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Book of Abstracts

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Investigating cluster configurations with the K600

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Isoscalar monopole and dipole excitations have been identified as powerful probes of clustering behaviour in nuclei. Both types of transitions are associated with cluster configurations, the dipole transitions are the parity-doublet structures and only occur for asymmetric cluster configurations. Antisymmetrised molecular dynamics calculations predict not only the excitation energies but also the transition strengths to the excited monopole and dipole states.

In recent years, a wealth of data have been taken with the K600 to investigate isoscalar monopole and dipole transitions using the α-particle inelastic scattering reaction to test these predictions of cluster behaviour. The results of three recent K600 experiments will be discussed in this talk including a coincidence experiment investigating charged-particle decays from ^{24}Mg.

Future experiments investigating the observed low-lying isoscalar dipole transitions in rare-earth nuclei, which have been tentatively linked to α-particle cluster configurations will be briefly introduced.

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Photoneutron reaction cross section measurements on 94Mo and 90Zr relevant to the p-process nucleosynthesis

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The photodisintegration cross sections for the 94Mo(γ,n) and 90Zr(γ,n) reactions have been experimentally investigated with quasi-monochromatic photon beams at the High Intensity γ-ray Source (HIγS) facility of the Triangle Universities Nuclear Laboratory (TUNL). The energy dependence of the photoneutron reaction cross sections was measured with high precision from the respective neutron emission thresholds up to 13.5 MeV.These measurements contribute to a broader investigation of nuclear reactions relevant to the understanding of the p-process nucleosynthesis. The results are compared with the predictions of Hauser-Feshbach statistical model calculations using two different models for the dipole γ-ray strength function. The resulting 94Mo(γ,n) and 90Zr(γ,n) photoneutron stellar reaction rates as a function of temperature in the typical range of interest for the p-process nucleosynthesis show how sensitive the photoneutron stellar reaction rate can be to the experimental data in the vicinity of the neutron threshold.

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Accelerator Centre for Exotic Isotopes (ACE Isotopes) pillar of the South African Isotope Facility (SAIF)

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The iThemba Laboratory for Accelerator Based Sciences is based around a K=200 Separated Sector Cyclotron (SSC) which is used for radionuclide production and for research in nuclear physics and radiobiology. It plans to build the "South African Isotope Facility", comprising two phases; the first is the Accelerator Centre for Exotic Isotopes (ACE Isotopes) and the second is the Accelerator Centre for Exotic Beams (ACE Beams). Here we focus an ACE Isotopes, for which initial funding has been approved.
Radionuclides are currently produced with the SSC for local and export markets, with only longer lived isotopes available for export. iThemba LABS presently supplies 20% of the worlds 82Sr, 40% of the worlds 68Ge/68Ga generator and all of its 22Na. Ace Isotopes will see the acquisition of a new cyclotron dedicated to the production of radionuclides for medicine. The accelerator will be a negative-ion machine, capable of accelerating protons to 70 MeV and delivering currents of up to 700μA. Isotope production will increase by more than a factor of two with the commissioning of the new cyclotron.
The high-current cyclotron will take radionuclide production away from the SSC, freeing it up for an increased tempo of research. iThemba LABS plans to build a "Low Energy Radioactive-Ion Beam" (LERIB) facility based on the Isotope Separation OnLIne (ISOL) method. The SSC will be used as the driver accelerator to deliver a proton beam to various carbide production targets. Because the "flat-topping" implemented on the SSC is optimized to supply currents of up 350μA of 66 MeV protons, this energy will be used on production targets – a uranium-carbide target has been designed to produce up to 2 ×1013 fission/s using a 66 MeV proton beam of 150 μA intensity. The "front-end", housing the target/ion-source will be a copy of the front-end developed for the SPES project, which is itself derived from the ISOLDE front-end. LERIB will supply low-energy (60 keV) RIBs for research, which includes the study of the ⊠-decay of exotic isotopes, the use of radioactive ions as probes to study the properties of materials and as a way extract radionuclides of interest for therapy and diagnostics.
The next phase, ACE Beams, will see the RIBs post-accelerated to energies of at least 5 MeV/A.

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Measurement of activity concentration of ^{238}U and ^{232}Th series radionuclides in beach sand with a multidetector ($LaBr_3$:Ce) gamma-ray spectrometer

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The activity concentrations of ^{238}U and ^{232}Th series radionuclides in beach sand were measured using a gamma-ray spectrometer comprising four $LaBr_3$:Ce (2" x 2") detectors without background shielding. The sample was placed 10 cm equidistant from the detectors and counted for 48 hours. This spectrometer allowed for measurement in singles and coincidence (gamma-gamma) modes. Time-stamped data were acquired and time correlation used to remove the background offline.
In coincidence mode, the minimum detectable activity (MDAs) were two orders of magnitude lower than in singles mode. The weighted activity concentration of ^{238}U series radionuclides in singles and

coincidence modes are 908 $\pm$ 70 Bqkg^{-1} and 972 $\pm$ 99 Bqkg^{-1} respectively. The weighted activity concentration of ^{232}Th series radionuclides in singles and coincidence modes are 1599 $\pm$ 70 Bqkg^{-1} and 1754 $\pm$ 185 Bqkg^{-1} respectively. Therefore we conclude that the results are consistent to within measurement uncertainty.

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The neutron production facility at the Lawrence Berkeley National Laboratory

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The Bay Area Neutron Group (BANG) has developed and characterized a high-intensity neutron source facility at the 88-Inch Cyclotron of the Lawrence Berkeley National Laboratory. A variety of white neutron sources have been produced via deuteron breakup on thick beryllium and tantalum targets with incident deuteron energies from 16-33 MeV. Neutron energy spectra are measured with activation foils and time-of-flight techniques. A flux of ~10^7 n/cm^2/s at 5 m from a beryllium breakup target is achieved with a 10 μA, 33 MeV deuteron beam. Efficient physical collimation of the breakup source allows for a closely-packed geometry of gamma ray detectors otherwise sensitive to neutron damage such as high-purity germanium.

Double-time-of-flight techniques are used to characterize scintillator response functions down to neutron energies (<100 keV) not previously feasible. Time-correlated single photon counting is used to characterize scintillator light decay over long time scales and high dynamic range. The facility is also used to measure cross sections for medical radioisotope production and to gauge equipment and materials damage response to neutron irradiation.

Furthermore, the facility has been recently tasked to measure inelastic neutron scattering cross sections through the assembly of a Gamma-Energy Neutron-Energy Spectrometer for Inelastic Scattering (GENESIS). High-purity germanium detectors in coincidence with twelve or more neutron scintillators will detect characteristic gamma rays in coincidence with scattered neutrons to determine the $d^3\sigma_{inl}/dE_n dE_n\, d\Omega$ triple-differential inelastic cross section of up to 50 MeV neutrons for a wide variety of nuclei. Additional support has recently been granted to use to measure short-lifetime independent fission fragment yields as well.

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Challenges in Laser Spectroscopy of the Heaviest Elements

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In recent years, laser spectroscopy techniques with highest sensitivity have been developed to reveal atomic and nuclear properties of exotic nuclei far from stability. Several new data on differential nuclear charge radii and electromagnetic moments of exotic nuclei have been obtained allowing us for example to infer their size and shape. However, the region of heaviest elements well above uranium was inaccessible. These elements do not naturally occur on earth and have to be produced artificially

in heavy-ion fusion reactions. However, small production rates on an atom-at-a-time scale and often short half-lives called for the development of tailored methods. Recently, a very sensitive resonant ionization laser spectroscopy method in combination with gas stopping methods has been developed experiments at GSI Darmstadt. It paved the wat to the first optical spectroscopy of the element nobelium [1]. Meanwhile many atomic states in nobelium were identified allowing the determination of nobelium's first ionization potential with high precision [2]. In addition, measurements of the isotope shift of an optical ground state transition in the nobelium atom for 252-254No and hyperfine spectroscopy of 253No were achieved [3]. The results provided differential charge radii and electromagnetic moments well described by nuclear models using energy density functionals. In the 2019 beamtime campaign at GSI the measurements were extended to 255No. This presentation will summarize the present status of investigations in the region of the heaviest elements and discuss future perspectives to extend laser spectroscopy to even heavier elements.
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Probing the QGP with heavy quarks in ALICE at the LHC

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Heavy quarks (charm and beauty) are regarded as ideal probes of the hot and dense deconfined QCD medium, the Quark-Gluon Plasma (QGP), formed in ultra-relativistic heavy-ion collisions at the LHC. They are produced in hard scattering processes in the early stages of a heavy-ion collision. In addition, their characteristic flavour is conserved throughout the evolution of the medium formed in these collisions. Therefore, heavy-quark measurements can give insight into the mechanisms of in-medium energy loss, propagation and hadronisation. The ALICE experiment is designed to study the QGP produced in ultra-relativistic heavy-ion collisions at the LHC. The detector, composed of central barrel ($|\eta|<0.9$) detectors as well as the muon spectrometer at forward rapidity ($-4<\eta<-2.5$), is well suited to study heavy-quark production,exploiting various experimental techniques. This talk will review recent results obtained in heavy-quark measurements by the ALICE Collaboration in heavy-ion collisions at LHC energies.

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Using jets and high transverse momentum particles to probe the Quark-Gluon Plasma

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Experiments at RHIC and the LHC have shown that a phase of matter, known as the Quark-Gluon Plasma (QGP), is produced in collisions of relativistic heavy-ions. This strongly interacting medium has partonic (quark and gluon) degrees of freedom and behaves like a nearly perfect fluid. Hard-scattered partons provide an ideal probe for the study of the QGP as they are produced early in the collision, prior to the QGP's formation. These scattered partons must then traverse the QGP and hadronize forming sprays of charged and neutral particles termed jets. Early measurements conducted at RHIC provided compelling evidence of significant energy loss of these highly energetic partons due to interactions with the hot and dense medium, a phenomenon name "jet quenching".
I will review the current status of the evidence for jet quenching from RHIC and the LHC and describe

how a variety of jet shape measurements are now being utilized to probe the mechanisms of the jet-medium interaction.

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Predictions of Fission Fragment Properties for Super-Heavy Elements

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The total deformation energy at the moment of neck rupture, for the heaviest nuclei for which spontaneous fission has been detected ($^{264-278}$Hs, $^{268-280}$Ds, $^{276-286}$Cn, $^{285-287}$Fl, $^{290-293}$Lv and ^{294}Og) [1,2], is calculated using the Strutinsky's prescription. The nuclear shapes just before scission are described in terms of Cassinian ovals defined for the fixed value of elongation parameter α=0.98 and generalized by the inclusion of four additional shape parameters: α_1, α_3, α_4, and α_6. Supposing that the probability of each point in the deformation space is given by Boltzmann factor, the distribution of the fission-fragment masses is estimated. The octupole deformation α_3 at scission is found to play a decisive role in determining the main feature of the mass distribution: symmetric or asymmetric. Only the inclusion of α_3 leads to an asymmetric division [3].

In this situation, the scission configuration has one almost spherical fragment with A_L ≈136 and one extremely deformed (neck shaped) complementary fragment. After rupture of the first neck (with smallest radius), the light spherical fragment is separated from the rest. The question is: will the heavy deformed fragment undergo a second fission or will it recover a more or less compact shape? In other words: is the fission of SHE binary or sequential-ternary? To give an answer, we study the potential energy surface of this complementary fragment in order to find its saddles and valleys. The position on this map of its shape at the scission of the SHE gives a hint about its post scission evolution. Such a study has been carried out for the scission configurations of ^{284}Cn, ^{286}Fl and ^{294}Og. In order to study more general trends, detailed calculations are performed in the unexplored region of super-heavy nuclei: the even-even Fl (Z=114), Lv (Z=116), Og (Z=118) and (Z=126) isotopes. For these nuclei, the most probable mass of the light fragment has an almost constant value (≈136) like in the case of the most probable mass of the heavy fragment in the actinide region. It is the neutron shell at 82 that makes this light fragment stable over such a large series of elements. Naturally, for very neutron-deficient isotopes, the mass division becomes symmetric when N = 2×82. In this way, the fission process of super-heavy nuclei smoothly joins the heavy-actinide systematics (from Fm to Sg) where the neutron-rich isotopes show a symmetric mass division [4].

Finally we examine the often discussed possibility that SHE decay preferentially by cluster emission (i.e., ^{208}Pb + the rest).

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[3] N. Carjan, F. Ivanyuk, Yu. Oganessian, Nucl. Phys. A 968 (2017) 453.
[4] N. Carjan, F. Ivanyuk, Yu. Oganessian, G. Ter-Akopian, Nucl. Phys. A 942 (2015) 97.

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Summary Talk

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The FOOT experiment: measuring light nuclei fragmentation cross sections up to 700 MeV/A

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Charged Particle Therapy has been demonstrated as a highly effective method for treating deep-seated tumours. About 90 facilities operate in the world, mostly using proton beams, while some of them also provide carbon-ion beams. Thanks to the energy release pattern of charged particles, characterized by the Bragg peak, the dose delivered to healthy tissues surrounding the tumour is minimized. Still, secondary particles produced by beam-tissue nuclear interactions pose an additional hazard that must be carefully taken into account in clinical treatment plans. With proton beams, target fragmentation generates low energy and short-range nuclear fragments with a high Linear Energy Transfer (LET). In case of carbon beams, projectile fragmentation is also relevant, as it produces longer-range fragments that release dose in healthy tissues after the tumour.
Measuring the cross sections of these processes up to 350 MeV/A is the main goal of the FOOT (FragmentatiOn Of Target) Collaboration, with 15 Institutions from 4 countries: an inverse kinematics approach will allow the detection of the 12C and 16O fragmentation generated in the interaction with graphite and hydrocarbons targets.
Proton- and light nuclei-induced nuclear fragmentation is also a relevant issue in the evaluation of radiation doses induced by the exposure to galactic cosmic rays, the main health risk for astronauts in deep space missions, a relevant topic given that current space programs focus on the exploration of the Solar system. For risk assessment and mitigation, Monte Carlo or deterministic transport codes are commonly used to calculate organ doses through different shielding materials. By measuring differential fragmentation cross sections of high-energy light ions in different shielding materials up to 700 MeV/A, the FOOT experiment will provide input required to improve the accuracy of the transport codes.

FOOT is designed as a portable detector that can easily operate in various facilities and collect experimental data with different beam conditions. The detector is optimized for heavy fragments identification through the measurement of their momentum, energy and time of flight, as well as the trajectory of the incident beam particle. For the measurement of light fragments all the subsystems after the beam monitor are replaced by an emulsion spectrometer, which measures the charge, energy and mass of the fragments.

Besides its physics motivations, the final design of the experiment, aiming at the measurement of differential cross sections with ~5% uncertainty for different beam-target combinations, and the present status of the development and performance of its components will be discussed.

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IAEA activities in support of the accelerator-based research and applications

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Promotion of nuclear applications for peaceful purposes and related capacity building is among the missions of the IAEA. In this context, accelerator applications and nuclear instrumentation is one of

the thematic areas, where the IAEA supports its Member States in strengthening their capabilities to adopt and benefit from the usage of accelerators. A number of activities are being implemented focusing on accelerator-based applications in multiple disciplines, such as ion beam analysis of materials relevant to fusion or future applications of radioactive beams.
This presentation aims at disseminating some of the currently running activities of the Physics Section of IAEA implemented through Coordinated Research Projects and Technical Cooperation projects, especially those aiming at facilitating access to accelerator facilities for the countries without such capabilities. In particular, the outcomes from two recent Technical Meetings on Ion Beam Analysis of materials relevant to energy production via fusion and on future applications of Radioactive Ion Beams will be reported. Plans for the establishment of an accelerator facility at Seibersdorf laboratories will also be presented.

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Informing neutron capture via surrogate (d,p gamma) measurements

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Neutron capture reactions are responsible for the synthesis of almost all of the elements heavier than iron: the slow (s) process proceeds on isotopes near stability; the rapid (r) process produces isotopes with short half-lives that subsequently decay towards stability. In hot r-process scenarios, final abundance patterns are relatively insensitive to neutron capture rates on waiting point isotopes. However, unknown neutron capture rates on specific isotopes can have significant impact [1] on final abundance patterns in freeze-out from hot scenarios, as well as colder scenarios when (n,gamma)-(gamma,n) equilibrium is not attained. To inform neutron capture rates important in reproducing observed r-process abundances requires a validated surrogate approach since direct measurements, even with beams of short-lived isotopes, are not feasible. The (d,p gamma) reaction has recently been demonstrated [2] to be a valid surrogate for neutron capture. Potel and coworkers [3] have shown how the inelastic breakup of the deuteron provides a neutron that can be captured. This reaction model enables calculations of the distribution of transferred angular momenta as a function of effective neutron energy, a critical ingredient in any surrogate approach. The surrogate reaction analysis approach developed by Escher and colleagues [4] was adopted in Ref. [2]. The observed gamma-decay probabilities for specific discrete transitions are fit with the Potel-model for compound nucleus formation; level density and gamma-ray strength function parameters are constrained by a Bayesian analysis. Optical model calculations of the entry neutron channel coupled to the deduced gamma-decay probability are used to calculate the neutron capture cross section as a function of neutron energy. To constrain neutron-capture cross sections on unstable nuclei, the GODDESS detector system [5] - that couples a Gamma-ray detector array to the Oak Ridge Rutgers University Barrel Array of position-sensitive silicon strip detectors - would be used to measure (d,p) reaction protons as a function of effective neutron energy and in coincidence with discrete gamma-ray transitions. The surrogate gamma-ray emission probabilities would be extracted and fit with the Escher-Potel framework to provide the gamma-decay probabilities as a function of entry spin-parity needed for calculations of neutron capture cross sections. The present contribution would summarize the (d,p gamma) surrogate neutron capture reaction validation, the GODDESS detector system, and the status of (d,p gamma) reaction measurements with stable and radioactive ion beams.

Work supported in part by U.S. Department of Energy National Nuclear Security Administration and Office of Science and the National Science Foundation. We thank the GODDESS collaboration for invaluable contributions.

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Structure of 40Mg

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The study of nuclei far from stability is one of the most active and challenging areas of nuclear structure physics. One of the most exotic neutron-rich nuclei currently accessible to experiment is 40Mg [1, 2], which lies at the intersection of the nucleon magic number N=28 and the dripline, and is expected to have a large prolate deformation similar to that observed in the neighboring lighter isotopes 32□38Mg [3]. In addition, the occupation of the weakly bound low-‘ p3=2 state may lead to the appearance of an extended neutron halo.
40Mg offers an exciting possibility and a rare opportunity to investigate the coupling of weakly bound valence particles to a deformed core, and the influence of near threshold effects on collective rotational motion. We will discuss the results of an experiment carried out at RIBF RIKEN to study low-lying excited states in 40Mg produced by a 1-proton removal reaction from a 240 MeV/u 41Al secondary beam. 40Mg and other final products were separated and identified using the Zero Degree Spectrometer, and prompt gamma rays were detected using the DALI2 array. Two gamma rays were observed, and the excitation spectrum shows unexpected properties compared to both neighboring Mg isotopes, and theoretical model predictions.
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Beyond standard mean field approaches to nuclear scattering: many body degrees of freedom

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The development of the Radioactive Ion Beam (RIB) facilities, allowing the study
away from the stability line, has unveiled the concept of a standard Mean Field Approach (MFA) to particle systems. Closely tied to the MFA idea the independent shell model was developed, which assumes that the interaction between the many-body nucleon system can be suitably represented by a MF potential for each single particle. The MFA has played an important role in the early days of nuclear Physics, and was able to explain many properties of nuclei, such as the origin of the magic numbers leading to additional stability.

However, current theoretical and experimental work have shown that along the nuclear landscape some magic numbers are either vanishing, receding or emerging, questioning earlier descriptions

of the nuclear quantum systems. More recently, structure studies and reactions analyses of single-nucleon knockout from a nucleus have demonstrated the need to go beyond this simplified MFA picture \cite{abinitio} and to consider many-body structure models comprising explicit nucleon-nucleon (NN) and three-nucleon (NNN) interactions {Wiringa14,Carlson15}, NN correlations, in particular neutron-proton correlations entirely absent in the MFA \cite{nature}. On the other hand the role of the many body degrees of freedom into the reaction dynamics might need to be taken into acount in special quantum systems or in key reaction observables {Cowley-00,Lay-16,Deltuva-19}.

A consistent analysis of available experimental data together with a theoretical analysis including key many body degrees of freedom, in structure and dynamics,is of utmost importance for the understanding of nuclear structure along the nuclear landscape and of nuclear correlations. In addition, on needs to identify the observables and/or kinematical regions to fingerprint many-body aspects. In particular, the measurement of analysing power in nuclear reactions with beams of polarized protons might shed light on this issue.

We shall discuss current measurements and theoretical analysis of reaction with proton probes. We also shall propose a set of future experiments for the understanding of many-body degrees of freedom in the nuclei structure and dynamics of the reaction.

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Combining fast neutron radiography with positron emission particle tracking in a tumbling mill system

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Understanding the behavior of flow within dynamic systems is important to optimize the required outputs from such active systems. Non-destructive methods offer a significant advantage since the system may be preserved over multiple studies. We present the first dual measurements of the steady-state flow of material within a laboratory scale tumbling mill system which combine observables obtained from fast neutron radiography (FNR) and positron emission particle tracking (PEPT). FNR measurements were made using the CV28 Isochronous cyclotron at the Physikalisch-Technishe Bundesanstalt, Braunschweig, Germany, and PEPT measurements were made using a Siemens HR++ PET scanner at PEPT Cape Town laboratories, iThemba LABS, South Africa. We offer comment on the usefulness of combining a 2D transmission technique (FNR) with a 3D emission technique (PEPT) in order to validate existing numerical models of flow conditions within the system of interest.

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Effect of deformation on the fine-structure energy scales of the neodymium isotope chain

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High energy-resolution proton inelastic scattering experiments with <i>E</i>_p = 200 MeV were performed on ^{142, 144, 146, 148, 150}Nd and ¹⁵²Sm in the excitation-energy region of the Isovector Giant Dipole Resonance (IVGDR) using the zero-degree mode of the K600 magnetic spectrometer of iThemba LABS. The effect of deformation on both the broad and the fine structure of the IVGDR in the rare-earth region was investigated. A goal of the present study was to extend, for the first time, the IVGDR measurements on these isotopes to high energy-resolution and confirm the <i>K</i>-splitting observed in previous photo-absorption measurements. The applicability of the photo-absorption data to the present study, owing to the low energy-resolution, is limited to broad structure comparisons only with the focus on the evolution of the shape of the IVGDR in the transition from spherical to deformed nuclei. Techniques based on the continuous wavelet transform have been implemented in order to perform a fine structure analysis on the high energy-resolution data obtained in the present study. Characteristic energy scales have been extracted from the experimental data and compared to those extracted from state-of-the-art theoretical predictions of the corresponding <i>B</i>(<i>E</i>1) strength functions. The conclusions of these comparisons will be presented.

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In-beam gamma spectroscopy with fast RI beams at RIKEN

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The presentation will address nuclear structure and shell evolution at extreme isospin values, studied via in-beam gamma-ray spectroscopy at intermediate energies following knockout reactions on a thick liquid hydrogen target. Besides an introduction of the setup, key results will be presented

that demonstrate the close cooperation between experiment and nuclear structure and reaction theory.

Particular emphasis will be laid on spectroscopy of the neutron-rich Ca isotopes 54,56Ca, in which the significance of 3N forces can be studied, and the assumed doubly magic nucleus 78Ni. The excitation spectrum of the latter provides first hints of the breakdown of magic neutron number N=50 and magic proton number Z=28 towards more excotic isotones and isotopes.

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R-process nucleosynthesis and related nuclear physics

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One of the major issues in modern astrophysics concerns the analysis and
understanding of the present composition of the Universe and its various constituting objects. Nucleosynthesis models aim to explain the origin of the different nuclei observed in nature by identifying the possible processes able to synthesize them. Though the origin of most of the nuclides lighter than iron through the various hydrostatic and explosive burning stages in stars is now quite well understood, the synthesis of the heavy elements (i.e. heavier than iron) remains obscure in many respects. In particular, the rapid neutron-capture process, or r-process, is known to be of fundamental importance for explaining the origin of approximately half of the A>60 stable nuclei observed in nature. The r-process was believed for long to develop during the explosion of a star as a type II supernova but recent observations tend to favour the merging of two compact objects. The recent observation of the binary neutron star (NS) merger GW170817 and its corresponding optical kilonova counterpart suggest that neutron star mergers are the dominant source of r-process production in the Universe.
Comprehensive nucleosynthesis calculations based on sophisticated multidimensional relativistic simulations show that the combined contributions from both the dynamical (prompt) ejecta expelled during NS-NS or NS-black hole (BH) mergers, and the neutrino and viscously driven outflows generated during the post-merger remnant evolution of relic neutron stars or BH-torus systems can lead to the production of r-process elements from Zr ($A \geq 90$) up to thorium and uranium with an abundance distribution that reproduces extremely well the solar distribution, as well as the elemental distribution observed in low-metallicity stars. The stellar nucleosynthesis requires a detailed knowledge not only of the
astrophysical sites and physical conditions in which the processes take place, but also the nuclear structure and interaction properties for all the nuclei involved. Both the astrophysical and nuclear physics aspects of the r-process nucleosynthesis will be discussed with a special attention paid to major open questions affecting our understanding of the r-process nucleosynthesis.

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The HISPEC/DESPEC project at GSI/FAIR H

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HISPEC/DESPEC project at FAIR include the nuclear structure program and explore gamma ray spectroscopy as a main experimental tool. With addition of specialized for the FAIR in-flight facility beams heavy ion and light particle detector setups, the project will address burning questions of shell evolution in astrophysical context of r-process waiting points. In particular, DESPEC-Phase0

experimental project at GSI and FAIR preparation has already started. The goal is to investigate different modes of decay in exotic and heavy nuclei with spectroscopic means. High resolution gamma ray spectroscopy measurement will be combined with a precise time measurement of the of emitted gamma rays to measure decay schemes and lifetime of the intermediate states. The associated beta particles, conversion electrons, heavy ions will be registered by DSSSD-array AIDA and scintillator detectors. The decay neutrons will be filtered out by the MONSTER detector. The experimental detector-setup will be presented together with the plans for commissioning and physics campaigns.

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ENSAR2 research infrastructures & international sister facilities

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The ENSAR2 (European Nuclear Science and Application Research 2) research infrastructures pursue fundamental and applied research in nuclear physics and related areas. These research infrastructures offer transnational access to users from across Europe and, for the first time since 1 March 2016, to international users as well. A few of these infrastructures will be presented in detail at this conference. In this talk, a short presentation of each of the remaining ENSAR2 facilities will be given. Furthermore, ENSAR2 signed MoUs with several international nuclear physics facilities. In this talk, I will briefly present two of these facilities: iThemba, Faure, South Africa and RCNP, Osaka, Japan.

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Ab initio theory for structure and electroweak properties of medium-mass nuclei

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In this talk I will discuss recent advances in the in-medium similarity renormalization group (IMSRG) which expand the scope of ab initio nuclear structure calculations to essentially all properties of light, medium-mass nuclei and beyond. When based on consistently derived two- and three-nucleon forces, these powerful approaches allow first predictions of the limits of nuclear existence, the proton and neutron driplines, and the evolution of magic numbers far from stability. I will also focus on recent extensions to fundamental problems in nuclear-weak physics, including a solution of the long-standing quenching puzzle in beta decays and calculations of nuclear matrix elements of neutrinoless double-beta decay for determining neutrino masses.

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Inverse-Oslo Method – a tool for expanding our understanding of the r-process

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Following the first observation of a neutron star merger [1] it became clear that this was one of the sites of the r-process [2]. With an astronomical site for the r-process known it has become more important than ever to have accurate nuclear input [3], and in particular accurate neutron capture rates for unstable neutron rich nuclei. Unfortunately, the neutron capture rates of short-lived nuclei are currently impossible to measure directly. However, the capture rates could be constrained by Hauser- Feshbach (HF) calculations [4], which relies on the -ray strength function (SF), nuclear level density (NLD) and the optical model potential to predict the capture cross section. Currently there are several models of the NLD and SF which in turn produces capture rates that deviate as much as 10^5 in HF calculations [5]. Although the capture rates cannot be directly measured, the SF and NLD can, even for very neutron rich nuclei with the beta-Oslo Method [6]. Recently, it has been shown that the Oslo Method can also be combined with inverse kinematics [7], expanding the Oslo Method to virtually any nucleus applicable, provided one can produce a reasonably intense beam.

The inverse-Oslo method has, for the first time, been applied on an experiment with a radioactive beam at HIE-ISOLDE at CERN. A 4.5 MeV/u ^{66}Ni beam hit a deuterated-polyethylene target at the C-REX particle array. -rays from the reaction were measured with the Miniball array and six large volume (3.5x8 inch) $LaBr_3$:Ce detectors added to boost the -ray efficiency.

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Investigating the influence of deformation on the low-lying electric dipole (E1) response in 144,154Sm

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The past decade has seen an increase in studies dedicated to understanding the low-lying electric dipole (E1) response, commonly referred to as the Pygmy Dipole Resonance (PDR). These studies revealed that the PDR has a mixed isospin nature, and that the use of complimentary probes is needed to fully understand this response. Since majority of studies on the PDR focussed on spherical nuclei, the influence that deformation has on the PDR response is yet to be understood.

Preliminary (p,p') studies on 154Sm performed at RCNP, showed potential evidence for a splitting in the PDR response similar to that of the Giant Dipole Resonance with deformation [1]. A tentative interpretation suggested that this splitting could be connected to the splitting of the resonance structure with respect to the K quantum number. In another investigation, liquid drop model calculations comparing the ratio between the transition probability of K=0 and K=1 contributions for the isovector and iscoscalar components of the PDR respectively, showed that the isoscalar part varies more dramatically with deformation [2].

Therefore, studies using the (α,α'γ) inelastic scattering reaction were performed on the spherical 144Sm and prolate deformed 154Sm at iThemba LABS. The experiments made use of the K600 magnetic spectrometer in 0° mode in co-incidence with BaGeL (Ball of High-Purity Germanium and large volume LaBr 3 :Ce detectors). In this talk, we will present the recent results of this study.

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A dilepton spectrometer for the study of giant resonances in nuclei

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The Giant Resonances are the collective modes of nuclear excitations at high frequencies. The decay of the isoscalar giant monopole resonance to the ground state of the nucleus provides key observables in nuclear structure such as insights to nuclear compressibility and density of states. These are important for nuclear astrophysics, however mostly the electromagnetic decay modes have been studied. The E0 part of these strength can only be measured with internal conversion or pair emission.

Internal pair formation studies are already undertaken in astrophysical related measurements in light nuclei and can be extended further with a dedicated spectrometer. Investigations of the isoscalar giant monopole resonances vary from the medium, rare-earth and actinide regions of the Segré chart. The measurement of these states via internal pair decay is both lacking and very promising.
A 4π dilepton spectrometer, PEPSI (positron-electron pair spectroscopy instrument) will be used to study highly excited states in nuclear matter. The spectrometer has been donated to iThemba LABS in 2018 in the spirit of collaboration by the Institute for nuclear Research, Hungarian Academy of Sciences, Hungary. The spectrometer, consisting of 20 electron and 12 positron magnetically focussing elements requires new telescopic detectors, detector elements, magnetic shielding and associated electronics. With the refurbishment, the spectrometer will be capable of measuring electron-positron pairs with good efficiency over a modest energy range (10-20 MeV) allowing for access to studies of isoscalar giant monopole resonances

The spectrometer will be integrated into the K600 spectrometer at iThemba LABS and 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 feasable.

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The Structure of ^{33}Si,^{35}S and the magicity of the N=20 gap at Z=14,16

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The structure of ^{33}Si and ^{35}S was studied by one-neutron knockout reactions from ^{36}S and ^{34}Si beams at 88 MeV/u incident on a ^{9}Be target. The prompt γ-rays following the de-excitation of ^{33}Si and ^{35}S were detected using the GRETINA γ-ray tracking array while the reaction residues were identified on an event-by-event basis in the focal plane of the S800 spectrometer at NSCL (National Superconducting Cyclotron Laboratory). The -1n reaction makes it possible to probe the neutron Fermi surface and its evolution between ^{34}Si and ^{36}S to see which of the nuclei ^{34}Si, ^{36}S or ^{40}Ca has the most (doubly) magic behaviour. The study of ^{40}Ca was performed previously using direct kinematics and it was observed that ^{40}Ca has a lot of ground state correlations. A previous ^{34}Si(-1n) knockout experiment was performed which could account for only three states in ^{33}Si due to limited statistics. The current experiment addresses limitations of the previous ^{34}Si(-1n) knockout experiment by observing and accounting for seven transitions. A level scheme has been built up to 5.5 MeV using the analysis of $\gamma\gamma$ coincidences. In addition parallel momentum distributions have been constructed and compared with theoretical predictions enabling orbital angular momentum assignments to each state. Spectroscopic factors obtained in this work are in good agreement with those from the previous ^{34}Si(-1n) reaction. In this presentation, I will show the latest results from these N=20 nuclei ^{33}Si ,^{35}S and compare to previous work and elaborate on future planned measurements at iThemba LABS.

This work is supported by the National Research Foundation of South Africa (NRF).

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Stellar Pyrotechnics: Nucleosynthesis in Classical Nova Explosions

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Classical novae are thermonuclear explosions that take place in the envelopes of accreting white dwarfs in stellar binary systems. The material piles up under degenerate conditions, driving a thermonuclear runaway. The energy released by the suite of nuclear processes operating at the envelope heats the material up to peak temperatures of (100 - 400) MK. During these events, about 10^{-3} - 10^{-7} solar masses, enriched in CNO and, sometimes, other intermediate-mass elements (e.g., Ne, Na, Mg, Al) are ejected into the interstellar medium.
This Century has witnessed an extraordinary progress in our understanding of the physics that govern classical nova explosions. Indeed, new tools and developments, at the crossroads of theoretical and computational astrophysics, observational astronomy, cosmochemistry, and nuclear physics, have revolutionized our view of such stellar beacons. The use of space-borne observatories has allowed a novel panchromatic view of nova explosions. In parallel to the elemental abundances inferred spectroscopically from the nova ejecta (almost in real time), cosmochemists can now provide isotopic abundance ratios from micron-sized presolar nova grains extracted from meteorites. Encapsulated in those grains is pristine information about the suite of nuclear processes that took place in their stellar progenitors in epochs that predate the Solar System itself. The dawn of supercomputing has provided astrophysicists with the appropriate arena to study complex physical phenomena, such as convective mixing during novae, that unavoidably require a multidimensional approach. Last but not least, nuclear physicists have developed new techniques to determine nuclear interactions close to nova energies.
In this talk, I will provide a multidisciplinary overview of nova nucleosynthesis, with emphasis on the role played by current nuclear uncertainties.

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The use of storage rings in the study of reactions at low momentum transfers

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Several nuclear reactions are best investigated when the momentum transfer to the nucleus is small. Among these are the IsoScalar Giant Monopole Resonance (ISGMR) which helps determine one of the parameters of the equation of state, namely the incompressibility of nuclear matter, and proton elastic scattering from nuclei which is sensitive to parameters of nuclear density such as the matter root-mean-square radius. These have been extensively studied in the past using stable beams. However, with the advent of radioactive ion facilities around the world, it is desirable to study these

reactions with unstable nuclei. The reactions, however, have to take place in inverse kinematics in which the radioactive ions impinge on a light target (hydrogen or helium). Simple kinematics calculations show that the outgoing recoil particles possess extremely low energies (down to few hundred keVs). External targets are, therefore, not suitable for these reactions. There are two alternative methods to deal with this challenge: either do the experiments in storage rings with gas jet targets or any other thin targets, or perform the measurements with an active target which also acts as a detector. In both cases, the energy threshold will be much lower than a fixed target of a reasonable thickness.
We have performed measurements with the radioactive 56Ni using both methods. In the ring measurements, proton elastic scattering was the main goal for this nucleus while feasibility studies were done with 58Ni and a helium target to investigate ISGMR. In this presentation, the experimental method used in the storage ring will be discussed along with some results to show the superiority of the rings for this type of measurements.

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Experimental study with light RIB at ACCULINNA-2

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An important upgrade of the Flerov Laboratory of Nuclear Reactions Radioactive Ion Beam facility at JINR is start of the operation of a new high acceptance device called ACCULINNA-2. An overview of the design, construction and commissioning studies of the ACCULINNA-2 separator are presented. The separator will be equipped with a modern cryogenic tritium target cell, with zero degree spectrometer including a neutron detector array, and the TPC detector. This opens a wide range of experimental possibilities. Preliminary results of the experimental study of ^{6}He + d scattering and search for the ^{7}H nucleus are presented. An overview of light radioactive ion beams experimental program is given.

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Testing ab initio theory in light nuclei with direct reactions

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An important fundamental question is how nature combines the building blocks, protons and neutrons, to form the large variety of complex manybody nuclei. Addressing this requires understanding the residual strong interaction, the nuclear force, between nucleons that characterizes the properties of the nuclei. This entails synthesizing observed properties of
nuclei and predictions from theoretical models that involve describing the many body quantum system and the nuclear force. Particularly important are formulating nuclear models from first principle, the ab initio approach. A complete understanding of the nuclear force remains a challenge. A major advance in this front has been the description based on chiral effective field theory. However, there are different prescriptions of the chiral interactions that need to be constrained with experiments. Rare isotopes with neutron-proton asymmetry bring in additional sensitivity in understanding the force and constraining the models. This presentation will discuss how experimental investigations of static ground state nuclear properties such as masses and radii and dynamic observables such as excitation spectra and nuclear scattering in light nuclei have opened ways to test the ab initio models, and exhibited the crucial importance of the threenucleon force.

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Nuclear spectroscopy with thermal neutrons and actinide targets in ILL

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Institute Laue-Langevin (ILL) is a reactor based European neutron source, which delivers a very intense neutrons for ~40 different instruments. There are two nuclear physics instruments in ILL, which use actinide targets. Lohengrin [1,2] is a fission recoil separator with very high mass and energy resolving power (A/ΔA =1500, E/ΔE = 100 − 1000). In 2018 series of successful experimental campaign was carried out with such as fast timing, conversion electron and fission studies using fission fragments. The overview of the campaign and preliminary results of the experiments will be presented.
FIPPS [3,4] is the new nuclear physics instrument of ILL for the prompt γ-ray spectroscopy of nuclei produced in neutron-induced reactions. Currently, (Phase 1) FIPPS consists of an 8 array of HPGe clover detectors and a pencil-like intense thermal neutron beam. The overview of the first fission experimental campaign with an active actinide target diluted in scintillator will be presented. In the near future upgrade of the instrument (phase 2) will be carried out using anti-Compton shield and the Gas-Filled-Magnet (GFM). The newly proposed GFM and physics opportunities will be discussed.

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Ion trapping at radioactive-ion-beam facilities for mass measurements

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The demand for ion traps at radioactive-ion-beam facilities has grown since beams can be tailored for the desired experiment. For mass measurements, these developments have been driven by the need for increasingly better precision, sensitivity, speed, and purification. The highest precision and resolving power can be achieved in a Penning trap. In contrast, speed and purification have benefited from the more recent introduction of multi-reflection time-of-flight (MR-TOF) mass spectrometers. Frequently, these devices are coupled to enhance the overall performance of the mass-measuring facility. The resultant mass determinations have revealed evolution of nuclear shells, elucidated nucleosynthesis, and been used to test the Standard Model. After a brief introduction of ion trapping, I will provide an overview of recent results from iontrapping mass spectrometers around the world before focusing on results from TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN).

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What do cancer radiotherapy and Mars exploration have in common?

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Nuclear interactions of charged particles with matter play fundamental roles in many fields of applied research. Many challenges in radiotherapy with ions and in space radioprotection are related to the investigation of the same nuclear processes and require similar approaches to be addressed.
The growing popularity of radiotherapy with protons and carbon ions as well as the interest in finding additional candidate ions (as helium or oxygen) calls for nuclear and dosimetry measurements to validate delivery techniques. Furthermore, nuclear processes could play a role in enhancing the treatment effectiveness and provide real-time verification of treatment planning versus treatment delivered.
The roadmap of space exploration predicts longer and further travels outside Earth orbit and the establishment of permanent outposts on other celestial bodies like Mars. It is now generally acknowledged that exposure to space radiation represents a major health risk for deep space missions. Currently, ad hoc radiation shielding is designed exploiting the nuclear fragmentation capability of the selected materials. Furthermore, the nuclear interactions of external radiation with the spacecraft and its contents represents the most important information for predicting the radiation risks inside a habitat.
Advancement in both radiotherapy and space radioprotection, experimental data have to be combined with calculations from theoretical and Monte Carlo codes to characterize the interactions of the primary particles with different media and, as a final step, to assess their biological effects and associated health risks.
Different experimental approaches for characterizing nuclear reactions of interest in both fields (and in particular fragmentation) will be presented. Examples of innovations in radiotherapy and space radioprotection obtained with the help of nuclear physics data will be also discussed.

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Studying the Pygmy Dipole Resonances with isoscalar and isovector probes

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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[1]. Indeed, the combined use of real and virtual phonons and experiments employing (α,α′γ) as well as (17O, 17O' 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.
A recent experiment[2], investigating the low-lying dipole states above the neutron emission threshold, seems to show that the splitting is not observed in this energy region. Unravel this aspect is of paramount importance to understand this mode, interesting by itself, which has strong implication on the symmetry energy as well as in the astrophysical r-process. Therefore, analysing this mode taking into account its dual aspect, isovector and isoscalar, in the excitation process can shed some light on the structure properties as well as on the reaction mechanisms.
Also in deformed nuclei, until now not extensively studied for the PDR, the use of both isoscalar and isovector probes can bring new perspectives in the study of the low-lying dipole states. Indeed, if the common picture of the PDR were true, namely that this mode can be generated by an out-of-phase oscillation of the neutron excess against a proton plus neutron core, therefore one should aspect to

have a separation of the pygmy dipole peak in two bumps. Which is the same mechanism leading to the splitting of the GDR: an out-of-phase oscillation of neutron against protons along the symmetry and its perpendicular axes.
A macroscopic model designed for nuclei with neutron excess shows that a suitable way to investigate the pygmy states in deformed prolate nuclei is through the use of isoscalar probes. The recent experiment performed at iThemba Labs on the deformed 154Sm nucleus studied via an inelastic scattering of α particle at 120 MeV[3] may enlighten and give new points of view about these novel excitation modes.

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Recent results from AGATA and VAMOS

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In this talk, the recent experimental program and physics opportunities at the large acceptance VAMOS++ spectrometer at GANIL will be presented.
The development of new detection systems of the spectrometer and their performances will be shown.
Recent measurements arising from the unique combination of the Advanced Gamma Ray Tracking Array (AGATA), VAMOS++ and EXOGAM will be reported. Namely, new results from the prompt and prompt-delayed g-ray spectroscopy of isotopically identified fission fragments will be used to discuss the evolution of shell structure in the vicinity of Z=50 (Sb isotopes) and N=50 shell closures (81Ga).
In addition, ongoing experimental program at VAMOS++ including fission dynamics using transfer induced fission in inverse kinematic and transfer reaction in inverse kinematics using MUGAST and AGATA will also be discussed.

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Exploring nuclear astrophysics with heavy-ion storage rings

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Heavy-ion storage rings coupled to radioactive ion beam facilities offer unique capabilities for nuclear structure and astrophysics experiments. There are presently three operational facilities, namely the Experimental Storage Ring (ESR) at GSI in Darmstadt, the experimental Cooler-Storage Ring (CSRe) at IMP in Lanzhou, and the Rare-RI Ring (R3) Facility at RIKEN at which several research programs are being pursued.

Well-established are mass measurements of short-lived nuclei as well as decay studies of highly-charged radionuclides. These nuclear properties are the important input for the astrophysical nucleosynthesis calculations. While the former determine the pathways of various processes on the chart of nuclides, the latter affect the final elemental abundances.

In addition, storage rings are being considered for nuclear reaction studies. Compared to external target experiments, here a thin windowless internal gas target combined with high revolution frequencies of stored ions offer advantageous conditions for a range of experiments. For instance it has been shown that proton capture reactions can successfully be measured in the ESR [1]. The goal is to conduct proton and alpha-capture reactions directly in the Gamow window of the astrophysical p-process.

Research programs at storage rings have proven their high discovery potential, which is clearly indicated by a number of new storage ring projects started around the world. In the last years it became evident that stored beams at low energies offer huge scientific potential. The TSR@HIE-ISOLDE project compiled physics cases in nuclear structure, astrophysics, atomic- and neutrino physics as well as for the tests of fundamental symmetries. Although, the project could not be realized at ISOLDE up to now, it is still listed among the top upgrades for the ISOLDE facility at CERN. The first dedicated low-energy storage ring is being commissioned at GSI. This is the CRYRING which is built behind the ESR.

In this contribution, recent experiments that have been performed at ESR and CSRe will be discussed. As an outlook, the perspectives of future experiments at the existing storage ring facilities as well as at the planned facilities will be outlined.

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Experimental studies on the nuclear chirality in the A~80 mass region

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Several experimental studies on the nuclear chirality in the A~80 mass region have been performed. We have reported 80Br as the first candidate for chiral nuclei in the A ~ 80 mass region, First experimental evidence of Multiple chiral doublet bands with octupole correlations have been reported in 78Br, which indicates that nuclear chirality can be robust against the octupole correlations. Chiral doublet bands were also observed in 82Br, and a better chirality was found in 82Br than 78Br and 80Br. Other experimental studies on the nuclear chirality in the A~80 mass region are still in progress.

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Scientific research activity at the Open Laboratory of Nuclear Physics of the University of Sao Paulo, Brazil

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The Open Laboratory of Nuclear Physics (LAFN, acronym in Portuguese) is the only accelerator laboratory in Brazil with research in basic and applied nuclear physics, and one of the in South America. It has a 8MV Pelletron tandem accelerator and its main experimental facility is the Radioactive Ion Beams in Brasil (RIBRAS) system [1]. It is the first RIB facility in the Southern Hemisphere, and the only in Latin America. Consists of a double superconducting solenoid system, which produces RIB by transfer reactions and purifies them with a degrader between both solenoids. The radioactive beams we produce currently are: 6He, 7Be, 8Li, 8B, 10Be, 12B with intensities between 103-106 pps

and with energies up to 3-5 MeV/n. Our main interest is the reaction mechanism with cluster structured weakly bound projectiles, the effect of the breakup on the other reaction channels. This subject is also studied with stable weakly bound beams as 6,7Li, 9Be, and with particle-gamma coincidences. I will present our actual results and our plans for the future.

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Exact analytical treatment of nuclear shape phase transitions in terms of the sextic oscillator

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The sextic oscillator V(r) = Ar^2 + Br^4 +Cr^6 + D/r^2 offers a flexible shape that can be used in the Bohr Hamiltonian to model transition between spherical and deformed shape phases in the r=beta variable. The general form of the sextic oscillator is not solvable, however, the A, B and C coefficients can be parametrized in terms of two independent parameters such that the problem reduces to a quasi-exactly (QES) form. This means that the lowest few energy eigenvalues and the wave functions can be determined in closed form, and the B(E2) values can also be calculated analytically [1,2].
The model has been applied to describe the transition between the spherical and gamma-unstable shape phases [1,2] for even-even nuclei near the Z=50 shell closure, and later it has been generalised to discuss further types of phase
transitions too (see e.g. [3]). Here we report on the extension of the model that allows the treatment of 22 energy levels instead of the original 10, while all the calculations remain analytically solvable [4]. Selected examples will be re-analysed within this extended framework.

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^{180}Ta nucleosynthesis in light of newly constrained reaction rates

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A small number of naturally occurring neutron deficient nuclides with proton number Z>33, referred to as p-nuclei, cannot be produced by neutron-capture processes [1]. Instead, these stable nuclides are thought to be produced by the photodisintegration (p-process) of slow-neutron capture (s-process) and rapid-neutron capture (r-process) seed nuclei [1]. However, for ^{180}Ta, the p-process is not sufficient to explain the observed solar abundances and additional processes are invoked. The ^{180}Ta production mechanism causes controversy since calculations show that several nucleosynthesis processes, sometimes exclusively, can reproduce the observed ^{180}Ta abundance [2], making it a particularly interesting case to study. Since the astrophysical sites for the nucleosynthesis of ^{180}Ta remain unknown, a combination of several nucleosynthesis processes is undeniably possible. However, the significance of individual processes cannot be clearly determined, as a result of the uncertainties on the reaction rates for ^{180}Ta due to the unavailability of experimental data, e.g. the radiative neutron capture rates of ^{179,180}Ta isotopes or other nuclear ingredients needed to constrain these rates, such as the nuclear level density (NLD) and γ-ray strength function (γSF) [3].

In the present experiment, these parameters were measured using the ^{181}Ta(^{3}He,^{3}He'γ) and ^{181}Ta(^{3}He,^{4}Heγ) reactions with 34 MeV beams, ^{181}Ta(d,d'γ) and ^{181}Ta(d,tγ) reactions with 15 MeV beams, and ^{181}Ta(d,d'γ) and ^{181}Ta(d,pγ) reactions with 12.5 MeV beams at the Oslo Cyclotron Laboratory (OCL). Using the SiRi array and the CACTUS array (26 NaI(Tl) detectors) to measure particle-γ coincidence, the NLD and γSF were simultaneously extracted below the neutron separation energy, through iterative procedures using the Oslo method [4]. From all six reactions involving ^{180,181,182}Ta, the neutron capture cross sections of astrophysical interest are calculated using the nuclear reaction code TALYS and compared to previous results. From this, the reaction rates are calculated and used in stellar evolution calculations to investigate the role of the s-process in the nucleosynthesis of ^{180,181}Ta and the role of p-process nucleosynthesis for ^{180}Ta in Type-II supernova. In this talk I will present the latest results on our work to constrain ^{180}Ta nucleosynthesis from the new experimental data.

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Investigating the Feasibility of using Neutron Activation to Measure Pollution in the Richards Bay Area

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The Neutron Activation Analysis technique is one of the most reliable techniques that can be used to analyze various materials in all phases (solid, liquid and gaseous). According to literature, the technique (when using the traditional approach of employing thermal neutrons) is sensitive to about 78 elements of the periodic table, and can be used to simultaneously analyze up to 35 elements. In this study, the feasibility of using the technique for routine industrial pollution measurements is investigated using FLUKA simulations and experiments.
The study area is Richards Bay, a town in the Nothern Coast of the province of KwaZulu-Natal. The area has various

heavy industrial activities, including aluminum smelting, sand dune mining, phosphate fertilizer production, operation of a kraft process paper mill and a ferrochrome plant. Studies conducted by Masok et al. (Masok et al., 2016) found that heavy metals such as Arsenic (As), Manganese (Mn) and Cadmium (Cd) were the main water contaminants, with Mn being above the target water quality range (TWQR). The elements of interest, which are typical pollutants from the industries mentioned are Mn, Pb, Cr, Fe, Ni, Cd, Sr and Zn. In this study environmental samples and certified reference materials were irradiated using fast neutrons, their spectra were measured and analyzed. The experimental results of the water CRM showed very few peaks, excluding background, while the soil CRM showed more peaks of the activated elements, albeit with very low count rates. Among the few elements that were identified are Al, Mn and As.

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Investigation of the Pygmy Dipole Resonance in atomic nuclei using photon scattering experiments

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The Pygmy Dipole Resonance (PDR) is an electric dipole excitation below and around the particle separation threshold [1]. It may be understood, in a macroscopic picture, as a neutron skin oscillation against an isospin-saturated core. Such additional dipole strength on top of the low-energy tail of the Giant Dipole Resonance (GDR) can have a great impact on reaction rates within nuclear synthesis processes, e.g., the rapid neutron-capture process [2,3]. Therefore, it is important to deepen our understanding of the PDR with systematic experimental and theoretical studies.
The so-called Nuclear Resonance Fluorescence (NRF) or photon scattering method is a commonly used experimental approach to study the low-lying dipole response of atomic nuclei [4]. The nuclei are excited from the ground state to an excited state via the absorption of a γ quantum. Due to the fact that photons transfer only small angular momenta, predominantly dipole and with a lower probability quadrupole transitions are excited. The subsequently emitted γ-ray of the de-excitation back to the ground state or to an energetically lower-lying excited state contains information about the level lifetimes, γ-decay branching ratios and spin and parity quantum numbers.
In general, there are two complementary kinds of NRF experiments. Continuous photon sources can be used to investigate a large energy region at once and to determine absolute transition strengths and spin quantum numbers due to the angular distribution of the emitted radiation. Such studies can be performed at, e.g., the bremsstrahlung facilities DHIPS [5] and γELBE [6]. Linearly polarized, quasi-monoenergetic γ-ray beams allow to selectively study excited states in a narrow energy range. In these experiments, branching ratios to lower-lying states can be identified and unresolved strength can be investigated due to the absence of the bremsstrahlung background. Additionally, the polarization in the entrance channel has the advantage that besides the spin quantum number also the parity quantum number can be determined. Such photon beams are provided at HIγS [7] and the upcoming ELI-NP facility [8].
After presenting the NRF technique and available experimental setups relevant for the investigation of the PDR, various results will be discussed.
This work is supported by the BMBF (05P18PKEN9).
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Radiopharmaceutical Radioisotopes

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Over 10,000 hospitals worldwide use radiopharmaceuticals and about 90% of the procedures are for diagnosis. The most common radioisotope used in diagnosis is 99Tc, with some 40 million procedures per year, accounting for about 80% of all nuclear medicine procedures worldwide. The global radioisotope market was valued at 9.6 billion in 2016, and is projected to grow to 17 billion in 2021. North America is the dominant market for diagnostic radioisotopes with close to half of the market share, while Europe accounts for about 20%.

A radiopharmaceutical is a drug that can be used either for diagnostic or therapeutic purposes. It is composed of a radioisotope bond to an organic molecule. The organic molecule conveys the radioisotope to specific organs, tissues or cells. The radioisotope is selected for its properties. Radioisotopes emitting penetrating gamma rays are used for diagnostic (imaging) where the radiation has to escape the body before being detected by a specific device (SPECT/PET cameras). Typically, the radiation emitted by isotope used for imaging vanishes completely through radioactive decay and normal body excretion. The most common radioisotopes used for imaging are: 99mTc, 123I, 201Tl, 111In, 67Ga, 68Ge/68Ga generators, 82Sr/82Rb generators and 18F. Radioisotopes emitting short range particles (alpha or beta) are used for therapy due to their power to lose all their energy over a very short distance, therefore causing a lot of local damage (such as cell destruction). This property is used for therapeutic purposes: cancer cells destruction, pain treatment in palliative care for bone cancer or arthritis. Such radioisotopes stay longer in the body than imaging ones; this is intentional in order to increase treatment efficiency, but this remains limited to several days. The most common therapeutic radioisotopes are: 131I, 90Y, 188Rh and 177Lu. Targeted Alpha Therapy (TAT) or alpha radioimmunotherapy, involve radioisotopes which have a short range of very energetic alpha emissions. Common alpha-emitting radionuclide includes 223Ra, 225Ac, 213Bi and 211At.

The aforementioned radioisotopes can either be produced at reasonable production capacity by a reactor or an accelerator. Before a radiopharmaceutical is available for routine clinical use, the radiopharmaceutical has to demonstrate its efficacy as regulated by the Food and Drug Administration (FDA) in the United States and the European Medicines Agency (EMA) in Europe. This process may generally take up to 5-8 years since inception.This presentation will provide a general overview of the commonly produced radiopharmaceuticals that is used in medicine worldwide.

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Coulomb excitation at LNL with the SPIDER-GALILEO set-up: present status and future perspective

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Low-energy Coulomb excitation is one of the simplest and well known tools to study the nuclear shape, for this reason is widely used at radioactive beam facilities. In particular in the case of ISOL facilities the energy and the intensity of the available beams are suitable for low-energy Coulomb excitation. The SPES facility for the acceleration of radioactive beams will soon provide the first exotic beams at the INFN Legnaro National Laboratories (Padua). With this in mind, the gamma spectroscopy group in Florence has developed and assembled a new particle detector to be used for Coulomb excitation studies of both stable and radioactive beams at LNL. The Silicon PIe DEtectoR (SPIDER) has been coupled to the GALILEO array of germanium detectors, and different experiments have been already performed.
In this talk the performances of the setup, a brief summary of the experiments already performed and the future perspectives with both the available stable beams at LNL and the future radioactive beams by SPES, will be presented.

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Beam intensity improvement of high energy heavy ions beams at iThemba LABS

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There is an increasing interest in high energy heavy ions beams for the study of heavy ion collision physics. The effective acceleration of heavy ions requires high charge states of elements which can in principle be produced in the electron cyclotron resonance (ECR) ion sources at iThemba LABS. However, the intensity of high charge state beams extracted from the source is limited and their transport must be therefore highly efficient. This is especially the case in the low energy region where charge exchange and space charge processes are dominant. In order to improve the transmission from the source through the injector cyclotron to the separated sector cyclotron (SSC), investigations of possible solutions are being investigated. The accomplishments obtained with the recently designed field gradient focusing spiral inflectors and a second 2nd-harmonic buncher will be presented.

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A low-pressure focal plane detector for the K600

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A new position sensitive detector system for the focal plane of the K600 magnetic spectrometer is currently being developed. The existing focal plane detectors (FPDs) were designed to detect Z≤2 ions with kinetic energies 30 MeV/u or higher. A new low-pressure gas-filled tracker combined with a stopping scintillator detector is required to allow for the efficient detection of heavier particles (Z>2) over a range of kinetic energies, as well as light particles (Z≤2) at lower kinetic energies (<30 MeV/u). The different physics cases currently envisaged that require the low-pressure gas-filled detector will be reviewed, and an overview of the design of the new FPD will be presented.

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Process and Stellar Weak Interaction Rates of Waiting Point Nuclei

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The stellar weak interaction rates of proton-rich N⍰Z nuclei in the A ~70 mass region play a critical role during the rapid proton capture process (rp process) in type-I x-ray bursts taking place on the surface of neutron stars accreting hydrogen/helium-rich material from a low-mass close companion star. Nucleosynthesis in explosive hydrogen burning at high temperatures and densities is characterized mainly by the rp-process, a sequence of proton captures and weak interaction processes, $\beta+$ decays and continuum electron captures. An essential role for the rp-process reaction network studies is played by the waiting point nuclei like 68Se and 72Kr on which our studies were focused. The competition between the proton capture rates and the rates of the weak interaction processes at the waiting points affects the process significantly influencing the nuclear energy production rate and consequently the luminosity curves, direct observables of a type I x-ray burst. This competition also determines the burst time scale, the extent of the abundance flow to heavier masses as well as the final composition of the burst ashes.

Self-consistent nuclear structure models able to describe the properties of the experimentally accessible proton-rich nuclei are needed to predict the characteristics of nuclei beyond the experimental reach. Robust predictions on Gamow-Teller strength distributions for the ground state and the thermally populated low-lying excited states in the stellar environment, temperature dependence of the β + -decay rates as well as temperature and density evolution of the continuum electron capture rates during the rp-process are needed to realistically evaluate the effects of weak interaction rates of waiting point nuclei on nucleosynthesis in x-ray bursts. We investigated the impact of complex Excited Vampir beyond-mean-field predictions of stellar weak interaction rates of 68 Se and 72 Kr nuclei dominated by shape coexistence and mixing [1,2] on the rp-process in type-I x-ray bursts.

To explore the influence on burst simulations we used a post-processing approach based on a one-zone model that was adjusted to match a 1-D multizone hydrodynamic result. We performed a series of calculations based on different accreted compositions of hydrogen/helium mixing and metallicity. A comparison of the results obtained using the complex Excited Vampir predictions to the ones based on standard values for the β + -decay rates is outlined discussing the energy generation rates, the hydrogen and helium consumption, and the abundance flow to Sn isotopes reached during the burst. The results are relevant steps towards improved estimates of x-ray burst nucleosynthesis, and

consequently, of the final abundances of the x-ray bursts required for modelling neutron star crust properties.

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Perspectives in Boron Neutron Capture Therapy of Cancer B

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Boron Neutron Capture Therapy (BNCT) is the only form of radiotherapy based on the induction of nuclear reactions selectively in the tumor cells. For these features BNCT has been used as an experimental therapy for disseminated tumors or for cancers for which there is no other effective treatment. Modern BNCT is facing a new era due to the most recent clinical results for the Glioblastoma and Head and Neck cancers [1-3], performed at research reactors, and the substantial change expected from the ongoing projects towards accelerator based neutron sources (ABNS) for this therapy, that can be built in hospitals [4].
In this talk the status of this therapy, the ongoing projects and some research lines towards the improvement of the therapy will be discussed. In addition to the search of more selective compounds in the nanoscale and the development of better neutron sources, there are different problems where active research is being carried. In the field of nuclear physics, an important problem of interest is the dosimetry and treatment planning which is based on Monte Carlo simulations. Reducing the uncertainties of the dose determination both in tumor and in healthy tissue is a key problem for improving the therapeutic outcome. For this purpose, work is being done towards the advances in the knowledge on relevant nuclear [5] and radiobiological data [6] for this application. This work requires experimentation that has to be done at nuclear research facilities by means of interdisciplinary research teams. These will be also described in this talk.

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Isomer spectroscopy of the Titanium isotopes toward N=40.

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The description of shell structure has evolved in recent years extending toward the driplines. The role of shell closures has been challenged and modifications of shell structure have been observed in short-lived nuclei with extreme proton-to-neutron ratio.
The harmonic oscillator shell gap at N=40 is reduced as protons are removed from Ni to Fe and Cr isotopes. Both ^{66}Fe and ^{64}Cr show a decreased energy of the yrast 2^+ state and increased transition probability B(E2; $2^+ \rightarrow 0^+$). The collective behavior is caused by quadrupole correlations which favor energetically the deformed intruder states involving the neutron $g_{9/2}$ and $d_{5/2}$ orbitals and proton excitations across the Z=28 sub-shell gap. Moreover, the proton-neutron tensor force, and in particular the strongly attractive monopole part, is expected to modify the shell structure in this region. These potential changes in the intrinsic shell structure are of fundamental interest for testing the validity of modern residual interactions and their predict power further from stability. The subtle interplay between such shell-evolution mechanisms provokes the modification of the magic numbers and gives rise to new regions of deformation and shape coexistence phenomena. Previous studies indicate ^{64}Cr as the center of a new region of prolate deformation. As in the case of ^{32}Mg along N = 20, shape coexistence should be expected in this region.

We will present some unpublished results from an experiment performed at the RIKEN Nishina Center for Accelerator-Based Science. A high intensity 238U beam impinging on a Be target was used to produce the nuclides of interest in in-flight fission. In the experiment the EURICA gamma-ray array surrounded the implantation detector AIDA into which the fragments of interest were implanted. The fragments were identified using the BigRIPS separator employing the DE-ToF-Brho method. New gamma transitions de-exciting isomeric states, as well as states populated in the beta decay have been identified. In particular new isomers in neutron-rich Ti isotopes are identified. The proposed spin and parity assignments will be motivated and the implication for the structure of the isotopes will be discussed in comparison to state-of-the-art shell-model calculations.

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In-flight Radioactive Isotope Beam Facilities and Nuclear Physics at RIKEN

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Since 1990's, the advent of in-flight radioactive isotope beams has created great opportunities for studies of the nuclear structure in short-lived exotic nuclei and of reactions with exotic nuclei, and many interesting natures of exotic nuclei have been discovered and our modern picture of the structure has been seriously questioned. In addition, the studies are essentially important for understanding the element synthesis processes in the universe, especially for those heavier than iron. To study the structure and reactions further, next generation heavy-ion accelerator facilities are being newly constructed or intensively discussed all over the world.
As one of the in-flight facilities, I would introduce the RI Beam Factor (RIBF) facility in Japan, and its scientific programs. Special emphasis would be given to selected highlights for nuclear physics as well as applied ones. Coming upgrades of the accelerator complex and scientific plans are introduced and discussed.

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Nature of the Pygmy Dipole Resonance: A multi-messenger approach

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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 140Ce we have combined the results from experiments using the (g,g'), (a,ag') at E = 134 MeV and (p,pg') 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 gamma3 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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Searching for Shape Coexistence in 70Se

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The shape coexistence phenomenon is prevalent in the Z~34 region, with multiple neutron-deficient even Ge [1] , Se [2] and Kr [3] isotopes each exhibiting the characteristic low-lying coexisting 0^+ bands which display quadrupole deformation different to that of the ground states.
In the selenium isotopes, coexisting shapes $^{72-78}$Se seem to show a prolate ground structure with coexisting oblate excitation [4,5,6], while in ^{68}Se the oblate structure appears to have become the ground state [7]. In ^{70}Se however, not only is the ground state shape uncertain [8], a low-lying 0^+ state has yet to be identified. Recent work in neighbor Kr isotopes has pushed to ^{70}Se's isospin partner ^{70}Kr and identified states thought to be part of a shape coexisting structure [9]. With our picture of the region rapidly evolving the uncertain structure of ^{70}Se stands out as a clear remaining question.

The SPectrometer for Internal Conversion Electrons (SPICE) is one of the latest generation of tools for studying Internal Conversion Electrons (ICE) [10]. The spectroscopic study of ICE is one of the primary means available for the study of electric monopole (E0) transitions, which are themselves a key observable in the study of nuclear shapes and shape coexistence.
Using SPICE an experimental investigation was undertaken at the TRIUMF ISAC-II facility which

aims to confirm the presence of the anticipated coexisting 0^+ band-head in ^{70}Se. Details of the device and experiment will be presented, alongside the latest results of analysis.

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Helium Decays of Excited States and Clustering in 17,18O

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Light nuclei are excellent test samples for structure models because of small number of included degrees of freedom. Recent progress in ab initio calculations of light nuclei in various frameworks demands more precise experimental spectroscopic data for identified key nuclear systems. The most advanced models are able to reproduce single particle and clustering features of light nuclei with up to 20 nucleons. Exotic cluster structures based on alpha-cores and valence neutrons are predicted and their experimental verification is crucial for further advancements in nuclear structure research. One of the key nuclear systems is oxygen isotopic chain where single particle concept and clustering are both clearly manifested. Available experimental results on these nuclei are still insufficient to unveil these exotic structures.
Studies of the 4He decays of the 17O excited states were performed by measurements of the 13C + 4He thick gas target resonant scattering at the Ruder Boskovic Institute Tandem accelerator at the beam energies E(13C) = 20, 25, 30, 33 and 35 MeV and the 13C + 9Be resonant particle spectroscopy measurements using the 13C beam energy of 72 MeV at the Institut de Physique Nucléaire Orsay Tandem accelerator. In these experiments highly pixelized large silicon detector arrays were used for identification of detected nuclei. The later experiment provides also results on the 4,6He decays of the 18O excited states. The 13C + 4He resonant elastic scattering experiment provided the excitation function of the 17O at ≈ 0◦ in LAB system. Obtained results extend the available data, covering excitation range 11.1 MeV < Ex(17O) < 13.8 MeV, and include states of particular interest at the 12.0 MeV and 13.6 MeV. Complete kinematics measurements of the 13C + 9Be reaction enable full reconstruction of the recorded events, identification of various reaction exit channels and identification of the decaying excited states. Decays of the 17O excited states into the alpha+13C and alpha+13C*(Ex = 3.7 MeV) are identified. New information on the alpha+14C and alpha+14C*(Ex ≈ 7 MeV) decays and, for the first time, evidence for the 6He+12C decay of the 18O excited states have been obtained. Decays by the 5He and 8Be emission are not observed. Obtained results are discussed in terms of clustering in neutron-rich oxygen isotopes. The results indicate possible exotic cluster structure in 18O.

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Nuclear Structure at the Australian National University through Moments, Monopoles and Transition Rates

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A vibrant program of nuclear structure studies through γ-ray and electron spectroscopy, together with magnetic-moment measurements, continues at the Australian National University. We have strong two-way international collaborations whereby we perform experiments at international facilities and also welcome international collaborators to perform experiments in our laboratory.

One of our research themes concerns the structure of nuclei near ^{132}Sn and the emergence of collective structures as protons are added to and neutron removed from ^{132}Sn. This work includes the analysis of Coulomb excitation data on radioactive beams from HRIBF (Oak Ridge National Laboratory) combined with on-going Coulomb excitation and magnetic- moment measurements at ANU on stable beams. Recently, with colleagues from the University of Kentucky, we have explored the development of collectivity in the ^{132,134,136}Xe isotopes by comparing detailed level schemes, transition rates and g factors with results of large-basis shell model calculations.

Electron and gamma spectroscopy underway for some years now to measure the radiative width of the Hoyle state is converging on a new value which improves the precision and differs by some tens of percent from the current adopted value. We are also focusing on E0 strengths near N=Z=28 in the stable isotopes of Cr, Fe and Ni. We are finding strong E0 transitions in the semimagic nuclides. Additional studies with international collaborators include E0 measurements on ^{24}Mg (UK) and ^{40}Ca (Japan).

Other work concerns: developing the time-dependent recoil-in-vacuum method for g-factor measurements on Na-like ions, developing fast timing measurements of g factors and lifetimes using LaBr3 detectors, and a reassessment of the Doppler broadened line shape method for lifetime measurements on picosecond states.

Highlights selected from our work will be presented.

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Double beta decay, weak axial coupling and reactor antineutrino spectra

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The neutrinoless double beta (0) decay of atomic nuclei is a possible way to access the nature and mass of the neutrino. These unknown features of the neutrino can be tackled by the 0- decay experiments. In a simplistic picture the rate of 0 decay depends on the second power of the double Gamow-Teller nuclear matrix element, M(0) GTGT, containing virtual transitions through various multipole states J of the intermediate nucleus. The matrix element is multiplied by the second power of the effective (quenched) value, geff A , of the weak axial-vector coupling gA. The coupling geff A plays an extremely important role in determining the 0-decay rate since the rate is proportional to its 4th power. The quenching issue, as also the nuclear matrix elements calculated in different

many-body formalisms, have become very important in the neutrino-physics
community due to their impact on the sensitivities of the present and future large-scale 0-decay experiments. The effective value of gA can be studied in single beta decays of various kinds, as also in the nuclear muon capture which involves momentum exchanges of the same order (100 MeV) as the 0 decay. In these cases geff A determines the beta-decay half-lives and spectrum shapes of the emitted electrons/positrons. It also determines the muon-capture rates together with the (effective) induced pseudoscalar coupling. Furthermore, recent experimental and theoretical efforts have lead to the first indications of a muon-capture giant resonance. The effective value of the axial coupling can have a strong impact on the beta-spectrum shapes, on 0-decay rates and, e.g., the analysis of the reactor-antineutrino anomaly. These issues have been discussed in the recent review articles [1,2].

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Nuclear Astrophysics at n_TOF neutron beam facility at CERN

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Neutron capture reactions are of utmost importance for the quantitative understanding of stellar nucleosynthesis and in a number of other significant topics of nuclear astrophysics. The n_TOF facility provides unique possibilities for establishing reliable and accurate data for this class of applications. To address the still open issues in stellar and primordial nucleosynthesis, the n_TOF Collaboration has been carrying out during the course of almost twenty years an ambitious experimental program on nuclear capture reactions with the aim of reducing the uncertainty on cross sections relevant to s-process nucleosynthesis and improve the reliability of astrophysical models. Several high-quality results have been obtained thanks to the innovative features of the neutron beam of the n_TOF facility at CERN, in particular the high resolution in the first experimental area at 200 m flight path and the very high instantaneous neutron flux, very convenient in particular for measurements of radioactive isotopes. More recently, the construction of a second experimental area at shorter flight path (20 m) opened the way to very challenging measurements of (n,γ) and (n, charged particle) reactions on isotopes of short half-life, or reactions with very low cross sections, or for isotopes available in a small amount.
After a brief description of the facility and of the detection systems employed in the measurements, the program of the n_TOF Collaboration in Nuclear Astrophysics will be presented in this talk, with particular emphasis on the recent results relevant for stellar nucleosynthesis, stellar neutron sources and primordial nucleosynthesis.

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Low-lying dipole strength in neutron-rich Ca isotopes 50,52Ca

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The neutron skin have attracted much attention in connection with the symmetry energy of the nuclear equation of state. The low-lying electric dipole modes, sometimes called as pygmy dipole resonance (PDR), located at 6~10 MeV is considered to be related to the neutron skin, since PDR is often considered as an oscillation of the excess neutrons against the isospin saturated core. However,

the origin and structure of PDR is still under debate.
Recently, a theoretical work showed that the PDR strengths are rapidly enhanced at the neutron number *N*=28~34, and it is due to the occupation of low angular-momentum orbit by the valence neutrons [1]. In addition, it is also shown that the PDR strength in 52Ca (*N*=32) is well correlated to the neutron skin thickness [2]. To investigate experimentally the evolution of the PDR strength in *N*=28~34 region and to constrain the neutron skin thickness of 52Ca, the electric dipole response of 50,52Ca have been measured by using the relativistic Coulomb excitation in inverse kinematics.
The experiment was performed at RIKEN RIBF. The secondary beams of 50Ca and 52Ca were produced via the fragmentation of 345 MeV/nucleon 70Zn primary beam. The 50,52Ca beams were impinged on Pb and C targets. The outgoing charged particles and neutrons were measured by the SAMURAI spectrometer and the neutron detectors, respectively. The neutron detectors were combination of NEBULA and the NeuLAND demonstrator. The de-excitation gamma-ray from the reaction residue was measured by the gamma-ray detector CATANA and LaBr3 detectors. The excitation energy of 50,52Ca was reconstructed by using the momenta of outgoing particles including the gamma-rays.

In this talk, we will report on the low-energy electric dipole strength in 50,52Ca and discuss its evolution along the neutron number.

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Indirect Experimental Methods and 12C+12C Fusion

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C-burning plays a pivotal role in astrophysics, from the nucleosynthesis of massive stars, to explosive scenarios in carbon-rich environments such as superbursts from accreting neutron stars and type Ia Supernovae [1-4]. Carbon burning occurs at temperatures greater than 0.4 GK, corresponding to center-of-mass energies exceeding 1 MeV. The dominant evaporation channels below 2 MeV are a and proton, leading to 20Ne and 23Na, respectively. In spite of the considerable efforts devoted to measure the 12C(12C,α)20Ne and 12C(12C,p)23Na 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, indirects approaches can represent a unique way for an accurate investigation at the relevant energies. In particular indirect information on the energy trend plus 24Mg levels that may play a role in the 12C+12C low-energy fusion has been obtained through the 12C+13C and 13C+13C fusion [6]. Recently, the Trojan Horse Method [7] has been applied in the measurement of the 12C(14N,α20Ne)2H and 12C(14N,p23Na)2H three-body processes [8]. The measurement was performed at 30 MeV of 14N 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 from indirect experiments will be presented and discussed.
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The Electron-Ion Collider

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The 2015 Long Range Plan for Nuclear Science in the US recommends a high-energy, high-luminosity polarized Electron-Ion Collider (EIC) as the highest priority for new facility construction after the completion of FRIB. A U.S.-based EIC has also recently been endorsed by the U.S.
National Academies of Sciences finding the scientific case for the EIC compelling, unique, and timely. The EIC will, for the first time, precisely image gluons in nucleons and nuclei. It will reveal the origin of the nucleon spin and will explore a new quantum chromodynamics (QCD) frontier of ultra-dense gluon fields.
This science will be made possible by the EIC's unique capabilities for collisions of polarized electrons with polarized protons, polarized light ions, and heavy nuclei at high luminosity.
In my talk I will give an overview of the physics motivation and program of an EIC. The talk will also cover the current machine designs as well as detector concepts.

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The highly efficient neutron detector NEDA reveals the structure of proton-rich nuclei populated in fusion-evaporation and transfer reactions.

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Over the last decades nuclear spectroscopy has shown its capabilities to investigate the effective nucleon-nucleon interaction in nuclear matter. Technically, this has been possible thanks to the continuous improvement in germanium γ-arrays performances and in their associated instrumentation, that has allowed an enormous increase of the experimental sensitivity.
In this presentation, I would like to discuss the progress achieved in nuclear structure physics thanks to the newly constructed neutron-detector array NEDA [1], that was recently coupled with the state-of-the-art gamma-ray spectrometer AGATA at GANIL. In particular, I will address the octupole collectivity development when approaching the N=Z line in the Xe isotopes. This mass region is noteworthy since the Fermi surface for both protons and neutrons lies between the non spin-flip orbitals $2d_{5/2}$ and the $1h_{11/2}$, with ΔL=ΔJ=3, where the octupole correlation is expected to be enhanced. In fact, the B(E3) transition probability measured in the neighbour isotope ^{114}Xe is one of the highest reported experimentally [2].
In addition, I will discuss the possibility to use in the future neutron detectors, such as NEDA, to perform inverse kinematics transfer reactions, with radioactive ion beams, where the emitted particle is a neutron. I will concentrate in the ^{36}Ca case, where the intruder 0^+ state in ^{36}Ca is predicted at 2.7 MeV, i.e. 720 keV below its mirror nucleus ^{36}S; this represents the largest Mirror Energy Difference (MED) in the whole Segr\'e Chart for bound states. This phenomenon has been dub Colossal Mirror Energy Difference (CMED) [3]. A two-proton transfer reaction, such as ^{3}He(^{34}Ar,n)^{36}Ca will give access to the intruder 0^+ to study its intruder nature.

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Recent developments at ISOL-based RIB facilities

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Radioactive ion beam research plays an essential role in answering key questions in the fields of, amongst others, nuclear physics and nuclear astrophysics. Progress depends to a large extend on continuous innovative developments in the production and manipulation of the radioactive ion beams and in instrumentation. Moreover, the field of radioactive ion beam research has reached a level of maturity where its "discovery frontier" (new isotopes/elements, new nuclear-structure phenomena) is being extended with a "high precision frontier".

In this contribution, a short overview of the different ISOL-based radioactive beam facilities and some examples of recent progress in the field of ISOL-based radioactive ion beam research will be discussed and their impact on the current research programs as well as on future program will be addressed.

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Radiation biophysics research at iThemba LABS

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iThemba Laboratory for Accelerator Based Sciences (LABS) is a multidisciplinary research facility that is based on the development, operation and use of particle accelerators and related research equipment. Besides the production of radioisotopes for medical applications, the radiation biophysics division at iThemba LABS provides a unique opportunity to perform applied nuclear physics research in Africa, which is closely linked to the medical field. By combining the expertise of the medical physics and radiation biology research groups at iThemba LABS, the overall goal of this research division is to explore the physical and biological interactions of different radiation qualities (both external radiation beams and radioisotopes) on a variety of biological systems. In addition, the division has a close collaboration with local universities in South Africa and international research institutes, in order to train the new generation of researchers in critical skills areas such as radiation biology.

The multidisciplinary research in the division covers many different topics which can be summarized in the following categories:

- Particle therapy
- Targeted radionuclides
- Radiation protection
- Space research

The medical research directions tie in with state-of-the-art radiation therapy where personalised medicine is becoming a reality. Both charged particles and targeted radionuclides will play an important role in the future of precision radiation therapy. Since major breakthroughs in this field are expected from radiobiology research, the division is investigating complex functional end points to elicit the biological response signature of charged particles across the molecular and tissue level and the impact of combined treatment regimens. The different research project are aligned with national research priorities by investigating the impact of HIV infection and ethnicity on the radiosensitivity of radiation therapy patients in South Africa.

The division serves the broader community by offering a biodosimetry service and is continuously upgrading and improving its capacities by undertaking radiation protection related research projects.

The unique neutron radiation modalities at iThemba LABS play a central role in these projects, since large uncertainties remain on the relative biological effectiveness of neutrons, particularly for low-dose and protracted exposures. In addition, the number of facilities that provide neutron beams for biological research is worldwide very limited.
Recently, the division started the INVEST project, which aims to optimize and validate a unique ground-based in vitro model to study space health effects. Space travel comprises a unique and complex stress model composed of physical (i.e. cosmic radiation and microgravity) and psychological stressors. Through this project we aim to optimise and validate a ground-based set-up to simulate the space environment for in vitro studies on lymphocyte subsets and hematopoietic stem/progenitor cells, in order to evaluate the impact of individual and combined space stressors on the immune system and leukaemia risks of astronauts. The implementation of this ground-based model at iThemba LABS over the next three years will result in the first space laboratory for life sciences in Africa, which will form a basis for future collaborations and innovative research projects.

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A microscopic treatment of correlated nucleons: Collective properties in stable and exotic nuclei

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Collective excitations are a common feature of several many-body systems and a widely observed phenomenon throughout the nuclear chart. A model which is often used to describe collective excitations is the random-phase approximation (RPA), where the excited modes are superpositions of 1 particle-1 hole configurations only. The RPA allows in general for a satisfactory description of excitations in nuclei, both low-lying states and giant resonances.
However, being based on a mean-field or independent-particle picture, the RPA model fails to reproduce the fragmentation and the spreading width of excitations. For example if one wishes to account for the spreading width of resonances, which can be observed experimentally, one has to go beyond this simple mean-field-based model. A possible way to do so is to add 2 particle-2 hole configurations in the model, which is known as Second RPA (SRPA). Yet SRPA in its standard form presents severe drawbacks, such as the double-counting of correlations, instabilities or divergences. All these limitations can be overcome by a correction method, consisting in a subtraction, the so-called Subtracted SRPA (SSRPA). A systematic application to the giant quadrupole resonances of selected spherical nuclei, ranging from ^{30}Si to ^{208}Pb, will be shown to demonstrate its corrective power.
A first extension of this scheme can be carried out to treat also open-shell nuclei. A second extension amounts to using a correlated ground state, thereby allowing to include pairing correlations for instance. Such methods will be presented with the corresponding first results.

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Gamma-Ray Imaging: Making Radiation Visible in 3D

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Gamma-ray imaging is a well-established modality to detect, localize, and track radioisotopes or materials that are attached to them. In well-established applications for gamma ray imaging in nuclear medicine, biomedical imaging, or astrophysics, the motion of the imaging instrument relative to the object is well defined and a limited field-of-view is sufficient to image within the constrained extension of the radiation field. In contrast to these "constrained" applications, in many radiological search and mapping scenarios, the radiation fields are not constraint and objects and source locations are not necessarily known prior to the measurement. Recent advances in computer vision along the development of compact and hand-portable imagers provide new means to map gamma-radiation in 3D by moving the instrument freely through unconstrained radiation fields.
In our Berkeley Applied Nuclear Physics program, we have developed hand-portable, omnidirectional coded-aperture and Compton-scattering based gamma ray imagers that are complemented with contextual sensors to realize what we call 3D Scene Data Fusion (SDF). Contextual sensors such as visual cameras and LiDAR are used to create 3D scenes while at the same time providing position and orientation estimates of the gamma-ray imager. 3Dfused gamma-ray images are then be produced by back-projecting the radiation into the scene in 3D, for example utilizing list-mode maximum-likelihood expectation maximization algorithms. SDF can be seen as the analog to dual-mode imaging in biomedical imaging as it combines sceneor anatomical images of the environment with gamma-ray images in 3D. This can be done in realtime and realized on a wide range of manned and un-manned platforms. We will discuss the basis of SDF and examples of applications to visualize gamma radiation in 3D, in real time, and in "color", i.e. according to gamma-ray energies and therefore for specific radioisotopes

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Radiation effects studies and Industrial Applications at JYFL

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After the start of space conquest studies of radiation induced effects on satellite electronics have been necessary to verify the operation of the components in the harsh radiation environment of space. The radiation errors can roughly be classified in two categories; Total Ionizing Doses (TID) and Single Event Effects (SEE). TID tests are carried out in numerous world existing Co-60 laboratories, but SEE -tests are conducted in much less common accelerator laboratories.

In this paper a RADiation Effects Facility, RADEF, located in the Accelerator Laboratory of University of Jyväskylä (JYFL), Finland, is introduced. RADEF performs SEE tests using a K130 cyclotron and Electron Cyclotron Resonance (ECR) type ion sources. The tests are done under the contract with European Space Agency, ESA. Since 2005 almost 100 customers have carried out test campaigns at RADEF. In addition to ESA and European satellite industry, many tests are also performed to other national space organizations like NASA (US), JAXA (JP), CNES (FR) and CNSA (CN). This industrial application work is done on a commercial basis by using about 20 % of laboratory's total beam time.

In most cases the use of a very large accelerator is not justified for radiation effect studies. It cannot provide fast and cost effective ion changes and the beam price is blocking too much off the total costs of the project. This can be done more economically using a medium sized cyclotron and high charge state beams by accelerating so-called ion cocktails. They contain several ion species with a wide range of linear energy transfer (LET) values in the target material. The cocktails are designed to contain ions with similar m/q fractions, enabling fast switching between the ion species. The beam intensities required are very low — about 106·s−1 or 100 fA is usually sufficient.

Currently most of the tests in Jyväskylä are done at 9.3 MeV/A energy achievable with the charge states produced by the 14 GHz ECR ion source. The space community has shown a strong desire to

reach 15 MeV/A, which is approaching the limits of what can be achieved without super conducting ECR technology. The desire has initiated a project to push the performance of regular conducting ECR by building an 18 GHz ion source HIISI (Heavy Ion Ion Source Injector). The evolution of RADEF from 500 MeV facility up to 2 GeV facility is discussed more detail in the paper.

The emerging technologies make electronics more susceptible to radiation and even relatively low radiation levels can lead to important risks, not limited only in space. This industrial networking has facilitated new applied research projects at RADEF. One example is RADSAGA (RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators), which is funded by EU and coordinated by CERN. The project brings, for the first time, together European industry, universities, laboratories and test-facilities in order to educate 15 PhDs, three of them doing thesis at RADEF. This paper also discusses the prospects for radiation effects that have emerged with RADSAGA project.

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Clustering and collectivity in the nuclear many-body dynamics

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In this presentation we discuss the emergence of clustering degrees of freedom in the nuclear many-body dynamics. We concentrate on alpha clustering broadly defined here as four-nucleon correlations that are of interest both as in-medium correlations and as real alphas seen in reactions.
Using configuration interaction approach and center-of-mass boosting technique we explore realistic and model hamiltonians assessing appearance and prevalence of clustering correlations, their collectivity and potential for bosonic enhancements in N=Z nuclei.
Interplay of these correlations with other dynamical features such as single-particle motion, pairing, collective rotations and particle decay are to be discussed.

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Evolution of the Dipole Response in the Stable Sn Isotope Chain: Polarizability, Pygmy Dipole Resonance and Gamma Strength Function

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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 on the Equation of State of neutron-rich matter [3-5]. They also shed new light on the much-discussed nature of the Pygmy Dipole Resonance (PDR) observed in nuclei with neutron excess [6,7]. Since the data also provide information on the spin-M1 strength [8,9], one can extract the full Gamma Strength Function (GSF) [10]. The high-resolution experiments furthermore allow an extraction of the level density (LD) [11], and the combined GSF and LD results permit a novel test of the Brink-Axel hypothesis for GSFs in the energy region of the PDR [11].
The chain of Sn isotopes represents a particularly interesting case to investigate the impact of neutron excess on the E1 response of nuclei in a systematic manner because their g.s. structure changes

little. We report results from a systematic study of the stable even-mass nuclei 112,114,116,118,120,122,124Sn on all of the above problems.

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Study QCD Phase Diagram in High-Energy Nuclear Collisions

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Exploring the QCD phase structure of hot and dense nuclear matter is one of the main goals of the RHIC Beam Energy Scan (BES) program. Started in 2010, the first RHIC BES program covered the center of mass collision energy of √□ = 7.7, 11.5, 14.5, 19.6, 27, 39, 54.4, 62.2 and 200GeV corresponding to the chemical potential range □ ≈ 420 − 20MeV. I summarize the properties of the medium created in ultra-relativistic heavy-ion collisions into three Cs: (i) Collectivity that represents the collective motion of the system including anisotropic flows; (ii) Chirality describes the results that are connected to Chiral properties, such as the recently hotly debated CME, CVE results; and (iii) Criticality covers the observations that may be linked to the illusive QCD critical point. For example, the end point of the first-order phase boundary. In this talk, I will focus on the results from the first phase BES at RHIC, especially on results that are related to Collectivity and Criticality. In addition, I will discuss the upgrades at STAR experiment and the physics for the second beam energy scan program at RHIC.

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Extreme Light Infrastructure-Nuclear Physics (ELI-NP) Present status and Perspectives

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Extreme Light Infrastructure – Nuclear Physics (ELI-NP) is a 310 Meuro project under implementation (2013-2020) in Măgurele, Romania. The aim of the project is to build a Pan-European Centre for scientific research in nuclear photonics based on two major instruments, a high-power laser system with 2x10 PW laser beams and a high intensity gamma beam system. ELI-NP will provide new opportunities for the study of fundamental processes that occur in light-matter interaction, will study the photonuclear reactions and will actively promote its applications for the benefit of society. A series of beyond state-of-the-art experimental setups are under construction around the two major

instruments. Present status of the implementation and the scientific program of the new Centre will be presented.