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NUCLEAR STRUCTURE: A UNIFYING PERSPECTIVE

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The quest of nuclear structure study is a unified view of the nuclear quantum mechanical many-body problem. A major step in this direction was taken 70 years ago with the Shell Model in the form of an independent-particle model. With residual interactions, this model has had enormous success that continues until today. However, nuclei are dominated by correlations, both deformation producing and so-called pairing: these lie beyond independent-particle behavior. The shell model can only reproduce nuclear transition rates with effective charges, which obscure how the nucleus self-organizes to achieve this. A presentation will be made that focuses on key data that constrain models for describing emergent collectivity.

MULTI-SPECTROSCOPIC INVESTIGATION OF ^{98}Ru AND SHAPE COEXISTENCE IN THE Ru ISOTOPE CHAIN

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The Ru isotopes with N<60 have often been interpreted within the spherical vibrational picture, and there exists a transition in the ground state structure with a well-deformed nature at N=62. Since examples of shape coexistence are abundant in this region, it is natural to expect it to occur in the Ru isotopes also; however, this is not well stablished. Recent work [1] suggested a crossing of configurations occurs between N=56 and N=58 and that the mixing is somewhat strong, in contrast to that which occurs in the well-established cases of shape coexistence in, e.g., Zr.

In order to investigate the structure of the Ru isotopes with N<60, we have initiated a program of detailed studies with multiple techniques. Excited states of ^{98}Ru were studied via beta decay of ^{98}Rh at iThemba LABS and the ^{100}Ru(p,t) reaction using the Q3D spectrograph at the Maier-Leibnitz Laboratory. States in ^{100}Ru were studied with the ^{102}Ru(p,t) and ^{103}Rh(p,alpha) reactions, and ^{102}Ru via Coulomb excitation with a ^{12}C beam, and the ^{103}Rh(d,3He) reaction. Selected results of these studies, and the insight they provide on the structure of the Ru isotopes, will be given.

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SYSTEMATICS OF ODD-Au ISOTOPES

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Excited states of odd-mass nuclei can be used as a powerful tool for studies of nuclear structure. Odd particle or hole serves as an observer of the even-even core. Order and energies of excited states yield information on core deformation; both axial and triaxial. In particular, low-spin states are sensitive to the triaxial parameter. However, they are very rarely observed in in-beam studies, because of their non-yrast character. In the talk, results on experiments performed at CERN-ISOLDE facility, University of Jyväskylä, and at iThemba Labs will be presented. Extensive systematics of excited states of odd-Au isotopes will be discussed. Several interesting issues related to this systematics will be presented in a detail.

LASER- AND DECAY-SPECTROSCOPY STUDIES OF LIGHT GOLD ISOTOPES AT ISOLDE

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The shape of the nucleus is one of its most fundamental properties. The interplay between the stabilising effects of shell closures and residual interactions between protons and neutrons gives rise to nuclear shape coexistence [1]. This phenomenon has been observed throughout the nuclear landscape. In particular, the neutron-deficient isotopes surrounding the Z=82 shell closure have proven a hot bed of coexisting structures.

In this talk, the results from laser- and decay-spectroscopy studies of gold (Z=79) isotopes will be presented. These measurements rely on the high sensitivity achieved by combining in-source laser resonance ionization spectroscopy, ISOLDE mass separation, the Windmill system [2], the Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF) [3], and the ISOLDE Decay Station (IDS) [4]. The results show an end to the region of well-deformed ground states and a return to sphericity in the lightest gold isotopes.

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COULOMB-EXCITATION EXPERIMENTS WITH THE Q3D SPECTROMETER AT MLL

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Coulomb excitation is a well-established method to investigate electromagnetic properties of low-lying excited states in atomic nuclei. The measured excitation cross sections can be directly related to *E2* and *E3* transition strengths, as well as to quadrupole moments of short-lived excited states, without any nuclear-model assumptions required. The first Coulomb-excitation experiments were performed in the 1950s, employing only particle spectroscopy. The advent of high-resolution gamma-ray spectroscopy in the 1970s enabled complex multi-step Coulomb-excitation studies of deformed nuclei, and the possibility to perform Coulomb-excitation experiments without gamma-ray detection has almost been forgotten. They still represent, however, an interesting alternative to the more popular gamma-particle coincidence measurements, especially for nuclei with low level density. I will present preliminary results of our recent experimental campaign with the Q3D magnetic spectrometer at Meier-Leibnitz Laboratory in Munich, with a focus on octupole and quadrupole collectivity in Zr isotopes.

LOW-ENERGY COLLECTIVITY IN ^{110}Cd STUDIED WITH COULOMB EXCITATION

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The even-mass Cd isotopes near mid-neutron shell were traditionally considered as the textbook examples of near-harmonic vibrational behavior. This widespread belief was based on the observed pattern of their low-lying excited states. The perspective was, however, complicated by large values of the quadrupole moments of the excited states in ^{114}Cd and the appearance of low-lying shape-coexisting intruder states. A fundamental question appears regarding the nature of collectivity of low-lying states, particularly 0^+ states in Cd nuclei, that were invariably interpreted as multi-phonon structures. Multi-step Coulomb excitation can provide essential data to advance our understanding of the nature of such low-energy states. Recently, ^{110}Cd has been Coulomb-excited with a ^{32}S beam at the Heavy Ion Laboratory in Warsaw. The first results from this measurement will be presented concerning electromagnetic properties of low-lying 0^+ states in ^{110}Cd and their deformation. These experimental findings will be compared to the most recent beyond-mean-field and general Bohr Hamiltonian predictions. Perspectives concerning multi-step Coulomb excitation measurements at LNL and HIL will be outlined.

COULOMB-EXCITATION AND BETA-DECAY STUDIES OF ^{104,106}Mo AT CARIBU WITH THE NEW EBIS

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Collective shape degrees of freedom have been a major direction in the study of the nuclear finite many-body problem for over 50 years. There is widespread evidence for quadrupole deformations, primarily of large prolate spheroidal deformation with axially symmetric rotor degrees of freedom. This naturally leads to the question of whether or not axially asymmetric rotor degrees of freedom are exhibited by any nuclei, with the implication of triaxial shapes. With respect to best cases for observation of triaxial shapes near the ground state, two regions stand out. The first is the Os-Pt region and the second is the neutron-rich Mo-Ru region, where low-energy 2_{2+} states are consistent with such an interpretation. Furthermore, the neutron-rich Mo-Ru region is expected to undergo a relatively rare instance of prolate-to-oblate shape evolution. Recent results from Coulomb-excitation and beta-decay studies of neutron-rich Mo-Ru isotopes will be presented. These experiments were conducted at the CARIBU-ATLAS facility of ANL using GRETINA-CHICO2. A survey of the equipment, techniques, and results will be presented. In addition, a comparison of ^{106}Mo Coulomb-excitation data with the old ECR and new EBIS ion sources will be highlighted.

COULOMB EXCITATION OF Rn ISOTOPES IN THE REGION OF LARGE OCTUPOLE COLLECTIVITY

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Reflection-asymmetric nuclei are of considerable interest for the understanding of nuclear structure, which arises as a consequence of strong octupole correlations which occur when states with $\Delta j=\Delta l=3\hbar$ lie close to the Fermi surface for both neutrons and protons. Octupole correlations are largest in the region with Z=88 and N=134. The Z=86 Radon isotopes lie close to the centre of the octupole-deformed region, but are difficult to study experimentally. Excited states have been identified in ^{222}Rn (N=136), forming an alternating-parity octupole band, but no states had been previously observed in the heavier isotopes. Unambiguous and direct evidence of octupole correlations can be obtained from a measurement of the electric octupole (*E3*) moment. An experiment has been performed using the MINIBALL spectrometer at ISOLDE to investigate the *E3* moment of some Ra and Rn nuclei. Excited states were populated via Coulomb excitation of post-accelerated Rn isotopes at 5MeV/A. Analysis of the intensities of transitions using the multiple Coulomb-excitation code GOSIA will provide a direct measurement of both electric quadrupole and octupole moments. The status of this work will be presented.

ENERGY OF THE ^{229}TH NUCLEAR CLOCK TRANSITION

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The first nuclear excited state in ^{229}Th- (called ^{229m}Th) has the lowest excitation energy of all known nuclear states.

The energy of only 7.8 ± 0.5 eV and its long lifetime make it a promising candidate for a nuclear optical clock. The large uncertainty in the excitation energy, however, impeded progress towards nuclear laser excitation. For this reason, the objective of the presented experiment is a precise determination of the ^{229m}Th excitation energy via internal conversion electron spectroscopy.

The concept and possible applications of a nuclear optical clock as well as a first direct energy measurement will be presented. In these experiments the energy of the isomer was to 8.28 ± 0.17 eV.

E0 TRANSITIONS IN MASS 12 TO 56 NUCLEI THROUGH PAIR CONVERSION SPECTROSCOPY

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Electric monopole (*E0*) transitions are sensitive tools to map out nuclear states with very different deformation at relatively low energies. For low mass nuclei excited 0^+ states are at several MeV above the ground state and internal pair conversion is the only way to characterise *E0* transitions. In this talk I will review selected examples of a research program at the ANU to study a range of nuclei where *E0* transitions are observed from states with very different configuration, including the Hoyle state in ^{12}C, superdefomation (^{40}Ca, ^{24}Mg) and shape co-existence ($^{50,52}Cr$ and $^{54,56,58}Fe$).

EXPERIMENTAL AND THEORETICAL STUDY OF BETA AND ELECTRON CAPTURE DECAYS IN THE CONTEXT OF RADIONUCLIDE METROLOGY

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Atomic and nuclear decay data of high-precision are mandatory for radionuclide metrology and are of importance in a wide range of communities, from fundamental research to nuclear medicine and nuclear energy industry. A novel experimental technique, metallic magnetic calorimetry, has been successfully adapted to measure low-energy beta and electron capture emissions in the last few years. Several high precision measurements of beta spectra have put strong constraints on the calculation of beta decays, highlighting an important discrepancy compared with the usual theoretical predictions. In addition, an experimental device based on silicon detectors is being developed for higher energies.

A specific code for calculating beta spectra, named BetaShape, has been developed to accurately account for the atomic effects, leading to excellent agreement with the measurements. A first simplified version of this code, including a database of experimental shape factors, was released few years ago. Recently, the calculation of electron capture decay has also been addressed. These recent achievements and ongoing work about the inclusion of nuclear structure are presented in detail.

High precision electron spectroscopy of Auger and conversion electrons and recent results of modelling Auger electrons from medical isotopes

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We have studied the low energy electron spectrum from the decay of ^{125}I, one of the commonly used radioisotopes with high resolution electron spectrometers. The measurement of the ratio of the conversion to Auger electron yields allowed to test transition rates from EADL. The observed line shapes also allowed to study secondary effects, like shake-off or the atomic structure effect.

With the development of a new semi-empirical correction the calculated Auger energies are much closer to measured ones, allowing a realistic description of the full espectrum from ~100 eV energy and higher.

RECENT RESULTS AT THE VITO BEAMLINE

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Located at ISOLDE, CERN, the VITO beamline is dedicated to providing spin polarized radioactive nuclei for various research topics. After polarization, the nuclei are implanted into a sample from which the resulting beta-activity is measured in opposing directions. The asymmetry in the detected beta counts is proportional to the degree of polarization. By applying a dipole excitation to the sample using an RF coil and detecting at which frequency the polarization is resonantly destroyed, the properties of the implanted nuclei and the environs can be probed. This technique, beta-NMR, is up to 10 orders of magnitude more sensitive than conventional NMR.

The recent highlights that will be presented in this contribution are, among others, the most precise measurement of the magnetic moment of ^{26}Na to date and the first successful polarization scheme of ^{35}Ar using lasers. The first result illustrates a 100 fold improvement in precision as compared to conventional measurements. The second features the first application multi-frequency optical pumping at ISOLDE in order to demonstrate the first direct polarization of a noble element using lasers.

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Neutrinoless Double Beta Decay and Nuclear Structure

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The present-day results of the calculation of the $0\nu\beta\beta$-decay nuclear matrix elements (NMEs) are discussed. Subject of interest are the accuracy and reliability of calculated NMEs associated with different neutrino mass mechanisms of the $0\nu\beta\beta$-decay. A connection between the $2\nu\beta\beta$-decay and $0\nu\beta\beta$-decay matrix elements is analyzed. A possible progress in the calculation of the double beta decay NMES within the QRPA approach is outlined and supported by the studies performed within schematic models. An impact of the quenching of the axial-vector coupling constant on double-beta decay processes is investigated and a novel approach to determine quenched value of gA is proposed.

STRUCTURE OF β-DECAY STRENGTH FUNCTION $S_{\beta}(E)$, SU(4) REGION AND QUENCHING OF AXIAL-VECTOR WEAK INTERACTION CONSTANT IN HALO NUCLEI

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In heavy and middle nuclei the energy of Gamow-Teller (GT) resonance (GTR) is larger than the energy of isobar-analogue resonance (IAR), EGTR > EIAR [1,2]. One of the consequences [3,4] of Wigner's spin-isospin SU(4) symmetry is EGTR=EIAR. SU(4) symmetry-restoration effect induced by the residual interaction, which displaces the GTR towards the IAR with increasing (N-Z)/A. In ^{6}Li nucleus [5] for low energy super-GT phonon [6] or GTR (experimental GT strength B(GT)=7.630gV2/4π) we have EGTR - EIAR = -3562.88 keV. In ^{11}Be nucleus for low energy (E=18.19 MeV) super-GT phonon or GTR (experimental GT strength B(GT) = 23gV2/4π) we have EGTR - EIAR = -2.97 MeV. Using these data and data about EGTR - EIAR from [1,2], we estimated that the value Z/N = 0.5 – 0.6 corresponds to the region, where EGTR ≈ EIAR, i.e. SU(4) region [5].

Resonance structure of the $S_{\beta}(E)$ for GT β-decay in halo ^{6}He and ^{11}Li nuclei is analyzed. The free-nucleon value of axial-vector weak constant gA is well known from neutron β-decay data: gA/gV = - 1.2723(23), (gA/gV)2= 1.6187. Inside nuclear matter value of gA is effected by many nucleon correlations [7] and quenched or enhanced value of gAeff might be needed to reproduce experimental data. Compare experimental total strength for β-transitions in gV2/4π units with the Ikeda sum rule in (gAeff)2/4π units, one can determine [1,2] the ratio of squared axial-vector and vector weak interaction constants value (gAeff /gV)2. We obtained that (gAeff /gV)2 = 1.27 ± 0.01 for ^{6}He β--decay, and (gAeff /gV)2 = 1.5 ± 0.2 for ^{11}Li β--decay.

Quenching of the weak axial-vector constant gAeff in halo nuclei is discussed.

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MICROSCOPIC ANALYSIS OF QUASIELASTIC SCATTERING AND BREAKUP REACTIONS OF NEUTRON-RICH NUCLEI $^{12,14}Be$

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A microscopic analysis of the optical potentials (OPs) and cross sections of quasielastic scattering of $^{12,14}Be$ on ^{12}C at 56 MeV/nucleon and on protons at energy near 700 MeV is carried out. The real part of the OP is calculated by a corresponding folding procedure and the imaginary part is obtained on the base of the high-energy approximation. The neutron and proton density distributions computed in different microscopic models for ^{12}Be and ^{14}Be are used. In the hybrid model developed and explored in our previous works, the only free parameters are the depths of the real and imaginary parts of the OPs obtained by fitting the experimental data. The role of the inelastic scattering channel to the 2^+ and 3^- states in ^{12}C when calculating the quasielastic cross sections, as well as the modified density of the ^{12}C target accounting for the surface effects are studied. In addition, the cluster model, in which ^{14}Be consists of a *2n*-halo and the ^{12}Be core, is applied to calculate the cross sections of diffraction breakup and stripping reactions in ^{14}Be + ^{12}C scattering and longitudinal momentum distributions of ^{12}Be fragments at energy of 56 MeV/nucleon. A good agreement of the theoretical results with the available experimental data of both quasielastic scattering and breakup processes is obtained.

RECENT PROGRESS ON TRANSVERSE WOBBLING

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The wobbling mode generally appears in the asymmetric top [1]. It is a clear evidence that the three moments of inertia are different. Transverse wobbling (TW) is a novel version thereof unique to triaxial nuclei [2]. It originates from the presence of large quasiparticle angular momentum. Most of wobbling bands are found in odd-proton nuclei. In this talk, I will introduce the very recent progress on the TW bands in the odd-neutron nucleus ^{105}Pd [3], and on the two-quasiparticle TW bands in the even-even nucleus ^{130}Ba [4].

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RECENT NUCLEAR STRUCTURE STUDIES AT IGISOL IV

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A fourth generation of IGISOL-facility in the Accelerator Laboratory of University of Jyväskylä has been used for variety of nuclear structure studies by applying decay spectroscopy, laser spectroscopy and precision mass measurements. In this presentation, some examples of the recent investigations are discussed and the latest hardware upgrades are presented.

The MARA low-energy branch (MARA-LEB)

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The MARA low-energy branch (MARA-LEB) [1,2] is a novel facility currently under development at the University of Jyväskylä. Its main focus will be the study of ground-state properties of exotic proton-rich nuclei employing in-gas-cell and in-gas-jet resonance ionisation spectroscopy and mass measurements of nuclei close to the N=Z line.

MARA-LEB will combine the MARA vacuum-mode mass separator [3] with a gas cell, ion guide system and a dipole mass separator for stopping, thermalising and transporting reaction products to experimental stations. The gas cell has been designed and built based on a concept developed at KU Leuven [4].

Laser ionization will be possible in either the gas cell or the gas jet. For this, a dedicated set of Ti:Sa laser systems will be available. The mass measurements will make use of a RFQ cooler buncher and MR-ToF [5], to be installed at the end of the transfer line.

In this contribution, we will outline the current status of the MARA-LEB facility, including simulation work of the RF ion guides and the ion optics for the transfer line.

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[2] P. Papadakis et al., AIP Conf. Proceed. 2011, 070013 (2018).
[3] J. Uusitalo et al., Acta Physica Polonica B, 50 (3), 319-327 (2019)
[4] Yu. Kudryavtsev et al., Nucl. Instr. and Meth. B 376, 345 (2016).
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DECAY SPECTRO HIGHLIGHTS FROM THE 2nd GRETINA CAMPAIGN AT ATLAS

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The GRETINA spectrometer has completed it is second campaign at the ATLAS facility at Argonne National Laboratory. The detector was placed at the target position of the Fragment Mass Analyzer (FMA), a vacuum mode recoil spectrometer. Measurements were performed where the detector was coupled to the FMA, to study proton rich and light nuclei, the CHICO II array to study nuclei via Coulomb excitation and multi-nucleon transfer reactions using both stable and radioactive ion beams, and to the GODDESS array for the study of direct reactions. In this talk, I will give a summary of the GRETINA program at ATLAS and present some selected results. In addition, I will give an update on GRETA, the 4π version of GRETINA.

SCOPY OF DEFORMED, NEUTRON-RICH NUCLEI USING THE X-ARRAY AND GAMMASPHERE

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The structure of deformed, neutron-rich nuclei in the rare-earth region is of significant interest for both the nuclear-structure and astrophysics fields. Although much progress is being made in our understanding of the r-process, a satisfactory explanation for the elemental peak in abundance near A=160 is still elusive. Understanding the origin of this peak may be a key to correctly identifying the astrophysical conditions for the r-process. Theoretical models of element production are dependent on masses and lifetimes of neutron-rich, deformed rare-earth nuclei in this region where little or no information is known. The available nuclear structure information is also scarce, owing to difficulties in the production of these nuclei.

In order to address these issues, an experimental program has been initiated at Argonne National Laboratory using high-purity radioactive beams produced by the CARIBU facility. Mass measurements using the Canadian Penning Trap (CPT) and beta-gamma coincidence studies using the SATURN moving tape system and the X-Array spectrometer, comprising of five Ge clover detectors, were carried out. A number of two-quasiparicle isomers were discovered in odd-odd nuclei using CPT and in several cases their properties were elucidated by complementary beta-decay studies. Evidences were found for changes in the single-particle structure, which in turn resulted in the formation of a sizable sub-shell gap at N=98 and large deformation.

Results from these measurements will be presented, together with predictions based on deformed shell model that includes effects of pairing and spin-depended, nucleon-nucleon interactions. The newly-commissioned beta-decay station at Gammasphere will also be discussed and results from the first experimental campaign will also be presented.

STUDIES OF ISOSCALAR COLLECTIVE EXCITATIONS USING ACTIVE TARGETS

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The isoscalar giant monopole resonance (ISGMR) measures the collective response of the nucleus to density fluctuations. The energy of this resonance is connected to the incompressibility of the nucleus, which, in turn, can be linked to the incompressibility of the infinite nuclear matter, an important ingredient of the nuclear-matter equation-of-state (EOS). The EOS plays an important role in the description of heavy-ion nuclear collision, the collapse of the heavy stars in super novae explosions and the description of neutron stars. The 20% uncertainty of the currently accepted value of the incompressibility of nuclear matter is largely driven by the poor determination of the EOS isospin asymmetry term. To improve upon the precision of this term, experimental measurements of isoscalar monopole modes are being carried out on isotopic chains, extending from the nuclei on the valley of stability towards exotic nuclei with larger proton-neutron asymmetry.

The isoscalar resonances are excited through low-momentum transfer reactions in inverse kinematics, that require special detection devices. At present, promising results have been obtained using active targets. Different measurements have been conducted on Ni isotopes far from stability: ^{56}Ni [1,2], ^{68}Ni [3,4]. In particular, the ^{68}Ni experiment is the first measurement of the isoscalar monopole response in a short-lived neutron-rich nucleus using inelastic alpha scattering. The ISGMR was found to be fragmented, with a possible indication for the soft monopole resonance.

To complete these results, a new experiment to study the isoscalar monopole modes in ^{68}Ni was be performed at LISE facility (GANIL) in July 2019, using inelastic scattering of alpha particles in inverse kinematics. For this measurement, the new generation active target ACTAR-TPC, able to guarantee better efficiency and resolution, was used. Preliminary results of these measurements will be discussed during the talk, together with an overview of future plans.

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IMPACT OF NUCLEAR MASSES ON THE CORE-COLLAPSE SUPERNOVAE SCENARIO

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Core-collapse supernova (CCSN) simulations are extremely sensitive to microphysics ingredients (nuclear and neutrino physics). The two main nuclear physics ingredients of these simulations are the equation of state and the electro-weak interaction rates (beta decay and electron capture).

The electron-capture process in particular governs the neutralisation of matter and determines the position of the formation of the shock wave, which ultimately leads to the explosion. The electron-capture rates depend in an important way on the composition of matter. The latter can be calculated using extended Nuclear Statistical Equilibrium (NSE) models. The NSE models depend in a crucial way on the masses of the different nuclei and are almost insensitive on the other nuclear and astrophysical inputs. In summary experiments dedicated to measure and to improve the masses and the electron-capture rates are mandatory for the study of core-collapse supernovae.

Last sensitivity studies identified the nuclei whose electron-capture rate play the most important role during the collapse phase. These nuclei are located close to the neutron dripline around ^{78}Ni and ^{128}Pd, thus around shell closures (N=50 and N=82 respectively).

In November 2017, new mass measurements of neutron-rich nuclei located around ^{78}Ni was realized with the JYFLTRAP Penning trap mass spectrometer at the IGISOL facility. Results from this experiment and the impact of mass models on the core-collapse scenario will be presented and discussed.

DECAY SPECTROSCOPY OF ISOTOPES ABOVE FERMIUM (Z>100)

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The single-particle level structure is a crucial factor for the stability and decay properties of the heaviest nuclei. However, experimental data are rather scarce in this region. New results serve as an important anchor for theoretical predictions and a possibility to predict the stabilized regions for super-heavy elements.

We carried an extensive study aimed at the nuclear structure of isotopes above fermium (Z>100) using alpha-CE, alpha-gamma and CE-gamma spectroscopy at the velocity filter SHIP in GSI Darmstadt. Besides alpha-decay spectroscopy, we also performed very first beta-decay studies in this region of nuclide chart.

The most recent results for selected isotopes in very heavy element region will be discussed. In particular, the observation of new multi-quasi particle isomers in ^{255}Rf, the very first EC-decay data for ^{258}Db and ^{254}Md will be presented. The opened questions related to decay systematics of odd-Z isotopes and possibilities for its future studies will be addressed, too.

INVESTIGATION OF β-DELAYED FISSION OF ISOMERS IN ^{188}Bi EMPLOYING ISOMER-SELECTIVE LASER IONIZATION

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In a β-delayed fission (βDF) process, an excited state populated via β decay (typically with E* < 10 MeV) undergoes fission. It represents so called low-energy fission, which is sensitive to structure of the nucleus. This phenomenon opens possibilities to study low-energy fission of exotic isotopes, for which other approaches would be extremely difficult or currently impossible [1].

This contribution will report on results of the βDF study of ^{188}Bi performed at ISOLDE (CERN). We employed isomer-selective laser ionization by RILIS and time gating to separate two long-lived isomers present in ^{188}Bi. Thus, in contrast to previous studies [2], we were able to investigate βDF of each isomer separately and evaluate their βDF partial half-lives and probabilities. For the high-spin isomer, mean total kinetic energy and fission fragment mass distribution were also deduced. The results will be compared to theoretical calculations within the HFB and QRPA [3] frameworks and to other results in this region of nuclear chart.

[1] A. N. Andreyev et al., Rep. Prog. Phys. 81, 016301 (2018).
[2] J. F. W. Lane et al., Phys. Rev. C 87, 014318 (2013).
[3] M. Martini et al., Phys. Rev. C 89, 044306 (2014).

Monopole decays and resonance studies at iThemba LABS

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The nucleus can exhibit a variety of shapes and configurations both in its ground state and when excited. For a nuclear system with nucleons in configurations such that the total spin is paired to zero, these form literally the foundations for how the nucleus takes its form. These 0^+ states, namely the excited states, have only a few well categorised examples in the whole nuclear landscape. The nature of the large number of 0^+ states which have to date been identified is unknown, partly due to the theoretical models used to interpret them, but moreover the lack of experimental measurements yielding further information.

An assessment of the connection between strong *E0* transitions and shape coexistence and elementary models of nuclear structure was done across the entire mass nuclear surface which elucidate how that much of the *E0* transition strength is associated with shape mixing. This is also borne out in the large collective modes in nuclei of the Giant Resonances at higher energies and frequencies.

Electric monopole (*E0*) studies at iThemba LABS have been recently started using in-beam reactions an electron spectrometer. The spectrometer coupled with an array of fast-timing detectors and Low energy photon spectrometers (LEPS) has been successfully commissioned and measurements of conversion coefficient and monopole strength parameter in ^{72}Ge and ^{72}Se determined from electron-gamma coincident measurement by ^{70}Ge(α,α') reaction.

For the study of higher-lying 0^+ states, the adaptation of the spectrometer to use a thick (10 mm) segmented Ge detector for detection of internal-pairs. GEANT4 simulations have been undertaken for the spectrometer, coupled to magnetic fields.

Highly excited states in nuclear matter must be accessed through a different portal. Studies of isoscalar giant monopole resonances will decay through electron-positron pairs in the energy range 10-20 MeV. The coincident measurement over this modest energy with good efficiency is planned through a refurbishment of a 4π dilepton spectrometer at iThemba LABS.

Coupling of both the spectrometers will be integrated into the K600 spectrometer at iThemba LABS operating in the 0-degree mode. Furthermore, when combined with other detectors, such as ALBA, utilising high detection efficiency for high-energy gamma-rays, then a unique niche area of physics is feasible.

Results of these measurements will be presented together with future plans for the spectrometers and further studies.

COMBINED IN-BEAM γ-RAY AND CONVERSION ELECTRON SPECTROSCOPY

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In-beam spectroscopic techniques have long been one of the most prominent tools in our effort to disentangle and interpret complex nuclear structure phenomena. A wealth of information has been collected using γ-ray and conversion electron spectrometers independently. However, when used separately they can provide only partial information of the nuclear de-excitation processes and consequently of nuclear structure. This becomes increasingly problematic in heavy nuclei, especially at low transition energies and high multipolarities, where internal conversion increasingly competes with γ-ray emission. In the last decade there has been increased interest in the development of high-efficiency combined γ-ray and conversion electron spectrometers for in-beam use. In this presentation we will focus on two such devices.

The SAGE spectrometer [1] operating at the Accelerator Laboratory of the University of Jyväskylä, allows efficient cross-coincidence measurements between γ rays and conversion electrons in stable-ion beam experiments. It combines the JUROGAM germanium-detector array with a highly segmented silicon detector and a solenoid electron transfer system. SAGE can be coupled to the RITU or MARA separators for recoil identification. The spectrometer is focused on studies of transfermium nuclei and the investigation of shape coexistence in the light lead region.

The SPEDE spectrometer [2] provides electron detection capabilities to the MINIBALL γ-ray detection array for in-beam experiments employing radioactive ion beams at HIE-ISOLDE, CERN. The setup will be primarily used for octupole collectivity and shape coexistence studies in Coulomb excitation experiments. The simultaneous observation of electrons and γ rays is especially important for the analysis of multi-step Coulomb excitation data.

[1] J. Pakarinen et al., Eur. Phys. J. A 50, 53 (2014)
[2] P. Papadakis et al., Eur. Phys. J. A 54, 42 (2018)

THE ELECTRON CAPTURE IN ^{163}Ho EXPERIMENT - ECHo

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The goal of the Electron Capture in ^{163}Ho (ECHo) experiment is the determination of the electron neutrino mass by the analysis of the electron capture spectrum of ^{163}Ho. The detector technology is based on metallic magnetic calorimeters operated at a temperature of about 10 mK in a reduced background environment. For the first phase of the experiment, ECHo-1k, the detector production has been optimized and the implantation process of high purity ^{163}Ho source in large detector arrays has been refined. The implanted detectors have been successfully operated and characterized at low temperatures, reaching an energy resolution below 5 eV. High statistics and high resolution ^{163}Ho spectra have been acquired and analyzed in the light of the recent advanced theoretical description of the spectral shape, considering the independently determined and more precise value of the energy available to the electron capture process, Q, and a dedicated background model. We present preliminary results obtained in ECHo-1k so far and discuss the necessary upgrades towards the second phase of the experiment, ECHo-100k.

TOTAL ABSORPTION SPECTROSCOPY ALONG THE N=Z LINE: NUCLEAR SHAPES AND ASTROPHYSICAL INTEREST

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Measurements of beta decay reduced transition probabilities are particularly relevant in nuclei far from the stability line. It has been demonstrated that a proper measurement of the Gamow-Teller strength distribution requires the use of the total absorption technique. Here I will present the experimental activities carried out at ISOLDE with the total absorption spectrometer Lucrecia, a large 4π scintillator detector designed to absorb a full gamma cascade following beta decay. Experimental results from several campaigns will be presented in the context of nuclear shapes and nuclear astrophysics. Present ideas and near-future proposals will be discussed.

THE QUADRUPOLE ROTATIONAL INVARIANTS - SOME TRICKS AND TRAPS

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The non-energy weighted quadrupole sum-rules called the Kumar-Cline sum rules [1,2] are widely used to discuss results from the Coulomb excitation experiments. On a basis of results obtained with the GOSIA code [3], one can evaluate, in a model-independent way the expectation values and the statistical distribution of the two moments in the intrinsic frame, providing clear information on nuclear quadrupole deformation and collective properties of the nuclear states. Moreover - the method become a very convenient platform to confront experimental results with various model calculations. This widely used tool has a few specific features, which may cause misunderstanding of the obtained values. A subjective choice of tricks and traps will be reminded and discussed.

[1] K. Kumar, Phys. Rev. Lett. 28 (1972) 249
[2] D. Cline, Ann. Rev. Nucl. Part. Sci. 36 (1986) 683
[3] T. Czosnyka, D. Cline, C.Y. Wu - Am. Phys. Soc. 28:745 (1983)

STUDY OF DEUTERIUM FUSION IN DENSE PLASMA GENERATED BY HIGH-POWER LASER IN NANO-TARGETS: PERFORMANCE OF TIMEPIX-3 DETECTOR IN ENVIRONMENT WITH HIGH ELECTROMAGNETIC NOISE

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The high-density plasma, generated by high-power lasers, is considered as suitable environment for study of processes in astrophysical objects and for production of energy from fusion of light nuclei. Intense efforts are spent on both experimental and theoretical investigations. Recently, the targets with nano-structure were introduced and generation of high yield of neutrons per consumed energy was observed. The experiment at CLAPA facility at Peking University was performed in order to verify these claims. The group from IEAP used Timepix-3 detectors and despite harsh environment was able to observe neutrons from deuterium fusion. Further experiments are planned in Peking University or elsewhere in the near future.

CONSTRAINING THE EQUATION OF STATE OF NUCLEAR MATTER FROM FUSION HINDRANCE IN REACTIONS LEADING TO THE PRODUCTION OF SUPER HEAVY ELEMENTS.

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The mechanism of fusion hindrance, an effect preventing the synthesis of superheavy elements in the reactions of cold and hot fusion, is investigated using the Boltzmann-Uehling-Uhlenbeck equation, where Coulomb interaction is introduced. A strong sensitivity is observed both to the modulus of incompressibility of symmetric nuclear matter, controlling the competition of surface tension and Coulomb repulsion, and to the stiffness of the density-dependence of symmetry energy, influencing the formation of the neck prior to scission. The experimental fusion probabilities were for the first time used to derive constraints on the nuclear equation of state. A strict constraint on the modulus of incompressibility of nuclear matter K0=240−260 MeV is obtained while the stiff density-dependences of the symmetry energy (γ>1.) are rejected.