

5th edition of the conference series on
Frontiers in Gamma Ray Spectroscopy (FIG2025)

TIFR, Mumbai, India

March 09-12, 2025

Book of Abstracts

FiG2025 Conference Scientific Program

09th March 2025

Inaugural session

08:00 – 09:00 Registration

09:00 – 09:20 Opening Remarks

09:20 – 10:00 The AGATA experimental campaign: High resolution gamma spectroscopy with MNT reactions, **Giacomo de Angelis** (INFN-Laboratori Nazionali di Legnaro)

10:00 – 10:30 High Tea

Session I

10:30 – 11:00 Probing the structure around the “heaviest” halo and “heavy” nuclei, **Navin Alahari** (GANIL, France)

11:00 – 11:30 Of Digitizers, Doppler & Dynamics: A Few Things that We Do at Our Place, **Rajarshi Raut** (UGC-DAE Consortium for Scientific Research, Kolkata Centre)

11:30 – 11:50 Symmetry and Nuclear Structure: Recent Evidences of Critical Point Symmetries in Atomic Nuclei, **Subhendu Rajbanshi** (Presidency University, Kolkata)

11:50 – 12:10 Various facets of nuclear structure around the ^{208}Pb region, **Ajay Y. Deo** (IIT Roorkee)

12:10 – 12:30 Probing intrinsic cluster-configuration of the ^9Be nucleus: an indirect approach, **Ananya Kundu** (SINP, Kolkata)

12:30 – 12:50 Nuclear structure studies close to doubly magic ^{100}Sn nucleus, **Dinesh Negi** (Manipal Institute of Technology, MAHE)

13:00 – 14:00 Lunch

Session II

14:00 – 14:30 Studies in Nuclear Structure & Nucleosynthesis using low and Medium Energy Proton Beam, **Indranil Mazumdar** (TIFR, Mumbai)

14:30 – 14:50 Interplay between single particle and collective mode of excitations in ^{40}K and ^{43}Ca , **Abhijit Bisoi** (IEST, Shibpur, Howrah)

14:50 – 15:10 Hindered isomeric transitions and favoured collective phenomena in A ~ 90 region" below, **Somnath Nag** (IIT BHU)

15:10 – 15:30 Investigation of Exotic Nuclear Shapes and Correlations in Transitional Nuclei, **Tarkeshwar Trivedi** (University of Allahabad, Prayagraj)

15:30 – 15:50 Nuclear phase transitions at N = 34, **Indu Bala** (IUAC, New Delhi)

15:50 – 16:20 Tea

Session III

16:20 – 16:40 Octupole correlations in ^{118}Xe ; A fresh look via lifetime measurement, **Sanjay Kumar Chamoli** (University of Delhi, Delhi)

16:40 – 17:00 Isoscalar Giant Resonances in deformed Rare-Earth Nuclei: Revealing a New Compression Mode in Quadrupole Resonance, **Soumya Bagchi** (IIT ISM, Dhanbad)

17:00 – 18:30 Discussion

10th March 2025

Session I

09:00 – 09:40 The NUSTAR project at FAIR: status and opportunities, **Zsolt Podolyák** (University of Surrey, United Kingdom)

09:40 – 10:10 The role of two-body interaction in the structure of nuclei in the vicinity of ^{100}Sn : First physics results using DEcay SPEcTroscopy at FAIR-Phase0, **Biswarup Das** (GSI Helmholtzzentrum für Schwerionenforschung, Germany)

10:10 – 10:40 Exploring shapes of very-neutron-rich isomeric fragments of ^{198}Pt with GRETINA, **Partha Chowdhury** (University of Massachusetts Lowell, USA)

10:40 – 11:00 Unravelling Multinucleon Transfer reactions via α/γ -decay spectroscopy: A doorway to access Terra Incognita, **Deepak Kumar** (TIFR, Mumbai)

11:00 – 11:30 Tea

Session II

11:30 – 12:10 Precision measurements of excited-state lifetimes and energies as a probe of rare nucleon correlations far from stability, **Bo Cederwall** (KTH)

12:10 – 12:40 Nuclear structure studies in $A \sim 100$ mass region, **Samar Sihotra** (Panjab University, Chandigarh)

12:40 – 13:10 Radiological investigations of soil samples from some part of Punjab, potential hazard indices, and their correlation with the application of fertilizers and pesticides, **Pushpendra P. Singh** (IIT Ropar)

13:10 – 14:00 Lunch

Session III

14:00 – 14:30 Metastable states in spherical and deformed nuclei, **S.K. Tandel** (Shiv Nadar Institution of Eminence, Delhi-NCR)

14:30 – 15:00 Recent findings and possibilities in structures of rare-earth nuclei using low-mass projectiles, **Somsundar Mukhopadhyay** (BARC, Mumbai)

15:00 – 15:20 A new low-energy, high-current accelerator in India: FRENA, **Akashrup Banerjee** (SINP, Kolkata)

15:20 – 15:40 Constraining the isospin properties of neutron star within effective energy density functional, **M. Bhuyan** (Institute of Physics, Bhubaneswar, India)

15:40 – 15:55 Multi quasiparticle-hole excitations in odd-odd and even-even nuclei near $A \sim 90$, **Vishal Malik** (TIFR, Mumbai)

15:55 – 16:10 Enhanced electric dipole transition strengths in ^{100}Ru , **Anindita Karmakar** (TIFR, Mumbai)

16:10 – 17:00 Tea

Session IV (Public lecture)

17:00 – 18:00 Recent Advances in Gamma-ray Imaging (Fundamentals to Applications), **Pawel Moskal** (Jagiellonian University, Kraków, Poland)

18:00 – 18:30 High Tea

18:30 – 19:30 Discussion

11th March 2025

Session I

09:00 – 09:30 The Heavy Ion Laboratory at the University of Warsaw- the next 30 years ahead, **Pawel Napiorkowski** (Heavy Ion Laboratory at University of Warsaw)

09:30 – 10:00 Probing yrast and near-yrast states in nuclei using INGA at VECC, **Sarmishtha Bhattacharyya** (VECC, Kolkata)

09:30 – 10:30 Theoretical efforts for nuclear isomerism, **Bhoomika Maheshwari** (GANIL, France)

10:30 – 11:00 Unlocking the potential of positronium physics through precision studies with J-PET, **Sushil Sharma** (Jagiellonian University, Poland)

11:00 – 11:30 Tea

Session II

11:30 – 12:00 Triaxiality and shape coexistence in $0\nu\beta\beta$ -decay candidates, **Nirupama Sensharma** (Argonne National Laboratory, USA)

12:00 – 12:20 Octupole collectivity in zirconium isotopes around $A = 90$ region, **Piku Dey** (University of Warsaw, Poland)

12:20 – 12:40 Quantum Computing relevant to Atomic Nuclei, **P. Arumugam** (IIT Roorkee)

12:40 – 13:00 Impact of quantum correlations on the fission fragment properties, **Pooja Siwach** (LLNL, USA)

13:00 – 14:00 Lunch

Session III

14:00 – 16:00 Poster session

15:50 – 16:20 Tea

16:30 – 17:00 *Nuclear Photonics, **Dimiter Balabanski** (ELI-NP, Romania) (**Zoom-talk**)

17:00 – 17:30 *Overview of SuperFRS and R3B experiments, **Haik Simon** (GSI, Germany) (**Zoom-talk**)

17:30 – 18:00 Microscopic investigation of wobbling motion in atomic nuclei, **Javid Sheikh**, (University of Kashmir) (**Zoom-talk**)

18:00 – 18:30 P1,P2,P3

19:00 – 21:00 Conference Dinner

*Tentative Title

12th March 2025

Session I

09:00 – 09:30 A journey from spherical shape to exotic symmetry breaking in a pyramidal nucleus– Role of Fast timing scintillator and high efficiency Clover arrays, **Tumpa Bhattacharjee** (VECC, Kolkata)

09:30 – 10:00 Recent developments in nuclear structure studies at IUAC, **R.P. Singh** (IUAC, New Delhi)

10:00 – 10:30 Triaxiality of Gamma Bands in Nuclear Landscape, **Suresh Kumar** (University of Delhi, Delhi)

10:30 – 11:00 Shell model study of allowed, forbidden and double beta decay, **Praveen C. Srivastava** (IIT Roorkee)

11:00 – 11:30 Tea

Session II

11:30 – 12:00 Exploring nuclear structure with PARIS, **Vandana Nanal** (TIFR, Mumbai)

12:00 – 12:20 Competition between the neutron-proton pair break-up for nuclei around $Z = 82$ shell closure, **Deepika Choudhury** (IIT Ropar)

12:20 – 12:40 Probing deep into the fission dynamics through Fission Fragment Spectroscopy, **Anagha Chakraborty** (Visva-Bharati University, Santiniketan)

12:40 – 13:00 Collective enhancement of nuclear level density and its significance in radiative capture, **Prakash Raut** (BARC, Mumbai)

13:00 – 14:00 Lunch

Session III

14:00 – 14:30 Radiation Detectors in Nuclear Medicine: A Review of Performance Evaluation, Re-cent Advancements, and Future Perspectives, **Ashish Jha** (TMC)

14:30 – 14:50 Measurement of Recoil and Spin Distributions Using Off-Beam and In-Beam Gamma-Ray Spectroscopy: A Study Relevant to Pre-Compound Emission, **Manoj Kumar Sharma** (University of Lucknow, Lucknow)

14:50 – 15:10 Nuclear Structure studies with Chebyshev Shape Parametrization, **Rhine Kumar A. K.** (Cochin University of Science and Technology, Kerala)

15:10 – 15:30 Summary Talk **A.K. Jain**

15:30 – 15:40 Concluding Remark

15:40 – 16:00 Tea

The AGATA experimental campaign: High resolution gamma spectroscopy with MNT reactions

Giacomo de Angelis ¹

¹ *INFN-Laboratori Nazionali di Legnaro*

Nuclear physics research is at the dawn of a new era. After the Big Bang and billions years of evolution, the universe has provided us around 2000 nuclei. Based on the information from these nuclei, nuclear theory has been established in order to understand the structure of the nucleus. The steady progress over the past twenty years in the development of high intensity stable beams and of beams of radioactive isotopes has allowed to vastly expand the objectives of experimental nuclear research. It is also becoming possible to study in the laboratory a range of nuclear reactions that take place in exploding stars, providing crucial information to understand how the chemical elements that we find on Earth were formed. With more than 2000 nuclei produced artificially and around 6000 expected to be produced in the facilities in operation or under construction in China, Europe, Japan and US, nuclear physics meets serious challenges. To achieve this ambitious goal, one needs to study the characteristics of unstable (radioactive) nuclei through their decays and the various nuclear interactions. Such unstable nuclei have also a wide range of applications (medicine, climate changes etc.). In this presentation I will discuss the AGATA experimental campaign ongoing at LNL, together with some of the results of the previous GANIL campaign, focusing on the potentialities of Multi-Nucleon Transfer reactions (MNT). I will also present future programs of the new SPES ISOL radioactive ion beam facility in particular on nuclear astrophysics and applications. We have recently tested in experiments performed at the ANL (USA) the capabilities of solenoidal spectrometers for n-capture reactions measurements using indirect approaches. As an example of the application of nuclear physics to societal issues, I will also report on the present status of the REMO-ClimOcean project, recently started in Spain and in Italy within the EU PNRR programs, with the aim to use radiotracers to monitor the adaptation of marine species to the new climatic conditions.

Probing the structure around the “heaviest” halo and “heavy” nuclei

A. Navin¹

¹*Grand Acc'el'érateur National d'Ions Lourds, Caen, France*

Understanding the evolution of nuclear structure going far from stability is a ongoing endeavour in our field. Various processes to explore the most optimum path, cover a wide range of energies and techniques, have been used to produce and characterize these nuclei. After a general introduction, the use of beams with intensities ranging over 10 orders of magnitude with energies ranging from around the Coulomb barrier at GANIL to fragmentation energies at the RIBF as to probe the structure of nuclei around $N = 16$ and 126 will be presented.

Of Digitizers, Doppler & Dynamics: A Few Things that We Do at Our Place

Rajarshi Raut¹

¹*On behalf of the Nuclear Physics Group, UGC-DAE Consortium for Scientific Research, Kolkata Centre.*

The research programme of the Nuclear Physics Group at the UGC-DAE CSR, Kolkata Centre, spans a panorama of topics in experimental nuclear physics. These include developments in the areas of digitizer based pulse processing and data acquisition along with the data processing software, developments for lifetime measurements, studies of single particle excitations in nuclei around shell closures and cross-section measurements of nuclear reactions using activation technique. The developmental endeavours have sustained a considerable number of research pursuits in the area of nuclear structure studies undertaken by multiple user groups from across the country. The most illustrious of these has been the campaigns of the digital INGA at VECC, Kolkata that has continued through several years while hosting more than 50 experiments using light (proton, alpha) and heavy (^{14}N , ^{16}O , ^{20}Ne) ion beams from the Room Temperature Cyclotron (RTC) at VECC. One of the principal components of the setup has been the digitizer (PIXIE-16, XIA LLC) based pulse processing and data acquisition system conceptualized and implemented by our Group [Nucl. Inst. Methods in Physics Research, A 893, 138 (2018)]. The system has facilitated in sustaining the campaigns in multiple phases that progressed through evolving number and type of detectors as well as changing experiment specific requirements. Our developments [Nucl. Inst. Meth. Phys. Res., A 841, 17 (2017)] in lifetime measurements using DSAM have facilitated [AAPPS Bulletin 34, 35 (2024)] in expanded application of the technique in different contexts outside the cliché. As far as the nuclear structure investigations are concerned, these primarily pertain to regions around the doubly-magic Ni- and Pb-cores wherein we have investigated [Phys. Rev. C 107, 024312 (2023), Phys. Rev. C 106, 044329 (2022)] the single particle excitations associated with the level structures of interest. The experimental observations have been interpreted through large basis shell model calculations that have identified the particle configurations of significance. Further, we are also using the gamma-ray spectroscopy techniques for cross-section measurements of alpha-beam induced reactions that produce radioisotopes of theranostic utilities. The excitation functions are being probed experimentally [Jour. Rad. Nucl. Chem. 333, 5589 (2024)] as well as in the statistical model calculations [Jour. Rad. Nucl. Chem. 333, 1467 (2024)] for insights on the associated parameters (optical model potential, pre-equilibrium emissions, level density and photon strength function). The presentation at FIG 2025 will be intended at taking the audience through these different endeavours and our vision of evolving into a wider research framework that'll cater to multidisciplinary objectives of more general interest.

The Nuclear Physics Group at the UGC-DAE CSR, Kolkata Centre currently consists of Dr. Sandeep S. Ghugre, Dr. Rajarshi Raut, Dr. Pankaj K. Giri, Mr. Anil Sharma, Mr. Soumalya Kundu and Ms. Aditi Das. RR and PKG acknowledge funding support under the ANRF (DST) Project No. CRG/2021/001011.

Symmetry and Nuclear Structure: Recent Evidences of Critical Point Symmetries in Atomic Nuclei

Subhendu Rajbanshi¹

¹DEPARTMENT OF PHYSICS, PRESIDENCY UNIVERSITY, KOLKATA

Like normal phase transition nuclei also exhibit transitions in phases which are not of the usual thermodynamic type but rather have similarities to the quantum phase transitions. This idea opens up a new era of research, focusing on the concept of ‘critical-point symmetries’ which describe the structure of nuclei at phase-transitional points. In Casten triangle when the spherical nuclei (vibrator $U(5)$) transform into the deformed $O(6)$ gamma soft nuclei then the transition point is called $E(5)$ whereas the spherical nuclei transit to deformed rotor ($SU(3)$ prolate) through the critical point is called $X(5)$. In recent times another special symmetry structure called $Z(5)$ draw the special attention which describe the nucleus at the prolate to oblate shape-phase transitional point. The experimental evidence of the $E(5)$ critical point was identified in ^{134}Ba and ^{128}Xe only, until today. Recently, we have established experimental evidence of exact $E(5)$ symmetry in ^{82}Kr . This prompts our motivation to study the phase transitional behaviour in nuclei throughout the nuclear chart. Our recent studies on ^{74}Se explore the possibility of another best $E(5)$ candidate in this nucleus. Our work establishes the first evidence of the Prolate to Oblate phase transition in ^{76}Se . The Bohr Hamiltonian solutions using separation of variable in five-dimension considering infinite well potential in beta along with gamma at 30 degree give epic reproduction of the experimental $B(E2)$ transitions of ^{76}Se which clearly resonate the claim of the occurrence of $Z(5)$ symmetry in ^{76}Se .

The structure of the $E(5)$ and $Z(5)$ symmetry and their inherent emergence in ^{82}Kr , and ^{74}Se and ^{76}Se will be discussed in detail.

Various facets of nuclear structure around the ^{208}Pb region

A. Y. Deo¹

¹IIT Roorkee, Roorkee, India

The heaviest doubly-magic ^{208}Pb nucleus displays interesting characteristics of nuclear structure by exhibiting strong octupole correlations and quadrupole collectivity. These octupole correlations are also reflected in the nearby nuclei wherein the excited states are seen to decay via enhanced E3 transitions. In some nuclei, the experimental transitions rates are observed to be in the 20 – 30 W.u. range for a single-octupole-phonon excitation, while for two-octupole phonon case they are ~ 40 W.u. This region also exhibit extremes of nuclear isomerism arising from pure intrinsic states which sometime couple to octupole phonon. The collectivity develops further with addition of several nucleons resulting into static octupole shapes in Ra-Th nuclei near $A \sim 220$. On the other hand, removal of nucleons, especially, the neutrons are responsible for different kind of collectivity resulting into the rotational-like bands known as shears bands. Although the region around the heaviest stable doubly-magic nucleus is rich the respect of nuclear structure effects and states up to triple neutron core excitation are reported in ^{212}Rn , several nuclei have only a couple of excited states while some nuclei haven't even been explored for high-spin states.

In view of the above, several experiments were performed to establish excited states, search for isomers and understand the evolution of octupole collectivity beyond ^{208}Pb using the national facilities at New Delhi, Mumbai and Kolkata. The gamma rays following the de-excitation process in the nuclei of interest were detected using a number of clover detectors. The analyses of the data from these experiments have established many new excited states in ^{207}At , $^{215,216}\text{Fr}$, $^{216,217}\text{Ra}$, and $^{217,218}\text{Ac}$. Some of these states are found to be longer lived with half-lives ranging from around 2 ns to a few microseconds. In fact, it was for the first time that the half-life ~ 2 ns was investigated with INGA array alone using the centroid-shift method.

In the talk, the recent results from our group will be discussed.

Probing intrinsic cluster-configuration of the ^9Be nucleus: an indirect approach

Ananya Kundu¹

¹*SINP, Kolkata, India*

The intrinsic cluster-configuration of the ^9Be nucleus has been probed by means of its influence on reaction dynamics in the $^9\text{Be}+^{110}\text{Pd}$ reaction. Measurement of the complete fusion excitation function at energies across the Coulomb barrier has been carried out using the INGA spectrometer, alongside the measurement of the elastic scattering angular distribution at a few overlapping energies. Both these processes are sensitive to the effects of coupling of internal degrees of freedom of the colliding nuclei to their relative motion. A unified description of fusion and elastic scattering at different energies has been attempted using Continuum Discretized Coupled Channels (CDCC) calculations that are contingent on the low breakup threshold of ^9Be . The calculations are modelled to incorporate the dissociation of ^9Be into either $8\text{Be}+n$, or $5\text{He}+4\text{He}$, or $4\text{He}+4\text{He}+n$ configurations. The role played by the structure of ^9Be in the ground state, resonant states as well as the non-resonant continuum has been investigated. The results and limitations of the different CDCC models will be presented.

Nuclear structure studies close to doubly magic ^{100}Sn nucleus

Dinesh Negi¹

¹Department of Physics, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal

Nuclei close to ^{100}Sn are a fertile testing ground of modern shell model theories. However, being very neutron deficient, these nuclei are still experimentally very difficult to access for their investigation (e.g. only half-life of the ground state of ^{100}Sn is known). Therefore, information about these nuclear systems is accessed from the study of their neighbours, which are relatively more than few nucleons away. With this as background, recently new experimental information in this mass region has been obtained by different research groups active in this area. In this talk, I would like to present these interesting findings.

Studies in Nuclear Structure & Nucleosynthesis using low and Medium Energy Proton Beam

Indranil Mazumdar¹

¹*Tata Institute of Fundamental Research, Mumbai, India*

Heavy-ion induced reactions have been playing a preeminent role in low and medium energy nuclear structure and reaction studies for well over last five decades. However, notwithstanding the dominion of heavy-ion physics, the light-ion induced reactions continue to remain relevant for both fundamental and applied research in nuclear physics. Continued efforts of over seven decades have yielded a huge body of information, both experimental and theoretical, from proton induced nuclear reactions. Proton induced elastic and inelastic scattering and capture reactions, provide crucial insights on structures of ground and low lying excited states, Giant Dipole Resonances (GDR) built upon ground and low lying states, possible cluster states in light nuclei etc. Proton induced scattering and capture studies have proved to be invaluable for testing nuclear reaction models and also nature of nucleon-nucleus interactions. Another important dimension of proton induced capture reaction is studies in nuclear astrophysics, namely, nucleosynthesis. Cross sections and astrophysical S factors of proton induced capture reactions ranging over few tens of keV to MeV provide information of element formations in different astrophysical environments and epochs. Moving over to applied physics, proton induced capture and scattering reactions are important in materials science, trace element analysis, reactor physics and power generation.

At TIFR, we have initiated a broad program to study important reactions of Nuclear Astrophysics and also nuclear structure at low excitation energies using low to medium energy proton beams from existing facilities in the country. In this talk I will summarize some of these efforts and present very new measurements. The talk is primarily aimed to create renewed interests in light ion induced reactions and revisit many unresolved problems of nuclear physics.

Interplay between single particle and collective mode of excitations in ^{40}K and ^{43}Ca

Rozina Rahaman¹, Abhijit Biso¹, Y. Sapkota², Arkabrata Gupta³, Ananya Das⁴, S. Ray⁵, S. Sarkar¹, Yashraj⁶, A. Sharma⁷, Bharti Rohilla⁸, I. Ahmed⁶, Kaushik Katre⁶, S. Dutt⁶, S. Kumar⁶, R. P. Singh⁶, R. Kumar⁶ and S. Muralithar⁶

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The study of the *sd*-*pf* interface nuclei gives us a unique opportunity to investigate the interplay between single particle and collective excitations. They generally show the characteristics of spherical single-particle excitations [1] and their excitation spectra are well explained by the spherical shell model [2]. However, in the Nilsson diagram, the low Ω orbitals from the *pf* shell, especially for $1f_{7/2}$, are sharply down sloping for increasing deformation. Therefore, one may expect deformed or super deformed structures with multi-hole multi particle configurations in these nuclei. Observation of deformed bands, even super deformation in a few nuclei around $A \sim 40$ [3] has therefore generated new interest in this region.

Spectroscopic information of ^{40}K and ^{43}Ca are limited. Their level schemes were extended only up to ~ 8 MeV and the spin and parity of most of the levels were not confirmed [4]. Lifetimes of all the levels are also not known. It is, therefore, felt necessary to explore them with modern detectors and data acquisition systems.

^{40}K and ^{43}Ca were populated through $^{27}\text{Al}(^{19}\text{F}, \alpha n p)^{40}\text{K}$ and $^{27}\text{Al}(^{19}\text{F}, n 2 p)^{43}\text{Ca}$ reaction with 68 MeV ^{19}F beam at IUAC, New Delhi using the INGA facility. From the analysis, the level schemes of these nuclei have been modified with new levels, spins and parities. In the case of ^{43}Ca , we are able to extend the level scheme up to the $J^\pi = 25/2^+$ band-terminating state, corresponding to the $\pi(1d_{3/2})^{-1}(1f_{7/2})^1 \otimes \nu(1f_{7/2})^3$ configuration. It has been found that the low lying negative and positive parity levels in ^{40}K are mostly single particle in nature, but the high-spin negative-parity states exhibit considerable configuration mixing in terms of particle partitions. In the case of ^{43}Ca , the positive-parity states show a linear relationship between $J(J+1)$ and excitation energy up to the band-terminating states. Large basis shell model (LBSM) calculations were performed in detail using the code OXBASH [5] and SDPFMWPN [6] interaction to interpret the experimental observation and studied the inter play between single particle and collective mode of excitations in these nuclei.

References:

1. <http://www.nndc.bnl.gov/ensdf/>.
2. R. Rahaman *et al.*, Phys. Rev. C **109**, 024318 (2024) and references there in.
3. E. Ideguchi *et al.*, Phys. Rev. Lett. **87**, 222501 (2001); Phys. Lett. B **686**, 18 (2010); Y.-C. Yang, Y.-X. Liu, Y. Sun, and M. Guidry, Eur. Phys. J. A **54**, 217 (2018).
4. P.-A. Söderström *et al.*, Phys. Rev. C **86**, 054320 (2012); P. Bednarczyk *et al.*, Eur. Phys. J. A **2**, 157 (1998).
5. B. A. Brown, A. Etchegoyen, W. D. M. Rae, and N. S. Godwin, MSU-NSCL Report No. 524, 1985. 6. W. D. M. Rae, NUSHELLX, <http://www.garsington.eclipse.co.uk>.

Hindered isomeric transitions and favoured collective phenomena in $A \sim 90$ region

Somnath Nag¹

¹*Indian Institute of Technology (Banaras Hindu University)*

The Fermi space in $A \sim 90$ is quite similar to that of $A \sim 150$ where ^{142}Gd has been reported to exhibit rotation of the nucleus about the classically forbidden longest principal axis, which is a result of interplay between the particles and holes within the available valence space. Along the same lines, ^{89}Zr was probed by our collaboration and it was found to be the $A \sim 90$ counterpart where the nucleus rotates around the longest principal axis at $I = 29/2$. This has set a benchmark to carry out similar studies in the neighbouring nuclei in $A \sim 90$. In the present talk, we will focus on Nb isotopes ($Z = 41$) and try to delve into the shape evolutions in some of the Nb isotopes. Interestingly, Nb isotopes are known to be rich in isomeric states which make them important not only from the point of view of nuclear structure rather due to the potential applications in nuclear astrophysics. The seminar will also talk about evolution of isomeric states in Nb isotopes, underlying configurations and possible coexistence of isomeric and collective states.

Investigation of Exotic Nuclear Shapes and Correlations in Transitional Nuclei

Tarkeshwar Trivedi¹

¹*Department of Physics, University of Allahabad, Prayagraj, India, 211002*

Atomic nuclei are complex, self-organized systems of protons and neutrons that display various exotic shapes. These shapes significantly influence the physical properties and behaviour of the nucleus, leading to fascinating phenomena that can be understood by considering the symmetry of the nuclear mean field and the relative orientation of the total angular momentum with respect to its principal axes. In particular, the nuclei lying mid-way between the closed shells at N or $Z = 28$ and 50 exhibit various structural features due to the presence of competing shell gaps and unique parity $g_{9/2}$ intruder orbital. The availability of valence nucleons in specific orbitals, along with nucleon-nucleon interactions leads to a variety of interesting phenomena. Recently, we have studied striking structural properties like shape coexistence and octupole correlation, wobbling in transitional nuclei using the Indian National Gamma Array facility, which has provided a decisive tool for examining the nuclear structure of a specific nucleus. These studies aim to enhance our understanding of underlying phenomena by measuring the properties of quantum systems through detailed gamma-ray spectroscopy, including DCO, linear polarization, angular distribution, and more. In this talk, an overview of these interesting structural features will be discussed.

Nuclear phase transitions at $N = 34$

Indu Bala¹

¹*Inter-University Accelerator Centre, New Delhi, 110067*

The neutron number $N = 34$ holds significant interest in nuclear structure physics due to the emergence of various phenomena around this number. For example, it shows magicity for exotic nuclei (nuclei with large neutron-to-proton ratio). Also, octupole correlations increase near particle number 34, due to the proximity of orbitals with $\Delta\ell = 3$, which deform the system towards reflection asymmetric shapes. All these observed phenomena are explained on the basis of orbitals available near Fermi surface, in this case, 1f, 2p and, 1g orbitals. Motivated by these intriguing properties, we investigated the ^{65}Ga nucleus ($N = 34$) experimentally and theoretically, to study its behaviour at medium and high spins and to identify features associated with $N=34$. A systematic exploration of neighbouring nuclei ($N = 32$ and $N = 36$) complements our study, offering deeper insights into their structural evolution.

In this talk, I shall try to correlate shell structures, shapes, and phase transitions in nuclei within the $A \approx 60$ region, particularly at excitation energies near 6 MeV (first pair-breaking energies) evidencing the critical point at $N = 34$, and highlighting the complex interplay between nuclear structure and phase transitions.

Octupole correlations in ^{118}Xe ; A fresh look via lifetime measurementSanjay Kumar Chamoli¹¹*Department of Physics and Astrophysics, University of Delhi, Delhi, India*

The Xe nuclei with mass $A < 120$ are perfectly placed to study the octupole correlations phenomena. For these nuclei, the presence of octupole driving $h_{11/2}$ and $d_{5/2}$ orbitals near the Fermi surface make them suitable to exhibit octupole correlation. Other than Xe nuclei such octupole correlations have also been reported in several other isotopes of Cs and Ba having $N < 70$. In previous high spin gamma ray spectroscopy measurements in ^{118}Xe nuclei though the octupole correlations have been reported in Refs. but in almost all the cases a precise data on parity assignments and the quadrupole moment of the bands involved were missing. Also, in cases where the octupole correlations has been discussed in relation to the observed inter-band transitions, 1022 keV ($7^- \rightarrow 6^+$), 846 keV ($9^- \rightarrow 8^+$), 726 keV ($11^- \rightarrow 10^+$) and 924 keV ($8^- \rightarrow 8^+$) in ^{118}Xe , the quoted $B(E1)$ values have errors in the range from 4% to 28%. One of the important sources of uncertainty in these E1 values is the quadrupole moment of the bands involved apart from the observed low intensity of these transitions. In the present work, the ^{118}Xe nucleus was re-investigated with the aim: 1) to confirm the suggested parities of various excited bands with polarization measurements and 2) to get a precise value of the quadrupole moment of the bands involved in octupole correlations by lifetime measurement of excited states. We have also performed the triaxial projected shell model (TPSM) calculations to investigate the observed band structures further.

High spin states in ^{118}Xe have been populated via ^{93}Nb (^{28}Si , xpyn) ^{118}Xe fusion-evaporation reaction at a beam energy of 115 MeV provided by the 15 UD Pelletron accelerator facility at the Inter University Accelerator Center, New Delhi. In the experiment, several new γ -transitions have been found and are placed appropriately in the level scheme. Theoretical study using the triaxial projected shell model (TPSM) approach suggests that the first band-crossing is due to the alignment of two neutrons, and a parallel band tracking the yrast configuration is the γ -band built on the two-quasi particle state. Enhanced E1 transition rates have been obtained between opposite parity bands, involving $vh_{11/2}$ and $vd_{5/2}$ orbitals having $\Delta j = \Delta l = 3$, indicates the presence of octupole correlation in this nucleus. More details of the analysis and the physics outcomes will be discussed during the presentation.

Isoscalar Giant Resonances in deformed Rare-Earth Nuclei: Revealing a New Compression Mode in Quadrupole Resonance

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The strength distributions of Isoscalar Giant Resonances have been investigated through inelastic alpha-particle scattering in $^{142,146-150}\text{Nd}$ and ^{172}Yb , where all but ^{142}Nd exhibit deformed characteristics. In this talk, I will show how nuclear deformation influences these strength distributions as we transition from spherical to prolate shapes. Furthermore, I will discuss the first-ever observation of overtone signatures in the Isoscalar Giant Quadrupole Resonance (ISGQR) strength distributions within Nd isotopes, which is a compression mode besides Isoscalar Giant Monopole Resonance and Isoscalar Giant Dipole Resonance.

The NUSTAR project at FAIR: status and opportunities

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The NUSTAR (NUclear STructure, Astrophysics, and Reactions) collaboration [1] is aimed at exploiting the opportunities offered by the FAIR facility. The FAIR-0 experimental campaign, using detection systems built for the future facility, is ongoing at the existing GSI accelerator complex since 2021. Preparation for moving from the present experimental areas to the new facility have started. It is foreseen that the higher transmission of the Super-FRS separator and the higher primary beam intensities of the SIS-100 synchrotron will be exploited from around 2028 and 2029, respectively.

The overarching physics case of the NUSTAR collaboration is centered around the fundamental question of how heavy elements are synthesized in the universe, especially in the rapid-neutron capture process. This needs information on a large number of observables, including nuclear masses, beta-decay lifetimes and beta-delayed neutron emission probabilities. In many of these experiments the HISPEC/DESPEC project, with essential Indian contributions, plays a central part.

I will present recent scientific and technical highlights, as well as the details on the transition from the existing GSI to the FAIR facility.

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The role of two-body interaction in the structure of nuclei in the vicinity of ^{100}Sn : First physics results using DEcay SPEcTroscopy at FAIR-Phase0

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The $N = Z = 50$ nucleus ^{100}Sn , is the heaviest self conjugate doubly magic nucleus. Neighboring nuclei south-west to the $N=Z$ line are dominated by the proton and neutron occupancy in the $g_{9/2}$ orbital. Here two body interaction between like and unlike nucleons plays an important role in determining various nuclear structure properties. The isovector interaction between like nucleons give rise to the seniority scheme, where seniority, ν , is defined as the minimum number of unpaired particles in a single j shell for a given configuration $|jn, I\rangle$. It is a conserved quantum number for a system with n identical particles, each with angular momentum j , interacting through a pairing force [1]. The isoscalar coupling on the other hand arises from the occupancy of unlike nucleons in close lying orbits. In this regard, the nuclei such as ^{94}Ru , ^{95}Rh and ^{96}Pd [2] were studied in the present experiment to explore the nature of seniority symmetry in the $g_{9/2}$ subshell for protons and the ^{94}Pd nucleus was studied to search for the competition between isoscalar and isovector couplings among the nucleons residing at the $g_{9/2}$ subshell [3].

The nuclei of interest were produced in the projectile fragmentation of a 850 MeV/nucleon ^{124}Xe beam impinging on a 4 g/cm² ^9Be target, as the first of a series of commissioning “FAIR-0” experiments with the DESPEC [4] experimental setup at the GSI- FAIR facility in Germany. The isomeric states of ^{94}Pd and ^{96}Pd were populated directly, whereas the β -decay of ^{95}Pd populates the isomeric states of ^{94}Ru and ^{95}Rh . The nuclei were implanted on an active stopper, AIDA, and the γ -rays of interest were detected using the six triple cluster HPGe detectors as well as 36 $\text{LaBr}_3(\text{Ce})$ detectors of the FAst Timing Detector Array (FATIMA)[5]. Direct lifetime measurements via γ - γ coincidences using FATIMA has been applied to determine the lifetimes for the yrast states below the isomer of the mentioned nuclei. The Generalised Centroid Difference (GCD) [6] method was implemented for the lifetime measurement in the picosecond regime. The transition rates were obtained from the measured lifetimes and the $\text{BE}(2)$ values were compared with the shell model calculations in various model spaces. With the remeasured ^{96}Pd lifetimes, the new results for the ^{94}Ru nucleus was successfully described using the $\Delta\nu=2$ seniority admixture allowed in the fpg model space using the Jun-45 interaction [7], on the other hand a large anomaly from the seniority scheme was found for the ^{95}Rh [8]. The transition rates for the ^{94}Pd was compared with the state-of-the- art shell model calculations to provide a successful interpretation [9].

Thus, in summary, the lifetime measurement for the yrast states of ^{94}Ru , ^{95}Rh , ^{94}Pd , and ^{96}Pd puts up a stringent test to the existing concept of isovector and isoscalar couplings between nucleons, and could possibly open up some new direction to understand the aspects of nucleon-nucleon interactions.

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Exploring shapes of very-neutron-rich isomeric fragments of ^{198}Pt with GRETINA

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The $A \sim 190$ Hf-Ta-W nuclei near the valley of stability have been well explored experimentally with fusion-evaporation and neutron-transfer reactions. Their collective excitations and high-K isomerism indicate robust axially-symmetric prolate shapes. On the other hand, long-standing predictions of prolate-to-oblate shape transition in very-neutron-rich isotopes of these elements have remained untested, as they cannot be accessed with the standard reactions. In this work, high-spin isomers in this region were populated by the first fragmentation of a ^{198}Pt primary beam at the National Superconducting Cyclotron Laboratory. The fragments were momentum-analyzed by the A1900 separator over a ~ 400 ns flight path, and implanted in a Si detector stack surrounded by the GRETINA array. A range of new and previously observed isomers, with half-lives from a few hundred ns to few hundred μs , were populated. With the gamma-gamma resolving power of GRETINA, first level schemes were constructed and collective excitations identified in this previously inaccessible region of the nuclear chart. Compared to its lighter neighbors, a sudden transition from prolate to a strong triaxial shape is observed in ^{189}Ta ($N = 116$), providing a critical experimental benchmark for competing model predictions. This collaborative work, spearheaded by UMass Lowell, involved researchers from Michigan State, Central Michigan and Western Michigan universities, RIKEN, Lawrence Livermore and Lawrence Berkeley National Laboratories, and the National Nuclear Data Center at Brookhaven National Laboratory. The work is supported by the U.S. Department of Energy and the National Science Foundation.

Unravelling Multinucleon Transfer reactions via α/γ -decay spectroscopy: A doorway to access Terra Incognita

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IGISOL, SuperFRS, and INGA-TIFR experiment collaborations

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Delving into the nuclear properties of heavy neutron-rich (n -rich) nuclei is essential for understanding the nucleosynthesis rapid neutron capture process (r -process) [1,2]. Multinucleon transfer (MNT) reaction process has emerged as a promising method in recent years for accessing n -rich heavy and super-heavy nuclei, including the nuclei around shell closure $N=126$ [3-5]. This has generated urgent interest in deciphering the MNT reaction process, which would eventually guide the production of n -rich heavy and superheavy isotopes/isomers of interest. The discovery of a new isotope ^{241}U using $^{238}\text{U}+^{198}\text{Pt}$ at RIKEN (Japan) and observation of large production of ^{211}Po isomer compared to ground state in $^{136}\text{Xe}+^{nat}\text{Pb}/^{209}\text{Bi}$ at IGISOL (Jyväskylä, Finland) have recently been made for the first time using MNT-induced reactions [3,4]. The spin distribution of the MNT product ^{211}Po , computed for the first time using a state-of-the-art Langevin-type model, qualitatively corroborates with the measured isomeric ratios. [4]. However, to achieve a more accurate description, further investigation is required for different target projectile systems at energies above Coulomb barrier [5,6]. A detailed experimental approach for the measurement of spin, yield, and angular distributions of MNT fragments will be discussed for heavy target-projectile systems using α/γ -decay spectroscopy.

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Precision measurements of excited-state lifetimes and energies as a probe of rare nucleon correlations far from stability

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I will discuss the results of recent lifetime and spectroscopic measurements with the AGATA and JUROGAM gamma-ray spectrometers in three unique regions of the extremely neutron deficient side of the Segrè chart, namely the corners of the doubly-magic triangles touching the $N = Z$ line with ($A \sim 170$, $Z \leq 82$, $N \geq 82$), ($A \sim 110$, $Z, N \geq 50$), and ($A \sim 90$, $Z, N \leq 50$). The first part of my talk will focus on the recent discoveries of the systematic occurrence of an anomalous evolution of $E2$ strength as a function of angular momentum (see, e.g. [1] and [2]) in W-Os-Pt isotopes with $A \sim 170$ and Te-Xe isotopes with $A \sim 110$, (first two regions) and possible clues to this puzzling phenomenon. The second part concerns gamma-ray spectroscopy of the deformed $N \sim Z$ nuclei ^{88}Ru [3] and ^{87}Tc [4] with the AGATA Advanced Gamma Tracking Array spectrometer at intermediate spin where perturbations of the rotational spectra indicate the presence of isoscalar pairing correlations. There are various experimental approaches to gauging whether this exotic and elusive pairing mode is embedded in the groundstate or excited-state nucleonic correlations or not [5]. In deformed $N \sim Z$ systems the influence on collective-rotational angular momentum states will be different, depending on the possible presence of an isoscalar component in the dominantly isovector type of pairing correlations. The evidence for such perturbations, and the difference between observations in odd- A and even-even systems, will be discussed.

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Nuclear structure studies in $A \sim 100$ mass region

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Nuclei in the $A \approx 100$ mass region exhibit a wide variety of nuclear shapes ranging from spherical to highly deformed. High spin states in deformed odd-odd nuclei in the rare-earth are of utmost important during the recent past because of observation of a number of interesting phenomena. Investigations have revealed diversity in band structures resulting from coupling of $g_{9/2}$, $d_{5/2}$, $g_{7/2}$, and $h_{11/2}$ valence nucleons and the core-excited configurations. The proton particle-hole excitations across the major shell gap are energetically possible due to strong proton pair correlations and proton neutron interaction between the spin-orbit partner orbitals. For the nuclei approaching $Z = 50$ from below, the proton Fermi surface lies near the oblate-driving high- Ω orbitals of the intruder $\pi g_{9/2}$ subshell. Strongly prolate-driving low- Ω $\nu h_{11/2}$ subshell orbitals are accessible at low excitation energies for the nuclei receding the $N=50$ Shell closure. The delicate interplay of strongly shape-driving $\pi g_{9/2}$ and $\nu h_{11/2}$ orbitals can influence the overall shape of the nucleus and result in γ -soft (triaxial) shapes with the modest deformation (ϵ_2) ~ 0.15 . The relevant intriguing triaxiality based phenomena such as magnetic rotation and degenerate twin bands have been reported in this mass region.

Radiological investigations of soil samples from some part of Punjab, potential hazard indices, and their correlation with the application of fertilizers and pesticides

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Metastable states in spherical and deformed nuclei

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Metastable states in atomic nuclei represent the manifestation of excitations which are proximate in energy but quite distinct from each other in terms of their underlying character. Such long-lived excited states have been established in nuclei with shapes ranging from spherical to highly deformed and have proved invaluable in advancing our understanding of the nature of the nuclear interaction in disparate situations. Results of our recent work wherein the longest-lived states at high excitation ($E_x > 7$ MeV) across the nuclear chart have been identified in the spherical nuclei ^{204}Pb ($Z = 82$), ^{205}Bi and ^{206}Bi ($Z = 83$) [1,2], will be presented. It has been demonstrated that half-lives up to $T_{1/2} = 8$ ms are possible at these extremes of excitation. Particle-hole excitations across the $Z = 82$ and $N = 126$ shell gaps are responsible for generating these states. In ^{207}Pb , a state with $T_{1/2} = 1.46(10)$ μs and $E_x = 8.835$ MeV, in this instance arising solely from the occupation of neutrons in the high-j, $i_{13/2}$ and $j_{15/2}$ orbitals, has been established [3]. The isotopes of Tl, specifically ^{200}Tl , ^{202}Tl and ^{203}Tl ($Z = 81$), have been found to exhibit nucleon-hole configurations with up to five neutrons, with the longest half-life being $T_{1/2} = 215$ μs [4,5,6]. Sphericity fades moving away from the doubly-magic ^{208}Pb and collective behavior emerges, however as long as the number of valence nucleons is not too large, intrinsic modes remain competitive. In the moderately-deformed Hg ($Z = 80$) and Pt ($Z = 78$) isotopes, the evolution of high-spin collectivity exhibits marked contrast to the behavior near the ground state [7,8]; these studies involved states with $T_{1/2} \approx 1$ -10 ns. In this regime, it is possible to realize the coexistence of metastable states arising from both intrinsic and collective modes. In ^{197}Au ($Z = 79$), a singular case of a spherical state with $T_{1/2} > 10$ s deexciting to a deformed one with $T_{1/2} = 8.8$ ns has been established [9]. Mid-shell nuclei are well-deformed, and if high-j orbitals with large components of intrinsic angular momentum along the symmetry axis are present, hindered decays arising from the so-called K symmetry, are evident. While the hindrances are pronounced in most instances, in a small number of cases, a significant dilution has been noticed and attributed to tunneling involving the triaxial degree of freedom. Our recent work on ^{173}W ($Z = 74$) has revealed the presence of a 3-quasiparticle state with $T_{1/2} = 93$ ns, having at least thirteen decay branches corresponding to a large range, from 1-10, of reduced hindrances [10]. All the above results on nuclei ranging from spherical to well-deformed will be presented at the conference.

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Recent findings and possibilities in structures of rare-earth nuclei using low-mass projectiles

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Research and new discoveries in nuclear structure physics, in particular, in the high-spin, high excitation energy domain employing heavy- to heavier-projectiles, delivered by the stable Heavy-Ion Beam (HIB) accelerators, have been phenomenal over the last few decades. Accelerators in India in conjunction with the success story of the INGA national collaboration, have played a major role in such endeavors. However, with the advent and progress of HIB machines coupled with the excitement of exploring high-spin physics, the plethora of possibilities, phenomena and unanswered physics in the low-spin domain using light projectiles, once the cynosure of nuclear structure physicists, have remain mostly buried during the intervening period.

However, recently a lot of interest has been generated to revisit the physics using light projectiles, such as alpha, proton, neutron etc. In our country the major workhorse for delivering high-energy alpha projectiles, the room-temperature cyclotron (RTC) at VECC, Kolkata, has been instrumental in this direction with successfully conducted multiple INGA experimental campaigns. In parallel, a new facility to carry out nuclear structure research at BARC, DURGA at Dhruva reactor, that employs thermal-neutron projectile from the reactor and a powerful hybrid gamma detector array integrated with an in-house developed digital data acquisition system, has been a force-multiplier in such efforts. The first experimental campaign by several research groups in the country is underway. Possibilities, opportunities and a few recent results from alpha+INGA and neutron+DURGA campaigns at VECC-Kolkata and BARC-Mumbai, respectively, will be discussed in the talk.

A new low-energy, high-current accelerator in India: FRENA.

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FRENA is India's first experimental nuclear astrophysics centre, with a 3MV Tandatron and various measurement end-stations. The accelerator is capable of delivering intense low-energy beams of a wide range of ions. The experimental setups are customised for conducting studies towards understanding the chemical origin of various elements. The stability of beam energy delivered by the FRENA accelerator enables precise measurement of nuclear reaction cross-sections, which are relevant to various astrophysical scenarios. This talk will provide an overview of the FRENA design, recent results as well as future scope

Constraining the isospin properties of neutron star within effective energy density functional

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We present a comprehensive investigation of the surface properties of neutron stars, with a particular emphasis on key parameters related to isospin asymmetry, such as symmetry energy, incompressibility, slope, and curvature.

To estimate these properties, we employ both non-relativistic and relativistic Energy Density Functionals (EDFs) with a broad range of parameter sets specifically chosen to satisfy the fundamental constraints of symmetric nuclear matter and pure neutron matter. Using these parameter sets, we conduct a detailed analysis of nuclear matter under extreme conditions, which is crucial for understanding the behavior of matter in neutron stars, where the neutron-to-proton ratio can be highly skewed. The maximum mass predictions for neutron stars, derived from these parameterizations, show strong agreement with the latest observational constraints on neutron star masses, indicating a realistic description of the equation of state (EoS) governing neutron star interiors. The sensitivity of neutron star mass radius relationships is particularly important, as small changes in the underlying EoS can lead to significant variations in the predicted properties of neutron stars. For example, the compactness of a neutron star is highly dependent on the stiffness of the EoS, which dictates how matter inside the star responds to compression. Furthermore, for the first time, we introduce incompressibility and symmetry energy as key factors in determining the behavior of neutron star matter under extreme pressures. Our analysis shows that their values are slightly influenced by the choice of parameterization. This work enhances the accuracy of neutron star simulations, provides a benchmark for future nuclear model validations, and significantly contributes to the interpretation of observational data from X-ray satellites, radio telescopes, and gravitational wave detectors, thereby advancing our understanding of astrophysical phenomena.

Multiquasi particle-hole excitations in odd-odd and even-even nuclei near $A \sim 90$ Vishal Malik,¹ R. Palit,¹ P. C. Srivastava,² Deepak Patel,² P. Dey,¹ D. Negi,³ A.Kundu,¹ A. Sindhu,¹ Biswajit Das,¹ U. Garg,⁴ Nidhi Goel,⁵ and Somnath Nag⁵¹Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai 400005, INDIA;²Department of Physics, Indian Institute of Technology Roorkee, Roorkee 247667, INDIA; ³Department of Physics, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal 576104, India⁴Physics Department, University of Notre Dame, Notre Dame, Indiana 46556, USA, ⁵Department of Physics, Indian Institute of Technology BHU, Varanasi 221005, INDIA

The investigation of nuclei in the mass-90 region provides insight into various aspects of both single-particle and collective excitations. Large-scale shell-model calculations have demonstrated good agreement with experimental data across both low- and high-spin states. High-spin states in the mass-90 region have been observed with multi quasiparticle configurations. The $g_{9/2}$ orbital plays a crucial role in generating both low- and high-spin states. The lower energy part of the level scheme is primarily dominated either by the excitation of fp protons to the $g_{9/2}$ orbital or by proton occupancy in this orbital. In contrast, the high-spin states are mainly driven by the coupled excitation of $vg_{9/2}$, particularly to $vd_{5/2}$, along with proton excitation across the $Z = 40$ shell gap.

In the $N = 50$ isotones— ^{86}Kr , ^{87}Rb , ^{88}Sr , ^{89}Y , ^{90}Zr [1], ^{91}Nb [2], ^{92}Mo [3], ^{93}Tc , ^{94}Ru , and ^{95}Rh —shell-model calculations have successfully explained neutron excitations from the $g_{9/2}$ orbital to $d_{5/2}$. But the E1 transitions are strictly forbidden within the $p_{3/2}$, $f_{5/2}$, $p_{1/2}$, $g_{9/2}$ model space in the absence of any pair of orbitals that satisfy the $\Delta l = \Delta j = 1$ condition. The E1 transitions can only underlie the core breaking excitations either from the $f_{5/2}$ and $p_{3/2}$ orbitals to the $g_{7/2}$ and $d_{5/2}$ ones, across the gap at $N, Z = 50$, or from the $f_{7/2}$ orbital to $g_{9/2}$ orbital across the gap at $N, Z = 28$. These transitions are generally quite weak and known to be characterized by $B(E1) \sim 10^{-5}$ W.u. The experimental transition rates of E1 transitions can highlight the importance of high j orbital (deep core excitation) that were not included in the large basis shell-model calculations.

The odd-odd nuclei in the mass 90 region are equally interesting because both the odd nucleons span the same $Z \sim 40$, $N \sim 50$ subshell space, providing a good testing ground to study the role of proton-neutron residual interaction and its influence on both the single-particle as well as collective motion. The odd-odd nucleus ^{90}Nb [4], with one proton particle and one neutron hole outside the $Z = 40$ and $N = 50$ shells, respectively, can provide us valuable information about the particle-hole interaction at low as well as high-spin states. Two experiments were performed: (1) $^{65}\text{Cu}(^{30}\text{Si}, x\text{pyn})$ at a beam energy of 120 MeV, and (2) $^{80}\text{Se}(^{18}\text{O}, x0\text{py}0\text{n})$ at 99 MeV. In-beam gamma-ray spectroscopy of ^{90}Nb [4] nucleus was carried out using (1), while for ^{92}Mo [3], both (1) and (2) experiments were used. The gamma rays were detected using the Indian National Gamma Array [5] having sixteen Compton-suppressed HPGe clover detectors at the TIFR, Mumbai. The level scheme of ^{92}Mo and ^{90}Nb nuclei was modified using angular distribution and polarization measurement. In ^{90}Nb we found an E3 transition decaying from 11^- to the ground state, 8^+ . However, the experimental $B(E3) = 0.020(4)$ W.u. indicates that the 11^- is not collective. Lifetime measurements have been carried out for some of the high-spin states, in ^{92}Mo , using the Doppler Shift Attenuation Method (DSAM) with the aim of probing the associated transition probabilities and look for possible enhancements of the same, particularly for the E1 transitions that are known underlie the core excitations for these ($Z > 40$, $N \sim 50$) nuclei. A relatively large $B(E1)$ of 1075.1 keV transition can be understood by the mutual enhancement of proton and neutron excitation.

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Enhanced electric dipole transition strengths in ^{100}Ru

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The breakdown of reflection symmetry and the presence of an intrinsic dipole moment result in a distinctive rotational band structure for octupole-deformed even-even nuclei. This structure features two alternating parity bands connected by relatively fast electric dipole (E1) transitions. Such properties are observed in even-even isotopes of Ra–Th ($Z\sim 88$, $N\sim 134$) and Sm–Ba ($Z\sim 56$, $N\sim 88$) nuclei, which exhibit permanent octupole deformation [1,2]. In a recent study, seven interleaved E1 transitions were identified in ^{100}Ru between the alternating parity bands [3]. To confirm octupole collectivity in ^{100}Ru , a direct level lifetime measurement is crucial to estimate the $B(E1)$ rates. The excited states of ^{100}Ru were populated via the $^{100}\text{Mo}(^4\text{He}, 4n)^{100}\text{Ru}$ reaction using a 45 MeV beam from the K-130 cyclotron at the Variable Energy Cyclotron Centre, Kolkata. Gamma rays were detected with the Indian National Gamma Array (INGA), consisting of 11 Compton-suppressed clover detectors positioned at 40° , 90° , and 125° relative to the beam direction. A 10 mg/cm^2 thick ^{100}Mo target was used. Data acquisition employed a 250 MHz, 12-bit PIXIE-16 digitizer (XIA LLC), recording 4×10^9 γ - γ coincidence events, of which 58% were attributed to ^{100}Ru . Angle-dependent asymmetric matrices were generated using BINDAS [4]. The lineshape analysis was carried out using the LINESHAPE package along with the development reported in Ref [5]. The velocity profiles for the ^{100}Ru residues at the three angles of 40° , 90° , and 125° were simulated using the stopping powers calculated by SRIM. Gated spectra for fitting lineshapes were extracted from the bottom gates of each of these 4 bands. The alternate parity bands show higher $B(E2)$ values than the other two high-spin negative parity bands of ^{100}Ru , indicating a higher collectivity. The $B(E1)$ rates of the interleaved E1 transitions among these bands show a two-order of magnitude larger transition rates compared to the single particle rates of other nuclei in this mass region [6].

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Recent Advances in Gamma-ray Imaging (Fundamentals to Applications)

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The detection of gamma rays is fundamental to research in nuclear and particle physics, as well as to diagnostics in nuclear medicine. This lecture will begin with a discussion of the basic principles of gamma-ray detection. We will then present the latest advancements in diagnostic imaging used in nuclear medicine, including a description of the Jagiellonian Positron Emission Tomograph (J-PET). The J-PET is the first multi-gamma-ray PET scanner capable of measuring the momentum and polarization vectors of gamma rays originating from positronium decay and the de-excitation of excited radionuclides [1,2]. Multi-gamma-ray detection enables imaging of positronium properties in living organisms, the study of matter-antimatter symmetries, and the investigation of the degree of quantum entanglement of photons from electron-positron annihilation.

We will present the first-ever clinical images of positronium properties in humans [3,4], and the first observation of non-maximal entanglement of photons from positronium annihilation in matter [5].

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The Heavy Ion Laboratory at the University of Warsaw- the next 30 years ahead

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„Nuclear Physics News” in 1994 reported: „New facility is born. It has been a good season for Polish heavy ion physicists and for Warsaw champagne dealers, as well. At the end of November 1993, the stocks of champagne were depleted after the first successful acceleration of 32 MeV $^{20}\text{Ne}^{2+}$ beam in the Warsaw Heavy Ion Cyclotron[...]”.

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

Probing yrast and near-yrast states in nuclei using INGA at VECC

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The structure of nuclei with valence neutrons or protons in the vicinity of magic shell closures depict several interesting features over different mass regions of the nuclear chart. The intriguing coupling of few valance particles or holes with respect to the closed core, results into a rich variety of level structure. The yrast and near-yrast states in these nuclei provide important information related to the single particle excitations and angular momentum coupling of valence nucleons. These nuclei provide an ideal testing ground to probe the single particle orbitals and their shape driving effects as a function of excitation energy, angular momentum and isospin. The different coupling mechanism of valence nucleons result into the observation of several new modes of excitations in nuclei, such as, magnetic rotational bands, chiral doublet bands, wobbling bands etc.. The unique parity high-j orbitals, available for both valence protons and neutrons, play a major role in driving the nuclei towards deformation. The presence of high-j intruder orbitals among the other orbitals of a particular shell also results into the occurrence of isomeric states. The light and heavy ion beams of specific energy range, available from Variable Energy Cyclotron (VECC), Kolkata, are ideal to probe some of these interesting aspects of the nuclei. Experimental investigations and results from INGA campaign at VECC will be presented.

Theoretical efforts for nuclear isomerism

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Nuclear isomers, which are longer-lived excited states of atomic nuclei, emerge due to structural peculiarities that hinder their decay processes. Advances in measurement techniques are revealing exotic isomeric properties, highlighting a critical need for enhanced and improved theoretical models for explaining nuclear isomerism. This involves exploring theoretical frameworks such as nuclear shell model (or, generalized seniority scheme) for near-spherical nuclei and symmetry based models which can reduce the dimensions for deformed nuclei such as the projected shell model and the interacting boson model.

Understanding these isomeric properties is vital due to their interdisciplinary applications in industry and science. For example, the progress on a nuclear clock using ^{229}Th hinges on the precise measurement of its isomeric transition. Another ambitious goal involves leveraging nuclear isomers as energy storage devices, and 12 candidates with half-lives in years meet the basic requirement of “isomer batteries”. Testing such longer-lived isomers presents significant experimental challenges, prompting a huge interest in processes such as the nuclear excitation by electronic capture (NEEC) for rather shorter-lived isomers with half-lives in minutes. These efforts rely on the accurate calculation of the involved electromagnetic nuclear matrix elements, however, a lack of theoretical understanding, especially for odd-odd nuclei, adds to the experimental challenge. Bridging these gaps calls for more theoretical efforts to decipher the isomeric existence and their respective decay probabilities. The role of nuclear theory in addressing these crucial aspects of isomer research will be discussed.

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Unlocking the potential of positronium physics through precision studies with J-PET

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Positronium (Ps), a leptonic atom consisting of a pair of matter (electron) and antimatter (positron) particles. As a purely leptonic object, Ps is free of hadronic background and therefore serves as an ideal system to test the bound state of quantum electrodynamics (QED) with high precision [1,2]. The well-defined quantum states of Ps allow rigorous tests of charge conjugation (C), parity (P) and time reversal (T) symmetries and their combinations, in particular CP and CPT [3]. Since the Standard Model strictly enforces CPT invariance, any observed violation in positronium decays would indicate new physics beyond the Standard Model [4,5,6]. Moreover, measuring the precise value of the decay rate of Ps atoms will provide a stringent test for QED predictions.

The Jagiellonian Positron Emission Tomograph (J-PET) - a multiphoton detector made of plastic scintillators – has proven to be a unique detector for the study of positronium decays [7,8]. J-PET enables the high-precision measurement of the angular correlations between the annihilation photons, leading to better constraint on the CP and CPT violating terms in positronium decays [7,8,9,10]. In addition, our study presents a new method to estimate the ortho-positronium decay constant from the 3γ and 2γ decay rates. We have obtained results that are an order of magnitude better than the previously reported best experimental value [11]. In this talk, I will briefly introduce the key features of the J-PET detector followed by its potential to reach new frontiers in precision research in fundamental physics by studying the decays of Ps atoms.

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Triaxiality and shape coexistence in $0\nu\beta\beta$ -decay candidates

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The electromagnetic properties of low-lying states in two isotopes predicted to undergo neutrinoless double-beta decay, ^{130}Te and ^{82}Se , have been studied through a series of high-precision multi-step Coulomb excitation experiments. These measurements were conducted at the ATLAS facility at Argonne National Laboratory (ANL) and the Legnaro National Laboratory (LNL). The experimental setup consisted of the GRETINA multidetector array coupled to the charge heavy-ion counter, CHICO2 at ANL and the AGATA array coupled to the particle detector SPIDER at LNL. These configurations enabled precise Doppler correction and clean kinematic separation of the scattered particles. A comprehensive set of transition and static E2 matrix elements were extracted from the measured differential Coulomb cross sections and used to deduce the intrinsic shape parameters - overall deformation and asymmetry - using the model-independent rotational invariant sum rules. The resulting shape parameters will be discussed in the context of shape coexistence within these isotopes, with emphasis on the role of axial asymmetry in describing the structure of these nuclei.

Octupole collectivity in zirconium isotopes around $A = 90$ regionPiku Dey¹¹Heavy Ion Laboratory, University of Warsaw, Poland

The collective excitation mode and its coupling with the single-particle excitation mode in atomic nuclei remain a fundamental issue in modern nuclear structure physics [1]. At low excitation energy, the rotational and vibrational spectra of even-even nuclei provide the simplest examples of collective modes, with quadrupole and octupole excitations comprising the latter one. Due to the almost spherical ground state of nuclei near the shell closures, quadrupole collectivity is seen to be less compared to the cylindrically symmetric deformed nuclei. In contrast, octupole excitations in these spherical nuclei have been observed by measuring enhanced electric-octupole transition strengths, $B(E3)$ values [2] associated with octupole phonon states. Additionally, the coupling between a valence nucleon and an octupole phonon can induce octupole collectivity in the neighboring odd- A nuclei having one particle outside the even-even core by acquiring a permanent octupole deformation [3]. In this context, zirconium isotopes around $A = 90$ region having semimagic $Z = 40$, draw attention for the assessment of the evolution of octupole collectivity across the isotopic chain. To explore such features, a series of new measurements have been performed on $^{90,91}\text{Zr}$ through different interaction mechanisms using hybrid setup of INGA and various ancillary detectors [4, 5]. Observation of the 31^- state has been confirmed through the relevant γ -decays in ^{90}Zr having coincidence detection of scattered projectiles in an annular double-sided Si-detector [6]. The $B(E3; 31^- \rightarrow 0\text{g.s.}^+)$ strength in ^{90}Zr has been extracted for the first time via Coulomb excitation technique by analyzing the yields of the γ -transitions and other spectroscopic data using the semi-classical least squares search code GOSIA [7]. In a separate heavy-ion fusion-evaporation experiment incorporating multifold γ -coincidence conditions in clover HPGe and LaBr₃(Ce) detectors, lifetime of the $11/21^-$ state in ^{91}Zr has been measured employing electronic fasttiming technique that leads to a significantly enhanced $B(E3; 11/21^- \rightarrow 5/2\text{g.s.}^+)$ value [8]. The extracted $B(E3)$ strengths have been compared with the random phase approximation calculations and Skyrme interactions. The above results will be discussed in consideration of recently published findings [9].

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Quantum Computing relevant to Atomic Nuclei

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The recent advances in utilizing 1) quantum computers for solving nuclear physics problems and 2) nuclear systems for quantum computing will be reviewed. While the former aspect is inherent to several many-body systems, the latter might require more attention that can potentially open several applications. Our efforts in this regard will be outlined with some recent results for coulomb scattering obtained by solving explicitly the time-dependent Schrödinger equation.

Impact of quantum correlations on the fission fragment properties

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Accurate knowledge of the fission fragment properties is crucial for several applications, such as the energy production in nuclear fission and national security application, but also for fundamental science with the understanding of nucleosynthesis and the stability of heavy elements. State-of-the-art models for simulating nuclear fission dynamics can reproduce the charge and mass distribution of fission fragments at best to within 10-20%. One of the reasons is that the most powerful techniques to date to extract the number of particles in the fission fragments neglect several important collective correlations that emerge from the nuclear dynamics. To properly incorporate these correlations, we explore how to extend the generator coordinate method (GCM) with the Gaussian overlap approximation (GOA) to the computation of fragment characteristics. The goal is to estimate the impact of quantum correlations on fission fragments and if the odd-even staggering in charge distribution of fragments can be better explained.

Support for this work was partly provided through Scientific Discovery through Advanced Computing (SciDAC) program funded by U.S. Department of Energy, Office of Science, Advanced Scientific Computing Research and Nuclear Physics. It was partly performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344. Computing support for this work came from the Lawrence Livermore National Laboratory (LLNL) Institutional Computing Grand Challenge program.

Nuclear Photonics

Dimiter Balabanski¹

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Overview of SuperFRS and R3B experiments

Haik Simon¹

¹*GSI, Germany*

Microscopic investigation of wobbling motion in atomic nuclei

Javid Sheikh¹

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**A journey from spherical shape to exotic symmetry breaking in a pyramidal nucleus –
Role of Fast timing scintillator and high efficiency Clover arrays**

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The structure of nuclei shows transitions among different shapes and displays a variety of symmetry as one plays with the number of its constituents, the protons and the neutrons. In this talk, our recent efforts to follow these changes as a function of nuclear shell gaps will be discussed.

In order to experimentally probe these fascinating phenomena occurring within the nuclear many body system demands the use of appropriate setups. The role of state-of-the-art fast timing array and high efficiency clover array for such experiments will be emphasized.

Recent developments in nuclear structure studies at IUAC

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In recent times nuclear structure studies at IUAC have been largely focused on the behaviour of transitional nuclei in different regions of the periodic table. These studies have highlighted the dynamic aspects of the behaviour of the nucleus as function of spin and excitation energy. Various established nuclear models for study of high spin properties of nuclei have been employed to understand the observed energy spectra and the transition probabilities, it is observed, however, that the descriptions by various models is still only qualitative; further, often, no model is good enough to describe all the observed features exhibited by these nuclei. Many of these studies have been done with part of the Indian National Gamma Array (INGA) detectors and some new ancillary devices. A large number of university groups have benefited from the above developments. In this talk I would like discuss some of the recent studies and the instrumentation developments at IUAC in the above context.

Triaxiality of Gamma Bands in Nuclear Landscape

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The shape and structure of nuclei are fundamentally described by the quadrupole deformation parameters, namely the axial parameter (β) and the triaxiality parameter (γ) [1]. The triaxiality parameter (γ) is closely linked to the gamma band observed in even-even nuclei and their band-head energy [2]. Different nuclear shapes can be illustrated for a given axial parameter (β) with variations in the triaxiality parameter (γ) between $30^\circ \leq \gamma \leq 60^\circ$. In this talk, I will provide an overview of the deformation parameters (β , γ) across the range of nuclei with $30 \leq Z \leq 80$ for all even-even isotopes using the Davydov and Filippov model [3] or the rigid triaxial rotor model (RTRM). The primary focus of this work is to explore the correlation between the quadrupole deformation parameters (β) with both the mass number and the triaxiality parameter (γ) to achieve a more straightforward description of nuclear shape. The staggering parameter [4] was also studied to mark the strong and intermediate triaxiality. The S(4) and S(5) energy staggering parameters were examined to explore triaxiality, it was found that the magnitude of these parameters increases with triaxiality (γ). Particularly, the $|S(4)-S(5)|$ becomes a relevant parameter to pinpoint the triaxiality in gamma bands.

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Shell model study of allowed, forbidden and double beta decay

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The beta decay study of nuclei is essential for a deeper understanding of weak interactions at the nuclear level and nucleosynthesis processes. We have done a comprehensive shell-model study of the $\log ft$ values for the forbidden β^- decay transitions in the region north-east of ^{208}Pb [1]. For this we have considered $^{210-215}\text{Pb} \rightarrow ^{210-215}\text{Bi}$ and $^{210-215}\text{Bi} \rightarrow ^{210-215}\text{Po}$ transitions and calculated half-lives and Q values for the concerned nuclei. Recently, several $\log ft$ values were observed corresponding to β^- decay from the (8^-) isomeric state of $^{2145}\text{Bi}^m$ at the CERN-ISOLDE facility, and for the first time we have reported shell-model results for these transitions.

Further, we have performed the large-scale shell-model calculations for the neutron-rich nuclei in the south region of ^{208}Pb in the nuclear chart with $76 \leq Z \leq 82$ [2]. These calculations have been performed without truncation in a particular model space for nuclei $N \leq 126$; additionally, particle-hole excitations are included in the case of core-breaking nuclei ($Z \leq 82$, $N > 126$). An extensive comparison with the experimental data has been made, and spin parities of several states have been proposed. The results of $N = 126$, 125 nuclei will be also presented [3].

To give more insights into the second-order weak interaction processes [4,5], we have investigated the $2\nu\beta\beta$ decay and $2\nu\text{EDEC}$ processes in different mass regions of the nuclear chart, employing large-scale shell-model calculations. We analyse the $2\nu\beta\beta$ decay of ^{76}Ge , ^{82}Se , $^{94,96}\text{Zr}$, ^{108}Cd , ^{124}Sn , $^{128,130}\text{Te}$, ^{136}Xe , and ^{150}Nd . The NMEs are computed for these nuclei, and the extracted half-lives are found to be in good agreement with the experimental data.

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Exploring nuclear structure with PARIS

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PARIS (Photon Array for studies with Radioactive Ion and Stable beams) is an international research project with the aim of developing and building a novel 4π gamma-ray calorimeter, employing modern scintillators. The PARIS array, employing CeBr₃/LaBr₃:Ce +NaI Phoswich detectors, can serve as an energy-spin spectrometer, a calorimeter for high-energy photons and a medium-resolution gamma-detector. India has been a major partner in PARIS right from the concept stage and has also contributed to various R&D aspects. The talk will present details of PARIS design and some highlights of the recent physics experiments employing PARIS at different accelerator facilities like GANIL , IPN / IJCLab at Orsay and CCB at IFJ PAN Krakow. The plans for physics program with INGA + PARIS will be discussed.

Competition between the neutron-proton pair break-up for nuclei around $Z = 82$ shell closure

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Nuclei near the doubly-magic $Z = 82$ shell closure exhibit both single-particle excitations at low spins and diverse collective rotational behaviours, including super-deformation, highlighting shape coexistence at high spins [1-3]. Even-even $^{200-208}\text{Po}$ isotopes, with two protons above $Z = 82$, exemplify the competition between two quasi-protons and two quasi-neutrons. Isomeric states arising from neutron proton configurations are well known in Pb and Hg and are expected in Po, with only two seniority [4] isomers observed in $^{198,200}\text{Po}$. Investigating ^{202}Po can enhance understanding of two-particle states and potential high-seniority isomers. Shears bands, formed by high-K neutron-proton coupling, are well established in Pb, Hg, and Bi ($A = 192-201$) but remain unreported in Po. Studying ^{202}Po , ^{201}Po analogous to ^{200}Pb , ^{199}Pb could reveal such structures and elucidate the role of the two protons above $Z = 82$ [5]. The detailed results of the spectroscopy of ^{201}Po and ^{202}Po will be presented at the conference.

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Probing deep into the fission dynamics through Fission Fragment Spectroscopy

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During the fission process, a compound nucleus undergoes a large-scale collective rearrangement within a time scale of the order of about 10^{-20} seconds. The fission fragments produced after the scission point subsequently de-excite via the emission of prompt gamma rays that carry the features of the underlying fission dynamics involved. Using Fission Fragment Spectroscopy (FFS) technique, one aims for efficiently detecting the de-exciting gamma rays [1]. This technique has been used extensively by our group for unveiling several fascinating features related to fission dynamics involving the fissioning systems, $^{232}\text{Th}(\alpha, f)$ and $^{235}\text{U}(n_{th}, f)$. These include: (i) quantifying S1 and S2 modes of fission presence in the multi-modal fission dynamics ; (ii) unveiling the influence of spherical and deformed proton- and neutron-shell closures in controlling the S1 and S2 fission modes; (iii) extracting the pair wise neutron multiplicity distribution profiles for the correlated fission fragments etc. The plethora of results [2-5] obtained from the rigorous and careful analysis will be presented at the conference.

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Collective enhancement of nuclear level density and its significance in radiative capture

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The collective enhancement of nuclear level density (NLD) plays a pivotal role in understanding nuclear structure and reactions, particularly influencing radiative capture processes. This enhancement arises from collective excitations, such as rotations and vibrations, which increase the density of accessible nuclear states.

The collective enhancement of nuclear level density and its fade-out in deformed ¹⁶¹Dy has been investigated by analysing the neutron evaporation spectra and revealed a substantial collective enhancement factor of 42 ± 2 at low excitation energies, aligning well with microscopic theoretical predictions. Recent experimental investigations have provided quantitative insights into this phenomenon. In a study focusing on the deformed nucleus ¹⁷¹Yb, neutron spectra were measured to probe the collective enhancement in NLD. The statistical model analysis of these spectra revealed a significant collective enhancement factor of 40 ± 3 , aligning with recent microscopic model predictions. This finding is notable, as it presents an anomalously large enhancement compared to measurements in nearby deformed nuclei. The study also combined these results with Oslo data below the neutron binding energy to construct a comprehensive energy-dependent profile of the collective enhancement. This detailed characterization underscores the substantial impact of collective excitations on NLD and highlights the necessity of incorporating these effects into models of nuclear reactions. The implications of collective enhancement extend to radiative neutron capture cross sections, which are crucial for astrophysical nucleosynthesis and nuclear technology applications. The increased NLD due to collective effects can significantly alter capture cross sections, thereby affecting element formation processes in stellar environments and influencing the design of nuclear reactors and transmutation systems. Understanding the magnitude and energy dependence of this enhancement is essential for accurate modelling of these processes.

Collectively, these studies underscore the necessity of incorporating collective enhancement effects in NLD models to achieve accurate predictions of radiative capture cross sections. Such considerations are indispensable for refining our comprehension of nucleosynthesis pathways and for the development of advanced nuclear technologies.

Radiation Detectors in Nuclear Medicine: A Review of Performance Evaluation, Recent Advancements, and Future Perspectives

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The medical application of radiation began with Wilhelm Röntgen's accidental discovery of X-rays in 1895. Early advancements included the Blumgart and Yens equipment, a modified Wilson's tube, which pioneered radiotracer flow mapping in the human body. A pivotal moment arrived in 1948 with Robert Hofstadter's invention of the NaI(Tl) scintillation detector, revolutionizing nuclear medicine. This led to Benedict Cassen's development of the first nuclear medicine imaging device, the rectilinear scanner, in 1950. Hall Anger's invention of the wide-field gamma camera in 1951 further transformed the field.

Subsequently, advanced imaging modalities like positron emission tomography (PET), single-photon emission computed tomography (SPECT), and specialized organ imaging devices such as cardiac SPECT, scintimammography, and positron emission mammography (PEM) emerged. Most of these systems rely on scintillation detectors to capture gamma rays for image formation. Subsequently, fusion imaging devices like PET/CT, SPECT/Computed Tomography (CT), and PET/Magnetic Resonance Imaging (MRI) were developed, improving diagnostic outcomes.

Recent technological shifts include the replacement of photomultiplier tubes with silicon photomultipliers (SiPMs) in many nuclear medicine devices. Another significant advancement is the adoption of cadmium zinc telluride (CZT) crystals in SPECT systems. Furthermore, two manufacturers have introduced SPECT systems with ring technology, enabling dynamic SPECT imaging and substantially increasing sensitivity.

Ongoing research focuses on future detector technologies, such as Lanthanum Bromide Scintillation Detector (LaBr₃), aimed at achieving timing resolutions below 100 picoseconds. Scatter imaging using plastic scintillation detectors, as explored in the J-PET project, is also a promising area. Additionally, machine learning and deep learning are being integrated into various stages of image acquisition and reconstruction to further enhance nuclear medicine imaging.

Measurement of Recoil and Spin Distributions Using Off-Beam and In-Beam Gamma-Ray Spectroscopy: A Study Relevant to Pre-Compound Emission

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The pre-compound emission process in light-ion-induced reactions has been well established over the past few decades [1-3], however, its role in heavy-ion reactions at low energy below 7 MeV/nucleon requires further investigations. Recent studies on heavy-ion-induced reactions involving ^{12}C , ^{14}N , ^{16}O and ^{19}F with target nuclei ^{159}Tb , ^{169}Tm , ^{175}Lu and ^{185}Ta suggest a significant contribution of pre-compound emission even at low energies $\sim 4\text{--}7$ MeV/nucleon, where the compound nucleus process is expected to dominate. Aiming to develop a mass number dependence systematics in pre-compound emission process, a precise analysis of measured excitation functions for several reactions induced by ^{12}C , ^{14}N , ^{16}O and ^{19}F beams on various target nuclei of ($A=159\text{--}185$) has been performed with statistical model code PACE4 [5,6]. An independent contribution of pre-compound emission has been determined for each target nucleus by comparing the measured cross-section values with theoretical predictions [6,7].

To explore the influence of momentum transfer in heavy-ion reactions, experiments have been carried out at the General Purpose Scattering Chamber (GPSC) and the Gamma detector Array (GDA) beam lines of the Inter University Accelerator Centre (IUAC), New Delhi, India employing off-beam and in-beam Gamma-Ray spectroscopy. These studies focused on measuring the recoil range distributions (RRDs) and spin distributions (SDs) of various reaction residues in the $^{12}\text{C}+^{169}\text{Tm}$, $^{16}\text{O}+^{159}\text{Tb}$, and $^{16}\text{O}+^{169}\text{Tm}$ systems at energies above the Coulomb barriers. The analysis of RRDs measurements shows two distinct linear momentum components corresponding to pre-compound and compound nucleus processes, however, the SDs indicate two distinct de-excitation patterns corresponding to the pre-compound and the compound nucleus processes. The experimental results of SDs are important, suggesting a relatively lower value of input angular momentum is associated with pre-compound emission as compared to the compound reaction processes. The present investigations throw a new insight into the low energy reaction dynamics of the heavy ion reactions. Further details of measurements and analysis will be presented.

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Nuclear Structure studies with Chebyshev Shape Parametrization

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Accurate nuclear shape parametrization is crucial for understanding collective dynamics and fission mechanisms. Traditional methods often struggle to capture complex deformations effectively. This work introduces a novel Chebyshev shape parametrization that leverages Chebyshev polynomials of the first kind to model nuclear geometries with greater precision. The nuclear surface is expressed as a series expansion in Chebyshev polynomials, where individual coefficients control key deformation features: one governs elongation, another regulates asymmetry, and a third refines the neck formation. To ensure physically realistic deformations, volume conservation and center-of-mass constraints are imposed. The potential energy surface (PES) is computed using the macroscopic Lublin-Strasbourg Drop (LSD) model. The Shell corrections will be incorporated in the model calculations appropriately. The Chebyshev parametrization proves to be a powerful tool for nuclear structure studies, particularly in the investigation of nuclear fission.

Evidence of chiral symmetry breaking in ^{141}Sm

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Over the past three decades, significant research has been dedicated to gathering definitive evidence for the presence of triaxial shapes in atomic nuclei. Nuclear chirality, one of the experimental signatures of triaxiality, is expected to occur in nuclei having high-j particle like and hole like orbitals align their angular momenta along the short and long axis respectively along with the collective angular momentum favors the intermediate axis. The three mutually perpendicular angular momentum vectors arranged themselves to form two systems of opposite chirality (Left handed and Right handed) which combines time reversal and spatial rotation of 180° , $\chi = \text{TR}(\pi)$. The spontaneous symmetry breaking in intrinsic frame results a degenerate doublet $\Delta I = 1$ band in laboratory frame with the restoration of chiral symmetry due to quantum tunneling.

In the present work, we have investigated the presence of chiral symmetry in the ^{141}Sm nucleus through the fusion evaporation reaction $^{116}\text{Cd} (^{30}\text{Si}, 5n) ^{141}\text{Sm}$ with the help of INGA array placed at TIFR, Mumbai. The ^{30}Si projectile of energy 149 MeV obtained from the TIFR BARC Pelletron LINAC facility at TIFR, Mumbai. We have observed 27 new gamma transitions and arranged them in the form of three dipole band structures DB1, DB2 and DB3. The excitation energy $E(I)$, kinetic moment of inertia $J(I)$ and the energy staggering $S(I)$ values for DB2 and DB3 in ^{141}Sm exhibits close similarity throughout the observed spin region reflecting same configuration of the bands. The absence of staggering of $S(I)$ values for both the bands indicates weak Coriolis interactions resulting from perpendicular angular momenta coupling of the single particle to that of the core. The energy degeneracy shows almost identical behavior indicating strong influence of the core rather than the valence particles. The absolute $B(M1)$ and $B(E2)$ transition strengths obtained from the measured level lifetime using Doppler shift attenuation method shows similar behaviour throughout the bands which are critical experimental observables for the bands being chiral partner. Present investigation predicts that the bands DB2 and DB3 in ^{141}Sm are based on a five quasiparticle configuration which is maiden in respect to the search for the chiral symmetry in atomic nuclei.

Z(5) Prolate to Oblate Shape Phase Transition in 76 Selenium

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Like normal phase transition nuclei also shows transition in phase. These phase transitions are not of the usual thermodynamic type, but rather they are quantum phase transitions. This idea opens up a new area of research, focusing on the concept of ‘critical-point symmetries’ (E(5), X(5), Z(5) etc), which describe the structure of nuclei at phase-transitional points. In Casten triangle when spherical nuclei (vibrator U(5)) transformed into deformed O(6) γ soft nuclei then the transition point is called E(5), the order parameter changes rapidly as a result discontinuity appear in order parameter hence E(5) is a first order phase transition. Similarly when the spherical nuclei transit to deformed rotor (SU(3) Prolate) then the critical point is called X(5). But Z(5) symmetry is very special in the sense that the order parameter changes continuously and this is off course a second order phase transition, the shape of the nuclei does not changes though the deformation parameter greater than zero.

In this work Z(5) Prolate to Oblate phase transition has been discussed using the Z(5) predicted energy levels and B(E2) transition strength. At first we solve the Bohr Hamiltonian using separation of variable in five-dimension considering Infinite potential well along beta of width β_w and Harmonic oscillator potential which is minima at $\gamma=30^\circ$. The experiment was done at Variable Energy Cyclotron Centre, Kolkata the ⁷⁶Se nucleus was produced through the reaction of the alpha projectile at 28-MeV with the Natural Ge target. The data were sorted using Coincidence Search program (MARCOS) developed at TIFR has been used to generate angle independent and dependent gamma-gamma matrices. RADWARE and INGASORT software's have been used to analyze the data. Ten new Z(5) gamma has been observed along with a new zero plus state and five new energy levels. The Z(5) predicted energy for ground state band (s=1, n-w=0), even gamma1 (s=1, n_w=2), odd gamam1 (s=1, n_w=1) and beta1 (s=2, n_w=0) bands are overlapped with their experimental energies up to some states, The B(E2) transition rates are also well reproduced for ground state band (s=1, n-w=0) even gamma1 (s=1, n_w=2), odd gamam1 (s=1, n_w=1) and beta1 (s=2, n_w=0) bands. The well agreement between the experimental energy and B(E2) values with the calculated results within the Z(5) model predicts that Z(5) symmetry may exist in the ⁷⁶Se nucleus.

In-beam γ -spectroscopy of the transitional nuclei $^{217,218}\text{Ac}$ Dhananjaya Sahoo¹¹*Department of Physics, Indian Institute of Technology Roorkee, Uttarakhand*

Structure of atomic nuclei in the neutron-deficient region beyond the doubly-magic ^{208}Pb has been a topic of interest since the last few decades. The valence nucleons outside the proton and neutron shell closures at $Z=82$ and $N=126$ play a crucial role in governing the underlying structure of these nuclei. Evolution of nuclear structure beyond ^{208}Pb is intriguing, as one observes single-particle excitations in nuclei near the closed shell, while collective modes of excitation, particularly octupole correlations, emerge in nuclei away from the closed shell, such as those in the Ra-Th region with $A \geq 220$. Consequently, nuclei lying between these two regions of structural phenomena are key examples of transitional nuclei, exhibiting the evolution of structure from single-particle to collective modes of excitation. The comprehensive γ -spectroscopic studies have established that Ac isotopes also follow a similar trend in the evolution of their underlying structural properties at $N=129$. In this work, we report on high-spin studies of $^{217,218}\text{Ac}$.

High-spin states in $^{217,218}\text{Ac}$ were populated using the $^{209}\text{Bi}(^{12}\text{C},\text{xn})^{217,218}\text{Ac}$ heavy-ion fusion-evaporation reaction. The 72 MeV beam of ^{12}C , provided by the 14-UD Pelletron LINAC Facility at TIFR, Mumbai, was bombarded on a self-supporting ^{209}Bi target of 4 mg/cm² thickness. The INGA array was used for the detection of the emitted γ -rays.

Previously, the level scheme of ^{217}Ac ($Z=89$ and $N=128$) was known up to an isomeric $I^\pi=29/2^+$ state with $T_{1/2} = 740(40)$ ns at 2013 keV. In the present study, the level structure is considerably extended up to $I^\pi = 41/2^+$ and 3.9-MeV excitation energy with addition of 22 new transitions. The experimental results are compared with those obtained from large-scale shell-model calculations. A systematic comparison with the $N=128$ isotones suggests that the level structures in ^{217}Ac result from a weak coupling of the odd proton ($h_{9/2}$ or $i_{13/2}$) to the even-even ^{216}Ra core, which is consistent with the shell-model configurations. Similarly, the level structure of ^{218}Ac , previously known with three alternating-parity sequences, is further extended with the addition of several new transitions. The spin and parity of the states are established on the basis of R_{DCO} and linear polarization measurements.

The detailed results will be presented at the conference.

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A new charged particle- γ coincidence setup at TIFR

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A new detector system has been developed to facilitate measurement of charged particles and γ -rays in coincidence, for nuclear structure and reaction studies using the BARC-TIFR Pelletron Linac facility, Mumbai. This system combines an annular double-sided segmented Si detector with the TIFR-INGA array of Compton-suppressed clover HPGe detectors. A digital data acquisition system has been configured for the setup, which was calibrated and tested using a ²²⁹Th radioactive source that emits α -particles along with γ -rays. The functionality and performance of the coincidence apparatus were demonstrated for Doppler correction of γ -transitions emitted during the in-flight de-excitation of the projectile and target in the ³⁰Si+¹⁹⁷Au Coulomb excitation experiment.

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Development of TCAD-based Neutron Radiation Damage Model for 4H-SiC Alpha-Particle Detectors

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4H-Silicon Carbide (4H-SiC) detectors have gained significant attention in nuclear scientific community due to their ability to operate in harsh environmental conditions, withstand high temperatures, and offer longer operational lifespans than traditional silicon-based detectors. The neutrons are the primary source of damage in nuclear reactors, with fluence levels reaching 10^{16} n/cm². Increased neutron fluence can cause damage to the SiC material, leading to the formation of electrically active traps. These traps can significantly degrade the performance of the detector, impacting key parameters such as Charge Collection Efficiency (CCE) and energy resolution. Therefore, understanding and mitigating the effects of neutron-induced damage are essential for ensuring the long-term reliability and effectiveness of SiC detectors in nuclear environments.

In this work, we have developed a TCAD-based neutron damage model for 4H-SiC alpha-particle detectors, validated through experimental results, to predict the detector characteristics at various neutron fluences. 2D detector structure is created in the TCAD simulator based on the work of Nava et al. [1]. The unirradiated forward and reverse I-V characteristics are first validated, as per the calibration procedure reported in our recent article [2]. Specifically, a novel Heavy-ion (HI) model is proposed [2] to account for drift- and diffusion-assisted charge collection, thereby validating CCE properties with detector bias.

The neutron irradiation-induced changes in detector properties are modeled according to the expression $N_T = \eta \cdot k \cdot \Phi_{1\text{MeV}}$, where N_T represents the trap concentration, η is the introduction rate, k is the hardness factor, and $\Phi_{1\text{MeV}}$ is the 1 MeV neutron fluence. Initially, η is calculated based on reported N_T at $\Phi_{1\text{MeV}} = 2 \times 10^{13}$ n/cm². N_T is varied to match the forward I-V at 2×10^{14} n/cm². Using the same η , reverse I-V and CCE are validated. For higher fluences $> 2 \times 10^{14}$, the simulations are conducted using the same η to assess the detector's performance. This model establishes a relationship between N_T and $\Phi_{1\text{MeV}}$, enabling predictions of detector performance at various fluence levels and operational lifetime. Eventually, the model aims to support the design of detectors, reducing the need for extensive experimental testing and minimizing associated costs.

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Possible Evidence of E(5) Symmetry Breaking in ^{74}Se

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Phase transitions in atomic nuclei have emerged as one of the most fascinating topics of investigation over the years. Two distinct critical phase transitional points were identified in the pathway of the spherical to deformed one. One situated in between the spherical and the γ -vibrational limit is termed E(5) symmetry breaking, whereas the other symmetry, X(5), falls in the path of γ -vibration to the deformed system [1]. The experimental evidence of the E(5) critical point was identified in ^{134}Ba and ^{128}Xe only, until today [1]. Recently, we have established experimental evidence of exact E(5) symmetry in ^{82}Kr [2]. This prompts our motivation to study the phase transitional behavior in nuclei throughout the nuclear chart. The present experimental study aims to investigate the E(5) critical point symmetry in the ^{74}Se nucleus.

The low-spin states of ^{74}Se are populated by the fusion-evaporation reaction $^{72}\text{Ge}(^4\text{He}, 2n)^{74}\text{Se}$ at beam energy 28 MeV obtained from K130 cyclotron, VECC, Kolkata. The de-exciting γ -rays were detected by the Indian National Gamma Array (INGA), which consists of 11 Compton suppressed clover detectors, positioned at three different angles.

In the present work, we have re-investigated the low-spin states of ^{74}Se [3,4] and several new γ -ray transitions have been established from the coincidence measurements. A partial levelscheme has been proposed which is compared with the possible E(5) levels [1]. A possible $\xi = 2$ family band along with the 0^+_{2} and 0^+_{3} states arising from the two phonons and three phonons are established. These observations corroborate the IBA prediction of E(5) dynamical symmetry in ^{74}Se . The detail structure of the E(5) symmetry and its emergence in ^{74}Se will be discussed at the time of presentation.

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Study of odd-even staggering in the alpha decay of 207-216Th isotopes

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Alpha decay serves as a powerful tool for investigating the structural properties of atomic nuclei, providing crucial insights into nuclear shell effects, magic numbers, and nucleon correlations. By examining decay energies (Q-value) and half-lives, researchers can unravel fundamental aspects of nuclear stability and clustering phenomena. Recently, Yang et al. [1] experimentally identified new thorium isotopes, ^{207,208}Th, and analyzed their alpha decay energies (Q α) in comparison with other Th isotopes. Their study revealed a distinct odd-even staggering (OES) pattern in nuclei with $Z > 82$ and $N < 126$, deviating from the traditionally assumed smooth trend in the decay energies.

Beyond decay energy, alpha emission is governed by multiple factors, including preformation probability (P₀), penetration probability (P) and assault frequency (ν_0). In the present work, we have performed a systematic alpha decay analysis of ²⁰⁷⁻²¹⁶Th isotopes using the preformed cluster model (PCM) [2, 3]. Our findings demonstrate that the observed odd-even effects in alpha decay energies are evident in the preformation and penetration probabilities as a function of neutron number of the daughter fragment. We have compared the calculated preformation probabilities with other theoretical approaches. The results provide deeper insights into nuclear pairing correlations, clustering effects, and their implications for alpha decay dynamics in medium-to-heavy nuclei, further contributing to the understanding of nuclear structure and stability aspects.

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Systematic study of superdeformed bands in Hg isotopes using semi-classical vibration distortion model

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For the first time, the semi-classical vibration distortion model has been applied to execute the systematic study of superdeformed bands (SD) in Hg isotopes. This model examines the effect of vibrational mode at high spins on SD nuclei. The parameters B_v and D in the energy expression of the model are obtained by least square fitting of experimental gamma transition energies. The model is employed to assign band head spin to all SD bands in Hg isotopes using root mean square deviation method (RMSD). This method shows that the band head spin depends on calculated gamma transition energies. The method involves the energy difference between calculated and experimental transition energies which are reported from chart of nuclides available at nndc website. It has been observed that the calculated and experimental transition energies are consistent with one-another. Thus, the point I of minimum deviation is the band head spin I_0 . We have also investigated the variation of calculated and experimental dynamic moment of inertia with frequency.

Investigation of Octupole Correlations in odd A Bromine Isotope

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Spontaneous symmetry breaking plays a crucial role in determining the exotic shapes and associated phenomena of the atomic nucleus. These shapes depend on the valence nucleons occupying specific orbitals and the nucleon-nucleon interactions. One of the fascinating phenomena is the occurrence of octupole deformation or a pear-like structure, which arises due to the breaking of reflection symmetry. In particular, the nuclei with nucleon numbers $Z \sim 34$ and $N \sim 42$, occupy $p_{3/2}$ and $g_{9/2}$ orbitals, and exhibit an angular momentum difference of $3\hbar$, resulting in octupole correlations in this region. Recently, the octupole correlations were reported in the ^{76}Br and ^{78}Br nuclei using in-beam gamma-ray spectroscopy measurements. However, the odd-A ^{77}Br isotope lying in the same vicinity has not been well explored. The high spin states of ^{77}Br nucleus were studied using the Indian National Gamma Array (INGA), consisting of 18 Compton-suppressed clover detectors at TIFR, Mumbai. During the experiment coincidence data is collected in the list mode and sorted into γ - γ matrices using the MARCOS program. These matrices were subsequently used to construct the level structure using the RADWARE program. Previously identified γ -rays in the level structure were verified, and new interconnecting γ -ray transitions were placed. The spin and electromagnetic nature of γ -ray transitions were determined using the RDCO and linear polarization measurement techniques. Additionally, transition probabilities were determined through lifetime measurements of excited states using the Doppler shift attenuation method. These combined measurements provide valuable insights into the octupole correlations in this nucleus.

Study of different nuclear structure phenomena around Z,N = 28

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The structures of odd-odd ⁵⁴Mn(Z=25, N=29), ⁵⁷Fe(Z=26, N=30) and ⁵⁵Mn(Z=25, N=30) have been studied [1-4] from an alpha-induced fusion evaporation reaction using high-resolution gamma-ray spectroscopy and lifetime measurement by Doppler Shift Attenuation Method (DSAM). The study is to investigate the influence of the single-particle *fp* and unique-parity, intruder *g*_{9/2} orbital in generating the excited states of these nuclei and thereby, to shed light on the nature of the debatable Z, N = 28 shell closure, the first one originated due to spin-orbit coupling [5-8]. The ⁴He + ⁵⁵Mn nuclear reaction/s with 34 MeV alpha beam from the K-130 cyclotron at VECC, Kolkata, was used to populate the nuclei and the de-excited prompt gamma rays were detected by the Indian National Gamma Array (INGA) comprised of 11 clover HPGe detectors and a LEPS placed at 3 different angles [1]. Different nuclear phenomena including spherical and near-spherical shapes, axial and non-axial deformations, and octupole correlation have been observed in the structure of these nuclei [1-4]. A unique magnetic rotational (MR) band involving only the negative parity orbitals across the Z=N=28 shell closure has been established in ⁵⁷Fe through the lifetime measurements [2-3]. This MR band, constituted by only *1f2p* orbitals, is found to have an ideal behavior that suggests the robustness of the Z=N=28 shell closure.

The octupole correlation has been identified in all these three nuclei [1,2,4] at lower excitation and compared with other nuclei. Deformed rotational bands, induced by *f*_{7/2} and *g*_{9/2} orbitals, have been identified in odd-A ⁵⁵Mn and ⁵⁷Fe and extended till band crossings [2,4]. The first evidence of triaxial shape in ⁵⁷Fe has also been observed through the gamma-vibration band [2]. In ⁵⁴Mn, the indication of the onset of deformation has been observed at higher excitation [1,2].

The results are interpreted in terms of theoretical calculations. The detailed results and outcome of these features will be presented at the conference.

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In-beam Gamma ray spectroscopy of ^{107}Sn nuclei

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This investigation aimed to explore the nuclear structure of odd-A ^{107}Sn nuclei at high spin, with proton number $Z=50$ and neutron number $N = 57$, using in-beam gamma-ray spectroscopy techniques. The fusion evaporation reaction $^{94}\text{Mo}(^{16}\text{O}, 3n)^{107}\text{Sn}$ was employed, utilizing a 70 MeV beam from the 15UD Pelletron Accelerator at the Inter-University Accelerator Centre (IUAC) in New Delhi. Gamma rays emitted from the reaction products were detected using the Indian National Gamma Array (INGA), equipped with seventeen Compton-suppressed Ge clover detectors positioned at varying angles relative to the beam axis. Subsequent offline analysis of gamma-gamma coincidence data enabled a systematic reconstruction of the level scheme of ^{107}Sn . Multipolarity assignments were based on the Directional Correlation of Oriented States (DCO) and Angular Distribution from Oriented Nuclei (ADO) ratios.

This study significantly expanded our understanding of the structure of states in ^{107}Sn by identifying over twenty-five new gamma-ray transitions, particularly at higher spin. Many of these new transitions originate from sequences with $\Delta I = 1$ or 2. While at low energy, these states have configuration of one neutron in either $g_{7/2}$ or $d_{5/2}$ coupled to ^{106}Sn core, the structures at higher energy have multi quasiparticle configuration. This study enables us to estimate the contribution of both the proton and neutron core excitations across the $N=Z=50$ shell gap to these states.

Evolution of quadrupole and octupole excitations beyond non-collective states in ^{114}Te

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The Te isotopes are known to exhibit collective vibrational features appearing on top of non-collective excitations [1]. Grinberg et al. [2] studied the existence of these structures with quasiparticle phonon model. However, due to a lack of theoretical and experimental B(E2) values, they were unable to explain the collective and non-collective behavior of these states. Therefore, it would be interesting to explore the collective and non-collective structure of these states within the framework of the relevant model. Also, Te isotopes have both the proton and neutron numbers close to the octupole magic number (56), so they are a good candidate to study this phenomenon. Octupole correlation has been established in neutron-deficient Te isotopes ($A \approx 108\text{--}110$) based on the B(E1)/B(E2) ratio. With this motivation, we planned to investigate the level structure of ^{114}Te .

The excited states of ^{114}Te were populated by the reaction $^{112}\text{Sn}(^4\text{He}, 2n)^{114}\text{Te}$ at a beam energy of 37 MeV using the K-130 cyclotron accelerator of the VECC, Kolkata. The de-excited gamma rays are detected by using the 7-compton suppressed clover detector placed at angles 125, 90, and 40.

In the present work, the level scheme of ^{114}Te has been extended by the addition of 35 new gamma transitions. The multipolarities of these gamma transitions are confirmed by the DCO and polarization asymmetry measurements. This nucleus is also found to exhibit octupole correlation based on B(E1)/B(E2) ratio and CDFT calculations. Furthermore, all the observed bands were probed within the framework of shell model calculation, and observation of non-collectivity at low spin was explained with calculated B(E2) values. Several non-collective oblate states at higher spins were discussed by using the ULTIMATE CRANCKING model because shell model calculations are found to deviate at higher spins. The calculated results from the UC menu were also able to explain the experimentally observed nearly degenerate 7^+ states. Thus, ^{114}Te presents a rich laboratory to study collective and noncollective excitation along with the prevalence of octupole softness.

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Interplay of Nuclear Shapes and Band Structures in Odd-Odd Tl Nuclei

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The investigation of nuclei near the proton shell closure at $Z=82$ is of considerable interest due to interplay of nuclear shapes driven by shell-effects, shape-coexistence, and proton-neutron interactions. Recent experiments have identified both triaxial and oblate configurations in odd-odd thallium (Tl) nuclei in the $A \sim 190$ mass region. In these systems, while the proton Fermi level is situated near the $3s_{1/2}$ orbital, the strongly shape-driving $h_{9/2}$ and $i_{13/2}$ Nilsson orbitals emerge at moderate deformations. Similarly, the neutron Fermi level, located near the $i_{13/2}$ orbital above $N=100$, plays a crucial role in defining the band structures observed.

Tl isotopes exhibit a wide range of shapes: neutron-rich $^{202,204}\text{Tl}$ [1,2] nuclei are nearly spherical, whereas neutron-deficient isotopes display various deformed configurations. Signatures of triaxiality, including chiral and t-band structures, have been observed in odd-A and odd-odd nuclei such as $^{193,194,195,198}\text{Tl}$ [3-6], and Magnetic Rotational (MR) bands have been detected in $^{194,197}\text{Tl}$ [7,8]. $^{189,191}\text{Tl}$ clearly exhibits prolate-oblate shape coexistence [9,10]. The nuclear structure of odd-odd $^{190,192}\text{Tl}$ remains relatively unexplored, with preliminary evidence hinting that these nuclei might be in a transitional state between axial and non-axial configurations.

To shed light on these unresolved issues, we performed two experiments. One experiment used a ^{30}Si beam from the BARC-TIFR Pelletron LINAC, and the other utilized a ^{16}O beam from the K-130 cyclotron at VECC. Both experiments employed fusion-evaporation reactions to produce the nuclei under investigation. The INGA setup, with upto 17 clover HPGe detectors, was used to record prompt gamma rays, leading to the establishment and extension of the level schemes with confirmed J^π assignments. Our new results reveal evidence for a MR band as well as octupole correlations in these nuclei. Further details will be presented at the conference.

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The observation of positive parity rotational bands in ^{123}Te

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The study of the nuclear structure with few valence protons above $Z=50$ major shell closure, is interesting for their structural diversity. In $A\sim 120$ mass region, we can expect here an interplay between the collectivity and the single particle excitations [1]. The collective deformation is mainly promoted by the valence neutrons laying in between $50 < N < 82$ and the single particle excitations are driven by few valence protons above $Z=50$ major shell closure. In this mass region, both the protons and neutron can avail the same orbitals, viz., $2d_{5/2}$, $1g_{7/2}$, $3s_{1/2}$, $1h_{11/2}$, $2d_{3/2}$. The availability of the unique parity $\nu h_{11/2}$ boost the presence of the shape driving effects.

Te ($Z=52$) isotopes have a proton pair above $Z=50$ major shell closure. From the systematic study of odd- A Te -isotopes, it has been noticed that there is much less study in the nuclei with $N=71$. However, extensive observations are available in the neighboring isotopes [2-5]. The strongly coupled and decoupled band structure based on available orbitals were already well studied in $^{117-121}\text{Te}$ [2,6-7]. It may be noted that in ^{123}Te [8] only negative parity bands were reported. In this situation, an experiment was performed at VECC, Kolkata, using 40 MeV α -beam from K-130 cyclotron on 5 mg/cm² thick self-supporting ^{122}Sn target. The Indian National Gamma Array (INGA) setup consisted of 11 Compton suppressed HPGe clover detectors and 1 LEPS detector, coupled to PIXIE-16 based digital data acquisition system [9] has been used to collect the γ - γ coincidence data. The list-mode raw data were processed using BiNDAS [10] sorting programs. The rotational band structures based on single particle positive parity orbital in ^{123}Te are investigated via this α -induced reaction. The observation of rotational band based on $\nu g_{7/2}$ rotational band in ^{123}Te is observed for the first time. The detailed results will be presented.

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Monte-Carlo Simulation of Decay Spectra

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Decay studies using high resolution γ -ray spectroscopy techniques provide precise information on the decay half-life and the decaying γ -rays from the low-lying states of a nucleus. In the present work, Monte-Carlo simulation studies have been carried out to generate the decay spectra obtained from HPGe detectors, namely, a single Ge crystal and Clover (four Ge crystals in a single cryostat) geometry. For this purpose, a code has been developed in Python3 programming language. To benchmark this code, relative efficiencies in the addback, sum and single crystal mode have been simulated by using the standard sources of ¹⁵²Eu and ¹³³Ba and compared with the same measured experimental data. These are found to be in good agreement with each other. The add-back factor has also been calculated and compared for both the cases. To validate the simulation results, a comparison has been made with the experimental spectra obtained from a recent experiment performed at the K-130 Cyclotron at the Variable Energy Cyclotron Centre (VECC), Kolkata. In this experiment, several La isotopes (mainly ¹³¹La, ¹³²La and ¹³⁰La) were populated by bombarding ¹⁴N beam at an energy of 115 MeV on a foil of ¹²⁴Sn. The decay half-lives of the aforementioned isotopes have been calculated precisely [1].

The following decays were considered for simulating the source: ¹³¹La $\rightarrow$ ¹³¹Ba, ¹³¹Ba $\rightarrow$ ¹³¹Cs, ¹³²La $\rightarrow$ ¹³²Ba, and ¹³⁰La $\rightarrow$ ¹³⁰Ba. The intensities of the decay transitions were obtained from the NuDat database of NNDC. The number of events for each decay were scaled by the corresponding cross-sections of the parent nuclei. The intensities per 100 decays, multiplied by the factor $\exp(-(\frac{\ln 2}{T_{1/2}})t)$ for every time step t , were taken as probabilities for simulating a particular decay transition. These intensities were multiplied by the detector efficiencies corresponding to the energy of that decay transition. For propagating a photon inside the detector, the following three interactions were considered: photoelectric effect, Compton scattering and pair production. The corresponding photon cross-sections were obtained from XCom web database provided by NIST [2]. To simulate the actual detector response, the deposited energies were multiplied by a Gaussian distribution having a standard deviation σ that depends on the detector resolution. The detector resolution is a function of the FWHM, which depends on detected energy. By comparing the simulated and experimental spectra, it is possible to determine the contribution of various decaying nuclei to the photo-peaks and validate the theoretical cross-sections predicted by PACE4 [3] calculations.

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Microscopic Interaction Potential for Heavy-Ion Fusion

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The determination of nucleus-nucleus interaction potential is a fundamental yet complex problem in nuclear physics [1]. This interaction plays a crucial role in modeling nuclear reactions, which provide significant insights into nuclear structure and are essential for understanding astrophysical processes in stars. Considerable progress has been made in studying fusion reactions of $^{12}\text{C}+^{12}\text{C}$ and $^{16}\text{O}+^{16}\text{O}$ by developing microscopic models for the interaction potential. One such model is based on the double-folding approach, which integrates nuclear densities with effective nucleon-nucleon (NN) interactions to determine the nuclear potential at various separation distances.

In this work, we present the double-folding method used for microscopic calculations of both Coulomb and nuclear potentials, incorporating direct and exchange components. These calculations employ an advanced density-dependent version of the effective M3Y nucleon-nucleon interaction, specifically BDM3Y1 [2], which is derived from the G-matrix elements of the Paris NN potential [3]. The inclusion of density dependence is critical for accurately reproducing the saturation properties of cold nuclear matter. By refining the interaction potential, this approach enhances our understanding of heavy-ion fusion mechanisms and contributes to improved modeling of nuclear reactions in various astrophysical scenarios.

The results obtained using this microscopic model have significant implications for both theoretical and experimental nuclear physics. They provide a more precise description of the nucleus-nucleus interaction potential, thereby improving predictions for fusion cross-sections and reaction dynamics. This study underscores the importance of incorporating density-dependent interactions in microscopic models to achieve a more realistic representation of nuclear forces. Results of the calculations will be presented during the conference.

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Chebyshev Shape Parametrization: A Novel Approach to Modeling Nuclear Deformation and Structure

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Precise nuclear shape parametrization is essential for investigating collective dynamics and fission mechanisms. However, conventional methods often struggle to capture complex deformations effectively [1, 2]. This work introduces a novel Chebyshev shape parametrization that employs Chebyshev polynomials of the first kind to model nuclear geometries with enhanced precision and flexibility [3]. In this approach, the nuclear surface profile is expressed as a series expansion in Chebyshev polynomials, where each coefficient is assigned to capture a specific aspect of nuclear deformation. In particular, one coefficient predominantly governs the elongation of the nucleus, another regulates the degree of asymmetry, and a third fine-tunes the formation of the neck region. This method offers a more realistic and versatile framework for modeling complex nuclear shapes compared to traditional parametrizations. To ensure physically consistent deformations, volume conservation and center-of-mass constraints are applied, allowing for realistic representations of intricate shapes. The total potential energy surface (PES) is calculated using the macroscopic Lublin-Strasbourg Drop (LSD) model, which incorporates deformation-dependent surface, Coulomb, rotational, curvature, and congruence energies [4, 5]. Validation against established parametrizations confirms the robustness of the method. When applied to high-energy fission systems, the framework reveals competing symmetric and asymmetric pathways through analysis of the potential energy surface. Distinct energy minima in the deformation subspace indicate both fission modes, with elongation dominating the primary path and asymmetry emerging as a viable channel. These findings underscore the method's precision in resolving multimodal fission dynamics, advancing insights into deformation-driven nuclear decay. By combining geometric versatility with rigorous energy calculations, the Chebyshev parametrization emerges as a transformative tool for nuclear structure research. Its applications extend to modeling heavy-ion reactions, exotic shapes, and dynamic processes, advancing our understanding of deformation phenomena across the nuclear landscape.

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Collective enhancement and shape transitions in nucleus

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The Nuclear Level Density (NLD), the number of energy levels per unit of excitation energy, is a crucial statistical property that exhibits a remarkable characteristic of rapidly increasing with higher excitation energy [1]. It plays a crucial role in understanding nuclear reactions, decay processes, and fission phenomena. Among the most relevant and widely discussed topics in recent NLD studies is the collective enhancement of level density (CELD) [2]. In a nucleus, collective rotation and vibration involving several nucleons couple to single particle excitations. These collective excitations add additional degrees of freedom, leading to a higher density of states at lower excitation energies compared to single-particle models. Since rotational effects are more dominant than vibrational effects, the collective enhancement of nuclear level density is more pronounced in deformed nuclei, where rotational excitations are stronger compared to spherical ones. This enhancement is introduced as an enhancement factor K_{rot} to the level density equation by Hansen et al. [3], which is a deformation-dependent parameter. The effect of collective enhancement fades out at higher excitation energies. Several experimental evidence of CELD has been reported over the years [4, 5]. In this study we explore the CELD and its fadeout at excited states of the nucleus.

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Searching for rare excitation modes near $N = 28$

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$N, Z = 28$ is a soft core [1], with excitations across this core being relative easier compared to other doubly magic cores. The core breaking coupled with the valence particles, the presence of deformation driving $g_{9/2}$ level and along with the nearby $p_{3/2}$, one can expect a plethora of excitation modes like single particle excitations, magnetic rotational bands, octupole correlations and chiral doublet bands. Recent theoretical investigations predict existence of multiple wobbling modes in this region [2] and experimental evidence relating to octupole correlation [3] have come up. In light of this, few gamma ray spectroscopy experiments have been carried out to search for these rare excitation modes in this region, understand the structure evolution and the role of $g_{9/2}$ level in it. The nuclei of interest are ^{59}Ni ($Z=28, N=31$), ^{57}Ni ($Z=28, N=29$), ^{56}Co ($Z=27, N=29$) and ^{59}Co ($Z=27, N=32$). Alpha beam from K-130 cyclotron at VECC was incident on an enriched, self-supporting, 18 mg/cm² thick ^{58}Ni target and ^7Li beam from the TIFR Pelletron LINAC facility was incident on 8 mg/cm² thick $^{55}\text{MnO}_2$ target on 6 μm thick mylar backing, to populate the excited states in the nuclei. INGA facility at VECC with 11 HPGe clover detectors and 1 LEPS and at TIFR with 18 HPGe clover detectors were used to detect the emitted gamma rays. In ^{59}Ni , there is indication of doublet band structure and the coupling of the core-excited states to the $g_{9/2}$ level. There are indications of octupole correlation in ^{56}Co . New band structures have been identified in ^{57}Ni , possibly arising due to triaxial shape. The detailed results would be presented in the conference.

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Spectroscopy of ^{150}Pm

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The ^{150}Pm is a neutron-deficient isotope and the investigation of its low-lying states is essential for understanding proton-neutron interactions. The $N = 89$ ^{150}Pm lies at the centre point of quantum phase transition (QPT) from $N = 88$ to $N = 90$ [1]. The population of the excited states of this nucleus is challenging as only scattering reaction with light ions or fusion with proton and deuteron are the only few routes that can be used with stable targets. As a result, populating higher angular momentum states is difficult task. In addition, the spectroscopic measurements on this nucleus are limited with the yields of the de-excited gamma rays due to insufficient production cross section. The reaction cross section for proton induced fusion on ^{150}Nd has been measured and the highest value was found to be 50 mb at 8 MeV [2].

In this work, low lying structure of ^{150}Pm has been studied using an array of six BGO suppressed Clover HPGe detectors. The large basis shell model calculation has been performed to interpret the experimental observations. A preliminary account of the work has been reported in Ref. [3]. The complete low lying structure including proposition on spin parity assignments will be discussed.

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Exploring shape co-existence in Sm nuclei near $N=90$

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The Nuclei close to $Z = 64$ (subshell closure) and near $N = 90$ (midshell), display a variety of shapes. Transitions from spherical ($U(5)$) to axially deformed quadrupole ($SU(3)$) structure are observed at $N = 90$. The Sm ($Z = 62$) isotopes, specifically ^{150}Sm ($N = 88$) and ^{152}Sm ($N = 90$), are the classical examples of this shape transition phenomenon [1]. Several quadrupole deformed shapes are expected to co-exist in the nuclei around $Z = 64$ and $N = 90$.

The region around $N = 90$ exhibits not only co-existence of various quadrupole shapes but also that of shapes with two different degrees of deformation ($\lambda = 2, 3$). Signatures of co-existence among $\lambda = 2$ quadrupole and $\lambda = 3$; $\mu = 0$ octupole shapes [2,3] have been seen in Sm ($N = 88, N = 90$) and its neighboring Gd ($N = 88$) nuclei. Therefore, Sm isotopes provide an ideal ground for systematically exploring the shape co-existence phenomena in atomic nuclei.

In this context, the ^{152}Sm nucleus was studied to explore the band structures developed on the excited 0^+ states. The excited states of ^{152}Sm were populated using the reaction $^{150}\text{Nd}(\alpha, 2n)^{152}\text{Sm}$ with 26 MeV α beam from K-130 cyclotron at VECC, Kolkata and the de-exciting gamma rays were detected using an array of 12 clover HPGe detectors. The details of the experimental setup, data acquisition and analyses can be found in Ref. [4,5] that also report a part of the experimental observations made. The new findings on shape-coexistence features in ^{152}Sm will be presented.

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High-K multi-quasiparticle band structures in ^{162}Er

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The rare earth nuclei in the $A \sim 160$ mass region, such as the deformed Er and Dy isotopes, have revealed an array of features and phenomena in their low- and high-spin structures. The Er isotopes have been investigated earlier up to very high-spin, providing evidence for the demise of static neutron pairing correlations at high spin [1]. Strongly-coupled, high-K, multi-quasiparticle structures have also been observed in transitional light Er isotopes [2].

In ^{162}Er , a half-life 88(16) ns for the level at $E_x=2026$ keV with a spin value of 7 [3] was reported earlier [4]. This reported half-life was subsequently remeasured with higher precision [5] using $\gamma\text{-}\gamma$ fast timing technique, and a revised value of 76(4) ns was adopted. Based on its excitation energy, decay pattern as well as BCS calculations, the $K_\pi=7^-$ assignment was adopted for this isomer [3]. This $K_\pi=7^-$ isomer in ^{162}Er was assigned the same $\pi 7/2^- [523] \otimes \pi 7/2^+ [404]$ two-proton configuration as in the cases of ^{160}Er and ^{164}Er . However, as no band was detected above this isomer in ^{162}Er , g-factor and alignment comparisons were ruled out [3].

In order to investigate this $K_\pi=7^-$ and other high-K isomers in ^{162}Er , and the band structures above those, a dedicated experiment was carried out at the room-temperature cyclotron (RTC) facility, VECC. The $^{161}\text{Dy}(\alpha, 3n)^{162}\text{Er}$ reaction at $E_\alpha=43$ MeV was used. Deexciting γ -rays were detected using the INGA facility that comprised of 11 Compton-suppressed clover HPGe detectors and one LEPS detector.

The subsequent data analysis has revealed more than one multi-quasiparticle states and strongly-coupled band structures above those with probable configurations involving high-J, high- Ω orbitals. The elusive strongly-coupled band structure above the $K_\pi=7^-$ isomeric level has been observed up to spin $I^\pi = (16^-)$. The energies of the γ -rays, deexciting the band-members, have been found to be almost exactly identical to those depopulating the states of the band above the $K_\pi=7^-$ isomeric level in ^{164}Er . Analysis of this $K_\pi=7^-$ isomeric band and other high-K band structures are being carried out and will be presented in detail.

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Advanced γ -Ray Imaging with Neural Network-Based Reconstruction

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This work presents Geant4 simulations and Neural Network (NN)-based reconstruction analysis of a novel γ -ray scanner developed through a collaboration between IIT Ropar and GSI Germany for high-performance imaging and spectroscopy. The system comprises a cerium-doped LYSO scintillator coupled with a 96-SiPM matrix, utilizing GSI-developed TAMEX electronics for precise interaction point detection. Experimental validation demonstrates a position resolution of ~ 1 mm, while Geant4 simulations achieve ~ 0.4 mm due to reduced electronics-induced noise. The implementation of an NN-based reconstruction algorithm significantly enhances spatial resolution compared to conventional barycenter methods. These results validate the system's spectral response and imaging capabilities, making it a promising tool for medical diagnostics, nuclear physics, and industrial inspection applications.

The conference presentation will discuss detailed results from Geant4 simulations and NN-based reconstruction.

The search for resonance energy and wave function of ^{62}Ca exotic halo nucleus using supersymmetric quantum mechanics

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The physics of exotic nuclei that existed along nuclear drip lines has been gaining attention since the advent of dedicated radioactive ion beam (RIB) facilities. A robust theoretical approach is implemented in this study to investigate ground and resonant levels of the weakly bound nucleus ^{62}Ca . A three-body ($^{60}\text{Ca} + n + n$) cluster model is adopted for this singly magic nucleus lying in the neutron drip line. For the ground state energy and wave function hyperspherical harmonics expansion (HHE) approach is employed, while supersymmetric quantum mechanics (SSQM) is used for the resonant state. To obtain the energy and normalized wave function of the system, the three-body Schrödinger equation is solved for a chosen set of two-body potentials. Which are chosen as standard GPT for nn pair while standard SBB for the core-n pairs. Parameters of the core-n interaction potential are tuned to satisfy the criteria that the ^{61}Ca subsystem is just unbound. The ground state wave function thus obtained is used to construct a one-parameter family of isospectral potential. The optimal value of the parameter used in the theoretical scheme introduces a dramatic effect on the derived potential. A relatively small value of the parameter in the range (0 to infinity) results in a sufficiently deep well followed by a sharp barrier facilitating effective trapping of the system for energies $E > 0$. In the HHE scheme, the three-body relative wave function is expanded in the complete set hyperspherical harmonics (HH) which on substitution in the Schrödinger equation and use of orthonormality of HH leads to an infinite set coupled differential equation (CDE). The set of CDEs is reduced to a single differential equation (SDE) by the use of the Raynal Revai Coefficient (RRC), Geometrical Structure Coefficient (GSC) and potential multipolar expansion. The resulting SDE is numerically solved using the renormalized Numerov method algorithm to get the wave function and energy. Finally, the SDE is again solved using the constructed one-parameter family of strictly isospectral for different positive energies. A trapping probability is then computed and plotted against energies to search the resonant energy and wave function. The appearance of a pronounced peak in the trapping probability versus energy profile indicates a resonance level. One can determine the precise width of resonance by back-transforming the wave function using the WKB method. The result of the calculation will be presented during the conference.

Theoretical Study of Positive-parity Bands in ^{99}Mo and ^{101}Mo

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The present study provides a theoretical investigation of the $\nu d5/2$ band of ^{99}Mo and the $\nu g7/2$ band of ^{101}Mo isotopes. The analysis is performed using various methods such as E-gamma over spin, kinetic moment of inertia, quasiparticles alignments, cranking model, and quasiparticle-plus-rotor model calculations

Investigation of 3H Capture in the 7Li + 50Ti Reaction

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Reactions involving weakly bound stable nuclei like ^6Li and ^9Be remain an interesting subject in low-energy nuclear reaction studies [1]. These reactions can lead to the production of neutron-rich nuclei, providing valuable insights into nuclear structure and reaction dynamics. The ground state of ^7Li exhibits a prominent $t + \alpha$ cluster structure, leading to multiple reaction channels such as breakup, transfer-breakup, incomplete fusion, and cluster transfer. The particle-gamma coincidence technique is a powerful tool for studying various reaction mechanisms in such reactions [2, 3]. Detection of triton(t) or α -particle as ejectiles in the outgoing channel, following the ^7Li -induced reaction with a ^{50}Ti target, together with discrete gamma-ray measurements, provides valuable insights into reaction dynamics. Furthermore, ejectile energy measurements serve as a crucial parameter in distinguishing various reaction mechanisms. The $^7\text{Li} + ^{50}\text{Ti}$ reaction, with a 20 MeV ^7Li beam (beam current 4 nA) was performed at 14UD Pelletron Linac Facility at TIFR in Mumbai, India. A self-supporting ^{50}Ti target (with enrichment $\approx 83\%$) was used. Seventeen Compton-suppressed clover HPGe detectors were positioned at various angles relative to the beam direction: three at 40° , 115° , 140° , and 157° each, one at 65° , and four at 90° to detect the deexciting γ -rays from the present reaction. Ten CsI(Tl) detectors each having dimensions of $1.5 \times 1.5 \times 0.3 \text{ cm}^3$ were installed inside the target chamber at a distance of 4 cm from the target center of the INGA setup to detect the outgoing charged particles. In our previous work [2], the population of ^{54}Cr has been investigated following the α transfer in the reaction $^7\text{Li} + ^{50}\text{Ti}$. In this work, we report the population of ^{53}V resulting from the triton transfer in the same reaction. The details of the result coming from this analysis will be presented at conference.

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Spectroscopic study of $^{76,77,78,79,80}\text{Kr}$

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Light krypton isotopes were among the first medium mass nuclei to indicate very large prolate deformation ($\beta=0.35$) stabilized by shell structure. Large shell gaps at $Z, N=34, 36$ for oblate shapes and at $Z, N=38, 40$ for prolate shapes result in very deformed ground-state configurations and prolate-oblate shape coexistence. In this article we report preliminary results of $^{76,77,78,79,80}\text{Kr}$.

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Optimal Decay Pathways in Metastable Nuclei: A Shortest Path Algorithm Approach

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In stellar nucleosynthesis, nuclei with metastable states undergo complex transitions through multiple excited states before reaching equilibrium between the ground and isomeric states. Identifying the most favourable decay pathways in such systems is crucial for accurately modelling reaction networks. This study employs the shortest path algorithm to systematically determine the optimal decay routes from all excited states to both the ground and isomeric states. By assigning transition probabilities as weights in a directed graph representation of nuclear levels, the algorithm efficiently computes the dominant pathways that govern equilibration. This method enables a quantitative evaluation of transition efficiencies and provides insights into temperature-dependent changes in decay routes. The approach is applied to the different nuclei, demonstrating its effectiveness in resolving the internal equilibration problem. The framework developed here can be extended to other astrophysically significant nuclei, improving the accuracy of nucleosynthesis models.

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Search For Pairing Re-entrance Phenomenon in Hot Rotating Nuclei

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The Pairing correlation is essential for understanding low-energy nuclear structure, particularly under varying conditions of temperature and angular momentum. At low temperatures and angular momentum, nucleons near the Fermi surface tend to pair up, leading to strong pairing correlations. However, as temperature (T) or angular momentum (J) increases, these pairing of nucleons is broken down and thus decrease in pairing correlations. But under specific conditions of temperature and angular momentum pairing can re-occur for specific neutron and proton number & this phenomenon is known as "pairing re-entrance phenomenon". This phenomenon was first predicted by Kammuri [1] and further explained by Moretto [2] using the Bardeen-Cooper Schrieffer theory at finite temperatures (FTBCS) and angular momentum. This re-entrance of pairing correlations significantly influences nuclear level density and can be probed by studying level densities as functions of temperature and angular momentum. In this work, we have searched for T and J dependent level density through fast neutron spectroscopy and looking for influence of the pairing correlation in Ge isotopes.

An experiment was carried out at BARC-TIFR Pelletron Linac Facility to investigate this phenomenon in $A \sim 70$ nucleus by using ^9Be pulsed beam of energy 28 MeV bombarding on self-supported ^{64}Ni targets (2 mg/cm²) to populate ^{73}Ge compound nuclei. The experimental setup included a 38-element BGO detector array for measuring gamma-ray multiplicity (fold distribution) and 15 liquid scintillation detectors for measurement of neutron using time-of-flight (TOF) technique. Fold distribution(number of gamma rays fired per events) for each BGO detector, PSD and TOF for LS detectors were collected in an event-by event mode using VME data acquisition system.

The TOF spectra obtained from the LS detectors were converted into neutron energy spectra using appropriate Jacobian transformations & efficiency correction. The experimental results show a small deviation with respect to the conventional statistical model calculation in fold gated (related to J) neutron evaporation spectrum for folds 6, 7 & 8 at $T \sim 1.55 \pm 0.05$ MeV and high $J \sim 14 \pm 2 \hbar$. This result shows a weak signature of pairing re-entrance phenomenon in ^{72}Ge which corroborates with theoretical predictions from FTBCS1 (Finite Temperature Bardeen-Cooper-Schrieffer1) approach [3]. This understanding throw light into the intricate interplay of temperature & angular momentum on pairing correlations for many body finite quantum systems.

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Search for E3 decay branch from 11^- isomer in ^{204}Po

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The nuclear structure near the $Z=82$ and $N=126$ shell closure is characterized by high spin isomeric states [1], emerging from the high- j intruder orbitals. Investigating these isomeric states is crucial as the observed transition rates and the associated nucleonic configurations provide an understanding of the nuclear properties, nuclear shape, and its evolution with deformation in heavy nuclei. The 11^- isomer originating from the $\pi(h9/2i13/2)$ configuration is frequent in even-even isotopes of Pb, Po, Rn, Ra, and Th [2] and references therein). The systematics of the 11^- isomer among various Po isotopes from $N=112$ to 126 has been discussed in the past [3,4]. The isomer decays via a spin-flip E3 transition [5] to the 8^+ isomer, having $\pi h9/22$ as the dominant configuration, except in $^{204,206}\text{Po}$. In this study, the spin-flip E3 decay branch from the 11^- state is recognized in ^{204}Po .

The excited states of ^{204}Po are populated using the $^{197}\text{Au}(^{11}\text{B},4n)$ fusion evaporation reaction and the γ -rays are detected using the INGA facility [6] at the Inter-University Accelerator Centre (IUAC) Delhi India. The two- and higher-fold events are recorded using the VME-based data acquisition system NIAS and MARS (Multi-parameter Acquisition Root-based Storage) software [7]. Further, the γ - γ matrices (symmetric and asymmetric) are constructed using in-house codes, and the data analysis is performed using the RADWARE [8] package. The 981.6 keV E3 decay branch from the 11^- to 8^+ isomer is identified with the help of various γ - γ coincidences. For the 93.1 keV E1 and 981.6 keV E3 decay branches from the 11^- isomer, the branching ratios and transition strengths are obtained. The E1 transition strength is found to be $5.7 \times 10^{-5}(4)$ W.u., which is close to the adopted value in the literature [9]. The E3 transition strength is found to be $11.5(30)$ W.u., and the systematic behavior will be discussed among various Po isotopes.

Simulation and Experimental Validation of Charge Transport in a Segmented Germanium Detector

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The advancement of gamma-ray spectroscopy has been significantly driven by the development of highly segmented germanium detectors. When combined with sophisticated techniques such as Pulse Shape Analysis (PSA) and Gamma-Ray Tracking (GRT), these detectors offer promising capabilities for gamma-ray imaging applications [1]. This study involves a comprehensive investigation of charge transport in a germanium crystal through detailed simulations, experimental validation, and characterization, along with necessary corrections for electronic effects. The primary objective of these simulations is to develop a theoretical database of signals corresponding to all possible interaction points within the detector volume. A planar, double-sided orthogonal strip detector with a 10×10 array of electrical segments aligned in both horizontal and vertical directions has been used for this work. Geant4 simulations have been employed to determine the energy deposition and interaction locations. The electric potential and field distribution inside the detector volume have been mapped as functions of position using the SolidStateDetector.jl package [2]. Various parameters, including operating voltage, detector geometry, and electrode configuration, have been incorporated into the simulations to ensure accuracy. The charge carrier drift and signal generation has been carried out using the weighting potential approach, incorporating drift velocity and mobilities from the AGATA Detector Library (ADL) [3]. A temperature model (Boltzmann model) has also been introduced to account for variations in charge transport behavior at different temperatures. Additionally, the impact of electronic effects introduced by the pre-amplifier has been accounted for by applying a response function to the simulated signals [4]. To validate the accuracy of the simulation framework, the generated signals have been compared with experimental scanning data obtained from the Position Sensitive Planar Germanium detector at GSI, Germany [5]. A detailed discussion of the results will be presented at the conference.

References:

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