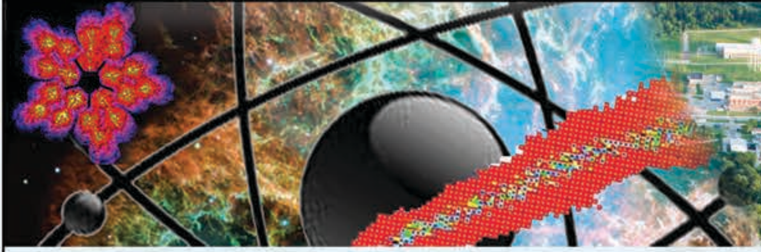

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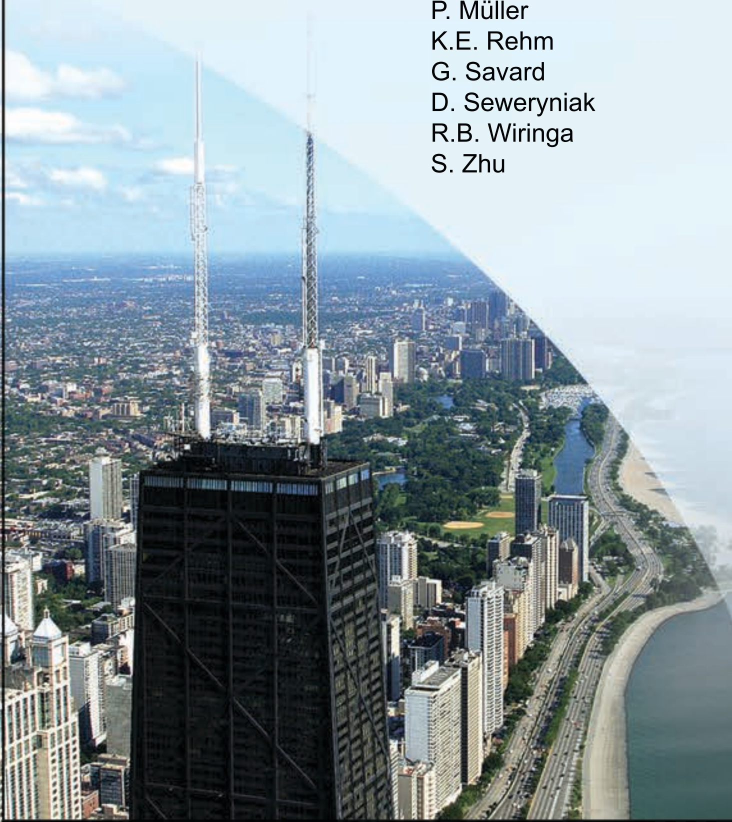

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TOWARDS SPECTROSCOPIC QUALITY ENERGY DENSITY FUNCTIONALS

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Density functional theories [DFT] (both in relativistic [covariant] and non-relativistic incarnations) are well established theoretical tools for the description of nuclear systems. However, there are still a number of important topics which have not been either addressed or satisfactorily resolved within their frameworks. One of them is the description of the single-particle degrees of freedom.

In our study of these degrees of freedom we use covariant density functional theory [CDFT] [1]. The polarization effects in time-even (deformation changes) and time-odd (single-particle alignments) mean fields induced by a particle(s) are well described in DFT. This shows that some aspects of the single-particle motion are described on average better and in a more consistent way in self-consistent DFT than in phenomenological microscopic+macroscopic (MM) method. On the other hand, systematic investigation of the energies of deformed one-quasiparticle states in actinide and rare-earth mass regions [2] shows that nuclear spectra are not that well described. It is obvious that the DFT theories do not possess spectroscopic quality description of the single-particle spectra which is achievable in the MM method as a consequence of the fit of the potential parameters to experimental single-particle energies. The sources of the discrepancies between CDFT and experiment are analyzed.

Although some improvements in the description of nuclear spectra can be achieved by better parametrization of the energy density functional, the analysis of Ref. [2] suggests that spectroscopic quality of their description can be achieved only in theoretical framework which takes into account particle-vibration coupling. This has been illustrated on the example of spherical nuclei in Ref. [3]. In this work, particle-vibration coupling is treated fully self-consistently within the framework of the relativistic particle-vibration coupling model and polarization effects due to deformation and time-odd mean field induced by odd particle are computed within CDFT. The impact of particle vibration coupling on different physical observables such as the energies of predominantly single-particle states, the spin-orbit splittings, the shell gaps, the energy splittings in pseudospin doublets will be illustrated in spherical nuclei ranging from light up to superheavy ones.

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Study of the low-lying structure of the N=49 nucleus ^{81}Ge

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The study of low-lying levels of nuclei near closed shells not only elucidates the evolution of nuclear shell structure far from stability, but also affects estimates of heavy element nucleosynthesis in supernova explosions. Currently, there is little experimental data for those nuclei away from stability. This is particularly the case on the the neutron-rich side, where changes in the shell structure are expected near the drip line. The low-lying levels of the N=49 nucleus ^{81}Ge have been studied by measuring the ^{80}Ge(d,p)^{81}Ge reaction at 310 MeV (3.875 MeV/u) in inverse kinematics at the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory. The excitation energies of low-lying levels were measured. The primary goal of this work is to determine the spins of ^{81}Ge levels using the observed angular distributions of protons. Details of the experimental setup and a status report on the data analysis will be discussed.

*This work was supported in part by the U.S. Department of Energy Office of Nuclear Physics and National Science Foundation.

Evidence for a smooth onset of deformation in the neutron-rich Kr isotopes

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Nuclei in the neutron-rich A≈100 mass region are well suited for the understanding of evolution of nuclear deformation from spherical to strongly deformed ground-state shapes. By adding only a few neutrons to the N=50 shell closure, deformation and, thus, collective effects occur quickly. For the Z=40 (Zr) isotopes, the neutron number N=56 becomes an effective shell closure, so that ^{96}Zr has characteristics of a doubly-magic nucleus. Adding only a few neutrons more, the Zr-isotopes get strongly deformed. This behaviour indicates a shape phase transition around N=60. For the Z=38 (Sr) isotopes the systematics show a similar behaviour, whereas for the Z=42 (Mo) and Z=44 (Ru) isotopes, this rapid change of the shape seems to be attenuated.
The aim of this work was to investigate the behaviour of the even-even Z=36 (Kr) isotopes in this phase transition region by determining the energies of the 2_1^+ states and their E2 decay transition strengths to the ground state in ^{94}Kr (N=58) and ^{96}Kr (N=60). Information on the energies of the first excited 2^+ states exist only for the Kr isotopes up to N=58. For N=60, contradictory results on this observable were published recently.
To clarify this contradiction several experimental runs were performed at the REX-ISOLDE facility at CERN between 2009 and 2011, utilizing the high-efficiency MINIBALL gamma-ray spectrometer and analyzing the emitted gamma-rays and scattered particles after the Coulomb-excitation reactions. The results of these experiments will be presented and discussed in the framework of the proton-neutron interacting boson model based on the constrained Hartree-Fock-Bogoliubov approach using the microscopic Gogny-D1M energy density functional.

Role of the $\nu(g_{9/2})$ orbital in the Ni isotopes*

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The A≈60 mass region of the nuclear chart provides a testing ground for the study of competing single-particle and collective excitations. One of the features of the region is the apparent doubly-magic character of ^{68}Ni (Z=28, N=40), as indicated by the high excitation energy of the 2_1^+ state and the low B(E2; $2_1^+ \rightarrow 0^+$) reduced transition probability. Interestingly, the neighboring N=40 isotones ^{64}Cr, ^{66}Fe and ^{70}Zn do not exhibit the same properties and the onset of collectivity has been suggested [1], implying that the N=40 shell gap is perhaps limited to the Ni isotopes. Recent investigations in ^{67}Ni [2], for example, attest to the relative weakness of the shell gap. Clearly, a number of structural effects play a role and recent theoretical work has pointed not only to the importance of the tensor force [3], but also to the role of shape-driving orbitals, in particular the $\nu(g_{9/2})$ and $\nu(d_{5/2})$ states [4].

Rotational structures associated with at least one $g_{9/2}$ neutron orbital have been observed in $^{55-57}$Cr and $^{56-61}$Fe isotopes [2]. By analyzing and comparing the properties of these observed high-spin structures, the evolution of the shape-driving effects by the $\nu(g_{9/2})$ orbital was inferred. In order to obtain information on shape-driving effects in the $^{60-65}$Ni isotopes from their behavior at high spin, an experiment was performed at ATLAS with Gammasphere and the Fragment Mass Analyzer (FMA). The Ni isotopes were produced by bombarding a 2 mg/cm^2-thick ^{26}Mg target with a ^{48}Ca beam at energies between 275 and 320 MeV. A and Z identification of the residues was achieved at the FMA focal plane. Excited states were populated with spins up to ~25 ħ and excitation energies as high as 22 MeV. Signatures for collectivity and large deformation were found in several of the Ni isotopes of interest. The results will be presented and compared to observations in other nuclei of the region and to calculations.

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Resolving $B(E2)$ Discrepancies in the Ni, Sn, and Te Isotopes by Coulomb Excitation in Inverse Kinematics

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Recent DSAM measurements of the stable Ni and Sn isotopes [1, 2] have shown significant deviations in the extracted $B(E2)$ values from the adopted literature [3]. In order to clarify these discrepancies, a HPGe and CsI array (CLARION+HyBall) was used to study the Coulomb excitation of ^{58,60,62,64}Ni($Z = 28$), ^{112,114,116,118,120,122,124}Sn($Z = 50$), and ^{130,134}Te($Z = 52$) in inverse kinematics with natural-carbon targets; this method has the benefit of employing pure beam and target combinations. Scattered target nuclei are measured at forward angles relative to the beam direction (corresponding to backward angles in the center-of-mass frame) to provide a clean trigger for selecting the γ-ray transitions from the Coulomb-excited beam and to normalize the integrated beam current through Rutherford scattering. Furthermore, a Bragg-curve detector was used at zero degrees to measure the energy losses through the target directly. The beams were kept at "safe" energies (i.e., surface separation > 5.1 fm) and the "safe" condition was checked directly by running at multiple beam energies (i.e., above and below "safe") for a few select nuclei. High-precision $B(E2; 0_1^+ \to 2_1^+)$ e^2b^2 values are obtained for these critical shell-model nuclei and are found to be in disagreement with the recent DSAM studies [1, 2].

*Research sponsored by the Office of Nuclear Physics, U.S. Department of Energy.

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Electron Capture Branching Ratio Measurement of ^{116}In Using the TITAN Facility

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We have investigated the electron capture (EC) decay of ^{116}In by means of in-trap decay spectroscopy at TRIUMF, Canada's National Laboratory for Nuclear and Particle Physics. This technique takes advantage of the intense and isotope-separated radioactive beams produced at ISAC, the ion trap facility called TITAN, and seven dedicated X-ray detectors placed around an open-access Penning trap. Compared to other techniques this setup provides a relatively low background environment of ions stored in the Penning trap allowing for weak EC branching ratio measurements.

The main focus of the in-trap decay spectroscopy program at TITAN is the measurement of weak EC branching ratios of several intermediate odd-odd nuclei in double beta decay [1]. These experiments will be performed to improve our knowledge of nuclear matrix elements related to neutrinoless double beta decay, which in turn are related to one of the key questions of neutrino physics, namely the character of the neutrino, i.e., Majorana or Dirac particle.

The ^{116}In EC branching ratio measurement was motivated by the current disagreement between experimental values obtained from charge-exchange reactions [2] and conventional EC/β decays [3]. Moreover, the experiment was also used for updating and further development of the experimental set-up with seven Si(Li) detectors assisted by digital electronics. A description of the technique, the experimental setup, and the ongoing analysis along with GEANT4 simulations will be presented.

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HIGH-SPIN HIGH-SENIORITY STATES IN TIN ISOTOPES

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The identification of states involving *n* identical nucleons in the same orbit *j*, i.e. states with the j^n configuration, is a straightforward application of the nuclear shell model. While there are numerous examples of states with seniority v=2 in the literature, only a few states with v=4 are known. The Sn isotopic chain is an ideal laboratory to study the case of $\nu(h_{11/2})^n$, particularly the highest spin states expected for *n*=4,5 and 6.

In our work, the $^{119\text{-}126}$Sn nuclei have been produced as fission fragments in two reactions, both using thick targets, induced by heavy ions: ^{12}C+^{238}U at 90 MeV bombarding energy, and ^{18}O+^{208}Pb at 85 MeV. Their level schemes have been built from gamma rays detected using the Euroball array. In order to identify new isomeric states in fission fragments, we have also performed another experiment using the SAPhIR fission-fragment detector, in order to trigger the Euroball array and isolate the delayed γ-ray cascades. For this purpose we have used the ^{12}C+^{238}U reaction at 90 MeV, with a thin ^{238}U target (0.14 mg/cm^2).

High-spin states located above the long-lived isomeric states of the even-A and odd-A $^{120\text{-}126}$Sn nuclei have been identified. Moreover new isomeric states lying around 4.5 MeV have been established in the even-A $^{120\text{-}126}$Sn from the delayed coincidences between the fission fragment detector SAPhIR and the Euroball array. All the states located above 3-MeV excitation energy are ascribed to several broken pairs of neutrons occupying the $h_{11/2}$ orbit. The maximum value of angular momentum available in such a high-*j* shell, i.e. for mid-occupation and the breaking of the three neutron pairs (seniority v=6), has been identified in several tin isotopes. It is the first time that such high-seniority states are established in spherical nuclei [1].

In this talk we will present and discuss these new results.

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NUCLEAR STRUCTURE IN THE NEUTRON-RICH N=50 REGION FROM HIGH-SPIN STUDIES: TOWARD ^{78}Ni

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The characterization of the N=50 shell gap, particularly its evolution with a large neutron excess, represents nowadays an intense effort of many nuclear physicists. In this intermediate-mass region the shell-model calculations suffer from a fragmentary determination of some basic inputs, i.e. the single particle energies and two-body matrix elements. For instance the prediction of the evolution of the N=50 gap at very large neutron excess needs the knowledge of the residual interaction energies for various $\pi\nu$ configurations, issued from the *fp* protons (28<Z<38) and the *dg* neutrons (N~50), which are mainly not known at the present time. Measurements of the level structure of some moderately neutron-rich nuclei provide data which can be compared with the results of state-of-the-art shell-model calculations, leading to the determination of these crucial parameters.

Whereas usual fusion-evaporation reactions do not allow populating high-spin states of these neutron-rich nuclei because of the lack of suitable stable beam-target combinations, fusion-fission reactions -combined to a powerful prompt γ spectroscopy- prove to be fruitful. We have undertaken the high-spin state study of many isotopes located around the N=50 shell closure. These nuclei were produced as fission fragments in the fusion reaction ^{18}O+^{208}Pb at 85 MeV bombarding energy, and studied with the Euroball IV array. One can for instance refer to our previous publications concerning $^{84}Se_{50}$ [1], $^{84,85}Br_{49,50}$ [2], ^{81,82,83,85}Se [3], $^{88}Rb_{51}$ and $^{86}Br_{51}$ [4].

In this talk, our most important results will be presented, including the latest ones obtained for the $^{81,83}As_{48,50}$ isotopes [5]. The selected cases will allow us to underline several physical aspects which govern the nuclear structure in this mass region, meaningful for the purpose of a reliable description of the ^{78}Ni behavior. In particular we will discuss: i) the weakening of the N=50 gap from the energies of the neutron-core excitation established in Kr and Se, ii) the mapping of the proton sub-shells above Z=28, iii) $\pi\nu$ interactions from studies of odd-odd N=49 and N=51 nuclei.

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Tidal Waves in ^{102}Pd:
A Rotating Condensate of Multiple *d*-bosons

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The low-lying collective excitations in even-even vibrational and transitional nuclei have been described semi-classically as quadrupole running waves on the surface of the nucleus [1]–the tidal waves in nuclei–and the vibrational-rotational behaviour have been interpreted as a rotating condensate of interacting d-bosons [2]. The tidal waves concept allows for the microscopic calculation of the energies and transition probabilities of yrast states by means of the cranked mean field theory. We investigated this concept by measuring lifetimes of the yrast band in the ^{102}Pd nucleus. The experiment was performed with GAMMASPHERE using the ^{76}Ge(^{30}Si, 4n)^{102}Pd reaction. The extracted B(E2)'s for the yrast band show an increase with spin consistent with the interpretation based on anharmonicities caused by the boson couplings.

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THE NO CORE SHELL MODEL IN AN EFFECTIVE FIELD THEORY FRAMEWORK

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One of the outstanding problems in nuclear-structure theory is the construction of two-body (and higher-body) effective interactions in a model (or basis) space. In this talk we discuss a recently developed approach to this problem [1], where one starts with an effective field theory (EFT), which contains only nucleonic fields and is formulated directly in a No-Core-Shell-Model (NCSM) space [2]. Such an approach helps us to understand the gross features of nuclear systems from a QCD perspective. It also leads to a new method for the construction of effective interactions suitable for NCSM calculations, which avoids uncontrolled approximations. Finally, we present applications to light nuclei within the pionless EFT and discuss future applications and extensions, such as to the pionfull EFT [1, 3, 4].

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Systematics of Low Energy Collective States in neutron-rich Cd Isotopes*

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The lowest lying levels in the neutron-rich even-even Cd isotopes have structures that resemble an anharmonic vibrator coupled to 2-proton intruder states. Deviations from this simple picture have been shown to occur in $^{112-116}$Cd isotopes [1,2]. In particular, none of the observed 0^+ and 2^+ states previously assigned as three phonon states decay in a manner consistent with a multiphonon state. If the explanation for the discrepancy between observed and expected decays of these states at least partially arises from mixing with intruder states, the picture should become more clear further from the neutron mid-shell as there will be less mixing of the N-phonon and intruder levels due to the increase in energy of intruder states. In order to determine the systematics of these states in Cd across the neutron shell we have measured the beta decays of the heavier even-mass ^{120,122,124,126}Ag isotopes.

Silver-120,122,124,126 ions were produced via the proton-induced fission of ^{238}U at the HRIBF at ORNL. Fifty MeV protons were bombarded on a UC_x target, and the fission products were then separated by the High Resolution Isobar Separator and deposited on a moving tape collector directly in the center of the LeRIBSS (Low-Energy RIB Spectroscopy station) array (in the cases of ^{122,124,126}Ag) or at the UNISOR mass separator CARDS array at the UNISOR separator (^{120}Ag).

Many new levels in ^{120,122,124,126}Cd have been observed. These results and an alternate interpretation of the structure of the Cd isotopes to the multiphonon model of the even-even Cd isotopes will be presented and discussed.

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Intermediate-energy Coulomb excitation of ^{58,60,62}Cr: The onset of collectivity toward $N = 40$

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Intermediate-energy Coulomb excitation measurements were performed on the neutron-rich chromium isotopes ^{58,60,62}Cr. The electric quadrupole excitation strengths, $B(E2\uparrow)=B(E2;\, 0^+_{\rm gs} \to 2^+_1)$, of ^{60,62}Cr were determined for the first time. The results quantify the trend of increasing quadrupole collectivity in the Cr isotopes approaching neutron number $N = 40$. The results are confronted with large-scale shell-model calculations in the $fpgd$ shell using the state-of-the-art LNPS effective interaction. Different sets of effective charges are proposed that provides an improved and robust description of the $B(E2\uparrow)$ values of the neutron-rich Fe and Cr isotopes in this region of rapid shell evolution. The ratio of the neutron and proton transition matrix elements, $|M_n/M_p|$, is proposed as a tool to discriminate between the various choices of effective charges.

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STUDY OF THE $^{13}B(d,p)^{14}B$ REACTION IN INVERSE KINEMATICS WITH HELIOS

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We have studied the $^{13}B(d,p)^{14}B$ reaction in inverse kinematics using HELIOS at the ATLAS facility at Argonne National Laboratory at 15.7 MeV/nucleon. Angular-momentum transfers and spectroscopic factors were deduced for the four lowest states in ^{14}B. The low-lying negative-parity states in ^{14}B are formed by the coupling of a single sd-shell neutron with a $0p_{3/2}$ proton hole. As such, it is an ideal candidate to provide information on the trends of the energies of the $1s_{1/2}$ and $0d_{5/2}$ single-particle orbitals at the extreme values of N/Z. The neutron single-particle structure is expected to resemble that of the next heaviest N=9 isotone ^{15}C, whose ground state wave function is well described by a $1s_{1/2}$ neutron coupled to an N=8 neutron core. In ^{14}B, a doublet of $(2,1)^-$ states are expected to be predominantly made up of $\pi(0p_{3/2})^{-1}\nu(1s_{1/2})$ configurations, and coupling of the proton hole to a $d_{5/2}$ neutron produces four negative-parity states with $J^\pi=(1,2,3,4)^-$. The $0d_{5/2}$-$1s_{1/2}$ splitting in ^{14}B is expected to be small, producing mixing between the $(1,2)^-$ l=0 and 2 configurations. Precise knowledge of the dominant orbital angular momenta, the degree of configuration mixing, and the spectroscopic factors for neutron transfer populating the low-lying negative parity states provides data with which we can test predictions of the shell model for this nucleus, and examine the trends of the single-particle energies at this extreme value of N/Z.

To examine these properties of ^{14}B, we obtained data for the $^{13}B(d,p)^{14}B$ reaction in inverse kinematics using an unstable beam of ^{13}B produced using the In-Flight method [1] at the ATLAS facility at Argonne National Laboratory. Protons from the $^{13}B(d,p)^{14}B$ reaction were detected and analyzed using the HELIOS device [2] at ATLAS, a large solenoid spectrometer specially designed to study transfer and other reactions in inverse kinematics. Bound and unbound states in ^{14}B were distinguished by detecting and identifying the recoiling ^{13}B and ^{14}B nuclei in a set of silicon ΔE-E telescopes at forward angles. Excitation-energy spectra and angular distributions for transitions to low-lying narrow states in ^{14}B will be presented, and the deduced spectroscopic factors for neutron transfer will be compared to the predictions of the shell model. This work was supported by the U. S. Department of Energy, Office of Nuclear Physics, under Contracts DE-FG02-04ER41320 and DE-AC02-06CH11357.

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Probing the Shape Transitions in ^{98}Sr and ^{98}Zr

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The nuclear mass region around $A = 100$ is of particular interest in the study of nuclear structure due to a fast evolution of the nuclear shape as a function of Z and N. This shape change is of particular interest in the $Z = 38$ and 40 Sr and Zr isotones which undergo a rapid change in there ground state deformation[1] between $N = 58$ and 60 transitioning from a nearly spherical shape to a strongly prolate, rigid deformation.

With the sudden change in ground-state shape in these isotopes, coexisting shapes are observed close in excitation energy[2, 3]. $E0$ transition strengths are sensitive to the difference in deformation of the two coexisting shapes as well as the mixing between them. These monopole transitions embody a wealth of nuclear structure information which can be directly related to simple models, in order to further a theoretical understanding of the region[4, 5].

In the present experiment, a surface-ionized ^{98}Rb beam was produced at the TRIUMF-ISAC Facility by impinging a 2μA 500 MeV proton beam onto a multilayered UC_x target. This radioactive beam was than implanted onto a tape system centered in the 8π HPGe spectrometer and PACES Si(Li) axillary detectors for collecting Internal Conversion Electrons(ICE). The combination of both the 8π and PACES allows the unique structure of the ^{98}Sr and ^{98}Zr isotopes to be sensitively probed in different combinations of γ-ICE coincidences. Results and interpretation of measured $E0$ strengths between the coexisting structures will be presented.

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β-delayed γ-ray spectroscopy of ^{196}Hg and its description within the extended supersymmetry

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The concept of nuclear structure supersymmetry has been observed and investigated in the Gold-Platinum mass region. Described in a group theory approach, it allows the simultaneous description of different nuclei forming so-called supermultiplets [1]. All members of a supermultiplet are distinguished by a constant number of IBFM [2] ν- and π-bosons and -fermions. The most popular example is the 'magic square' – consisting of ^{194,195}Pt and ^{195,196}Au – of the $U_\nu(6/12) \otimes U_\pi(6/4)$ extended supersymmetry.

Recently, efforts were made to investigate the expansion of the Au-Pt supermultiplets by a fifth member: the neighboring even-even Hg isotopes [3]. For the square around ^{194}Pt, this corresponds the two-fermion–five-boson supermultiplet member ^{196}Hg.

We report on a $\gamma\gamma$ angular-correlation experiment to complete the data on low-spin states in ^{196}Hg. The experiment was performed at WSNL of Yale University using a 28-MeV proton beam activating an enriched ^{198}HgS target. The ^{196}Hg γ-ray transitions following the decay of the β-unstable ^{196}Tl were observed off-beam with the YRAST-Ball Clover array. Due to the β-decay selection rules, the $J = 2^-$ ground-state decay of ^{196}Tl should populate preferably low-spin states in ^{196}Hg.

With the new data, we now refit ^{196}Hg as so-called two-fermion–five-boson member of the supermultiplet around ^{194}Pt [3]. The new fit parameters significantly rise the $\langle \sigma_1, \sigma_2, \sigma_3 \rangle = \langle 5, 1, 0 \rangle$ multiplet in energy. These states correspond to proton-neutron interactions and are also known as mixed-symmetry states.

We present our results of the β-delayed γ-ray spectroscopy of ^{196}Hg and discuss its description within the $U_\nu(6/12) \otimes U_\pi(6/4)$ extended supersymmetry model.

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Systematic study of transition probabilities in $^{182-190}$Pt isotopes

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Recently, it has become possible to measure the quadrupole transition probabilities of the yrast band structures in Pt-isotopes [1]. The transition probabilities depict remarkable variations with low-spin states exhibiting an increasing trend and high-spin states showing a pronounced drop. The increasing trend has been partially explained using the two band mixing model [1]. The drop in the transition probabilities for the high-spin states is expected to be due to the rotational alignment of particles.

In the present work, we have studied $^{182-190}$Pt isotopes using the triaxial projected shell model (TPSM) approach [2]. This model has been recently used to address an unsolved issue regarding the existence of low-lying K=3 bands in Er-isotopes. It has been demonstrated [3] that these bands are, in fact, the projected γ-bands from the two-quasiparticle states. $^{182-190}$Pt isotopes have well developed γ-bands and, therefore, are naturally described using the TPSM approach. We have performed a detailed study of Pt-isotopes and it is shown that the deformations, ε and ε', that reproduce the yrast- and γ-bands in these nuclei also provide a consistent description of the evolution of the transition probabilities with spin. Further, we show that non-axial deformation is quite crucial to describe the increasing trend of the BE(2) for low-spin states. The drop for high-spin states is shown to be due to the rotational alignment of neutrons.

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Results from d(^{30}Mg, p)^{31}Mg at REX-ISOLDE

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In a β-NMR experiment at REX-ISOLDE the ground state of ^{31}Mg, located right at the edge of the "island of inversion" was determined to be a $1/2^+$ state [1]. In the only theoretical calculation that yielded the same spin and parity for the ground state this state contains more than 90 % intruder configuration [2]. This calculation makes predictions for the excited states in ^{31}Mg, concerning spins, parities and configurations that can be tested using transfer reactions.

In order to start a transfer reaction program in inverse kinematics at REX-ISOLDE with the gamma-spectrometer MINIBALL a new setup (T-REX [3]) was built, covering a large solid angle for light charged particles using silicon ΔE-E telescopes. In the first T-REX experiment the reaction d(^{30}Mg, p)^{31}Mg was studied to obtain information on the excited states of ^{31}Mg. The analysis of the shape of the angular distribution of protons from the reaction populating the second excited state at 221 keV allowed the determination of the transferred angular momentum and provided for the first time a direct measurement of the parity of this $3/2^-$ state. Comparison of total 1n transfer cross sections with DWBA calculations for $\Delta L = 0, 1, 2$ allowed for the extraction of the cross sections for the ground and first excited state as well.

The cross section of the second excited state is found to be a factor four lower compared to the DWBA calculations than the cross sections of the two other states. Comparison to Nilsson model calculations indicates a possible shape co-existence of an oblate deformed second excited state and prolate deformed ground and first excited state.

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COLLINEAR LASER SPECTROSCOPY - AN EFFICIENT PROBE OF SHELL STRUCTURE EVOLUTION BEYOND *N*=28 IN THE *Z*=20 REGION

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In recent years the development of new shell closures at *N*=32 and *N*=34 in neutron rich nuclei has been a topic of much theoretical controversy and experimental interest. Collinear laser spectroscopy can provide both sensitive and model independent measurements of the influence of shell closures on four key ground state nuclear observables. The spin, magnetic moment, quadrupole moment and most significantly the change in size of the nucleus taken together provide a 'complete' picture of the evolution of collective and single particle aspects of the nuclear ground state. Given the substantial interest in this region of the chart and almost complete absence of laser spectroscopy data for neutron rich nuclei beyond *N*=28 we have initiated a programme of development and measurements at CERN-ISOLDE.

Here we will report our first measurements of the neutron rich Potassium isotopes $^{47..51}$K and Calcium isotopes $^{48..52}$Ca. These preliminary results will be presented in the context of regional systematics and the implications for nuclear theory will be considered. Taken together these results can provide a substantial insight into the nature on *N*=32. In the next stage of this programme we will extend our measurements across *N*=34. The technique developments planned for these challenging experiments will be explored and our present technical progress examined.

Nuclear Masses and their Importance for Nuclear Structure Studies

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The mass of the nucleus reflects the total energy of this many-body system and thus is a key property for a variety of nuclear structure investigations. It is obvious that the knowledge of nuclear masses is indispensable for developing the theory of the nucleus.

Modern experimental techniques, like storage ring or Penning trap mass spectrometry, have pushed in recent years the limits of sensitivity, resolution and accuracy. This has allowed to access exotic species very far from the valley of beta-stability. This could be done due to tremendous progress in production and preparation techniques for short-lived nuclides, e.g. by new target and ion sources combinations and the development of a multi-reflection time-of-flight separator.

The use of new manipulation techniques for stored ions has improved the resolving power by almost two orders of magnitude giving access to low lying isomeric states. The mass accuracy achieved even for very short-lived species in the ms regime and below allowed, e.g., to probe the shell structures and their evolution toward the neutron dripline or to perform in some regions fine examinations of the mass surface. The latter includes many exciting results like, for instance, an intriguing observation in the heavy mass region reflecting either a N = 134 subshell closure or an octupolar deformation, testing of isospin symmetry in mirror nuclei, behavior of proton-neutron interaction across the closed shells, sensitivity of masses to collective structure of the nucleus and many others.

In this review recent trends in the determination of nuclear masses, their impact on nuclear structure studies and the comparison to modern calculations will be presented.

A PHASE-FREE QUANTUM MONTE CARLO METHOD FOR THE NUCLEAR SHELL MODEL

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The shell model provides a powerful framework for nuclear structure calculations. The nucleons beyond an inert magic core are confined in a valence shell and interact through an effective two-body potential generally determined from the G-matrix method. However, the applicability of the shell model remains limited by the exponential growth of the many-body space with the number of valence nucleons and with the size of the one-body space. The quantum Monte Carlo (QMC) methods may thus be considered as a potentially attractive alternative to the direct diagonalization of the Hamiltonian matrix. The many-body problem is indeed reduced to a set of stochastic one-body problems describing independent particles in a fluctuating external field. Up to date, the QMC approaches of the shell model, see [1], lead to the ground-state and the thermodynamic properties of nuclei, but a detailed spectroscopy is not reachable. Furthermore, they suffer from a common pathology of fermionic QMC methods, namely the sign/phase problem, which strongly contaminates the convergence of the calculation.

In this context, we will present a new QMC method, providing the "yrast spectroscopy" of nuclei, and in which the sign/phase problem is managed through the constrained path approximation [2, 3], a technique that is widely used in the *ab initio* nuclear calculations and in condensed matter physics.

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0 AND 1 ħω SHELL MODEL DESCRIPTION OF THE MIRROR NUCLEI ^{22}Ne AND ^{22}Mg

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The ^{22}Ne nucleus has been well studied experimentally. Below excitation energy of ~ 6.35 MeV, fourteen states are reported in the "Adopted Levels" [1] of NNDC with well defined spin and parity. Twelve of them have positive parity and two of them have negative parity. The experimental situation for the mirror nucleus ^{22}Mg, which is more difficult to reach, is much less clear. Up to excitation energy of ~ 6.35 MeV, sixteen states are reported in Refs. [1, 2], the majority of them having no fixed spin and parity. A comparison of the structure properties of ^{22}Ne and ^{22}Mg is interesting because in nucleosynthesis ^{22}Mg can be formed through the capture reaction ^{21}Na(p, γ) for which the cross sections will depend on the J^{π} values of ^{22}Mg states around the threshold energy (5.50 MeV) and above.

To make a 0 and 1 ħω shell model description of sd shell nuclei, we have recently developed the PSDPF interaction [3]. With this new interaction, the properties (excitation energies and electromagnetic transitions) of positive and negative parity states can be calculated. What the positive parity states are concerned, the main building block of our interaction is USDB [4].

For the pair ^{22}Ne- ^{22}Mg, our calculations using the PSDPF interaction predict fifteen states in the excitation energy range up to ~ 6.35 MeV. In our contribution to the conference, we will propose based on the shell model calculation a one to one level correspondence between ^{22}Ne and ^{22}Mg. In particular what the negative parity states are concerned, three states are identified in ^{22}Ne: 2^- at 5146 keV, 3^- at 5910 keV and 0^- at ~ 6234 keV, they correspond to the mirror states in ^{22}Mg : 2^- at 5006 keV, 3^- at 5838 keV and 0^- at 6046 keV.

We will present a comparison between the shell model predictions obtained by PSDPF and the experimental level energies and electromagnetic transitions in both mirror nuclei ^{22}Ne and ^{22}Mg.

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Nuclear Structure of Neutron Rich Gadolinium

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Nuclei in the region of $^{162-165}$Gd are well deformed and therefore have excitation modes that are well explained by the collective model. We report results from two separate experiments. The first comes from the beta-decay of Eu isotopes produced at the HRIBF facility at Oak Ridge National Labratory and measured at the Low-energy Radioactive Ion Beam Spectroscopy Station (LeRIBSS). The second study comes from the prompt decay of ^{252}Cf fission fragments measured with Gammasphere. From the beta-decay experiment we have measured the decays of $^{162-165}$Eu. We report collective band structures in ^{162,164}Gd as well as the first partial level scheme of ^{163}Gd and the first gamma ray associated with ^{165}Gd. In addition we present new measurements of the half-lives of $^{162-164}$Eu. We have also obsereved the gamma vibrational band up to 6^+ in ^{162}Gd. We highlight the complementary role between the beta-decay studies and the prompt decay of fission fragments.

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GFMC CALCULATIONS OF SPECTROSCOPIC OVERLAPS IN $A \leq 8$ NUCLEI

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Green's function Monte Carlo (GFMC) calculations of spectroscopic overlaps are reported for $A \leq 8$ nuclei. The realistic Argonne v_{18} two-nucleon and Illinois-7 three-nucleon potentials are used to generate the nuclear states [1]. The overlap matrix elements are extrapolated from mixed estimates between variational Monte Carlo and GFMC wave functions [2]. The overlap functions are used to obtain spectroscopic factors and asymptotic normalization coefficients, and they can serve as an input for reaction calculations.

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Beta-delayed neutron spectroscopy with an ion trap

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The properties of β-delayed neutron (βn) emission are important in basic and applied nuclear physics. The neutron spectra and branching ratios of βn emitters reflect the evolution of nuclear structure in neutron-rich nuclei. Branching ratios can affect the population of heavy elements in the universe resulting from the astrophysical *r* process. Energy spectra and branching ratios of βn emitters are also important to stockpile stewardship and the safe design of nuclear reactors. Recently we demonstrated a novel technique for βn spectroscopy using $^{137}I^{+}$ ions confined to a $\sim$1mm^3 volume within a Paul trap [1, 2]. By measuring the time-of-flight spectrum of ions recoiling from both the β and βn processes, the βn branching ratio and spectrum can be determined. This recoil-ion technique has several advantages over techniques that rely on neutron detection: the recoil ions are easily detectable; complications due to scattered neutrons and γ-rays are avoided; and the βn branching ratio can be extracted in several different ways. Our demonstration measurement achieved an absolute precision of $\sim$1% in the βn branching ratio and 10-20% energy resolution in the neutron spectrum over the range 200-1500 keV, with 30 ions/sec delivered to the trap. A campaign of measurements is currently underway at Argonne with a 10$\times$ improvement in coincident detection efficiency and energy resolution reaching $\sim$3%. A further-upgraded version of this experiment is planned at Argonne's CARIBU facility. The recoil-ion technique will be described and the status of the current campaign and future prospects for the CARIBU experiment will be discussed. Prepared by ANL under Contract DE-AC02-06CH11357, LLNL under Contract DE-AC52-07NA27344, and Northwestern U. under Contract DE-FG02-98ER41086.

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A Digital Data Acquisition System for Gammasphere

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A new digital-based data acquisition system for Gammasphere is under development. This system leverages the electronics designed by the GRETINA collaboration. At the center of this development are the GRETINA 10-channel digitizer modules which digitize the Ge preamplifier signals at a 100MHz rate [1]. The new DAQ will increase event throughput significantly over the existing system while addressing multiple repair and maintenance issues. New hardware and firmware to integrate the GRETINA electronics with Gammasphere is being developed, allowing for a staged changeover so that the experimental program is not adversely affected. In the first phase of the project, both the current VXI based analog system and the digital DAQ run in parallel and share a common trigger and clock. In Phase II, firmware and software changes will be implemented for both the digitizer and trigger modules allowing Gammasphere to operate optimally as a Compton-suppressed array. In Phase III, the Gammasphere VXI electronics will be placed with new hardware which allows the digital data acquisition to mimic the performance of the analog system, however, with superior throughput rates which can be up to 10 times greater than currently possible. Phase I is now complete and results from first in-beam tests will be presented. New firmware for both the digitizer and trigger modules is currently being implemented and results from the first performance tests will be presented as well Finally, a description of the design for the VXI replacement boards will be discussed. This research is supported by the DOE Office of Nuclear Physics under Contract No. DE-AC02-06CH11357.

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OCTUPOLE COLLECTIVITY AT N=90

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A leading issue is whether the stable N=90 isotones, ^{150}Nd, ^{152}Sm and ^{154}Gd, are a manifestation of a phase transition [1] or shape coexistence [2]. Very recently, Garrett *et al.* [3] showed that ^{152}Sm exhibits a new type of shape coexisting structure, coexisting $K^\pi = 0^-$ octupole bands. These bands carry the distinctive signature of unusually large *E1* decay strengths and favor a shape coexistence picture over a phase transition interpretation. In the chain of $N = 90$ isotones, the aforementioned questions might also be addressed in ^{150}Nd, which possesses a similar ground-state deformation as ^{152}Sm, by studying its low-lying level structure.

Excited states in ^{150}Nd have been investigated with the ^{150}Nd(n,n$'\gamma$) reaction at the the University of Kentucky 7-MV Van de Graaff accelerator facility. The previously known $K^\pi = 0^-$ band and a new $K^\pi = 2^-$ band are established, and lifetimes are determined for all reported band members. The lifetime data reveal an enhanced pattern of *E1* transition strengths, similar to that observed in ^{152}Sm, thus establishing a systematic pattern for the octupole collectivity in the N=90 isotones. This pattern lies outside of the various model descriptions put forward for nuclei in this region.

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NEW INTERPRETATION OF THE LOW-LYING COLLECTIVE NUCLEAR STRUCTURE OF ^{94}Zr

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Inelastic neutron scattering with the detection of emitted γ rays, *i.e.*, the (n,n'γ) reaction, has been utilized at the University of Kentucky Accelerator Laboratory for many years to study the structure of stable nuclei [1]. The Doppler-shift attenuation method (DSAM) has been applied to determine the lifetimes of nuclear states [2]. Through γ-ray excitation function and angular distribution measurements, detailed level schemes of the low-spin states of stable nuclei can be established. Several years ago, we identified the second 2^+ state in ^{94}Zr at 1671.4 keV as the lowest mixed-symmetry state, based on the observation that the 752.5-keV transition from this state to the first excited 2^+ level at 918.8 keV had a large B(M1) of $0.31 \pm 0.03\ \mu_N^2$ [3]. In addition, the B(E2) of the transition from this state to the ground state was found to exhibit an unusually large value of 7.8 ± 0.7 W.u. [3], larger than the $B(E2;2_1^+ \rightarrow 0_1^+) = 4.9 \pm 0.3$ W.u. [4]. This nucleus thus emerged as the only known example of an excited 2^+ state having a larger B(E2) to the ground state than the first excited 2^+ state. Through new measurements with the (n,n'γ) reaction and a study of the radioactive decay of ^{94}Y (18.7 min), using the 8π array of Compton-suppressed detectors at TRIUMF, we have continued our studies of ^{94}Zr in an attempt to understand this anomaly and to characterize this nucleus more fully. We have determined the lifetime of the 1671.4-keV 2^+ state with DSAM using metallic zirconium and zirconium oxide scattering samples of natural isotopic composition and find this lifetime to be longer than that reported by Elhami [3]. In addition, the ^{94}Y decay studies have revealed previously unobserved transitions, which lead to a new interpretation of the low-lying structure of ^{94}Zr.

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TWO AND FOUR PROTON DECAYS IN ^{8}C AND ^{12}O GROUND STATES AND THEIR ISOBARIC ANALOGS

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Two-proton decay of the proton-rich members of the A=8 and 12 quintets (T=2) have been studied. The ^{8}C ground state and its isobaric analog state (IAS) in ^{8}B were created in neutron and proton knockout reactions from a ^{9}C beam at the National Superconducting Cyclotron Laboratory. The decay products were detected in the HiRA array and the parent nuclei were reconstructed using the invariant mass method. Using a ^{13}O beam produced at the Texas A&M Cyclotron facility, the ^{12}O ground state and its IAS in ^{12}N were produced and the two-proton-decay products detected. Highlights of this work are:

- The ground state of ^{8}C decays into an α particle and four protons. From the correlations between the decay products, we infer that decay was not five-body in nature, but proceeded as two sequential steps of two-proton decay passing through the ^{6}Be intermediate state. The first two-proton step had an enhanced "diproton" component.

- The width of the ^{12}O ground state was determined to be less than 72 keV, incompatible with previous measurements, but consistent with theoretical predictions.

- The IAS's of ^{8}C in ^{8}B and ^{12}O in ^{12}N were found to undergo two-proton decay to the IAS's in ^{6}Li and ^{10}B, respectively. These states represent a new class of two-proton emitters where single-proton decay is energetically allowed, but isospin forbidden, whereas two-proton decay conserves both quantities. This was the first observation of the IAS in ^{12}N.

- For isospin symmetry, the masses of the quintets should follow a quadratic dependence on isospin projection given by the isobaric multiplet mass equation (IMME). Using our new values of the masses of the observed states, we find the A=8 quintet has deviations from the IMME where the A=12 quintet is consistent with it.

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Time dependent simulation of g factors based on apriori atomic structure calculation and from recoil-in-vacuum measurement

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The precise measurements of nuclear magnetic moments (or nuclear g factors) of excited states provide an excellent tool for determining the nuclear wavefunctions of excited states. Since the nuclear magnetic moments reflect microscopic structures of the nuclear states, they can be used to study the evolution of nuclear structure as a function of excitation energy, spin and isospin, and provide a stringent test on nuclear theories. The transient field (TF) technique[1] has been used for decades to measure nuclear g factors for excited states with ~ps lifetimes. However, the determination of the TF strength is usually complicated. The target used in a TF experiment is usually "thick" and consists of several layers which may induce a large radioactive background in experiments especially with radioactive ion beams (RIB).

The recoil-in-vacuum (RIV) technique [2] is one way to measure the nuclear g factors for short-lived states which may avoid the difficulties mentioned above. RIV was first introduced in the 1970's but was seldom used in g factor measurement due to the complexity of the electronic configurations and the associated difficulty in calibrating the hyperfine interaction. With the advanced atomic theory now available, the hyperfine interaction may be calculated from first principles. For the first time, a dynamic time dependent Monte Carlo simulation method [3] based on atomic-structure calculation package GRASP2K was built to extract g factors in RIV experiments. The method was tested by simulating previously reported g factors for which G_ks values were measured in RIV experiments. The g factors extracted from the simulation are in good agreement with the previously report values. Compared to other methods, this simulation method is free of adjustable parameters. Once the electronic configurations are chosen, they do not need to be changed when used for different nuclear spin states or different isotopes. This method can be widely used in different reactions that align the spins of the nuclear states. These reactions include Coulomb excitation, transfer reaction, fusion evaporation and fission. Examples shown in this talk are from Coulomb excitation and fusion evaporation.

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SEARCH FOR INTRUDER STATES IN ^{66,67}Co*

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In the region below ^{68}Ni, competition between states associated with near-spherical shapes and with deformed proton-intruder configurations has been proposed recently for ^{64,66}Mn [1] and ^{66,67}Co [2-4], where large spin differences between the states result in distinctive isomers. In ^{66}Co, two 1^+ states below 1 MeV were identified; these were attributed to (possibly mixed) spherical and deformed intruder configurations. In ^{67}Co, observed $1/2^-$, $3/2^-$, and $5/2^-$ levels were suggested to be low-lying members of a collective $K^{\pi}=1/2^-$ band (of $\pi p_{3/2}$ intruder origin) amid the spherical states [3]. The intruder nature of such states in both nuclei was not confirmed, however. Doing so would provide valuable input for tuning the single-particle energies and interactions needed for large-scale shell-model calculations of nuclei requiring the full $fpg_{9/2}$ (or even larger) model space, particularly addressing excitations across the Z = 28 shell gap.

Deep-inelastic reactions between a 440-MeV ^{70}Zn beam and a thick ^{208}Pb target were recently studied with Gammasphere at ATLAS to search for evidence at higher spins supporting the assignment of intruder configurations for low-lying states. Beam timing of one pulse every ~410 ns allowed the data to be separated into prompt and delayed time regions with which gamma-ray coincidences above, across, and below isomers could be examined. Furthermore, cross-coincidences between the beam-like (Co) and target-like (At) reaction products, of which many of the latter have known isomers, are observable in combinations of prompt/delay gating in our data. In this way, the level schemes of ^{66,67}Co can be extended to higher spins despite a lack of known high-spin coincidences within the Co nuclei themselves. Results of this search will be presented.

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STRUCTURE OF NUCLEI NEAR THE 0ν2β CANDIDATE ^{76}Ge*

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The nucleus ^{76}Ge is a candidate for neutrinoless double beta decay. For theoretical models to be able to accurately calculate the relevant nuclear matrix element for this decay mode, it is important to have a firm understanding of the properties of the nuclei in question. Extending the level schemes of neighboring nuclei to higher spins can provide a robust test of various models, such as fine-tuning the single-particle energies and effective interactions in large-scale shell-model calculations involving the $p_{3/2}p_{1/2}f_{5/2}g_{9/2}$ proton and neutron subspace.

Neutron-rich Ge isotopes were studied in several experiments with Gammasphere at ATLAS. Beams of ^{76}Ge were incident upon thick ^{238}U, ^{208}Pb, and ^{198}Pt targets in (deep-)inelastic reactions, populating excited states up to moderate spins. No previous high-spin work has been done on ^{75,77}Ge, with most existing data coming from beta decay, neutron capture, or transfer reactions. The level schemes for both nuclides have been extended, including the first observation of strongly coupled band structures. In some cases, spin and parity assignments are strengthened by angular-correlation measurements.

In addition, excited states in ^{76}Ge itself were studied in these same data sets. The gamma band has been identified up to a tentative $I^{\pi} = 9^{+}$. The properties of this band point to ^{76}Ge having a rigid triaxial shape at low spins, a characteristic that is rarely seen across the nuclear chart.

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Search for anti-magnetic rotation in odd-A ^{107}Cd

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The phenomenon of anti-magnetic rotation (AMR) is new and rare compared to the well established Magnetic Rotation (MR) [1]. In $A \sim 110$ nuclei ($Z \sim 50$), the high-Ω $g_{9/2}$ proton hole(s) and low-Ω $h_{11/2}$, $g_{7/2}$ neutrons play an important role favoring AMR. Firm experimental evidence of AMR in even-even nuclei has been reported in only three cases, namely $^{106,108,110}Cd$. The first observation of AMR in an odd-A nucleus ^{105}Cd was recently reported by us [2]. A recent calculation by Zhao et al. [3] explained AMR in ^{105}Cd in a self-consistent microscopic way confirming most of our interpretations. In this paper, we present the first evidence of multiple AMR bands in an odd-A ^{107}Cd nucleus [4]. The pair of positive parity bands, (bands 5 and 6), are built on $g_{7/2}(h_{11/2})^2$ neutron configuration. We propose that the increase in spin in these bands is due to the closing of a pair of $g_{9/2}$ proton angular momentum vector towards the neutron angular momentum vector. We have measured the lifetimes of the high spin states (above $27/2^+$) in the positive parity signature partner bands 5 and 6 of the odd-A ^{107}Cd nucleus by using DSAM and $B(E2)$ values have been extracted. These $B(E2)$ values are found to decrease sharply with increase in spin. For both the bands 5 and 6, generation of high spin states beyond spin $23/2^+$ occurs due to the gradual closing of the proton vectors towards the aligned neutron vectors along with some core contribution. The observed rapidly decreasing B(E2) values with increasing spin along with constant $\Im^{(2)} \sim 20\ \hbar^2 MeV^{-1}$ and large $\Im^{(2)}/B(E2)$ ratio ($> 100\ \hbar^2 MeV^{-1}(eb)^{-2}$) increasing with spin, for both the bands 5 and 6 establish that both the bands are examples of AMR bands. We have checked this by using the semi-classical model for AMR for the proposed configuration ($\nu g_{7/2}(h_{11/2})^2 \otimes (\pi g_{9/2})^2$). The calculated and empirical $B(E2)\ vs.\ I(\hbar)$ are in good agreement favoring our interpretation. This is the first definitive result indicating the existence of two AMR bands in any nucleus. It is rather interesting to point out that the yrast sequence of bands does not seem to display the characteristics of AMR as has been seen in other Cd isotopes so far.

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Measurements of the $^6He + p$ Resonant Scattering

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We present results of an experiment ^{6}He+CH_2 performed in the RIBRAS [1] double solenoid system. The ^{6}He secondary beam was produced by the ^{9}Be(^{7}Li,^{6}He) reaction at the ^{6}He energies 14.7, 16.8, and 18.9MeV. A thick CH_2 foil was used as a target. We observed the protons, deuteron, tritons and alpha particles produced in reactions of the ^{6}He beam and the CH_2 target. Measurements of the elastic scattering p(^{6}He,p) have been performed at three different incident energies E= 3.2, 7.8 and 11.3MeV to observe states of the ^{7}Li [2] around excitation energies of $E_{exc}^{^7Li} = 10.4 - 11.6$MeV.

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Dipole Response of ^{76}Ge and ^{76}Se, and γ-γ Angular Correlations in ^{76}As

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Structural knowledge of the A=76 triplet Ge, As, and Se is of importance to ongoing theoretical studies of the hypothetical neutrinoless double-beta ($0\nu2\beta$) decay mode of ^{76}Ge. While the parities of many low-lying states of the intermediate nucleus ^{76}As are known, the only state with unambiguous spin assignment is the ground state. The low-energy dipole strength distributions of the stable ^{76}Ge and ^{76}Se may provide a test to certain models used to calculate the matrix element of the $0\nu2\beta$-decay mode, as well as provide information on the pygmy dipole resonance for a mass region in which low-energy dipole strength is not well-studied to date. Photon scattering data on ^{76}Se obtained in experiments at the S-DALINAC and the High-Intensity Gamma-ray Source (HIGS) are in the process of publication.

A photon scattering experiment has been performed at the S-DALINAC facility, TU-Darmstadt, to study low-lying dipole strength in ^{76}Ge. The enriched target was irradiated with a bremsstrahlung bream of 9 MeV endpoint energy, and γ-rays after resonant absorption were detected using two Compton-suppressed HPGe detectors. A γ-γ angular correlations experiment to study low-lying states in ^{76}As has been performed at WNSL, Yale University. Excited states in ^{76}As were populated using the ^{76}Ge(p,n) reaction with 6 MeV incident protons. γ-rays were detected by 10 Compton-suppressed clover detectors and two LEPS detectors mounted in the YRAST Ball array. Preliminary results will be presented.

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Production of ^{40}Mg Following 2p Knockout from ^{42}Si

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The experimentally observed collapse of the N=28 shell closure in $^{42}_{14}$Si has suggested a large oblate deformation at Z=14 and N=28. The isotonic nucleus ^{40}Mg may be expected to have mid-shell character, and a similarly large deformation. Combined with the fact that it may lie at the edge of the neutron drip-line for Z=12, ^{40}Mg is a key nucleus for understanding single-particle and shape evolution in the sd-fp shell, as well as the possible effects of weak binding, and benchmarking theories describing the most exotic nuclei.

The inclusive two-proton knockout reaction cross-section for ^{42}Si into ^{40}Mg has been measured in an experiment performed at the RIBF, at RIKEN Nishina Center. A secondary ion beam of ^{42}Si was produced following fragmentation, and identified through the BigRIPS fragment separator. Following reactions on a thick ^{12}C target, five ^{40}Mg were uniquely identified in the ZeroDegree spectrometer, and the inclusive two-proton knockout cross-section into ^{40}Mg was measured for the first time. Comparison with shell-model calculations suggests that the cross-section is consistent with a drastic change in nuclear shape between the ^{42}Si and the ^{40}Mg ground states. We report on the cross-section results, and implications for understanding shape evolution along the N=28 isotonic chain.

Collectivity Near ^{64}Cr: A New Region of Deformation

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The dominance of intruder configurations in the well-known island of inversion surrounding ^{32}Mg has been attributed to a reduced N=20 sd-fp shell gap arising from the tensor monopole component of the effective nucleon-nucleon interaction. At higher masses, a similar mechanism results in a narrowing of the N=40 harmonic oscillator shell closure below Z=28. First evidence for a weakening of the N=40 shell gap, and onset of quadrupole collectivity has been observed in the Cr and Fe isotopes as a steady decrease of the first 2^+ energies through N=40. Excited-state lifetime measurements have confirmed collectivity in the Fe isotopes up to N=40, and added to mounting evidence for a new island of inversion centered on ^{64}Cr.

The collectivity of ^{66,68}Fe isotopes and ^{64}Cr has been studied via intermediate-energy Coulomb excitation at National Superconducting Cyclotron Laboratory. Secondary beams of ^{66}Fe, ^{68}Fe and ^{64}Cr were excited on a Bi foil at the target position of the S800 spectrograph, in which recoils were identified. De-excitation gamma rays were detected using the scintillator array CAESAR. Preliminary results for the B(E2: $2_1^+ \rightarrow 0_1^+$) of ^{66,68}Fe and ^{64}Cr will be presented, and discussed in terms of the evolution of collectivity near Z=24 and N=40.

NUCLEAR STRUCTURE STUDIES OF ^{76}SE AND ^{76}GE FROM INELASTIC NEUTRON SCATTERING

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For many years, double-beta decay has been the focus of searches to discover physics beyond the standard model. Experimental confirmation of the lepton-number violating process of neutrinoless double-beta decay ($0\nu\beta\beta$) would achieve such a goal by identifying the neutrino as its own anti-particle, *i.e.*, a Majorana particle. Furthermore, such a confirmation would yield the absolute mass scale of neutrinos, provided that the nuclear matrix elements (NMEs) involved in the calculation are understood to a high degree of accuracy[1]. An excellent candidate for an investigation of the existence of $0\nu\beta\beta$ is the decay of ^{76}Ge to ^{76}Se. In order to help constrain theoretical models used for calculating the $0\nu\beta\beta$ NMEs, an aim of our experiments is to increase the overall knowledge of the level structure of both ^{76}Ge and ^{76}Se.

Another area of interest for these nuclei is mixed-symmetry states (MSS). Cooper *et al.*[2] recently identified a candidate for the ^{76}Se $2^+_{MS,1}$ at 3.214 MeV. While this state exhibits many of the properties expected of the MSS, the energy is relatively high when compared to the 2 MeV excitation energy of a typical $2^+_{MS,1}$. A similar situation may exist for ^{76}Ge, but no MSS has yet been identified.

Still another structural feature of these two isotopes is shape coexistence. ^{76}Ge is of particular interest due to the low excitation energy of the first-excited 0^+ state. Quadrupole moments extracted from multistep Coulomb excitation support the presence of different shapes for the ground and first-excited 0^+ states in the even-mass Ge isotopes[3]. By measuring transition rates and identifying potential members of bands in both ^{76}Ge and ^{76}Se, information can be added to the overall picture of shape coexistence in this region.

In an effort to address the above-mentioned areas of interest, excitation function and gamma-ray angular distribution measurements utilizing the ^{76}Ge(n,n'γ) and ^{76}Se(n,n'γ) reactions were performed at the University of Kentucky at neutron energies ranging from 2.0 MeV to 4.0 MeV. These measurements will yield information on level spins and parities, level lifetimes, transition multipolarities, and transition probabilities.

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THE STUDY OF ^{116}Sn VIA GAMMA-RAY AND CONVERSION-ELECTRON SPECTROSCOPY

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With the advent of radioactive beams and sophisticated detector systems, the evolution of the nuclear structure of the closed proton shell Sn isotopes between neutron closed shells at N=50 and N=82 and beyond is a fertile ground for study. In addition, it is possible to study the interplay of shell and collective effects and shape coexistence in the neutron rich tin nuclei in great detail through beta, gamma-ray and conversion-electron spectroscopy.

Motivated by previous work on the cadmium isotopes [1], we have revisited the ^{116}Sn (Z=50; N=66) nucleus, which is already known to exhibit evidence for shape coexistence and collectivity [2]. Using a ^{116}In beam produced via the ISOL technique at TRIUMF, Canada's Laboratory for Nuclear and Particle Physics, the beta decay of ^{116}In to ^{116}Sn has been observed with the 8π spectrometer and its suite of ancillary detectors.

Our goal was to obtain high-statistics spectroscopic information as a means to search for weak gamma-ray and/or beta branches not previously observed, and to detect *E0* transitions, which are signatures of shape coexistence (owing to the presence of $I^{\pi} = 0^{+}$ excited states). We intend to extend this program to other neutron-rich singly closed-shell nuclei at a later date.

In this presentation, we discuss the structure of the ^{116}Sn nucleus, as revealed through the use of gamma-ray and conversion-electron coincidence spectroscopy to identify $I^{\pi} = 0^{+}$ excited states as well as *E0* transitions, in order to augment and improve the existing knowledge of the structure of ^{116}Sn.

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HIGH SPIN STRUCTURE OF ^{201}Tl ISOTOPE

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Variation of the nuclear deformation as a function of angular momentum for chain of Tl isotopes makes them interesting candidates to test the predictions of different theoretical models involving the coupling of core and single particle degrees of freedom. Tl isotopes with one proton hole in Z=82 shell and a few neutron hole in N=126 shell are expected to have spherical structure at lower excitation while the deformation sets in for higher spin states. The intruder $\pi h_{9/2}$ and $\pi i_{13/2}$ states play important role for the structure of higher spin states. For odd A Tl isotopes ground state spin is ½, and the $\pi h_{9/2}$ orbital above the Z=82 shell closure is accessible by the odd proton for oblate deformation. Rotational band build on $9/2^-$ isomeric level have been reported [1, 2] for $^{195-199}$Tl. In case of ^{201}Tl, a few members of the $9/2^-$ rotational band have been observed from deuteron induced fusion reaction [3]. The aim of the present work is to extend the knowledge of the band structures to higher spin states and to search for non-yrast side bands.

The fusion evaporation reaction ^{198}Pt(^{7}Li,xn) at 45 MeV has been exploited to populate the excited states of ^{201}Tl. The beam is obtained from Pelletron LINAC facility, Mumbai, India, and the target was a 1.3 mg/cm^2 self-supporting foil. Gamma rays were measured with 15 Clover detectors of Indian National Gamma Array (INGA). They were arranged in six angles with two clovers each at $\pm 40^0$ and $\pm 65^0$, while four of them at 90^0 and three at -23^0. The time stamped data was taken in γ-γ coincidence condition, using a digital data acquisition system.

From the raw data γ-γ matrices and γ-γ-γ cubes with various time windows were generated. In order to assign the spin and parity of the levels DCO and IPDCO analysis are in progress. Twenty-six new transitions are identified in ^{201}Tl from the present work. The band built on $9/2^-$ isomeric level is extended up to 4864- keV. A single particle plus rotor model including the Coriolis term was used in Ref. [3] to interpret lower spin members of the $9/2^-$ band of ^{201}Tl. At higher spin, a change in the oblate structure is expected, similar to what have been observed in the corresponding Hg core. Detail descriptions of the levels, bands and their interpretation will be discussed in the conference.

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PROBING THE CHARACTER OF THE PYGMY DIPOLE RESONANCE

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The electric dipole strength distribution in atomic nuclei is dominated by the well known isovector Giant Dipole Resonance (IVGDR). In neutron-rich nuclei an additional concentration of low-lying $E1$ strength, the electric Pygmy Dipole Resonance (PDR), below and around the particle threshold has been observed. Real-photon scattering experiments are a common tool to study the PDR, because they provide a highly selective excitation of low-spin states from the ground state. On the contrary, e.g. α particles are a complementary probe that interacts with the nucleus also through strong interaction.

Therefore the $(\alpha, \alpha'\gamma)$ reaction was used systematically in the semi-magic nuclei ^{140}Ce, ^{138}Ba, ^{124}Sn, the non-magic nucleus ^{94}Mo, and the lighter and doubly-magic nucleus ^{48}Ca, in order to gain knowledge about the PDR structure [1, 2, 3]. The $(\alpha, \alpha'\gamma)$ coincidence experiments were performed at the Big-Bite Spectrometer (BBS) at KVI, Groningen, together with an array of HPGe detectors for γ spectroscopy. Experimental methods and results for the experiments with a focus on ^{94}Mo and ^{48}Ca will be presented.

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FAST NEUTRON SPECTROSCOPY WITH Cs_2LiYCl_6*

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As the frontiers of nuclear physics are pushed forward towards the neutron drip line and exotic nuclei, solutions to challenges faced by researchers demand advances in detector technology. Neutron spectroscopy has always proven to be a particular challenge due to the complex nature of most detector response functions, and represents an area where new detectors hold the potential to open new avenues of physics. Cs_2LiYCl_6:Ce (CLYC) has generated recent interest as a thermal neutron detector [1] due to its excellent neutron/γ-ray pulse-shape discrimination and energy resolution. Preliminary work using a 1"x1" detector has yielded intriguing results [2] for the possibility of employing CLYC for fast neutron spectroscopy. The response of this detector to mono-energetic neutrons was studied at the University of Massachusetts Lowell 5.5 MV Van de Graaff for neutron energies over a range of 0.8 MeV to 2.0 MeV, produced via the ^{7}Li(p,n) reaction. In the fast neutron response, a broad continuum from the ^{6}Li(n,α) reaction was observed, as well as a peak due to the ^{35}Cl(n,p)^{35}S reaction, which had not previously been reported in literature at the time. This reaction, with a Q-value of +615 keV, yields single peaks with an average resolution of 9%, making CLYC a promising candidate for a fast neutron spectrometer in the energy range of ∼0.5 to 3 MeV. Simulations using MCNPX have been used to corroborate our initial findings and investigate methods by which the practical measurement range can be extended to at least 10 MeV. The ability of CLYC to directly measure fast neutron energies without resorting to time-of-flight techniques is further complemented by its performance as a γ-ray spectrometer. These capabilities point to some interesting future applications in prompt and beta-delayed neutron studies at next generation facilities such as CARIBU.

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MICROSCOPIC LEVEL DENSITY FOR NUCLEONS AND DEFORMED CORE

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Realistic models of nuclear level densities (see e.g. ref. [1]) are usually based on some type of counting of many-particle-many-hole excitations of nucleons in a mean field. In addition, one must consider pairing, and also collective degrees of freedom, such as rotations and vibrations.

A key point in evaluations of the level density is the choice between the spherical or the deformed coupling scheme for the angular momentum, applying, respectively, the Bethe formula or the Ericsson formula [2]. We show that the two schemes can be related more directly to each other than previously described: For deformed nuclei the phase space is extended by the degrees of freedom of a deformed core, which can contribute to the level density at a very modest expense in energy. For small deformations it will cost much energy to bring the angular momentum of the core into play, and the density of states becomes considerably smaller.

One should have a gradual transition from one scheme to the other as function of deformation, and this we investigate in two ways:

a) Comparing data to theory. For all nuclei with calculated deformation larger than $\epsilon_2 \geq 0.05$ we have evaluated the level density at the neutron separation energy. Our results indicate that it requires a deformation of size about 0.2 to fully develop the deformed coupling scheme.

b) A schematic model with exact treatment of the angular momentum, which continuously evolves from the Bethe coupling scheme to the Ericsson scheme. That is a many-particles plus rotor model. A number of nucleons in specific shell levels are combined with, and interacting with, a deformed core carrying a realistic moment of inertia scaling with the deformation. For example, for angular momentum I=2 and with 4 particles in the sd shell, the coupling of particle angular momenta allows for a total of 21 states, while the addition of the core enhances the space to 180 states. We show how this enhancement of level density smoothly sets in with increasing deformation.

These considerations of nucleons and core shed new light on the so-called "rotational enhancement of level densities" [3].

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High-spin isomers in the transitional Os, Ir and Au isotopes

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Studies of the even-even osmium isotopes and the odd-proton isotopes of iridium and gold near stability have been carried out using deep-inelastic reactions and time-correlated γ-ray spectroscopy. Nuclei in this region are known to be gamma-soft [1] with competition expected between multi-particle configurations associated with different, configuration-dependent, shapes as well as collective excitations. The results are drawn from measurements made using 6 MeV per nucleon, pulsed and chopped ^{136}Xe beams provided by the ATLAS facility at Argonne National Laboratory. The beams were incident on targets of enriched ^{186}W, ^{192}Os and natural ^{197}Au. Gamma-rays were detected with Gammasphere, with 100 detectors in operation. The main data analysis was carried out with γγγ cubes with various time-difference conditions, and also with time constraints relative to the pulsed beam to select different out-of-beam regimes.

Level schemes up to relatively high spins have been established for ^{190}Os , ^{192}Os and for the neutron-rich isotope ^{194}Os, for which only limited information was known previously (e.g. Ref. [1,2]). Several long-lived 3-quasiparticle isomers have been identified in ^{191}Ir and ^{193}Ir [3] and new results will be presented for the gold isotones, including ^{195}Au. These will be discussed in the context of the expected structures produced by relatively stable tri-axial shapes predicted by configuration-constrained potential energy-surface calculations, as well as from dynamical effects such as oblate alignment [4]. An emerging issue is that very low-lying states associated with the 12^+, $i_{13/2}{}^{2}$ neutron-hole configuration are persistently predicted, possibly resulting in, as yet undiscovered (i.e. missed), long-lived beta-decaying isomers. These prospects will be outlined.

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ADVANCING AB INITIO NUCLEAR STRUCTURE STUDIES TOWARD MEDIUM-MASS NUCLEI

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We report on investigation of the low-energy states of *p*- and *sd*-shell nuclei in the framework of the ab initio symmetry-adapted no-core shell model. We demonstrate an important role of many-particle correlations associated with large quadrupole deformations and low intrinsic spins. Our findings suggest that one can enhance the reach of ab initio framework toward medium-mass nuclei by utilizing a small subspace of symmetry-adapted configurations that retains the ability to factorize center-of-mass degrees of freedom exactly. This, in turns, allows for ab initio structure and reactions studies, including nuclei in the proximity of the proton-dripline.

Systematic character of low-lying $E1$ strength in time-dependent mean-field calculation including pairing correlation

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We investigate the low-lying electric dipole mode ($E1$) which is often called Pygmy dipole resonance (PDR) using time-dependent mean-field calculation systematically.

Our time-dependent method is derived from the time-dependent Hartree-Fock-Bogolibov theory (TDHFB) represented in canonical basis with the BCS approximation for pairing functional, which we call Cb-TDHFB [1]. Cb-TDHFB calculation can be executed in the three-dimensional coordinate-space representation with reasonable computational cost which is several times as much as TDHF. Our systematic calculation includes pairing correlation in the BCS approximation and full effects of deformation.

We investigate the $E1$ strength (or PDR) which appears in less than 10 MeV, using the Cb-TDHFB with Skyrme effective interaction (SkM*) and BCS-type pairing functional for about 300 kinds of nuclei. We found the neutron number dependence of PDR in heavy mass region around $N = 82$ similar to behavior of PDR in light mass region ($A < 60$) [1, 2]. We discuss the effects of pairing correlation for PDR and the relation between PDR and the energy distance from chemical potential to the top of barrier evaluated on single-particle motion.

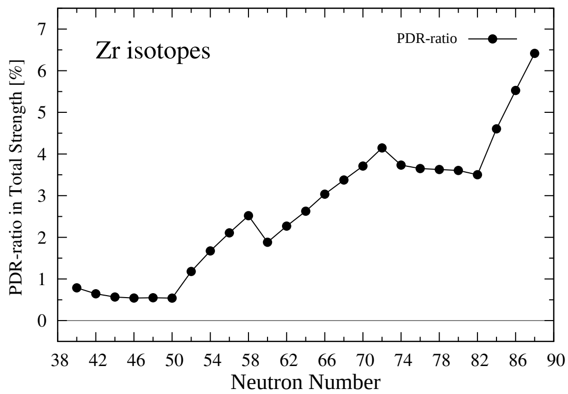

Figure 1: Neutron number dependence of PDR-ratio in the total $E1$ strength for Zr even-even isotopes ($N = 40 \sim 88$).

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PRECISION MASS MEASUREMENTS BEYOND NEUTRON-RICH ^{132}Sn AT JYFLTRAP

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Atomic masses of nuclei near the doubly magic nucleus ^{132}Sn are of key interest for nuclear structure studies. Precise atomic masses allow the extraction of quantities such as neutron and two-neutron separation energies through which changes in nuclear structure can be revealed. Additionally, high-precision mass values in this region contribute to studies of the r-process nucleosynthesis path in nuclear astrophysics.

We have measured atomic masses of several nuclei near ^{132}Sn at the University of Jyväskylä, Finland, using the JYFLTRAP double Penning trap setup [1]. The nuclei of interest were produced using the IGISOL method [2] which results in a fast and chemically inselective extraction of short-living ions. Our measurements extended to the neutron rich nuclei ^{135}Sn, ^{136}Sb and ^{140}Te. Several of the nuclei have low-lying isomeric states. Since high-precision mass measurements with Penning traps require monoisomeric samples, we used a sophisticated cleaning method to remove the unwanted states [3].

Masses were measured to a precision on the order of 5 keV or better. Not only ground state masses were measured but also isomeric states where applicable. The achieved precision afforded a detailed study of neutron pairing [4]. In this contribution, experimental results and comparison to theoretical calculations will be presented.

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STRUCTURES IN HEAVY-ION FUSION CROSS SECTIONS AT ENERGIES ABOVE THE COULOMB BARRIER

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Some of the structures that are observed in heavy-ion fusion cross sections at energies far above the Coulomb barrier are interpreted as caused by the penetration of successive (in angular momentum) and well-separated (in energy) centrifugal barriers. The structures are most pronounced in the fusion of light, symmetric systems, where the separation of barriers is relatively large, but there are indications that they may also exist in heavier systems. Structures in heavy-ion fusion data at energies close to the Coulomb barrier are usually best revealed by plotting the barrier distribution for fusion, which is defined as the second derivative of the energy weighted fusion cross section. It is shown that a good way to reveal the structures at energies far above the Coulomb barrier is to plot the first derivative of the energy weighted fusion cross section. This method is illustrated by analyzing the high-energy fusion data for ^{12}C+^{12}C [1] and ^{16}O+^{16}O [2], and comparisons are made to coupled-channels calculations [3]. The possibility of observing similar structure in the fusion of heavier systems is discussed.

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Collinear Laser Spectroscopy of Praseodymium at TRIGA-LASER and COLLAPS/ISOLDE

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The nuclear magnetic moment of the neutron-deficient isotope $^{140}Pr^{+}$ is of particular interest due to its importance for the explanation of the observed modulated electron capture decay of hydrogen-like ^{140}Pr in the ESR storage ring at GSI [1]. Additionally, the sign of its magnetic moment needs also to be confirmed because it has been used to explain the counter-intuitive observation of a reduced electron-capture rate in helium-like ^{140}Pr ions compared to the hydrogen-like species [2]. A theoretical description is given in [3]. The knowledge of the nuclear magnetic moment will also allow further laser spectroscopic investigations of the hydrogen-like ion at the storage ring.
Collinear laser spectroscopy is a common technique to determine nuclear ground state properties, e.g. the nuclear magnetic moment. As a first step we have performed collinear laser spectroscopy of the stable isotope $^{141}Pr^{+}$ at the TRIGA-LASER experiment at the research reactor TRIGA Mainz. The measurements provide information on the strength of the investigated transition and an estimation of the detection efficiency and accuracy that can be reached in an on-line experiment. During a first beamtime at the COLLAPS experiment at ISOLDE/CERN the interesting isotope ^{140}Pr could not be measured. However, the nuclear magnetic moments of $^{135,136,137}Pr$ were determined.
The results on the hyperfine splitting parameters of the stable ^{141}Pr and the radioactive isotopes $^{135,136,137}Pr$ are presented and discussed.

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Spectroscopy of very heavy elements at the limits with the Super Separator Spectrometer S^3

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The new SPIRAL2 [1] LINAG accelerator, developed for production of high intensity deuteron beam dedicated to intense radioactive beams production, will also deliver unprecedented high intensity stable beams. Used in conjunction with the Super Separator Spectrometer (S^3) [2], it will open new horizons for the physics of nuclei with low production cross-section and rare nuclei at the extreme limits of the nuclear chart.

Present limits for Spectroscopy of heavy elements was recently pushed down to 10 nb level [3] for prompt spectroscopy and a first step in Super Heavy Elements (SHE) detailed spectroscopy (SHE) was done with first prompt spectroscopy of ^{256}Rf (Z=104) [4].

The S^3 project operated in the framework of the SPIRAL2 project aim at pushing these limits down in order to enable a major step in the spectroscopy of heavy and super heavy elements. Based on the existing expertise and the latest technologies, the S^3 collaboration is preparing the best possible focal planes [5] for spectroscopy of VHE/SHE elements, spectroscopy around ^{100}Sn and SHE synthesis.

After an introduction on S^3 the Physics case, the latest developments for the S3 focal-plane elements will be detailed.

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Three-nucleon forces in medium mass nuclei near N = 32 investigated through precision mass measurements at TITAN

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The Penning trap mass spectrometer at TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) is a precision device for providing mass measurements on short-lived singly and highly-charged ions. Nuclear masses are well established for studying nuclear structure. Through systematic examination of the mass surface important deviations from the shell model in nuclei far from the valley of stability have been found, for example, the discovery of the new magic number N = 16 and in understanding the island of inversion [1-3]. Recently, the region near N = 32, 34 [4] has been of great interest for nuclear structure because of the prediction of the emergence of new sub-shell closures. To test these predictions TITAN has undertaken a precision mass measurement campaign in the region of doubly-magic $^{48}Ca_{28}$, in which the magic number N = 28 is not reproduced in theoretical predictions employing nucleon-nucleon (NN) only forces. New calculations in a chiral effective field theory (EFT) with three nucleon (3N) forces, which have already shown its success in explaining the oxygen anomaly [5], have been completed for the Ca isotopes. Here we present results of the mass measurements of $^{49\text{-}52}Ca$ and $^{47\text{-}51}K$ measured with the Penning trap at TITAN [6-7]. The predicted two-neutron separation energies with 3N forces agree well with the new measured values, and also reproduce other measured observables in the Ca isotopes [4], which deviate greatly from the tabulated values in the 2003 Atomic Mass Evaluation.

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Future Opportunities with GRIFFIN

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GRIFFIN (Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei) is a new array of 16 large-volume HPGe Clovers being installed at TRIUMF-ISAC during 2014 to upgrade the 8pi spectrometer for beta-decay studies of spallation-produced exotic beams. GRIFFIN will take advantage of all the existing ancillary detectors of the 8pi which include an array of 20 plastic scintillators (SCEPTAR) for coincidence beta-tagging, 5 Si(Li) detectors (PACES) for internal conversion electron measurements and an array of 10 fast scintillators of BaF2/LaBr3 (DANTE) for measurements of short-lifetimes of excited states in daughter nuclei. In addition GRIFFIN will couple to the new DESCANT array of liquid scintillators to enable beta-delayed neutron emission studies. A new state-of-the-art digital data acquisition system is being developed to enable very large data through-put as well as high-precision measurements of Super-Allowed Fermi beta decay.

GRIFFIN will constitute an increase in the gamma-gamma efficiency of close to a factor of 300 over the current 8pi setup and facilitate investigations of exotic nuclei produced at ISAC and the future ARIEL facilities. An overview and the progress of the project will be presented along with a discussion of future opportunities with the GRIFFIN spectrometer when it is fully operational in 2015.

Gamma-ray spectroscopy of low-spin normally to high-spin superdeformed band structures in $^{62}_{30}$Zn$_{32}$

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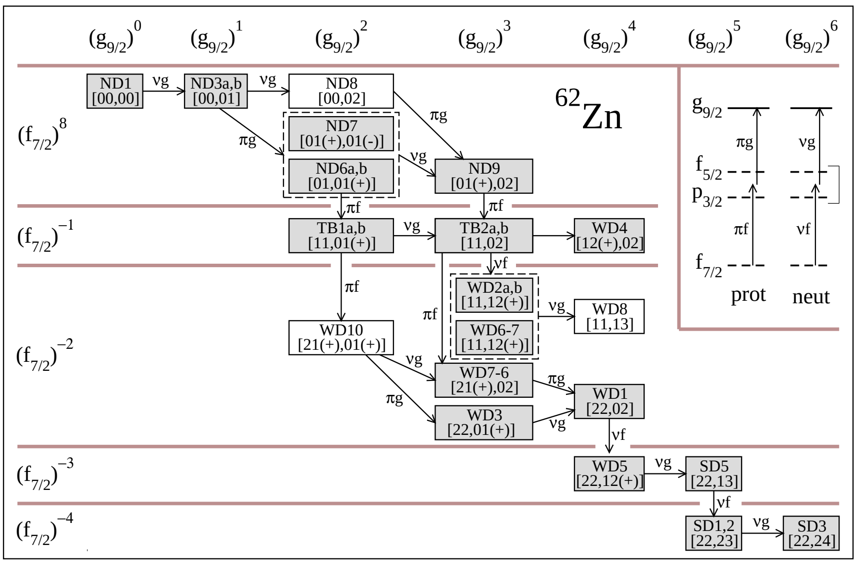
Comprehensive experimental knowledge of the $^{62}_{30}$Zn$_{32}$ nucleus has been obtained from the combined statistics of four different experiments. The Gammasphere Ge-detector array in conjunction with the 4π charged-particle detector array Microball was used to detect the γ-rays in coincidence with evaporated light particles. In total twenty-seven band structures have been observed in ^{62}Zn, twenty for the first time. The resulting extensive decay scheme comprises almost 260 excited states, which are connected with more than 450 γ-ray transitions. The multipolarities have been determined for the γ-ray transitions and as a result spin-parity assignments are given for nearly all energy levels. The collective structures are compared with results from configuration dependent Cranked Nilsson-Strutinsky calculations. They predict that successive proton and neutron excitations above and across the $Z = N = 28$ shell gap give a smooth configuration chain sequence from the low-spin to the high-spin observed bands. These assignments are specified in the figure, where boxes with configurations which appear well established are shaded. The present results give suggestions on specific modifications of the standard Nilsson parameters in the mass $A \sim 60$ region.



Configurations $[p_1p_2, n_1n_2]$ assigned to the observed bands in ^{62}Zn grouped according to the number of holes in the $1f_{7/2}$ orbitals (p_1, n_1) and particles in the $1g_{9/2}$ orbitals (p_2, n_2). The $+$ and $-$ signs refer to the signature of the $f_{5/2}p_{3/2}$ particles. Starting from the [00,00] ground-state configuration, arrows indicate how the observed bands are created from successive proton and neutron excitations defined in the inset.

LIFETIMES OF EXCITED STATES IN NEUTRON-RICH NUCLEI

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Lifetimes of low-lying excited states have been measured for a very wide range of neutron-rich nuclei in an experiment using the recoil-distance Doppler shift technique after fusion-fission reactions in inverse kinematics. In an experiment at GANIL a beam of ^{238}U was accelerated to an energy of 1475 MeV and directed onto a ^{9}Be target. The ^{247}Cm compound nucleus fissions while still inside the target foil. The fission fragments exit the target with high velocities and are strongly forward focused due to the inverse kinematics. The velocity of the fission fragments was slowed using a degrader foil, which was placed in a plunger device at micrometer distances from the target. After passing through the degrader, one of the two fission fragments was detected and identified in mass, atomic number, and charge state event by event using the VAMOS spectrometer, which was rotated to 20° with respect to the beam axis and equipped with a new, improved detection system at the focal plane. Gamma rays were detected around the target position with the segmented germanium clover detectors of the EXOGAM array and correlated with the fission fragment identified in VAMOS. The lifetime of excited states are extracted from the intensities of the fast and slow components of Doppler-shifted gamma rays as a function of the target-degrader distance. More than 200 nuclides with masses between $70<A<140$ were identified in VAMOS, allowing lifetimes to be measured for a wide range of nuclei under identical experimental conditions. The setting of the spectrometer was optimized for the transmission of neutron-rich isotopes of elements with Z=40-50, where lifetimes of excited states are only poorly known. Deformation and collectivity changes rapidly in this region of the nuclear chart, making the measurement of electromagnetic transition rates a stringent test and benchmark for nuclear structure models.

In a second experiment a similar technique was used to extract lifetimes of excited states in neutron-rich Zn isotopes populated in deep-inelastic collisions between ^{76}Ge projectiles and a ^{238}U target. The experiment was carried out at Legnaro National Laboratories and used the highly segmented germanium detectors of the AGATA Demonstrator array coupled to the PRISMA magnetic spectrometer. The experiment yielded an unexpectedly long lifetime for the 4^+ state in ^{74}Zn. The combination of *B(E2)* values from the lifetime measurement and excitation probabilities from a Coulomb excitation measurement at ISOLDE [1] gives information on the spectroscopic quadrupole moment for the 2^+ state in ^{74}Zn.

Results from both experiments will be presented and compared to theoretical predictions.

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NEUTRON-RICH LEAD ISOTOPES PROVIDE HINTS ON THE ROLE OF EFFECTIVE THREE-BODY FORCES

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Electromagnetic transition rates, in particular for E2 transitions, are a sensitive and well-studied probe of nuclear structure: their dependence on the nuclear wave function offers the possibility of strict tests of theoretical models. Usually, B(E2) rates are calculated in a restricted shell-model space and they are then renormalized with constant effective charges. However, even large-scale shell-model calculations may fall short in reproducing the experimental data, as in the case of proton-rich tin isotopes [1,2]. In this regard, there is a common but bad practice of neglecting effective three-body forces and two-body transition operators when calculating the B(E2) values which could be the origin of the problems encountered [3]. We have recently performed an experiment to measure the transitions rates from the seniority-isomers of semi-magic neutron-rich lead isotopes and they show indeed discrepancies with shell-model estimates. This region of the nuclide chart has been so far scarcely explored due to its high mass and neutron excess, which oblige to exploit fragmentations reactions with relativistic uranium beams. Consequently, neutron-rich nuclei beyond ^{208}Pb were populated by using a 1 GeV*A ^{238}U beam at GSI. The resulting fragments were separated and analyzed with the FRS-RISING setup [4,5]. Many neutron-rich isotopes were identified for the first time and a significant number of new isomers were hence discovered, enabling to study the structure of these isotopes. The new exotic isotopes observed extend up to ^{218}Pb along the Z=82 shell closure and up to N=134 and N=138 for the proton-hole and proton-particle Tl and Bi nuclei, respectively. New isomers were observed in $^{212\text{-}216}$Pb, in ^{217}Bi, in ^{211,213}Tl and in ^{210}Hg. In the talk, the experimental results will be presented as well as state-of-the-art shell-model calculations pointing out how the measured isomeric B(E2)s in neutron-rich lead isotopes seem to require state-dependent effective charges to be correctly reproduced. It will be shown how this is related with the aforementioned neglect of effective three-body forces, whose introduction improves the agreement with the experimental data. The unexpected structure of the very exotic ^{210}Hg isotope will also be discussed.

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SHELL-STRUCTURE AND PAIRING INTERACTION IN SUPERHEAVY NUCLEI: ROTATIONAL PROPERTIES OF THE Z=104 NUCLEUS ^{256}Rf

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The rotational band structure of the Z=104 nucleus ^{256}Rf has been observed up to a tentative spin of $20\hbar$ using state-of-the-art γ-ray spectroscopic techniques at the University of Jyväskylä, Finland. This represents the first such measurement in a superheavy nucleus whose stability is entirely derived from the shell-correction energy. The observed rotational properties are compared to those of neighbouring nuclei and it is shown that the kinematic and dynamic moments of inertia are sensitive to the underlying single-particle shell structure and the specific location of high-j orbitals. The moments of inertia therefore provide a sensitive test of shell structure and pairing in superheavy nuclei which is essential to ensure the validity of contemporary nuclear models in this mass region. The data obtained show that there is no deformed shell gap at Z=104, which is predicted in a number of current self-consistent mean-field models.

Details of the experiment carried out and the in-beam and decay spectroscopic data obtained will be presented. Perspectives for future studies of this type will also be discussed.

Measuring the absolute decay probability of ^{82}Sr by counting ions and gamma-decay spectroscopy*

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We have developed a method of implanted ion counting in order to determine the absolute decay probability of the 776.5 keV γ-ray transition in the decay sequence of ^{82}Sr$\rightarrow$^{82}Rb$\rightarrow$^{82}Kr. A 215 MeV beam of ^{82}Sr was produced at the Holifield Radioactive Ion Beam Facility [1] and passed through an ionization chamber that counted and identified the ions before they were implanted into thin aluminum foils. The foils were then removed from the system and placed in front of a calibrated Ge detector that counted the 776.5 keV, $2^+ \rightarrow 0^+$ in ^{82}Kr. We deduced the probability per decay of ^{82}Rb for the 776.5 keV γ-ray in ^{82}Kr to be 0.1493(37) in agreement with the accepted [2] average value of 0.1508(16). This new technique measures directly the number of decaying nuclei in a given sample and significantly reduces the dependence on knowledge of the complete decay level scheme. See ref. [3] for more details.

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BETA DELAYED NEUTRON EMISSION – NEW PERSPECTIVE ON R-PROCESS NUCLEI WITH VERSATILE ARRAY OF NEUTRON DETECTORS AT LOW ENERGY (VANDLE)

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Beta-delayed neutron emission (βn) is a prevalent decay channel for a majority of the very neutron-rich nuclei. It is of particular importance in r-process modeling and influences the final isotopic abundance distribution. While many nuclear models predict nuclear lifetimes and branching ratios of the r-process nuclei, very little is known experimentally about the energy spectrum of the neutrons from βn branches that provide direct information about the unbound states populated through beta decay. These measurements constitute a better test of nuclear models than simply using lifetimes and branching ratios.

The new Versatile Array of Neutron Detectors at Low Energy (VANDLE) [1] was commissioned at the Holifield Radioactive Ion Beam Facility (HRIBF). The HRIBF uses proton-induced fission to produce unique, intense and high isotopic purity beams of neutron-rich fission fragments. We have measured neutron energy spectra in key regions of the nuclear chart: near the shell closures at ^{78}Ni and ^{132}Sn, and for the most deformed nuclei at Z=37. Many of these nuclei lie directly on the r-process path [1]. Of the 29 βn emitters studied, only 4 relatively long-lived isotopes were previously measured. For some of the most exotic nuclei, narrow and intense peaks in the neutron energy distribution indicate the presence of resonances, which are most likely signatures of the excitation of deeply bound "core" states. VANDLE has the unique ability, for a time-of-flight scintillator array, to measure neutron energies as low as 100 keV, which is critical for making credible comparisons between experiment and theory. Preliminary results from the most prominent measurements will be presented.

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Band Structures and Nucleon Alignments in ^{175}W and ^{173}W*

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Spectroscopy of rotational bands in the A∼180 region is crucial to delineate the complex interplay between Nilsson orbitals in axially-symmetric prolate deformed nuclei. Highly excited rotational states in ^{175}W and ^{173}W were populated at Argonne National Laboratory via a 230 MeV ^{50}Ti beam from the ATLAS accelerator incident on a thin ^{128}Te target. The resulting fusion-evaporation reaction led to the population of ^{175}W and ^{175}W in the 3n- and 5n-evaporation channels, respectively. Decays from excited states were detected with the Gammasphere array, and Radware software was used to analyze symmetric γ-coincidence cubes and hypercubes.

Rotational bands in ^{175}W and ^{173}W, built on a $1/2^-[521]$, $p_{3/2}$ configuration [1], have been extended up to spins of 35 and $40\hbar$ respectively, beyond the second nucleon alignment. Bands built on a $7/2^+[633]$, $i_{13/2}$ configuration have been extended to 27 and $38\hbar$, respectively, in ^{175}W and ^{173}W. Several new states in the the $5/2^-[512]$, $h_{9/2}$ neutron bands have also been identified. Rotation alignments resulting from AB and BC $i_{13/2}$ neutron, and $h_{11/2}$ proton crossings have been observed at rotational frequencies around 0.25, 0.35 and 0.50 MeV, respectively. The crossing frequencies are consistent with predictions of our Woods-Saxon cranking calculations. Details of systematics in this region [2, 3] and results of cranking calculations will be presented.

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IN-BEAM COMPOUND NUCLEAR X-RAY MULTIPLICITIES – SOME RECENT RESULTS AND PROSPECTS FOR ATOMIC-NUMBER MEASUREMENTS FOR SHES

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In several past studies, prompt (in-beam) characteristic compound nuclear x-rays from evaporation residues were measured in heavy-ion fusion reactions. For light compound nuclei ($A_{cn} \leq 100$) x-ray multiplicities are of the order of a percent or less, but strongly increase with compound nucleus mass due to increasing electron conversion. In these earlier measurements with beams of protons and ^{4}He (Grenoble), ^{4}He and ^{12}C (Groningen), ^{6,7}Li (Indiana University), and a range of systematic studies with ^{28}Si and ^{32}S beams at Argonne, K x-ray multiplicities $\langle M_K \rangle$ were measured for compound nuclei as heavy as A ~ 200. While considerable fluctuations are observed due to nuclear structure effects, average values for $\langle M_K \rangle$ larger than 1 are observed for the heavier systems. From a semi-empirical estimate that we carried out at the time in comparison with a compilation of all the data, we found an average trend approximately consistent with a $A_{cn}^{4.5}$ dependence.

That a single compound nucleus can emit more than 1 x-ray is a consequence of the fact that the filling times of an empty inner atomic orbit (typically 10^{-13} to 10^{-14} seconds) is significantly shorter than the typical lifetime of nuclear levels decaying by electron conversion (typically the pico-second range for the heaviest systems), such that subsequent conversions are possible in the decay cascade of a compound nucleus. For nuclei around A ~ 300 (e.g., super heavy elements) a simple extrapolation of our semi-empirical estimate would predict K x-ray multiplicities of ~5, perhaps even higher in a most favorable case. This could provide the opportunity for determining the nuclear charge of a (tagged) single compound nucleus if other experimental constraints (such in-beam count rate in the detectors etc.) will allow this.

To pursue this further we have now, as a first step, analyzed $\langle M_K \rangle$ results from recent ^{48}Ca beam induced nuclear structure studies on Pb and Bi targets, leading to compound nuclei of nobelium and lawrencium isotopes. The results, as well as concepts for experiments with the necessarily very high beam intensities needed for SHE studies, will be presented and discussed in this talk.

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On the evolution of the neutron $0d_{5/2}$ and $1s_{1/2}$ orbitals in neutron-rich $0p$-$1s0d$ shell nuclei*

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A detailed look into the evolution of the $0d_{5/2}$ and $1s_{1/2}$ neutron orbitals has been performed using the ^{19}O(d,p) and ^{17}N(d,p) reactions at beam energies of 6.6 MeV/u and 13.5 MeV/u, respectively. The experiments were carried out in inverse kinematics with radioactive beams produced by the ATLAS in-flight facility, and protons in coincidence with heavy ion recoils were detected by the helical orbit spectrometer (HELIOS) [1]. Eight levels in ^{20}O, including a previously unobserved $J^\pi = 3^+$ level at $E^* = 5.23$ MeV, and at least three states in ^{18}N, were observed with measurable strengths. Q values were measured with an energy resolution of ~200 keV, and spectroscopic factors were extracted from angular distributions through a distorted wave Born approximation analysis. Results from the ^{19}O$(d,p)^{20}$O reaction established the $\ell = 0$ and 2 strength distributions in this region, and allowed for the determination of the $J = 0, 2$ and 4, $T = 1$ $\langle (0d_{5/2})^2 J|V|(0d_{5/2})^2 J\rangle$ empirical two-body matrix elements of the NN interaction. Identification of $0d_{5/2}$ and $1s_{1/2}$ dominated levels in ^{18}N, those having large overlaps with the ^{17}N ground state, illuminates the $N = 11$ transition region between ^{19}O, which has a $J^\pi = 5/2^+$ ground state and a high lying $1/2^+$ excited state, and the exotic $J^\pi = 3/2^+$ ^{17}C nucleus [2]. In addition to empirical systematics, results will be discussed in terms of modern $0p$-$1s0d$ and $1s0d$ confined shell-model interactions, as well as their impact on clarifying the underlying mechanisms leading to the evolution of the magic numbers [3].

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High-spin Structure of Neutron-rich $^{248\text{-}250}$Cf (N=150-152)*

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Experimental studies of the excitations of the heaviest elements around Z ~ 100, A ~ 250, whose unexpected stability is attributed to shell effects, provide important checks of theoretical model predictions, in particular for the location of the next higher spherical shell gaps. While fusion- evaporation reactions have led the way for the spectroscopy of the heaviest elements with $Z \geq 100$, complementary information gathered from $Z < 100$ nuclei via deep-inelastic and transfer reactions provides a more comprehensive template for understanding both collective and single-particle behavior in this region, where proton and neutron orbitals in the highest oscillator shells are active participants. In our quest for understanding the structures of transplutonium elements [1], we report here on new spectroscopic observations in the relatively neutron-rich nuclei $^{248\text{-}250}$Cf (Z=98, N=150-152).

High-spin states in $^{248\text{-}250}$Cf nuclei were populated via deep-inelastic and transfer reactions using a ^{208}Pb beam incident on a radioactive ^{249}Cf target. Prompt γ rays were detected with the Gammasphere array. The ground-state bands of ^{248}Cf and ^{250}Cf [2] have been extended to high-spins and the $K^{\pi} = 2^{-}$ octupole band in ^{248}Cf has been observed for the first time. In addition to the previously observed ground-state bands of ^{249}Cf [1], a new pair of bands built on a neutron single-particle orbital has been identified. These spectroscopic studies bridge a gap that existed in the systematics for N = 150, 151 and 152 isotones. The complete alignment systematics for isotopes and isotones of $^{248\text{-}250}$Cf show interesting variations. Possible connections to non-axial octupole collective effects that have been shown to be important in this region [3] will be discussed. The new data will be presented in the context of the extended systematics of this region and available theoretical predictions for the neutron-rich, transplutonium $N \geq 150$ nuclei.

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Particle-γ coincidence studies shedding new light on intrinsic states in ^{235}U and ^{237}U

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The uranium isotopes between A=234-238 are of interest for a variety of physics and applications reasons. Of particular relevance to the present work, the even-even nuclei in this region exhibit unusual pairing correlations, for example, puzzlingly large population cross sections are observed for excited 0^+ levels via two-neutron transfer reactions [1]. Historically, these uranium isotopes have been studied in detail using a variety of different approaches applying either γ-ray or charged particle spectroscopy. Despite this, the structure information for this isotopic chain remains incomplete, even at low energies.

A seldom utilized but powerful approach to structure studies is the marriage of charged-particle detection in pickup reactions to γ-ray spectroscopy with modern, high-efficiency detector arrays. The ability to tag on outgoing ions provides unprecedented isotopic selectivity as well as energy and angular distribution information for the specific states populated in a given reaction. Coupling this to coincident γ-ray information, a single particle-γ event details the nucleus formed in the reaction, which level was populated and how it subsequently decayed.

The present work focuses on low energy, low spin structure studies of the uranium isotopes ^{234}U to ^{238}U. The experiment was performed at Lawrence Berkeley National Laboratory using a 28 MeV proton beam, incident on ^{236}U and ^{238}U targets. Particle-γ and particle-fission coincidence data were collected over the course of a week using the STARS-LIBERACE silicon-telescope and γ-ray arrays. Results for odd-mass ^{235}U and ^{237}U (populated via the (p,d) reaction channel) will be presented. The data include several newly identified intrinsic states. Of specific interest is the $3/2^-$[501] Nilsson state hitherto unobserved in both nuclei. It has been suggested that the presence of steeply upsloping, oblate deformation-driving Nilsson states such as the $3/2^-$[501] orbital, may play a role in the abnormal pairing correlations observed in the neighboring even-even uranium isotopes [2,3].

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Search for two-phonon octupole vibrational bands in $^{92,94,96}Sr$ and $^{95,96,98}Zr$

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For the collective octupole (λ=3) surface vibrations associated with the 3^- phonon, only seven spherical nuclei ^{208}Pb, ^{96}Zr, and $^{146,147,148}Gd$, ^{144}Nd and ^{146}Sm have been reported to have possible two-phonon octupole vibrational states since the discovery of a two-phonon octupole vibrational $19/2^-$ state in ^{147}Gd in 1982. Two-phonon octupole vibrational (POV) states should be a quartet of 0^+, 2^+, 4^+ and 6^+ states. It is expected that the octupole vibrations in the spherical nuclei follow the nearly harmonic vibrational limit because the octupole 3^- phonon is formed by a collective contribution of many particlehole excitations between well separated single-particle orbitals.

Six and one new gamma transitions were identified in ^{94}Sr and ^{96}Zr, respectively, from the spontaneous fission of ^{252}Cf. Excited states in $^{92,94,96}Sr$ and $^{95,96,98}Zr$ were reanalyzed and reorganized to propose the new two-phonon octupole vibrational states and bands. The spin and parity of 6^+ are assigned to a 4034.5 keV state in ^{94}Sr and 3576.4 keV state in ^{98}Zr. These states are proposed as the two-phonon octupole vibrational states along with the 6^+ states at 3483.4 keV in ^{96}Zr, at 3786.0 keV in ^{92}Sr and 3604.2 keV in ^{96}Sr. The positive parity bands in $^{94,96}Sr$ and $^{96,98}Zr$ are the first two-phonon octupole vibrational bands based on a 6^+ state observed in spherical nuclei. It is thought that in $^{94,96}Sr$ and $^{96,98}Zr$ a 3^- octupole vibrational phonon is weakly coupled to an one-phonon octupole vibrational band to make the two-phonon octupole vibrational band. Also, the high spin states of odd-A ^{95}Zr levels are interpreted to be caused by the neutron $2d_{5/2}$ hole weakly coupled to one- and two-phonon octupole vibrational states of ^{96}Zr. The new one- and two-POV bands in ^{95}Zr are, for the first time, proposed.

MODERNIZATION OF VASSILISSA SEPARATOR FOR HEAVY ELEMENT SPECTROSCOPY INVESTIGATION

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In the past, various types of reactions and identification techniques were applied in the investigation of formation cross sections and decay properties of transuranium elements. The fusion-evaporation reactions with heavy targets, recoil - separation techniques and identification of nuclei by the parent-daughter generic coincidences with the known daughter-nuclei after implantation into position-sensitive detectors were the most successful tools for production and identification of the heaviest elements known presently. This technique may be further improved and presently it may be very promising for the identification of new elements, search for new isotopes and measurement of new decay data for the known nuclei.

Within the past 15 years, the recoil separator VASSILISSA [1] has been used for the investigations of evaporation residues (ERs) produced in heavy ion induced complete fusion reactions. In the course of the experimental work a bulk of data on ERs formation cross sections, synthesized in asymmetric reactions was collected.

With γ and β detector arrays, installed at the focal plane of the VASSILISSA separator, detailed spectroscopy of Fm–Lr isotopes was performed during last 5 years.

In the years 2004 – 2010 using the GABRIELA (**G**amma **A**lpha **B**eta **R**ecoil **I**nvestigations with the **EL**ectromagnetic **A**nalyser) set-up [2] the experiments aimed to the gamma and electron spectroscopy of the transfermium isotopes, formed at the complete fusion reactions with accelerated heavy ions were performed. Isotopes of No and Lr, synthesized at the $^{48}Ca+^{207,208}Pb \rightarrow ^{255,256}No^*$, $^{48}Ca+^{209}Bi \rightarrow ^{257}Lr^*$, $^{22}Ne + ^{238}U \rightarrow ^{260}No^*$ reactions were studied. The experiments with high intensity ^{22}Ne beam showed, that for slow evaporation residues rather high (~10%) transmission efficiency need to be obtained. In this case for α–γ and α–β coincidences used in the study of the isotopes of 104 and 105 elements good statistics could be obtained during one month of the experiment.

Accumulated experience allowed us to perform ion optical calculations and to design the new experimental set up, which will collect the base and best parameters of the existing separators and complex detector systems used at the focal planes of these installations [3].

New experimental set up, the velocity filter, is now developing for synthesis and studies of the decay properties of heavy nuclei. At the focal plane of the separator GABRIELA set up (α, β, γ detectors array) will be installed.

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Studies of light neutron-excess nuclei from bounds to continuum

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In light neutron-excess systems, many kinds of molecular structures are discussed from the view point of the clustering phenomena. In particular, much attention has been concentrated on Be isotopes. The molecular orbital (MO) around the ^{8}Be (=α+α) core, such as π^- and σ^+ associated with the covalent binding of atomic molecules, have been shown to give a good description for the low-lying states of these isotopes [1]. In their highly-excited states, furthermore, recent experiments revealed the existence of the interesting resonant states, which dominantly decay to the ^{6,8}He fragments [2]. In this report, we show the unified study of the exotic cluster structures of even Be isotopes (=α+α+XN, X=2,4,6,8) from bound states to continuum states.

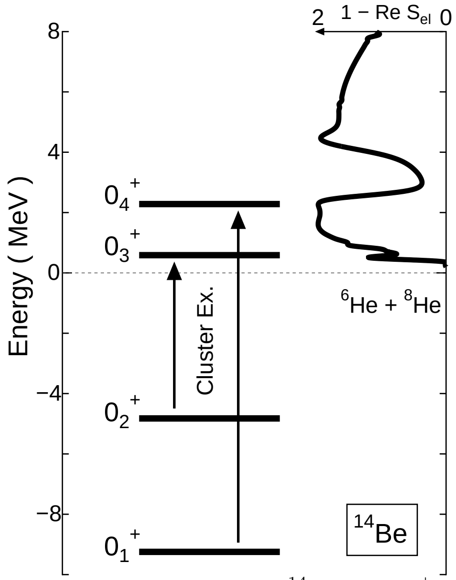

FIG. 1: Energy levels in ^{14}Be (J^π=0$^+$). The curve above the zero energy show the total reaction cross section in the collision of ^{6}He$_{g.s.}$+^{8}He$_{g.s.}$. Two arrows represent the cluster excitations from the bound states.

We applied the generalized two-center cluster model (GTCM), in which the formations of various chemical bonding structures such as covalent MOs and the atomic orbital (AO) with ^{x}He+^{y}He, can be described in a unified manner [3,4]. Due to the consistent treatment of chemical bonding structures, this model can also handle the nuclear reactions from AOs to MOs, which are observed in continuum above particle-decay thresholds [4]. An example of the application of GTCM to ^{14}Be=α+α+6N with the J^π=0$^+$ state is shown in Fig. 1.

First, we solved the bound state problem, and two energy levels are obtained (0_1^+ and 0_2^+). Next, we solved the scattering problem of ^{6}He$_{g.s}$+^{8}He$_{g.s.}$ and calculated the scattering matrix (a curve in the right side of Fig. 1). In the continuum region, we identified two resonances, 0_3^+ and 0_4^+, in the scattering matrix. These states correspond to the cluster excitation mode from the bound states, as shown in Fig. 1. Specifically, the two resonant states are generated by the excitation of two α's relative motions in the bound states. As a result of a cluster excitation, the AO structures, such as ^{6}He$_{g.s.}$+^{8}He$_{g.s.}$ and ^{6}He(2_1^+)+^{8}He$_{g.s.}$, are developed in the 0_3^+ and 0_4^+ states, respectively. We performed the similar calculations for other Be isotope ($^{8\sim16}$Be) and confirmed that, in these systems, the similar ^{6,8}He clusters such as ^{10}Be=α+^{6}He, ^{12}Be=^{6}He+^{6}He (α+^{8}He), ^{16}Be=^{8}He+^{8}He are realized in the excited states embedded in continuum. In ^{12}Be, we found that resonant structures are strongly excited through the two neutrons transfer, α+^{8}He $\rightarrow$ ^{6}He+^{6}He [4]. We discuss a strong interplay between the low-energy transfer reactions and the nuclear structures.

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Characterization of Germanium Double-Sided Strip Detectors*

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New technologies for making γ-ray detectors position sensitive have many applications in space science, medical imaging, homeland security, and in nuclear structure research. One promising approach uses high-purity germanium wafers, in Low Energy Photon Spectrometer (LEPS) geometry, but with segmentation of the electrodes into strips forming a Double-Sided Strip Detector (DSSD). The combination of data from adjoining strips, or pixels, is physics-rich for Compton image formation and polarization studies. However, combining these data is very sensitive to charge loss and various kinds of cross-talk [1]. In the early part of this century rapid progress was made in improving the size and segmentation of the wafers. Unfortunately, the momentum slowed, despite many technical issues still being unresolved, leaving a promising approach unfulfilled. One problem lay with the use of lithium as a contact material, as although it made a good rectifying contact, it had sufficient mobility to prevent the fabrication of narrow, closely spaced electrodes with high fidelity for charge collection, and low cross-talk. Several alternatives were tried including using phosphorous and amorphous germanium electrodes. In this paper we report on a new contact technology developed by PhD's Co., and the prospect for a new generation of superior imaging germanium wafers.

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Spectroscopy of light astatine and francium nuclei

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Complementary in-beam and delayed spectroscopy have been performed for odd-mass neutron deficient astatine and francium isotopes [1, 2]. The gas-filled recoil separator RITU [4] combined with the focal plane spectrometer GREAT [3] and the in-beam array JUROGAM [5, 6] were employed in these studies.

New isomers, based on the $1/2^+$ and the $13/2^+$ states, were identified in the astatine and francium nuclei by means of combined electron and γ-ray spectroscopy. In addition, prompt γ rays were studied in order to search for possible shape coexistence in these nuclei. To motivate this search, results in the studies [7, 8, 9] reveal an onset of ground-state deformation when crossing the proton drip line in the odd-mass astatine and francium nuclei.

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Spectroscopic factors from the $^{111}Cd(\vec{d},p)^{112}Cd$ single neutron transfer reaction

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The cadmium isotopes have been cited as excellent examples of vibrational nuclei for decades, with multi-phonon quadrupole, quadrupole-octupole, and mixed-symmetry states proposed. From a variety of experimental studies, a large amount of spectroscopic data has been obtained, recently focused on γ-ray studies. In the present work, the single-particle structure of ^{112}Cd has been investigated using the $^{111}Cd(\vec{d},p)^{112}Cd$ reaction. The high energy resolution investigation was carried out using a 22 MeV beam of polarized deuterons obtained from the Maier-Leibnitz Laboratory at Garching, Germany. The reaction ejectiles were momentum analyzed using a Q3D spectrograph, and 115 levels have been identified up to 4.2 MeV of excitation energy. Spin-parity has been assigned to each analyzed level,and angular distributions for the reaction cross-sections and analyzing powers were obtained. Optical model calculations have been performed, and the calculated angular distributions were compared with the experimental cross-sections and analyzing powers. Many additional levels have been observed compared with the previous (d,p) study performed with 8 MeV deuterons, including strongly populated 5^- and 6^- states. The former was previously assigned as a member of the quadrupole-octupole quintuplet, based on a strongly enhanced B(E2) value to the 3^- state, but is now re-assigned as being predominately $s_{1/2} \otimes h_{11/2}$ two-quasineutron configuration.

BUILDING THE NEUTRON MULTIPLICITY FILTER NEDA

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The NEDA project aims at the design and construction of a new neutron multiplicity filter to be used as an ancillary detector for the state of the art germanium arrays, with both intense stable as well as radioactive ion beams.

One of the possible methods of studying yrast and yrare states of extremely neutron deficient nuclei is by using heavy-ion induced fusion-evaporation reactions. In such experiments, the nuclei of interest are however produced with very low cross sections and clean reaction channel selection is essential. This can be done by detection of neutrons and charged particles emitted from the compound nucleus. In fact, this is the efficiency and quality of the detection of particles which determines the limits of acquiring experimental information on more and more exotic and interesting structures. As the most interesting reaction channels are almost always associated with the emission of two or more neutrons, constructing a new powerful neutron detector array – a neutron multiplicity filter – is a key point here. The NEDA project aims at building an array which will have efficiency for clean detection of events with two neutrons emission 4-6 times higher then existing arrays. The efficiency gain for larger neutron multiplicities will be even higher.

Extensive computer simulations were performed in order to establish optimum size of a single NEDA detector unit, as well as the geometry of the entire array. The Geant4 neutron interaction model was evaluated and the results of the simulations were verified by the experimental data collected for two existing neutron detectors. Conclusions on the detector size and the status of the geometry design of the NEDA array will be presented.

Two different scintillator materials were considered for NEDA. One is standard, proton based one, commonly used in several existing neutron detection arrays (BC501A). Another one is deuterated (BC537), in which protons content were basically replaced by deuterons. The deuterated scintillator is of interest because it in principle may produce signal which is more correlated with the energy of the incident neutron, due to the anisotropic angular distribution of the neutron-deuteron elastic scattering. Such a property could make possible distinguishing single neutrons scattered between multiple detectors from real multiple neutrons, by correlating time-of-flight of neutrons with the energy measurement.

Properties of the two scintillators were evaluated in the simulations. Additionally, four geometrically identical prototype detectors were purchased by the NEDA collaboration, two filled with BC501A and two with BC537. The detectors were tested and compared using neutron and gamma-ray emitting radioactive source. Results on the neutron detection efficiency as a function of the incoming neutron energy will be shown. Correlations of the light yields with the energy of the incoming neutrons will be discussed. Procedures for the the neutron-γ discrimination and neutron multiplicity determining algorithms will also be presented.

Discovery of 18 new isomers using in-flight fission of 345 MeV/u ^{238}U: Evolution of the shell structure and shape coexistence

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A comprehensive search for isomers among fission fragments of 345 MeV/u ^{238}U has been performed at RIKEN RI Beam Factory (RIBF) to investigate evolution of shell structure and nuclear shape in the very neutron-rich nuclei with Z ~ 20 to 50. Fission fragments were analyzed and identified using the BigRIPS in-flight separator [1, 2], and delayed γ-rays were measured at the focal plane using three clover-type germanium detectors. In total we identified 54 microsecond isomers over a wide range of neutron-rich exotic nuclei, including observation of 18 new isomers: ^{59m}Ti, ^{90m}As, ^{92m}Se, ^{93m}Se, ^{94m}Br, ^{95m}Br, ^{96m}Br, ^{97m}Rb, ^{108m}Nb, ^{109m}Mo, ^{117m}Ru, ^{119m}Ru, ^{120m}Rh, ^{122m}Rh, ^{121m}Pd, ^{124m}Pd, ^{124m}Ag and ^{126m}Ag. The fruitful spectroscopic information allows us to propose (or extend) level schemes of the observed isomers: ^{59m}Ti, ^{82m}Ga, ^{92m}Br, ^{94m}Br, ^{95m}Br, ^{97m}Rb, ^{98m}Rb, ^{108m}Nb, ^{108m}Zr, ^{109m}Mo, ^{117m}Ru, ^{119m}Ru, ^{120m}Rh, ^{122m}Rh, ^{121m}Pd, ^{124m}Ag and ^{125m}Ag. We also investigate the nature of nuclear isomerism for these isomers that is sensitive to evolution of the shell structure and shape coexistence. For instance, the existence of ^{59m}Ti suggests that the N=34 sub-shell gap between $\nu p_{1/2}$ and $\nu f_{5/2}$ gets smaller as the neutron number increases due to the attractive monopole interaction [3]. Shape isomerism is discussed for $^{97m,98m}Rb$ and ^{95m}Br based on the well-known shape coexistence in the region with N~60 and Z=38-42 [4]. We speculate shape isomerism of $^{117m,119m}Ru$, $^{120m,122m}Rh$, ^{121m}Pd and ^{124m}Ag, in analogy to the N~60 shape coexistence. The region at N~75 and Z~39-45 is predicted to be a new deformation region by a nuclear mass model [5].

In this paper, we present our experimental results and the proposed nuclear isomerism. The relevant nuclear structure and its evolution are also discussed.

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Nuclear structure relevant to neutrinoless double-β decay: the valence neutrons in ^{130}Te and ^{130}Xe

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In order to help constrain predictions of nuclear matrix elements relevant for neutrinoless double-β decay, we have made a measurement of the valence neutron properties of the ground states of ^{130}Te and ^{130}Xe. The ^{130}Te isotope is the neutrinoless-double-β-decay candidate used in the CUORE experiment attempting to measure this hitherto unobserved decay mode. This measurement used a cryogenic Xe target developed at Berkeley. It is found the $0h_{11/2}$ and $1d$ orbitals dominate the vacancies in these isotopes, with the $2s_{1/2}$ making a small contribution. The data suggest the $0g_{7/2}$ is fully occupied. The difference between the ground-state wave functions of the parent and daughter is therefore mostly in the $0h_{11/2}$ and $1d$ vacancy. This is in contrast to recent theoretical calculations [1] where the $g_{7/2}$ also plays a role. The role of pairing, important for assumptions made in QRPA calculations, had been previously studied for ^{130}Te [2]. Here we add new information for ^{130}Xe. Proton-pair correlations indicate a significant splitting of the BCS correlations in these nuclei for protons, but there is no such splitting evidence for neutrons in the neutron-pair removal reactions. To better define the difference between initial and final states, data are also needed on the valence protons, where the $Z = 64$ shell gap may play a significant role; comparisons between ^{128,130}Te(d,^{3}He) data of Auble *et al.* [3] and recent theory [1] indicate a similar discrepancy, with there being no observed occupancy in the $0h_{11/2}$ orbit. This work was supported by the US Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH-11357 (Argonne) and Grant No. DE-FG02-91ER-40609 (Yale), NSF Grant No. PHY-08022648 (JINA), and the UK Science and Technology Facilities Council.

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SPICE - a new in-beam conversion-electron spectrometer at TRIUMF

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The SPectrometer for Internal Conversion Electrons (SPICE) is a state-of-the-art electron spectrometer being designed for in-beam studies with accelerated radioactive ion beams at TRIUMF. The internal conversion electrons emitted following nuclear reactions, are guided by a permanent magnetic lens to an array of 8 segmented Si(Li) detectors. The detectors are positioned 115 mm upstream from the target, and shielded from the target by a 30 mm-thick photon shield made from a tungsten alloy. Two different sets of permanent magnetic lenses are designed, which are optimized for different energy ranges. The full electron energy efficiency of the low-energy lens is in excess of 5% between 80 keV and 500 keV, peaking at 12% for 200 keV. The full electron energy efficiency of the high-energy lens is in excess of 5% between 300 keV and 1300 keV, peaking at 12% for 500 keV. SPICE is operated in conjunction with the TIGRESS array, which will allow for gamma-electron coincidence measurements. In this setup, TIGRESS is equipped with 12 HPGe Clover detectors and has an absolute gamma-ray efficiency of 12% at 1332.5 keV.

The main experimental focus for SPICE will be in the investigation of highly-converted transitions, for example E0 transitions between states of ground- and excited bands in nuclei displaying shape coexistence.

SPICE will be assembled in fall 2012, and stable-beam commissioning is planned in spring 2013. An overview of the design principles, simulations, and practical issues will be discussed together with the present state and an outlook of future goals.

Search for shears bands in ^{202}Po

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The coexistence of different shapes in the same nucleus is a well established feature for many nuclei. The region around the double magic ^{208}Pb nucleus is of particular interest in this respect because a variety of shapes – spherical, oblate, prolate and superdeformed prolate – have been observed [1]. Shape coexistence dominates the low energy spectrum of the neutron deficient polonium isotopes with A<200. On the other hand "shears bands" resulting from magnetic rotation of structures formed in the coupling of high–j proton–particles with high–j neutron–holes were also observed in light mass lead ($191 \leq A \leq 202$) and bismuth ($198 \leq A \leq 203$) [2] isotopes. Recently similar bands were proposed in ^{204}At and ^{206}Fr [3]. In Po (Z=84) the valence protons occupy the orbitals that produce the proton component of the "shears bands" via core–excitation in the Pb isotopes. Here we report on a detailed study of nuclear structure of ^{202}Po, the isotone of ^{200}Pb where dipole bands have been observed [4].

Excited states in ^{202}Po were populated using the ^{194}Pt(^{12}C,4n) reaction at 76 MeV beam energy at the ANU Heavy Ion Facility. Pulsed beams ~1 ns wide with 1704 ns separation were used in order to identify isomeric states. Comprehensive γ–γ–t and X–γ–t as well as *CE-t* and γ–t data were obtained using the CAESAR array and Super–e electron spectrometers, respectively. Many new transitions have been assigned depopulating states up to $\sim 25\hbar$. The level scheme of ^{202}Po [5] has been significantly extended and includes several candidates for "shears bands". The M1 multipolarity of the cascade transitions have been firmly established from the conversion coefficients. Large ($\sim 10^4$) experimental $B(M1)/B(E2)$ are also implied. The new results will be presented and implications for the understanding of the structure of the polonium isotopic chain will be discussed.

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LASER SPECTROSCOPY OF STABLE ^{55}Mn I USING BECOLA AT NSCL

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Collinear laser spectroscopy [1] was performed on stable manganese-55 atoms at the National Superconducting Cyclotron Laboratory at Michigan State University using the laser spectroscopy system of the BEam COoling and LAser spectroscopy (BECOLA) facility [2]. Manganese ions were produced using a commercial plasma ion source [3] and accelerated to 15 keV. The ion beam passed though a charge-exchange cell (CEC) [4] where the manganese ions were neutralized via atomic charge-exchange reactions with a sodium vapor. The ground ($3d^5 4s^2\ ^6\mathrm{S}_{5/2}$) and various metastable states of neutral manganese-55 were populated in the ion-atom collisions in the CEC. Sodium was chosen as the charge-exchange vapor because the electronic-ground state of sodium is nearly resonant with metastable states in manganese; for example, the $3d^5 4s4p\ ^8\mathrm{P}_J$ ($J = 5/2, 7/2, 9/2$) triplet near 18500 cm^{-1}. The manganese-55 atomic beam was co-propagated with laser light. Hyperfine spectra were measured by detecting the laser-induced fluorescence of the ground- and metastable-state excitations. The transitions studied had wavelengths in the range of 350 to 400 nm. Measured transition-line shapes had full-width at half-maxima of $\sim$50 MHz, allowing for precise determination of the values of the hyperfine A and B coefficients. The laser excitation schemes developed in the present measurements will set the framework for future laser-probing studies to elucidate nuclear electromagnetic moments and charge radii of radioactive manganese isotopes produced using the Coupled Cyclotron Facility at NSCL.

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STUDY OF THE ^{84}GA BETA-DECAY AT THE ALTO FACILITY

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A recent advance in the production and purification of radioactive ion beams have made a region of nuclei near the doubly magic ^{78}Ni more accessible for the experimental studies. This region, with very neutron-rich ^{78}Ni hypothetically considered as a doubly magic core, is interesting in terms of nuclear structures. There is an increasing interest in studying the evolution of the collectivity of neutron-rich nuclei beyond $N = 50$. Germanium isotopes are well known to undergo collective effects such as vibrations or gamma softness. It is particularly interesting to study ^{84}Ge as it is the most exotic even-even ($N = 52$) nucleus beyond $N = 50$ presently accessible to experiment. The nature of the collectivity can be probed by measuring the excitation energies of the first $2+, 4+, 0+$ states. This experimental information is important to guide the emerging shell-model effective interactions in this region and provide us the microscopic description of the origin of this collectivity.

We have studied β-decay of a neutron rich ^{84}Ga isotope at the ALTO facility in IPN Orsay (France). The fission fragments were produced with photo-fission reaction induced by 50 MeV electron beam in a thick UCx target. For the first time the maximum electron driver beam intensity at ALTO - 10μA - was used. The gallium atoms were selectively ionized with a newly developed laser ion source. With this ion source the ionization of the gallium was more than ten times higher compared to the surface ion source previously used by our group. The ions were separated with the PARRNe mass separator and implanted on a movable mylar tape. Two germanium detectors in close geometry were used for the detection of γ-rays and γ-γ coincidence measurement, and a plastic $4\pi\beta$ for beta tagging.

The improved level scheme for ^{84}Ge will be presented and compared with the shell model calculations performed with ANTOINE code using “ni78-jj4b“ interaction which is the modified version of the residual interaction developed by Sieja (IPHC Strasbourg) with the ^{78}Ni core.

Beta-decay properties of ^{85,86}Ge and ^{86,87}As*

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The decay studies of radioactive nuclei far away from the valley of beta-stability are often the sole option for probing nuclear models in such exotic nuclear systems, hence helping to extrapolate nuclear properties into unknown territories.

Recent decay studies of ^{238}U fission products performed at the Holifield Radioactive Ion Beam Facility (HRIBF) included the most neutron-rich isotopes of germanium (Z=32) and arsenic (Z=33) known to date. The isobaric contaminants in the beams were suppressed by using molecular beams GeS and AsS. It allowed us to study the decay properties of ^{85}Ge, ^{86}Ge, ^{86}As and ^{87}As. The beta-decay half-life of ^{86}Ge was measured for the first time and the lifetimes of ^{85}Ge, ^{86}As and ^{87}As were determined with much better accuracy and precision. These new half-life values support the recent theoretical modeling of the beta-decay process within the DF3a+CQRPA framework [1].

The beta-decay properties of ^{85,86}Ge and ^{86,87}As and the structure of respective daughter nuclei will be presented and discussed.

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First Results from Modular Total Absorption Spectrometer at the HRIBF (ORNL, Oak Ridge)*

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The Modular Total Absorption Spectrometer (MTAS) has been recently constructed at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory. It consists of 19 NaI(Tl) hexagonal shape modules, with a full energy gamma ray efficiency approaching 90% around 300 keV. The description of MTAS coupled to the on-line mass-separator at the HRIBF is given in [1].

Total Absorption Spectrometers (TAS) capable of detecting most of the gamma transitions occurring during the decay process are perfect tools for establishing a true beta feeding pattern. TAS-aided experiments are particularly important for neutron-rich nuclei, where beta strength is highly distributed over many final states. Knowledge of the correct beta feeding pattern is important for the analysis of the structure of parent and daughter activities as well as for the determination of the decay heat released by fission products during nuclear fuel cycle.

The decays of over twenty ^{238}U fission products have been studied with MTAS during first on line experiment at the HRIBF. Already online data for some isotopes show significant discrepancy between observed beta feeding and corresponding database values. In this contribution first results for mass A=86 and A=87 nuclei will be presented. Impact of the new data on the decay heat calculation will be discussed as well.

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$E1$ Strengths in ^{11}Be from Low Energies Coulomb Excitation*

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The accuracies of ∼10% and ∼5% for the $B(E1)$ between the bound states [1, 2] and to the continuum of ^{11}Be [3], respectively, have been measured, but with discrepancies ∼15% between the reported strengths for the latter. This one neutron halo nucleus has the strongest known $E1$ transition between the bounds states and the strength to the continuum exhausts the majority of the non-energy weighted sum-rule. In the current work, the $E1$ strengths to the $1/2^-$ at 320 keV and the continuum from the ground state of ^{11}Be were investigated with Coulomb excitation on a ^{196}Pt target at $E(^{11}\mathrm{Be})$=1.73, 2.09, and 3.82 MeV/nucleon using the TIGRESS/Bambino array at TRIUMF. To minimize the impact of break-up reaction mechanisms on the analysis, only the two lowest energies were used to determine the $B(E1)$'s from the yields of the $1/2^-$ to $1/2^+$ relative to the 2^+ to 0^+ in ^{196}Pt, see Fig. 1.

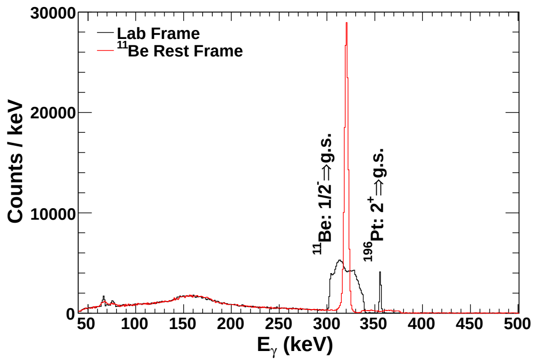

Figure 1: The background subtracted particle-γ coincidence spectra at $E(^{11}\mathrm{Be})$=18.9 MeV.

The analysis is carried out using a semi-classical reaction code, Gosia, [4] and a quantum mechanical reaction code, the extended continuum discretized coupled channels model (XCDCC) [2]. The strength between bound states in ^{11}Be is deduced using Gosia and XCDCC relative to the ^{196}Pt cross section calculated using the adopted value for the $B(2^+ \rightarrow 0^+)$ of 0.274(1) e^{2}b^2. The latter, which includes an extended wave function for ^{11}Be assuming a deformed core+coupled-channels particle cluster model [5], is also used to determine the $E1$ strength to the continuum by calculating the influence on the yields of the 320 keV transition. The $B(E1)$ value of 0.102(2) e^{2}fm^2 deduced from our preliminary analysis between the bound states is ∼12% lower than the lifetime measurement and agrees with the results from intermediate energy Coulomb excitation. The higher accuracy achieved in the present work will not only help resolve the discrepancies of the previous works but also help isolate the importance of contributions from individual terms of the NN interactions in models that describe halo systems such as the No-Core Shell Model plus Resonating Group Method [6]. The experimental details, our results and its implications will be presented.

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HIGH-PRECISION HALF-LIFE MEASUREMENT FOR THE SUPERALLOWED β^+ EMITTER ^{14}O

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High-precision measurements of superallowed Fermi β decays between 0^+ isobaric analog states have provided an invaluable probe of the Standard Model description of the electroweak interaction. These measurements have been used to test the conserved vector current (CVC) hypothesis, the existence of scalar and right-handed currents in the electroweak interaction, and possible extensions of the Standard Model [1]. Half-life measurements of the lightest of these, ^{10}C and ^{14}O, are of particular interest as it is the low-Z superallowed decays that are most sensitive to a possible scalar current contribution.

There are two primary methods for measuring superallowed β decay half-lives; one can directly count the β particles or measure the gamma activity since, with a branching ratio of 99.4%, ^{14}O decays to an excited state of the daughter ^{14}N which then emits a 2.3 MeV γ-ray. Comparing the experiments that detected the 2.3 MeV γ-rays and those that perform β counting measurements yield results that disagree with each other at the level of 0.11% or 1.3σ. The same systematic discrepancy exists for the current ^{10}C half-life measurements. This provides motivation for a set of high-precision half-life measurements for ^{10}C and ^{14}O via both γ-ray photopeak and direct β counting techniques at TRIUMF to address the systematics between the methods used. The detector set-up to be used consists of the 8π γ-ray Spectrometer—a spherically symmetric array consisting of 20 Compton suppressed High-Purity Germanium detectors—and the Zero-Degree Detector—a fast plastic scintillator placed at the end of the beam line within the 8π.

The first of several experiments—specifically looking at ^{14}O—was performed at TRIUMF's Isotope Separator and Accelerator facility in November 2011. This talk will highlight the importance of these measurements and preliminary results will be presented.

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Core-excited states and split proton-neutron quasi-particle multiplets from isomeric decays in $^{122-126}$Ag

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Neutron-rich silver isotopes were populated in fragmentation of a ^{136}Xe beam and a relativistic fission of ^{238}U. The fragments were mass analyzed with the GSI Fragment separator and subsequently implanted into a passive stopper. Isomeric transitions were detected by 105 HPGe detectors. Five new isomeric states were observed in $^{122-126}$Ag nuclei. The level schemes of ^{123,125}Ag, previously known, were revised and extended. The isomeric transitions, de-exciting the nanosecond isomers were observed for the first time. The excited states in the neutron-rich odd-mass silver isotopes are interpreted as core-excited states. The isomeric states in the even-mass silver isotopes are discussed in the framework of the proton-neutron split multiplets. Shell model calculations, performed for the most neutron-rich silver nuclei, i.e. ^{125,126}Ag, are compared to the experimental data.

Triaxiality and the changing nature of K-isomers in tungsten nuclei from A=182 to A=190

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While deformed nuclei in the A≈180 region are well known to exhibit isomers whose long lifetimes are caused by the fact that the only available isomeric decay transitions violate K-conservation [1], the possible limits to the existence of K-isomers in neutron-rich nuclei are not well defined. Isomers have been observed in some neutron-rich cases using methods such as deep-inelastic reactions [2], relativistic fragmentation [3] and direct mass measurement [4]. Of these, the latter two methods can access more neutron-rich nuclei, but the level schemes that are obtained are generally of limited extent compared to those obtained using deep-inelastic reactions.

We have pursued a program of measurements using deep-inelastic reactions between beams of about 6 MeV/nucleon ^{136}Xe ions incident on a range of the most neutron-rich, stable, rare-earth targets. These studies have been performed at Argonne National Laboratory and used Gammasphere to observe the gamma rays emitted from weakly populated neutron-rich nuclei in the presence of an intense background of more strongly populated nuclei closer to stability. The experiments have successfully probed the structure of K-isomers in regions that were previously inaccessible and have resulted in detailed level schemes for nuclei up to 4 neutrons past stability.

Our published results for ^{190}W clarified the conflicting observations of a long-lived state and showed that the isomer was due to a low-energy M2 transition that was in fact K-allowed [5]. However, other isomers observed in ^{186}W, ^{188}W and ^{190}W seem to show a decreasing trend in K-hindrance with increasing neutron number, possibly associated with increasing triaxiality [5]. In this contribution we will present new level schemes for ^{182}W, ^{184}W, ^{185}W, ^{186}W and ^{187}W that further illuminate these trends in K-hindrance. The results include the first high-spin level schemes for ^{185}W and ^{187}W, as well as greatly expanded decay schemes for isomers observed previously in ^{184}W [6] and ^{186}W [7], including spin, parity and configuration assignments. The lifetime of the high-spin isomer in ^{186}W was previously only known to be greater than one millisecond [7], but has now been shown to be 2.9 s. The implications for predictions of very long-lived states in the neutron-rich A≈190 region will be discussed. *Research supported by the Australian Research Council as well as the DOE Office of Nuclear Physics under Contract No. DE-AC02-06CH11357.*

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LOW-ENERGY ENHANCEMENT IN THE γ STRENGTH WITH IMPACT ON ASTROPHYSICAL REACTION RATES

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The recent discovery at the Oslo Cyclotron Laboratory of a low-energy increase in the γ strength function of light and medium-mass nuclei [1] has the potential of increasing neutron-capture rates up to two orders of magnitude for very neutron-rich nuclei [2], see Fig. 1. The presence of this increase at low γ energies has very recently been confirmed in ^{95}Mo from data taken at the Lawrence Berkeley National Laboratory [3]. However, the question is whether this structure persists when approaching the neutron drip line.

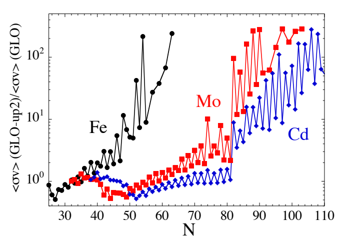

Figure 1: Ratios of Maxwellian-averaged (n, γ) reaction rates at $T = 10^9$ K using a γ strength with a low-energy increase(GLO-up2) and without (GLO) [2].

In this talk, the present status of the low-energy increase will be discussed. Fresh data on Cd and Fe isotopes will be presented. For the latter, data taken with large-volume $LaBr_3$(Ce) crystals borrowed from the INFN-Milano group will also be showed. Calculations of reaction rates and the possible impact on the stellar r-process will also be discussed.

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Shape coexistence in the neutron-deficient isotope ^{187}Tl

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Since the discovery of a large isotope shift in light Hg nuclei by Bonn *et al.* [1], it has been established that shape coexistence is essentially universal for neutron-deficient nuclei near $Z = 82$ [2]. A prominent example is ^{186}Pb, in which the presence of three low-lying 0^+ states is interpreted as evidence for coexistence between prolate, oblate, and spherical shapes [3]. Its even-even neighbour, ^{188}Pb also exhibits triple shape coexistence, but as a contrast, this is evidenced by the presence of isomeric states with characteristic spins and parities $J^\pi = 8^-,\ 11^-,$ and 12^+ ($E \sim 2600$ keV), as expected for the favoured configurations arising within potential wells of different shape [4, 5].

Two isomers with comparable energies and microsecond lifetimes were identified previously in the neighbouring odd-mass nucleus, ^{187}Tl [6]. While they are most likely three-quasiparticle states, their configurations and shapes are unknown. Since shape coexistence was already observed for single-particle states in ^{187}Tl [7, 8, 9], it is possible that the isomers are coexisting prolate and oblate structures, paralleling those observed in ^{188}Pb.

A new study of ^{187}Tl was initiated at the Lawrence Berkeley National Laboratory using the ^{159}Tb(^{32}S,4n)^{187}Tl reaction, in which the 1.2 mg/cm^2 target was backed with 4.5 mg/cm^2 ^{197}Au. The pulsed beam with an energy of 154 MeV was provided by the 88-inch cyclotron, and Gammasphere was used to detect the emitted γ-rays.

New structures above the microsecond isomers were observed, as well as extensions to the known single-particle structures. They include confirmation of the $h_{11/2}$ band, which is interpreted to have a prolate deformation larger than previously predicted [8], observation of the unfavoured signature of the $h_{9/2}$ prolate band, and possible enhanced prolate deformations associated with the $i_{13/2}$ structure. Configurations for the isomers will be discussed in the context of predictions from multi-quasiparticle calculations.

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Observation of mutually enhanced collectivity in self-conjugate ^{76}Sr

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The shape of the atomic nucleus is determined by the interplay of macroscopic and microscopic effects within this finite quantum many-body system. Self-conjugate nuclei give an opportunity to study the role of neutron proton correlations in deformation and have attracted a great interest due to drastic shape evolution along the $N = Z$ line. In these nuclei, proton and neutron shell effects can act coherently, promoting an extreme sensitivity of nuclear properties to small changes of nucleon numbers. Strong ground-state deformation is expected to occur for $N = Z$ nuclei above $Z = 36$ from the 2^+ energy systematic as well as from theoretical predictions and reduced transition strengths B(E2) can guide our understanding of the onset of collectivity along the $N = Z$ line.

In this talk, we will report on the first determination of B(E2; $2^+ \to 0^+$) for the $N = Z = 38$ nucleus ^{76}Sr obtained from the measurement of the 2^+ state lifetime using γ-rays line shape technique [1]. ^{76}Sr nuclei were produced at the NSCL in charge exchange reaction from fast secondary ^{76}Rb beam. γ-rays emitted at the reaction target position were measured with the SeGA HPGe array in coincidence with reaction residues detected in the S800 spectrometer. Results will be discussed in the light of available data and theoretical predictions to provide insight into the evolution of shell structure and collectivity in this region.

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Lifetime Measurements in ^{160}Gd

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The nature of low-lying excitations, $K^{\pi} = 0^{+}$ bands in deformed nuclei remain enigmatic in the field, especially in relationship to quadrupole vibrations. One method of characterizing these states is by reduced transition probabilities, B(E2) values, a measure of the collectivity. These values can be measured directly by Coulomb excitation or calculated from measured lifetime values. Within the deformed region, there are five stable Gd isotopes, three of which have been studied to obtain B(E2) values, a fourth, ^{160}Gd is the focus of this work. We have examined ^{160}Gd with the (n,n$'\gamma$) reaction and neutron energies up to 3.0 MeV to confirm known 0^{+} states and to determine their lifetimes through DSAM measurements. Gamma-ray excitation functions and angular distribution measurements have been performed and preliminary results will be presented.

Indications of Deformation Along the N = 40 Isotones*

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The rapid development of collectivity in the N = 40 region as protons are removed from the $f_{7/2}$ single-particle state is suggested by the dramatic drop in energy of the first excited 2^+ state from ^{68}Ni to ^{64}Cr [1,2] and the increase in B(E2) along the Fe isotopic chain. Recent experiment results in the odd-A ^{67}Co nucleus have suggested the presence of a $½^-$ deformed state attributed to a $\pi p_{3/2}$ intruder configuration [3-4]. Numerous experiments have focused on the even-even and odd-A Cr and Fe nuclei but little is known about the neighboring odd-odd Mn and Co isotopes. The low-energy level structure of ^{67}Co motivated a search for deformed and spherical levels in the odd-odd Co and Mn nuclei [5-6] populated through beta decay.

The low-energy level structures of ^{66,68}Co were studied via the beta decay of ^{66,68}Fe produced from the fragmentation of a ^{86}Kr beam at the NSCL and delivered to the Beta Counting System (BCS) for characterization. Isomeric and beta-delayed gamma-ray transitions were observed following the identification of the radioactive ions. Based on the inferred low-energy level structures of the odd-odd ^{66,68}Co isotopes the spins and parities of the isomeric states were altered from previous literature values.

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MANY-BODY DYNAMICS IN A RELATIVISTIC FRAMEWORK: SPECTRAL PROPERTIES OF EXOTIC NUCLEI

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Aiming at a universal and precise approach to nuclear low-energy dynamics, many-body correlations beyond mean field are studied by self-consistent methods within a covariant framework. Recent developments based on Green's function techniques enable a parameter-free treatment of the correlations caused by the coupling of single-nucleon and vibrational degrees of freedom [1].

A set of self-consistent models going far beyond the simple mean field approach is developed and applied to the shell structure and to spectroscopic factors [2], to isovector and isoscalar giant and soft modes [3], and to Gamow-Teller and spin-dipole resonances [4] in ordinary and exotic nuclei. The recent application of the developed approach to superheavy nuclei [2] describes the evolution of the nuclear shells in Z = 120 isotopes, representing hypothetically an island of enhanced stability.

The microscopic nature, consistency and universality of these methods make them an ideal tool to describe and interpret experimental data and to provide the consistent nuclear physics input for astrophysical applications. It is shown how the comparison with experimental spectral data of high resolution constrains both the underlying covariant energy density functional and the implemented many-body coupling schemes.

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HIGH-SPIN STRUCTURES OF NEUTRON-RICH ^{112,114,115}Rh

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Neutron-rich nuclei in the $A = 110$ region are of great interest in both theory and experiment because they are characterized by shape coexistence and shape transitions, including triaxial shapes. In this region, the active proton orbitals, midway in the $\pi g9/2$ subshell, drive the nuclear shape toward oblate, prolate, or triaxial deformations, while the neutron Fermi levels, below or near the bottom of the $\nu h11/2$ subshell, drive the shape to prolate or triaxial deformations. These tendencies have been observed in the yrast bands of neighboring odd$-A$ nuclei,which are built on the above orbitals. Especially, the proton orbitals originating from the $g9/2$ subshell are influenced by the triaxial nuclear deformation. The appearance of triaxial deformations and soft shape transitions were found in nuclei of $Z > 41$.

We investigated the high-spin structures of three neutron-rich Rh isotopes in this mass region, ^{112,114,115}Rh, by studying prompt γ rays measured in the spontaneous fission of ^{252}Cf with the Gammasphere detector array at Lawrence Berkeley National Laboratory. The role of triaxiality in these isotopes were examined by total-Routhian-surface, triaxial-projected-shell-model, and rigid-triaxial-rotor-plus-quasiparticle-model calculations, respectively. Systematic studies of signature inversion in odd-odd Rh and evolution of triaxiality in odd-even Rh isotopes were investigated. An $N = 68$ effect was observed, which may be associated with the prolate-to-oblate shape transition in this mass region. Possible chiral symmetry in ^{112,114}Rh were discussed. More details will be presented.

Current Status of the EURICA project at RIKEN

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The EUROBALL RIKEN Cluster Array project (EURICA) is a β decay and γ-ray spectroscopy research campaign established at the Radioactive Isotope Beam Factory (RIBF). At RIBF radioactive beams are produced by fission and fragmentation reactions, and are purified in-flight by the BigRIPS fragment separator. EURICA consists of 13 high-purity Ge cluster detectors [1] from the previous EUROBALL and RISING projects [2], together with double-sided silicon-strip detectors for β-decay counting, half-life and β-decay Q-value measurements. The EURICA spectrometer is located at the focus F11 of the ZeroDegree spectrometer. There are also plans to complement the array with $LaBr_3$ detectors for measuring the life-time of short-lived excited states. The array has now been commissioned and the first experimental campaign is expected to start in June 2012. In this contribution we will present the current status and future plans of the EURICA project.

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Evidence for Triaxial Strongly Deformed Structure in ^{164}Hf*

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Significant progress has been made in the study of nuclear triaxiality, including the observation of the characteristic wobbling mode in several odd-A Lu and Ta isotopes around A∼165. Theoretical investigations predict that some Hf nuclei might be the best candidates for such studies, e.g., see figure for the triaxial strongly deformed (TSD) minima at $(\varepsilon, \gamma) \approx (0.4, \pm 24°)$ in ^{164}Hf. However, TSD bands have only been observed in ^{168}Hf [1,2], which are very weak and could not be linked to known levels. Recently we have performed a Gammasphere experiment for ^{164}Hf. Preliminary data analysis revealed two exotic bands which have large initial alignments ($>20\hbar$) and do not exhibit the proton alignment at $\hbar\omega$∼500 keV seen in other ND bands, indicating that high-j intruder proton orbitals are already occupied at low frequency in the bands. The distinctive properties of the bands suggest that they are likely associated with the predicted TSD, rather than the ND, minimum. The bands are significantly stronger than the TSD bands in ^{168}Hf. They have been linked to known levels, and cross the yrast line at spin 32, as compared to spin ∼48 in ^{168}Hf. Further results and theoretical calculations will be presented.

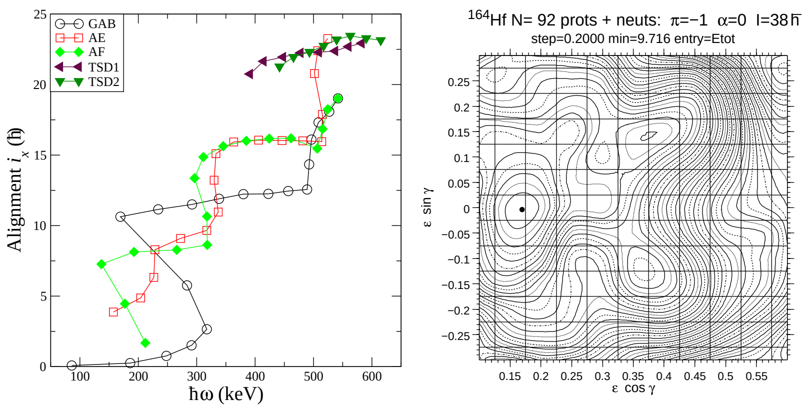

Figure 1: Left: Aligned angular momenta of the exotic (TSD1 and TSD2) and the ND bands. Right: Potential energy surfaces calculated with the ULTIMATE CRANKER codes.

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B(E2) Transition Strengths of Neutron-rich Carbon Isotopes in a Seniority Scheme *

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Neutron-rich Carbon isotopes, experimentally accessible up to the drip line, provide a unique ground to systematically examine spectroscopic information in search for exotic new phenomena. Of particular interest, is the understanding of how proton and neutron degrees of freedom are coupled near the drip line.

Lifetime measurements in ^{16,18,20}C isotopes, using the RDDS method, have been recently carried out at NSCL [1,2], and provide important information about the structure of these nuclei.

In this work we attempt to interpret the derived B(E2) transitions strengths in terms of a seniority inspired scheme [3]. The semi-empirical analysis shows an important role played by proton excitations, driven by the effective reduction of the $\pi p_{3/2}$-$\pi p_{1/2}$ spin-orbit splitting. This is due to the effect of the tensor component of the nuclear force [4], similar to the situation seen in the $^{89-95}$Y isotopes[5].

This simple approach allows us to make predictions about spectroscopic factors for proton removal reactions and magnetic moments of the 2_1^+ states that can be tested experimentally.

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New half-lives of r-process nuclei in the vicinity of ^{78}Ni

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The β-decays of neutron-rich nuclei near the doubly magic ^{78}Ni were studied at the Holifield Radioactive Ion Beam Facility (HRIBF) using an electromagnetic isobar separator. The half-lives of ^{82}Zn (228±10 ms), ^{83}Zn (117±20 ms) and ^{85}Ga (93±7 ms) were determined for the first time. These half-lives were found to be very different from the predictions of the global model used in astrophysical simulations [1]. The experimentally measured values were applied to calibrate a new Density Functional used for half-life calculations. It was observed that in the region of interest of this work, half-lives are very sensitive to the ordering of proton single particle states. A sample rapid neutron capture nucleosythesis calculation using our new set of measured and calculated half-lives shows a significant redistribution of isobaric abundances and a strengthened yield of A>140 nuclei.

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α-decay of excited states in ^{12}C

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Recently it was suggested that the state in ^{12}C at an excitation energy of 7.65 MeV ($J^{\pi} = 0^{+}$), the Hoyle state, can decay via a mechanism that produces three α-particles of almost equal energy [1]. High-resolution triple-α coincidence data were used to reconstruct the decay of the excited states in ^{12}C at 7.65 MeV ($J^{\pi} = 0^{+}$) and 9.64 MeV ($J^{\pi} = 3^{-}$). These data were gathered at the Texas A&M University K500 cyclotron facility, where a ^{10}C beam impinged on a Be target and reaction products were detected using four Si E-ΔE detectors. The results of this experiment are consistent with the α-particle decay of both levels proceeding exclusively through $^{8}\text{Be}_{g.s.}$. In the first of these cases, the Hoyle state, upper limits of 0.45% and 3.9% (at the 99.75% confidence level) are set for an equal-energy alpha particle decay process and a process uniformly spanning three-body phase space (respectively) [2]. The limit for the equal-energy α-particle decay is much lower than the result claimed in [1].

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Single-neutron levels near the N=82 shell gap

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Nuclei with a few nucleons beyond shell closures are important in understanding the evolution of single-particle structure, which is critical to the benchmarking of nuclear models. With radioactive ion beams, studies near the double shell closure ^{132}Sn have been made possible. While the single-neutron states in ^{133}Sn with N=83 have recently been verified to be highly pure [1], it is important to study further from the N=82 closed shell. The (d,p) reaction was measured with the radioactive ion beams of ^{126}Sn and ^{128}Sn in inverse kinematics at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory, utilizing the SuperORRUBA silicon detector array. Angular distributions of reaction protons were measured for several states in ^{127}Sn and ^{129}Sn in order to determine angular momentum transfers and deduce spectroscopic factors. Such information is critical for calculating direct (n,γ) cross sections for the r-process and for constraining shell model parameters in the A$\sim$130 region. In addition, in order to obtain more precise energy levels, particle-gamma coincidence data were acquired for the inverse (^{9}Be,^{8}Be) reaction at the HRIBF using a HPGe and CsI array (CLARION+HyBall). Combined with previous experiments on ^{130}Sn and ^{132}Sn, these results provide a complete set of (d,p) reaction data on even tin isotopes between stable ^{124}Sn and doubly magic ^{132}Sn. This work is supported in part by the U.S. Department of Energy and National Science Foundation.

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POPULATION OF STABLE HAFNIUM NUCLEI VIA FUSION OF HELIUM-6 FRAGMENTS IN THE BREAK-UP OF LITHIUM-7

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The DIAMANT charged-particle detector from ATOMKI has been coupled with the AFRODITE gamma-ray spectrometer at iThemba LABS in a collaboration enabled by a bilateral intergovernmental agreement. This has facilitated the study of incomplete fusion reactions in the bombardment of a Ytterbium-176 target with a beam of 50 MeV Lithium-7 ions. The beam was generated as a collaborative effort between ion source experts at iThemba LABS and the Flerov Laboratory for Nuclear Reactions (FLNR) of the Joint Institute for Nuclear Reactions (JINR), Dubna.

Particle-Identification (PID) spectra from DIAMANT generated from custom-built VXI electronics clearly show the detection of protons, tritons and alpha particles, which, when gated on, allowed the selection of gamma-ray coincidences detected with AFRODITE when the respective complementary Helium-6, Helium-4 (α) and triton fragments fused with the target.

Analysis of the charged-particle selected gamma-ray coincidence data enabled the identification of Hafnium-180 in the proton-gated E_γ–E_γ correlation matrix (see figure 1), as well as Hafnium-178, including the band based on the $T_{1/2}$ = 31a $K^\pi = 16^+$ four-quasiparticle state. Hafnium-178 is also evident in the triton-gated matrix.

The relative yields of the incomplete fusion products will be compared with the predictions of the CACARIZO code

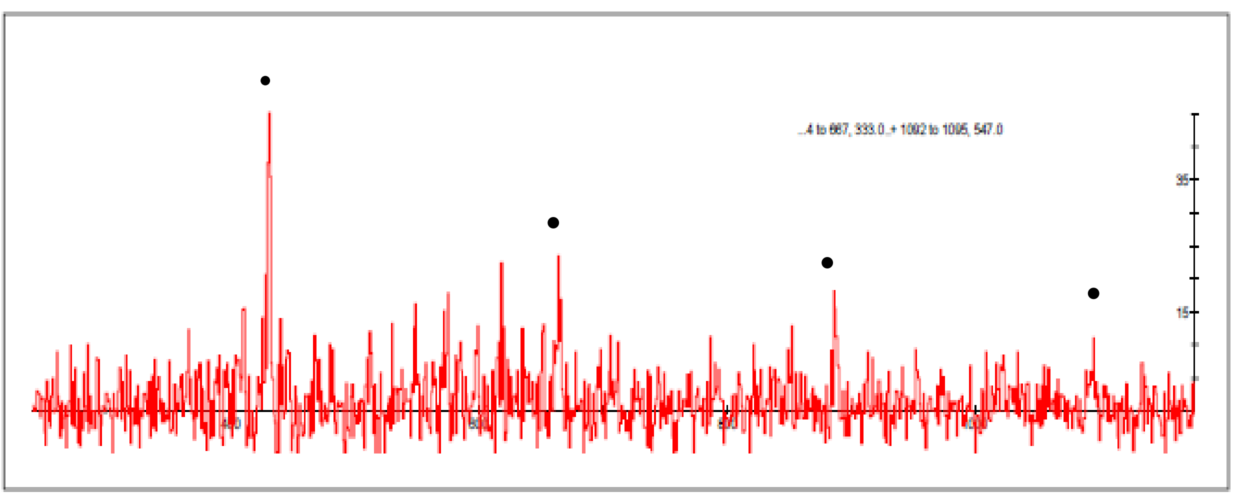

Figure 1: Sum of gates for the ground-state band of ^{180}Hf obtained from the proton-gated matrix, populated by the fusion of the complementary ^{6}He fragment of the ^{7}Li beam and evaporation of 2 neutrons,

STUDY OF ^{74}NI COLLECTIVITY BY COULOMB EXCITATION.

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The study of the evolution of the shells far from stability provides useful information which can be linked to the shape and symmetry of the nuclear mean field. Nuclei with large neutron/proton ratio allow to probe the density dependence of the effective interaction. It has also been shown that tensor and three-body forces play an important role in breaking and creating magic numbers, being a key element of the shell evolution along the nuclear chart.
Of particular interest is the region of ^{78}Ni. The spin-isospin non-central component of the nucleon-nucleon interaction is expected to modify the relative energies of the single particle states reducing the Z=28 energy gap for large neutron numbers. In such contest particle-hole excitations across the gap are expected to be strongly enhanced driving to enhanced collectivity. Lifetime measurements for the determination of the B(E2) values of the low lying transitions are therefore very important to constrain the interaction used for the shell model calculations.
We have recently measured the B(E2; 0+→2+) of ^{74}Ni in an intermediate energy Coulomb excitation experiment performed at NSCL (MSU).
The ^{74}Ni beam has been produced by fragmentation through the ^{86}Kr + ^{9}Be reaction at 150 MeV/u. The primary beam was provided by the Coupled Cyclotron Facility of the NSCL, and the production reaction fragments were analyzed using the S1900 fragment separator. The secondary beam contained ^{74}Ni ions with an intensity of ~ 2 pps. An Au foil of 600 mg/cm^2 was used as secondary target and, after Coulomb excitation, ions where identified at the focal plane detector system of the S800 spectrograph. A total number of 24,106 ^{74}Ni events has been collected.
The first 2+ state of ^{74}Ni was Coulomb excited and the γ-rays emitted in the deexcitation of the level were measured using the 4π CAESAR array. This detector is composed of 192 CsI(Na) scintillator crystals and was placed at the secondary target position. A total of about 100 counts have been measured for the 1.022 MeV 2+ →0+ transition. The analysis of the data is presently going on, preliminary results do not indicate an enhanced value for the electromagnetic transition matrix element.

High-spin isomer and structure of the odd-odd nucleus ^{210}Fr

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The shell model has been very successful in describing the structure of nuclei near the doubly magic ^{208}Pb core (see Ref. [1] for example). Moving away from shell closures the assignment of nuclear configurations to observed states is complicated by factors such as core polarisation [1, 2] and state mixing [3]. As a result, shell model calculations with many quasiparticles outside the lead core (eight in ^{210}Fr) lose the accuracy observed near the closed shells. This, together with the search for high-spin isomeric states in the Fr isotopes [2, 4], has motivated the present work.

The structure of ^{210}Fr has been investigated through the ^{197}Au(^{18}O, 5n)^{210}Fr reaction with a 5.5mg/cm^2 gold target and a beam at an energy of 97 MeV. Chopped and pulsed beams from the 14UD Pelletron accelerator at the ANU Heavy Ion Facility were used to initiate the reaction. The CAESAR array consisting of eleven high-purity germanium detectors was used to perform time-correlated γ-ray spectroscopy. A level scheme was deduced for ^{210}Fr with states up to $25\hbar$ and excitation energy around 6 MeV. The level scheme is in significant disagreement with that recently reported in a parallel study by Kanjilal *et al.* [5].

Structural features, common for nuclei near ^{208}Pb, have been discovered in ^{210}Fr. They include a 10^- isomer similar in structure to that in nearby nuclei [6, 7]. The focus of this presentation is the observation of an isomer with $\tau \sim 600$ ns at $J^\pi = 24^+$. A similar isomer in both heavier [4] and lighter [2] Fr isotopes is observed to decay by characteristic enhanced $E3$ transitions (B($E3$) $\sim$ 30 W.u.) that can be explained through the coupling of the 3^- octupole vibration to the $i_{13/2}$ to $f_{7/2}$ proton transition. However the new level scheme for ^{210}Fr reveals less enhanced $E3$ transitions. Possible causes including specific state mixing will be discussed.

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STRUCTURE OF ^{9}C FROM THE ^{10}C(*d,t*)^{9}C REACTION AND THE RELIABILITY OF AB-INITIO TRANSFER FORM FACTORS

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The structure of the neutron-deficient nucleus ^{9}C is poorly known. Only a few excited states have been observed and little information exists on their single-particle characteristics. The measured ground-state magnetic dipole moment is anomalously small in comparison to the mirror nucleus ^{9}Li, suggesting possible higher order configurations in the ground state wave function. Both ^{10}C and ^{9}C are accessible via *ab-initio* calculations using modern techniques such as the Quantum Monte Carlo (QMC) approach [1]. In addition to the excitation energies in the A = 9 and 10 systems, it is possible to calculate the spectroscopic overlaps that are relevant for the neutron-removing reaction ^{10}C(*d,t*)^{9}C with the wave functions for both ^{9,10}C. In order to test the predictions from this and other calculations of the neutron-pickup spectroscopic factors, we have studied the ^{10}C(*d,t*)^{9}C reaction, in inverse kinematics. The radioactive ^{10}C beam was produced at the ATLAS In-flight facility through the *p*(^{10}B, ^{10}C)*n* reaction using a 185-MeV ^{10}B beam incident on a cryogenic H_2 gas cell. The secondary ^{10}C beam had an energy of 171 MeV and an intensity of approximately 2×10^{4} pps. The beam was incident on a 650 μg/cm^2 deuterated polyethylene $(CD_2)_n$ target. Tritons were detected in a series of annular double sided silicon detectors covering Θ_{lab} between 8 and 42 degrees. The heavy recoils from particle-bound, or unbound states in ^{9}C were detected in a set of forward-angle silicon detectors in a ΔE-E configuration. The ground-state transition was clearly observed and angular-distribution data were extracted. The neutron-pickup spectroscopic factor was deduced from a comparison with distorted-wave Born approximation calculations, with bound-state form factors calculated either with the usual approach of calculating a *n*-^{9}C bound state in a Woods-Saxon potential, or from wave functions derived from QMC calculations. A comparison between the results using these two methods will be presented providing insight into the reliability of form factors for nucleon transfer derived from *ab-initio* approaches. Work was supported by the U. S. Department of Energy, Office of Nuclear Physics, under Contracts DE-FG02-04ER41320 and DE-AC02-06CH11357.

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Characterization of new structures in octupole deformed thorium and radium nuclei

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Various physics themes have been addressed, during the AGATA Demonstrator experimental campaign at LNL [1], by exploring different mass regions in the nuclear landscape, ranging from the study of the hydrogen burning CNO cycle in the light ^{15}O nucleus to the spectroscopy of heavy nuclei in the actinide region. Most of the performed experiments aimed at the study of the evolution of shell closures and nuclear collectivity in neutron-rich nuclei, around N=40,50 (Cr, Ni, Cu, Zn, Ge) and N=82 (Sn), using AGATA in conjunction with the large-acceptance magnetic spectrometer PRISMA in grazing regime. Nonetheless high-fold-coincidence experiments in stand-alone mode, studying nuclei populated by fusion-evaporation reactions, have been performed as well.

In the latter context a ^{18}O(95MeV)+^{208}Pb fusion-evaporation experiment was performed, where AGATA was used to characterise new structures observed in the octupole-deformed light-actinide nuclei ^{220}Ra and ^{222}Th [2]. The primary goal of the experiment was to measure the linear polarizations of transitions linking new rotational-like structures [3] to the yrast octupole bands in these nuclei, and in the case of ^{222}Th, to measure the linear polarizations of inter-band dipole transitions in the new structure. The gamma-ray interaction positions within the AGATA detectors are used to reconstruct the scattering angles of the transitions of interest, and hence determine their linear polarizations. Establishing whether inter-band dipole transitions in the new structure in ^{222}Th are E1 or M1 is crucial to its possible interpretation as an excited alternating-parity octupole band. Although the gamma-ray spectra are dominated by gamma rays from fast fission, the fission background can be effectively removed by gamma-ray gating. In this contribution the preliminary results will be presented.

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LIFETIME MEASUREMENT OF THE 6.79 MeV STATE IN ^{15}O WITH THE AGATA DEMONSTRATOR

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An accurate determination of the lifetime of the first excited $3/2^+$ state in ^{15}O is of paramount importance in the determination of the astrophysical S–factor and the derived cross section for the ^{14}N(p,γ)^{15}O reaction, the slowest one in the CNO cycle [1, 2, 3].

The preliminary results of a new direct measurement of this nuclear level lifetime are discussed. The first excited states in ^{15}O (and ^{15}N) were populated via fusion–evaporation and nucleon–transfer reactions of ^{14}N on ^{2}H (implanted at the surface of a ≈4 mg/cm^2 Au layer) at 32 MeV beam energy, provided by the XTU Tandem at LNL. Gamma rays were detected with 4 triple clusters of the AGATA Demonstrator array, placed close to the beam line, providing a continuous angular distribution of the emitted gamma rays. The energy resolution and position sensitivity of this state–of–the–art gamma spectrometer have been exploited to investigate lifetimes of nuclear levels in the ≈fs range via the Doppler Shift Attenuation Method. The deconvolution of the lifetime effects on the line–shapes of the gamma peaks from the ones due to the kinematics of the emitting nuclei has been performed by means of detailed Monte Carlo simulations of the gamma emission and detection. Coupled–channel calculations for the nucleon transfer process have been used for this purpose. The comparison of experimental and simulated spectra of high–energy gamma rays, de–exciting ≈fs lifetime levels, will be shown for the 6.79 MeV transition in ^{15}O and for known cases in ^{15}N, together with details of the chi–square analysis. Preliminary lifetime estimates will be discussed and compared with previous data available in the literature [3].

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HALF–LIFE MEASUREMENTS OF NEUTRON–RICH NUCLIDES ^{93}Br AND ^{93}Kr

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Half–lives are one of the most basic observables for radioactive nuclides. Many nuclear theories aim at reproducing known values and extrapolating (or predicting) properties of those nuclides, which are beyond experimental reach. Nuclear properties greatly change when one is moving away from the valley of stability; therefore, the precise and correct experimental determination of observables is most important for most exotic isotopes.

The region around Z = 40 and N = 56 subshell closures is rich in many interesting and surprising features. The interpretation of many phenomena relies on comparison of experimental data with theoretical calculation therefore the accurate knowledge of basic observables is crucial. Additionally some of the proposed r–process paths [1] include the nuclides of interest of this work. The correct interpretation of r–process abundances requires knowledge of both half–life and β–delayed neutron branching ratio.

We present results of study of beta–decay of two isotopes, ^{93}Kr and ^{93}Br at HRIBF. New measured half–lives are $T_{1/2} = 1.20(6)$ s for ^{93}Kr and $T_{1/2} = 148(18)$ ms for ^{93}Br, where both results revise previously measured values [2]. Additionally the β–delayed branching ratio $P_n = 80(10)$ % and a new decay scheme were obtained for ^{93}Br. Results are compared with previously reported values as well as with theoretical calculations.

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Probing Gamow-Teller transition strength in β-decay of ^{79}Cu

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Experiments investigating the area around ^{78}Ni continue to provide insights about the evolution of nuclear shell structure. Having only one proton outside the closed shell, ^{79}Cu provides the best insight into the influence of the $\pi f_{5/2}$ orbital on the changing structure of Cu and neighboring isotopes as exhibited by the ground state spin change in the midshell for odd-mass Cu isotopes [1]. The beta decays populates both bound states in ^{79}Zn as well as known states in ^{78}Zn [2] through beta-delayed neutron emission. The direct branch to $N = 49$ ^{79}Zn gives key information about the structure of nuclei near ^{78}Ni.

Protons bombarding a UC$_x$ target at HRIBF produced ^{79}Cu. Isobarically separated ^{79}Cu ions were implanted in a moving tape collector at LeRIBSS where we observed the beta-decay with plastic scintillators and Clover gamma-ray detectors. With the higher intensities available at LeRIBSS, we have identified the beta-decay channel populating ^{79}Zn identifying several new level in the daughter. We have also determined new values for the beta-decay half-life and neutron branching ratio. The results are interpreted using a DF3a density functional [3] with the Fermi and Gamow-Teller beta-decay strengths determined self-consistently using DF3a+CQRPA formalism [4]. We also compare the results with shell model calculations using various types of residual interactions.

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ANALYSIS OF HIGH-SPIN ROTATIONAL SEQUENCES IN ^{168}W

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Rotational sequences in the ^{168}W nucleus were studied from data produced from the ^{118}Sn(^{55}Mn, $p4n$) reaction. This data set yielded a multitude of new findings for ^{168}W, including 9 new bands and over 90 new gamma rays[1]. These new structures are interpreted within the framework of the cranked shell model, and with the assistance of recent publications involving large multi-band nuclei [2, 3], tentative configuration assignments are discussed.

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COLLINEAR LASER SPECTROSCOPY STUDIES AT BECOLA FACILITY AT NSCL

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The BEam COoler and LAser spectroscopy (BECOLA) facility [1] has been constructed and commissioned at National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. BECOLA will be used to perform both laser hyperfine structure measurements and atomic/nuclear spin manipulation using optical pumping and nuclear-magnetic resonance techniques for rare isotopes at low counting rates. BECOLA was designed to accept low-energy (< 60 keV) beams from the NSCL gas stopping stations and also from the future Facility for Rare Isotope Beams (FRIB) [2] without any modification to the system. Charge radii and nuclear moments of light transition metals will be initially targeted [3], which are difficult to produce at other facilities. On-line operation of BECOLA is foreseen to start in 2013.

There are two major components to BECOLA; the cryogenic beam cooler and buncher, and the collinear laser spectroscopy system. The cooler/buncher will reduce the emittance of the incoming beams and provide short ion bunches to increase the detection sensitivity of the laser-induced fluorescence measurements and greatly facilitate studies of radioactive ions produced at low rates [4]. The cooler/buncher is under construction and will be commissioned in 2012. The collinear laser spectroscopy system is fully commissioned using stable beams (K, Ca and Mn) from an offline ion source. A 15-keV beam from the offline ion source was transported to the laser spectroscopy beam line. A charge-exchange cell (CEC) was used for experiments that require atomic (neutral) beams by neutralizing ion beams via charge-exchange reactions with an alkali vapor. Resonant fluorescence was collected using an ellipsoidal reflector and detected by a photomultiplier tube. The CEC for neutral beams or the ellipsoidal reflector of the photon detection system for ion beams were operated on a variable potential to change the incoming ion-beam velocity, to tune the Doppler-shifted laser frequency into resonance with the hyperfine transition of interest [5]. The detected fluorescence was recorded as a function of the scanning voltage.

The initial science program at BECOLA as well as the overall performance characteristics of the laser spectroscopy system determined by stable beams will be presented.

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Evolving high-j single-particle energies

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Recent theoretical models that include the tensor component of the strong nuclear force [1] have been successful in describing the evolution of single-particle energies, where proton single-particle energies are modified as neutrons fill specific orbits, and vice versa. The most dramatic shifts seen thus far are in light, exotic nuclei. However, more detailed, quantitative studies can be performed on stable nuclei with precision spectrometers and intense beams.

This collaboration has made measurements to determine the evolution of high-j single-particle energies outside of the $Z = 50$ shell closure. States in $Z = 51$ isotopes were populated via the single-proton adding reactions, (α, t) and (^{3}He,d). The goal was to build upon results from a previous (α, t) study [2] by examining the fragmentation of high-j strength with greater statistics and provide further information regarding the low-j states. Reconstruction of their energy centroids shows an increase in the separation of the $\pi g_{7/2}$ and $\pi h_{11/2}$ orbitals. This is in agreement with calculations that include the tensor force.

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RIGID NATURE OF SD BANDS IN COMPARISON TO THE NORMAL DEFORMED BANDS

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The rigid nature of the SD bands has always been one of the distinguishing characteristics of the SD bands. A 4-parameter formula has been applied to 234 superdeformed (SD) bands to obtain the band moment of inertia J_o and the nuclear softness parameter σ. Based on a broad classification of SD bands into three broad categories of major to minor axes ratio (***x***), a systematic of J_o and σ are presented. The σ values of most of the SD bands are found to be smaller in magnitude than those of the normal deformed (ND) bands. Further, the softness is found to be correlated to the nuclear shape; larger the axis ratio (***x***) or the deformation, smaller is the softness σ, implying more rigidity. On an average, the J_0 values follow the expected $A^{5/3}$ trend. However, a significant spread in the J_0 values is also noticed. While this may be partly due to the spread in the ***x***-values, other reasons cannot be ruled out.

Lifetime measurements of low-lying states in ^{63}Co and ^{65}Co

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The harmonic-oscillator $N = 40$ shell closure have been shown to suddenly disappear by removing protons from the ^{68}Ni. With the $\pi f_{7/2}$ shell not fully filled, it is predicted a quadrupole deformation due to the interaction of this protons with neutrons promoted to the *sdg* shell [1]. Neutron-rich cobalt isotopes on the other hand have one $f_{7/2}$ proton hole with respect to the spherical Ni isotopes and one proton more than the deformed Fe isotopes. While the occurrence of a low-lying state $1/2^-$ in ^{67}Co have been interpreted as a collectivity manifestation [2] driven by the $p_{3/2}$ intruder proton orbital, the trend followed by the $9/2^-$ and $11/2^-$ multiplet respect to the Ni 2^+ excitation states on the Ni cores agree with the spherical behaviour manifested by the $N = 40$ shell closure. Albeit reduced transition probabilities provides much more rich information about the collective character on this transitions. For this purpose, lifetimes for the $(11/2^-)$ excitation states in both ^{63}Co and ^{65}Co isotopes have been measured employing the Recoil-Distance-Doppler-Shift method. Experimental $B(E2)$ values are compared with large-scale shell model calculations [3], leading us to draw some conclusions on the role of the $d_{5/2}$ and $g_{9/2}$ neutron orbitals in the erosion of the $N = 40$ harmonic oscillator subshell closure.

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New experimental data on the one quadrupole phonon excitation of mixed proton-neutron symmetry ($2^+_{1,\mathrm{ms}}$) in the $A = 130$ region

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The one quadrupole phonon excitation of mixed proton-neutron symmetry, the $2^+_{1,\mathrm{ms}}$ state, is a fundamental building block of nuclear collectivity in near-vibrational nuclei [1]. Its unique experimental signature is a strong M1 decay to the 2^+_1 state. A powerful tool for the identification of the mixed-symmetry state is projectile Coulomb excitation in combination with the Gammasphere spectrometer at the ANL [2]. In order to further establish a systematical overview of the evolution of the mixed-symmetry state in the A=130 region, Coulomb excitation experiments have been performed on the nuclei ^{130,132}Ba. Ions of these Isotopes have been accelerated to 445 MeV by the ATLAS accelerator at the Argonne National Laboratory and have been excited in a thin ^{12}C target. Gamma rays have been detected by the Gammasphere spectrometer array. From the observed relative excitation cross-sections of the populated levels, the reduced transition probabilities of the electromagnetic decays have been deduced. From the $B(M1; 2^+_{1,\mathrm{ms}} \to 2^+_1)$ strength distributions, fragments of the mixed-symmetry state could be identified. In synopsis with experimental results for the nuclei ^{136,138}Ce [2, 3], and ^{124,126,128,130,132,134}Xe [4], that have been obtained with the Gammasphere spectrometer at the ANL as well, these new data allow for a complete overview over the evolution of the $2^+_{1,\mathrm{ms}}$ mixed-symmetry state in the stable even-even nuclei of the $A = 130$ region.

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ODD-PARTICLE SYSTEMS IN SHELL MODEL MONTE CARLO: CIRCUMVENTING A SIGN PROBLEM

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Shell model Monte Carlo (SMMC) is a powerful and general method for calculating thermal and ground-state properties of finite-size quantum many body systems. For systems with a small number of particles, e.g., atomic nuclei and cold atoms in a trap, it is important to perform the calculations for a fixed number of particles. This can be accomplished in SMMC using particle-number projection. However, this projection leads to a sign problem for an odd number of particles, resulting in the rapid growth of statistical errors at low temperatures. This has hampered the application of SMMC to odd-particle systems.

We introduce a novel method within the shell model Monte Carlo approach to calculate the ground-state energy of a finite-size system with an odd number of particles by using the asymptotic behavior of the imaginary-time single-particle Green's functions. The method circumvents the sign problem that originates from the particle-number projection. We apply this method to calculate pairing gaps of nuclei in the iron region. Our results are in good agreement with experimental pairing gaps.

HIGH SPIN STATES IN ^{194}Tl: STRUCTURAL CHANGE IN $\pi h_{9/2} \otimes \nu i_{13/2}$ CONFIGURATION IN Tl ISOTOPES ?

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The proton Fermi surface for the Tl isotopes lies just below the Z = 82 magic gap and hence the ground state of Tl nuclei are mostly spherical. However, the $\pi h_{9/2}$ orbital intrudes near the proton Fermi surface for deformed shape. The neutron Fermi surface, on the other hand, lies near the deformation driving $i_{13/2}$ orbital for the Tl nuclei in A ~ 190 region. This leads to the rotational bands built on the $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration in odd-odd Tl isotopes [1, 2]. An oblate deformation for this band has been reported for ^{190}Tl [1] whereas in ^{198}Tl a possible chiral structure has been reported for this band by Lawrie et al. [2] which they have associated with a triaxial shape. This indicates a change in structure for the above configuration in Tl isotopes with neutron number. However, the bands based on the $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration in other odd-odd Tl isotopes in A ~ 190 region are not well studied to compare with the above two limiting cases.

The high spin states in ^{194}Tl were studied in the present work by γ-ray spectroscopy method with the aim to characterize and compare the above band with the other odd-odd Tl nuclei in this region and also to identify other band structure in this nucleus. The high spin states in ^{194}Tl was studied by Kreiner et al. [3] using two Ge(Li) detectors but the level scheme was highly incomplete. The high spin states in ^{194}Tl was populated by fusion evaporation reaction ^{185,187}Re(^{13}C, xn)^{194}Tl at 75 MeV. The beam was delivered from the Pelletron Linac facility at TIFR, Mumbai. The gamma rays were detected using INGA array with 15 clover detectors at the time of the experiment. A digital data acquisition system [4] was used in this experiment. γ–γ and γ–γ–γ coincidence relations were used to propose a new level scheme of ^{194}Tl with 19 new γ-lines including two new band structures. Definite spin-parities were assigned from the DCO and IPDCO measurements. The $\pi h_{9/2} \otimes \nu i_{13/2}$ band has been identified beyond the band crossing. The comparison of the properties of this band and the theoretical calculations indicate very similar structure for the above configuration in ^{190}Tl, ^{194}Tl and ^{198}Tl. The details of the experiment, analysis and interpretation will be discussed.

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High-precision mass spectrometry and laser spectroscopy at the nuclear research reactor TRIGA Mainz

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Highly precise measurements of nuclear ground state properties, in particular atomic masses and charge radii of neutron-rich nuclides, are a powerful tool to study their nuclear structure and to benchmark the predictive power of nuclear models. The objective of the TRIGA-SPEC experiment [1] at the TRIGA research reactor in Mainz is to obtain model-independent data by means of Penning-trap mass spectrometry and collinear laser spectroscopy on neutron-rich fission products. These are produced on-line by thermal neutron-induced fission of ^{235}U, ^{239}Pu or ^{249}Cf. The fissionable target is placed in a recoil chamber close to the reactor core. The transport of the fission products from the recoil chamber through the biological shield of the reactor, and ultimately the preparation of a mass-selected, cooled and bunched low-energy ion sample for high-precision experiments on nuclides with half-lives of below 1 s are the main challenges of TRIGA-SPEC. The present status of the ion production and preparation will be given along with first results. Off-line mass measurement results with relevance to neutrino physics will also be presented [2].
TRIGA-SPEC also serves as a test bench for technical developments relevant for the MATS and LaSpec experiments [3] within NUSTAR at the future FAIR facility.

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Testing Shell Stabilization at $N = 80$; g factor of the 2_1^+ state in ^{138}Ce.

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The study of observed mixed symmetry states in $N = 80$ isotones, namely ^{134}Xe [1], ^{136}Ba [2] and ^{138}Ce [3] manifest a large effect of single-particle structure on the evolution of these collective excitations. The $M1$ transition strength between the $(2^+_{1,ms})$ state and the nearby lower-lying $(2^+_{1,fs})$ state in ^{138}Ce was found fragmented while in ^{134}Xe and ^{136}Ba the strength remains largely unfragmented. The reason for the observed fragmentation of $M1$ strength was attributed to the presence of a $\pi g_{7/2}$ subshell closure at $N = 58$ [3]. The proposed concept of shell stabilization [3] suggests that mixing of the one-phonon mixed symmetry state with the neighboring multiphonon 2^+ excited states with similar proton configurations must occur in ^{138}Ce, whereas in ^{134}Xe and ^{136}Ba, the $(2^+_{1,ms})$ remains relatively pure. To prove the validity of the concept of shell stabilization, a measurement of the g factor of the 2_1^+ in ^{138}Ce was done.

The low-lying excited states in ^{138}Ce were populated via inverse Coulomb excitation on a 1 mg/cm^2 thick ^{24}Mg target at ATLAS, ANL. To measure the g factor, the recoil into vacuum technique was employed and attenuation of the angular distribution of emitted $2_1^+ \rightarrow 0^+$ γ rays was measured. The experimental setup included the Yale plunger device and Gammasphere. A Cu stopper of about 15 mg/cm^2 thickness was used to stop the beam and a Si particle detector was mounted at zero degrees behind the stopper inside the plunger device. The results of the ongoing analysis will be presented which would provide a constraint on the single-particle wavefunctions contributing to the collective states in the $N = 80$ isotones and guide theory in developing a consistent and predictive picture of the underlying single-particle dynamics.

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REPEATABILITY IN HIGH-SPIN NUCLEARE STRUCTURE

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We present the experimental evidence of *Repeatability*, a general property of high-spin nuclear structure data, consisting of dense recursive equidistance correlations that we observed in the differential coincidence gamma-ray energy distributions of several nuclei in the rare-earth region. Repeatability is not an exotic but an abundant property that however remained hidden for decades primarily because it is almost perfectly dissimulated by the complexity of the data; moreover it is obscured even by the more outstanding particular phenomena that scientists discovered and studied along many years, like regularly-spaced superdeformed bands, bands with staggering moments of inertia, or bands with identical or similar moments of inertia, which we designate here in one word as regularity-based phenomena.

Repeatability is a general, inclusive, and integrative property that comprises the particular regularity-based phenomena; and not vice-versa, it is neither the sum of regularity-based phenomena, nor it can be reduced to any of them. It is only by establishing this clear subordination relationship when one can really speak about repeatability as a standalone property.

Moreover, repeatability is not only a ground of that or that class of phenomena, but the ground of structure of deformed rare-earth nuclei. Indeed, there is a full decomposability of the data in classes "modulo repeatability" for each nucleus. That is, instead of the juxtaposition of two immiscible limits, the ordered macroscopic deformed core, and the random microscopic quantum shells, through repeatability there is an overall dense regular behavior rule, including in a coherent way the above limits. To underline, this is not a theoretical construction, but the outcome of the experimental ground. Repeatability is the substratum property, the "fabric" of which the nuclear structure is built.

Through repeatability the energy levels of a nucleus become the *geometrical locus* of a certain object that integrates the known rotational bands, whose occurrence is unexpected at the quantum level but which is a leitmotif at larger scales of the physical universe. Different observables of the quantum nuclear motion are given by different symmetries of this object. This re-establishes a sense of visuability in the quantum realm.

Study of High-Spin States in $N\sim80$ Isotones using Radioactive ^{17}N Beam Induced Fusion Reaction

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High-spin states have been studied in the limited mass region, such as the neutron deficient nuclei close to the β-stability line, by fusion reaction using the combination of the stable beams and stable targets. New γ-ray spectroscopy method using fusion reaction induced by the direct low-energy (around 5-10 MeV/u) RI beam enables to search for the exotic deformations and collective motions of the unobserved high-spin states in wider mass region. We could succeed in developing this new method by the high-S/N measurement using the highly sensitive detection system based on the event-by-event analysis. Selection of the beam correlated events enable high-S/N measurement to reduce the natural background as well as γ rays emitted after the β decay of RI beam.

This new method by using RI beam induced fusion reaction was successfully applied to produce high-spin states in proton mid-shell nuclei with around $N\sim80$ and $Z\sim56$ in the mass region close to stable nuclei. Shape evolution and high-spin isomer are expected to be observed at high-spin states, as these nuclei have neutron valence holes and proton valence particles against the core with magic number of 82. Direct low-energy ^{17}N RI beam of 5.5 MeV/u was provided using the RCNP fragment separator, EN beam line, at RCNP, Osaka University. The ^{17}N RI beam was produced by the direct reaction of ^{9}Be(^{18}O,^{17}N)^{10}B with the primary beam energy of 10 MeV/u and the beam intensity could be obtained to be around 10^5 pps using the primary beam of around 1 pμA. High beam-energy resolution and smaller beam-spot size could be achieved. We have studied the ^{135}La and ^{136}La isotopes produced by the secondary fusion reactions of ^{124}Sn(^{17}N, 6n) and ^{124}Sn(^{17}N, 5n). The previous reported level schemes were contradiction with each other by using the stable B beam. However, we revised the level schemes of these two La isotones and we could find a new high-spin isomer with $T_{1/2}$=187(27) nsec in ^{136}La by the prompt- and delayed-$\gamma\gamma$ coincidence measurements using the time information of beam and γ-ray detection.

We will present these new results and discuss about the nuclear structure of these La isotopes.

Ab initio widths and asymptotic normalizations

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Ab initio treatments of nuclear structure describe the energy levels of light nuclei very successfully in terms of the underlying nucleon-nucleon interaction. As attention now shifts from energy spectra to other observables, development of *ab initio* descriptions of scattering and reactions is widely recognized as being particularly important.

Many narrow unbound states of nuclei already have approximate *ab initio* descriptions in the form of pseudobound wave functions with square-integrable wave functions. Their computed energies are believed to be accurate, but they differ from the true wave functions by having decaying instead of oscillating structure in their low-amplitude tails. If energy widths could be computed from these solutions, it would be considerably more efficient than separate calculations of the same widths using explicit scattering boundary conditions.

I will describe the calculation of energy widths using an integral over the accurately-computed interaction region of the pseudobound wave function. Such calculations strongly resemble the Lippman-Schwinger equation and generate accurate approximations to the long-range asymptotics of the wave function from variational solutions that are accurate at short range. I have applied this method to pseudobound states computed from the variational Monte Carlo (VMC) method using the Argonne v_{18} + Urbana IX Hamiltonian. I will show that the results correspond well to widths measured in the laboratory, and I will discuss their application to J^π assignments of states of ^{9}Li, ^{8}B, ^{7}He, and ^{9}He. I will also demonstrate that the integral method predicts widths more accurately than do approaches based on factorizing widths into products of computed spectroscopic factors and single-particle widths.

Bound states also possess "virtual widths" that specify the amplitudes of their tails in the energetically-forbidden region. The virtual widths are generally specified as *asymptotic normalization coefficients* (ANCs), which can be determined experimentally from either analytic continuation of scattering phase shifts or (more recently) from the same arsenal of transfer, knockout, and breakup reactions that is used in more traditional spectroscopic factor measurements. ANCs can be computed from *ab initio* wave functions by very nearly the same integral method as widths, and I will present ANCs calculated in this way for nearly every possible virtual emission of an $(A-1)$-body bound state from an A-body bound state with $A \leq 9$. Where experimental measurements exist, they are in good agreement with the calculations. However, several of our results remain ripe subjects for experimental tests.

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Structure of Mg Isotope Studied by β-Decay Spectroscopy of Spin-Polarized Na Isotopes - Shape Coexistence in ^{30}Mg -

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Much attention has been paid on the exotic structure of neutron-rich nuclei around “island of inversion”, characterized by the neutron magic number $N = 20$ [1]. However, most of the information on the excited states of these nuclei, such as spin and parity, has not been known well.

We have been studying the structure of Mg isotopes in the region of the $N = 20$ island of inversion, to clarify the structure change as a function of the neutron number. The experiments are being performed by our unique method of β-decay spectroscopy taking advantage of highly-spin-polarized radioactive nuclear beams at TRIUMF. The β-decay asymmetry in the Na-isotope decay enables unambiguous spin-parity assignments of the levels in the daughter Mg isotope, and it becomes possible to compare the experimental data and theoretical predictions on a level-by-level basis.

We will present the results of the β decay of ^{30}Na$\rightarrow$^{30}Mg was performed. New 14 γ transitions and new 4 levels in ^{30}Mg have been found in this work. Spins and parities were successfully assigned for 10 levels in ^{30}Mg for the first time by the β-decay asymmetry and γ-ray intensity balance. The decay scheme of ^{30}Na has been constructed. The observed levels and log-ft values were compared with theoretical calculations based on the shell model [2] and HF + RPA method [3]. It is suggested that the ^{30}Mg levels at 1.788 MeV [(0_2^+)], 3.460 MeV [$(2)^+$], 4.967 MeV [1^+], and 5.414 MeV [2^+] have deformed shapes with intruder configurations. The state at 2.466 MeV [(2_2^+)] has different nature both from the spherical ground state and the deformed four levels. It is proposed that the 2_2^+ level is the band-head of the predicted γ-band.

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Nuclei from the Islands of SHE

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The talk is devoted to experimental verifications of the theoretical prediction about existence of the "stability islands" in the domain of hypothetical super heavy elements (SHE).

Cold fusion (^{208}Pb + ^{50}Ti, ^{54}Cr,.. ^{70}Zn) [1, 2] and hot fusion reactions (Act. + ^{48}Ca) [3, 4] have been used for the synthesis of the heaviest nuclei. They led to the discovery of about 90 new isotopes with Z=104-118 and N=151-177. The decay properties of synthesized nuclei were compared with the theoretical calculations made in various theoretical models. It is shown that the obtained results provide direct evidence of the existence of the super heavy nuclei, which considerably shifts the nuclear mass limit and expands the Periodical Table of the chemical elements.

The talk presents experimental approaches to the production and study of SHE, with several details concerning registration and identification of rare events as well as prospects for the future program of research.

The experiments were carried out at the UNILAC (GSI, Darmstadt) and at the U-400 heavy ion cyclotron (FLNR, Dubna). The synthesis and studies of the heaviest nuclei in ^{48}Ca induced reactions was performed in collaboration with LLNL (Livermore, USA), ORNL (Oak Ridge, USA), Vanderbilt University (Nashville, USA), PSI (Villigen, Switzerland) and RIAR (Dimitrovgrad, Russia).

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Role of $\pi i_{13/2}$ orbital for the structure of nuclei near Z = 82 magic gap

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The high spin structure of nuclei in the Pb region around mass A ~ 190 has attracted many experimental and theoretical investigations in recent years. The competition between deformation driving high-j ($\pi i_{13/2}$ and $\pi h_{9/2}$) orbitals and the spherical magic gap at Z = 82 near the proton Fermi surface give rise to interesting structural phenomena in these nuclei, e.g the shape coexistence in Pb isotopes. The neutron number play important role in determining and stabilizing the shape of the nuclei in this region. In even-even Po (Z = 84) isotopes, the ratio of excitation energies of 4^+ and 2^+ remains close to the vibrational limit until N = 112 [1], below which it starts to increase towards the rotational limit. Significant deviations in the level structure are also observed in Tl (Z = 81) isotopes around N = 114 for configurations involving the $\pi i_{13/2}$ and $\pi h_{9/2}$ intruder orbitals. The odd proton nucleus ^{195}Bi, with neutron number N = 112, is an interesting transitional nucleus whose two immediate odd-A neighbors on either side have different shapes at low excitation energies. Spherical shape dominates in ^{197}Bi and deformed bands (built on $\pi h_{9/2}$ and $\pi i_{13/2}$ levels) observed for ^{193}Bi. In other words, the neutron magic gap at N = 126 seems to reinforce the Z = 82 magic gap until at least N = 114 to induce spherical shapes in the heavy Bismuth nuclei. It is, however, an open question whether the effect of this reinforcement continues up to even lower values of the neutron number. On the other hand, rotational band based on the intruder $\pi i_{13/2}$ orbital have been observed in lighter odd-mass Tl nuclei but this state has not yet been identified above ^{193}Tl (N= 112) [2]. So, it is interesting to study the intruder $\pi i_{13/2}$ orbital above ^{193}Tl.

Therefore, for detailed understanding of the effect of $\pi i_{13/2}$ orbital, we have studied the high spin states in ^{195}Bi and ^{197}Tl nuclei, i.e, above and below the Z = 82 shell closures. Excited states in these nuclei were populated via the fusion-evaporation reactions ^{181}Ta(^{20}Ne, 6n) ^{195}Bi at 130 MeV and ^{197}Au(^{4}He, 4n) ^{197}Tl at 48 MeV of beam energy from the VECC K130 cyclotron in Kolkata, India. INGA array with 8 Compton-suppressed Clover detectors were used for the first experiment and a smaller array of detectors were used for the second experiment.

We have observed a rotational band based on $\pi i_{13/2}$ configuration in ^{195}Bi, indicating an onset of deformation in Bi isotopes at N = 112. The $\pi i_{13/2}$ state in ^{197}Tl has been identified and a systematic of this intruder orbital in Tl isotopes has been made. No rotational band was observed based on this orbital in ^{197}Tl. The details of the experiments, analysis and theoretical calculations will be discussed in the conference. We acknowledge the help of the cyclotron operators at VECC.

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Measurement of the ^{26g}Al(d,p)^{27}Al Reaction to Constrain the ^{26g}Al(p,γ)^{27}Si Reaction Rate

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The long-lived radioactive nuclide ^{26}Al was the first radioisotope detected in the interstellar medium, by observation of the 1809-keV γ ray associated with the beta decay of its ground state (^{26g}Al). The nuclide has been the subject of several subsequent astronomical studies, resulting in a detailed directional map of its galactic distribution. Due to its half life of $\sim 7.2\times10^5$ years, which is short on stellar timescales, its abundance is indicative of ongoing nucleosynthesis within our galaxy.

Wolf-Rayet stars and asymptotic giant branch (AGB) stars have been suggested as possible locations contributing to ^{26}Al production. At T $\geq$ 0.03 GK, where ground and metastable states of ^{26}Al are decoupled, the ^{26g}Al(p,γ)^{27}Si reaction is expected to be the main destruction mechanism for ^{26}Al, thus impacting the net ^{26}Al synthesis rate. At these stellar temperatures, the dominant contribution to the ^{26g}Al(p,γ) reaction rate is capture through low lying resonances in ^{27}Si, the strengths of which have not been measured.

It is vital to constrain the destruction of ^{26}Al in order to determine the contribution of giant stars to the overall galactic abundance of ^{26}Al. However, due to small cross sections, it is impractical to measure the strengths of the lowest energy (dominant) resonances directly, and proton transfer reactions (which yield spectroscopic information on the states of interest) are experimentally problematic. An alternative indirect approach has been conducted by measuring mirror states in the ^{27}Al nucleus, using ^{26g}Al(d,p)^{27}Al reaction to determine neutron spectroscopic factors and hence obtain information about the ^{27}Si structure from mirror symmetry. The measurement was conducted at the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory, using a beam of $\sim$5 million ^{26g}Al per second and a $\sim$150 μg/cm^2 CD_2 target. Proton ejectiles were detected in the SIDAR and ORRUBA silicon detector arrays. Details of the motivation, experiment, data and astrophysical implications will be discussed. * *This work was supported in part by the US Department of Energy Office of Nuclear Physics and the National Science Foundation.*

Recent results from INGA on excitations of transitional nuclei

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Study of band structures of nuclei from symmetry consideration plays an important role in understanding different phenomena in nuclear structure. In selected regions of nuclear landscape, axial symmetry is broken and these nuclei, referred to as transitional nuclei, are described using the triaxial deformed mean-field. There are several empirical observations indicating that axial symmetry is broken in transitional regions. The structure of the gamma vibrational bands and its decay provide information about the nature of triaxial shapes. In addition, the chiral rotation is uniquely related to the triaxial nuclear shapes. Recently, RMF calculations [1] predict multiple chiral bands in some of the odd-odd isotopes of Ag, Rh and In owing to their triaxial shape. In the present paper, we would discuss the recent results from gamma-spectroscopy study on odd-odd isotopes in A $\sim$ 110 region [2, 3].

The experiments were performed using the Indian National Gamma detector Array (INGA) consisting of Compton suppressed clover detectors. Currently, INGA is set up at Pelletron Linac accelerator facility at Mumbai, as a part of a collaboration between BARC, IUAC, SINP, TIFR, UGC-CSR-KC, VECC and different Universities. The array is designed for 24 Compton suppressed clover detectors providing around 5% photopeak efficiency. Recently, a digital data acquisition system with 96 channels (based on Pixie-16 modules developed by XIA LLC) has been implemented for this Compton suppressed clover array [4].

A detailed spectroscopic study has been carried out for ^{112}In with the INGA using ^{16}O + ^{100}Mo reaction. The polarization and lifetime measurements were performed for the two strongly populated dipole bands. Comparison of the tilted axis cranking model calculation with the measured B(M1) transition strengths of the positive and negative parity bands firmly established their configurations. The measurements along with the TAC calculations suggest small axially symmetric deformation for ^{112}In at lower excitation energy in contradiction to the predictions of RMF calculations [3]. Further measurement of the crossover E2 transitions in dipole band with higher statistics is planned. In addition, the recent results on high spin states of neighbouring odd-odd isotopes will also be discussed.

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SAGE SPECTROMETER
STATUS AND FIRST RESULTS

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In-beam γ-ray and electron spectrometers have long been used as tools to probe the structure of atomic nuclei. However, if used separately they can provide only partial information of the nuclear de-excitation processes and consequently of nuclear structure. This becomes increasingly problematic in heavy nuclei, especially at low transition energies and high multipolarities, where internal conversion competes strongly with γ-ray emission. The simultaneous measurement of γ–rays and conversion electrons can provide crucial information on nuclear configurations via g-factor measurements, which can be determined through branching ratios involving a transition favoured in γ-rays (E2) and one favoured in conversion electrons (M1).

The SAGE spectrometer [1, 2] allows efficient cross-coincidence measurements between γ-rays and conversion electrons by combining the JUROGAM II germanium detector array with a highly segmented silicon detector and a solenoid electron transfer system. It employs digital front-end electronics and is coupled with the RITU gas-filled recoil separator and the GREAT focal-plane spectrometer for Recoil-Decay Tagging studies.

SAGE has been employed so far in the study of transfermium nuclei (^{251}Md, ^{253}No and ^{255}Lr) and the investigation of shape coexistence in the light lead region (in mercury, lead and radon nuclei) and also in samarium (the first coulomb excitation experiment with SAGE).

Here the setup will be briefly described and selected results from the experiments will be presented.

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Quasifree scattering reactions in inverse kinematics as a tool for spectroscopic studies

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Nucleon-knockout reactions with radioactive-ion beams have provided valuable information regarding, for instance, the evolution of shells towards the driplines. These reactions have been particularly successful for investigating the valence nucleons, since the use of Be or C targets and the requirement for the survival of the core localizes the reaction at the surface of the nucleus. On the other hand, the use of proton targets allows the study of both valence and deeply bound nucleons. At relatively high beam-energies it is valid to assume that a proton from the target knocks a nucleon or a cluster out of the beam-nucleus without any further violent interactions between the nucleus and the incident or outgoing particles (quasifree scattering). If the outgoing particles and the residual fragment are detected, one obtains a complete momentum measurement and a better control of final state interactions. In addition to the single-particle shell structure, the nucleon-nucleon correlations can also be investigated using these reactions.

In this contribution we will present a compilation of results from experiments employing quasifree scattering reactions in a wide range of nuclei; all the experiments have been carried out at the R^3B setup at FAIR which is unique in performing kinematically complete measurements of reactions with high-energy radioactive beams around few hundred MeV/nucleon. In particular, we will discuss results from a benchmark experiment on ^{12}C in which both bound and unbound states have been studied, from an experiment probing the two-proton halo candidate ^{17}Ne in which the s, d relative content of the halo wave function has been extracted and from two experiments probing the O isotopic chain and the Ni isotopic chain in which preliminary relative cross sections along the chain have been extracted using proton-rich CH_2 and C targets.

GFMC CALCULATIONS OF ELECTROMAGNETIC MOMENTS AND TRANSITIONS IN $A \leq 9$ NUCLEI INCLUDING MESON-EXCHANGE CURRENTS

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Green's function Monte Carlo (GFMC) calculations of electromagnetic moments and transitions, including two-body meson-exchange current (MEC) contributions are reported for $A \leq 9$ nuclei. The realistic Argonne v_{18} two-nucleon and Illinois-7 three-nucleon potentials are used to generate the nuclear wave functions [1]. Two-body electromagnetic current operators have been derived in both a standard nuclear physics approach [2] and a new chiral effective field theory (χEFT) formulation with pions and nucleons including up to one-loop corrections [3]. The χEFT currents have been tested in few-nucleon systems, and they provide a satisfactory description for the cross sections of thermal neutron radiative captures on the deuteron and ^{3}He.

Results will be presented for ^{7,8,9}Li, ^{7,9}Be, ^{8}B and ^{9}C, including charge radii, magnetic and quadrupole moments, and $M1$ and $E2$ transitions. The two-body MEC contributions provide significant corrections to both the magnetic moments and $M1$ transitions.

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CORIOLIS INTERACTIONS IN ODD-ODD PROTON EMITTERS

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Odd-odd nuclei pose a tough challenge for structure calculations, which is evident from the long standing ambiguities in assigning the ground state spin and parity for some of the well deformed and most stable isotopes of heavy nuclei. In the present work we undertake the important task of formulating a proper theoretical framework comprising the Coriolis interaction, to study proton emission from odd-odd deformed nuclei. We have used two quasiparticle plus rotor model (TQPRM) [1] based on the mean field defined by Woods-Saxon potential, with the inclusion of all the important terms like Newby shift and neutron-proton residual interaction. Decaying proton is assumed to move in a single-particle Nilsson level, which corresponds to resonance of the unbound proton with respect to the core, generated by the Coulomb and centrifugal barriers [2]. We will discuss our results for the proton emitter ^{112}Cs for which we have done the calculations for the probable ground state spin $I^{\pi} = 3^{+}$ of ^{112}Cs [3] by considering mixing of levels close to the Fermi surface. Effect of coriolis interaction on various observables will be presented. We will demonstrate that this formalism would be helpful in assigning spin and parity of the decaying state more precisely.

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High Resolution Timing with Digital Electronics

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The newly built Versatile Array of Neutron Detectors at Low Energy (VANDLE)[1] was designed to study neutron spectroscopy in nuclei populated by beta-decay and transfer reactions. The neutron energy is determined by the time-of-flight technique. A time resolution less than 1 ns is necessary due to VANDLEs geometry. To this end, an algorithm, for the extraction of subsample time information from digitized waveforms, was developed using XIAs DGF Pixie-16 hardware.

The algorithm fits a user defined function to the digitized waveform, and the timing is extracted from the fitted parameters. A validation procedure was developed to test the accuracy of the algorithm's results. The performance was characterized with an arbitrary function generator, obtaining time resolution better than 1 ns for signals of amplitudes between 20 mV and 1 V.

The response of the algorithm to photomultiplier signals was studied using a detector made of a small piece of scintillator material with photomultiplier tubes coupled on each side. The prototype simulates a VANDLE module, and was used to determine the resolution and walk of the algorithm at two digitization frequencies: 100 MHz and 250 MHz. The results of these tests show that both frequencies provide excellent subsample timing, with a better response at low signal amplitudes for the 250 MHz system. The timing algorithm and custom triggering scheme simplified the design of VANDLEs electronics. These developments allow VANDLE to detect neutrons with energies as low as 100 keV.

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Developments of HFB solvers and continuum effects in deformed drip-line nuclei

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With the developments of RNB facilities in the world, one of their major scientific goals is the study of unstable nuclei towards the drip-lines. This is crucial for benchmarking the existing nuclear models and thus improve the model precision for nuclear energy and nuclear astrophysics. In theoretical descriptions of drip-line nuclei, one of the key issues is the proper treatment of continuum effects, which is important not only for ground state properties and but also for nuclear excitations. The coordinate-space Hartree-Fock-Bogoliubov (HFB) approach was demonstrated to be able to treat the bound states, quasi-particle continuum and resonances on an equal footing [1]. This method, referred to as the $\mathcal{L}^2$ discretization, is rather accurate compared to exact solutions with outgoing boundary conditions [1]. However, in deformed cases the coordinate-space HFB approach results in an very large configuration space and supercomputing becomes essential [2]. To this end, we developed a 2D coordinate-space HFB solver HFB-AX using a hybrid MPI and OpenMP programming model, and a 3D solver MADNESS-HFB based on multi-wavelet techniques and sophisticated parallelism programming methodologies [2]. With these latest coordinate-space HFB solvers, we can study the drip-line nuclei within large boxes and other important problems that require big computations. We are also interested in looking for some intriguing phenomena near drip-lines, for example, deformed halo structures, islands beyond the neutron drip-line and pygmy resonances.

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LOW-LYING STRUCTURE OF ^{132,134}Xe FROM INELASTIC NEUTRON SCATTERING

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Unlike the transition from spherical vibrators to axially symmetric rotors, little is known about the transition from spherical vibrators to gamma-soft nuclei. The nature of this transition is also unclear, *i.e.*, whether it is a gradual transition or a more defined one for which a critical point exists, as proposed by Iachello [1]. The stable isotopes of xenon span a region which exhibits this lesser understood shape transition. While ^{136}Xe shows evidence of being a spherical vibrator, the lighter xenon nuclei display gamma-soft behavior.

Many possible measurements to examine the nuclear structure of the xenon isotopes are constrained, as the Xe isotopes are gases under ambient conditions. Solid targets are much more amenable to typical methods, but xenon being a relatively inert gas renders the fabrication of such targets challenging. Highly enriched ($> 99.9\%$) samples of ^{130,132,134,136}Xe were converted to solid XeF_2, yielding approximately 10 g of each difluoride. These samples were used for studies at the University of Kentucky 7-MV Van de Graaff accelerator facility using inelastic neutron scattering, the $(n, n'\gamma)$ reaction, with gamma-ray detection. For ^{134}Xe, excitation function data were obtained for $E_n = 2.0 - 3.5$ MeV, as well as angular distribution data for $E_n = 2.2$, 2.7, and 3.5 MeV. Also, excitation functions for ^{132}Xe at $E_n = 1.8 - 3.4$ MeV were obtained; in addition, angular distributions were completed for $E_n = 2.2$, 2.7, and 3.4 MeV.

Lifetimes of several low-lying levels were determined for both isotopes using the Doppler-shift attenuation method. Also, branching ratios, mixing ratios, and reduced transition probabilities were determined for some of the transitions, allowing comparisons to be drawn with the proposed mixed-symmetry states [2, 3]. New excited 0^+ states have been identified as well.

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Shape coexistence, triaxiality and isomerism in Nd nuclei close to the N=82 shell closure

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The nuclei around the N = 82 shell closure are a fertile field of spectroscopic investigations both at low and high spins: at low spins the presence of isomers based on simple particle-hole excitations helps to establish the favored quasiparticle configurations in a specific nucleus and to test the suitability of various nuclear potentials, whereas at high spins the nucleus acquires a stable triaxial shape with $\gamma \approx +30°$ [1]. The use of high efficiency γ-arrays like JUROGAM and GREAT placed at the entrance and focal plane of RITU can be successful in the identification of very weak transitions populating and de-exciting long-lived isomeric states, which are essential for determining the energy and spin-parity of the isomer, and to identify the level structures built on it. Recent results on ^{138}Nd, ^{139}Nd and ^{140}Nd from experiments performed with JUROGAM, GASP and EUROBALL will be presented, and their interpretation using Cranked Nilson-Strutinsky, Cranked+BCS+RPA and tilted axis cranking models will be discussed. Candidates for wobbling motion, a multitude of triaxial bands at high spins and of dipole bands at medium spins strongly support the stable triaxiality at high spins in this mass region.

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The structure of ^{16}C: Testing shell model and *ab initio* approaches

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Excited states in ^{16}C were populated via the ^{9}Be(^{17}N,^{16}C+γ)X one-proton knockout reaction. The lifetime of the 2_1^+ state in ^{16}C was measured using the recoil distance method. The extracted lifetime of $\tau_{2_1^+} = 11.4^{+0.76}_{-0.85}(stat) \pm 0.7(syst_{B\rho})^{+0.0}_{-1.5}(syst_f)$ ps yields a deduced B(E2; $2_1^+ \rightarrow 0_1^+$) $= 4.21^{+0.34}_{-0.26}(stat)^{+0.28}_{-0.24}(syst_{B\rho})^{+0.64}_{-0.00}(syst_f)$ e^2fm^4 value in good agreement with a previous measurement [1]. The one-proton knockout cross section is used to extract the proton amplitude of the ^{16}C 2_1^+ state, which confirms the neutron dominant character of this state. Gamma-ray branching ratios between the 2_2^+ state and the 2_1^+ and ground states were also determined. The results are compared with $p - sd$ Shell Model and No-Core Shell Model (with NN and $NN + NNN$) calculations. The implications of (not) including three-body forces will be discussed.

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INITIAL TEST RESULTS FROM THE OAK RIDGE ISOBAR/ISOMER SEPARATOR "ORISS"

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ORISS – Oak Ridge Isomer Spectrometer and Separator – is a linear multi reflection time of flight mass analyzer. It will be used to produce mono-isotopic samples of short-lived radioactive isotopes for nuclear spectroscopy. To separate all isobars, a mass resolving power of up to 40,000 is required, to separate isomers, a mass resolving power of > 400,000 is desirable. Since most nuclides of interest are produced in small quantities, an overall efficiency of 50% is desired. ORISS is complete and basically functional and will be used at a nuclear physics facility in the near future.

ORISS consists of a gas-filled radiofrequency cooler and buncher quadrupole (RFQ) which accepts a mass separated ion beam of 100 eV kinetic energy and converts it into an ion cloud of < 1mm diameter, a linear time-of-flight section [1], in which the to-be-separated ions travel up to several hundred laps between two electrostatic mirrors, and either a time-of-flight detector where tof spectra are recorded or a Bradbury-Nielsen gate which transmits ions of interest to a nuclear spectroscopy detectors. For test purposes, stable ions are supplied by an off-line ion source.

The RFQ, the linear tof section, and the BN gate were tested individually. The RFQs were tested with a tof detector located in front of their exit aperture with ^{133}Cs and O_2 ions, and tof peaks of 9 ns and 4.2 ns FWHM were observed, respectively. The linear tof section was tested using an un-cooled ion population and a tof detector, and a maximum mass resolving power of 110,000 (FWHM) was obtained after 300 laps with N_2 ions. The physical separation of CO and N_2 was demonstrated with the BNG. After assembling the RFQ and the tof section into one complete system, these tests are being repeated. The present best results are mass resolving powers of 480,000 (FWHM) for O_2 ions, and 283,000 (FWHM) for ^{132}Xe ions, both after 400 laps or tof of 13.6 and 27.7 ms, respectively. Large tail portions are present in the tof spectra and degrade the practical resolving power. The non-constant mass resolving power for different mass numbers and the tail portions may well be caused by the lack of a single-AMU input beam of controlled intensity and space charge effects in the RFQs. We will describe the existing system as well as planned experiments to determine the transmission and space charge effects.

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NUCLEAR STRUCTURE STUDY OF ^{106}Pd FROM THE INELASTIC NEUTRON SCATTERING REACTION

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Quadrupole shape vibrations are considered to be a fundamental degree of freedom of nuclei. Several candidates in the $_{48}$Cd and $_{46}$Pd region have been proposed as examples of good quadrupole shape vibrators; however, in recent studies of ^{112,114,116}Cd [1, 2, 3], serious discrepancies from the vibrational decay pattern were found, suggesting a breakdown of the quadrupole vibrational picture. Moreover, Coulomb excitation studies of ^{106,108}Pd [4] show that the quadrupole vibrational degree of freedom is important for the description of the low-spin level structure in these nuclides, but the vibrational picture cannot explain all their observed decay properties, not even for the two-phonon vibrational states. New experimental data in the palladium nuclei are needed to obtain better insight into their low-energy collective structure.

The low-lying states of ^{106}Pd have been studied with the (n,n$'\gamma$) reaction at the University of Kentucky 7-MV Van de Graaff accelerator facility. Excitation functions with neutrons of energies *(E_n)* from 2.0 to 3.8 MeV in 0.1-MeV steps, angular distributions measurements with E_n=2.2, 2.7 and 3.5 MeV, and $\gamma\gamma$-coincidence data at E_n=3.3 MeV were used to characterize the decay of the excited states in ^{106}Pd. Level lifetimes were also obtained with the Doppler-shift attenuation method (DSAM).

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Laser Assisted decay spectroscopy at CRIS

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A new decay spectroscopy station has been developed for the Collinear Resonant Ionization Spectroscopy (CRIS) experiment at ISOLDE. CRIS uses laser radiation to stepwise excite and ionize an atomic beam for the purpose of ultra-sensitive detection of rare isotopes and hyperfine structure measurements. The technique offers the ability to purify an ion beam that is heavily contaminated with radioactive isobars, including the ground state of an isotope from its isomer allowing sensitive secondary experiments to be performed. Laser spectroscopy provides a measurement of the spin of the ground and isomeric states in the parent nucleus, while the level structure of the daughter nucleus would come from the complementary decay spectroscopy. The decay spectroscopy station, consists of a rotatable wheel implantation system with silicon detectors for charged-particle detection, and up to three high purity germanium detectors around the implantation sight for γ-ray spectroscopy. Data from the on line commissioning of the CRIS beam-line and the decay spectroscopy station, using ^{207}Fr at the ISOLDE facility, will be presented.

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SPECTROSCOPY OF NUCLEI IN THE REGION OF ^{68}Ni PRODUCED BY MULTI-NUCLEON TRANSFER REACTION

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Neutron-rich isotopes are a continuous source of new information on the behavior of the nucleus and sometimes of unexpected phenomena, from the discovery of halo-nuclei to the disappearance of the well-established magic numbers. Responsible for these changes could be the proton-neutron monopole interaction that could reorder the single-particle orbits. While the experimental information obtained for nuclear systems has been limited for decades to nuclei close to the stability line, the continuous experimental developments allow nowadays the study of exotic nuclei far from stability.

A neutron-rich region, where new magic numbers may appear and others disappear, is the one bounded by N = 28-40 and Z = 20-28. As a matter of fact, it has been shown that a new sub-shell closure is present at $N = 32$ but only for $Z = 20$ [1]. The appearance of this new shell gap has been explained [2] in terms of a strong spin-flip $\pi 1f_{7/2} - \nu 1f_{5/2}$ proton-neutron monopole interaction. More recently new experimental data has shown that near the sub-shell closure at N=40 a new region of nuclear deformation sets in, leading to the disappearance of the sub-shell closure at N=40 for $Z < 28$ [3, 4]. This has been explained by large-scale shell model calculation using the new effective interaction LNPS [5]. In the present contribution new unpublished experimental results on neutron rich Co isotopes which display shape coexistence will be shown and discussed in terms of the same shell-model calculation.

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New Geiger-Nuttall Law for Alpha Decay of Heavy Nuclei

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New α-decay data of heavy nuclei are collected and systematic analysis shows that there is a sudden change between the logarithm of decay half-life and the reciprocal of the square root of decay energy across the N=126 shell closure. In order to reproduce this sudden change, the new Geiger-Nuttall law is proposed where the effects of the quantum numbers of α-core relative motion are naturally embedded in the law. The remedy achieved by a very simple parametrization of these effects is remarkable. By adding new terms to the Geiger-Nuttall law, the parameters in the formula of decay half-lives need not be changed, except for some odd nuclei. This is an important development to the original Geiger-Nuttall law which is valid for the ground-state transitions of even-even nuclei with N$\geq$128. The law is generalized to the favored and hindered transitions of the N$\leq$128 nuclei and of high-spin isomers. The results of this article point to the simplicity of the underlying mechanism of the decay.

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Systematic Calculations of α-decay Half-lives and Branching Ratios for Deformed Heavy Nuclei

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Alpha decay has long been a powerful tool to probe the nuclear properties of unstable nuclei, and it has been used as a reliable way to identify new synthesized superheavy elements and isomeric states. Based on the cluster model of alpha particle and daughter nucleus, we present the generalized density-dependent cluster model (GDDCM) and the multi-channel cluster model (MCCM) to study the α-decay properties of heavy and superheavy nuclei [1-3]. The coupled-channel effect resulting from nuclear deformation is consistently taken into account by the exact solution of the quasibound coupled-channel Schrödinger equation with outgoing Coulomb wave boundary conditions [1-3], rather than the WKB barrier penetration probability. Systematic calculations are carried out for well-deformed even-even nuclei. The calculated half-lives are found to be in good agreement with the available experimental data. Moreover, in contrast to the traditional semi-classical approximations which usually overrate the branching ratio to highly excited state by one order of magnitude, the five-channels microscopic calculations give a precise description of the fine structure observed in α decay. This could be useful for future researches of alpha decay of heavy nuclei.

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MULTIPLE OCTUPOLE BANDS AND SHAPE CHANGE IN ^{221}TH*

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Alternating-parity level structures connected by strong E1 transitions represent one of the experimental signatures for an octupole-deformed nuclear shape. Such bands have been found, particularly around ^{224}Th and ^{146}Ba [1]. A study of ^{221}Th seems interesting for two reasons. First, there is a marked difference from the structure of ^{219,223}Th [2,3]. In the latter nuclei, pairs of nearly degenerate spin-parity states I^+ and I^- (parity doublets) are found that give rise to two bands, whereas in ^{221}Th only one band is reported [3]. Hence, delineation of the non-yrast structure of ^{221}Th is desirable. Second, the concentration of decay intensity in one band, like in an even-even nucleus, predestines ^{221}Th as a case for studying the feeding of octupole bands. Indeed, for ^{222}Th an octupole to reflection-symmetric shape transition has been predicted at high spin (e.g. Fig. 39 of Ref. [1]). The experimental study of ^{222}Th [4] remained somewhat inconclusive with respect to this issue, and a study of ^{221}Th is complementary.

The nucleus has been studied using the ^{207}Pb(^{18}O,4n) ^{221}Th, E_{lab} = 96 MeV fusion-evaporation reaction and the Gammasphere + HERCULES detector combination. HERCULES helps to separate the γ rays of the evaporation residues from those of the dominant fission products. Based on selected γ-ray coincidence data, the previously reported level scheme [3] has been improved as follows: *(i)* The yrast octupole band has been corrected at medium spin ($I^\pi = 31/2^+$, $33/2^-$) and extended up to $I^\pi = 39/2^+$ and $37/2^-$. Here, the alternating-parity level structure appears to be cut off, but the level scheme extends farther. The placement of a higher lying transition establishes a spin of 43/2. *(ii)* The non-yrast structure of ^{221}Th includes another octupole band. The band has similar B(E1)/B(E2) ratios as the yrast band ($3 \cdot 10^{-6}$ fm^{-2} on average), but is elevated by 400 keV relative to the latter.

The discussion of ^{221}Th will focus on two aspects: *(i)* The rotational frequency reached at the highest spins ($\hbar\omega$ = 0.26 MeV) concurs with the critical frequency for the predicted shape transition in ^{222}Th. *(ii)* The absence of parity doublets in ^{221}Th is related to the low K value of the ground-state configuration.

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The First Experiments with ANASEN

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The Array for Nuclear Astrophysics Studies with Exotic Nuclei (ANASEN) is a new active target detector designed for direct and indirect measurements of the key astrophysical nuclear reaction rates and to study structure of exotic nuclei using rare isotope beams. The main components of ANASEN are the cylindrical array of position sensitive silicon detectors backed by CsI(Tl) scintillator detectors and the position sensitive array of gas proportional counters with carbon fiber anode wires. The same gas is used as a target and as an active volume for the gas proportional counters.

The first experiments with ANASEN were performed at John. D. Fox Superconducting Linear Accelerator Laboratory at Florida State University. Rare isotope beam facility RESOLUT was used to produce beams of ^{6}He, ^{8}B, ^{17}F and ^{19}O ions. Excitation functions for ^{6}He+α, ^{8}B+p and ^{17}F+p elastic scattering were measured in the broad range of energies. These experiments were designed to study structure of ^{10}Be (focusing on clustering phenomena in this nucleus), ^{9}C and ^{18}Ne. The structure of ^{20}O nucleus was studies using the ^{19}O(d,p) reaction. Overview of the results from these first experiments with ANASEN will be presented.

The ANASEN project is a collaboration between Florida State University and Louisiana State University. It is funded by the NSF Major Research Instrumentation grant.

Spin distributions in the quasi-continuum of N $\sim$ 90 shape-transition Gd nuclei via the (p, d) and (p, t) reactions

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Historically it has proven extremely difficult to probe the properties of low-spin highly-excited states lying far above the yrast line in the bound quasi-continuum. A variety of difficulties attend such studies ranging from the limited choice of reactions available that populate such non-yrast states to the very large and rapidly increasing level density that precludes study of individual states and imposes a statistical approach. Such states are strongly populated in light ion induced reactions, such as (n,γ), (p,d) etc. and thus play important roles in nuclear astrophysics studies, and in a variety of practical applications including reactor designs. Here we present the first measurement of the initial spin distribution of the bound quasi-continuum region, from $\sim$ 3 to 8 MeV excitation energy, following the (p,d) and (p,t) reactions on ^{154}Gd and ^{158}Gd targets. The proton beam was provided by the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory at an energy of 25 MeV. A silicon telescope array, STARS, was utilized to detect light charged particles whilst coincident γ rays were detected with the five compton suppressed HPGe clover detectors of the LIBERACE array.

We find that the angular momentum transfer into the bound quasi continuum increases with excitation energy following both (p,d) and (p,t) reactions. For excitation energies between $\sim$ 3 and 8 MeV, assuming a single dominant angular momentum transfer component, the measured angular distribution for the (p,d) reactions is well reproduced by DWBA calculations for ΔL = 4 $\hbar$ transfer, whilst the (p,t) reactions are better characterized by ΔL = 5 $\hbar$. A linear combination of DWBA calculations, weighted according to a distribution of L-transfers (peaking around ΔL = 4 - 5 $\hbar$), is in excellent agreement with the experimental angular distribution for the ^{158}Gd(p,t) reaction.

The combination of particle and γ ray detection provides several other unique opportunities to probe the quasi-continuum region which will be presented, including results pertaining to the sharp rise in density of states above the pair-gap and feeding patterns between the quasi-continuum and low-lying discrete states.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

MODEL FOR MASS FRAFGMENTATION OF URANIUM FISSION BY NEUTRONS

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Experimental measurements have been made for mass fragmentation by fission of uranium by non-thermal as well as thermal neutrons. However, in spite of the fact that more than 70 years have passed since the discovery of the fission process, no successful theory has so far been developed to explain the fragmentation. We have proposed a model to explain the uranium fission mass fragmentation by neutrons. The mass yields on fission of various isotopes of uranium by thermal as well as non-thermal neutrons of energies 8.1 MeV, 100 MeV, 160 MeV and 200 MeV have been explained by using this model and are in good agreement with experiment.

MULTIPAIR APPROACH TO PAIRING IN NUCLEI

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Pairing plays a crucial role in the description of both finite and infinite nuclear systems. BCS and projected BCS (PBCS) approaches are quite common tools to treat pairing. These theories share an important feature: they provide a description of the nuclear ground state in terms of just one collective pair. PBCS, in particular, proposes a ground state wave function that is simply a condensate of such a pair. The scenario that the exact ground state (when available) of a pairing Hamiltonian exhibits can be, however, very different from that suggested by PBCS. This is the case, for instance, of the so-called reduced-BCS or picket-fence model which describes a system of fermions occupying a set of doubly degenerate equally spaced levels and interacting via a pairing force with constant strength. The corresponding ground state is a product of collective, distinct pairs (either real or complex) irrespective of the pairing strength.

Aiming at realizing a description of the ground state of a general pairing Hamiltonian in terms of collective, distinct pairs by limiting as much as possible its computational cost, we have developed an iterative variational procedure which allows a sequential determination of the pairs through diagonalizations of the Hamiltonian in restricted model spaces. Each diagonalization is meant to generate one collective pair at a time while all the others act as spectators. All pairs are by construction real. This procedure takes inspiration from a somewhat analogous iterative approach recently proposed to search for the best description of the eigenstates of a generic Hamiltonian in terms of a selected set of physically relevant configurations [1].

Different applications of the method are provided that include comparisons with exact and PBCS results. The quantities that are examined are correlation energies, occupation numbers and pair transfer matrix elements. In a first application within the picket-fence model, the method is seen to generate the exact ground state for pairing strengths confined in a given range. Further applications of the method concern pairing in spherically symmetric mean fields and include simple exactly solvable models as well as some realistic calculations for middle-shell Sn isotopes. In the latter applications, two different ways of defining the pairs are examined: either with $J = 0$ or with no well-defined angular momentum. In spite of generating some (limited) violations of the total angular momentum, the latter choice reveals to be globally more effective leading to results that, under some circumstances, are found to be basically exact even for realistic pairing Hamiltonians.

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PHOSWICH WALL: A HIGH SEGMENTATION AND EFFICIENCY DETECTOR SYSTEM FOR REVERSE-KINEMATICS REACTIONS FOR MEASUREMENTS OF COULOMB EXCITATION AND TRANSFER IN CONJUNCTION WITH GRETINA/GRETA*

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With the development of "slow" radioactive beams at Argonne (Caribu) and Michigan State University (ReA3 and FRIB), it has become imperative to develop a suitable, effective and efficient detection system that can be coupled with the Gretina/GRETA high resolution γ–ray arrays. We have designed and constructed such a system based on four Hammamatsu H8500 5x5-cm^2 outer dimension, 8x8 pixels multi-anode PMT's (6.08x6.08 mm^2 pixel size). The θ_{lab} coverage is between 9^o and 73^o. The Phoswich arrangement consists of 1-3 mg/cm^2 fast-plastic scintillators (ΔE), followed by 2.3-mm thick CsI(Tl) detectors (E) optically coupled to the PMTs. The CsI(Tl) provides good identification between α-particles and protons down to a couple of MeV, and the ΔE-E Phoswich good Z resolution up to Z=12. The design is optimized for heavy projectiles with energies up to 10 MeV/A. A variant of this system without the CsI(Tl) provides the so-called Super-HERCULES, a detector for fusion reactions and fission-fragment spectroscopy with higher efficiency than the present device.

The readout system includes high-density pulse-shape discrimination (PSD) 8-channel chips with up to 3 gates with adjustable widths and delays. Sixteen 2-chip boards with on-board 13-bit ADC's are read via a USB to VME interface. Cable linear delays ensure the preservation of the fast–plastic rise time.

Use of the optical cross-talk to the face and corner neighboring pixels provides sub-pixel position resolution for the target-like fragments of ~0.5 mm. This corresponds to a θ resolution of 0.5^o for all θ. For large θ the resolution in ϕ is as good. This high degree of position resolution coupled with the binary character of the reactions of interest provides full characterization of the reaction parameters and good center-of-mass angular distributions. Examples of PSD resolution, and the position determining algorithms will be shown. The conditions for high-resolution studies in transfer reactions like (d, p), (^{9}Be, ^{8}Be), (^{9}Be, ^{8}Li), (^{7}Li, ^{8}Be), (^{11}B, ^{10}Be), (^{11}B, ^{12}C) will be outlined. Kinematics calculations for some key reactions of interest will be discussed. The unique capability of the system for proton transfer in addition to neutron transfer will be shown.

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RMF + BCS DESCRIPTION OF DRIP LINE NUCLEI OF N = 28 ISOTONE

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In the present investigations we have employed relativistic mean-field plus BCS (RMF + BCS) approach [1, 2, 3, 4] to carry out a systematic study for the ground state properties of even-even neutron magic nuclei represented by isotones of N = 28. One of the prime reason of this study has been to look into the role of low lying resonant states which have been found earlier in the investigations of proton magic isotopes of nuclei [1, 2] to act akin to the bound states leading to accumulation of additional loosely bound neutrons. Eventually this resulted in the existence of highly neutron rich nuclei. In some cases, even the occurrence of halo formation, for example in the heavy Ca and Zr isotopes, has been predicted [1, 2]. Naturally, it would be interesting to see if there exists a parallel phenomenon in the case of proton heavy isotones of neutron magic nuclei referred to above. It is found that the same mechanism does persist and the proton single particle resonant states are found to occur. However, the phenomenon gets restricted to the accumulation of only a few protons due to the disruptive Coulomb forces amongst protons. This has been illustrated through the example of proton rich isotone $^{58}_{30}Zn_{28}$ lying at the two proton drip-line of the N = 28 isotonic chain. The low lying proton single particle resonant states in this case are $1f_{5/2}$, $2p_{3/2}$ and $2p_{1/2}$, which are akin to the bound states in nuclei. Due to their resonant nature they are found to help in accommodating more protons giving rise to the existence of proton rich nuclei. The results include the calculated RMF potential, the single particle proton radial wave functions, the single particle energy levels and pairing gaps etc. The detailed nature of the wave functions and that of pairing gaps for the single particle states helps to identify the resonant state as well as other important states which lie near the Fermi surface and play significant role to influence the physical properties of the isotopes.

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Photon Detection System for Collinear Laser Spectroscopy Measurements at NSCL

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The BEam COoler and LAser (BECOLA) spectroscopy facility [1] will be used to perform collinear laser spectroscopy [2] measurements on rare isotope beams at National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University in order to extract nuclear properties such as the charge radius $<r^2>$, magnetic dipole moment μ, and electric quadrupole moment Q from the measured atomic hyperfine structure.

A photon detection system consisting of an ellipsoidal reflector made of polished aluminum is used for detection of laser induced fluorescence. The system is based on a design [3] from the University of Mainz in Germany. The co-propagating ion/atom beam and laser light pass through one focal point of the ellipse, and laser-induced fluorescence of the ion beam is efficiently directed to the second focal point of the ellipse. The photon detection system can be used for near UV (< 400 nm) light with a head-on Hamamatsu H11123 photomultiplier tube (PMT) at the second focal point [4]. An alternate PMT (a side-on Hamamatsu R10699), which detects IR light, relies on guiding the light from the second point of the ellipsoidal reflector through a 120 mm polished metal mirror tube to the PMT. Optimization of the IR configuration will be discussed with the goal of increasing the sensitivity of the photon detection system to measure the atomic hyperfine structure of rare isotope beams. FRED Optical Engineering Software [5] was used to simulate the light collection efficiency at both the second focal point of the ellipsoidal reflector and the detection plane of the PMT in the IR configuration. Simulation results and its performance will be presented for the IR light collection system. This work was supported in part by NSF grant PHY-1102511.

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Pygmy Dipole Resonances in medium-heavy neutron-rich nuclei

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The Pygmy Dipole Resonance (PDR) is a soft dipole excitation occuring in proton neutron asymmetric nuclei where excess nucleons form a skin around the isospin symmetric core-nucleus. This skin is excited to oscillations against the core at energies around the one nucleon separation threshold [1].

Though the PDR is much weaker than the Giant Dipole Resonance it can have a huge impact on the astrophysical r-process and, hence, on the isotopic abundance in a solar system [2]. Also by studying the PDR constrains on the equation of state of nuclear matter can be done which has a direct influence on model calculations of neutron stars [3].

At GSI (Darmstadt, Germany) a new experiment runs in May and June 2012. The PDR will be studied via Coulomb excitation in inverse kinematics on neutron rich Sn isotopes up to the neutron dripline by using the R^3B-LAND setup where a system of different detectors allows a complete kinematics analysis of all reaction participants.

Upgrates of the detector system, especially a new fiber detector with nxyter front-end [4], allows particle identification with a higher mass resolution. Furthermore, the statistics will be improved and the quadrupole excitation can be studied for the first time by using two different beam energies.

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NUCLEAR COLLECTIVE MOTION: THEORETICAL CHALLENGES

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The main problem of the current nuclear structure is the lack of conceptual development. The nuclear theory has to face

- **C**ollective motion on the border of continuum;
- **H**eavy nuclei mechanisms of clustering;
- **A**nharmonic collective Hamiltonian for soft nulcei;
- **L**ocation of collectivity on the map of interactions;
- **L**arge amplitude collective motion beyond time-dependent mean field;
- **E**xplanation and justification of the standard models: IBM, GM, CM;
- **N**uclear rotation modes at large neutron excess;
- **G**eometric chaoticity, random interactions, and thermalization;
- **E**xistence of meson fields in nuclei and their role in collective motion.

The presentation aims to formulate the unsolved problems, reveal its important details, and suggest perspectives of development of the consistent microscopic theory.

SMALL RESONANCES ON THE TAIL OF THE GIANT DIPOLE RESONANCE

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The level density and γ-strength functions are fundamental properties of the atomic nucleus and important input parameters in reaction cross-section calculations, used in reactor physics simulations and astrophysics models of formation of heavy elements in explosive stellar environments. The nuclear physics group at the Oslo Cyclotron Laboratory has developed a unique technique to extract simultaneously the level density and γ-strength function from primary γ-ray spectra [1]. The Giant Electric Dipole Resonance (GEDR) dominates the γ-strength function. The focus of this talk however would be the smaller resonances found on the low energy tail of the GEDR. One of these is the scissors mode observed (at around 3 MeV) in deformed nuclei [2]. Another is observed at around 7-9 MeV might be due to neutron skin oscillations [3]. In addition an unexpected enhancement of the γ-strength function at low gamma energy has been observed in several nuclei [4]. The origin of this enhancement is still not understood and remains a challenge to explain theoretically.
I will present the latest result from experiments done in Oslo, including not yet published data on actinide nuclei, relevant for the Thorium fuel cycle, where we observe the scissors mode resonance for several actinide nuclei [5]. These resonances should be included when calculating reaction cross-sections.

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E0 MEASUREMENTS OF 202,204RN AND 154SM USING THE SAGE SPECTROMETER AT JYFL

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The E0 transition strength between two nuclear states is particularly sensitive to changes in the mean squared radius of the nucleus and is therefore a potential probe of change in nuclear structure. The SAGE spectrometer at JYFL, designed to measure conversion electrons in super-heavy elements, was used to selectively measure E0 transitions conversion electrons in ^{202,204}Rn with alpha tagging and in ^{154}Sm. Measurements of E0 transition strengths within nuclei can probe the onset of shape-coexistence, such as in the light Rn nuclei, or examine changes from spherical to deformed ground states in isotopic chains, such as near ^{152}Sm.

The conversion electron data will be shown and conversion coefficients and E0 transition matrix elements, where obtained, will be discussed in the context of current nuclear models.

PEAR SHAPES AND HEART SHAPES IN THE LIGHT ACTINIDE REGION

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Nuclei in the light-actinide region, close to Z=90 and N=134 are known to possess large reflection-asymmetric octupole deformations due to the presence of octupole driving (Δl=Δj=3) orbitals such as $\pi(f_{7/2} - i_{13/2})$ and $\nu(g_{9/2} - j_{15/2})$ near the Fermi surface. The characteristic signatures of octupole deformation have now been observed in around 20 nuclei in the light-actinide region using gamma-ray spectroscopy [1]. This region is therefore an excellent testing ground for the stabilization of octupole deformation with angular momentum. For the even-even nuclei, the knowledge is, however, largely restricted to yrast states in bands built on the ground states.

In order to study non-yrast states in some of these nuclei, an experiment has been performed at Argonne National Laboratory using the HERCULES [2] detector together with the Gammasphere spectrometer. The ^{18}O+^{208}Pb fusion-evaporation reaction was used to populate high-spin states in ^{222}Th and ^{219,220}Ra, close to the centre of the octupole-deformed region. The detection of gamma rays in coincidence with evaporation residues has reduced the background from prompt fission. New structures and new high-spin states have been observed in these nuclei, for example, the yrast octupole band of ^{219}Ra has been observed up to a tentative spin of 63/2 ħ. The results are compared to various theoretical approaches including a recent one which explains the bands in this region in terms of the condensation of rotation-aligned octupole phonons [3].

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TRIAXIALITY IN NEUTRON-RICH MO AND RU ISOTOPES FROM DSAM LIFETIME MEASUREMENTS*

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Evidence for a triaxial nuclear shape is often inferred from spectroscopic data at very high spin. Most recently, the ultrahigh-spin data of ^{158}Er have been discussed in this context [1]. Suggestions for regions with prominent γ-soft/permanently triaxial shapes at low to moderately high spin have also appeared in the literature, including the heavy-Zr region ($Z \geq 40$, $N \geq 60$). This region has attracted interest from different points of view: a phenomenological (low-lying 2^+_2 states), an experimental (e.g. lifetime measurements of Ref. [2]), and a theoretical one (e.g. Nilsson-Strutinsky calculations of Ref. [3]).

As in Ref. [2], nuclei in this region were populated via spontaneous fission. A ^{252}Cf source with a 228 μCi α activity, mounted on a Pt backing, was used. The experiment ran with the Gammasphere + HERCULES detector combination over a period of 17 days. HERCULES helped to determine the fission axis, thereby providing an orientation axis for the emission angles of the fission-fragment γ rays detected in Gammasphere. This allowed for "normal" DSAM measurements, i.e., for the analysis of asymmetric γ ray line shapes, in contrast to Ref. [2].

For $^{102-108}$Mo and $^{108-112}$Ru, typically in the range of the 8^+_1 to 16^+_1 states, transition quadrupole moments, Q_t, have been obtained with good precision. Combined with previous measurements at lower spin, this quantity exhibits a moderate downward slope as spin increases. For the side bands of ^{104,106}Mo and ^{108}Ru, $B(E2)_{in}/B(E2)_{out}$ ratios for sets of in-band and decay-out transitions have been obtained as well. In the context of the Alaga rule, K = 2 and K = 0 assignments for the excited and ground bands, respectively, are found to be appropriate. This supports a discussion of the nuclear shape in terms of the γ degree of freedom.

In Ref. [3], two triaxial minima with similar quadrupole shape and γ values of opposite sign have been predicted for the nuclei under discussion. At that time, it was argued that the ground bands are triaxial with $\gamma < 0$. The measured Q_t values contradict the calculations: They suggest, at least for the higher spins, sets of deformation parameters, β_2 and γ, where $\gamma > 0$. However, the calculations of Ref. [3] are perhaps obsolete in that they do not allow the rotational axis to change direction. Contemporary calculations are under way and their results will be compared with the new experimental Q_t moments.

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Proposed methods to improve the performance of the SAGE spectrometer

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The SAGE spectrometer is one of the few devices capable of detecting prompt gamma ray radiation together with conversion electrons on-line. The structure and the operational principles of the device are detailed in [1, 2, 3]. Experiment campaign between January and April 2012 produced in general good data but some of the features related to design are still to be improved. During one of the experiments the carbon foil unit designed to hold a pressure gradient between the RITU [4] magnetic dipole and the SAGE high voltage area was generating an extensive gamma ray background. The exact reason of this effect is unknown but it was seen that the background was diminished extensively by removing the carbon foil directly in sight of the JUROGAMII HPGe-detectors [5]. The design of the detector has been shown to be non-optimal for detecting high energy electrons due to the small average pixel size compared to the range of the high energy electrons in silicon [6]. Despite the proven high voltage barrier method (described in [7] and [8]) a high delta electron background is still present.

A proposed methods and designs to improve the overall performance of the SAGE spectrometer ranging from analysis methods for filtering out the delta electron background to direct modifications to the spectrometer design itself will be discussed.

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SHELL MODEL DESCRIPTION OF PHOSPHOROUS AND SULFUR ISOTPES*

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The structure of $^{32-39}$P and $^{31-41}$S isotopes is described in the framework of the state-of-the-art large-scale shell-model calculations, employing the code ANTOINE and the recently devised SDPF-U[1] and SDPF-NR[2] effective interactions. Protons are restricted to fill the sd shell, while neutrons are active in the $sd-pf$ valence space. Results for both positive and negative level energies, orbital occupations, and electromagnetic observables are compared with the available experimental data, and with those obtained with the extended pairing plus quadrupole-quadrupole-type forces with inclusion of monopole interaction (EPQQM) [3].

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STRUCTURE OF LOW-LYING OCTUPOLE STATES IN THE MASS 160 REGION

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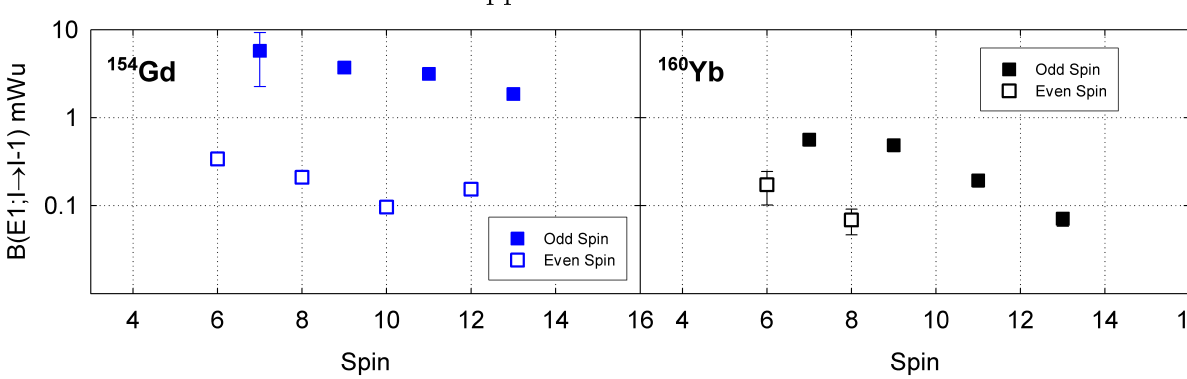
Recent theoretical work [1] suggested that nuclei in the rare earth region around $Z \sim$ 64-70 and $N \sim$ 90-94 may exhibit excited states that are tetrahedrally deformed. A consequence of a purely tetrahedrally deformed band is the absence of a quadrupole deformation, and the corresponding suppression of in-band E2 transitions. *Odd-spin*, negative parity bands (npb) with small ratios of in-band B(E2) to out-of-band B(E1) ratios, in the vicinity of nuclei such as $^{156}_{64}Gd_{92}$ [1] were early candidates for tetrahedral rotation. However, these bands are always accompanied by *even-spin* npb's with large B(E2)/B(E1) ratios.

The tetrahedral hypothesis has since been ruled out by recent experimental values of quadrupole moments, implying that the odd and even spin bands have the same deformation [2]. As a result, absolute B(E1) values can be inferred in a number of cases, as shown below. The large differences between out-of-band B(E1) values remained a mystery.

At the iThemba LABS cyclotron, using the AFRODITE array, a growing list of nuclei have been studied in this region, including ^{158,160}Yb, ^{156,158,160}Er, ^{158}Dy, and ^{152,154}Gd allowing a comprehensive set of systematics to be obtained.

In all cases low-lying odd and even spin npb's were observed, with the even-spin bands having larger B(E2)/B(E1) values. We find a more reasonable description of these bands as octupole vibrations of the nucleus, and explain the B(E1) anomalies within the framework of the Random Phase Approximation.



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Decay spectroscopy of neutron-rich nuclei around ^{38}Al

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An experiment in fall 2010 at RIBF (Radioactive Isotope Beam Factory at RIKEN, Japan) investigated N=20 nuclei above ^{29}F and the midshell region around ^{38}Al. These nuclei were produced by relativistic projectile fragmentation of a 345 AMeV ^{48}Ca primary beam from the superconducting ring cyclotron SRC with an average intensity of 70 pnA. The secondary cocktail beam was separated and identified with the BigRIPS [1] fragment separator and the ZeroDegree spectrometer (ZDS). The unambiguous particle identification was achieved by the multiple measurement of the energy loss (ΔE), time of flight (TOF) and magnetic rigidity ($B\rho$) event-by-event. The identified fragments were implanted in the CAITEN [2] detector (Cylindrical Active Implantation Target for Efficient Nuclear-decay study). The main part of this detector is a 4×10^4-fold segmented plastic scintillator with the shape of a hollow cylinder. To reduce background decay events the scintillator was moved axially and vertically similar to a tape-transport system. Implantations and decays were correlated in time and space. For the first time β-delayed γ-rays were measured (with three germanium clover detectors) in the neutron-rich isotopes ^{37,38}Si. With β-γ-γ coincidences after the decay of ^{37}Al five new γ transitions could be placed in a tentative level scheme of ^{37}Si. Applying the same methods after the decay of ^{30}Ne the low-energy level structure of ^{30}Na which was reported in [3] could be reproduced. Significantly more precise half-lives for the implanted nuclei were measured and tentative level schemes of daughter nuclei could be determined.

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HOW WELL DO THE BEST NUCLEAR MATTER SKYRME FORCES PERFORM IN FINITE NUCLEI?

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A recent survey [1] has performed an extensive analysis of published Skyrme force parameterisations for their ability to satisfy conditions derived from experimentally-constrained nuclear matter properties. The list of parameterisations which pass all the tests is short, and contains some of the least widely-used Skyrme forces.

We survey these forces, covering the nuclear matter constraints [1] and exploring their behavior in finite nuclei. Some interesting results occur, including an ability of one to reproduce the isotope shifts in ^{208}Pb [2] with an unaltered spin-orbit force, and a good reproduction of pygmy dipole strength in ^{76}Se [3]. We discuss their reproduction of fission barriers, binding energies and neutron skins, with reference to the nuclear matter properties. Perspectives for future fitting constraints are discussed.

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ODD-Z SUPERHEAVY ELEMENT STUDIES: NEW RESULTS FOR ELEMENTS 113, 115 AND 117

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Odd-Z superheavy nuclei offer the opportunity to study the hindrance effects of an odd-proton on its decay properties. Long alpha decay chains have been observed for isotopes of elements 117 [1,2] and 115 [3,4,5] using ^{48}Ca + ^{249}Bk and ^{48}Ca + ^{243}Am reactions, respectively. Results of recent experiments at the Dubna Gas-Filled Recoil Separator aimed at studying production cross-sections, excitation functions, and nuclear decay properties for isotopes of elements 117, 115 and 113 will be presented. A total of 31 atoms of $^{288}115$ have been produced in physics experiments so far at four ^{48}Ca energies, providing excitation function and alpha-decay spectra of the produced isotopes that establishes these events to be the product of the 3n-evaporation channel and confirms discovery of elements 113 and 115 in 2003 [4]. The broadening of the alpha spectrum for isotopes later in the decay chains indicates potential population of excited states. Production of $^{289}115$ in both the two neutron evaporation channel of the ^{48}Ca + ^{243}Am reaction and as a decay product of the parent nucleus $^{293}117$ produced in the ^{48}Ca + ^{249}Bk reaction provides a cross-bombardment consistency check on the data and strongly supports the discovery of element 117 [1,2].

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GYROMAGNETIC RATIOS IN STABLE AND NEUTRON-RICH SEMI-MAGIC NUCLEI BY THE RECOIL IN VACUUM METHOD

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Several theoretical approaches have predicted the g factors of 2_1^+ states in the semi-magic Sn isotopes, and in neutron-rich Te isotopes near ^{132}Sn [1, 2]. However, the experimental data have remained incomplete. In this paper we present new g-factor measurements by the recoil in vacuum (RIV) method [3], systematically covering the stable even tin isotopes between ^{112}Sn and ^{124}Sn, and neutron-rich ^{126}Sn. Tellurium isotopes, including semimagic ^{134}Te produced as a radioactive beam, have also been studied. The experiments were performed at the Holifield Radioactive Ion Beam Facility (HRIBF) by Coulomb exciting ~ 3 MeV/u beams in inverse kinematics on carbon targets, and using the CLARION+HyBall arrays to observe the perturbed particle-γ angular correlations. The measurements on the radioactive beam of ^{134}Te have sufficient precision to distinguish between the model calculations, which predict $g(2_1^+)$ values ranging from 0.5 to 0.86 [1].

To establish the requirements for future measurements on neutron-rich Ni isotopes, the RIV method has also been applied to 1.8 MeV/u ^{62}Ni beams, for which $g(2_1^+)$ is known.

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STABLE EXCITATIONS IN NUCLEI WITH PION-EXCHANGE EFFECTS

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Data from the recently published 5-volumes compilation of excitations of all nuclei (Springer LB I/25) were used to check the observed by J. Schiffer *et al.* and T. Otsuka *et al.* stable character of excitations in A-odd Sb-isotopes (N=72-82) due to the tensor force effects. The parameter of the slope (161 keV, excitation versus N) was confirmed by the presence of stable intervals 160 keV in neighbour isotopes ^{122,124}Sb (maxima in sum spacing distribution). The same period was found in the sum distribution of excitations in all Z=odd nuclei with Z=51-57 (data contained in the 3-rd volume of Springer compilation).

Expected similar effect of stable excitations in nuclei around Ca (Z=16-20, parameter 644 keV=8x161 keV) was confirmed with the analysis of data from the first volumes of this compilation (data on F, Na, Ca and Sc isotopes) [1].

The important role of the large shells for observation of stable energy excitations (and stable intervals) was found in data for nuclei with Z=60-78 where proton are in the shell $1h_{11/2}$ similar to that of neutrons in shell $1h_{11/2}$ in Sb-isotopes.

The influence of nucleon structure on nuclear properties suggested by S. Devons [2] are considered together with the observation by C. Detraz that "the nucleus is one specific case, the coldest and most symmetric one, of hadronic matter" [3].

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RECENT DEVELOPMENT OF PROJECTED SHELL MODEL FOR THE STUDY OF EXOTIC STRUCTURES[1]

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We report on several recent developments of Projected Shell Model [1] for the study of exotic nuclear structures. The basic concept of shell model calculation for heavy nuclei with the angular-momentum-projection technique will be discussed. These new developments are closely related to the current interest for the structure of neutron-rich nuclei [2, 3, 4, 5], the mixing effects of high-K isomers [6, 7], and the microscopic mechanism of shape phase transitions [8].

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STRUCTURE OF MEDIUM-LIGHT NUCLEI NEAR THE PROTON DRIP LINE

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Radioactive nuclei at or just beyond a drip line are of much interest, but measuring properties of these systems is very difficult. Conversely, many have mirror nuclei on or near the "valley of stability", where properties are known, often to very high precision. With the MCAS formalism (Multi-Channel Algebraic Scattering) we predict several spectra far from stability by the use of mirror systems; firstly, model parameters are fixed for neutron-nucleus scattering where the compound system has a stable ground state, and then the protons and neutrons are interchanged to examine the unstable system. Specifically, we show results for nuclei of mass 15, 17 and 19. In the absence of measured levels with which to assess these predictions, the ground state energy can be compared with values from mass equations and from systematic trends we have found in known threshold excitations of mirror systems.

Linear alpha-chain structure in ^{16}O

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Alpha cluster levels in light nuclei are not only of interest of the studies on nuclear structures but also of great importance in nuclear astrophysics. In particular, the four-α chain structure [1] in ^{16}O was studied in this work using the two reactions of ^{12}C+α and ^{13}C(α,n) at the FN tandem accelerator of University of Notre Dame. The α-decay from the populated ^{16}O states was measured with an array of four double-sided silicon-strip detectors [2]. By constraining the decay via ^{8}Be and reconstructing the kinematics we have mapped out the excited states in ^{16}O above the 4-α threshold. Results on the possible rotation band of the linear alpha-chain structure will be reported.

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Coriolis Anti-Pairing effect and the angular-momentum dependence of Moments of Inertia

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The constrained HFB (CHFB) equation was solved by the perturbation treatment of the Coriolis term based on the BCS solution [1] to describe Coriolis-Anti-Pairing (CAP) effect [2]. On the other-hand, the effect of the pairing gap on the moments of inertia and its relation to the rigid-body value are estimated by Bohr-Mottelson [3] and Bengtsson and Helgessen [4]. Here, we connect both technique for CHFB equation and obtain the rough estimation for the angular-momentum dependence (I-dependence) of moments of inertia for the triaxially deformed case[5, 6] in the algebraic form. Especially, we propose an extensive application of the cranking model to the triaxially deformed nucleus, where pairing gap is affected by the direction of rotation. Although the model starts from the mean-field, i.e., CHFB equation, we assume the similar mechanism works in the highly excited high spin states. The gap equation is solved to determine $\xi_i = 2\Delta_i/\delta_i$ ($i = x, y$ and z), where Δ_i is the gap parameter and δ_i is the average energy distance between the levels connected by single-particle angular momentum components. The I-dependence in moments of inertia, which has been introduced as a phenomenology and its importance has been demonstrated in describing energy levels of the TSD bands [5, 6], is given in an approximate algebraic form through I-dependence of pairing gap (Δ) on the basis of microscopic model. It is noticeable that the finiteness of a nuclear system prevents the rapid decrease of Δ and keeps its finite value even in high spin states.

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Hindered proton collectivity in $^{28}_{16}S_{12}$: Possible magicity at $Z = 16$

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The reduced transition probability $B(\mathrm{E2};0^+_{gs} \rightarrow 2^+_1)$ for the proton-rich nucleus ^{28}S was obtained experimentally using Coulomb excitation at 53 MeV/nucleon [1]. The experiment was performed using the RI Beam Factory accelerator complex at RIKEN Nishina Center. The resultant $B(\mathrm{E2})$ value 181(31) $\mathrm{e^2fm^4}$ is smaller than the expectation based on empirical $B(\mathrm{E2})$ systematics [2]. The proton and neutron transition matrix elements, M_p and M_n, for the $0^+_{gs} \rightarrow 2^+_1$ transition were evaluated from the $B(\mathrm{E2})$ values of ^{28}S and the mirror nucleus ^{28}Mg. The double ratio $|M_n/M_p|/(N/Z)$ of the $0^+_{gs} \rightarrow 2^+_1$ transition in ^{28}S was obtained to be 1.9(2), showing the hindrance of proton collectivity relative to that of neutrons. These results indicate the emergence of the magic number $Z = 16$ in the $|T_z| = 2$ nucleus ^{28}S.

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THEORY OF PYGMY MODES IN CHARGE ASYMMETRIC NUCLEI

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In recent theoretical investigations of electromagnetic response functions along isotopic and isotonic chains new low-energy modes of nuclear excitations are explored. The studies are based on a method incorporating density functional theory and multi-phonon coupling which allows for a self-consistent and fully microscopical description of complex excitations of different multipolarities and energies in stable and exotic nuclei [1, 2].

The analysis of transition densities and currents at low energies reveal a clear indication of specific signals of nuclear skin oscillations which are distinct from other surface vibrations and the giant resonances known from stable nuclei. These signals are found as well in dipole and quadrupole response functions and they are related to pygmy dipole and quadrupole resonances [1, 2]. Even though the pygmy dipole strength is mostly of electric character [3], the presence of skins is found to induce also M1 strengths at about the same energy region. These new observations contribute to the understanding of the spin dynamics of the nucleus. The results are compared to experimental data [4].

In general, the information on pygmy resonances reveals new aspects on the mechanism of excitation of the nucleus with fundamental and astrophysical consequences. In this connection, studies of rapid neutron-capture processes in photonuclear reactions are of special interest in order to probe the s-process branching nuclei [5] which are of importance for the nucleosynthesis.

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High-statistics study of 110Cd via β decay

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The stable even-even Cd isotopes have been considered as some of the best examples of nuclei possessing vibrational motion and to display shape coexistence. A program of detailed study, via very-high-statistics beta-decay measurements of these isotopes has been able to provide vital information on weak, low-energy decay branches that are often the most important transitions needed to assess collectivity. The β decay of 110In to 110Cd using the 8 π spectrometer at the TRIUMF-ISAC radioactive beam facility was performed to seek these branches. The data were collected in scaled-down γ singles and γ-γ coincidence mode, and 850 million events were sorted into a random-background-subtracted γ-γ matrix. The interacting boson model was used to predict the level energies and electromagnetic transition strengths in 110Cd and compare them with experimental results. The properties of multi-phonon vibrational and intruder states have been investigated. Details of current analysis will be presented.

THE FUSION OF ^{11}LI WITH ^{208}PB

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One of the most active areas of research with radioactive beams is the study of the fusion of weakly bound nuclei, such as the halo nuclei. The central issue is whether the fusion cross section will be enhanced due to the large nuclear size of the halo nucleus or whether fusion-limiting breakup of the weakly bound valence nucleons will lead to a decreased fusion cross section.

We studied the fusion of ^{11}Li with ^{208}Pb at TRIUMF. The intensity of the ^{11}Li beam (chopped) was 1000 p/s and the beam on-target time was 114 hours. The stacked foil technique was used to step the beam energies from 40 to 29 MeV (Ec.m. = 27-38 MeV) throughout the array. The α-decay of the stopped EVRs was detected in a α-detector array at each beam energy in the beam-off period (the beam was on for $\leq$ 5ns and then off for 170 ns). The geometrical efficiency of detection of the decay α-particles has been calculated to be approx. 20 per cent. To verify this, we measured the evaporation residue yield for the well-known ^{7}Li + ^{209}Bi reaction [1].

We have previously measured the evaporation residue cross sections when ^{9}Li, the ^{11}Li core, fuses with ^{208}Pb. [2] We also have done HIVAP calculations of what we might expect for evaporation residue cross sections if ^{11}Li were to fuse with ^{208}Pb rather than breakup. The At isotope patterns observed on-line are not those observed for the ^{9}Li + ^{208}Pb reaction but are consistent for expectations of complete fusion. For example, we observe ^{215}At which is predicted [3] to result from ^{11}Li + ^{208}Pb fusion but was not observed in the ^{9}Li + ^{208}Pb reaction. Similarly we can use other EVR isotopic ratios, such as the ^{213}At/^{214}At ratio, to define the situation. The observed evaporation residue yields suggest that, to some extent, ^{11}Li has fused with ^{208}Pb.

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Electromagnetic Transition Rate Studies with the TIGRESS Integrated Plunger

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Accurate transition rate measurements are fundamental probes of nuclear structure and provide stringent tests for theoretical models important to our understanding of the nucleus. Precision Doppler-shift lifetime measurements and Coulomb excitation studies with intense re-accelerated radioactive beams from the ISAC-II facility at TRIUMF play an important role in this pursuit. To this end, the TIGRESS Integrated Plunger (TIP) has been developed for picosecond-ordered lifetime measurements of exotic nuclei via in-beam gamma-ray spectroscopy with TIGRESS, a high-efficiency and Compton-suppressed segmented germanium clover array. Together with its extensive suite of auxiliary charged-particle detectors, TIP permits simultaneous and model-independent measurements of reduced quadrupole transition strengths and static quadrupole moments using the combination of sub-barrier Coulomb excitation and Doppler-shift lifetime measurements.

For such measurements, both highly-segmented and modular silicon detector arrays have been implemented for kinematic reconstruction of inelastic scattering events in coincidence with gamma-ray detection. In addition, the incorporation of a 3π CsI(Tl) array for light charged-particle identification will provide enhanced reaction channel selectivity for lifetime measurements following fusion-evaporation reactions. A discussion of this addition to the nuclear structure program at TRIUMF and an overview of recent experimental progress will be presented.

^{19}Mg Two-Proton Decay Lifetime: A New Application of the Recoil Distance Method

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Two-proton decay lifetime measurements of light even-Z nuclei beyond the proton drip line exemplify the struggle of spectroscopy at the limits of existence. As the interplay of the Coulomb and centrifugal barriers influence the emission of unbound protons, precise lifetime measurements of these exotic species hold promise to shed light on the nuclear wave function and valence proton correlations. An adaptation of the Recoil Distance Method has therefore been developed at the National Superconducting Cyclotron Laboratory (NSCL) for lifetime studies of short-lived proton-emitting nuclei. This variant of the Köln/NSCL plunger technique utilizes a thin silicon double-sided strip detector positioned downstream of the reaction target to measure the energy loss ratio of the two-proton decay precursor and heavy-ion decay residue.

The pioneering measurement investigated the ^{19}Mg ground state two-proton decay lifetime. The ratio of ^{19}Mg and ^{17}Ne energy losses at various target-detector distances was measured in coincidence with ^{17}Ne decay residues in the S800 Magnetic Spectrograph. Simulated heavy-ion lineshapes generated over a broad range of lifetimes were fit to the energy loss signatures. The best-fit lifetime was found to increase from 0.39(9) ps to 2.44(54) ps as a function of an increasing prompt production (from reactions rather than two-proton decays) of ^{17}Ne. These results are significantly shorter than the previously reported lifetime of 5.8(22) ps [1] and three-body decay model predictions [2] and are indicative of the challenge in understanding how valence proton orbital configurations impact particle stability beyond the drip line. An overview of this sensitive experimental technique for picosecond-ordered proton-decay lifetime measurements will be presented.

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Energy Density Functional Analysis of Shape Evolution in N=28 isotones

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The structure of low-energy collective states in proton-deficient $N = 28$ isotones is analyzed using structure models based on the relativistic energy density functional DD-PC1 [1]. The relativistic Hartree-Bogoliubov model for triaxial nuclei is used to calculate binding energy maps in the β - γ plane. The evolution of neutron and proton single-particle levels with quadrupole deformation, and the occurrence of gaps around the Fermi surface, provide a simple microscopic interpretation of the onset of deformation and shape coexistence. Starting from self-consistent constrained energy surfaces calculated with the functional DD-PC1, a collective Hamiltonian for quadrupole vibrations and rotations [2, 3] is employed in the analysis of excitation spectra and transition rates of ^{46}Ar, ^{44}S, and ^{42}Si [4]. The results are compared to available data, and previous studies based either on the mean-field approach or large-scale shell-model calculations.

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SEARCH FOR PARTICLE-HOLE INTRUDER STRUCTURES IN ^{64}Co AND ADJACENT NUCLEI

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Following the discovery of the particle-hole intruder structure in $^{67}Co_{40}$ [1], two low-energy 1^+ levels were identified in $^{66}Co_{39}$ whose decay to levels of $^{66}Ni_{38}$ proved to be highly selective [2]. As only a single low-energy 1^+ level is expected in ^{66}Co, the second 1^+ level is also a candidate for a particle-hole intruder configuration. In this paper, a new study of the decay of $^{64}Co_{37}$ to levels of $^{64}Ni_{36}$ along with the decay of $^{64}Fe_{38}$ to levels of $^{64}Co_{37}$ will be reported. Additional new high-spin structure will also be reported for ^{64}Co. New results include the observation of dramatic changes in the population and decay of low-energy levels in the ^{62,64,66}Ni sequence, along with significant shifts in the low- and medium-energy structure of ^{62,64,66}Co that provide insight into the configurations of the ^{66}Co levels.

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SCRIT Electron Scattering Facility at RIKEN

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The SCRIT (Self-Confining Radioactive isotope Ion Target) method has already been confirmed that it can be used for electron scattering experiment for unstable nuclei[1]. The R&D experiments of SCRIT were done at KSR (Kaken Storage Ring), Kyoto University and luminosity was estimated nearly 10^{26}cm^{-2}s^{-1} with the trapped ions of 10^6 at electron beam current 80 mA[2].

An electron scattering facility, which consists of a microtron type electron accelerator (RTM: Racetrack Microtron), an electron storage ring (SR2: SCRIT-equipped RIKEN Storage Ring) and an ISOL (Isotope Separator Online) involving an RI generator, had already been constructed in 2010 at RIKEN Nishina Center to realize electron scattering experiments for unstable nuclei with SCRIT technique[3].

Stable ^{133}Cs ion was used as a target and the energy of electron beam was set to 150 MeV at the present testing experiment. The stored electron beam current is about 250 mA with lifetime around 200 minutes. To measure the scattered electron from the target, an electron detection system, which consists of a drift chamber, plastic scintillation detectors and two calorimeters, was employed. The trajectories and energy of scattered electrons are determined by the drift chamber and two calorimeters. The detector system covers the scattering angle from 25° to 50°. From the vertex distribution and energy loss in the calorimeters of scattered electrons, the number of elastic scattered electrons from Cs ion target was obtained and the luminosity was determined to be 10^{27}cm^{-2}s^{-1} at beam current 200 mA.

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Collective Structures at Ultrahigh Spin in the Rare Earth Region: A New Chapter in the Story of Rapid Nuclear Rotation and A New Challenge for Understanding Triaxiality in Nuclei

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In the rare earth nucleus ^{158}Er, many fascinating phenomena that occur with increasing excitation energy and angular momentum have been observed. The latest one is a spectacular return to collectivity in the form of three rotational bands at spins beyond band termination [1, 2]. These three bands have been suggested to possess a triaxial strongly deformed shape based on a comparison of transition quadrupole moments (Q_{t}) between experiment and theory [3, 2]. Some questions arising in the above comparison, which represent a challenge for understanding triaxiality in nuclei, will be discussed. The recent discoveries in ^{158}Er opend a new chapter in the story of rapid nuclear rotation and have also triggered a comprehensive project to explore such phenomena in the light rare earth nuclei, for example, ^{157}Ho [2]. New results on ^{157}Ho (and, possibly, those from the to-be-performed ^{160}Yb DSAM experiment) will also be presented.

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ON THE DECAY OF ^{102}Rb

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Experimental investigations of the β-decay properties of nuclei which lie along the astrophysical r-process are becoming possible with modern facilities and detection systems. In this experiment, a ^{102}Rb beam was produced by 500 MeV, 10 μA protons impinging on a multilayer UC_x target at TRIUMF-ISAC Facility. The beam of ^{102}Rb ions was implanted on a tape-transport system at the center of the 8π spectrometer. The 20 HPGe 8π γ-ray detectors were coupled with SCEPTAR for coincidence β-tagging and DANTE, an array of six $LaBr_3$ detectors for fast gamma-ray timing. A preliminary analysis has allowed the first identification of the 4^+ to 2^+ transition in the daughter nucleus, ^{102}Sr, and extended the level schemes of several other A=102 and 101 nuclei. A near identical low-lying band structure with $^{98,\ 100}$Sr nuclei has been observed, indicating the rigidly deformed rotational nature continues towards to the N=66 midshell. The current experimental measurements of ^{102}Rb β-decay half life as well as the β-delayed neutron emission and β-decay branching ratio will help refine nuclear models and astrophysical network calculation inputs. A description of the experimental setup and procedure will be presented along with the results of the ongoing analysis.

Structural evolution in the A≈100 region

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The mass A≈100 region above the N=52 shell closure is well-known for its richness in structure, and structural changes. Due to the proximity of the major N,Z=50 shells, as well as the Z=38,40 sub-shell closures, there is strong competition between microscopic and collective degrees of freedom, a challenge for nuclear models of both types that allows to get insight on the intersection of both. Very different structural evolution paths occur within a very small region - from fast onsets of deformation (e.g., Zr, Sr, Mo chains) to rather gradual development in neighboring chains , i.e. Ru and (as recently revealed) the Kr isotopic chain [1, 2]. The available data in this region allowed us to develop a plunger technique for the simultaneous measurement of excited state lifetimes and g factors via TDRIV (time-dependent recoil-into-vacuum), which we referred to as the g-Plunger technique [3]. High-precision lifetimes yielded by g-Plunger measurements complement our picture of structural evolution in Ru isotopes [4], challenge literature values of g factors in Pd isotopes, and establish the effect of configurational isospin polarization in Zr isotopes [5, 6, 7], relating to the onset of collective proton-neutron symmetric and mixed-symmetric states [8]. First recent results in the Mo isotopic chain give hint to the structural evolution of mixed-symmetry states from spherical to deformed nuclei. This work is supported by U.S.DOE under grant no. DE-FG02-91ER40609.

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The low-energy enhancement in photon strength*

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Over the last decade several measurements in medium mass nuclei (mainly by the Oslo group) have reported a low-energy enhancement in the photon strength function. Although much effort has been invested in unraveling the mysteries of this effect, its physical origin is still not understood. I will discuss our model-independent experimental approach to investigate the possible existence of this enhancement.

Our experiment was designed to study statistical feeding from the quasi-continuum (below the neutron separation energy) to individual low-lying discrete levels in ^{95}Mo produced in the (d,p) reaction. A key aspect to successfully study gamma decay from the region of high-level density is the detection and extraction of correlated particle-gamma-gamma events, which was accomplished using an array of Clover HPGe detectors and large-area annular silicon detectors. The entrance channel excitation energy into the residual nucleus was inferred from the detected proton energies in the silicon detectors. Gating on gamma-transitions originating from low-lying discrete levels specifies the state fed by statistical gamma-rays. Any particle-gamma-gamma event in combination with specific energy sum requirements ensures a clean and unambiguous determination of the initial and final state of the observed gamma rays. With these constraints the statistical feeding to individual discrete levels is extracted on an event-by-event basis.

I will present the latest results [1] and compare our data to the photon strength function of ^{95}Mo measured at the University of Oslo [2]. In particular, I will address questions regarding the existence of the low-energy enhancement in the photon strength function.

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Correlations in direct two-proton knockout and details of the reaction mechanism

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In surface-grazing collisions with a light target nucleus the sudden removal of two protons from an intermediate-energy neutron-rich projectile has been shown to proceed as a direct reaction. In addition to giving spectroscopic information, this type of reaction promises a rather unique tool assign spins by measuring the momentum distributions of the heavy reaction residues. In a two-nucleon removal reaction three reaction mechanisms contribute to the cross section: the inelastic removal of both nucleons, the elastic removal of one nucleon and inelastic removal of the second, and the elastic dissociation of both nucleons. The direct two-proton knockout reaction from a ^{28}Mg beam at 93 MeV/u has been studied at NSCL. First coincidence measurements of the heavy ^{26}Ne projectile residues and the removed protons enabled the relative cross sections from each elastic and inelastic nucleon removal mechanism to be determined. These more final-state-exclusive measurements are key for further validation of this direct reaction and its use for quantitative spectroscopy of highly neutron-rich nuclei. The relative and absolute yields of the three contributing mechanisms are compared to reaction model expectations based on the use of eikonal reaction dynamics and *sd*-shell model structure amplitudes. The kinematic correlations of the removed protons are also analyzed. Comparisons with phase-space simulations show that a majority of the triple-coincidence events with two protons display correlations consistent with a two-body, diproton-like removal mechanism. The fraction of such correlated events is also consistent with the fraction of spin $S = 0$ two-proton configurations in the entrance-channel ^{28}Mg ground state wave function. This result promises access to a new, more specific probe of the spin and spatial correlations of valence nucleon pairs in exotic nuclei produced as fast beams.

Modular Total Absorption Spectrometer at the HRIBF on line test facility (ORNL, Oak Ridge)*

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The Modular Total Absorption Spectrometer (MTAS) has been constructed and applied to the decay studies of ^{238}U fission products at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory. Total absorption spectroscopy of fission products is important for the verification and development of nuclear structure models, as well as for the determination of decay heat released by radioactive nuclei during nuclear fuel cycle.

The MTAS detector array consists of 19 NaI(Tl) hexagonal shape detectors, each one is ~53 cm long and ~20 cm maximum diameter. MTAS efficiency for full energy deposition of a single gamma ray approaches nearly 90% around 300 keV and it is over 75% for a 5 MeV γ-transition.

Auxiliary detectors include two segmented 1-mm-thick silicon strip detectors placed inside the MTAS array around the tape transporting collected activities. These Si-counters cover over 80% of the solid angle for beta-energy loss detection and help to center the radioactive samples inside MTAS. The entire MTAS array is surrounded by over 12,000 pounds of lead and paraffin shielding.

In January 2012 MTAS was placed on-line at the HRIBF mass separator, at the so-called On-Line Test Facility (aka UNISOR separator). Over twenty decays of fission products have been studied using MTAS. The experimental results will be discussed in [1] and the hardware and experimental techniques will be described here.

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Nuclear shape changes in collective and non-collective rotations

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With the cranked Woods-Saxon model, we have made a systematical search for possible stable triaxial shapes in atomic nuclei. The calculations give that Ge and Se isotopes can have triaxial deformations, with the maximum triaxiality of $\gamma \approx 30$ found in the ground and rotational states of ^{64,74}Ge [1]. The triaxial shape is quite soft in the ground state, but becomes stable with increasing rotational frequency. The triaxiality in the mass-70 region can be understood by Z (N) = 32 triaxial shell gap.

Using configuration-constrained potential-energy-surface (PES) calculations, we have investigated the deformation effect on the structures of superheavy nuclei, giving significant effect from the high-order β_6 deformation [2]. The deformed shell gaps at N=152 and Z=100 are increased due to the existence of β_6 deformation. The inclusion of the β_6 parameter can significantly improve the description of the heaviest high-K isomers. Furthermore, we have investigated possible high-K isomers in the second well of actinide nuclei [3], finding that the reflection-asymmetry β_3 deformation can remarkably influence the fission path. Many high-K fission isomers have been predicted [3]. In mass-190 neutron-deficient nuclei, multi-quasiparticle (multi-qp) excitations extend the coexistence of prolate and oblate shapes [4]. The possible superdeformed (SD) multi-qp high-K states are systematically predicted in the mass-190 region. These SD high-K states would be populated in future experiments.

Within the projected shell model (PSM), we have performed spin-conserved PES calculations. Such calculation has been tested in shape-soft mass-190 nuclei (neutron-deficient or -rich), showing that deformation-changing effect can be significant for rotational motion. The present calculations can well interpret the properties of observed γ-ray spectra in the soft nuclei. The observed shape evolution in Mg isotopes can also been reasonably reproduced with the spin-conserved PES based on a modified Nilsson potential.

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SPINS, MOMENTS AND SIZES OF $^{100\text{-}130}$Cd BY LASER SPECTROSCOPY

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We report on the first study of cadmium by high-resolution laser spectroscopy. Nuclear spins, electromagnetic moments and root mean square charge radii of ground and isomeric states have been determined along the chain, ultimately reaching the neutron 50 and 82 shell closures. These experimental data provide a solid basis for enhancing the nuclear theories in the vicinities of the doubly magic ^{100}Sn and ^{132}Sn. Specific nuclear-structure questions, for instance, whether the cadmium isotopes are spherical vibrators or rigid rotors, can now be resolved.

The technique of collinear laser spectroscopy was applied at ISOLDE-CERN. The first part of the program studied the intense beams of $^{106\text{-}124,\,126}$Cd, which also covered the β^- isomers in that range. For enhanced sensitivity the exotic species towards ^{100}Cd and ^{130}Cd were measured as bunched beams and making use of an exotic atomic transition at 214nm. The later also clears the path to other isotopic chains so far inaccessible by laser spectroscopy due to atomic transitions deep in the UV spectrum. Long-lived β^- isomers were observed in ^{127}Cd and ^{129}Cd for the first time. The measurements determined the ground-state spins as being 1/2, 3/2, and 5/2 in close relation with the corresponding single-particle orbitals. Evidence is found whether the isomeric configuration is $11/2^-$ in all isotopes, or it is replaced by one of the predicted $7/2^-$ or $9/2^-$ collective states. The data are sensitive to changes in the degree of collectivity between the ground states and the isomers, not only from their quadrupole moments, but also through their charge radii.

In this contribution the experimental results and their preliminary interpretation will be presented in the context of the shell structure in the vicinity of Z=50 and its evolution towards the neutron 50 and 82 shell closures.

Roles of deformation and neutron excess on pygmy resonance

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Physics of unstable nuclei is one of the central fields of nuclear physics. There have been many attempts to investigate the collective modes of excitation unique to neutron-rich nuclei. Among them, the low-lying dipole excitation has been studied actively in connection with the influence on the nucleosynthesis. The recent experiment at RIKEN showed that the neutron-rich Zr isotopes located close to the r-process path are largely deformed [1]. Thus, the effects of deformation on the low-lying dipole excitation are discussed in the present contribution.

The collective excitations are studied based on the time-dependent density-functional theory. We developed a framework of the deformed quasiparticle-random-phase approximation where the Skyrme and the pairing energy-density functionals are consistently treated and the continuum effects are described by solving the equations in the coordinate space [2]. This method was first applied to the low-lying dipole excitation in the neutron-rich Mg isotopes [3]. We found the significant coupling effects between the dipole and octupole excitation modes due to the nuclear deformation, and the enhanced strengths for the compression-dipole and isoscalar-octupole excitations in the low-energy region.

A systematic calculation for the low-lying dipole excitation in the Zr isotopes ranging from the stability line to the neutron-drip line is performed using a newly developed calculation code [4] which is designed for use in the massively paralleled computers. And we study the roles of deformation and neutron excess simultaneously. Figure 1 shows the isovector-dipole transition strength distributions in $^{100-114}$Zr as an example of the calculations. These isotopes are prolately deformed, which gives rise to the deformation splitting of the giant dipole resonance. Beyond $N = 70$, we can see that the pygmy resonance develops at around the excitation energy of $6 - 7$ MeV. The spatial structure of the transition density to the pygmy mode is investigated in detail.

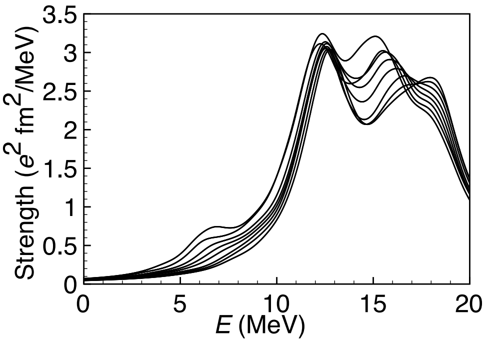

Figure 1: $E1$ strength distributions in $^{100-114}$Zr.

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NUCLEAR COLLECTIVE MOTION: THEORETICAL CHALLENGES

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In spite (or because of) the great progress in computations related to nuclear structure, the main problem currently is in the lack of conceptual development. In theory of nuclear collective motion, we are essentially bound by the same approaches which were formulated 30-40 years ago and the main improvement is quantitative (computational). The typical questions for the new stage of nuclear theory could be:

- microscopic justification and explanation of standard models (IBM, geometric models, cranking model);
- collective motion on the border of continuum, especially for nuclei far from stability;
- mechanisms of clustering in medium and heavy nuclei;
- rotation and other modes at large neutron excess;
- existence of meson fields in nuclei and their role in collective motion;
- large amplitude collective motion beyond time-dependent mean field;
- tunneling of complex objects;
- role of "incoherent" interactions, chaos and thermalization.

The presentation will discuss some of these issues from the personal viewpoint.

Neutron-proton correlations in *N*=*Z* nuclei

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The present work aims at describing the *N*=*Z* nuclei ^{96}Cd, ^{92}Pd and ^{94}Ag having their valence nucleons confined to the $1g_{9/2}$ sub-shell by means of aligned isoscalar neutron-proton pairs. A shell-model wave function analysis has been carried out for the four holes system (^{96}Cd) using different shell-model interactions and including various two-nucleon pairs. The study of the low-lying spectroscopy of the six and eight holes systems (^{92}Pd and ^{94}Ag respectively) has been performed using a mapping to the interacting boson model.

First β-Decay Study with CARIBU and Gammasphere: $^{142}Cs \rightarrow {}^{142}Ba^{*}$

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As part of the commissioning of the CARIBU facility at ATLAS, a beam of ^{142}Cs ions from CARIBU was charge bred and, subsequently, accelerated to ~ 6 MeV/A by the ATLAS superconducting linac before being transported to the target location of the Gammasphere spectrometer. For 16 hours, a beam of 10^3 ^{142}Cs ions/s was implanted in a Pb foil and γ radiation following β decay ($T_{1/2}$ = 1.68s) was detected by the 101 Compton-suppressed germanium detectors of the Gammasphere array. The power of the CARIBU-Gammasphere combination for β-decay investigations was demonstrated.

The known ^{142}Ba level scheme was considerably expanded: 215 γ–ray transitions have been identified and placed into an expanded level scheme with 71 states. Furthermore, a large number of spin-parity assignments were made based on the measured angular correlations. High-precision *log ft* values were determined as well. The data provide important new information about the nature of low-spin excitations in this nucleus. In particular, new information is obtained about the strength of octupole correlations and the nature of other low-lying excitations.

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^{230}Th at High Spin: Searching for Multi-Octupole Phonon Phenomena*

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Octupole correlations play an important role in determining the level structure of nuclei throughout the periodic chart. Microscopically, octupole correlations are the result of the long-range, octupole-octupole interaction between nucleons occupying pairs of orbitals which differ by 3 units in both orbital and total angular momentum. If the strength of the correlations is sufficient, rotational bands with alternating parity are observed, and these structures have been interpreted as resulting from the rotation of an octupole-deformed nucleus [1]. It has been known for some time that this description cannot account for all of the experimental observables. Recently, an alternative description has been proposed [2] which interprets these states as resulting from rotation-induced condensation of octupole phonons with their angular momentum aligned with the rotational axis. The occurrence of alternating parity states results when the rotations of the condensate and the quadrupole-shaped nucleus synchronize.

Experimental evidence for the phenomenon of rotational-aligned octupole-phonon condensation [2] has been observed in ^{240}Pu [3] and ^{238}U [4]. In order to study this phenomenon in ^{230}Th, a prime candidate according to Ref. [2], an "unsafe Coulex" experiment was carried out at ATLAS. The octupole band was extended up to spin 29. In addition, three positive-parity bands were observed for the first time. With increasing spin, the octupole sequence and the ground state band (gsb) start forming a smooth sequence of states with alternating spin and parity. Furthermore, the Routhian of the octupole band becomes lower than that of the gsb at rotational frequencies above 0.24 MeV. A band built on the second 0^+ state at 567 keV was discovered in this experiment. However, it decays only into the gsb, and as such does not appear to be a candidate of a double-octupole phonon band.

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Gamma-Ray Coincidence and Fast-Timing Measurements Using $LaBr_3$(Ce) Scintillator Detectors and Gammasphere*

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Gamma-ray radiation detectors that can operate at room temperature with superior energy and time resolutions are finding increased applications in basic nuclear physics research, as well as in many other fields, such as national security, medicine, radioactive waste measurements and elemental material analysis. While germanium-based detectors have the best energy resolution, they lack good timing properties, having an intrinsic time resolution of ~5 ns for 1-MeV γ rays. On the other hand, BaF_2 scintillator detectors have better time resolution, but their energy resolution is compromised. New scintillator detectors based on the $LaBr_3$(Ce) technology offer the promise to assemble practical multi-detector devices that can have good time and energy resolution, as well as large efficiency, thus making them an attractive choice for many practical applications.

We have undertaken γ-ray coincidence and fast-timing measurements using two $LaBr_3$(Ce) scintillator detectors, 1" by 1" crystals coupled to XP20D0B Photonis photomultiplier tubes. The performances of these detectors were tested by collecting singles spectra using a calibrated multi-radionuclide source that was located ~2" in front of the detectors. An energy resolution of 2.0% and efficiency of 0.007% were obtained for the 1332-keV γ ray of ^{60}Co, while at 165 keV (^{139}Ce), the efficiency was 0.1%, but the energy resolution was worse at 6%.

In addition, the $LaBr_3$(Ce) detectors have also been combined with Ge detectors in order to ascertain the advantages of using the Ge detectors with their superior energy resolution to select the γ cascade of interest and $LaBr_3$(Ce)-$LaBr_3$(Ce) and $LaBr_3$(Ce)-rf coincidences to obtain lifetimes of excited states down to ~50ps. Three measurements have been performed using (a) a ^{177m}Lu radioactive source ($T_{1/2}$=160 d) placed in the middle of Gammasphere, (b) a ^{178m}Hf source surrounded by two $LaBr_3$(Ce) detectors and a Ge Clover detector, and (c) an in-beam measurement in Gammasphere using fusion evaporation to demonstrate timing between the rf of the beam pulse and a $LaBr_3$(Ce) detector. Detailed results from these studies will be presented, including the possible implementation of an array of such detectors at the beta-decay counting station of Caribu and the Facility for Radioactive Ion Beams (FRIB), which is currently under construction.

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