6th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX6)

Monday 29 October 2018 - Friday 02 November 2018

Protea Hotel Fire & Ice

Book of Abstracts

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Fission of heaviest nuclei

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The charge (mass) distributions of fission fragments resulting from lowand high-energy fission of the isotopes of Fm, No, and Rf are studied with the statistical scission-point fission model. The calculated results are compared with the available experimental data. The difference between the shapes of mass and charge yields is explored at different excitation energies.

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The continuous quest for reaching new Horizons @ GANIL

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Nuclei at the extremes of existence provide a playground for searching and understanding simple and regular patterns that are found in the structure of complex nuclei. Reactions involving nuclei at the extremes of stability not only allow us to amplify specific aspects of the nuclear interaction and observe new phenomena but also provide important inputs for "applied" fields ranging from finding potential isotopes for medicine to understanding astrophysically important processes. Radioactive Ion Beams have been the workhorse for the production and characterization of nuclei with a large asymmetry of neutrons and protons. In parallel, studies using reactions with beams far from the dripline (stable beams) coupled with improved sensitivity at energies around the Coulomb barrier have allowed us to probe nuclei under new conditions involving both high isospin and angular momentum.

In this talk, we will first give flavor of recent results and opportunities using intense stable and short-lived beams (ISOL and fragmentation) and a variety of new and state of art equipment at GANIL, to probe the three axis of nuclear physics namely excitation energy, angular momentum and the asymmetry of neutrons and protons. The talk will also mention on new inroads and at energies around the Coulomb barrier using a large acceptance spectrometer coupled with a gamma array, into exploring a) physics at a possible new frontier for nuclear physics namely BOTH high spin and isospin and b) potential of the production of new isotopes around and beyond the neutron shell N=126 for nuclei below Pb by multinucleon transfer. The current status of the of LINAC along with the associated equipment (SPIRAL2) and future plans for the high intensity frontier will also be presented.

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Light charged particle multiplicities in fusion and quasifission reactions

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The light charged particle evaporation from the compound nucleus and from the complex fragments in the reactions 32S+100Mo, 121Sb+27Al, 40Ar+ 164Dy, and 40Ar+natAg is studied within the dinuclear system model. The possibility to distinguish the reaction products from different reaction mechanisms is discussed.
From the comparison of the calculated light charged particle (LCP) multiplicities and experimental data, we show the possible overlap of the decay products from different reaction mechanisms. With increasing the bombarding energy the ratio of the LCP multiplicity from the fission-like fragments to the LCP multiplicity from the compound nucleus increases due to the increase of fission and quasifission probabilities. The simultaneous description of the LCP multiplicities and of the production cross sections of the evaporation residues and complex fragments gives us a chance to distinguish the reaction products from different reaction mechanisms. The calculated LCP multiplicities show weak dependence on the reasonable variation of the level density parameter, and stronger dependence on the Coulomb barrier heights.

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Design and Development of GRAT (Giant Resonances Active Target), a dedicated target for studying resonances in nuclei.

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Energies of the Giant Monopole Resonance (GMR) modes and the Giant Quadrupole Resonance (GQR) modes are directly related to the incompressibility of finite nuclear matter (KA) from which the incompressibility of infinite nuclear matter(K_∞) can be deduced by comparing the experimental data with the theoretical predictions such as fully consistent Random Phase Approximations (RPA).The 20% uncertainty of the currently accepted value (K_∞ = 230±40 MeV) [1] is largely driven by the poor determination of the asymmetry term (K=-500±50 MeV) [2]. To improve upon the precision of this term, experimental measurements are being carried out on isotopic chains extending from the nuclei on the valley of stability towards exotic nuclei with larger proton-neutron asymmetry.

Previous measurements of isoscalar resonance modes for ^{56}Ni [3] [4] and ^{68}Ni [5] [6] with MAYA active target [7] at GANIL were made using inelastic scattering of alpha and deuteron particles in inverse kinematics. The excitation energies were derived with precisions around 10%, which has a direct impact on the uncertainty of K_∞. This large uncertainty was due to the experimental limitations of the MAYA active target that can reconstruct the recoil particles in the center of mass angles between 3 and 8 degrees. Since the cross section for these type of reactions is concentrated at very small center of mass angles (very high between 0 and 3 degrees) corresponding to very low energies, a dedicated target which can maximize the coverage as low as 0.2 degrees is being developed to improve upon the detection efficiency. This thin target is designed to be roughly four times the length of MAYA in order to increase the cross section and operates at a very low pressure to maximize the reconstruction efficiency for the lowest center of mass angles. The long target is wrapped with 10∗10 cm and 1mm thick double-sided stripped silicon detectors, which will increase the energy resolution by an order of magnitude, compared to MAYA. The track reconstruction will be done using 2∗2 mm square pads and a CERN MICROMEGAS amplifier. The design, optimization and construction of this project will be discussed during the talk.

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Microscopic description of pygmy dipole resonance in neutron-rich Ca isotopes

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The structure of exotic neutron-rich nuclei is one of the main science drivers in contemporary nuclear physics research. An attention has been devoted to effects of varying the ratio between the proton Z and neutron N numbers on different nuclear structure characteristics of nuclei deviated from their valley of β-stability. One of the phenomena associated with the change in N/Z ratios is the pygmy dipole resonance (PDR). One of the successful tools for describing the PDR is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived from Skyrme energy density functionals (EDF). Such an approach can describe the properties of the low-lying states reasonably well by using existing Skyrme interactions. Due to the anharmonicity of the vibrations there is a coupling between one-phonon and more complex states. The main difficulty is that the complexity of calculations beyond standard QRPA increases rapidly with the size of the configuration space, and one has to work within limited spaces. Using a finite rank separable approximation for the residual particle-hole interaction derived from the Skyrme forces one can overcome this numerical problem.

As an illustration, we study the properties of the low-lying dipole states in the even-even nuclei $^{40-58}$Ca. Using the same set of the EDF parameters we describe available experimental data for ^{40,44,48}Ca and give the prediction for $^{50-58}$Ca. In particular, there is an impact of the coupling between one- and two-phonon states on low-energy $E1$ strength of ^{40,44,48}Ca. We predict a strong increase of the summed $E1$ strength below 10 MeV, with increasing neutron number from ^{48}Ca.

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Towards first experiments with brilliant gamma-beams at ELI-NP*

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At the Extreme Light Infrastructure – Nuclear Physics (ELI-NP) facility, high-power laser pulses together with high-brilliance gamma beams will be the main research tools. The status of the construction of the facility, the expected parameters of the gamma-beam system and the implementation scheme of the different instruments will be reported. The emerging nuclear photonics research program at ELI-NP will be presented with emphasis on the commissioning and day-one experiments which are under preparation. The program addresses nuclear resonance fluorescence experiments, photonuclear reaction studies of interest to nuclear astrophysics, precise cross-section measurements of photoneutron reactions, studies of the strength of giant collective motions and soft modes in nuclei, photofission research and numerous applications of societal benefit. The physics cases of the flagship experiments at ELI-NP will be discussed, as well as the related instruments which are under construction for their realization.

*Work supported by the Extreme Light Infrastructure Nuclear Physics (ELI-NP) Phase II, a project co-financed by the Romanian Government and the European Union through the European Regional Development Fund – the Competitiveness Operational Programme (1/07.07.2016, COP, ID 1334)

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Latest Developments of The South African Isotope Facility

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The latest developments with the Radioactive-Ion Beam project of iThemba LABS, the South African Isotope Facility, SAIF, will be reported [1]. SAIF has two phases, the first of which comprises the Low-Energy Radioactive-Ion Beam (LERIB) project together with the ACE Isotopes (Accelerator Centre for Exotic Isotopes) project. ACE isotopes calls for the installation of a commercial, off-the-shelf 70 MeV cyclotron for radionuclide production. It will remove radionuclide production from the existing Separated Sector Cyclotron (SSC) accelerator, allowing it to be dedicated to research. The partially-funded LERIB project, is an ISOL project that will be capable of producing neutron-rich beams of high-intensity, by using 66 MeV protons from the SSC to fission natural uranium at an initial rate of up to 6×10^{12} f/s. The target/ion-source at the heart of LERIB is a copy of the SPES [2] front-end, in a collaboration between iThemba LABS and INFN-Legnaro, Italy. In future, the power of the primary beam can be increased to give a fission yield of up to 2×10^{13} f/s. The beams from LERIB will be of low-energy, 60 keV - suitable for decay studies and implantation in materials as radioactive probes. Phase 2 of the SAIF project is the Accelerator Centre for Exotic Beams (ACE Beams). It will eventually see the addition of a post-accelerator, likely a LINAC, to take beams from the LERIB to high-energies for research into sub-atomic physics.

[1] R.A. Bark PoS(INPC2016)100
[2] http://www.scholarpedia.org/article/The_LNL_radioactive_beam_facility

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Gamma-gamma coincidence measurements of natually occuring radioactive materials

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Measurements of activity concentration using gamma - gamma coincidence is better than single measurement in terms of minimizing spectrum background, summing effects and pulse pile-up \cite{metwally}. Detection limits can be improved by eliminating the internal activity in $LaBr_3$:Ce scintillator through gamma - gamma coincidence condition \cite{Drescher}. An array of $LaBr_3$:Ce (2" by 2") detectors connected to a Digital Signal Processing system were used for measurement of natural occuring radioactive materials (NORM) in 1L Marinelli beakers for particular measurements with U ore and Th ore. Gamma - gamma coincident spectra were generated by setting software gates on $\gamma - \gamma$ matrices associated with the U and Th ore samples respectively. The results of these measurements will be presented and discussed.

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The first-excited 2+ state in 14C

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B(E2: 2+⟶0+) values of neutron-rich even-even carbon isotopes have been reported up to ^{20}C and do not only provide important information on the evolution of the underlying structural mechanism towards the drip line but also provide critical constraints for theoretical models. The B(E2: 2+⟶0+) value in ^{14}C can be indispensable to advance our understanding of the Carbon isotopic chain. However, the experimentally determined B(E2: 2+⟶0+) value for ^{14}C exhibits persistent inconsistencies with that obtained from theoretical models, including the no-core shell model. The safe Coulomb excitation experiment of ^{14}C at Florida State University took advantage of the unique beam capabilities and the availability of high-efficiency large volume LaBr3 detectors and the S3 double sided silicon strip detector. The preliminary results from the experiment to attempt the Coulomb excitation of ^{14}C will be presented.

This work was supported by the National Research Foundation of South Africa under grant number 105205 and by the U.S. DOE by LLNL under Contract DE-AC52-07NA27344.

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Isospin mixing studied via GDR

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The electric dipole (E1) response of a nucleus is mainly concentrated in the Giant Dipole Resonance (IVGDR) which is located at energies higher than the particle binding energy. The GDR in medium-heavy nuclei in a range of temperature between 1-3 MeV and in a large window of angular momentum was investigated in many experimental and theoretical works and, thus, a solid base exists. It is possible, therefore, to use the � decay of the IVGDR as a probe to study other aspects of nuclear structure as for example the restoration/breaking of the isospin symmetry. In fact, in self-conjugated nulei in a Isospin zero state, the �-decay of the IVGDR is expected to be strongly reduced because of the isospin selection rules. The measurement of the IVGDR gamma decay provides a direct measurement of the degree of violation of the Isospin symmetry and therefore a direct measurement of the isospin mixing phenomena. This observable is also necessary in the estimation of the Vud term in the Cabibbo-Kobayashi-Maskawa matrix. At the INFN laboratories of Legnaro a series of experiments were performed, using a combined system of LaBr3:Ce and HPGe detectors (i.e. AGATA and GALILEO), These experiments were focused to the measurement of isospin mixing in mid mass nuclei. The results achived for 80Zr and the status of the data-analysis for the case of 60Zn will be shown and discussed.
The gamma decay of the IVGDR built on ground state nuclei can be ideally measured using a higly

monocromatic and intense gamma beam as that which will be provided by ELI-NP. In this case, the measurement of the photon and neutron decay of the IVGDR provides information on the decay strength, on the branching ratio and on the IVGDR wave function. In addition, it will also be possible to measure the gamma decay of the Pygmy Dipole Resonance (PDR) which shows up in the energy region 6 - 12 MeV and represents a new collective excitation mode of a dipole oscillation of neutron-skin against a core nucleus. T

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Search for second order response of nuclei to isospin probes and their connection to double beta decay

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In order to get quantitative information on neutrino absolute mass scale from the possible measurement of the 0νββ decay half-lives,the knowledge of the Nuclear Matrix Elements (NME) involved in such transitions is mandatory.Interesting studies were performed in the eighties, exploring (π+,π-) Double Charge Exchange (DCE) reactions on different nuclei with the main aim to unveil features of the nuclear response useful for ββ-decay[1] Unfortunately, such studies were abandoned quite soon, also due to the very different operators governing the two physical processes. One of the key concern was about the indirect excitation of the fundamental double spin-isospin Gamow-Teller modes by the spinless pions. Recently the use of heavy-ion induced double charge exchange (DCE) reactions as tools towards the determination of information on the NME has been proposed in Italy[2] and Japan[3].The basic point is that there are a number of similarities between the two processes, mainly that the initial and final state wave functions are the same and the transition operators are similar,including in both cases a superposition of Fermi,Gamow-Teller and rank-two tensor components[4]
The NUMEN project at INFN-LNS laboratory in Italy proposes to explore the whole network of nuclear reactions connecting the initial and final nuclear states of the ββ-decay. This includes DCE, Single Charge Exchange (SCE), multinucleon transfer reactions, elastic and inelastic scattering with the purpose to fully characterize the properties of the nuclear wave functions entering in the 0νββ decay NMEs.Experimental campaigns are ongoing at INFN-LNS in order to explore medium-heavy ion induced reactions on target of interest for 0νββ decay. These studies are complemented by a strong activity on the theoretical side, especially tailored to give a detailed description of the challenging DCE reaction mechanisms.Recent results obtained by the (20Ne,20O) DCE reaction and competing channels, measured for the first time using a 20Ne cyclotron beam at 15 AMeV on 116Cd 130Te and 76Ge targets will be presented at the Conference.
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The role of pairing in heavy-ion induced transfer reactions

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An experimental campaign to study heavy-ion induced one- and two-nucleon transfer reactions has been performed at INFN-Laboratori Nazionali del Sud in Catania (Italy). In particular reactions induced by 18O and 20Ne beams at energies above the Coulomb barrier on different target isotopes have been explored with high resolution (both in energy and angle) and in a quite wide angular range including zero degrees. The aim of this study is two-fold. First of all, the experimental observations and the analysis of the reaction mechanism in two-nucleon transfer reactions in a quantum-mechanical description can give interesting information on the role of the pairing force in populating specific excited states and resonances, such as the so called Giant Pairing Vibration. Moreover, the study of multi-nucleon transfer cross-sections is a crucial aspect for recently proposed research projects involving the use of nuclear reactions of double charge exchange in relation with the physics of neutrinoless double beta decay. The multi-nucleon transfer mechanism could compete with the double meson exchange mechanism in double charge exchange reactions and their role must be understood in order to extract accurate information on the nuclear matrix elements of interest.

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PARIS: status and the latest results

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This contribution reports of the status of construction and the latest experimental results obtained with use of the novel scintillator based calorimeter named PARIS [1]. Thanks to use of LaBr₃-NaI and CeBr₃-NaI phoswiches, it is characterized by good energy and timing resolution and efficiency, especially for high energy gamma-rays. Due to this properties it can be used to measure gamma-rays coming from decay of Giant Resonances and discrete gamma transitions with moderate energy resolution. Moreover, the granularity of PARIS make possibility to use it as multiplicity filter.

First experimental results obtained with use of PARIS detectors in IPN Orsay, GANIL and IFJ Krakow will be presented. Status of the building of the PARIS array and its current data readout in analogue and digital way will be discussed. Also the perspectives for construction of PARIS and its use in different facilities will be presented.

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Nuclear incompressibility from spherical and deformed nuclei

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The problem of the nuclear incompressibility is a longstanding one. Deducing the incompressibility of nuclear matter from the compression modes of finite nuclei is not straightforward [1]. Whereas some consensus has been reached that from magic nuclei the value of the incompressibility K should be around 240 MeV, this number comes anyhow from the analysis of isoscalar giant monopole and

dipole in magic nuclei only.
There are new measurements in open-shell nuclei that point to lower values of the nuclear incompressibility. Also, deformed nuclei are becoming object of increasing interest.
In axially deformed nuclei, the K=0 components of the monopole and quadrupole resonances are coupled. This fact is likely to affect the extraction of the nuclear incompressibility K, and we focus on the following questions in the present contribution: how does the monopole-quadrupole coupling affect the extraction of K from the monopole measurements in deformed nuclei? Is the incompressibility affected by deformation?
Theoretical arguments and results from quasi-particle Random Phase Approximation (QRPA) will be presented and critically discussed.

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Gamma decay of pygmy states in 90,94Zr from inelastic scattering of light ions

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The study of the low lying electric dipole strength is attracting considerable attention, in connection with the possible existence of a new collective mode arising from the oscillation of the N=Z core against the neutron skin in neutron rich nuclei. This is the so called Pygmy Dipole Resonance (PDR).

From the experimental point of view it was shown the importance of studying the nature of PDR states using different probes for its excitation. The aim of the work to be presented is to investigate the isospin character of the PDR states by comparing high resolution data on their population with the (α,α'γ) reaction (isoscalar character, surface-sensitive), the (p,p'γ) reaction (mainly isoscalar character, better sensitivity to the inner transition density), and the (γ,γ') (isovector character). Results on experiments focused on the low-energy part of the E1 response in 90,94Zr nuclei will be discussed. In particular, the data were obtained using the (p,p'γ) and (α,α'γ) inelastic scattering reactions at energies Ebeam,p = 80 MeV and Ebeam,α =130 MeV, respectively. The inelastically scattered particles were measured by the high-resolution spectrometer Grand Raiden at RCNP, Osaka University. The gamma-rays emitted following the de-excitation of the Zr target nuclei were detected using both the clover type HPGe detectors of the CAGRA array and the large volume LaBr3:Ce scintillation detectors from the HECTOR+ array.

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Pairing in highly excited nuclei

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Pairing in highly excited nuclei

Nguyen Dinh Dang

Recent achievements in the study of pairing effects on the properties of highly excited nuclei are discussed. In particular, the nuclear level density and radiative gamma-ray strength function are simultaneously described within a consistent approach based on the exact pairing in good agreement with the experimental data for 170 - 172 Yb isotopes. The gamma-ray strength function is described within the phonon-damping model, which explains the increase of the width of the giant dipole resonance with temperature and angular momentum [1]. Exact pairing is also important in describing the data of angular-momentum gated nuclear level densities in hot rotating 96 Tc nucleus within the interval of excitation energy of 5 - 15 MeV [2]. It is also shown that pairing plays an important role in maintaining a nearly constant value of temperature at low excitation energy, and offers in this way a consistent description of the nuclear level density, which goes smoothly from the low-energy region below 5 MeV to the higher one (up to 20 MeV for Ni isotopes and 10 MeV for Yb isotopes) without the need for matching the constant-temperature model at low energy and the Fermi-gas one at high energy as often performed by using the composite level-density formula [3]. Finally, the effect of exact pairing is incorporated in the Skyrme-Hartree-Fock mean field to study the properties of bubble nuclei 22 O and 34 Si nuclei [4] at finite temperature.

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Fine structure of the Isoscalar Giant Monopole Resonance in 24 Mg, 58 Ni and 90 Zr using alpha inelastic scattering at zero degrees

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The last few decades have proved to be quite exciting in the field of nuclear structure physics.High energy-resolution proton inelastic-scattering experiments revealed that giant resonances carry fine structure as a signature of the damping mechanisms involved. For the first time itis now possible to achieve such high energy-resolution measurements with intermediate energy (specifically 200 MeV) alpha-particle inelastic-scattering reactions at zero degrees. The choice of scattering angle as well as the projectile was motivated for as together they achieve the preferential excitation of the Isoscalar Giant Monopole Resonance (ISGMR). As part of the longstanding WITS/IKP Darmstadt/iThemba collaborative program on the investigation of properties of Nuclear Giant Resonances, these experiments have been performed using the Separated Sector Cyclotron (SSC) at the iThemba LABS and the K600 magnetic spectrometer for a range of nuclei including 24 Mg, 58 Ni and 90 Zr. Preliminary results will be presented.

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Deformation dependence of the IsoVector Giant Dipole Resonance: The Nd and Sm isotope chains revisited

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The shape transition of the IsoVector Giant Dipole Resonance from the spherical ^{142}Nd to the deformed ^{150}Nd nuclei in the even-even $^{142-150}$Nd chain was established using proton inelastic scattering at zero degrees. Comparisons were made to previous photo-absorption results obtain at Saclay. Some discrepancies that have implications for astrophysical applications were found. It should be noted that a global reanalysis of data taken using the Saclay method indicates that the (γ,n) cross sections are systematically too large and that the (γ,2n) cross sections are too small. Based on this and on the (p,p′) results for the Nd isotope chain, ^{144,148,150,152} Sm and ^{154}Sm have been measured to allow for isotone comparisons between the two chains and comparisons to the corresponding results obtained at Saclay with the aim of clarifying the observed discrepancies. The results of the comparisons will be presented and discussed.

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Searching for clustering structure effects of reacting partners through competing fast and thermal emission processes

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Clustering phenomena are well known in nuclear physics. Nuclear reactions which involve the emission or capture of clusters of nucleons are particularly interesting to investigate the interplay between the nuclear structure and reaction dynamics [1]. Indeed, clusters in nuclear systems can be related to their dynamical formation or their structural presence (pre-formation) in nuclei. While for light nuclei several links between cluster emission and its connection with nuclear structure and dynamics have been pointed out [1,2], this is less obvious when moving towards heavier systems, where the determination of pre-formed clusters within nuclear matter is more complicated and there is still a lack of experimental evidences of such structure effects. An interesting way to investigate the structural properties of medium mass systems is to study, in central collisions, the competition between evaporation and fast emission, namely pre-equilibrium, of light particles and clusters as a function of entrance channel parameters [1].
As a first step of an experimental campaign, which is still ongoing at the Legnaro National Laboratories (Italy), the two systems 16O + 65Cu and 19F + 62Ni, leading to the same compound system 81Rb, have been studied at the same beam velocity (16 AMeV) using the GARFIELD + RCo multi-detector system [3]. The aim is to investigate how possible effects of clustering structures in the reaction partners could affect the reaction mechanism interplay. Angular distributions and light charged particles emission spectra in coincidence with evaporation residues have been measured up to very forward angles. Selected experimental data have been compared with the predictions of different statistical and dynamical models, filtered through a software replica of the experimental apparatus. Recent results of the data analysis will be presented.

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Nuclear structure at the proton drip line

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Most of the nuclear structure properties of exotic nuclei at the proton drip line can be probed by the observation of proton radioactivity [1,2]. Due to the very small cross sections for their production and quite short half lives, it is the only possibility to gather information about their spectroscopic properties. Therefore, the observation and theoretical interpretation of proton radioactivity plays an important role in present Nuclear Physics studies. It provides a way to define the limits of stability at the proton rich side of the nuclear chart, as it was the case for charges Z between 50 and 83, and in some cases with Z<50 .
The position of the proton drip line influences the path of nucleosynthesis in explosive astrophysical scenarios, but the path depends on the existence of specific resonances in proton drip-line nuclei [3], and on the knowledge of proton separation energies specially, in the region of Z<50. However, it is possible though the interpretation of proton emission data, to impose well defined constraints on these energies, and reduce uncertainties in nuclear astrophysics models.
We have developed the non-adiabatic quasiparticle model [4], a non-relativistic microscopic approach, which includes the excitation spectra of the daughter nucleus and the residual interaction in a consistent way. The model, describes deformed odd-even and odd-odd emitters, with axial and triaxial symmetry,and it has been quite successful to interpret decay data and infer structure properties of proton emitters [5-10].
Within non relativistic microscopic models, the nuclear potential is completely determined from phenomenology, in contrast with the ones derived from covariant density functional theory (CDFT) [11], a fully relativistic quantum field theory, which incorporates a more fundamental input. We have applied CDFT to perform a selfconsistent study of proton radioactivity [12], which was very successful.

From the above discussion, one can conclude that a very solid theory exists that can describe proton radioactivity, interpret the data, and predict features of the structure of nuclei at the extremes of stability. It is the purpose of this talk to discuss recent developments in the study of proton rich nuclei, and their relevance to nuclear astrophysics.

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Gamow-Teller Transitions in Nuclei: An Overview

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Spin and isospin are unique quantum numbers in nuclei defined as "Finite Many-body System consisting of Two Fermions." Therefore, Gamow-Teller (GT) excitations caused by the spin-isospin (\sigma \tau) operator are unique in the sense that they can reflect the critical part of nuclear structure as well as nuclear interactions. In addition, they are the most common nuclear weak process in

the Universe.
GT transitions can be studied in \beta decays as well as charge-exchange (CE) reactions. From the \beta-decay studies absolute values of GT transition strength *B*(GT)s can be derived. However, they can access only the low excitation-energy region due to the limitation coming form finite decay *Q*-values. On the other hand, it was found that the CE reactions performed at intermediate incoming energies (*E*_in > 100 MeV/nucleon) and 0-degrees can access the GT strengths up in the highly excited region. Thus, CE reactions, in particular (*p,n*) reactions, gave an overview of the GT response of nuclei [1]. The well-known GT excitation carrying the main part of the available GT strength is the GT Resonance (GTR) that has been systematically observed as a broad bump at excitation energies *Ex* ~ 9 - 15 MeV.
The (3He,*t*) reactions at RCNP preformed at 140 MeV/nucleon have achieved one-order-of-magnitude better resolutions compared to (*p,n*) reactions (~30 keV) [2]. They have shown that the main part of the GT strength can also be concentrated in a low-lying discrete GT state called the "Low-energy Super Gamow-Teller (LeSGT) state" [3]. Largely different features of GT responses are discussed for various nuclei with a large mass range and from them we try to deduce the overview of GT strength distributions. In addition, the "isospin symmetry" is introduced to make connections between beta-decay and CE-reaction studies[2].

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Stepping into the light with High Power Laser and Brilliant Gamma beams at ELI-NP

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In the last decade the "laser world" is experiencing a "revolution" leading to a new paradigm in science and technology. Laser intensities have increased by 6 orders of magnitude in the last few years. The power (1015 Watts) concentrated in these extremely short burst of light (10-15s) are such that the laws of optics change in a fundamental way. This allows to access energy domains which have never been explored before. Based on these premises, the European Strategic Forum for Research Infrastructures (ESFRI) has selected a proposal called the Extreme Light Infrastructure (ELI). The ELI will be built as a network of three complementary pil-lars in Hungary, Czech Republic and Romania at the frontier of laser technologies, funded by EU regional funds for a total investment of about 1 Billion euros (around 300 Meuros per site) in the time period 2012-2018. The ELI-NP pillar (NP for nuclear physics) will develop a scientific program using two 10 PW (1015 W) lasers and a Compton back-scattering high-brilliance and intense low-energy gamma beam, a combination of laser and accelerator technology at the frontier of knowledge. The extreme high power density will be used for acceleration of electrons to many tens of GeVs within centimeter distances, which is currently only possible in kilometre-long accelerators. Another exciting perspective is to produce dense bunches of energetic protons and ions resulting from the interaction of high power lasers with gas jets or thin foils of matter. Such power densities are comparable to stellar environment conditions. The new brilliant gamma beam facility at ELI-NP will be used to study key nuclear reactions relevant to nucleosynthesis. One of them is the fusion reaction rate between alpha particles and carbon nuclei to produce oxygen (4He + 12C → 16O) which lies at the root of life on earth. Multi step reactions, such as fission-fusion, will be used to address questions regarding the formation of heavy elements in the universe. These extreme conditions will also lead to applications in imaging, gamma tomography, in the field of nuclear security regarding the management of sensitive nuclear materials or subjecting materials to intense radiation fields for space mission applications.

These ions can be used to induce secondary reactions on specific materials leading to a new generation of radio isotopes for diagnostics in medicine or to be used for cancer treatment directly.
The present status of the implementation of the ELI-NP facility as well as the new perspectives in Nuclear Physics and Astrophysics and their applications will be described. The impact of this emerging science will be illustrated through specific examples related to health, energy and economical and educational implications of this Large Scale Facility in the host country.

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Electric dipole strength and dipole polarizability in 48Ca within a fully self–consistent second random–phase approximation

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The Second Random Phase Approximation (SRPA) is a natural extension of Random Phase Approximation obtained by introducing more general excitation operators where two particle-two hole configurations, in addition to the one particle-one hole ones, are considered. Only in the last years, large-scale SRPA calculations, without usually employed approximations have been performed [1,2].
The SRPA model corrected by a subtraction procedure [2] designed to cure double counting, instabilities, and ultraviolet divergences, is employed for the first time to analyze the dipole strength and polarizability in 48Ca [3]. All the terms of the residual interaction are included, leading to a fully self-consistent scheme. Results are illustrated with two Skyrme parametrizations, SGII and SLy4 and compared with the experimental data recently obtained at RCNP-Osaka, employing the (p,p') reaction at forward angle [4].
The results obtained with the SGII interaction are particularly satisfactory. In this case, the low–lying strength below the neutron threshold is extremely well reproduced and the giant dipole resonance is described in a very satisfactory way especially in its spreading and fragmentation. Spreading and fragmentation are produced in a natural way within such a theoretical model by the coupling of 1 particle−1 hole and 2 particle−2 hole configurations. Owing to this feature, we may provide for the electric polarizability as a function of the excitation energy a curve with a similar slope around the centroid energy of the giant resonance compared to the corresponding experimental results.
This represents a considerable improvement with respect to previous theoretical predictions obtained with the random−phase approximation or with several ab−initio models. In such cases, the spreading width of the excitation cannot be reproduced and the polarizability as a function of the excitation energy displays a stiff increase around the predicted centroid energy of the giant resonance.
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LaBr3:Ce detectors response function and linearity for high energy gamma rays

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γ-rays in the energy range 6 − 38 MeV were produced and sent into two large volume LaBr3:Ce crystals (3.5''x8'') at the NewSUBARU facility, with the goal of investigating the response function of the detectors. By comparing the experimental spectra of the two detectors we deduced the linearity

of the system, separately of the two crystals and of the two PMT + VD associated. Moreover, Monte Carlo simulations were performed in order to reproduce the experimental spectra. The photopeak and interaction efficiencies both in case of a collimated beam and an isotropic source were also evaluated.

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Studying the decay of 46Ti* at different excitation energies and through different entrance channels: does partner structure influence the competing mechanisms and the following compound nucleus decay?

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The exclusive study of light charged particles emission in hot light composite systems is a useful tool to underline possible structure effects on the competition between different reaction mechanisms and, in particular the possible evidence of nuclear clustering effects, which may change the expected decay chain probability. In particular, studying the competition between pre-equilibrium and thermally emitted particles the influence of projectile cluster structure may be evidenced: the NUCL-EX collaboration (INFN, Italy) has carried out an extensive research campaign on pre-equilibrium emission of light charged particles from hot nuclei [1].
In this framework, the reactions 16O+30Si, 18O+28Si and 19F+27Al at 7 MeV/u and 16O+30Si at 8MeV/n have been measured using the GARFIELD+RCo array [2] at Legnaro National Laboratories, as a first step, where the fast emission mechanisms could be kept under control. After a general introduction on the experimental campaign performed on different systems, which have evidenced anomalies in the alpha-particle emission channel, this contribution will focus on the analysis results obtained in the measurement reported above, showing in an exclusive way the observed effects related to the entrance channels. The experimental results will be compared to model prediction, for which the same filtering and complete event selection have been applied. This has been performed in order to take into account all possible distortions introduced due to finite geometry and analysis selection.

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A beyond-mean-field description for nuclear excitation spectra: applications of the subtracted second random-phase approximation

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The second random–phase approximation (SRPA) is an extension of the standard random–phase approximation (RPA) where two particle–two hole (2p2h) configurations are included together with the RPA one particle–one hole (1p1h) configurations. This beyond mean– field model allows for reliable quantitative predictions to describe the widths and the fragmentation of excited states, due to the coupling between 1p1h and 2p2h elementary configurations.
I will present the formal developments and the practical applications that we have realized in the last years. One important recent achievement was the development of a substantial implementation of the SRPA model, based on a subtraction procedure. This subtraction method was tailored to cure double–counting problems encountered when effective interactions are used in beyond mean–field models, within energy–density functional theories. At the same time, this procedure cures all the instabilities and divergences present in the standard SRPA and produces renormalized single–particle excitation energies. The subtracted SRPA (SSRPA) provides a well–defined theoretical framework for quantitative predictions on nuclear excitation spectra.
Several applications to low–lying states and giant resonances will be shown: for instance, a systematic study on giant quadrupole resonances in medium-mass and heavy nuclei (centroids and widths) will be presented. In addition, a related topic will be discussed, namely the modification (enhancement) of the effective masses induced by the beyond-mean-field SSRPA effects.

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QRPA predictions of the E1 and M1 gamma-ray strength functions using the D1M Gogny interaction

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Within the framework of a global microscopic approach, all the nuclear input required for nuclear reaction predictions are being, step by step, derived from a sole nucleon-nucleon effective interaction, namely the D1M Gogny force [1]. Nuclear masses [1], deformations, radial densities and level densities [2] have already been obtained and have shown a rather good agreement with experimental data either directly or when used, for instance, to derive optical models [3]. We now focus on the radiative strength functions within the QRPA approach [4], and in particular, aim at producing tables of gamma-ray strength functions for both E1 and M1 transitions. The current status of this project will be discussed with a particular emphasis on the consequences on capture cross section modelling.

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Are the Molybdenums Fluffy Too?

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"*Why are the tin isotopes fluffy?*" has remained, for nearly a decade, a fundamental open problem in nuclear structure physics: models which reproduce the isoscalar giant monopole resonance (ISGMR) in the "standard" doubly-closed shell nuclei, ^{90}Zr, ^{208}Pb, overestimate, by as much as 1 MeV, the ISGMR energies of the open-shell tin and cadmium nuclei [1-4].

To further elucidate this question as also to examine *when* this "fluffiness" appears in moving away from the doubly-closed nucleus ^{90}Zr, and *how* this effect develops, we have carried out measurements of the isoscalar giant resonance strength distributions in a series of molybdenum nuclei. The measurements were performed for ^{94,96,97,98,100}Mo, using inelastic scattering of 100 MeV/u α particles at the Research Center for Nuclear Physics, Osaka University. The targets, with thicknesses ~ 5 mg/cm^2, were enriched to an isotopic purity of approximately 95%. The measurements on all nuclei were performed within the same experiment so as to minimize any systematic effects in the final results. The versatile, high-precision mass spectrometer, Grand Raiden, provided small angle $(0-10°)$ spectra virtually free of all instrumental background. The resulting double-differential cross sections can be used to reliably extract ISGMR strength distributions using a multipole decomposition analysis; this procedure is currently in progress. The extracted ISGMR strengths will be presented. It is hoped that these results, in combination with previously published results for the ISGMR strength in ^{90,92}Zr and ^{92}Mo [5], will provide important information for possible refinements of theoretical models in describing this mode in open- and closed-shell nuclei alike.

This work has been supported in part by the National Science Foundation (Grant Nos. PHY-1713857 and PHY-1419765), and by the Liu Institute for Asia and Asian Studies, University of Notre Dame.

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The Inverse-Oslo method

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The recent measurement of the Neutron Star Merger event by LIGO [1] and subsequent optical measurements have revealed that Neutron star mergers are probably one of the primary sites for the r-process of nucleosynthesis [2]. An important source of uncertainty in the r-process models is the nuclear data input [3], especially important is the neutron capture cross-section which is directly observable for only a handful of nuclei close to stability.

The Oslo Method provides an alternative, indirect route to constrain the neutron capture cross-sections by providing the nuclear level density (NLD) and γ-ray strength function (γSF) which are important in Hauser-Feshbach calculations. The method requires experiments where the γ-ray distribution is measured as a function of excitation energy. This has been achieved for several years with transfer reactions with light ion beams, eg. p,d,^{3}He,α, at the Oslo Cyclotron Laboratory and more recently in β-decay experiments [4]. A new class of experiments have recently joined the 'Oslo Method family', namely the inverse kinematics experiment. The NLD and γSF of ^{87}Kr was successfully extracted from a experiment with a ^{86}Kr beam hitting a deuterated polyethylene target at iThemba LABS in early 2015. With the addition of inverse kinematics we are now able to probe the NLD and γSF of virtually any nuclei that can be accelerated in the lab. The γSF and NLD of ^{87}Kr will be presented together with Hauser-Feshbach calculations of the neutron capture cross-section of ^{86}Kr. In addition there will be preliminary results from new inverse-kinematics experiments with Kr, Ni and Xe beams.

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Investigating the Evolution of the Pygmy Dipole Resonance with deformation in Samarium isotopes

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Investigating the low-lying electric dipole *(E1)* response referred to as the Pygmy Dipole Resonance (PDR) has garnered a lot of attention in recent years, with both experimental and theoretical studies dedicated to this topic. Within the hydrodynamic model, the PDR has been interpreted as an oscillation of excess neutrons against a proton-neutron saturated core [1,2]. The PDR is of particular

interest due to the link between its strength and the neutron skin thickness associated with the density dependence of the symmetry energy at saturation, which has implications for the way in which we can constrain the nuclear equation of state.

The role that deformation plays on the PDR is yet to be established. In a preliminary 154Sm(p,p') study performed at RCNP, evidence for a splitting in the PDR response similar to that of the Giant Dipole Resonance with deformation was observed [3]. A tentative interpretation suggested that this splitting could be connected to the splitting of the resonance structure with respect to the K quantum number.

Since the PDR has a mixed isospin nature, it can be investigated using both isoscalar and isovector probes. An investigation using liquid drop model calculations to compare the ratio between the transition probability of K=0 and K=1 contributions for the isovector and isoscalar components of the PDR respectively showed that the isoscalar part varies more dramatically with deformation [4].

As such, an investigation using the (α,α'γ) inelastic scattering reaction at 120 MeV on the deformed 154Sm nucleus was performed at the iThemba LABS in Faure, making use of the K600 magnetic spectrometer in 0° mode in co-incidence for the first time with BaGeL (Ball of Germanium and LaBr detectors). In this talk, we will present recent results of this study.

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OPTIMIZATION OF ELECTRON SPECTROMETER IN LENS-MODE OPERATION

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The study of monopole transitions via excited 0+ states requires the measurement of internal conversion electrons and internal pair formation using an electron spectrometer. Such a spectrometer, consisting of a solenoid magnet transporter and a Si(Li) detector with an array of LaBr3, is undergoing development at iThemba LABS. Performance of the electron spectrometer has been investigated using radioactive sources produced at iThemba LABS. The spectrometer has been used in lens mode with the field swept under computer control. Transmission and efficiency, as well as the momentum resolution of the swept lens, are presented. Commissioning experiments are due to take place in July 2018 using an alpha beam at a maximum of Eα = 30 MeV with a beam current of 10enA on isotopically enriched 70Ge which will provide an opportunity to investigate E0 transitions in the target nucleus. This serves as a sensitive probe for the study of shape coexistence in nuclei since the monopole strength parameter is related to the change in mean square radius between the initial and final 0+ states.

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Structure of 33 Si, 35 S and 36 S nuclei and the N=20 shell gap

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The project focuses on studying the evolution of the N=20 shell gap. The shell gaps have been previously investigated through studies of nuclear levels, using various experimental approaches namely: Coulomb excitation, knockout reactions, transfer reactions and g-factor measurements. In exotic nuclei with an imbalanced number of neutrons and protons, significant modifications of the nuclear structure have been observed. A detailed study of the evolution of the shell gaps will lead to a comprehensive understanding of the structure of atomic nuclei. In order to investigate the evolving shell structure, it is necessary to determine single particle observables such as spectroscopic factors of the states involving the active
orbitals at these shells gaps. A knockout reaction is the first set of data for this project, the experiment was performed at MSU/NSCL laboratory using the GRETINA gamma-ray tracking array and S800 spectrometer. The knockout reaction was performed using inverse kinematics with a ³⁶S secondary beam incident on a ⁹Be target. The nuclei of interest studied are ³³Si, ³⁵S and ³⁶S. Various transitions in these nuclei have been identified from the analysis of add-back Doppler corrected spectra and a level scheme has been built from the resulting analysis. In addition, parallel momentum distributions have been constructed to investigate the possible nature of the different states.

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Impact of Neutron Star Merger and Supernova Nucleosynthesis on the Element Genesis and Neutrino Physics

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GW170817/SSS17a was an event of the century that opened a new window to multi-messenger astronomy and nuclear astrophysics. Optical and near-infrared emissions among many other observables suggest that their total energy release is consistent with radiative decays of r-process nuclei predicted theoretically although no specific r-process element was identified. Core-collapse supernovae (both MHD Jet-SNe and ν-SNe) are viable candidates for the r-process. MHD Jet-SNe explain the "universality" in the observed elemental r-process abundance pattern in metal poor stars. Neutron star merger (NSM), on the other hand, could not contribute to the early Galaxy for cosmologically long merging time-scale for slow GW radiation. Nevertheless, NSM is still a possible explanation for the solar-system r-process abundance. We propose a novel solution to this twisted problem by carrying out NSM and SN r-process nucleosynthesis calculations with Galactic chemo-dynamical evolution [1-3].
We also discuss the impact of SN nucleosynthesis on the physics of neutrino oscillations. The elements at A = 80-100 originate from many processes such as r-, s-, rp-, γ-, ν-, νp-processes [4,5]. We find that νp-process operates strongly with amounts of free neutrons being supplied even on proton-rich (Ye > 0.5) condition via p(ν, e+)n reactions when one takes account of the effects of collective neutrino oscillations [6]. Reaction flows can reach the production of abundant p-nuclei 94Mo, 96Ru, etc. This nucleosynthetic method turns out to be a unique probe indicating still unknown neutrino-mass hierarchy.

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Spectroscopy of rare isotopes with direct reactions

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Rare Isotopes located far from the valley of stability bring new insight into the evolution nuclear structure. Our knowledge on the properties of neutronand proton-rich nuclei guide our understanding of the state of matter in extreme neutron-rich systems such as neutron stars and supernovae and heavy element synthesis. The presentation will outline how radioactive (RI) beams are allowing us to uncover the unknown properties of rare isotopes and leading to revelation of unconventional forms of nuclei such as, nuclear halo and skin structures and fundamental changes of nuclear shells that break the bounds of our traditional knowledge. The discussion will show examples of how low-energy re-accelerated RI beams from the Isotope Separator Online (ISOL) facility at TRIUMF are used to study Borromean nuclei at the drip-lines to uncover features of soft dipole resonance in the halo nucleus, 11Li and unbound excited states in other light Borromean nuclei.
The new features of the rare isotopes challenge our understanding of the nuclear force bringing new insight. It has been a century-long challenge to understand the nuclear force between protons and neutrons forming manybody nuclei, from the fundamental basis of quantum chromodynamics (QCD). The formulation of the chiral effective field theory has paved the closest link with QCD making it possible to predict some observable properties of many-body nuclei. The presentation will show selected examples from recent achievements of how observations with rare isotopes compare with ab initio theoretical predictions with chiral forces demonstrating high sensitivity to refine our understanding of the nuclear interaction.

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Search for the rare gamma-decay mode in 12C

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The triple α reaction is one of the most important reactions for the nucleosynthesis in the universe because it is a doorway reaction to synthesize heavier elements. An α particle is

captured by ^{8}Be, which is a two α resonant state, to form a triple α resonant state. Most of such triple α resonant states decay back to 3α particles, but a tiny fraction of those states decay to the ground state in ^{12}C by emitting γ rays. The branching ratio between the γ and α decays of the triple α resonant states is a key parameter to decide the triple α reaction rate.

The triple α reaction proceeds via the Hoyle state at normal stellar temperature, but the high-energy triple α resonant states such as the 3_1^- and 2_2^+ states in ^{12}C play a very important role at higher temperature $T_9 > 1$ like supernovae, first stars, and so on. Nevertheless, the γ-decay probability of the 3_1^- state is still unknown.

Recently, we measured the inelastic proton scattering off ^{12}C under the inverse kinematic condition in order to determine the γ decay width of the 3_1^- state in ^{12}C. The γ-decay probability of the 3_1^- state is quite as small as 10^{-7}, therefore we introduced a thin solid hydrogen target and the recoil proton counter "Gion" to realize the low background measurement. We successfully identified the γ-decay events by measuring the recoil proton and ^{12}C in coincidence instead of detecting the γ ray.
With the careful data analysis, we finally determined the γ decay width of the 3_1^- state for the first time.

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CROSS SECTION MEASUREMENTS OF LIGHT ION PRODUCTION USING (P,XP) REACTIONS

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Neutron-rich beams are being developed at iThemba LABS to study nuclear structure away from stability. This is also the opportunity of deepening our understanding of astrophysical origin of elements. The interest of using (p,xp) reactions in the production of exotic nuclei, lies in the fact that proton beams have a large penetrating power and can be produced with high intensity. Some measurements have been performed at iThemba LABS using, 7Li, 9Be and natB targets with proton projectiles of energy 50 MeV and 66 MeV. The detection setup included two electron spectrometers composed of a 5mm thick plastic scintillator, for energy loss measurement, and a thin window Germanium detector (LEPS) for residual energy measurement. The E- ΔE technique with this combination of detectors allows particle identification and high-resolution measurement simultaneously. Lanthanum Bromide detectors where also used to measure gamma particles. Some preliminary results will be presented. Beryllium and Boron are chosen here because they can be used in oxide, carbide or nitride form that can sustain large temperature amplitudes and therefore can be used in place as Uranium carbide in the current design of the ISOL source of iThemba LABS. This is important as there is no significant cost or resources implications. In addition, light targets produce a lot less species which makes debugging easier. The results of this investigation will be used to evaluate the feasibility of light neutron rich beams at iThemba LABS.

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Galactic Production of 138La: Impact of 138,139La statistical properties

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The odd-odd neutron-deficient 138La is very long-lived but one of the less abundant nuclei in the solar system. It is expected to be one of 35 p-nuclei. Most p-nuclei with A>110 are thought to be produced by photo-disintegration of s- and r-process seed nuclei. However, this photo-disintegration cannot satisfactorily explain the observed abundance of 138La and more exotic processes such as the electron neutrino capture on 138Ba have been called for to explain its synthesis [1, 2]. The neutrino reaction can to some extent explain the observed abundance of 138La but the significance of the photo-disintegration process cannot be ruled out due to the limited knowledge and uncertainties of nuclear properties entering the 138La production, such as nuclear level densities (NLD) and Photon Strength Function (PSF) [2]. These are critical model input parameters for the astrophysical reaction rate calculations. Measurements are necessary to place the nuclear properties on a solid footing in order to make statements regarding the importance of neutrino reactions. In this presentation I will discuss our recently measured NLD and PSF of 138,139,140La and their impact on the galactic production of 138La. This work has also been been published on Phys. Lett. B. 744 (2015) 268 and Phys. Rev. C. 95 (2017) 045805.

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Low Pressure Focal Plane Detectors for the K600: A design study

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Magnetic spectrometers have proven to be very useful in the world of experimental nuclear and astrophysics. The focal plane detection system instrumenting these spectrometers is instrumental in their success. A new focal plane detection system is envisaged for the K600 QDD magnetic spectrometer at iThemba LABS in Cape Town, South Africa. The existing focal plane detection system, consisting of two multi-wire drift chambers (MWDCs) and plastic scintillators, is designed to detect light ions (H and He isotopes) at medium energies (50-200 MeV). To be detected these particles go through a lot of material before reaching the scintillators and an event is registered. This affects the low energy threshold for operation of the K600. This study will quantify the low energy limitations as well as investigate the material budget for a new low energy detector. A conceptual design for a new focal plane detection system will be explored.

This work is supported by the National Research Foundation South Africa

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Structure and Responses of nuclei studied by real-time evolution method

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Recently, we proposed a new theoretical method which enables to study nuclear structure and responses in an unified way. This method, named real-time evolution method, utilizes the equation-of-motion of interacting nucleon wave packets. It will be demonstrated that this method is very powerful theoretical tool which beyond the small amplitude approximation (RPA).

As an example of the application, Following topics will be discussed.
1. The structure and excitation modes of the Hoyle state
2. The structure and decay pattern of pygmy dipole resonances

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The study of giant resonances excited by scattered protons at CCB IFJ PAN in Kraków

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The Cyclotron Center Bronowice (CCB) is the proton beam facility at the Institute of Nuclear Physics Polish Academy of Sciences Poland which, except proton cancer therapy, offers the possibility of using proton beams for nuclear physics investigations. Among others, the measurement concerning study of collective excitations was performed.
The experiment aimed at investigation of gamma decay of collective modes in stable nuclei 208Pb. It concerned mainly the study of giant resonances (giant quadrupole resonance, GQR and giant dipole resonance GDR). In addition the region where the pygmy dipole states (PDR) are present, was explored as well.
During experiment high-energy gamma rays and scattered protons were measured in coincidence mode with the use of HECTOR + KRATTA setup. High efficiency 8 big BaF2 detectors of HECTOR array was used to measure the high-energy gamma rays together with the cluster of PARIS type phoswiches (9 LaBr3-NaI or CeBr3-NaI crystals) and one large volume LaBr3 scintillator. The good timing of BaF2 detectors of the HECTOR array (≈1 ns) was exploited to define well the coincidence condition and thus to reduce the accidental coincidences and other sources of background. Scattered protons (their scattering angle and energy) were measured by the KRATTA array consisted of 24 triple telescopes made of silicon detectors and two CsI crystals. The KRATTA detectors were placed at forward angles while HECTOR was mounted at backward direction and PARIS at 90 degrees, both outside the vacuum scattering chamber where target was installed.
The first experiment aiming at study excitation of 208Pb was preceded by several test measurements done as a preparation of detectors for coincidence measurement. During the talk obtained results and attempt to their theoretical description as well as experimental method will be discussed.

The study is supported by the Polish National Science Centre (NCN) grants Nos.: 2015/17/N/ST2/04034 and 2015/17/B/ST2/01534; and ENSAR2 EU project.

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Enhancement of E1 strength in nuclei with the neutron skin and halo

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The neutron skin and halo structures have attracted much attention from the experimental and theoretical point of view. The neutron skin thickness is supposed to have correlations with symmetry energy parameters in the nuclear equation of state, and thus a lot of studies on the skin thickness have been performed. On the other hand, the neutron halo is one of the most exotic structures in modern nuclear physics. The halo is due to the loosely-bound neutrons in and around the neutron-dripline nuclei, and halo nuclei have very large nuclear radius. Although shapes of the skin and halo are completely different from each other, enhancement of low-lying E1 strength can be seen for the both structures. While the enhancement of nuclei with neutron skin is called Pygmy Dipole Resonance (PDR), that of halo nuclei is called soft E1 excitation. The soft E1 excitation is solely related to the single-particle structure of the halo neutrons, and the E1 strength distribution can be well understood especially for one-neutron halo. On the other hand, the PDR is much complicated and the origin is still under debate. In this context, accumulating the experimental data on the PDR is desired. In this presentation, we will briefly review the study of halo structure in neutron-rich nucleus ^{37}Mg. And then, we will introduce a recent experimental study of the PDR of ^{208}Pb. We have measured angular differential cross sections for the ^{208}Pb(p, $p\gamma$) reaction at 80 MeV by using the clover detector array CAGRA and the Grand Raiden spectrometer at Research Center for Nuclear Physics (RCNP), Osaka University. The angular distribution is considered to be sensitive to the characteristics of the transition density, which allows us to elucidate the contribution of the PDR. The recent status of the data analysis and preliminary result will be presented.

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Threshold physics - precision measurements in light nuclei

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This talk will report recent experimental results from the decay of
carbon-12
and other light nuclei, performed by the group in Birmingham. Using the
MC40 cyclotron
and also experimental facilities across Europe we have pushed the
conventional particle
spectroscopy techniques to the limits, in order to shed light on the
cluster structure
in nuclei.

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On the discovery of a new light particle in high energy nuclear transitions

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Dark matter is currently one of the greatest unsolved mysteries in physics. Recently we have observed an anomaly in the internal e+e- decay of 8Be [1]. It turned out [2] that this could be a first hint for a 17 MeV X-boson (X17), which may connect our visible world with dark matter. The possible relation of the X17 to the dark matter problem as well as the fact that it might explain the (g-2)μ puzzle, triggered an enormous theoretical and experimental interest in the particle, hadron and atomic physics community. Zhang and Miller discussed in detail any possible explanations with nuclear physics origin without any success [3].

Using a significantly modified and improved experimental setup, recently we reinvestigated the anomaly observed in the e+e- angular correlation by using the new tandetron accelerator of our institute. This setup has different efficiency curve as a function of the correlation angle, and different sensitivity to cosmic rays resulting practically independent experimental results. In this experiment, the previous data were reproduced within the error bars. The 8Be anomaly was a strong motivation for further experiments to study possible signals of a new force interacting with nuclei and electrons.

I am going to discuss the preliminary results of a few follow-up experiments. We obtained new results for high energy transitions in 4He and 12C, which also supports the existence of the X17 particle. The γγ-decay of X17 boson was also studied in order to distinguish between the vector and pseudo scalar scenario suggested recently by theoretical group [4,5]. According to the Landau-Yang theorem, the decay of a vector boson is forbidden by double γ-emission, however a pseudoscalar one is allowed. The possibilities of further nuclear physics studies of the X-boson in small laboratories will also be discussed.

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Study of giant resonances in storage ring experiments with EXL

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Inelastic scattering of exotic nuclei on an internal gas-jet target of a storage ring allows for a new access to study giant resonances, applicable also for radioactive nuclei. The differential excitation cross section can be measured down to very small scattering angles in the CM system with high angular resolution, making this approach particularly suited e.g. for the study of giant monopole resonances.
As proof of principle, the ISGMR in the stable nucleus 58Ni [1] has been studied at the ESR of GSI (Darmstadt, Germany) using an early version of the EXL set-up [2].
The status of the EXL project and future plans at GSI/FAIR, e.g. the study of the ISGMR in 56Ni, will be presented on behalf of the EXL collaboration.

This work was supported by German BMBF (06DA9040I, 05P12RDFN8, and 05P15RDFN1), the European Commission within the Seventh Framework Program through IA-ENSAR (Contract No. RII3-CT-2010-262010), the Hungarian OTKA Foundation No. K106035, the Sumitomo Foundation, the National Natural Science Foundation of China (Contract No. 11575269),the Helmholtz Association of German Research Centre through the Helmholtz-CAS Joint Research Group HCJRG-108, HIC for FAIR, GSI-RUG/KVI collaboration agreement,TU Darmstadt-GSI cooperation contract, and the STIBET Doctoral program of the German Academic Exchange Service.

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Peculiarities of interaction of weakly bound lithium nuclei at low energies

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[2]

The review presents the latest experimental data on the total reaction cross sections (σR) and elastic scattering angular distributions of light weakly bound nuclei 6–9,11Li [1].
A review of papers on the interaction of weakly bound 6-9Li and 11Li nuclei published so far and their analysis shows that there are no experimental data on σR and it is necessary to measure it for Li-isotopes at energies from the Coulomb barrier Bc=3–4 MeV up to 10-40 MeV/A on 28Si, 27Al, 9Be, and 12C nuclei.
The new data on σR for reactions 8,9Li+28Si in the energy range 5–30 MeV/A with their analysis are presented in [2]. In the σR energy dependence of 9Li+28Si reaction, a "bump", i.e., a local increase in the cross section in the energy interval 10-30 MeV/A, was first observed. Therefore, this dependence requires further theoretical analysis and experimental study.
Large σR values detected in the σR(E) dependence, as well as their rapid increase in a short energy interval in the low-energy region, can lead to a release of a large amount of energy, which is interesting in terms of search for new energy sources of the future.
The obtained new data (the existence of an anomalous increase in the σR) in a narrow energy range 10-30 MeV/A in the (6He, 9Li)+28Si reactions at Bc energies will enable scientists to explain important questions of nucleosynthesis (nuclear astrophysics).
One of the most important features explaining why light elements are abundant in the universe is the increase in the interaction cross sections in the sub-barrier energy region in nuclear reactions with weakly bound nuclei. This effect is especially strongly manifested for light cluster nuclei 6,9,11Li and nuclei with a neutron halo 6,8He and 11Li. The main channels of interaction of such nuclei are transfer, breakup and complete-fusion reactions.

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Pygmy dipole resonances in deformed nuclei

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It is well established that the study of the low lying dipole states, the so called Pygmy Dipole Resonance (PDR), can be fruitful done by using an isoscalar probe in addition to the conventional isovector one due to the fact that their transition densities show a strong mixing of their isoscalar and isovector components. The combined use of real and virtual phonons and experiments employing $(\alpha, \alpha\gamma)$ as well as (^{17}O, ^{17}O' γ), for the investigation of the PDR states has unveiled a new feature of these states: the splitting of the PDR. Namely, the energy region of these low-lying dipole states can be separated in two parts: the lower part is excited by both the isoscalar and isovector interactions while the high energy part is populated only by the electromagnetic probes.

In deformed nuclei the Giant Dipole Resonance (GDR) peak is separated in two parts. Each of them corresponds to an out-of-phase oscillation of neutron against protons along the symmetry and its perpendicular axes. A common picture of the PDR consider that this mode can be generated by an out-of-phase oscillation of the neutron excess against a proton plus neutron core. If this were true then the same mechanism leading to the splitting of the GDR should be valid also for the low lying dipole states, therefore producing a separation of the pygmy dipole peak in two bumps.

A strong isoscalar-isovector mixing at the nuclear surface is found for the transition densities calculated within a simple macroscopic model. These results are corroborated by some microscopic calculations.

The macroscopic model is designed for nuclei with neutron excess. It consists in a deformed core surrounded by a deformed skin formed by the neutron excess. An out of phase oscillation of the skin against the core is allowed and the corresponding transition densities are constructed. This simple model shows that a suitable way to investigate the pygmy states in deformed prolate nuclei is through the use of isoscalar probes. Measurement of the pygmy excitations along an isotope chain with increasing deformation may give new perspectives about these novel excitation modes.

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Unravelling 12C, the ISGMR and the Hoyle's ghost.

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The 14C(p,t)12C reaction was employed to investigate the much-discussed excitation energy region above the Hoyle state: there is evidence that suggests that in addition to the broad 0+ state at 10.3 MeV, an additional 0+ resonance is required at ~8.7 MeV. AMD calculations suggest that the Isoscalar Giant Monopole Resonance (ISGMR) may contribute to this region and suggest two distinct oscillation modes may play a role. The development of a new multi-channel R-matrix fitting programme aims to provide new insight by simultaneously analysing low-energy resonance data from multiple experiments (with different reaction channels). Moreover, a multi-channel two-level approximation is implemented which may help determine the contribution to this region from the ghost of the Hoyle state and any associated coherent interferences with other 0+ states.

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Neutron-capture reaction rates for astrophysical applications

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The rapid neutron capture process (r-process) is responsible for the synthesis of approximately half of the abundance of the heavy elements. The recent LIGO and Virgo gravitational-wave detection of a direct signal from two colliding neutron stars, combined with the wealth of follow-up measurements across the electromagnetic spectrum, demonstrated that an r-process had occurred during the collision. However, despite knowing at least one location for the r-process, many open questions remain. The uncertainties in the nuclear physics inputs present a large barrier to accurately model the r-process abundances in large-scale nucleosynthesis calculations. Masses, β-decay half-lives, β-delayed neutron emission probabilities and neutron-capture reaction rates are the main nuclear properties needed in r-process calculations. Of this set of nuclear input, the neutron-capture rates are the most uncertain and difficult to measure with theoretical predictions ranging over orders of magnitude far from stability. In this talk the indirect determination of neutron-capture cross sections using the "⊠-Oslo" technique to provide information on level densities and g-ray strength functions will be discussed. The level density and strength function are critical inputs for constraining the neutron-capture rates, especially in very neutron-rich regions important in "cold" r-process scenarios.

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Nuclear response at zero and finite temperature

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Recent developments of the relativistic nuclear field theory on the proton-neutron response and on the finite-temperature formalism will be presented. The general non-perturbative framework, which advances the nuclear response theory beyond the one-loop approximation, is formulated in terms of a closed system of non-linear equations for the two-body Green's functions. This provides a direct link to ab initio theories and allows for an assessment of accuracy of the approach.

The response theory is extended for the case of finite temperature. For this purpose, the time blocking approximation to the time-dependent part of the in-medium nucleon-nucleon interaction amplitude is adopted for the thermal (imaginary-time) Green's function formalism. The method is implemented self-consistently in the framework of Quantum Hadrodynamics and designed to connect the high-energy scale of heavy mesons and the low-energy domain of nuclear medium polarization effects in a parameter-free way. In this framework, we investigate the temperature dependence of dipole spectra in the even-even medium-heavy nuclei with a special focus on the giant dipole resonance's width problem and on the low-energy dipole strength distribution. Its behavior, together with the temperature dependence of the Gamow-Teller resonances, are studied for their potential impact on the r-process nucleosynthesis.

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What do we learn from our giant resonances experiment?

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Nuclear matter incompressibility (KNM) is an important physical constant, unfortunately it cannot be measured directly. The location of the isoscalar giant monopole resonance (ISGMR) can be directly related to the incompressibility coefficient of nuclear matter (NM) by comparing experimental measurements of EGMR with energies calculated using specific microscopic interactions. This provides a unique relationship between EGMR and KNM.

Our program use the 240 MeV alpha beam from the Texas A&M University K500 superconducting cyclotron bombarding foils in the target chamber of the multipole-dipole-multipole (MDM) spectrometer. Inelastically scattered alpha particles are measured at small angles including 0o where the angular distributions of the isoscalar giant resonances show distinct features.

GMR strength, close to 100% of the energy weighted sum rule (EWSR), in many nuclei between 12C and 208Pb has been extracted and is generally consistent with KNM = 220 - 240 MeV. Studies in Sn and Cd isotopes have been used to set better constraints on parameters such as L and Kτ. of the symmetry energy.

In some nuclei, however, EGMR values (and hence KA) are not consistent with the general picture. These anomalies raise the issue of what is left out of the calculations relating KNM to KA values for specific nuclei, and what effect they might have in the overall extraction of KNM.

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Statistical Properties of highly-deformed Samarium isotopes

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The rare-earth isotopic chain of Samarium provides an excellent opportunity to systematically investigate the evolution of nuclear structure effects from the near spherical (β2=0.09) 144Sm isotope to the highly-deformed system (β2=0.34) 154Sm. As the nuclear shape changes, statistical properties such as the nuclear level density (NLD) and γ-strength function (γSF) are expected to be affected. In particular resonance modes, such as the Pygmy Dipole (PDR), Scissors Resonances (SR) and the recently discovered Low-Energy Enhancement (LEE) in rare-earth region may reveal interesting features when their evolution is investigated across several nuclei in an isotopic chain. Most reliable knowledge can be obtained when results from several different experiments are compared. An experiment was performed in September 2016 at Oslo Cyclotron Laboratory (OCL) where the NaI(Tl) γ-ray array, silicon particle telescopes and 6 high-efficiency LaBr3:Ce detectors were utilized to measure particle-γ coincidence events from which the NLDs and γSFs will be extracted below the neutron separation energy threshold, Sn, using the Oslo Method (A. Schiller et al. 2000). The deuteron beam with 13 and 15 MeV energies was used to populate excited states in 154,155Sm through the inelastic scattering (d,d'γ) and the transfer reaction (d,p). Based on the results from these measurements, the extracted NLDs and γSFs will be used to investigate the evolution of nuclear structure effects in 154,155Sm and provide complementary information to the 154Sm(p,p')154Sm and

154Sm(α,α'γ)154Sm data on resonance features that lie on the low-energy tail of the GDR. In addition, the results will further provide a near-complete picture on the evolution of the PDR, SR and/or the LEE as the isotopic chain transitions from near spherical to very deformed systems. In this talk I will present preliminary results of this investigation of statistical properties for 154,155Sm in comparison to the previous and recent measurements of 148,149Sm and 151,153Sm isotopes, respectively, and ongoing measurements of 152,153Sm at OCL.

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185W(n,gamma) Cross Sections Constrained with Electromagnetic Quantities of 186W

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At certain locations in the s-process path, there are unstable nuclei with beta-decay rates comparable to the neutron capture rates. This opens up a new possible pathway for the s-process: instead of just undergoing beta decay, the radioactive nucleus could also survive long enough to capture a neutron. Hence, the s-process splits into two branches; these special cases are called s-process branch-point nuclei and they are of special interest because they provide information on the stellar neutron density at the s-process site. On the other hand, they are problematic because their (n,γ) cross section is usually not accessible via direct measurements. Three such branch-point nuclei are addressed in this project: 185W, 186Re and 186Os, which are of particular interest due to the Re-Os cosmochronology: the 187Re −187Os pair may be used as a cosmochronometer to determine the duration of the stellar nucleosynthesis before our solar system as formed. However, the existence of the above mentioned branch-points induces complications. Hence an improved determination of the (n, γ) cross-sections for these nuclei is essential. In this conference I will present the newly determined cross-sections of 185,186W(n, γ) reactions which have been constrained using the experimental nuclear level densities and photon strength functions of 186,187W nuclei. These statistical nuclear properties were measured at the cyclotron laboratory of Oslo using 186W(d, X) reactions (where X = p, d, t) and beam energy of 13 MeV.

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High-resolution gamma-ray spectroscopy at Legnaro National Laboratories: the avenue to SPES

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The Legnaro National Laboratories have a long-standing tradition in gamma-ray spectroscopy. They hosted the most recent HPGe arrays, from GASP, one of the first Compton-shielded large HPGe array to AGATA, the first operational tracking array worldwide, that is also planned to be one of the major instrument at the time of the SPES reaccelarated ISOL beams.

In this context, a new resident gamma-ray spectrometer GALILEO has been developed. After a 1-y long commissioning campaign, a physics campaign started. In such campaign, GALILEO has been combined with a light-charge particle and a neutron array, EUCLIDES and NEUTRON WALL, respectively, for the investigation of neutron-deficient nuclei. The first results will be reported and a perspective towards SPES will be given.

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Lifetime measurements in 44Sc excited states using LaBr3 :(Ce) detectors coupled with the AFRODITE array

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The progressive development of the scintillator detectors has made it possible to do perform direct determination of electronic lifetimes. 2” x 2” LaBr₃ :(Ce) detectors provide a combination of excellent time resolution and good energy resolution. With these detectors it is possible to undertake direct lifetime measurements of excited nuclear states down down to hundreds of picoseconds. Six 2” x 2” LaBr₃ :(Ce) detectors were coupled to the AFRODITE array as their first in-beam experiment. AFRODITE consisted of eight HPGe clover detectors as well two 3.5” x 8” LaBr₃:(Ce) detectors. A particle telescope was used to select the desired reaction channel. The reaction of interest ⁴⁵Sc(p,d) ⁴⁴Sc was carried out at a beam energy of 27 MeV. Through this reaction, excited states that have lifetimes which are apt for the characterization of the 2” x 2” LaBr₃ :(Ce) detectors were populated. One of the nuclei of interest in these studies, ⁴⁴Sc, has states with a wide range of lifetimes at low to moderate energies. Various techniques such as the slope method and the centroid shift method have been employed to extract the lifetimes of the excited states. All these endeavours will seek to unveil the quadrupole moment of nuclei and their intrinsic behavior.

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Gamma decay of the isovector giant dipole resonance of ^{90}Zr and its finestructure

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The giant resonance(GR) is a collective mode of nuclei. Our group has researched giant resonances of many kinds of nuclei such as Ca, Zr, Pb with high energy resolution by using Grand Raiden magnetic spectrometer[1]. These days their excitation mechanism, for example sum rule and electric dipole polarizability, is well researched[2]. But the decay mechanism of GRs still has large ambiguity.

Research on gamma decay of GRs can give us its damping information which reflects the nuclear finestructure.

This summer we plan to measure the gamma decay from the IVGDR in ^{90}Zr via $(p, p'\gamma)$ reaction. The experiment will be performed at the Research Center for Nuclear Physics, Osaka University in Japan and make a coincidence between Grand Raiden spectrometer and $LaBr_3$ detectors to catch the gamma ray from thr GDR. 10 nA proton beam which is accelerated to 400 MeV by K400 ring cyclotron will be bombarded to 4 $\mathrm{mg/cm^2}$ thickness ^{90}Zr target. ^{90}Zr is excited by coulomb excitation and we analyze the scattered proton at extreme forward angle including zero degree. The excitation energy acceptance of spectrometer will be 7-33 MeV, which fully covers the bump of the GDR. Since the gamma decay branching ratio to ground state from the GDR is expected to be very small(of the order of 10^{-2}), we need an effective gamma ray detection system. We will use 12 large volume (89 mm ϕ * 203 mm length) $LaBr_3$ detectors which were developed by Milano group[3] and they will cover 30$\%$ of 4pi. It will be the first time in the world to measure the gamma decay of the GDR with high excitation energy precision. In this presentation I will give a talk about the experimental result and discuss about the giant resonance decay physics.

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Study of the Jacobi shape transition in A ≈ 30 nuclei

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The study of exotic Jacobi shapes in nuclei have attracted much attention in recent times [1-4]. The presence of a distinct low energy component around 10 MeV in the giant dipole resonance (GDR) spectrum, originating from Coriolis splitting in a highly deformed rotating nucleus, can be used as a signature of the Jacobi shape transition. The measurement of high energy γ rays from the decay of GDR in 31P nucleus and a self-conjugate α-cluster nucleus 28Si, populated at the same initial excitation energy and angular momenta, was carried out to study the Jacobi shape transition [5]. While the Jacobi shape transition is observed in 31P, the self-conjugate α-cluster nucleus 28Si exhibits a vastly different GDR lineshape characteristic of a prolate deformed nucleus. Based on these observations is 28Si [5] and 32S [6], it is proposed that the nuclear orbiting phenomenon exhibited by α-cluster nuclei hinders the Jacobi shape transition. Further, the present work suggests a possibility to investigate the nuclear orbiting phenomenon using high energy γ rays as a probe.

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NATURE OF PYGMY DIPOLE EXCITATION IN 74Ge

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In recent times, considerable progress has been made in the understanding of isospin nature of the pygmy dipole excitation both experimentally and theoretically. On experimental side, this has been due to advancement of techniques which now make it possible to compare the excitation pattern by probes of different isospin nature [1].

In this conference, we present results of such comparative study done on the pygmy dipole excitation in 74Ge. The pygmy dipole states built on the ground state are excited by the inelastic alpha scattering. The excitation pattern thus observed is compared to that of observed in the photon scattering done on the same nucleus [2]. Experiment for the 74Ge(alpha,alpha')74Ge' reaction was done with the AFRODITE array and a set of two identical charged particle telescopes of square silicon detectors [3]. The results show the presence of two energy regions between 6 to 9 MeV, which adhere to the scenario of the recently found splitting of the region of dipole excitations into two separated parts: one at low energy, being populated by both isoscalar and isovector probes, and the other at high energy, excited only by the electromagnetic probe. Relativistic quasiparticle time blocking approximation (RQTBA) calculations show a reduction in the isoscalar E1 strength with an increase in excitation energy, which is consistent with the measurement. This study may be the first step to learn more about the relation between isospin-splitting and neutron skin.

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TOROIDAL MODE: FROM GIANT RESONANCE TO INDIVIDUAL STATES

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Last years the toroidal dipole resonance (TDR) attracts a high attention [1-4]. This mode is located at the energy of the pygmy dipole resonance and is believed to form the low-energy part of the isoscalar giant dipole resonance. The TDR is the only known dipole {\it vortical} mode in the family of intrinsic electric excitations.Just TDR perhaps generates the pygmy dipole resonance at the nuclear surface region [3]. Last years, various TDR properties were explored by our group within the self-consistent Skyrme Quasiparticle Random-Phase Approximation (QRPA), see review [4].However the TDR still has many open problems and even its experimental observation can be disputed [5].

In this connection, we propose a new route to study the toroidal mode: to switch the effort from TDR (embracing many states and masked by other multipole modes) to {\it individual} well-separated low-energy toroidal states. As was recently shown [6], such states can exist in low-energy spectra of light nuclei with a strong axial prolate deformation. For example, in 24Mg, this state appears as the lowest dipole K=1 excitation. These states can be easier discriminated and identified in experiment than TDR. Being observed, they could serve as excellent test cases to probe various reactions for vortical nuclear excitations. As a first step, we discus the possibility to observe the toroidal individual states in inelastic electron scattering.

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Development of a spectrometry system for measurement of internal-pair studies

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A new approach to studying excited 0^+ states is being introduced at iThemba LABS. It involves the study of low-lying electric monopole (E0) transitions which proceed via internal conversion (IC) and internal pair formation (IPF). Precise measurement of these processes require use of unique tools and techniques, such as an electron spectrometer. An electron spectrometer is currently under development at iThemba LABS, where investigation of its properties is being done both through measurements and simulations using Geant4 code coupled with a magnetic field grid mapped by the OPERA-3D package. Once fully operational, this device will be used to measure nuclear decay via emission of conversion elelctrons or electron-positron pairs.

Measurements of this kind will help in firmly identifying and characterizing the nature of excited 0^+ states in nuclei, for example in the ^{50}Ti nucleus where potential existence of admixtures of 0^+ excited states with 2^+, 3^+ and 4^+ states are still unresolved. Moreover, availability of such a facility will go a long way in availing the most needed experimental data on E0 transitions, which not only provides a thumbprint for shape coexistence in nuclei but also help elucidate phenomena relating to nuclear compressibility and isotope and isomer shift, as well as provide sensitive tests on various models of nuclear structure.

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Enhanced nuclear dipole polarizability and continuity of shell effects in the quasi-continuum of medium-mass nuclei

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Assuming the validity of the Brink-Axel hypothesis, the puzzling low-energy enhancement or up-bend in the photon-strength function of medium-mass nuclides with A ≈ 50 contributes to a substantial induction of the nuclear dipole polarizability in the quasi-continuum region. Revealing shell effects are manifested by drops of polarizability in the ground states of semi-magic nuclei with N = 50, 82 and 128. Similar drops in the up-bend contribution at N = 28 may reflect the continuing influence of shell closures below the nucleon separation energy. The low-energy enhancement for the available heavy nuclei presents, however, a negligible contribution to the nuclear polarizability.

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Evolution to neutron rich isotopes in the fine structure of the Isoscalar Giant Monopole Resonance in 40,42,44,48Ca using alpha inelastic scattering at zero degrees

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Previous studies have shown that fine structure in the excitation energy spectra of nuclear giant resonances can be attributed to different physical processes. For example, characteristic energy scales of the fine structure for the Isoscalar Giant Quadrupole Resonance (ISGQR) arise mainly from the collective coupling of the ISGQR to low-lying surface vibrations, while on the other hand it has been shown that Landau damping is the main mechanism leading to the fine structure phenomenon in the isovector giant dipole resonance. It is important to determine which processes are responsible for the fine structure in the ISGMR, particularly in the 40,42,44,48Ca isotope chain with its systematic increase in neutron number. Moreover, study of the ISGMR is of special significance because knowledge of its centroid energy and width provide direct information on nuclear incompressibility. As part of the longstanding WITS/IKP Darmstadt/iThemba collaborative program on the investigation of properties of Nuclear Giant Resonances, experiments were performed using the Separated Sector Cyclotron of iThemba LABS, together with the K600 magnetic spectrometer using inelastic scattering of 200 MeV alpha particles at zero and four degrees (0o and 4o) from 40,42,44,48Ca for measurements in the region of ISGMR with a good energy resolution of 86 keV (FWHM). In addition, following an autocorrelation analysis, J π = 0+ level densities can also be extracted. Preliminary results will be presented.

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Nuclear polarizability effects at low and high excitation energies

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Virtual excitations are responsible for the polarization of atoms and molecules and give rise to the well-known van der Waals forces between two neutral atoms or molecules, which are far enough apart for the overlap between the wave functions to be neglected. In nuclei, electric-dipole virtual excitations via high-lying states in the giant dipole resonance can also polarize the ground and excited states of nuclei. This polarization phenomenon is a second-order effect in Coulomb-excitation theory and is directly related to the static nuclear polarizability. At low energies, the nuclear polarizability affects quadrupole collectivity in light nuclei more substantially than previously assumed. Here we present Coulomb-excitation reorientation-effect measurements of the first 2+ states in 10Be and 12C together with ab initio calculations, and show how the nuclear polarizability may influence nuclear collectivity at higher excitation energies.

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Giant resonances in Tin-region unstable nuclei

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The equation of state (EoS) of nuclear matter not only governs the femto-scale quantum many-body system, namely nuclei, but also plays an important role in the structure of neutron stars and in supernova phenomena. In particular, the EoS of isospin asymmetric nuclear matter attracts much interest from the viewpoint of the existence of heavy neutron stars. The asymmetric term of incompressibility, K_τ, can be a benchmark for various EoSs because it can be directly deduced from the the energies of the isoscalar giant monopole resonance (ISGMR) measured along an isotopic chain, such as tin isotopes, or isobaric chain. The present value of K_τ is -550$\pm$100~MeV and its error is relatively larger than those of other parameters of the EoS. In order to improve the K_τ value, the measurement on the isotopic chain should be extended to unstable nuclei. A doubly magic tin isotope, ^{132}Sn, has been chosen as a flagship for the measurements of unstable tin isotopes because of its large isospin asymmetry and double magic nature.

The measurement of deuterium inelastic scattering off ^{132}Sn was performed at RIBF in RIKEN. The secondary beam of ^{132}Sn was produced from ^{238}U primary beam and it impinged on an active target system CAT-S based on a time projection chamber with silicon detectors. The CAT-S is filled with 0.4-atm deuterium gas, which is detector gas and target simultaneously. The excitation energy and scattering angle in center-of-mass frame is obtained from the four momentum of beam measured by beam line detector system and the one of recoil measured by CAT-S.

In this paper, I will discuss the giant resonances in ^{132}Sn and its neighboring nuclei together with the current status of systematic measurement of giant resonance in unstable nuclei around ^{132}Sn.

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Novel excitation modes of nuclei using INGA: Results and Opportunities

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Many important properties of nuclei can be inferred from the investigation of their excited states at varying angular momentum. The Indian National Gamma Array (INGA) campaigns at the three accelerator facilities within India have contributed significantly in recent years to such studies. INGA was set up at as a part of a collaboration between BARC, IUAC, SINP, TIFR, UGC-CSR-KC, VECC and different Universities. A long experimental campaign of INGA coupled to a digital data acquisition system has been completed at TIFR-BARC Pelletron Linac Facility at TIFR, Mumbai. About 45 experiments based on proposals from different groups have been completed during the experimental campaign of INGA at TIFR. Selected results related to the novel excitation modes of atomic nuclei from this array will be presented. Finally, we will discuss the plan to augment the INGA program by strengthening the gamma detection facilities and adding new ancillary detector systems.

Acknowledgement: The author would like to acknowledge the support of INGA PICC and the contribution of the INGA collaborators from TIFR, IUAC, BARC, SINP, IUC-DAE-Kolkata centre, VECC, IITs and Universities for the success of INGA campaign at TIFR. This work was partially funded by the Department of Science and Technology, Government of India (No. IR/S2/PF-03/2003-II). We are thankful to the Pelletron LINAC Facility staff for providing excellent beam during all experiments of the campaign.

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Pygmy resonances in the mirror

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The origin of low-energy E1 strength remains an open issue even in the case of stable nuclei. An important question is whether a collective resonance develops (often called pygmy resonance) and accordingly what mechanisms could generate or hinder it. The answer holds particular relevance for predictions about shell structure, the softness of the symmetry energy, phonon coupling, and broad resonances in the continuum.

The majority of related studies, both theoretical and experimental, have focused on neutron-rich nuclei. Here I focus on analyses and predictions for N = 20 isotones [1], which include the stable and symmetric 40Ca and the magic drip-line nucleus 48Ni, and how they compare with their mirror Ca isotopes [2]. The mirror nucleus of the very exotic 48Ni, namely 48Ca, is stable and has been thoroughly studied. The comparisons help one address the role of shell effects and the continuum in determining the strength distribution – see also a related study of Ni isotopes [3]. The models used for this work include pairing (QRPA) or the continuum (CRPA).

Indeed, larger amounts of E1 strength in the asymmetric N = 20 isotones are predicted than the amounts of strength predicted or detected in equally asymmetric Z = 20 mirror nuclei, pointing unambiguously to the importance of structural effects, as opposed to global parameters like absolute asymmetry, in determining the E1 spectrum at low energy. An exotic collective excitation is found most likely in 46Fe but perhaps also in 44Cr and 48Ni. I will show that a correct, converged treatment of threshold transitions (as in CRPA), and therefore of extended wave-functions, is important for the description of proton pygmy states since the proton emission threshold is extremely low. Ongoing investigations focus on the role of the effective mass in the modeling [4].

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From the nuclear EoS straight to nuclear collective motion

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Our understanding of nuclear giant and pygmy resonances translates into an understanding of the nuclear equation of state (EoS) and vice-versa: the incompressibility of nuclear matter determines the energy of the giant monopole resonance (GMR), the symmetry energy and its slope are gleaned from the dipole spectrum, and so on. The most widely used theoretical tool for analyzing such connections is the energy-density functional (EDF), exemplified in particular by the Skyrme model, which provides usefully analytical expressions for the EoS.

After decades of work and hundreds of EDF models, open issues abound: the "fluffiness" of Sn isotopes; the nature of pygmy resonances, let alone their relation to the EoS; the model dependence of the correlation between the dipole polarizability and the symmetry-energy slope. Furthermore, traditional EDF models are plagued by artificial correlations which obscure physical ones. Finally, most available models fail to reproduce reasonably constrained EoS properties.

We have developed a method for extracting a generalized, Skyrme-type EDF for nuclei starting from any given, immutable EoS of homogeneous matter, i.e., with no fine tuning of the latter [1,2]. The scheme takes advantage of a natural Ansatz for homogeneous nuclear matter dubbed KIDS (Korea: IBS-Daegu-SKKU) and basic EDF theory tenets. The parameters which cannot be constrained from homogeneous matter (those encoding the explicit momentum dependence and the spin-orbit force) are fitted to the ground-state energies and charge radii of only 40Ca, 48Ca, and 208Pb, but reproduce the properties of nuclei throughout the nuclear chart successfully, given a realistic EoS. For the first time we find that the above bulk and static nuclear properties do not depend on the effective mass: the model is free of related artificial correlations.
The scheme thus validated can be used to systematically examine the dependence of giant and pygmy resonances on specific EoS parameters. As first applications to report we consider 1) the simultaneous description of the GMR of 120Sn and 208Pb and 2) effects of the symmetry energy parameters on the nuclear response.

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The study of the Pygmy Dipole Resonance at iThemba LABS

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The Pygmy Dipole Resonance (PDR), the low energy part of the electric dipole response in nuclei, is particularly relevant to investigate the nuclear structure and for its connections with photodisintegration reaction rates in astrophysical scenarios. Studies on the PDR are currently almost exclusively focused on spherical nuclei. For deformed nuclei, several theoretical and experimental works have been performed to investigate the response of the Giant Dipole Resonance (GDR) while there are only a few on the PDR.

iThemba LABS, South Africa, is a suitable laboratory for the experimental study of the PDR. The use of the high-energy resolution magnetic spectrometer and an array of γ-ray detectors is a perfect combination to investigate the nature of the PDR. In particular, since very few measurements on the PDR have been performed in deformed nuclei up to now, a research activity was started in 2015 to provide such information. A support was developed to couple the γ-ray detectors (BaGeL − Ball of Germanium and LaBr detectors) with the K600 magnetic spectrometer. The structure was completed in October 2016 and the first K600+BaGeL experiment was performed to study the electric response of 154Sm via inelastic scattering of α particles. The results of this experiment together with those performed using other reaction probes will provide new insights into the role of the deformation in the excitation of the PDR.

A project to increase the γ-ray detection efficiency of the iThemba LABS setup was recently funded by the South African National Research Foundation (NRF). This project consists in the extension of the γ-ray detector array AFRODITE, up to 17 HPGe clover detectors, and in the construction of the African LaBr3:Ce Array (ALBA), an array of 23 large volume LaBr3:Ce. These arrays can be coupled to the K600 spectrometer and silicon arrays for γ-particle coincidence measurements allowing for a new generation of experiments with a much-increased efficiency for detecting γ decay compared to arrays currently available worldwide.

An overview on the PDR in spherical and deformed nuclei will be given in connection with the recent results and future possibility for these studies at iThemba LABS.

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Octupole excitation in super heavy nuclei and J=4 isomeric states in N=100 isotones described by a same QRPA approach

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Known to be well adapted for the description of giant resonances, the QRPA formalism can also, with the same accuracy, describe low energy vibrational states whether with a highly collective or with a single-particle character. The QRPA approach based on the Gogny interaction developed in Bruyères-le-Châtel [1] can be applied to spherical as well as to axially deformed nuclei, from light (i.e. oxygen) to superheavy elements [2]. At the end of the calculation the transition probabilities for the decay of the QRPA excited states toward the ground state are obtained, regardless of the transition multipolarity. In addition, recent developments allow us to study odd nuclei.

In this talk I will present recent successes obtained by the QRPA approach in the reproduction of two experimental findings : octupole excitations around 249Cf [3], and K=4 isomeric states in N=100 isotones [4].

In superheavy odd nuclei our approach is able to produce low energy octupole excitations in agreement with recent experimental data on 251Fm [3]. After specifying some points of the odd system treatment, the octupole electric B(E3) and quadrupole magnetic B(M2) transition probabilities will be discussed with respect to data along the N=150 chain.

Our axially-symmetric-deformed QRPA approach has also been applied to the N=100 isotones in order to describe the J=4 isomeric states. Since calculated half-lives for pure K=4 states are too large by several orders of magnitude, Coriolis coupling between QRPA states has been introduced (4). The formalism related to the induced K-mixing will be explained, and results about the mixing amplitudes in isomeric states will be used to interpret the variation of the lifetime along the isotonic chain (4).

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BRANCHING RATIO MEASUREMENTS OF CLUSTER STRUCTURES IN 18O*

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This talk will outline the current state of the analysis investigating proposed rotational bands in 18O. These bands, some of which are expected to have 12C ⊠ 2n ⊠ α or 14C ⊠ α structures, were proposed to exist by previous measurements at the Maier-Leibnitz Laboratory [1]. To determine the absolute α-particle decay widths of those states, we performed an experiment, also at the Maier-Leibnitz Laboratory. We used a similar set-up,but in addition included an array of silicon detectors. The latter allowed for high-resolution reconstruction of the momenta and energies of decay products, as well as particle
identification.

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Work supported by: STFC (UK)
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Nuclear structure studies relevant to double beta decay of 136Xe

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In addition to establishing the Majorana nature of neutrinos, obtaining the absolute neutrino mass scale is now the focus of several large-scale neutrinoless double beta decay experiments. The current challenge in determining the neutrino mass accurately depends on the calculation of nuclear matrix elements
(NME's) in the select nuclei where these decays can take place. It is well known that the dominating uncertainties in the calculated NME values arise from the model dependence of these calculations.

In this talk, we will present some recent experimental results using high-resolution spectroscopy from 136,138Ba(p,t) and 138Ba(d,a) reactions that will be useful for future NME calculations for the double beta decay of 136Xe -> 136Ba.

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The nuclear symmetry energy and the breaking of the isospin symmetry: how do they reconcile with each other?

Authors: Xavier Roca Maza[None]; Gianluca Colò[None]; Hiroyuki Sagawa[None]

In this contribution, we will analyze and propose a solution to the apparent inconsistency between our current knowledge of the Equation of State of asymmetric nuclear matter, the energy of the Isobaric Analog State (IAS) in a heavy nucleus such as 208Pb, and the isospin symmetry breaking forces in the nuclear medium. This is achieved by performing state-of-the-art Hartree-Fock plus Random Phase Approximation calculations of the IAS that include all isospin symmetry breaking contributions. To this aim, we propose a new effective interaction that is successful in reproducing the IAS excitation energy without compromising other properties of finite nuclei [1].

[1] X. Roca-Maza, G. Colò, and H. Sagawa. Nuclear symmetry energy and the breaking of the isospin symmetry: How do they reconcile with each other? Phys. Rev. Lett. (accepted), 2018.

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Ab Initio Description of Collective Excitations

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The theoretical description of collective excitations in nuclei with all their facets – such as giant resonances, low-lying strength, fragmentation, and fine structure – has been the domain of phenomenological models so far. Only recently, first ab initio methods have been proposed to adress the collective response. These approaches transfer the powerful ab initio tools for ground states and low-lying excitations developed over the past decade to the description of the collective response. In this way, collective phenomena can be explored in the same theoretical framework as low-lying excitations and ground-state observables, using the same state-of-the-art realistic nuclear interactions.

We present an ab initio approach to collective excitations and strength distributions build on the No-Core Shell Model (NCSM), which is one of the standard ab initio methods for the p- and lower sd-shell. We combine it with the so-called Lanczos strength-function method to directly extract the transition strength distribution of various electromagnetic modes. Using different two and three-nucleon interactions from chiral effective field theory, we investigate the electric monopole, dipole, and quadrupole response of the even oxygen isotopes from 16-O to 24-O as well as selected helium and carbon isotopes. This Strength-Function NCSM describes the full energy range from low-lying excitations to the giant resonance region and beyond in a unified and consistent framework, including a complete description of fragmentation and fine-structure. This opens unique opportunities for understanding dynamic properties of nuclei from first principles and to further constrain nuclear interactions. We demonstrate the computational efficiency and the robust model-space convergence of our approach and compare to established approximate methods, such as the Random Phase Approximation, shedding new light on their deficiencies.

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Recent progress in quest of spin and spin-isospin excitations

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I discuss recent progress in quest of spin and spin-isospin excitations by hadron inelastic scatterings, single- and double-charge exchange reactions. One topics is the quenching problem of IS and IV spin excitations. Other topics will be
double Gamow-Teller excitations by double charge-exchange reactions. I will report recent theoretical studies of IS quenching problem in sd-shell nuclei and HFB+QRPA results of double Gamow-Teller excitations.

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Search for γ-transitions from clustered states in 16O*

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An overview of the 12C(α,γ)16O experiment at the University of Birmingham's MC40 cyclotron is presented in this work.

The experimental set-up was a combination of the existing charged particle expertise and capability of the group and the ability to measure the emitted gamma rays using our new LaBr3 detector array. The motivation for this is to measure or put constraints on the B(E2)s for the 16O nucleus. Such observations aid the assignment of rotational levels built on cluster configurations.
This work is part of my PhD research.

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Stellar weak-interaction rates from deformed QRPA calculations

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Weak-interaction rates in several nuclear mass regions are studied in scenarios characterized by densities and temperatures of astrophysical interest. The study includes even-even and odd-A nuclei in the pf-shell region, as well as neutron-deficient and neutron-rich medium-mass isotopes. Nuclei in these mass regions are involved in presupernova formations, in the rapid proton and in the rapid-neutron capture processes, respectively. The weak rates of these selected nuclei, including beta-decay and electron capture, are relevant to understand the late stages of the stellar evolution and the nucleosynthesis of heavier nuclei [1,2].

The nuclear structure involved in the weak processes is described within a quasiparticle proton-neutron random-phase approximation with residual interactions in both particle-hole and particle-particle channels on top of a deformed Skyrme Hartree-Fock mean field with pairing correlations [3].

In a first step, the energy distributions of the Gamow-Teller strength, as well as the beta-decay half-lives are discussed and compared with the available experimental information, measured under terrestrial conditions from beta-decay in the case of the unstable nuclei [4,5] and from charge-exchange reactions in the case of stable nuclei [6]. Subsequently, the sensitivity of the weak-interaction rates to both astrophysical densities and temperatures is studied [7]. Two issues are particularly addressed. First, the relative contribution of thermally populated excited states in the decaying nucleus to the total rates and secondly, the electron captures from the degenerate electron plasma in the star that can modify substantially the electron-capture rates measured in the laboratory.

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Multi-messenger investigation of the Pygmy Dipole Resonance

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Beside the Giant Dipole Resonance (GDR), many nuclei show the feature of additional low-lying electric dipole (E1) strength below and around the particle separation energies, which is usually denoted as Pygmy Dipole Resonance (PDR) [1]. The existence of the PDR in nearly every studied nucleus and the smooth variation of its properties lead to the assumption that the PDR is a newly discovered collective mode. While some of the gross characteristics are reproduced by different theoretical model descriptions, its detailed structure and the degree of collectivity are a matter of ongoing discussions. Most of the so far available experimental data has been obtained in photon induced reactions or coulomb excitation [1]. Photon-induced reactions alone are, however, not sensitive to the structure of the E1 excitations. We have therefore started a campaign to provide additional experimental data using complementary probes or observables. For the semi-magic nucleus 140-Ce we have combined

the results from experiments using the (g,g'), (a,a'g) at E = 134 MeV and (p,p'g) at E = 80 MeV reactions, the letter one is the first time this reaction has been used at this energy to investigate the PDR [2]. In addition, recently the decay properties of the PDR in 140Ce have been determined for the first time with high precision using the novel g^3 setup at HIgS [3]. For each experimental reaction and observable corresponding calculations have been performed within the Quasi-particle Phonon Model (QPM), i.e. all observables are compared simultaneously based on the same wave functions. This multi-messenger investigation provides a comprehensive test of the quality of the theoretical model [2]. The results for 140Ce and an outlook to further investigations will be presented.

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Clustering and vibrations in the time-dependent DFT approach

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Time-dependent nuclear density functional theory (TDDFT) is a well-suited tool to describe heavy ion collisions and nuclear vibrations. Here we present a study of nuclear vibrations and reactions focusing on the aspect of nucleonic clustering in the intermediate states.

Nuclear vibrations are studied in 3D computational box without any symmetry assumptions on an equidistant grid. Usually periodic boundary conditions are considered in those calculations. However those are prone to introduce finite volume effects due to standing waves. A standard way to remedy this finite volume effect is to introduce absorbing boundary conditions altering the dynamics of the system. We demonstrate that by using twist-averaged boundary conditions (TABC), averaging over multiple calculations with different Bloch boundary conditions, one can reduce finite-volume effects drastically without adding any additional parameters associated with absorption at large distances. Moreover, TABC are an obvious choice for time-dependent calculations for infinite systems. Since TABC calculations for different twists can be performed independently, the method is trivially adapted to parallel computing.

To visualize emergent clusters, we use the nucleonic localization function, which is based on the probability of finding two nucleons with same spin and isospin in the vicinity of each other. This measure was originally introduced for electronic structure calculations and was proven to be an excellent indicator for clustering in time-independent nuclear DFT calculations.
We demonstrate that the localization function for the TDDFT solutions of collisions of light and intermediate nuclei reveals a variety of time-dependent modes involving nuclear cluster structures. For instance, the 16O + 16O collision results in a vibrational mode of a quasi-molecular 4He - 12C - 12C - 4He state. For heavier ions, a variety of cluster configurations are predicted.
We conclude that the nucleonic localization is also an excellent measure of clustering in time-dependent simulations and gives important insights into the reaction mechanism. It reveals the presence of collective vibrations involving cluster structures, which dominate the initial dynamics of the fusing system.

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Statistical Properties of 133 Xe and 85 Kr from Inverse Kinematics Reactions.

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The low energy enhancement (LEE) has a potential of increasing the Maxwellian-Average cross sections (MACS) by up to two orders of magnitude. This theoretically predicted effect is pronounced in the mass region towards the neutron drip line. However, to this date there is no experimental data, which proves or disproves the existence of the low energy enhancement in the neutron rich nuclei. This is due to the limitation of the currently existing experimental techniques, which are mostly applicable to the nuclei that are located in the valley of beta stability. In this work we explore the possibility of probing the LEE, neutron rich nuclei, using inverse kinematics experiments and the ratio method of extracting the photon strength function. Thus I will present preliminary results for the 84Kr(d,p)85Kr and 130Xe(d,p)133Xe reactions that were performed at iThemba LABS using the beam energy of 300 MeV.

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Strong neutron pairing in the core+4n 18C and 20C nuclei

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Pairing correlations play crucial roles in atomic nuclei and in quantum many-body physics in general. They are responsible for the odd-even staggering observed in the binding energy of atomic masses, for the fact that all even nuclei have a J=0+ ground state, and for their small moment of inertia as compared to a rigid body. More generally, pairing correlations imply a smoothing of the level occupancy around the Fermi energy surface, an enhancement of pair transfer probabilities, as well as a superfluid behaviour in the nuclear rotation and vibration. Transition from BCS (Bardeen Cooper-Schrieffer) to BEC (Bose-Einstein Condensation) pairing correlations has been evoked from the modelling of the interior to the surface, respectively, of some neutron-rich nuclei.

Recently, the existence of quasi-bound tetra-neutron resonances, formed as an ensemble of four interacting neutrons, was proposed on the basis of experimental results. Even if a quasi-bound resonance would not be confirmed, the coupling of four neutrons can, as for two neutrons, play a significant role inside atomic nuclei to account for its superfluidity. Despite its tremendous importance, the real observation of the decay of paired or tetra nucleons is still lacking or very scarce, as difficult to evidence.

In the present work, we used the high-energy nucleon knockout reactions 19N(-1p)18C*and 21N(-1n)20O* as a 'piston' (possibly via the coupling to giant modes) to suddenly promote neutron pairs of 18C and 20O respectively into the 16C+n+n and 18O+n+n continuum. Dalitz plots and correlation functions are used to analyze triple correlations in these systems over a decay energy up to 12~MeV above the corresponding two-neutron emission thresholds. An attempt is made to link these observables to the role of the reaction mechanism and to the pairing configurations of 18C and 20O, where the four neutrons above the 14C and 16O cores may be coupled in pairs or in tetraneutron configurations.

Future perspectives and preliminary results on similar 2n correlations observed in the unbound 28F nucleus, obtained at the RIKEN-SAMURAI facility, will be also presented, if enough time.

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Role of Tensor Force in Magnetic Dipole Transitions in Cr-52

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Theoretical calculations of spin and orbital components of the M1 dipole strength in ^{52}Cr are made using the Skyrme effective interaction in which the full tensor interaction has been included (Barton and Stevenson, 2018). The tensor terms have a substantial effect on the structure of the strength function, with different tensor strengths resulting in enhancement or suppression of strength at different energies while keeping the overall envelope of strength in the correct region as compared with experiment. We see in particular, strong effects arising from the **s**.**F** term in the Skyrme mean field, which represents a spin-dependent interaction. This term appears to be vital in producing strength in the key region around 8 MeV, yet is usually not included in standard Skyrme force calculations.

(Barton and Stevenson, 2018) M. C. Barton and P. D. Stevenson, submitted to J. Phys. G arXiv:1709.07823

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Recent Results from Proton Scattering Experiments at RCNP

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I will report on the recent results from the proton scattering experiment with the high-resolution spectrometer at RCNP. The talk will cover the following subjects, the relative weights of which depends on the selected aural presentations of the other collaborators.
1) The electric dipole response of nuclei measured by Coulomb excitation: the electric dipole polarizability and the constraint on the symmetry energy parameters.
2) Spin-magnetic dipole excitations in the self-conjugate even-even nuclei in the sd-shell: quenching of the IS and IV spin-M1 strengths, p-n spin-correlation and IS p-n pairing in the ground state.
3) Pygmy dipole resonances and their gamma-decay studies.
4) Gamma-strength functions studied by the excitation from the ground state.
5) Nuclear level densities studied by the spectrum analysis of the high-resolution inelastic scattering data.
6) On going projects and the plans in near future

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Fine and Gross Spectral Features of New Modes of Nuclear Excitations

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The emergence of low-energy dipole strength in nuclei with neutron excess, named pygmy dipole resonance, has triggered a great deal of experimental and theoretical effort.

Despite of many experimental and theoretical evidences for the close relationship between the pygmy dipole resonance and the neutron skin, there is currently no direct method to experimentally extract the neutron skin thickness from the pygmy dipole resonance. This could be related to the fact that at excitation energies below the neutron separation energy the pygmy resonances of dipole or higher multipolarity coexist with a variety of modes, such as the tail of giant resonances and multi-phonon excitations. The question that arises in this connection is how to differentiate the contributions of different origin to the low-energy photoabsorption spectra and in particular the pygmy dipole and giant dipole resonance modes which are supposed to have the largest impact to energy-weighted sum rules. For that purpose, we performed investigations in our theoretical approach which is based on highly advanced microscopic theory incorporating the energy-density functional and extended with multi-phonons quasiparticle-random-phase approximation. The obtained results could clearly separate pygmy resonance mode from other excitations. Of particular interest is the description as well of the fine structure of pygmy resonances. The relation of the latter to nuclear polarizability and symmetry energy and astrophysics is investigated.
Furthermore, energy-density-functional plus quasiparticle-phonon model (EDF+QPM) approach was implemented in first systematic studies of low-energy nuclear quadrupole response in neutron-rich Sn nuclei and it was able to predict a new mode of excitation named pygmy quadrupole resonance. The theoretical predictions within the EDF+QPM theory were further confirmed by independent measurements of low-energy quadrupole states with different probes which allow to identify the pygmy quadrupole resonance. The observed spectroscopic features of the pygmy quadrupole resonance are well described by the theory.

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Stellar carbon-burning via the Trojan Horse Method

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The 12C+12C fusion channel at low energy plays a critical role in astrophysics to understand stellar burning scenarios in carbon-rich environments [1-4]. The temperature for carbon burning to occur ranges from 0.8 to 1.2 GK, corresponding to center-of-mass energies from 1 to 2 MeV. The dominant evaporation channels below 2 MeV are alpha and proton, leading respectively to 20Ne, 23Na. In spite of the considerable efforts devoted to measure the 12C(12C,α)20Ne and 12C(12C,p)23N cross sections at astrophysical energies, they have been measured only down to 2.14 MeV, still at the beginning of the astrophysical region [5]. As known, direct measurements at lower energies are extremely difficult. Moreover, in the present case the extrapolation procedure from current data to the ultra-low energies is complicated by the presence of possible resonant structures even in the low-energy part of the excitation function. For these reasons the Trojan Horse Method [6,7] can represent a unique way for an accurate investigation at the relevant energies. This has been done recently by measuring the 12C(14N,α20Ne)2H and 12C(14N,p23Na)2H three-body processes at 30 MeV of beam energy in the quasi-free (QF) kinematics regime, where 2H from the 14N Trojan Horse nucleus is spectator to the 12C+12C two-body processes. The cross section experiences a strong resonant behaviour with resonances associated to 24Mg levels. As a consequence, the reaction rate is strongly enhanced at the relevant temperatures. Results, which have been recently accepted for publication in Nature, will be presented and discussed.

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Investigating the candidate 5-alpha cluster state in 20Ne at Ex = 22.5 MeV with the 22Ne(p,t)20Ne reaction

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The study of alpha-cluster in light nuclei have been well documented with experimental evidence. In the recent experiment performed at iThemba LABS using (p,t) reaction on 22Ne with the K600 magnetic spectrometer, a tentative candidate for 5-alpha cluster state at 22.5 MeV, which is situated at 3.3 MeV above the 5-alpha break-up threshold was found. However, this state could not be accounted for by theoretical shell-model calculations and angular distribution data taken at forward angles including zero degrees. In the present project, (p,t) reaction on 22Ne has been carried out at zero degrees using the K600 magnetic spectrometer at iThemba LABS in order to confirm the existence of this state. A proton beam with an energy of 80 MeV from the Separated Sector Cyclotron (SSC) facility impinged on a 22Ne gas target at lab angles of zero-dergee was considered. Preliminary results of these experiments will be discussed.

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Evolution of the Electric Dipole Response in the Stable Sn Isotope Chain

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Inelastic proton scattering at very forward angles and energies of a few hundred MeV has been established as a new tool to study the complete E1 response in nuclei in the excitation energy region between about 5 and 25 MeV [1,2]. Such data are crucial to determine the dipole polarizability of nuclei, which in turn provides important constraints on the neutron skin thickness and the Equation Of State (EOS) of neutron-rich matter [3-5]. They also shed light on the much-discussed nature of the Pygmy Dipole Resonance (PDR) observed in nuclei with neutron excess [6-8].

The chain of Sn isotopes represents a particularly interesting case to investigate the impact of the neutron excess on the E1 response of nuclei in a systematic manner because their g.s. structure changes little. We report first results from a systematic study of the stable even-mass nuclei $^{112-124}$ Sn covering n/p ratios 1.24 - 1.48.

Supported by the DFG under contract SFB 1245 and by the JSPS KAKENHI, Grant No. JP25105509.

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The GDR gamma-decay gated by isomers in 188Pt: preliminary results from the PARIS + nuBall experiment

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A study of the γ-decay of GDR formed in a hot compound nucleus will be held in June 2018 at IPN Orsay with the use of the PARIS + nuBall set-up with 18O on 174Yb reaction. It is a very first experiment in which PARIS detectors will be used for this type of measurement and to fully take advantage of these detectors, they will be placed in a non-standard, wall geometry.

The main goal of the experiment is to study a link between characteristics of the compound and residual nuclei by investigating the case of the 192Pt compound nucleus and its 4n decay channel leading to the 188Pt residue. 188Pt is a nucleus known for its ground state prolate shape and high-spin triaxial band, and a simultaneous detection of high- and low-energy γ rays will facilitate measurement of the feeding to both of these deformations. 36 PARIS detectors will be employed to measure high-energy γ rays from the GDR decay, while low-spin discrete transitions measured by 24 clover HPGe and 10 coaxial Ge detectors of nuBall will be used for gating on the decay paths of choice.

During the talk, the setup will be presented in detail along with the method of analysis. A special emphasis will be put on the analysis of the PARIS part of the data. Very preliminary results will be shown as well.

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Opportunities in nuclear science and applications at iThemba LABS

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iThemba LABS has embarked on an extensive renewal and enhancement program with the ultimate aim to provide our users with competitive and state-of-the air research facilities for nuclear physics experiments. During the presentation I will provide an overview of the facilities of the Department of Subatomic Physics at iThemba LABS. In particular, I will focus on the latest developments to improve the high-energy neutron beam facility, the K600 spectrometer and the status of the ALBA and AFRODITE gamma-ray arrays.
I will highlight some of the ongoing and future measurements which are possible with the improved detection systems. These measurements include, but are not limited to, the pygmy and scissors resonances, gamma-decay from giant resonances, photon strength functions and electron spectroscopy.

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Search for new E1 states in neutron rich nuclei around neutron separation energy

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Recently new experiments using fast radioactive beams and the highly efficient gamma detection arrays AGATA and DALI2 gave new results on the search for new E1 excitations around the threshold in neutron rich isotopes. Results will be presented together with an outlook for forcoming experiments combining different target and arrays.

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Analog pygmy-dipole resonance and low-lying charge-exchange dipole state in neutron-rich nuclei

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Response of atomic nuclei to external fields reveals the occurrence of a variety of modes of excitation, and the quest for unique modes of excitation in exotic nuclei has been a major subject in nuclear physics. The low-energy dipole mode or the pygmy dipole resonance (PDR) has been a central issue for its collectivity and the correlation with the neutron skin thickness.

The isovector (IV) dipole modes can be excited by the charge-exchange reactions as well. Then, the investigation of the IV modes not only in the Tz = 0 but Tz = 1 and -1 excitations could lead us to a deeper and universal understanding of the character and structure of the excitation modes, such as the isospin character of the PDR.

In this talk, I will discuss the possibility of the emergence of the low-lying charge-exchange dipole modes uniquely in neutron-rich nuclei based on nuclear density functional theory. Furthermore, I will discuss the deformation effects on the charge-exchange dipole resonances to try to generalize the deformation splitting mechanism seen in the Giant Dipole Resonance.

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Production of conversion-electron sources

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Two solenoid electron spectrometers were donated to iThemba LABS by Orsay in France. These lens spectrometers are currently under refurbishment. They will be used to study higher energy electrons which results from internal conversion (IC) process, a process whereby an atomic nucleus emits an electron instead of γ−ray emission. This process can only occur between two 0+. An emitted electron may come from the K, L1 and L2 shell depending on the transition energy. IC is an important component of most nuclear decay schemes. In order to balance decay schemes correctly, one needs to know the internal conversion contribution to each transition as expressed by its internal conversion coefficient (ICC). The two spectrometers will be used for experiments, both standalone and used with the tape station.
Measurements of IC and ICC around Z≈50 have been conducted for the past few decades [e.g. ref.1, 2]. Unfortunately, over the decades, tabulated ICC values have differed significantly from one calculation to another by a few percent. Although for many applications such differences can be tolerated, transitions used in critical calibrations require very precise and accurate ICC values 1. E0 transitions (which result from IC) are a sensitive indicator of structure in nuclei, reflecting shape transitional regions, deformation, and intruder states.
In order to expand knowledge of IC and ICC around Z≈50 region, a set of different nuclei which emit conversion-electrons will be produced. Such sources will be used to characterise the lens. The sources of interest are 120Sb, 169Yb and 109Cd. Furthermore, basic research in conversion-electron spectroscopy with short-lived sources will be conducted. This will also help to investigate the applicability of this method in production of sources at iThemba LABS using the RERAME facility.

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Recent progress in experimental studies of the Pygmy Dipole Resonance

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In the last years it has become obvious that a combination of different experimental approaches is necessary to understand the structure of electric dipole strengths in atomic nuclei (see, e.g., refs. [1-12]) and to be able compare it to theoretical models. Due to the high level density in the energy region of interest, a selective excitation mechanism selective spectroscopy are key requirements of the experiments. In this talk the most recent results of experiments using bremsstrahlung and monoenergetic photon beams, medium-energy and low-energy hadronic probes will be discussed.

Supported by the DFG (ZI 510/7-1).

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