisted of a mixture of D_2 and C_4H_{10}, which was equivalent, in terms of targets number, to the use of a 5 mg/cm^2 of CH_2 and 10 mg/cm^2 of CD_2, at the same time. The particles of interest escaped the active volume, and an array of silicon detectors was used to measure the residual energy. The reconstruction of the tracks inside the target allows to measure in an event-by-event basis the interaction point and thus improving significantly the final resolution [3,4].

In this talk, I will present the preliminary particle identification, the reconstructed E_x spectrum and the differential experimental cross sections for different channels measured in the experiment. Additionally, I will discuss the improvements of our technique with respect to the standard methods.

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Isomers and octupole correlations in transitional nuclei beyond ^{208}Pb

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The reflection-asymmetric pear shape in nuclei is characterized by the appearance of interleaved states of opposite parities connected by enhanced electric dipole transitions [1]. In the $A \sim 220$ region, the presence of proton and neutron orbitals with $\Delta j = \Delta l = 3$ near the Fermi surface gives rise to strong octupole correlations in nuclei with $Z \sim 88$ and $N \sim 134$. The nuclei with stable quadrupole and octupole deformation exhibit rotational-like alternating parity sequences with large $B(E1)/B(E2)$ ratios ($\sim 10^{-6}\ fm^{-2}$). However, in the case of lighter nuclei where deformation is not fully developed, near-constant transition energies and spin-dependent staggering of $B(E1)/B(E2)$ ratios are observed [2]. The octupole correlations begin to emerge in nuclei with $Z \geq 87$ and $N \geq 129$ above the shell closures. Parity doublets, which are a clear signature of octupole correlations in odd-A and odd-odd nuclei, were recently reported in ^{216}Fr ($Z = 87$ and $N = 129$) at intermediate energies [3]. Also, ^{217}Ra ($N = 129$ isotone of ^{216}Fr) displays the evidence of octupole collectivity as two out of the three sequences observed at low excitation energies are connected by enhanced $E1$ transitions [4]. Since these nuclei lie in the transitional region between the shell closure and the deformed region, the interplay between single-particle and collective modes of excitations leads to complex level structures. It is well known that the isomeric states play a pivotal role in elucidating important aspects of nuclear structure as well as to test the applicability of various nuclear models. Thus, the presence of isomers in the transitional nuclei and their decay properties are expected to provide more insight into the evolution of collectivity in this region.

In order to investigate excited states in ^{216}Fr, an experiment was performed at IUAC, New Delhi. The detailed information concerning the experimental setup and the data analysis procedures is discussed elsewhere [5]. Three new isomers, one at low excitation energy and two at high excitation energy, were identified in ^{216}Fr. The half-lives of these isomeric states were extracted using centroid-shift and decay-curve analyses. The properties of the low-lying (11^+) isomeric state were compared with that of the similar isomeric state in neighboring doubly-odd nuclei. Also, large scale shell-model calculations were employed for a more quantitative understanding of the isomeric state and the states to which it decays. The simultaneous presence of isomers at low- and high excitation energies hints at a pronounced change in structure above the intermediate states, where octupole correlations were observed. In addition, another experiment was performed to study high-spin states in ^{217}Ra and the preliminary data analysis suggests a striking similarity in the level structures of the $N = 129$ isotones. The detailed experimental results will be presented and discussed in the conference.

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Are "β" bands triaxially superdeformed bands?

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P - 30

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The search for Triaxial Superdeformed (TSD) bands in the N$\sim$90 isotones has been a subject of interest for the past two-three decades [1-7]. The focus on these studies has been mainly confined to ultra-high spin states. In these studies, high spin structures with enhanced deformation have been reported and associated with the phenomenon of Triaxial Superdeformation.

The phenomenon of TSD bands has recently become more interesting as recent theoretical predictions in the same region (N$\sim$90 isotones) suggests that the phenomenon of TSD bands may also be found at low spin, with 0^+ states or the so-called β band being the most promising candidate.

In this work, we present a comprehensive dataset comprising of low-lying positive parity bands (β and γ bands) in even-even isotopes with N $\sim$ 88 to 92 and proton numbers Z $\sim$ 62 (Sm) to 70 (Yb). The data are compared with the solutions of the five-dimensional collective Hamiltonian (5DCH) based on the covariant density functional theory (CDFT). The results of this comparison are presented here and the implication on the interpretation of the first excited 0^+ states is there from discussed.

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Pairing dynamics in nuclear reactions

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We present results of collisions of medium mass nuclei, ^{90}Zr+^{90}Zr and ^{96}Zr+^{96}Zr obtained within time-dependent density functional theory (TDDFT) extended to superfluid systems, known as time-dependent superfluid local density approximation (TDSLDA). We discuss qualitatively new features occurring in collisions of two superfluid nuclei at energies in the vicinity of the Coulomb barrier. We show that a *solitonic excitation*—an abrupt pairing phase distortion—reported previously [1], increases the barrier for capture generating effective repulsion between colliding nuclei. Moreover we demonstrate that pairing field leads to qualitatively different dynamics at the Coulomb barrier which manifests itself in a slower evolution of deformation towards a compact shape. Last but not least, we show that magnitude of pairing correlations can be dynamically enhanced after collision. We interpret it as a dynamically-induced $U(1)$ symmetry breaking, which leads to large-amplitude oscillations of pairing field and bear similarity to the pairing Higgs mechanism.

Pairing correlations in nuclear systems are one of the best known characteristics of non-magic atomic nuclei [2-4]. Various features related to high spin phenomena, indicate that these correlations are crucial for our understanding of nuclear structure and dynamics. Pairing in atomic nuclei is usually theoretically described on a mean-field level, where the concept of pairing field plays the key role. It implicitly assumes the existence of superfluid phase described by the complex field playing the role of the order parameter. Although the average magnitude of this field is an important ingredient of any theoretical description of medium or heavy nuclei, the other features related to this degree of freedom are usually omitted in the context of nuclear dynamics. These features include spatial modulations (oscillations) of the order parameter, where both the magnitude and the phase may vary in space and time.

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Study of spontaneous fission half-lives in actinide and superheavy nuclei

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Study on the half-lives of the spontaneous fission processes of doubly even actinide and superheavy elements in the range of Z=90 to Z=110 within the semiclassical WKB framework is performed, where the dynamical least-action fission path in 4D Fourier deformation space includes nuclear elongation, mass asymmetry, neck and nonaxiality degrees of freedom. This path is defined by an appropriate Fourier decomposition whose amplitudes are treated as variational parameters to minimize the action integral. This method is an efficient alternative to often used polyline method which seems to be effective in low dimension (e.g. 2D) deformation spaces and getting more and more demanding in 3 or 4D spaces.
The fission barrier is based on the Lublin-Strasbourg Drop (LSD) approach while the microscopic shell effects are taken into consideration within the Strutinsky and projected BCS methods. The spontaneous fission half lives are determined using the inetria tensor calculated macroscopically in the irrotational flow framework as well as the microscopic perturbative-cranking mass parameters.
In this way it has been possible to adjust, in the first of above approaches, a single scaling parameter that allow to rescale all macroscopic mass tensor components to get the best reproduction of the experimental half lives for actinides.
Further, with this parameter we try to reproduce and predict the corresponding half lives for some selected superhavy nuclei. Finally we compare the half-life estimates done for both the macroscopic and microscopic mass parameters.

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

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Understanding the phenomenon of shape evolution in atomic nuclei has been one of the main quests in nuclear physics. While throughout the nuclear chart the evolution of a spherical ground-state shape into a deformed one is usually a gradual process, in the Zr isotopic chain an abrupt shape transition is observed at N=60. This dramatic onset of deformation in ^{100}Zr was recently well reproduced in the state-of-the-art Monte Carlo Shell Model calculations [1, 2], which also predict that the same deformed configuration may coexist at higher excitation energies in the lighter Zr isotopes. The ^{98}Zr is of particular interest in this regard as it is a transitional nucleus which lies on the interface between both spherical and deformed nuclear phases. Thus, significant amounts of experimental and theoretical research efforts have been made to study the shape coexistence phenomena in ^{98}Zr [3,4,5,6]. While they demonstrate a good overall description of the ^{98}Zr nuclear structure, the interpretation of the higher-lying shape coexisting bands is still uncertain. In particular, several discrepancies between theoretically calculated and experimentally deduced reduced transition probabilities were noted, highlighting the need for further investigations. Based on the above, a $beta$-decay experiment was performed at TRIUMF-ISAC facility utilising the $8pi$ spectrometer in conjunction with auxiliary $beta$-particle detectors to measure the branching ratios and multipolarity mixing ratios for the transitions in ^{98}Zr. The high-quality and high-statistics data obtained with this setup allowed for the determination of branching ratios for very weak transitions important for assigning band structures. Furthermore, gamma-gamma angular correlation measurements enabled both spin assignments and mixing ratio determinations. The new results will be presented, and discussed in relation to both the MCSM and recent IBM configuration mixing calculations.

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Reaction Cross Section Measurements for The Enhancement of Applicability of Glauber Model to Heavy Neutron-Rich Nuclei

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The reaction cross section (σ_R) or the interaction cross section (σ_I) for atomic nucleus is closely related to the nuclear radius and the nuclear density distribution. The study of nuclear radii through measurements of σ_R or σ_I has revealed exotic features of unstable nuclei since 1980s [1-3].

In these studies, the method to deduce nuclear radii from the measured σ_R is based on the Glauber model. The Glauber model is the optical limit approximation of the Glauber theory, which can uniquely calculate σ_R using nuclear radii as inputs. The applicability of the Glauber model for light nuclei ($Z\leq30$, $A<100$, such as Al) has been well studied. In those studies, many precise σ_R data are compared with the Glauber model in the energy range of 30$\sim$400 MeV/nucleon[4].

The future focus of the study of nuclear radii is to perform measurements in medium and heavy mass region, which give crucial information of neutron skin formation in atomic nuclei. To measure radii of heavier ($Z\sim>50$, $A>100$) nuclei, it is necessary to study the applicability of the Glauber model in this mass region. The applicability of the Glauber model to medium and heavy nuclei is being also investigated [5] by theoretical approach, and it is expected that Glauber model underestimate σ_R as an increment of Z. It is because of the model from electromagnetic interactions such as Coulomb dissociation (e.g. 6 $\%$ underestimation for Pb + C system)[5]. It is important to compare these theoretical calculations with experimental data to discuss the applicability of the Glauber model. However, accurate σ_R data for medium and heavy nuclei is currently scarce.

In this study, we perform σ_R measurements for the medium and heavy mass region where there is a lack of data. σ_R for ^{12}C on Fe, Nb, and Pb targets were measured at the beam energies from 70 to 350 MeV/nucleon, and σ_R for ^{27}Al on Fe, Nb targets were measured at the beam energies from 70 to 100 MeV/nucleon, at HIMAC (Heavy Ion Medical Accelerator in Chiba) facility. The transmission method was employed for σ_R measurement, and $B\rho$-TOF-ΔE and E-ΔE methods were used for particle identification before and after the reaction target. The data is compared to the Glauber model and also EMD calculation [6]. In the presentation, we will report the detailed results of our experiments and discuss the applicability of Glauber calculation to heavier nuclei.

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Structure of light atomic nuclei studied with nuclear reaction ^{14}N + ^{10}B

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Light nuclei are an excellent laboratory in which to examine the basic principles of nuclear structure and interaction. Both aspects of nuclear structure, single-particle dynamics and nucleon correlations which result in clustering, are the most pronounced in light nuclei due to the small number of important degrees of freedom in these systems. In recent years even the first principle (Ab Initio) calculations [1], as well as some mean field based models [2] describe cluster structures well. Two-centre nuclear structures have been identified so far in Be isotopes, particularly in ^{10}Be [3]. Indications for more complex structures have been found in both theoretical [4] and experimental [5] studies of C isotopes and even in some heavier nuclei [6]. Similar to the role of B and C isotopes in understanding of the evolution of clustering from two to three center, the N isotopes are interface between three and four center structures. Role of the additional proton and neutron(s) on the three- (N isotopes) and four-center (F isotopes) cluster structures is even less clear, mainly due to the missing experimental information. Detailed spectroscopic information for nuclei from B to F can provide crucial information for understanding clustering and its evolution with increasing number of nucleons and/or α-clusters.

With the aim to study clustering in this range of nuclei, experiment was carried out at the INFN Laboratori Nazionali di Legnaro, using the 95 MeV ^{14}N beam and ^{10}B target. Reaction products were detected with the setup of six highly segmented silicon telescope detectors, each consisting of 20 μm thick single sided strip detector ΔE and 1000 μm thick double sided strip detector E, covering polar angels from 15 to 70 degrees, allowing for clear identification of the reaction products using the standard ΔE-E approach. Preliminary results on part of the collected experimental data show that reaction channels of interest are observed. Ongoing analysis of the excited states of ^{10,11}B, ^{11,12,13}C, ^{14,15}N, ^{15,16,17}O and ^{17,18,19}F shows that the two-center clustering is present in all isotopes. With further analysis three- and four-center cluster structures will be examined and with full data set partial widths for various decays, an important characteristics to reveal their structure, will be deduced. Preliminary results on the observed excited states will be presented and their possible cluster structure discussed.

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Studies of Relativistic Effects in Three Nucleon Systems

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Understanding of forces acting between nucleons is a hot topic in nuclear physics. Few-nucleon systems are ideal laboratories for testing theoretical approaches which describe interaction between nucleons. In a medium energy range the properties of such systems are successfully modeled with the use of the realistic potentials, supplemented with the three-nucleon force (3NF) models, coupled-channel calculations, also with Coulomb force included, or potentials based on chiral perturbation theory. Experimental investigations of the deuteron breakup reaction (d+p $\rightarrow$ p+p+n), the simplest 3-body system, support very strongly existence of 3NF effects [1,2] and the Coulomb interaction between protons [3].

At higher energies, around 200 MeV/A, also relativistic effects start play a role in the system dynamics [4]. The relativistic treatment of the three-nucleon system has been recntly developed in [5, 6]. The relativistic effects can significantly increase or decrease, depending on the phase-space region, the breakup cross section. While at 65 MeV the influence of relativistic effects are rather moderate, at 200 MeV they can change the cross sections even by a factor of 2. The existing database for the breakup reactions at higher energies is very scarce [7,8]. With such limited database, it is not possible to draw more general conclusions concerning the role of the relativistic effects and its interplay with the 3NF effects.

In order to test the predictions the new measurement at 200 MeV proton beam has been performed at the Cyclotron Center Bronowice in Kraków (Poland). It focuses on selected configurations of the breakup protons, where only the relativistic effects play a role, as suggested by the theoretical findings [5]. The data have been collected with the use of the KRATTA [9] detectors and the solid CD$_2$ (deuterated polyethylene) target. Results of this mesurement will allow one to verify the state-of-the-art theoretical calculations for relativistic effects in the deuteron breakup process. In this contribution we would like to present the first results of our experiment.

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Indirect measurement of the (n, γ) ^{127}Sb cross section

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Nuclei in the ^{135}I region have been identified as a possible bottleneck for the i process. Nuclear properties such as the Maxwellian-averaged cross section are indispensable tools when trying to explain nucleosynthetic processes, but the instability of the region prevents us from carrying out direct measurements. In order to investigate it, we propose an indirect approach.
At the Oslo Cyclotron Laboratory we carried out the ^{124}Sn$(\alpha, p\gamma)^{127}$Sb reaction in order to extract the nuclear level density and the γ ray strength function of ^{127}Sb using the Oslo method, with the aim of calculating the Maxwellian-averaged cross section and the neutron-capture rate of the A-1 nucleus ^{126}Sb. The level density in the low excitation-energy region agrees well with known discrete levels, and the higher excitation-energy region follows an exponential curve compatible with the constant temperature model. The strength function between $E_\gamma \approx$ 1.5-8.0 MeV presents several features, such as an upbend and a possibly double-peaked pygmy-like structure. None of the theoretical models included in the nuclear reaction code TALYS seem to reproduce well the experimental data.
The Maxwellian-averaged cross section for the ^{126}Sb$(n, \gamma)^{127}$Sb reaction has been experimentally constrained by using our level-density and strength-function data as input to TALYS. The results show good agreement with the JINA REACLIB, TENDL and BRUSLIB libraries, while the ENDF/B-VIII.0 library predicts a significantly larger cross section.

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Isomer studies for r-process nucleosynthesis[*]

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The potential energy surfaces of even-even super-heavy nuclei are calculated within the macroscopic-microscopic method [1]. The spontaneous fission and α decay life-times are evaluated using the one-dimensional WKB method [2] and the Gamow-type model [3], respectively. The Fourier parametrization [4] is used to describe nuclear shapes. The Lublin Strasbourg Drop [5] is used to determine the macroscopic part of nuclear energy. The Yukawa-folded [6] single-particle energies are used to evaluate the Strutinsky shell energy [7] and the BCS method to obtain the pairing energy correction. The evaluated nuclear binding energies, fission-barrier heights, and Q_α energies agree well with the experimental data [8]. Also the spontaneous fission and the α-decay life-times are reproduced fairly well [9].

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CALIFA: A versatile calorimeter and spectrometer for R^3B at FAIR[*]

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CALIFA @ R3B/FAIR is a highly segmented detection system based on CsI(Tl) scintillation crystals with readout via avalanche photodiodes (APD). It aims to detect gamma rays and light charged particles. CALIFA consists of around 2000 detection units and each detection unit has to be characterized. CALIFA is operated since 2019 in Cave-C of GSI for FAIR phase 0 experiments. For this characterization an automatic system has been created.

The main goal of the characterization system for the APDs is to provide controlled conditions for testing the APDs and the measurement of the variance of the output. For this work, the system has to control two parameters: bias voltage and temperature. The temperature of the system is controlled via a Peltier unit.

The light signals from a pulsed LED was employed as testing source for the APDs. The green LED, with maximum wavelength of 520 nm, is chosen to mimic the signals of the CsI(Tl) crystals.

The system allows the determination of the important parameters of the APDs: The gain correlation to bias voltage as well as the temperature coefficient. This is crucial information for CALIFA: Specifically, the temperature coefficient will be used to adjust the gain in case of temperature deviations during the experiment.

The status and results of the characterization system will be presented.

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Analysis of ^{12}C + ^{93}Nb reaction: Production of clinically relevant ^{101m}Rh via ^{101}Pd[*]

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The organometallic complexes of Rh carry significant biological appeal as chemotherapeutic agents. For instance, [Rh(I)COD bipy]$^+$Cl$^-$ acts against L1210 Leukemia [1], Rh (II) Carboxylates against Ehrlich ascites carcinoma [2], etc. Radiolabelled compounds are being investigated to aid the assessment of drug efficacy and delivery. The radioactive isomer of ^{101}Rh, i.e., ^{101m}Rh (T$_{1/2}$=4.34 d), can make up a promising radiolabeling agent as it decays to ^{101}Ru (stable) with 92.8% e$^-$-capture (ϵ). The emitted low energy and intense γ-rays of 306.9 keV (81%) are favorable for in-vivo diagnostic imaging, whereas its Auger and Coster-Kronig e$^-$–flux is useful in targeted radiotherapy. Though its production has been several times achieved through light-ion induced reactions [3] to ensure high yield, heavy-ion reactions have been rarely attempted. Indeed, the heavy-ion reaction yield of a radionuclide can not compete with that produced through a light-ion reaction; however, it can offer a reasonable yield of the desired radionuclides for several applications, including the pilot experiments. The ^{12}C+^{93}Nb reaction study [4] presently discusses the production of ^{101m}Rh both as an evaporation residue (ER) and its growth as a daughter product of its precursor ^{101}Pd (T$_{1/2}$=8.47 h).

The experiment was carried out at the 14UD BARC-TIFR Pelletron facility, Mumbai, India. ^{12}C beam up to 77 MeV impinged upon stacked foil assemblies of ^{93}Nb and ^{27}Al with 1.3–3.0 and 1.5–1.8 mg/cm^2 thickness, respectively, resulting in 39.5–75.9 MeV range. Subsequently, γ–ray measurements assured the populated ERs, viz., ^{103,102,101}Ag, ^{101,100}Pd, ^{101m,100,99m,97}Rh, ^{97}Ru, ^{96,95,94}Tc, and ^{93m}Mo. The maximum measured yield for ^{101}Pd at the end of bombardment (EOB) is 869 MBq/C, while it is 112 MBq/C for ^{101m}Rh at 71 MeV. The yield for the other co-produced radionuclides has also been estimated. The crucial task to ensure the radiopharmaceutical-grade production of ^{101m}Rh is to maximize its ingrowth from ^{101}Pd's decay through 100% ϵ and eliminate the contamination from other co-produced Rh isotopes. The production of ^{100}Rh, ^{99m}Rh, and ^{97}Rh with T$_{1/2}$=20.8 h, 4.7 h, and 30.7 min, respectively, were observed in the target matrix. The waiting period (T$_w$) of 32 h after the EOB would provide the optimum yield of ^{101m}Rh, where nearly 93% of ^{101}Pd atoms disintegrate. The estimated yield of ^{101m}Rh increases to 786 MBq/C at 71 MeV after 32 h. Meanwhile, the contamination from other Rh isotopes nearly subsides, which may assist the chemical separation. It envisages a reasonably pure ^{101m}Rh, capable of being incorporated into compounds of medical relevance. The estimated time evolved thick target yield of ^{101m}Rh after T$_w$ is nearly 1.2 GBq/C for 41 mg/cm^2 thick target between 39-91 MeV energy window. The study suggests that the industrial-scale production of ^{101m}Rh is possible using a high current accelerator followed by an efficient chemical separation that has not been studied here.

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Lifetime measurements of low-lying excited states in ^{190}W with DESPEC

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A study was undertaken to obtain insight into the shape evolution of neutron-rich isotopes in the A$\sim$190 mass region from prolate to oblate structures using the DEcay SPECtroscopy (DESPEC) employed at the focal plane of the FRagment Separator (FRS), GSI, Germany. A fragmentation reaction was used with a 1 GeV/u ^{208}Pb primary beam ($2x10^9$ particles/spill) on a 2.7 g/cm^2 thick ^{9}Be target. During the experiment the FRS was setting was centered on ^{188}Ta. The ions were implanted into a highly-pixilated silicon detectors (AIDA) coupled to a combination of gamma-ray spectrometers for fast-timing (FATIMA) in conjunction with HPGe detectors for high-resolution energy measurements. The experimental goal was to measure the lifetimes and energies of the first excited states of neutron-rich Os, W and Hf isotopes. These measurements will help to quantify the degree of collectivity in the region of interest, and to search for fingerprints of the prolate-oblate shape transition.

The theory can be constrained by measuring the B(E2) values in ^{190}W, which will give a direct measure of collectivity. In addition, the measurement of B(E2) strengths will yield so-called transitional quadrupole moments, Q$_t$, which for a prolate-oblate transition will display a minimum at the most γ-soft nucleus, before rising again toward more oblate deformed isotopes. From previous studies [1,2], one may expect ^{190}W as the isotope closest to the O(6) γ-soft structure. This is also supported by microscopic calculations [3], or from a simple extrapolation of IBM-1 parameters, which evolve smoothly over the W isotopic chain.

This talk focuses on lifetime measurements using FATIMA of low-lying 4$^+$ and 2$^+$ states in ^{190}W populated following the isomeric decay from the 10$^-$ state. The data provide information on the B(E2) values, which in turn give information on the degree of beta-deformation.

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Study of ^{19}F (p, α) reaction in low energy regions

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^{19}F(p,α) reaction is one of the crucial reactions in the CNO Cycle. It has the utmost importance in the astrophysical region particularly below the Coulomb barrier [1]. In an astrophysical scenario of ^{19}F(p,α), the importance of astrophysical S-factor is crucial for the understanding of discrepancies in fluorine nucleosynthesis [2-4] and the contribution of resonant or non-resonant part in low energiesn[5-9]. The Trojan horse measurements predicted the presence of 113 KeV resonance contributions to the S-factor [4]. However, the low energy S-factor also has a significant contribution from non resonant part [7-9]. Our recent calculation shows an appreciable non-resonant contribution to Sfactor in low energy region [9]. The S-factor (S (0)) from the DWBA calculation using recent andnold data sets is found to be 20.357 MeV-b with 40 % uncertainty. The calculation is comparable to NACRE non-resonant value [10]. So, the measurement of ^{19}F(p,α) to get sufficient data points at low energy region is necessary. For that purpose, good quality of target is one of the key factors for this reaction. LiF targets are deposited on self-supporting Ag backing using vacuum evaporation. The thickness of deposited Lithium fluoride is measured by three line alpha sources (n^{239}Pu, ^{241}Am, and, ^{244}Cm). The thickness of deposited LiF targets is 224 μg/cm^{2}. The XPS confirms the presence of Li and F on surface of targets. An experiment is planned at FRENA facility, Kolkata to measure astrophysical S-factor in low energy regions.

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^{7}Li + ^{93}Nb: A study of complete versus incomplete fusion*

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In heavy ion fusion reactions, projectiles carry large angular momentum and kinetic energy to interact with the target nucleus and form an excited composite system. If the composite system has viable angular momentum, it moves towards statistical equilibrium and forms the compound nucleus. The complete fusion (CF) process may be hindered due to pre-equilibrium emission or projectile fragmentation at higher incident energies. Projectile breakup leads to incomplete fusion (ICF) with partial momentum transfer. One or more fragments of the projectile may fuse with the target nucleus leading to an excited incompletely fused composite system with reduced mass and charge compared to that formed via complete fusion. Breakup probability in loosely bound nuclei (^{6,7}Li, ^{9}Be, etc.) is expected to be large in comparison to well-bound nuclei [1,2]. Therefore, the understanding of the dynamics of CF and ICF near and above the barrier became more important in the reactions induced by weakly bound projectiles.
In the present work, the study of CF-ICF processes for ^{7}Li-induced reaction on ^{93}Nb target [3] has been studied with dynamical cluster-decay model (DCM) [4] based on quantum mechanical fragmentation theory [5] in the energy range of E$_{c.m.}$=18-28 MeV. This collective clusterization approach with hot-compact orientations of quadrupole deformations has been used to calculate the CF and ICF cross sections. In the CF process, emission of clusters (p3n, p4n and $alpha$3n) took place along with 3n and 5n, and these clusters emission have been dealt incorporating proper binding energies of clusters [6]. While in the ICF process, ^{7}Li which is a weakly bound projectile breaks up into α+t and α fuses with the ^{93}Nb target forming ^{97}Tc* CN which decays via 1n and 2n channel contributing to ^{95,96}Tc [3]. The CF and ICF processes have been investigated by fragmentation potential, preformation probability, and scattering potentials in the DCM framework. The cluster $alpha$3n is observed with a peak in the fragmentation potential's plot at both ℓ values implying that it is least probable as compared to other clusters in the decay. Further, in comparison of preformation probability for both decay processes, i.e., CF and ICF, it is observed that both compound nuclei ^{100}Ru* and ^{97}Tc* decay via broad symmetric preformation structure. In the CF process, two humps are visible due to intermediate mass fragments and complementary fragments, which are missing in the ICF process. However, DCM is able to reproduce the total cross sections at all energies for CF and ICF processes with its optimized neck-length parameter ($\triangle$R).

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Improved calculation of electron phase-space factors in electron capture

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Electron capture on nuclei plays an important role in several domains which include, but are not limited to, astrophysics (core-collapse, thermonuclear supernova), medicine (I-123 as a tracer to thyroid imaging), nuclear waste (Ca-41).

Although the electron capture is known for over 80 years now, there is a need for improvement of the decay rate calculation due to their errors with respect to the experimental data. The decay rate contains two distinct parts: the nuclear matrix elements, which involve the nuclear structure of the parent and daughter nuclei and electron phase-space factors, which are described by the dynamics of the captured electron.

My work focuses on the improvement of the calculation of electron phase-space factors. I used a more accurate electron wave function for the bound electrons obtained as a self-consistent solution of the Dirac-Hartree-Fock-Slater equations for the initial and final atoms (the excited configuration of the final atom was taken into account). The wave function was obtained with a slightly modificated version of the Fortran subroutine package RADIAL. For that, several codes in Wolfram Mathematica and Shell Scrip were implemented.

For better results, the exchange and overlap correction was introduced using the Vatai's approach. The calculation was performed for allowed and forbidden unique beta transitions. To have a direct comparison with the experimental data, I computed the decay probability ratios for electron captures from different electronic shells, which are independent of the nuclear structure effects.

The present work opens the path to extend the computation of the electron capture rates for many other nuclei that undergo allowed and forbidden unique beta decays and to include other corrections related to the accurate calculation of the phase space factors.

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Beta decay spectroscopy of the neutron-rich ^{137}Te and ^{136}Sb isotopes

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Nuclei around ^{132}Sn play significant role in nuclear structure and nuclear astrophysics. Their nuclear structure properties, like mass (A), half life ($T_{1/2}$), P_n & P_{2n} values, are essential to reproduce the r-process abundances and to understand the origin of the elements in the universe [1,2]. By investigating the nuclear configuration of states around the ^{132}Sn core, the extension of the magic core may be traced. Thus, the polarization effect of valence particles on this core can be studied in detail [3,4]. The neutron-rich ^{137}I nucleus with three valance protons and two valance neutrons outside the ^{132}Sn core is investigated in this work. Since the low-spin excitations knowledge of ^{137}I has been relatively poor [5], it is of special interest to investigate such three valence-proton systems beyond the magic number $Z = 50$ and gain an important information on the nuclear structure in the region. We also investigated the β decay of the ^{136}Sb isotope.

We employed β-delayed γ-ray spectroscopy to study excited states in ^{137}I and ^{136}Te from the β decay of ^{137}Te and ^{136}Sb, respectively. These nuclei are produced in the neutron-induced fission of ^{235}U. The new β-decay level schemes of ^{137}I and ^{136}Te are established, together with new information on their half-lives. The β-delayed neutron emission probability P_n values are also deduced. The experimental results are an important input to the theoretical description of nuclei in the region and provide essential information on the first-forbidden transitions beyond $N = 82$ and $Z = 50$.

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Energy released by electron capture into atomic subshells of ^{84m}Rb isomer for different ionization degrees[*]

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The main purpose of this research is to evaluate the optimal conditions for detailed knowledge of the nuclear excitation by electron capture (NEEC) process for selected nuclear isomers (i.e. metastable excited states of atomic nuclei) of a few elements. Following the first experimental observation of ^{93m}Mo isomer depletion via NEEC [1], we have made a theoretical investigation related to the ^{84m}Rb isomer ($T_{1/2} \sim$ 20.26 min). It is worth underlining that for an ^{84m}Rb isomer the probability of the NEEC process can be even higher than for the ^{93m}Mo isomer [2, 3].
In order to observe the NEEC process we have performed a quantitative analysis of atomic conditions for the long-lived ^{84m}Rb isomer with spin parity 6^-. Its DS with spin parity 5^- lies only 3.05 keV above the ^{84m}Rb isomer and is itself a shorter-lived isomer (9 ns) that subsequently decays, releasing a substantial amount of stored nuclear energy (466.64 keV). To design the optimal conditions for observation of the NEEC process crucial is to take into account a beam of some suitable higher-Z nucleus reacting with a lower-Z target to produce the ^{84m}Rb isomer (with the initial recoil kinetic energy of ions that exceed the NEEC resonance energy). Moreover, crucial is to obtain the values of resonance kinetic energies required for the NEEC process to occur in the case of electron capture into specific atomic subshells for assumed configurations. Therefore we have calculated the appropriate atomic energy levels in ^{84}Rb ions. The calculations have been performed for subshells with the main quantum number 3 $\leq n \leq$ 5 and the orbital quantum number l up to l = 2 by means of the relativistic MCDF method [4-6].
The results of the presented study may be a starting point for applied research related to allowing the controlled release of energy stored in the nuclear isomer of selected elements, which should contribute to developing a concept of new, unconventional, and ultra-efficient nuclear batteries.

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Shape phase transition at N=90 and isotopic fission yields using high precision mass measurements at the FRS-IC*

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Investigations of the nuclear shapes, especially at the transition point, are improving our understanding of the nuclear structure evolution. The transition between the nuclear shapes is observed in the evolution of the two-neutron separation energy (S_{2n}) and its first derivative (dS_{2n}) over the neutron number [1]. Accurate measurements of the atomic masses are essential for observations of the deviations from linearity of the S_{2n} and dS_{2n} which would indicate a possible shape transition. Moreover, they contribute to a better understanding of the fission fragments probability distribution, by allowing for measurements of the Isotopic Fission Yields (IFY).

An experimental program that aimed at measuring the fission fragments of a ^{252}Cf source took place at the Fragment Separator - Ion Catcher [2] setup at GSI. Here, atomic masses with a relative accuracy down to $2 \cdot 10^{-8}$ [3] are measured using time-of-flight mass spectrometry. The results presented in this contribution are covering the region around N=90 where shape phase transition is expected to occur. The measured mass values of the fission fragments are compared with the literature and the corresponding trends of the S_{2n} and dS_{2n} are discussed. First results on a new measuring method for IFY will be presented.

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Beta decay of neutron rich bromine isotopes studied by means of Modular Total Absorption Spectrometer [*]

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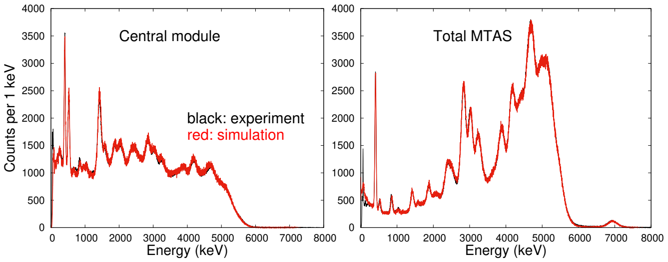
An overview of the β decay of neutron rich bromine isotopes measured with Modular Total Absorption Spectrometer (MTAS) will be presented. Neutron rich bromine isotopes have large ^{235}U cumulative fission yields and large Q_β energies, therefore they make large contributions to reactor decay heat and may create many detectable reactor anti-neutrinos. These large contributions means a complete knowledge of the decay schemes, including β-n branches, is of the utmost importance. Analysis of ^{87}Br decay shows a missing β-feedings to highly excited levels as well as incomplete γ-decay patterns for the known levels, even though it is a relatively well studied case (161 known levels, 226 known γ-transitions). Our analysis uses a multi spectra simultaneous fitting technique, which fits β-decay branches to the experimental spectra from different modules (or their sums) in parallel with the total MTAS energy spectrum. The ^{87}Br Total MTAS (total absorption energy spectrum, all modules) experimental and reconstructed spectra as well as Central module spectra are presented below.



Analysis results of the MTAS data for neutron-rich, β-delayed neutron emitting bromine isotopes will be shown. The impact of the evaluated isotopes on reactor decay heat calculations as well as on the reactor anti-neutrino anomaly will also be presented.

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Algebraic translationally invariant approach to small nuclear systems

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The ab-initio no-core shell model approach is very successful in describing systems up to medium mass nuclei [1]. This approach to the many-body problem is very successful due to growing computational-npower. Theoretical developments in the no-core framework would allow us to use the computational systems more effectively or get more precise results for bigger systems.
In the harmonic oscillator (HO) basis, a popular approach for the s-shell nuclei is to use Jacobi coordinates to describe a system [2]. We need antisymmetric and translationally invariant state vectors to characterize a nuclear system. Therefore, we need to eliminate the center of mass (cm) motion to ensure translational invariance. For this task, the Jacobi coordinates are very attractive since they allow the explicit removal of the cm coordinate.
For the p-shell, the situation is a bit different. Often antisymmetrization procedures based on the one-particle Slater determinants (sd) are used. This is based on the fact, that the antisymmetrization in the Jacobi coordinates becomes too complicated due to the large symmetry group algebra.
In our research, we are trying to solve this problem and employ the Jacobi coordinates for the p-shell nuclei, particularly the six-body systems. We construct the coefficients of fractional parentage (cfps) to get the antisymmetric state vectors for the calculation of observables. We construct the state vectors in the binary cluster formalism with so-called Λ operators [3]. The state vectors are constructed in the J-scheme, which required heavy use of the angular momenta algebra. We construct the Λ operators from the two-particle transposition operators of the symmetric group S_6.
To get the Λ operators in the HO basis we need the representations of the transformations of the Jacobi coordinates which become very complex for the p-shell nuclei. To solve this, we introduce the algebraic approach.

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Excitation function of ^{24}Mg above the ^{12}C + ^{12}C decay threshold

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The nucleus ^{24}Mg is interesting from the point of view of nuclear structure and nuclear astrophysics. Its spectrum of excited states exhibits a large number of resonances that could decay into several different channels. A comprehensive study of resonant structures, particularly those associated with ^{12}C+^{12}C configurations in the ^{24}Mg system is important for better understanding of nuclear structure configurations, and it may also have a notable impact on the ^{12}C+^{12}C fusion reaction rate, which plays a vital role in the behaviour of highly developed stars. The total S-factor for the ^{12}C+^{12}C reaction has been measured down to a center-of-mass energy of $E \approx$ 2.1 MeV [1], below the Coulomb barrier for this reaction ($\approx$ 8 MeV). The cross section at the lowest measured energy is very small (below 1 nb), and so the direct measurements at even lower energies would be very challenging. Therefore, it is more convenient to study this reaction by means of indirect measurements. In order to study the resonant structures of ^{24}Mg in the energy range of interest for carbon burning (15-17 MeV), we measured the ^{20}Ne+^{4}He resonant scattering using the thick gas target in inverse kinematics technique [2]. The measurements were performed at INFN-LNL in Legnaro at two ^{20}Ne beam energies, 58 and 69 MeV. The excitation function of ^{24}Mg was measured using an array of eight double sided silicon strip detectors. Six detectors were placed with their surfaces parallel to the incident beam direction, and the remaining two were placed at forward angles, one of which was preceded by a thin single sided silicon strip detector. A similar experiment was done by our group several years ago [3]. The objective of this work was to overcome the difficulties of the previous experiment, and to obtain additional data on the excited states. We will report on the most recent results extracted from singles data collected in the detectors at 0° and 10°. The measured excitation spectra of ^{24}Mg exhibit a complicated structure with a large number of overlapping resonances in the energy range between 13 and 19 MeV. The excitation energies deduced from this work are found to be in agreement with those obtained from previous measurements [3]. The data analysis is currently in progress. The next step would be to look for the possibly existing ^{12}C+^{12}C resonance by reconstructing the ^{12}C+^{12}C coincidence events collected in the detectors at forward angles. The presence of a resonant structure in the measured excitation function inside the effective stellar energy window would be an indication for a considerably larger rate of the ^{12}C+^{12}C reaction. In the future, we plan to run complementary measurements using an advanced setup that will facilitate the detection and characterization of resonances in the ^{12}C+^{12}C system.

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Comprehensive study of the β-decay of ^{71}Kr

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The β-decay of ^{71}Kr is of great interest on one hand from the astrophysical point-of-view, as it lays on the path of *rp*-process, on the other hand from the nuclear physical point-of-view, as it's a decay between mirror nuclei near the proton-dripline. Furthermore shape co-existence is suspected in this region to be present[1,2,3].

In order to have a comprehensive study of this decay, a secondary beam containing primarily ^{71}Kr was produced via bombardment of a beryllium target, using a ^{78}Kr primary beam at the RIKEN-RIBF facility in Japan. The fragments were identified by the BigRIPS separator using standard ΔE-$B\rho$-ToF method, then stopped in a double-sided silicon strip array (WAS3ABi). The β-particles and the β-delayed protons were detected in the silicon detectors, while the β- and ε_p-delayed γ-rays were measured by a surrounding HPGe cluster array (EURICA) [4,5].

The half-life was measured using three independent methods (implant-β, implant-β-γ and implant-proton correlations). After thorough analysis of the decay data, we have built the decay-scheme of ^{71}Kr, identifying 8 new levels and 26 new gamma-transitions. The ε_p branching ratio was measured with a 50-fold increased precision compared to the earlier experimental value [6].

The details of the analysis and an outlook on future theoretical interpretations will be presented.

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Beta decay of A=142 isobars improved by means of MTAS array[*]

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Beta-decays of fission products were measured using the Modular Total Absorption Spectrometer (MTAS) at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL). Partial results on the short-lived ^{142}Cs decay were discussed at the earlier Letter [1], while this follow up work is presenting the results obtained for the full A=142 chain ^{142}Cs $\rightarrow$ ^{142}Ba $\rightarrow$ ^{142}La $\rightarrow$ ^{142}Ce.

MTAS is a an array of 19 NaI(Tl) hexagonal NaI(Tl) modules of the total active mass of nearly 1000 kg [2-4]. The segmented silicon counters covering over 90% solid angle and placed at the middle of MTAS provide a beta trigger signal with a high efficiency. The studied A=142 isobars have large cumulative fission yields, e.g., 5.7% for ^{142}Ba and 5.8% for ^{142}La in the thermal neutron indiced fission of main nuclear fuel component ^{235}U [5]. Therefore, the reliable information on their beta stregth pattern is important for the evaluation of the decay heat release at nuclear reactors [6] and for the analysis of the reactor anti-neutrino reference flux, see examples [1,7].

The final results on the A=142 beta decay chain including the decay heat and the interactions of emitted anti-neutrinos with a detector matter will be presented.

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High-spin spectroscopy of ^{215}Fr: connecting gaps between single-particle and collective modes of excitation

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Nuclei between a well-deformed mid-shell region and the shell closure offer a suitable ground for understanding the evolution of nuclear structure. A study of an isotopic chain can be appropriate to understand whether the shape transition is sudden or smooth. The region between the well-deformed Ra-Th nuclei (A $approx$ 220) and the doubly-magic ^{208}Pb, in particular, is suitable for studying the evolution of octupole collectivity. It has been reported that parity-doublet structures, which are signature of octupole collectivity, emerge suddenly at N = 129 [1]. The francium isotopes (Z = 87) with 126 $\leq N \leq$ 130 form the lower boundary of octupole-deformed actinide region and connect the two distinct regimes of nuclear structure. A recent study from our group, reported the parity doublet structures in ^{216}Fr [2]. Although, it was observed that level structure does not follow the regular pattern of rotational bands, enhanced octupole correlations are evident from the small energy splitting and large $B(E1)/B(E2)$ values [2]. Thus, it was suggested that ^{216}Fr provides a lower limit (Z = 87, N = 129) in the trans-lead region from where the octupole correlations emerge. In continuation with the above study, a detailed study of ^{215}Fr is performed to get more insights into the evolution of nuclear structure from near-spherical to octupole deformed shapes [3].

Excited states in ^{215}Fr were investigated using the ^{208}Pb(^{11}B, 4it n)^{215}Fr heavy-ion fusion-evaporation reaction [2, 3]. The ^{11}B beam in the 54-62 MeV energy range, from the 15-UD Pelletron accelerator at IUAC, New Delhi, was impinged on a self-supporting ^{208}Pb ($\approx$99 enriched) target of $\sim$6 mg/cm^2 thickness. The γ rays from the residual nuclei were detected using Indian National Gamma Array (INGA). Detailed information about the experiment, data sorting and data analysis procedure can be found in Refs. [2, 3]. The level scheme of ^{215}Fr has been investigated in details up to 55/2$hbar$ and 4.8 MeV excitation with the addition of 52 new γ-ray transitions. The overall structure of ^{215}Fr is understood by coupling of an unpaired proton in the $h_{9/2}$ or $i_{13/2}$ orbitals to the even-even core of ^{214}Rn or ^{216}Ra. The experimental results were compared with the shell-model calculations and an overall good agreement was observed. The half-lives of the isomeric states have also been revisited and a revised value of 11.4(14) ns was obtained for the 39/2$^-$ isomeric state, which resolves the discrepancy in the earlier reported values. Detailed results on ^{215}Fr and a comparative study of ^{215,216,217}Fr isotopes will be presented during the conference.

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High-spin states in ^{212}Po above the α-decaying (18$^+$) isomer

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Spectroscopic data in the trans-fermium region are rather scarce. High-spin studies in nuclei with few particles/holes around the Z = 82, N = 126 double shell-closure, populating the same high-j orbitals, can provide complementary and crucial information about the single-particle level structure of these nuclei. A particularly rich phenomenology also arises around the lead double shell closure due to the interplay between the single-particle behaviour and the 3$^-$ ^{208}Pb collective vibration. This collective states lies particularly low in energy, and lowers in energy still with increasing particles added to the valence space [1]. This collective excitation can couple to the single-particle transitions between Δj=Δl=3$\hbar$ orbits producing particularly fast E3 decays [2].
In this region, the ^{212}Po isotope level scheme has been known up to a α-decaying (18$^+$) state. Two new γ rays have been observed in the excitation spectrum of this isotope using γ-decay spectroscopy with the RISING setup at GSI, Darmstadt. They have been assigned to the 23$^+$ $\rightarrow$ 21$^-$ $\rightarrow$ 18$^+$ yrast cascade. Lifetime measurement of the two states suggests M2 and E3 assignment to the two transitions. Though with relatively low statistics, these are the first observations of high-spin states above the ^{212}Po 45-s (18$^+$) isomer, by virtue of the selectivity of the FRS separator obtained via ion-by-ion identification of ^{238}U fragmentation products. Comparison with shell-model calculations points to shortfalls in the nuclear interactions involving high-j proton and neutron orbitals.

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^{208}Tl	4,8 ± 0,7
^{214}Bi	6,2 ± 0,9

Element	Abundance
K	0,1 ± 0,0 %
Th	13,4 ± 2,0 ppm
U	1,2 ± 0,2 ppm

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