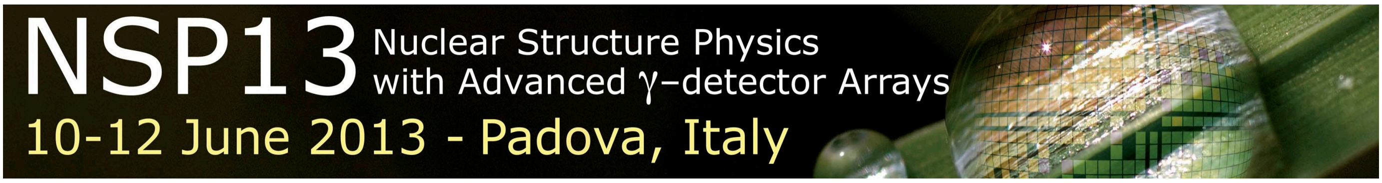

Book of abstracts

Nuclear Structure Physics

with

Advanced Gamma–Detector Arrays

NSP13

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AGATA MODULES AS COMPTON POLARIMETERS FOR THE MEASUREMENT OF GAMMA-RAY LINEAR POLARISATION

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We have investigated the ability of AGATA modules to measure the linear polarisation of gamma rays, exploiting the dependence of the Compton scattering differential cross section on the azimuthal angle. To this aim, partially polarised gamma rays have been produced by Coulomb excitation of the first excited state of ^{104}Pd and ^{108}Pd which deexcite to the ground state by emission of gamma rays of 555.8 keV and 433.9 keV, respectively. The position of the Agata array was chosen to select gamma rays at angles not far from 90 degrees to the beam direction. The azimuthal distributions, with respect to the reaction plane, of the first Compton scattering for a properly selected sample of these gamma rays have been evaluated and compared with the corresponding distribution for the unpolarised 661 keV gammas from a ^{137}Cs source. The instrumental distortions in the measured distributions appear to cancel almost exactly in the ratio R_phi of the COULEX data to those of the 661 kev gammas, and a clear signal of linear polarisation becomes apparent. The amplitude of the cos(2 phi) modulation has been compared to the theoretical linear polarisation of gamma rays from Coulomb excitation (calculated with the help of the GOSIA code) to deduce the experimental analysing power, which turns out to be about 45% in both cases.

A ``theoretical'' value of the average analysing power has been deduced from the values calculated, for each of the selected events, as a function of the Compton scattering angle, taking into account the experimental uncertainty on the coordinates of the interaction points. A satisfactory agreement between theoretical and experimental values has been found.

COLLECTIVITY IN N=Z MASS 70 NUCLEI

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There has been intense physics interest in the structure of self-conjugate medium mass nuclei in recent years [1-3]. Specific effort has been undertaken to map out the development of collectivity above mass 60, with emphasis on the influence of the deformation-driving $g_{9/2}$ orbital. A number of even-even nuclei in this area have been studied, with B(E2) values deduced for ^{64}Ge, ^{68}Se, ^{72}Kr and ^{76}Sr (see ref. [4] and references therein). However no published measurements exist for the intervening odd-odd N=Z nuclei. An experiment was thus conducted to continue the mapping of deformation in the A=70 region by measuring the lifetime of the first excited 2+ state in the odd-odd N=Z nucleus ^{70}Br.

Excited states in ^{70}Br were populated via one-nucleon-knockout at the NSCL facility at Michigan State University. De-excitation gamma rays were detected using the SeGA array, recorded in coincidence with recoils identified in the S800 spectrograph. The lifetime was deduced using the recoil distance Doppler shift technique, made possible through the use of a new differential plunger apparatus (TRIPLEX). The lifetime of the 2+ state in neighbouring ^{70}Se was also measured for comparison, due to recent controversy over the shapes of the two nuclei. Lifetimes of low-lying states in ^{70}Br, ^{70}Se and other neighbouring nuclei will be presented and discussed.

[1] A. Petrovici, J. Phys. G Nucl. Part. Phys., 37 064036 (2010)
[2] K. Kanecko *et al.,* Phys. Rev. Lett., 109 092504 (2012)
[3] M. Hasegawa *et al.*, Phys. Lett. B, 656 51-55 (2007)
[4] A. Lemasson *et al.*, Phys. Rev. C, 85 041303(R) (2012)

COLLECTIVITY IN NEUTRON-RICH CO AND MN ISOTOPES GOING TOWARDS N = 40

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In the last decade, a large experimental a theoretical effort has been devoted to the study of the sub-shell closure N=40 and the evolution of the magic number N=50 for the Ni isotopic chain. Meanwhile the N=50 ^{78}Ni excited states represent still nowadays an experimental challenge, the evolution of the sub–shell closure at N=40, when taking away protons from the Ni core, has been thoroughly studied. In fact, it has been measured that, by removing protons from the $f_{7/2}$ shell below ^{68}Ni, the N=40 subshell gap vanishes and a new region with large quadrupole deformation appears, as is the case of ^{66}Fe and ^{64}Cr [1,2]. A large theoretical effort within the shell-model framework has been done to describe this development of deformation and it has been shown that only by the inclusion of the $d_{5/2}$ neutron orbital beyond N=50 the deformation can be reproduced in this so called new island of inversion [3,4]. In this work we employed the AGATA demonstrator coupled to the PRISMA spectrometer to study the low–lying excited states in the neutron–rich Co. With one proton hole respect to Ni, Co isotopes present both collective and single–particle states [5,6]. We have also studied the excited states in neutron–rich Mn isotopes (three proton holes respect to Ni). The lifetimes of the excited states in ^{63,65}Co as well as ^{59,61}Mn have been measured employing the Recoil Distance Doppler Shift method.
The experimental B(E2) values have been compared with LSSM calculations, which lead us to draw some conclusions on the role of the $d_{5/2}$ and $g_{9/2}$ neutron orbitals in driving collectivity below ^{68}Ni.

[1] W. Rother *et al.*, Phys. Rev. Lett. 106, 22502 (2011)
[2] A. Gade *et al.*, Phys .Rev. C81, 051304 (2010)
[3] E. Caurier *et al.*, Eur. Phys. Jour. A. 15, 145 (2002)
[4] S. Lenzi *et al.*, Phys. Rev. C82, 54301 (2010)
[5] A. Dijon *et al.*, Phys. Rev. C83, 64321 (2011)
[6] D. Pauwels *et al.*, Phys. Rev. C79, 44309 (2009)

COLLECTIVITY OF THE 4+ STATE IN ^{70}ZN STUDIED VIA COULOMB EXCITATION

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Shell evolution in the vicinity of ^{68}Ni has recently attracted many theoretical and experimental investigations. By now it has been clearly established that the presumed subshell closure at N=40 is not very pronounced. While the intruder character of the $1g_{9/2}$ and $2d_{5/2}$ neutron orbital induces collectivity by pair excitations from the *fp* shell into the $g_{9/2}$ orbital, the parity change hinders quadrupole excitations and therefore mimics the properties of a doubly magic nucleus in ^{68}Ni, i.e., a high 2_1+ energy and a low B(E2; 2+ → 0+) value. Adding valence nucleons to the N=40 open shell leads to a rapid increase of collectivity, with an interplay of both collective and single–particle degrees of freedom. Such rapid changes indicate underlying complex effects and make this region ideal for testing theoretical calculations.
While measurements of B(E2; 2+ → 0+) values are useful to investigate the evolution of collectivity along isotopic chains, even more insight into the collective behavior can be gained by measuring lifetimes of higher-lying states. Almost all stable and neutron-rich Zn isotopes present an anomalously low B(E2; 4+ → 2+)/ B(E2; 2+ → 0+) ratio of 1 or less, which is normally observed only around closed shells. A strong increase of collectivity of the 4+ state was observed for ^{70}Zn [2] and could not be explained in the framework of nuclear structure models. A recent lifetime measurement [2] yielded a considerably longer lifetime of this state, yet its accuracy was not sufficient to draw firm conclusions. Given the complex scheme of low-lying states in ^{70}Zn including many nearly degenerate transitions, Coulomb excitation seemed a more appropriate method to study this nucleus. A dedicated Coulomb excitation measurement has been recently performed at the Heavy Ion Laboratory, University of Warsaw, to measure B(E2; 4+ → 2+) in ^{70}Zn. For this study, the EAGLE array coupled to a compact setup of 48 PIN–diodes was used. The preliminary result will be presented.

[1] D. Muecher *et al.*, PRC 79 (2009) 054310
[2] C. Louchart *et al.*, PRC, accepted for publication.

CONFIGURATIONS AND DECAY HINDRANCES OF HIGH–K STATES IN ^{180}HF

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Nuclei in the A=180 region are characterized by quite favorable conditions for the realization of K isomers. These include rigid, axially symmetric deformed shapes, and the presence of both proton and neutron orbitals near the Fermi surface with large projections of the intrinsic angular momentum along the symmetry axis. K isomers constitute a very effective spectroscopic means of investigating both intrinsic and collective excitation modes. While K–isomeric decays offer insight into the degree of conservation of the K quantum number, high–K rotational bands yield information about the properties of the underlying core.
Multi–quasiparticle high–K states are observed in ^{180}Hf through excitation with a 1.4 GeV ^{207}Pb beam obtained from the ATLAS accelerator at Argonne National Laboratory, incident on an enriched, 250 mg/cm^2 ^{180}Hf target. Both prompt and delayed gamma rays were detected using the Gammasphere array, and several new high–K structures identified, in addition to the K isomers already established from previous work [1]. Lifetimes of isomeric states in the nanosecond–microsecond range are measured using centroid-shift and decay measurements within the microsecond coincidence time window. Configurations for the high–K states involve two, four and six quasiparticles, with states up to K=22 established. High–K states are found to be progressively more favored with increasing excitation energy. The K quantum number is quite robust up to the highest observed spins as evidenced by large values of reduced hindrance for isomeric decays. Rotational bands built on several high–K states are identified, and the measured branching ratios in these structures have allowed assignment of underlying configurations. Multi–quasiparticle calculations using the Lipkin–Nogami approach for pairing, with blocking included, reproduce the observed high–K energies quite well.

[1] R. D'Alarcao *et al.,* Phys. Rev. C 59, R1227 (1999).

COULOMB EXCITATION OF RE–ACCELERATED ^{208,210}RN AND ^{206}PO AT MINIBALL

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In regions near magic nuclei, seniority can be regarded as a good quantum number. In the trans–Pb nuclei near the Z=82 and N=126 shell closures, relative high–j single–particle proton orbitals dominate the structure and thus levels up to I=2j–1 could, in principle, be understood within the seniority scheme. In N=122, N=124 and especially in the closed shell N=126 isotones with Z≥82, behaviour of the B(E2) values resembling the seniority scheme predictions has been observed. These nuclei lie in, or at the boundary of the region where seniority scheme could persist. However, contributions from collective excitations can not be ignored when moving away from the N=126 closed shell. To date, surprisingly little is know of the transition probabilities between the low–spin states in this region.
In the present study, B(E2;0+ → 2+) values have been measured in ^{208,210}Rn and ^{206}Po nuclei through Coulomb excitation of re–accelerated radioactive beams in inverse kinematics. The radioactive beams were produced at ISOLDE by bombarding a UCx primary target with 1.4 GeV protons. The mass separated radioactive beams were re–accelerated with the REX–ISOLDE linear accelerator to 2.8 MeV/u and delivered to the target position of the MINIBALL γ–ray spectrometer, which recorded γ rays following Coulomb excitation. The resulting B(E2;0+ → 2+) values in ^{208,210}Rn and ^{206}Po are presented and discussed in terms of systematics and relevant nuclear models. The present study provides new insight into the interplay between collective excitations and single–particle regime near N=126.

DECAY SPECTROSCOPY OF EXOTIC NUCLEI AT RIBF

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Decay spectroscopy is expected to provide a great chance to look inside the structure information of nuclei far from the stability. A new project EURICA (EUROBALL RIKEN Cluster Array) has been launched to perform experimental campaign of decay spectroscopy, utilizing gamma–rays detectors (EUROBALL Germanium Cluster detectors) and new generation radioactive beam facility (RIBF) at RIKEN[1,2].
A first EURICA campaign with U–beam was conducted in 2012 December to study isomeric and beta–delayed gamma–spectroscopy of very neutron–rich nuclei around doubly–magic nuclei ^{78}Ni and ^{128}Pd region. Highly segmented double–sided silicon–strip detectors (WAS3ABi)[3], located in the center of EURICA, was employed as an active stopper of produced isotopes transferred from the BigRIPS and ZeroDegree spectrometer. In this paper, we will report our preliminary results obtained by the EURICA spectrometer and future perspective of decay spectroscopy at RIBF.

[1] H.J.Wollersheim et al., Nucl. Instrum. Meth. A 537, 637 (2005).
[2] S.Nishimura, Nucl. Phys. News Vol. 22, 39 (2012); P.–A. Soderstorm *et al.*, submitted to Nucl. Instrum. Meth. B (EMIS Conference).
[3] S.Nishimura, submitted to RIKEN Accel. Prog. Report.

DEFORMED HARTREE–FOCK AND ANGULAR MOMENTUM PROJECTION THEORY FOR NUCLEAR SPECTROSCOPY

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The use of Deformed Hartree–Fock and Angular Momentum Projection theory for studying the structure and high–spin spectroscopy of nuclei will be discussed. Using multi–shell model spaces and effective interactions some results will be presented about K–isomers, rotation–aligned bands, super–deformed bands, excited deformed bands in spherical nuclei (spectra and electromagnetic transitions) [1,2].
The usefulness of the model as a theoretical tool for nuclear structure will be emphasised.

[1] Zashmir Naik and C.R. Praharaj, Phy. Rev. C67, 054318 (2003).
[2] C.R. Praharaj and S.K. Ghorui, ICFN5 (2012).

DIFFERENTIAL PLUNGER LIFETIME MEASUREMENTS OF PROTON–UNBOUND NUCLEAR STATES (DPUNS)

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A new differential–plunger device, DPUNS, has been commissioned to measure the lifetimes of excited states beyond the proton drip line. DPUNS has been coupled to the Jurogam II and RITU spectrometers at the University of Jyvaskyla using proton tagging and to isolate the weakly populated nuclei of interest. Recoil Distance Doppler Shift measurements have been employed to measure the lifetimes of exited nuclear states in these exotic nuclei. So far, our new experiments have measuring the lifetimes and extracting deformations for states in the near–spherical proton emitters, ^{109}I and ^{151}Lu. However, even for these somewhat easier to understand near–spherical proton emitters, the theoretical situation is somewhat complex. Current calculations based on the CD–Bonn potential tend to underestimate the spectroscopic factors and overestimate the B(E2) reduced transition probabilities for the unbound states in ^{109}I, whereas, the opposite situation is found in ^{151}Lu. As part of this work, our collaboration is developing a non–adiabatic model which has the ability to self–consistently calculate energy levels, electromagnetic transition rates and proton decay tunneling rates within a common theoretical framework. Prior to this work, theoretical tunneling calculations have relied on deformations which were inferred from the alignment properties of the states built upon the proton decaying state. With these new lifetime measurements, the extracted deformations should be more reliable.
In summary, this talk will review the new experimental and theoretical knowledge obtained from our measurements in this region of exotic nuclear states and will close with a discussion of potential future experiments and additional knowledge that can be gained from a study of deformed proton emitters.

ELECTROMAGNETIC AND WEAK INTERACTION DECAYS OF NUCLEI FAR FROM STABILITY

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According to our previous studies of electromagnetic and weak–interaction decays in unstable nuclei within the framework of the Interacting Boson–Fermion Model of nuclear structure, a suitable extension of the model is introduced, including collective and single–particle degrees of freedom, in order to describe the related processes in isotopes far from the beta–stability valley and near the neutron and proton drip lines.
Analytic formulae are carried out in the limiting symmetries of the model which provide useful insight into the structure properties of exotic nuclei and possible indication of existence of mixed–symmetry states strongly excited in Gamow–Teller beta decays.
Moreover, the Interacting boson Model, IBM, in its simplest version is applied to the study the structural properties of exotic nuclei far from equilibrium, mainly produced through heavy–ion collisions in many advanced facilities, in order to verify the validity of the model and its prediction capability for isotopes and configurations different from the usual ones along the beta–valley stability, namely in the region of heavy and superheavy nuclei. To this aim, one has to estimate the effective boson numbers and then use them to calculate the E2 transition strengths connecting ground–state, beta and gamma roto–vibrational bands for both actinides and superheavy elements in the frame of IBM. From comparison between the estimated theoretical B(E2) intensities and the available experimental data for the actinide nuclei, a remarkable agreement in the SU(3) dynamical limit of IBM is obtained and useful predictions for the B(E2) values in the superheavy region for possible comparisons with available as well as future measurements in the existing or future facilities.

ELECTROMAGNETIC NATURE OF THE NUCLEAR INTERACTION

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Bieler, a Rutherford student, imagined in 1924 a magnetic attraction equilibrating an electrostatic repulsion between the protons. Here the roles of magnetic and electrostatic interactions are switched round. In this approach there is no hypothetical kinetic energy thus no mysterious strong force. Since the discovery of the neutron and the magnetic moments of the nucleons, nobody, as far as I know, has tried to apply electromagnetism to the nuclear interaction. As it is well known, there is an attraction between an electric charge and a neutral conductor. In the deuteron, the positive charge of the neutron is repelled and the negative charge is attracted by the proton with a net attraction. The repulsion between the magnetic moments equilibrates the electrostatically induced attraction. The calculated value is –1.6 MeV not too far from the experimental value –2.2 MeV) proving that the usual assumption of the too feeble electromagnetic interaction is incorrect. All the H and He isotopes have been calculated with approximation errors between 4 and 30 %. The calculated seven hydrogen and eight helium isotopes stay satisfactorily along their corresponding experimental curves. The electromagnetic theory predicts the order of magnitude of the ratio between nuclear and chemical energies: $m_p/m_e/\alpha$=137 x 1836 = 251,000.

EVIDENCE OF SUBSHELL GAP AT N=72 IN NEUTRON–RICH NUCLEI

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The search and study of new regions of shell closure for nuclei away from stability is a topic of current interest in nuclear structure physics. A recent experiment indicates that the predicted [1] spherical N=70 subshell gap does not have a substantial effect at N=68 for Zr isotopes [2]. It is of interest to know the precise location and magnitude of the subshell gap, if any, in the neutron–rich region.
Systematic studies from measurements of nuclear masses have provided vital indications of shell closures. New magic numbers for nuclei near the neutron drip line can be identified by surveying neutron separation energies and interaction cross sections. In the present work, the neutron number dependence of experimental one–neutron separation energies (Sn) [3], and excitation energies of the first excited state are reported. Nuclei with odd N even Z and odd N odd Z for fixed neutron excess, in the region N=55–75 have been investigated. It is found that there is a small change in the slope of neutron separation energies at N=72 with increase in neutron number. Moreover, systematic calculations using the Nilsson–Strutinsky approach, of excitation energies of the first excited state E(2+) for a chain of even–even Sr and Zr isotopes exhibit a marked increase at N=72 probably due to lower deformation of these nuclei. The E(4+)/E(2+) values show a pronounced dip at N=72. These are in accordance with the change in slope at N=72 in the corresponding experimental mean–square charge radii. All of the above are consistent with a subshell gap at N=72, rather than at N=70 in neutron rich nuclei.

[1] M. Bender *et al.,* Phys. Rev. C 80, 064302 (2009).
[2] T. Sumikama *et al.,* Phys. Rev. Lett. 106, 202501 (2011).
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EVOLUTION OF COLLECTIVITY IN THE VICINITY OF PB–208

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A systematic experimental program has been started to derive the evolution of quadrupole collectivity near the heaviest stable doubly–magic nucleus Pb–208. Here, B(E2;0+ → 2+)–values are being measured via relativistic Coulomb excitation. Despite the fact that the energy, E(2+), and strengths, B(E2;0+ → 2+), of the first 2+ state in even-even nuclei is one of the key quantities in nuclear structure physics, surprisingly little is known about the latter in the direct neighbourhood of the heaviest stable doubly–magic nucleus Pb–208.

In October 2012 an experiment was conducted within the PRESPEC–AGATA campaign at the UNILAC–SIS accelerator complex at the GSI Helmholtzcentre for Heavy–Ion Research in Darmstadt, Germany. Following the fragmentation of a 1 AGeV Pb–208 primary beam, heavy Pb, Hg, and Pt secondary beams were prepared by the GSI Fragment Separator and focused onto a gold target foil. Gamma rays were measured by AGATA and HECTOR, and the outgoing ions were discriminated by the LYCCA detector system.

Results from the ongoing data analysis will be presented and compared to contemporary nuclear structure model calculations.

EXOTIC ROTATIONS AND SENIORITY ISOMERS IN ND NUCLEI

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The existence of triaxial nuclei has been the subject of a long standing debate. The possibility of soft and rigid triaxiality has been proposed very early, and many theoretical and experimental studies have been devoted to this intriguing phenomenon since then. More recently two unique fingerprints of triaxiality in nuclei have been intensively studied: the wobbling motion [1] and the dynamic chirality [2]. These exotic types of motion were observed in specific regions of the nuclear chart: the wobbling motion in the odd–even Lu nuclei with A _ 160 [3], the chirality primarily in the odd–odd and odd–even nuclei with A _ 130 nuclei [4, 5]. We have recently studied the Nd nuclei up to very high spins and identified several bands, which were interpreted as the manifestation of various types of collective motion: tilted axis rotation, principal axis rotation along the short and long axes, wobbling motion, chiral bands [6].
Another phenomenon revealed by our recent results on the Nd nuclei with neutron numbers just below the N=82 shell closure, is the shape coexistence. It is induced by the existence of some high–spin seniority isomers which are built on a spherical shape and are surrounded by triaxial bands. The shape coexistence phenomenon is well described by Cranked Nilsson Strutinsky calculations. All these types of excitation and their interpretation will be discussed and exemplified with recent results obtained on Nd nuclei.

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EXOTIC STRUCTURE AND DECAY OF MEDIUM MASS NUCLEI NEAR THE DRIP LINES WITHIN BEYOND–MEAN–FIELD APPROACH

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The interest for the investigation of medium mass nuclei near the drip lines goes beyond the frontier of nuclear structure and dynamics.
Detailed knowledge of the properties and decay rates of nuclei near the drip lines are required by the simulation of many astrophysical objects.
The structure and dynamics of proton-rich A~70 nuclei and neutron–rich A~100 nuclei are influenced by shape coexistence effects. A realistic description of shape coexistence phenomena requires beyond–mean–field approaches.
A self–consistent description of exotic structure and beta–decay of proton–rich A~70 nuclei as well as neutron–rich A~100 nuclei within the complex Excited Vampir variational approach using realistic effective interactions in large model spaces will be presented.

FROM GASP TO ROSPHERE: GAMMA–RAY SPECTROSCOPY AT NIPNE–BUCHAREST

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First, a brief overview of some outstanding results obtained with GASP within the Italian–Romanian collaboration will be given. Then, recent developments for gamma–ray spectroscopy at the Tandem Laboratory in Bucharest are presented. The ROSPHERE (ROmanian array for SPectroscopy in Heavy ion REactions) array, now in use at this laboratory, is a 'sphere' with 25 detector positions. HPGe of ~50% relative efficiency, with anti-Compton shields, can be used in these positions, for 'classical' gamma–ray spectroscopy experiments, like gamma–gamma coincidences and DSAM and plunger lifetime determinations. Until now, however, the most successful use of this setup was that as a mixed array, with both HPGe detectors and LaBr3:Ce scintillator detectors. The fast timing properties and relatively good energy resolution of the lanthanum bromide detectors allowed the extension of the fast timing method for nuclear lifetime determinations to in–beam experiments with fusion–evaporation, incomplete fusion and fragmentation reactions with alpha particle and various heavy ion beams. Lifetimes of nuclear excited states can be measured in the domain from several tens of ps to ns, a range that only partially overlaps with that of other methods and usually highlights interesting nuclear structure effects. Some physics cases will illustrate the performances of this array.

GAMMA RAY SPECTROSCOPY AT AN EXTERNAL NEUTRON BEAM OF THE INSTITUT LAUE LANGEVIN

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Gamma ray spectroscopy at external neutron beams offers unique possibilities for nuclear structure studies. The present talk summarises the recent efforts within the EXILL campaign, in which a highly efficient HPGe detector cluster was put around the intense cold neutron beam Pf1b at the Institut Laue Langevin (ILL). The setup consisted of clover detectors from the EXOGAM array, coaxial detectors from the GASP array and clover detectors from the ILL. All detectors were mounted with AntiCompton shields at a close distance to a sample to allow prompt spectroscopy studies. Data were taken with a trigger free digital acquisition system. The campaign included several detailed (n,gamma) studies and spectroscopy of fission products populated in neutron induced fission of ^{235}U and ^{241}Pu. Lifetime measurements with the fast timing technique using 16 $LaBr_3$:Ce scintillators in combination with 8 clover detectors were also done. A comparison of first results to experimental data obtained from in–pile (n,gamma) experiments and from measurements with spontaneous fission sources will be presented. Finally an outlook of further developments for multi detector setups at neutron beams will be given. Here the concept of the ILL project FIPPS will be introduced, a combination of a fission fragment mass spectrometer with HPGe–detector clusters.

GAMMA SPECTROSCOPY AS A TOOL TO SEARCH FOR PARTICLE–PHONON COUPLED STATES: STATUS AND PERSPECTIVES

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The coupling between a particle and a phonon is a very important issue in nuclear structure studies, being a key process at the origin of the anharmonicities of vibrational spectra, quenching of spectroscopic factors and damping mechanism of giant resonances. The experimental and theoretical investigation of this problem is presented in connection with gamma spectroscopy works on neutron–rich nuclei around ^{48}Ca and ^{64}Ni. Results are reported from experiments performed at Legnaro National Laboratory, NIPNE (Bucharest) and ILL (Grenoble), using complex detection systems such as PRISMA-CLARA, ROSPHERE and EXOGAM. It is shown the feasibility of complete in–beam gamma spectroscopy, in terms of angular distributions, polarization and lifetime analysis, allowing to firmly establish spin and parity of excited states and their nature. The focus is, in particular, on ^{47}Ca, ^{49}Ca and ^{65}Cu nuclei, which provide evidence for particle–phonon coupled states based on the 3– octupole phonons of the ^{48}Ca and ^{64}Ni cores, respectively. They are among the few fully established examples of particle–vibration coupling in nuclei with mass A<100, showing the robustness of nuclear collectivity in rather light systems. Perspectives will also be given in connection with similar type of studies around the ^{132}Sn core, of great interest for future experiments with radioactive beams.

GAMMA SPECTROSCOPY IN THE FERMIUM REGION AT SHIP

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Besides the synthesis of new superheavy elements detailed nuclear structure investigations are an important tool helping to reveal information on the location and strength of the next spherical proton and neutron shells above the ^{208}Pb (Z=82, N=126). Of specific interest are well prolate deformed nuclei beyond the deformed neutron shell N=152 and Z=100 (fermium) where levels relevant for an expected shell gap at Z=114 come close to the Fermi level.
Recent developments of alpha, gamma and conversion electron (CE) spectroscopy techniques opened the door to investigate the structure of heaviest nuclei (A>250). The results of those experiments provide crucial information on the structure of these nuclei and are stringent tests for nuclear models.
At the velocity filter SHIP at GSI Darmstadt we performed an extensive program aimed at nuclear structure studies of trans–fermium isotopes using CE–gamma and alpha-gamma spectroscopy. Besides single particle isomers we observed or investigated in details several K isomers having high spins and excitation energies [1–4].
In this contribution the main results from these measurements will be presented and discussed, in particular those from the gamma–spectroscopy measurements of ^{253}No and ^{253}Md [4]. The contribution will aim also at possibilities and limits of the used detector setup. An example is the gamma–decay spectroscopy of heavier nuclei at the focal plane of the separator, for example K isomers in rutherfordium isotopes, which would require the use of larger germanium arrays.

GAMMA–RAY SPECTROSCOPY AT GANIL

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The EXOGAM array is a high efficiency germanium-array installed at GANIL since 2001. It is heavily used to study the structure of exotic nuclei produced in heavy–ion induced reactions. Most of the time, the array is coupled to other ancillary detectors, and in particular to the VAMOS large acceptance spectrometer. Another key setup is the combination of EXOGAM, the Neutron Wall – a large array of liquid scintillator to measure neutrons – and DIAMANT, a light–charged particle CsI multidetector.
In this talk some examples of studies of neutron–rich nuclei around ^{68}Ni performed with VAMOS will be shown. This includes some lifetime measurements as well as the combined prompt and delayed gamma–ray spectroscopy of nuclei produced in deep–inelastic reactions. The coupling of EXOGAM with the Neutron wall and DIAMANT is designed to study neutron deficient nuclei. This has been done in the region below ^{100}Sn, for N~Z nuclei located close to the proton line. The results obtained for the self–conjugate N=Z=46, ^{92}Pd seem to underline the role of the isoscalar T=0 neutron–proton pairing in the profound modification of the low–lying level scheme. As a by–product, a full characterization of EXOGAM as a Compton polarimeter has been performed and the structure of ^{91}Ru has been studied in great details.

GAMMA–RAY SPECTROSCOPY AT TRIUMF–ISAC: RECENT RESULTS, PERSPECTIVES AND FUTURE OPPORTUNITIES

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Versatile Germanium–detector array is essential to exploit the unique scientific opportunities at TRIUMF Isotope Separator and ACcelerator (ISAC). The TIGRESS array and its associated auxiliary detectors has been designed for reaction studies with accelerated ion beams. The 8π spectrometer and its powerful suite of ancillary detectors is optimized for a wide program of research in the fields of nuclear structure, nuclear astrophysics and fundamental symmetries with low–energy radioactive beams. Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei (GRIFFIN) will replace 8π spectrometer and take advantage of its auxiliary detectors. Recent results of experiments with TIGRESS and 8π will be presented.

GAMMA–RAY SPECTROSCOPY WITH GRETINA AT NSCL

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In early summer 2012, the Gamma–Ray Energy TRAcking In–beam Nuclear Array GRETINA was installed in front of the S800 Magnetic Spectrograph for in–flight gamma–ray spectroscopy campaign with fast beams of rare isotopes. In this type of experiments rare–isotopes beams provided by the Coupled Cyclotron Facility of the National Superconducting Cyclotron Laboratory (NSLC) are delivered onto a reaction target placed at the center of GRETINA. Reaction residues are detected in the spectrograph in coincidence with gamma rays in GRETINA. The high spatial resolution of GRETINA allows to perform accurate Doppler–shift reconstruction of the gamma–ray energies emitted by the reaction residues moving at velocities typically exceeding 30% of the speed of light. GRETINA's tracking capability enables to acquire gamma-ray data of high spectral quality. More than 20 experiments have been performed covering topics in nuclear structure and nuclear astrophysics. This presentation will summarize the performance of GRETINA in this powerful configuration for fast beam spectroscopy and give an overview on the physics program accomplished in this campaign.

GAMMA–RAY SPECTROSCOPY WITH LARGE VOLUME SCINTILLATOR DETECTORS

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In the last 10 years a large number of new high light–yield scintillator crystals have been discovered. The most famous among them are $LaBr_3$:Ce crystals. Even though large volume $LaBr_3$:Ce detectors are available since only 2008–2009 some newly arrays with large volume crystals are already in operation as for example HECTOR+ which consists of ten 9 x 20 cm $LaBr_3$:Ce detectors and eight 14.5 x 17.5 BaF2 detectors. The arrays has been coupled to the AGATA demonstrator in both the LNL campaign with stable beams and in the GSI PRESPEC campaign with radioactive beams.
The properties of large volume cylindrical 3.5" x 8" $LaBr_3$:Ce scintillation detectors cannot be easily derived from those of small and medium sized detectors. In fact, self absorption, possible crystal in–homogeneities (both of which are more likely to appear with scaled up dimensions), plus the much longer mean free path of the scintillation light towards the photo–cathode and photo–multiplier tube (PMT) non–idealities, can all variously affect the detector performance. Therefore the properties of these large volume detectors in terms of signal lineshape, linearity, energy and time resolution will be discussed.
In addition the very preliminary results concerning the analysis of the data in the GARFIELD–LNL, AGATA–LNL and PRESPEC–GSI campaign, where large volume scintillator detectors, had been used will be presented. In particular the topics of Isospin Mixing, Pygmy Dipole Resonance, Dynamical Dipole and low lying collective states will be discussed

GRETINA: STATUS AND FUTURE PLANS

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The gamma ray tracking array GRETINA started operation at MSU in spring 2012. It was installed at the target position of the S800 spectrometer at NSCL. Currently it has 7 modules each with four 36–fold segmented Ge detector, covering 1–pi solid angle in the angular range of 60 to 90 degrees. The tracking detectors have the unique ability of resolving the energy and position of the individual interaction points and establishing the gamma–ray scattering sequence. GRETINA with S800 is a powerful combination for fast radioactive beam experiments at NSCL; their high position resolution is crucial for Doppler correction to achieve good energy resolution; their higher efficiency overcomes the low intensity of exotic beams and extends the range of study to more neutron–rich and proton–rich nuclei; and gamma ray tracking reduces background and improves spectral quality. More than 20 experiments have been approved by the PAC and will be completed by July of 2013. We will report on selected results from the campaign of GRETINA at the MSU and discuss the future plans.

HIGH–SPIN YRAST ISOMERS IN ^{204}HG

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This work reports the observation of high–spin states in ^{204}Hg using time–correlated γ–ray spectroscopy to identify isomers populated in deep–inelastic collisions of a ~1.4 GeV ^{208}Pb beam on a thick 238U target. A high–spin isomer with τ>1 μs has been found and the observed γ–ray decay has established the yrast states below it, including another isomer with τ=33(3) ns.
Spin and parity assignments were based on conversion coefficients deduced from intensity balance and on the observed γ–decay patterns.
The experimental results are compared with shell model calculations that include four holes in the entire configuration space between ^{132}Sn and ^{208}Pb.
Observed agreement with the calculation gave the supplementary arguments to the spin–parity assignments and clarified configurations of experimental states.
The τ>1 μs isomer is suggested to be the $\pi h^{-2}_{11/2}\nu^{-2}_{13/2}$, 22+ states that results from the coupling to maximum spin available for the four valence holes. Few prompt transitions feeding the isomer were also observed.

HIGH SPIN SPECTROSCOPY OF NUCLEI AROUND Z=82

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The spectroscopic studies of near spherical nuclei with few valance nucleons below or above the shell closure offer a good scope to observe a rich variety of single particle excitations, especially those which involve the nucleons residing in the strongly shape driving proton and neutron intruder orbitals. The interplay between the collective and single particle motions of the nucleons gives rise to band structures based on multi–quasiparticle configurations. Particularly, the nuclei around Z=82 Pb region are known to show rich variety of structural phenomena and are of topic of research interests for both experimental and theoretical work for long time. The heavy Tl and Bi isotopes in mass region190–200 are interesting cases to study the various nuclear deformations as a function of angular momentum due to the interaction between the core and the single particle or hole. It is also important to identify the single particle intruder configuration and the band structures built on it. The presence of high–j unique parity orbitals results into the occurrence of yrast isomers in the level scheme of these nuclei. The $h_{9/2}$ proton intruder orbital from above Z=82 is available for both prolate and oblate deformation in case of Tl isotopes and a rotational band has been systematically found to be built on a low lying 9/2– isomeric state for odd–A Tl isotopes. High spin level structure and role of intruder orbitals in some of the Bi and Tl nuclei in the above mass region have been experimentally investigated using the Indian National Gamma Array (INGA) of Clover Ge detectors. Multi–quasiparticle bands including a magnetic rotational band have been proposed for ^{194}Tl. The high spin structures of heavier Tl isotopes have been significantly extended. A rotational band based on a 13/2+ bandhead has been proposed in ^{195}Bi, indicating an onset of deformation at N=112 in Bi isotopic chain. The detail experimental results will be presented.

IN–BEAM GAMMA–RAY SPECTROSCOPY AT THE RIBF

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In the Radioactive Isotope Beam Factory (RIBF) stable primary beams of energies up to 345 MeV/nucleon are used to produce radioactive isotope beams via in–flight separation with the BigRIPS fragment separator. For in–beam gamma-ray spectroscopy experiments these radioactive beams are incident on a secondary target for Coulomb excitation, inelastic scattering, or knockout reaction measurements. While ejectiles are measured with the ZeroDegree spectrometer, gamma rays are detected by the NaI(Tl) scintillator based DALI2 array. The first in–beam gamma–ray experiments performed at the RIBF targeted the "Island of Inversion", a region in which the standard ordering of shells is disturbed by neutron intruder configuration across the N=20 shell gap. Recent experiments include the first spectroscopy of ^{54}Ca, the regions around the doubly–magic ^{78}Ni and ^{100,132}Sn nuclei, as well as investigations on the N=28 shell closure erosion around ^{42}Si.
Besides showing (preliminary) selected results from these first experiments and a description of the gamma–ray spectroscopy setup, an outlook on future gamma–ray spectroscopy campaigns at the RIBF including the active liquid hydrogen target MINOS will be given.

IN-VIVO RANGE MEASUREMENT OF THERAPEUTIC PROTONS FROM PROMPT GAMMA EMISSION

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Proton beam therapy is emerging as a major radiation therapy modality for cancer patients due to the improved dose distribution of protons, which allows for increased dose to the tumor while sparing surrounding healthy tissues. This work addresses the problem of range uncertainty through the development of a detector, which will measure proton range in each patient during beam delivery with millimeter accuracy, effectively eliminating proton range uncertainty. During proton interactions with atoms in tissues, gamma rays, including prompt photons from nuclear reactions and delayed photons from the decay of unstable products, are emitted. The rate of secondary radiation used in the measurement is low, making accurate measurement challenging. We have used the MCNPX simulation package to model a detector consisting of 35 Cesium Iodide crystals with dimensions of 9x9.9x0.4 cm and a lead based collimator grid with 0.4cm thick plates. A Gaussian proton pencil beam impinged on a cylindrical water phantom with a diameter of 10 cm. The distance between the cylinder axis and the collimator surface was approximately 20 cm. We simulated the response of the detector to several mono–energetic pencil beams delivering protons in the energy range 80MeV–160MeV. A sigmoid curve fit to the spatial distribution of the simulated gamma emission data was used in order to locate an edge in gamma emission pattern that is correlated with the position of the Bragg peak. These simulations of a prompt gamma detector for in–vivo range measurement for therapeutic proton beam scanning suggest that range measurement for individual pencil beams (spots) may be feasible. Further work will address the optimization of the detector geometry and placement, as well as advanced detector design.

INVESTIGATION OF EXOTIC NUCLEI WITH ABSOLUTE TRANSITION PROBABILITIES

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Nuclei far from the valley of stability are of current interest in nuclear structure physics. Especially, big effort has been devoted to investigate the evolution of collectivity of nuclei with large isospin.
In order to gain experimental data related to this topic reactions with radioactive beams or deep inelastic reactions have been successfully used. With both types of reactions absolute transition probabilities can be determined using the plunger technique. Dedicated plunger devices have been designed to accommodate the specific issues imposed by these reaction types. In this presentation the following examples will be presented: 1. Reaction with radioactive beams at intermediate energies (≈100 MeV/u). The experiments were performed at the NSCL/MSU. Low lying yrast states in $^{58,60,62}Cr$ isotopes were populated in 1p–knockout reactions using high purity $^{59,61,63}Mn$–beams at E ~ 95 MeV/u which were produced by fragmentation of a ^{82}Se beam at 140 MeV/u on a Be target. The $^{59,61,63}Mn$–beams were separated from other fragments by the A1900 separator. The reaction products of of the secondary knockout reaction were identified by the S800 spectrograph and the gamma–spectra were measured by the Segmented Germanium Array (SeGA). The measured transition probabilities will be compared to shell model calculations as well as to neighboring Fe nuclei close to the sub–shell closure at N=40. 2. As an example of a lifetime measurement using deep inelastic reactions at grazing angles an experiment on $^{84,86}Se$ will be presented. The experiment was performed at the LN Legnaro using the PRISMA–AGATA setup with a plunger device especially constructed for such experiments. First preliminary results will be discussed.

INVESTIGATION OF HIGH–SPIN STATES NEAR N=50 SHELL CLOSURE IN SEARCH FOR EMERGENCE OF COLLECTIVITY USING INGA

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The excited states of nuclei near closed shell at high angular momentum states have attracted lot of attention in theoretical and experimental research. They provide suitable laboratory for testing the interactions of shell model states, possible presence of high spin isomers and help in understanding the emergence of collectivity as the higher orbitals are occupied. An experimental program has been pursued with INGA coupled with a digital data acquisition system to look for emergence of collectivity at high spin in nuclei near shell closure [1]. The Indian National Gamma Detector Array (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. In the present work, we will discuss the initial results from the spectroscopic study of the high spin states of the ^{89}Zr and ^{90}Nb. High spin states in these nuclei were investigated using ^{13}C + ^{80}Se and ^{28}Si + ^{65}Cu reactions. The excited levels have been observed up to 12 MeV excitation energy and spin ~ 49/2 hbar in Zr [2]. The DCO and polarization measurements were carried out to assign the spin and parity of different states. The measured results will be compared with the shell model calculations. In addition, a regular dipole band has been observed which is extended up to 49/2 hbar. Results of Cranking model and deformed Hartree–Fock model calculations agree well with the measured level energies and transition strengths, indicating the emergence of collectivity at high spin in ^{89}Zr. Future plan to couple a highly segmented charged particle array to INGA for such investigations will be discussed.

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ISOSPIN SYMMETRY VIOLATION IN SD SHELL NUCLEI

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The influence of isospin nonconservation is important for testing the fundamental symmetries underlying the Standard Model, e.g., corrections to superallowed 0+ → 0+ –decay rates [Towner and Hardy (2010)], and is pivotal for computing theoretical amplitudes for nucleon transfer reaction which violates isospin selection rule [Blank and Borge (2008)]. Recently, we have constructed a realistic isospin-nonconserving (INC) shell–model Hamiltonian in *sd* shell. The INC Hamiltonian consists of an isospin–conserving Hamiltonian, i.e. either USD [Brown and Wildenthal (1988)], or USDA, or USDB interactions [Richter and Brown (2008)], a Coulomb interaction, and a phenomenological charge–dependent forces of nuclear origin. All charge–dependent strengths were determined by a least–squares fit to reproduce newly compiled experimental coefficients of the isobaric multiplet mass equation (IMME) [Y.H.L. et al. (2013)] with very low root–mean–square deviation values ~33 keV [Y.H.L. et al. (2013)]. This INC Hamiltonian provides an accurate theoretical description of the isospin mixing in nuclear states.

We present two of the important applications: (a) the microscopic description of staggering behavior of IMME isovector and isotensor coefficients; and (b) the breaking of the quadratic IMME in A=24,28,32 quintets. Overall, this new INC Hamiltonian shows its robustness in providing an accurate theoretical description of the isospin mixing in nuclear states of sd shell nuclei.

LIFETIME MEASUREMENTS BY DOPPLER METHODS WITH THE ROSPHERE ARRAY

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The Doppler techniques (DSAM – Doppler Shift Attenuation Method and RDDS Recoil Distance Doppler Shift) are widely used gamma–ray spectroscopy techniques aimed at measuring the lifetime of excited nuclear states by using the Doppler shift of the de–exciting gamma–ray transition as a stopwatch. The RoSphere setup installed at the Bucharest TANDEM was used for lifetime measurements by the DSAM method in heavy ions and alpha induced reactions and by the RDDS method, in connection with a plunger device build following the Cologne design. Combined with in–beam fast timing technique, the lifetime experiments yielded a quasi–complete study of ^{120}Te, part of a wider experimental campaign aimed at studying the collective behaviour in light Tellurium isotopes. The specific details of the methods and reaction mechanisms will be discussed and results will be presented.

MEDIUM–MASS NUCLEI FROM CHIRAL EFFECTIVE FIELD THEORY INTERACTIONS

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As ab–initio calculations of atomic nuclei enter the A=20–100 mass range, one of the biggest challenges is to provide accurate predictions for the vast majority of open–shell (degenerate) isotopes. I discuss recent developments of ab–initio nuclear structure theory for medium–mass nuclei, with focus on extensions to open–shell systems and inclusion of three–body forces. I then present the latest results of Gorkov–Green's function method, including the first applications with two– and three–body forces from chiral effective field theory in several isotopic chains around oxygen and calcium.

MIRROR DISPLACEMENT ENERGIES AND NEUTRON SKINS

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Mirror displacement energies and neutron skins A gross estimate of the neutron skin [0.80(5) (N–Z)/A fm] is extracted from experimental proton radii, represented by a four parameter fit, and observed mirror displacement energies (CDE). The calculation of the latter relies on an accurately derived Coulomb energy and smooth averages of the charge symmetry breaking potentials constrained to state of the art values. The only free parameter is the neutron skin itself. The Nolen Schiffer anomaly is reduced to small deviations (rms=127 keV) that exhibit a secular trend. It is argued that with state of the art shell model calculations the anomaly should disappear. Highly accurate fits to proton radii emerge as a fringe benefit.

MIRROR ENERGY DIFFERENCES AND THE J=2 ANOMALY

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The study of differences in excitation energy between analogue states in isobaric multiplets allows to verify the validity of isospin symmetry and independence as a function of the angular momentum. These differences are of the order of tens of keV and can be well reproduced by state–of–the–art shell model calculations. Several nuclear structure properties can be deduced from these data, such as the alignment of nucleons along rotational bands, the evolution of the nuclear radius and the identification of pure single particle excitations across two main shells. In addition, the isospin breaking of the nuclear interaction is suggested by the systematic comparison with data. The different ingredients that enter the calculation of the Coulomb energy differences between mirror nuclei are discussed in comparison with the experimental data of nuclei in the $f_{7/2}$ and in the *sd* shell.

NEDA: NEUTRON DETECTOR ARRAY FOR SPECTROSCOPY STUDIES

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Future studies of exotic nuclei will mainly be performed by using reactions induced by radioactive as well as high-intensity stable heavy ions. The need for efficient neutron detection is not only required in heavy–ion fusion–evaporation reactions close to the proton dripline, but also as ”veto” detectors for suppression of reaction channels with high neutron multiplicity in studies of neutron–rich nuclei.
The new NEutron Detector Array (NEDA) is a collaborative European effort to construct a modern neutron detector array for experiments with stable and radioactive ion beams. The project benefits from the long–standing experience developed with the realization and use of the Neutron Wall, a highly efficient medium granularity neutron detector array used in combination with the EUROBALL spectrometer and later with EXOGAM. The new device will be versatile and optimized for the operation with stable beams and second generation radioactive ion–beam facilities (SPES, SPIRAL2, FAIR, etc.). NEDA will be composed of 355 detectors, covering a solid angle of about 2pi and will be used as an ancillary detector of AGATA, GALILEO, EXOGAM2 and PARIS. Digital electronics with pulse-shape discrimination capabilities will be used. NEDA will allow the selection of neutron channels in nuclear reactions, providing multiplicity and energy information. It will be realized in different stages, the first one being an upgraded version of the Neutron Wall.
A large effort has been devoted, so far, to the validation of the simulations and test of the future prototypes of NEDA. New detector materials as well as traditional ones have been investigated and characterized, in particular, deuterated liquid scintillators as BC537 and the conventional BC501A. Pulse shape discrimination algorithms have been investigated for both liquid scintillators. A design study of the NEDA array geometry is being performed in order to optimize the granularity, the solid angle coverage in conjunction with the future gamma–ray arrays. In this presentation, the physics domain of NEDA as well as the status of the R of the NEDA detector array will be discussed.

NORMAL AND INTRUDER CONFIGURATIONS IN NEUTRON–RICH CO ISOTOPES: COMPETITION BETWEEN SPHERICAL AND DEFORMED SHAPES

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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 both the developments of a diffuse neutron surface that could fade the spin–orbit interaction as well as 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 $\_1f_{7/2}$ – $\_1f_{5/2}$ 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 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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NUCLEAR SHAPE EVOLUTION THROUGH LIFETIME MEASUREMENT IN NEUTRON RICH NUCLEI

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A new interest for exotic nuclei further away from the valley of stability arises due to the possibility to use refined experimental methods. In particular, the neutron rich side of the valley still offers a lot of interesting features to be discovered. Our recent experiments on nuclei around A=100 aim at discovering part of these features trough lifetime measurements and will help understanding nuclear shape evolution in neutron rich nuclei. In this mass region, shapes are changing rapidly, which is reflected in the theoretical calculations by the prediction of occurrence of prolate, oblate, or triaxial shapes. These predictions vary as a function of the theoretical model used, thus experimental measurements will have important implications.

The neutron–rich isotopes were produced trough a fusion–fission reaction performed at GANIL in inverse kinematics with a ^{238}U beam. The aim of this experiment was to extend information on the evolution of the collectivity in this mass region by measuring the lifetimes of excited states in more neutron–rich nuclei and up to higher spins. A and Z identification of the fission fragments was performed with the VAMOS spectrometer, while the EXOGAM spectrometer was used for the γ–ray detection. The RDDS (Recoil Distance Doppler Shift) method has been applied to extract the lifetime of excited states. To our knowledge this is the first experimental attempt to perform a RDDS experiment on fission fragments, which are identified in A and Z on an event–by–event basis. Results on the complex analysis performed to achieve the identification of the fission fragments up to Z=54 and A=150 and on the new lifetime values will be presented.

A complementary experiment has been performed recently at ILL to measure lifetimes of excited states in the same range of nuclei but populated with a neutron induced reaction on a Pu target. Lifetimes have been measured via the fast-timing method using $LaBr_3$ detectors and the EXOGAM array, which will extend the range of measurable lifetimes to ns. This will give information either on the deformation or on the role of the triaxiality in these nuclei.

NUCLEAR STRUCTURE STUDIES OF HEAVY NUCLEI

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The investigation of the structure and stability of the heaviest elements has been a constant theme in nuclear physics research since the 1940's. In the last decade or so, a wealth of new data has been produced, both in terms of new elements (up to Z=118) and in detailed spectroscopic studies of nuclei with masses above 240. Such studies provide data concerning nuclear parameters such as masses, decay modes, half–lives, moments of inertia, single–particle properties, etc., in systems with the highest possible number of protons. The main focus of current experiments is the search for the next closed proton– and neutron– shells beyond the doubly magic ^{208}Pb. This search can be made directly, by producing nuclei in the region of interest (Z>112 and N>176), or indirectly through the study of lighter deformed nuclei where the orbitals of interest at sphericity are active at the Fermi surface.
Nuclei in the region of ^{254}No are produced with cross–sections large enough to allow in–beam studies using recoil–decay tagging techniques. Advances in digital electronics and data acquisition have led to the observational limit in this region being pushed down to the level of ten nanobarns, as demonstrated by recent studies of ^{246}Fm and ^{256}Rf. In addition, the capabilities of focal plane spectrometer devices have been greatly improved, which has recently allowed the structure of a number of high–K isomeric states to be determined in a systematic manner. New instruments such as the recently commissioned SAGE combined conversion–electron and gamma–ray spectrometer provide additional information such as conversion coefficients to aid determination of transition multipolarities.
Examples of recent highlights in in–beam studies of heavy elements will be presented.

ON THE ELUSIVE LINKS BETWEEN HIGH–K AND LOW–K STATES IN ^{176}LU AND ^{180}TA

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Nature's heaviest naturally occurring odd–odd isotopes, ^{176}Lu and ^{180}Ta have a pair of high and low–K levels at low energies formed by parallel or anti–parallel coupling of the unpaired proton and neutron to give a total projection, K=|Omega p ± Omega n |. One consequence of this is the formation of a long–lived 9– state in ^{180}Ta, the only naturally occurring nuclear isomer, with a lifetime of t_m>1 x 10^{16} years, 77 keV above the Kpi=1+ short–lived ground state. The opposite situation occurs in ^{176}Lu: it exhibits a long–lived Kpi=7– ground state and a 1– short-lived isomer at 123 keV. Both nuclei present issues for nucleosynthesis; ^{180m}Ta in terms of its abundance, creation, and survival in stellar environments; ^{176}Lu because, while definitely s–process (a possible s–process chronometer or thermometer), it could be destroyed through neutron capture to the short–lived beta–decaying state. Furthermore, photon excitation via intermediate–K states, passing from the 1– isomeric level to the ground state, or the equivalent transition in the opposite direction, could either increase or decrease its abundance, and that of ^{176}Hf. (See Refs. [1,2], for example.)
The presentation will cover some recent results [3,4] from gamma–ray spectroscopy that bear on these issues, partly in the context of the relationship between the strong resonances observed in laboratory photo–activation (see, for example, Ref. [5]) and the nuclear structure problem of associating these resonances and their properties with specific excited states.

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PROMPT GAMMA–RAY SPECTROSCOPY OF N=50 FISSION FRAGMENTS

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Studies in the region around ^{78}Ni are essential to test the interactions used in shell–model calculations to see if any new physics manifests itself far from stability. It's necessary to investigate the structure of nuclei in the A=80–90 regions via prompt gamma–ray spectroscopy, following the proton induced fission of thick ^{238}U target, using the Jurogam II array located in Jyvaskyla in Finland. The aim of this part of experiment is to investigate particle–particle nuclei outside the presumed doubly magic nucleus ^{78}Ni, to see if can be used as an inert core and to gain information on single–particle energies which are poorly known. The new results obtained in three nuclei located around the N=50 gap shell: ^{84}Se, ^{83}As and ^{88}Br will be reported. To assign spin and parity values, a systematic study of N=50 isotones and shell–model calculations have been performed. Some interactions are in agreement with experimental results for yrast states at low spin. At higher energy particle–hole core excitations appear and these are outside the valence space used. Thus, more sophisticated interactions are required.

SIMULATING THE POSITION SENSITIVITY OF THE SEGMENTED ITHEMBA LABS HPGE DETECTOR

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The iThemba LABS detector is made up of four end–closed coaxial, front tapered, electrically segmented n–type germanium crystals, packed closely together in one cryostat. The dimensions of each crystal are: 60 mm width before shaping and 90 mm long. The cathode of each crystal is electrically segmented into 8 contacts with depth segmentation at 35 mm, implying that the back segments are 55 mm long. This results in a total of 36 electronic channels of which 32 are associated with the outer contacts and 4 with the inner core contacts of the detector. The inner core contacts provide high resolution measurements of gamma–ray energy deposition for each crystal whilst the outer contacts provide information about the locations of the gamma–ray interaction inside the detector.

The position sensitivity of this segmented iThemba LABS HPGe detector is investigated through simulation using the Multi-Geometry Simulation code. This code simulates the electric potential, electric field, drift velocity, weighting potential and generate the expected pulse shape from an arbitrary gamma-ray interaction's position within the germanium detector volume. When the charge sensitive pre–amplifier response for the segmented iThemba LABS HPGe detector is convoluted with the total current produced by the MGS, the resulting charge pulse is effectively slowed and smoothed. Using this code, the pulse shape response at the inner and outer contacts has been generated changing the radius, angle and depth of gamma–ray interaction positions within the germanium detector volume. Changes in the pulse shapes reflecting changes in the position of the interaction point were observed. This confirms that the detector is sensitive to the exact position of the gamma–ray interaction. The details about the simulated position sensitivity of the segmented iThemba LABS HPGe detector will be discussed.

STRUCTURE AND ROTATIONAL STATES IN 168HF NUCLEUS

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The structure of neutron–deficient ^{168}Hf nucleus is studied in the framework of deformed Hartree–Fock formalism using surface delta interaction [1] for protons and neutrons in the $sdg_{7/2}h_{11/2}$ space (protons) and $fph_{9/2}i_{13/2}$ space (neutrons). The ground band, RAL band due to rotation–alignment of $i_{13/2}$ neutrons and the interaction of these two bands along with the excited large K bands are investigated. The B(E2) and B(M1) values are given and compared with the available experimental data. Predictions of some high spin bands are made.

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STRUCTURE OF EXOTIC NUCLEI THROUGH NUCLEAR MOMENT AND TRANSITION PROBABILITY STUDIES

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The studies of exotic nuclei have revealed some new phenomena including modifications of the shell structure or appearance of regions of rapid onset of deformation. The nuclear moments and transition probabilities are among the observables that could shed light both on the single–particle and collective nuclear properties. Therefore they could prove of key importance in regions where interplay between spherical and deformed features is considered.
The neutron–rich A~100 region has attracted important experimental and theoretical interest for several decades. One of the most sudden onset of deformation throughout the nuclear chart is observed at N=60 for a number of isotopic chains lighter than Molybdenum. The south border of this region has been roughly established few decades ago but more detailed studies for the microscopic origin of the deformation have become possible only recently with the advances of radioactive ion beams techniques. Coulomb excitation studies of the odd–mass Rubidium isotopes, 93–99Rb, have been performed at REX–ISOLDE using the Miniball setup. The low–energy structure in those isotopes, and their transition probabilities obtained, show distinctively different feature for the quasi spherical nuclei (^{93,95}Rb) below and the well–deformed ones (^{97,99}Rb) above N=60. These results establish ^{97}Rb as the corner stone of the region of deformation allowing for a clear identification of the orbitals on which it is built.
Obtaining high precision g–factor information on short-lived picosecond states is a non–trivial task. The experimental techniques usually applied, as e.g. TF or RIV, require calibration measurements on known states. This can be overcome performing time–dependent studies using charge states for which the hyperfine field can be calculated from first principles. The g(2+) of ^{24}Mg has been measured at ALTO, Orsay using the Orsay Universal Plunger System (OUPS) in combination with the ORGAM array. Time Dependent Recoil In Vacuum technique on H–like charge states has been applied for the first time in “radioactive beam geometry”. The preliminary results, showing the power of this method and demonstrating its applicability for precise moment studies of picosecond states, will be presented.

STUDY OF HIGHLY–EXCITED STATES IN ^{140}CE VIA INELASTIC SCATTERING OF ^{17}O

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Giant Resonances are collective modes of excitation of atomic nuclei, providing useful information on nuclear structure and on the effective nucleon–nucleon interaction. It is possible to excite such resonances with different probes as for example: photons, charged particles or heavy ions, followed by subsequent decays by emission of particles and γ's. Below particle threshold, a large fraction of highly excited states has been found to be of a dipole nature and it has been associated to the Pygmy Dipole Resonance, caused by the oscillation of the neutron skin against the inert proton–neutron core.

Main aim of this study is a deeper understanding of the nuclear structure properties of the Pygmy Dipole structures in ^{140}Ce, excited via inelastic scattering of a ^{17}O ion beam. Comparison with previous results for this nucleus, investigated in (γ,γ') and (α,α') experiments, will be helpful for drawing final conclusions.

The experiment was performed at Laboratori Nazionali di Legnaro, Italy. Inelastic scattering of ^{17}O projectiles at 20 MeV/A was used to excite the resonance modes in the ^{140}Ce target (2.5 mg/cm^2 thick). Gamma rays were registered by 5 AGATA triple clusters and 8 large volume scintillators ($LaBr_3$), useful for high γ–energy. The detectors were mounted at a distance of about 20 cm from the target position,

resulting in a full absorption efficiency of about 0.8% at 10 MeV. The scattered ^{17}O ions were identified by two ΔE–E Si telescopes of the TRACE array mounted inside the scattering chamber at 9° (which is the grazing angle for the reaction) with respect to the beam axis. The telescopes consisted of 2 segmented Si–pad detectors, each made of 60 pixels (with a pixel size of 4x4 mm2) covering an active area of 20x50 mm2. The resulting solid angle for the Si telescope was about 100 msr.
During the talk, issues concerning complex data analysis will be discussed and preliminary results of the experiment will be presented.

STUDY OF NUCLEON TRANSFER AND KNOCKOUT REACTIONS WITH HIGH–RESOLUTION GAMMA–RAY SPECTROSCOPY

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Nucleon-transfer reactions like (d,p) or (t,p) have been a well–established tool to investigate the single–particle properties of nuclei for many decades. Applied to exotic nuclei they have to be performed in inverse kinematics and, in many cases, combined with gamma–ray spectroscopy.
The region around the ``island of inversion'' where the traditional shell closure at N=20 disappears has been studied at REX–ISOLDE (CERN)[1,2] with the MINIBALL array consisting of 24 six–fold segmented HPGe detectors [3] and the particle detector T–REX [4]. Similar investigations have been performed around ^{68}Ni evaluating a local shell closure at N=40 [5].
For more energetic beams nucleon–knockout reactions are a similar tool. A possible new magic number at N=32 or 34 beyond ^{48}Ca has been addressed at GSI by studying neutron–rich Ti and Sc isotopes [6,7]. The combination of the FRS with MINIBALL allowed for the measurement of exclusive momentum distributions. Nucleon–knockout reactions are also a sensitive method to populate different configurations in the final nucleus by varying the primary beam. This has been exploited recently to study neutron–rich Mg and Na isotopes at NSCL employing the GRETINA array for gamma–ray detection [8].
We will present the status of the research programs as well as discuss the perspectives for future experiments at HIE–ISOLDE (CERN) and with R3B at FAIR.
This work is supported by the German BMBF (grants No. 06DA9036I, 05P12RDCIA, and 05P12RDFN8), HIC for FAIR, EU through EURONS (No. 506065) and ENSAR (No. 262010) and the MINIBALL and REX-ISOLDE collaborations.

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STUDY OF SHAPE TRANSITIONS IN THE NEUTRON–RICH OS ISOTOPES

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The nuclei with A~190 between Hf and Pt exhibit a great variety of nuclear phenomena, including K–isomerism, triaxiality and shape transition across the isotopic chain. This region has been in fact a crucial testing ground for the nuclear models aspiring at the description of such complex nuclear phenomena. Of particular interest is the transition from axially symmetric deformed, prolate (gamma = 0 deg.) to oblate (gamma = 60 deg.) shapes in the neutron–rich Os isotopic chain. While a study by Wheldon *et al.* [1] of the neutron–rich ^{194}Os nucleus populated via deep–inelastic reactions suggests a prolate shape for its yrast states, Podolyak *et al.* [2] proposed an oblate shape for the ground state of ^{198}Os by comparing the excitation energies of the first and second 2+ states. The ground state of ^{196}Os, the even–even isotope lying between the two previously mention ones, is predicted to be prolate, oblate or gamma–soft by different state–of–the–art nuclear models. This region of the Segrè chart is very difficult to study experimentally, only fragmentation and multi–nucleon–transfer reactions can be used to populate neutron–rich nuclei in this region, hence the knowledge for this nucleus is limited to two excited states without any known gamma transition [3]. To further elucidate this shape transition, the key nucleus ^{196}Os was investigated in–beam using the AGATA demonstrator and the large acceptance heavy ion spectrometer PRISMA at LNL, Italy. A two nucleon transfer from a ^{198}Pt target to a stable ^{82}Se beam was utilised to populate medium–high spin states of ^{196}Os. The ongoing data analysis for AGATA and PRISMA spectrometer will be discussed together with the latest results for ^{196}Os.

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THE 49/2+ ISOMER IN ^{147}GD – STUDY OF THE MOST COMPLEX ISOMERIC DECAY

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The LINAC–ALPI accelerator at LNL and the GASP array were used to perform gamma spectroscopy experiment aimed at two separate goals. The first one was to test the possibility to observe the Coulomb excitation of ^{147}Gd states located above the 49/2 isomer in a secondary scattering of reaction products in the ^{208}Pb catcher. The second goal was to clarify the gamma branching in the earlier studied isomeric decay. The ^{76}Ge + 290 MeV ^{76}Ge fusion evaporation reaction produced abundantly the ^{147}Gd high–spin isomeric state and the collected gamma coincidence data were analysed taking into account both aims of the experiment.

A brief summary of the analysis concerning the Coulomb excitation test will be followed by an extended presentation of results obtained in the study of the ^{147}Gd isomer decay. The gamma coincidence analysis revealed in this decay more than 300 gamma transitions with intensities down to about 10^{-4} per decay level. All of them were safely placed in the level scheme, which in some parts had to be substantially modified compared to previous results [1,2]. A nearly perfect intensity balance observed at all populated levels indicated the completeness of the presently established decay scheme and fully confirmed the earlier anticipated complexity of the gamma branching. The intensity balance allowed to extract total electron conversion coefficients for many low energy transitions which uniquely characterized their multipolarity. Together with the earlier measured angular distribution coefficients [1,2] and electron conversion results [2], spin and parity values could be unambiguously assigned to nearly all of the populated levels. The 49/2+ assignment [2] of the isomer was confirmed and assignments of all populated levels revealed the decay paths through yrast and many non–yrast states.

The studied decay presents the most complex isomeric decay known today in the whole chart of nuclides.

1. R. Broda *et al.*, Z.Phys.A305, 281 (1982)
2. O. Bakander *et al.,* Nucl.Phys.A389, 93 (1982)

THE AGATA CAMPAIGN AT GANIL

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The GANIL facility, Caen (France), will host the European AGATA germanium array from 2014 to 2015. AGATA will be coupled to the VAMOS spectrometer and/or other available ancillary detectors using the high intense stable heavy ions beam delivered by the GANIL cyclotron and the radioactive beam delivered by the SPIRAL1 facility. At GANIL, the AGATA spectrometer can be couple with a large number of detector making the setup very versatile. In this presentation a review of the future campaign will be presented.

THE CONTINUOUS–ANGLE DOPPLER-SHIFT ATTENUATION METHOD – SUB–PICOSECOND LIFETIME MEASUREMENTS WITH POSITION–SENSITIVE HPGE DETECTOR ARRAYS

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The Doppler–shift attenuation method (DSAM) is a well–established technique for the determination of sub–picosecond nuclear level lifetimes. It is based on analyzing the characteristic shape of Doppler–broadened photo–peaks from nuclear transitions observed at specific observation angles in in–flight γ–ray spectroscopy experiments, when the de–excitation of a nuclear level occurs while the emitting nucleus is being decelerated in a thick target.
We have extended the method in order to exploit the possibilities arising from state–of–the–art position sensitive HPGe detector arrays by analyzing the Doppler–broadened peaks not only as a function of the Doppler–shifted γ–ray energy, but also as a continuous function of the polar angle of γ–ray detection with respect to the incident beam direction. This approach significantly boosts the sensitivity and applicability of the method. The corresponding two–dimensional fit algorithm in the energy – polar detection angle (Eγ, θγ) space is also applicable to conventional HPGe detector arrays without intrinsic position–sensitivity. We have furthermore extended this new technique to experiments with relativistic ion beams, where we analyze Doppler–corrected, two–dimensional γ–ray spectra in the (Eγ, θγ) space without stopping the beam ions in the target. This is especially useful for experiments with radioactive and/or cocktail beams, because it avoids the accumulation of radioactivity at the target position and makes ion identification behind the reaction target possible. With this "differential" DSAM technique, a second sensitivity region for level lifetimes in the range of 100ns arises from geometric effects.

THE N=20–28 AND N=40 ISLANDS OF INVERSION: THE PHYSICS PICTURE.

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The physics underlying the appearance of the so called "islands of inversion" will be described in the framework of large scale shell model calculations, with special emphasis in the structure and correlation energies of the intruder states. Evidences will be presented suggesting the merging of the N=20 and N=28 islands in the Magnesium isotopes.

THE PRESPEC–AGATA IN–BEAM SPECTROSCOPY CAMPAIGN AT GSI

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The goal of the PRESPEC–AGATA project is to investigate the structure of exotic nuclei by performing in–beam gamma–spectroscopy experiments employing the SIS–FRS accelerator complex at GSI. The experimental set–up currently includes 19 AGATA high–resolution tracking gamma detectors providing about 10% full energy efficiency at 1 MeV. A set of advanced heavy ion detectors is used identification and tracking of exotic nuclei selected and transported through the fragment separator FRS. An active target and the heavy ion calorimeter and ToF detector LYCCA–1 complete the arrangement. The set–up constitutes the first full implementation of the HISPEC experiment for NUSTAR at the future FAIR facility.
After successful commissioning, a first series of relativistic Coulomb excitation and secondary fragmentation experiments were performed in Autumn 2012. They dealt with the determination of B(E2) values in neutron–rich unstable Pb, Hg and Pt isotopes, fine structure of the pygmy resonance in ^{64}Fe, Coulomb excitation of yrast–trap states in ^{52}Fe and life times in neutron–rich Zr and Mo nuclei. First results show an unrivaled sensitivity of the set–up, surpassing the predecessor experiment RISING by at least one order of magnitude, offering unique access to the structure of exotic nuclei.

THE STRANGE CASE OF 210HG: AN UNEXPECTED STRUCTURE

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The neutron–rich lead and mercury region has been so far scarcely explored due to its high mass and neutron excess, which force the use of fragmentation reactions with relativistic beams. 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. Many neutron–rich isotopes were identified for the first time and a significant number of new isomers were hence discovered, enabling us to study the structure of these isotopes. The new exotic isotopes bserved 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 $^{212–216}$Pb, in ^{217}Bi, in ^{211,213}Tl and in ^{210}Hg. The isomers in $^{212–216}$Pb correspond to the expected seniority scheme, with an 8+ isomer from neutrons coupling in the $g_{9/2}$ shell. Considering that the same isomers was observed in ^{208}Hg, one would expect the two–proton hole Hg isotopes to follow the same scheme. On the contrary, the observed isomeric states in ^{210}Hg correspond to the expected seniority scheme and to an unexpectedly low–lying state, indicating a sudden change in nuclear structure with respect to ^{208}Hg. A similar situation happens in ^{211,213}Tl isotopes with respect to the standard seniority isomer observed in ^{209}Tl. Therefore, the experimental data seem to suggest a modification of the expected nuclear structure in this scarcely–explored region of the nuclide chart. Several possibilities will be discussed, considering the systematics of electromagnetic transition rates and the predictions of shell model with realistic interactions.

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