

ISOLDE Workshop and Users meeting 2011

Monday, 5 December 2011 - Wednesday, 7 December 2011

CERN

Book of Abstracts

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Welcome

Medium Mass Nuclei I / 44

ISOLTRAP masses for nuclear structure and the r process

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Precision Penning-trap mass measurements carried out in the heavy-mass region are very suitable to investigate mainly topics related to the rapid-neutron-capture process and nuclear structure. Higher-order nucleon interactions caused by small changes in the binding energy, which are expected to be small compared to the total mass, yet very localized. In conjunction with the mass measurements on Xe and Rn, the masses of the Fr isotopic chain provide accurate mass values over the entire region of the prediction of the octupole component from the finite-range drop model and help to investigate the conditions associated with octupole shapes.

The heavy-mass region is also of interest due to the process of fission that can allow the r-process to recycle. Mass measurements are important as input data for modeling and for adjusting the parameters of different mass models. The r process can take different paths corresponding to astrophysical conditions that respect the waiting-point validity approximation. Now, the adjacent isotope chains of Fr produced five new masses which can be used to add beta-decay energies which are important for the evaluation of beta-decay half-lives that greatly influence the r-process. In addition, the successful determination of the mass as well as the half-life of ^{82}Zn with ISOLTRAP is valuable input for the r-process waiting point ^{80}Zn .

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Coulomb Excitation of Isomeric states of ^{70}Cu

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Extensive studies on Cu neutron-rich isotopes have been performed in recent years at REX-ISOLDE in the aim to investigate the nuclear structure in the vicinity of the $N=40$ sub-shell closure. In particular the study of odd-odd $^{68,70}\text{Cu}$ nuclei was reported in [1] where for the first time low-energy Coulomb excitation measurements with isomeric radioactive post-accelerated beams were performed. For the case of ^{70}Cu , a $\pi\pi = 6-$ isomeric beam was used to study the multiplet of states (3-, 4-, 5-, 6-) arising from the $\pi 2p_{3/2}^2 \nu 1g_{9/2}$ configuration. The isomeric nature of the 6- and 3- states was experimentally determined in previous work [2]. The beam was produced at ISOLDE, CERN by selective laser ionization technique and then post-accelerated by REX-ISOLDE to about 2.8 MeV/nucleon. Gamma rays were detected with the MINIBALL high resolution Ge detector array. The 4-state of the multiplet was populated by Coulomb excitation and the reduced transition probability $B(E2, 6-\rightarrow 4-)$ value was determined. The remaining member of the multiplet, the 5- state, was not observed in this experiment.

To provide complementary information about the energy levels and reduced transition probabilities of the connecting transitions within the states of the multiplet, a new experiment was performed using a $\pi\pi = 3-$ isomeric beam. Besides the known transition deexciting the 4- state [1], gamma

rays of 511 keV were observed for the first time and were unambiguously associated to the 5- state deexcitation. This observation fixes the energy, spin and parity of this state, completing the low-energy level scheme of ^{70}Cu . Moreover $B(E2)$ values for all the possible E2 transitions within the multiplet are now precisely measured. A comparison with large-scale shell model calculations using different interactions and model spaces, shows the importance of proton excitation across $Z=28$ shell gap and the role of the $d_{5/2}$ neutron orbital.

[1] I. Stefanescu et al. PRL98, 122701 (2007)

[2] J. Van Roosbroek et al. PRC69, 034313 (2004)

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Beta-decay studies of neutron-rich Mn isotopes

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The neutron-rich Mn-decay studies are of particular interest due to the recently observed rapid onset of deformation just below the 'semi-magic' ^{68}Ni ($Z=28, N=40$), in the Co, Fe and Cr isotopes. Large-scale shell-model calculations are on the verge of explaining quantitatively the observed nuclear structure, but the experimental benchmarks in this region are still limited. The beta-decay study of neutron-rich manganese isotopes around $N=40$ presents a wealth of new and systematic nuclear-structure information in the iron, cobalt, and even the nickel isotopes for critical assessments of the state-of-the-art effective interactions.

In October 2009, Mn-decay data were successfully acquired for the masses $A=58,60-68$, which were produced in a proton-induced fission of ^{238}U and selected using RILIS and mass separation in HRS. The Mn ions were implanted on a moveable tape system surrounded by three thin plastic Delta-E beta detectors and two MINIBALL clusters for gamma detection. The detector signals were processed by digital electronics.

Thanks to the selectivity of the laser ionization and the combination with previous work at the Leuven Isotope Separator On-Line setup on Fe and Co decay, beta-decay feeding patterns and spin assignments could be obtained. We will present results for the decay chains of $^{63,65,66,67,68}\text{Mn}$. New spin assignments are made changing the interpretation of previous data and, for the $A=66$ mass chain, comparisons with shell-model calculations will be presented.

Medium Mass Nuclei I / 25**Nuclear structure studies of the neutron-rich Rubidium isotopes using Coulomb excitation****Author:** Christophe Sotty¹**Co-author:** Georgi Georgiev²¹ CSNSM Centre de Spectrometrie Nucleaire et de Spectrometrie de² CSNSM**Corresponding Author:** christophe.olivier.sotty@cern.ch

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The neutron-rich $A=100$ mass region has recently attracted a high interest of the nuclear structure studies. In this area of the nuclear chart one can observe the most sudden transition from spherical to well deformed shapes. This occurs by adding just few neutrons for the Zr ($Z=40$) and Sr ($Z=38$) isotopes across $N=60$. Some works claim as well that this phase transition allows the presence of a shape coexistence at $N\sim 60$.

The onset of deformation at $N = 60$ is clearly observed between the Zr and Rb isotopes from the two-neutron separation energies from mass measurements. However, a recent study of the Kr isotopes at ISOLTRAP [1] showed no deformation observed for the ground states of Kr's. This has been confirmed as well in a Coulomb excitation measurement [2]. The interplay between down-sloping and up-sloping neutron orbitals [3, 4, 3] is evoked as one of the main reasons for the sudden change at $N = 60$. The question stays which are the active proton orbitals and what is their contribution to the structure of the region. The Coulomb excitation study which we report here aimed at identifying these orbitals in the neutron-rich Rb's - the last isotopic chain showing the onset of deformation. An additional interest towards $^{93,95,97,99}\text{Rb}$ comes from astrophysical aspect. According to some of the scenarios the r-process path might go through those exact nuclei.

The nuclei of interest were produced at ISOLDE, CERN using an UCx target. $^{93,95,97,99}\text{Rb}$ were post-accelerated up to 2.83 MeV/u using REX-ISOLDE and Coulomb excited on a secondary target ($^{60}\text{Ni}, ^{120}\text{Sn}, ^{196}\text{Pt}$) positioned in the center of the Miniball array used for particle and gamma-ray detection.

A number of excited states in ^{93}Rb were previously known from beta-decay and isomeric studies [5]. The results from the present measurement allowed for a firm spin and parity assignments of those states and for determining their transition probabilities. The observed gamma-ray spectrum for ^{95}Rb strongly resembles the one of ^{93}Rb . This should allow obtaining very similar information on the structure of those assumed spherical nuclei. On contrary the Coulomb excitation spectrum of ^{97}Rb shows completely different characteristics with a higher number low-energy transition being populated. The gamma-gamma coincidences allowed building a level scheme that indicate the presence of rotational-band like structure in this deformed nucleus. The present status of the analysis

will be discussed and the obtained level schemes and transition probabilities would be compared with theoretical calculations.

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Laser spectroscopy of neutron deficient gallium isotopes.

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Laser spectroscopy has been performed on isotopes of gallium at ISOLDE using the gas-filled linear Paul trap ISCOOL. Ground state nuclear spin values, magnetic dipole moments, electric quadrupole moments and mean-square charge radii have been extracted for isotope masses in the range $A=63$ to 74 . The experiment was performed to determine the potential development of a proton skin in the neutron deficient Ga isotopes. The ground state spin of ^{63}Ga was measured and the change in charge radius from ^{71}Ga was extracted. This talk will present the results from the neutron deficient Ga isotopes and present charge radii measurements across the gallium isotope chain from $A=63$ to 82 .

Medium Mass Nuclei I / 36

A first determination of the beta-neutrino angular correlation at the WITCH experiment

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Low energy precision experiments for the search of exotic components in the weak interaction are complementary to the high energy experiments at the colliders dedicated to discover new particles. In the case of the WITCH experiment the beta neutrino angular correlation after nuclear beta decay is studied. A deviation from the distribution as predicted by the standard model will reveal the exotic interactions.

For the study of the weak interaction WITCH combines a Penning trap arrangement to provide a scattering free source of beta-decaying nuclides with a MAC-E filter setup to analyze the recoil energy distribution. This year in June the first coarse recoil energy spectrum could be obtained, which allowed a first extraction of the beta neutrino angular correlation coefficient with statistical uncertainty of 50%. With further developments and longer experiment time it is expected to push the statistical uncertainty in the October run below 1% during the October run.

In this talk the results for the beta neutrino angular correlation a of the WITCH campaigns are presented and discussed.

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Experiments with stored highly-charged ions at ISOLDE: TSR@HIE-ISOLDE proposal

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Stored in heavy-ion storage rings, secondary beams enable a wide range of nuclear physics experiments. Such experiments profit, e.g., from high resolving power and excellent quality of cooled beams, from high revolution frequencies, which allows to “recycle” exotic nuclei, from ultra-high vacuum conditions, which allows to preserve high atomic charge states, from low background conditions, etc. These are some of the reasons, that a variety of novel ideas has been proposed in the recent years in addition to the well-established scientific programs on in-ring mass and half-life measurements.

However, many suggested experiments require stored, highly-charged exotic nuclei at relatively low energies of a few MeV/u. Therefore, it is of interest to explore the possibility of installing a storage ring at an ISOL facility, which naturally delivers low-emittance low-energy beams. To be more specific, we propose to store HIE-ISOLDE beams in a storage ring, where we would like to perform

precision experiments. In this contribution we will present the proposal, outline the physics cases and give the present status of the project.

HIE-ISOLDE / 4

HIE-ISOLDE: Status Report of the Project and Highlights

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The HIE-ISOLDE project is a major upgrade of the existing ISOLDE radioactive ion-beam facility at CERN. The present energy of 3MeV/u for post-accelerated radionuclides will be boosted to up to 10 MeV/u which will allow experiments to address all exotic nuclides produced at ISOLDE using, e.g., Coulomb excitation and nucleon transfer reactions. A R&D program on the superconducting linear accelerator is ongoing, including cavity manufacturing with prototype and sputtering tests. Besides the energy upgrade, the beam quality has already been improved and the beam intensity will be increased in the future with the upgrade of the CERN injector chain. An overview of the HIE-ISOLDE project and the present status is given.

HIE-ISOLDE / 30

HIE-ISOLDE SRF development activities at CERN

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The HIE-ISOLDE project has initiated a new development phase on the SRF domain at CERN. In particular, the HIE-ISOLDE project aims at the construction of the 32 Quarter Wave Resonators (QWRs) using the Nb on Cu sputtering technology. We describe the refurbishment of the test infrastructure and the activities from the cavity production to the cold test, including quality assurance procedure for the correct handling of the resonators.

HIE-ISOLDE / 9

HIE-ISOLDE Beam Characteristics and HEBT Layout

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The expected beam characteristics will be presented for each stage of the HIE linac upgrade at 5.5 MeV/u, 10 MeV/u and for decelerated beams at 0.45 MeV/u, along with the layout for the HEBT line.

HIE-ISOLDE / 19

Beam Instrumentation for the HIE-REX linac

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In the framework of the High Intensity and Energy (HIE)-ISOLDE project, a beam instrumentation R&D program is on-going for the superconducting upgrade of the REX linac (HIE-REX). An overview of the main beam diagnostics developments is presented, focusing on the challenging specifications required by the superconducting linac. The project includes intensity and transverse profile monitors to be implemented in the very narrow space available between the foreseen cryomodules. A longitudinal profile monitor to be placed downstream the linac will provide energy and timing beam distributions and will allow for a fast phase-tuning of the foreseen 32 superconducting cavities.

Solid State and Bio Physics I / 46

Advanced functional oxides

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Ionic and electronic transport in functional oxide materials is of great relevance for applications in the field of energy and data storage, e.g. solid oxide fuel cells (oxygen ion conductivity), oxygen permeation membranes (ambipolar diffusion of oxygen), or data storage materials (electronic and/or ionic conductivity). In this contribution our recent work on the influence of defect inter-actions, grain structure and space charge effects, and electronic structure will be discussed for highly non-stoichiometric crystalline and amorphous oxides.

The general phenomenon of a maximum in the oxygen ion conductivity against dopant fraction will be analyzed in terms of defect interactions [1] and using density functional theory and kinetic Monte Carlo simulations [2]. In nanocrystalline oxide ion conductors, space charge effects at grain boundaries and surfaces hinder oxygen ion transport [3]; on the other hand, the grain boundaries are conductive for protons, even at room temperature [4].

Highly non-stoichiometric and amorphous oxides exhibit fascinating electronic properties. Internal disproportionation reactions can induce an insulator-metal transition [5] and may have an immediate impact on applications such as electronic devices and permanent data storage. This novel mechanism and its implications will be discussed considering experimental and theoretical results for amorphous and highly non-stoichiometric gallium oxide.

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Solid State and Bio Physics I / 29

Mössbauer spectroscopy of ⁵⁷Co implanted ZnO

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We have implanted ^{57}Co ($T_{1/2}=271$ d.) into ZnO single crystals, with the aim of elucidating some controversies in the Mössbauer literature on ^{57}Fe impurities in ZnO. It is shown that some of the data obtained on ^{57}Fe in ZnO has been misinterpreted. The results show that implantation $>1\text{E}14/\text{cm}^2$ leads to incorporation of $\sim 20\%$ of the probe atoms into distorted substitutional sites, the remainder is found on damage sites of interstitial character. Upon annealing at 773 K (30 min.), the substitutional fraction shows less distortion from the lattice, and part of the interstitial fraction has been mobilized to form precipitates. The results show that magnetic precipitates form easily in transition metal doped ZnO, affecting interpretations of dilute magnetism.

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Mg lattice location in group-III nitrides

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The group-III nitrides (GaN, InN and AlN) are semiconductors with a large band gap which can be adjusted by combining the different nitrides into alloys. This provides them with the interesting electrical and optical properties used to create the light emitting diodes LED (from UV to red). For this the nitride semiconductors must be doped positively (p-type) and negatively (n-type), however they are unintentionally n-type doped, which makes the p-type doping a great challenge.

The introduction of small concentrations of dopants in specific lattice positions of a semiconductor may modify the electrical properties of the whole material[1,2,3]. Depending on whether Mg becomes interstitial or substitutional it can work as a p-type dopant or compensate other dopants. Though other impurities have been predicted to introduce p-type defects in the nitrides, Mg was the most successful one so far[4].

Using on-line emission channeling [1,3,5] the lattice site location of the radioactive probe ^{27}Mg ($t_{1/2}=9.5$ min) was measured directly, in GaN, AlN and InN. In that respect, the use of a Ti target during this year's Mg RILIS run allowed for the first time to produce clean beams of ^{27}Mg that are free of isobaric stable ^{27}Al and short-lived ^{27}Na (300 ms) contamination. We found that during room

temperature implantation most of the ^{27}Mg atoms occupy substitutional sites of Ga, Al and In in GaN, AlN and InN respectively. However, also a significant fraction of Mg was found in hexagonal sites in AlN and GaN. The remaining Mg was found in random sites of the semiconductor lattice. In order to investigate the temperature dependence of the Mg lattice location and the recovery of the crystal from implantation related damage the implantation and measurements were also performed at higher temperatures. We found the hexagonal interstitial Mg in AlN only for implantation temperatures of 300°C and below but not for implantation temperatures of 600°C and above. In GaN, interstitial Mg was still observed at 600°C but absent at 800°C . Our results hence gave the first direct evidence of the existence of interstitial Mg in GaN and AlN and also indicated its thermal stability. In the case of InN it was found that it recovers completely from implantation damage by annealing at 300°C .

Solid State and Bio Physics I / 38

Innovative radioisotopes for nuclear medicine

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We report on first results with ISOLDE radioisotopes collected in the frame of the LOI-121.

We were able to demonstrate in vivo PET and SPECT imaging using ^{152}Tb and ^{155}Tb for the first time. Also in-vivo PET imaging with the long-lived in vivo generator $^{140}\text{Nd}/^{140}\text{Pr}$ was demonstrated, thus enabling longitudinal in vitro and in vivo PET monitoring of the biodistribution of antibodies over many days.

Various carrier-free Auger electron emitters are used for basic radiobiological research on the microdosimetry of such short-range radiation.

Yields and beam contaminants were determined for a variety of radioisotopes that are of interest for medical applications.

An outlook will be given on the planned research program and possible midterm upgrades (Hle-Isolde).

REX-ISOLDE Commemoration / 47

Ten Years of Physics with REX-ISOLDE

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The “Radioactive EXperiment at ISOLDE” (REX-ISOLDE) was proposed at the end of 1994 to perform a pilot experiment to study neutron-rich isotopes around $N=20$ and 28 using Coulomb excitation and transfer reactions. A novel concept to accelerate the existing low-energy, singly-charged ISOLDE beams and a new high-efficiency gamma-ray array, called Miniball, dedicated to low-multiplicity experiments were proposed. In 2001, first radioactive beams were accelerated to 2.2 MeV/u and used

for physics studies. Later upgrades allowed to rise the final energy to 3 MeV/u. After ten years of operation, REX-ISOLDE has enlarged its scope far beyond the original plans. Isotopes as light as ^8Li and as heavy as ^{224}Ra have been used for Coulomb excitation, few-nucleon transfer reaction or fusion evaporation studies to name a few.

In this contribution we will highlight some of the physics results and emphasize ISOLDE's unique opportunities. In addition we will give a brief historical note on how the concept of REX-ISOLDE came about.

REX-ISOLDE Commemoration / 52

The REX-ISOLDE post accelerator – from first stumbling beams to sophisticated ion juggler

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REX-ISOLDE has now been operational as post-accelerator of radioactive ion produced at ISOLDE for over ten years. Close to 100 isotopes from 30 different elements have been accelerated and delivered to numerous experiments at varying beam energies. The technical challenges encountered during the installation and commissioning phase of the machine will be briefly reviewed, and the present performance of REX-ISOLDE will be compared with the initial specifications and predictions given in the proposal from 1994. Subsequent to the installation the machine has undergone continuous development in order to respond to different experimental requirements concerning, for example, beam energy and purity; ion mass range and lifetime; and beam intensities and timing structure. The different methods addressing these issues will be discussed. Finally, a glimpse of the performance that can be expected from the machine in the future will be given.

REX-ISOLDE Commemoration / 31

MINIBALL at REX-ISOLDE: pioneering position-sensitive Ge detectors

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With the approval of the REX project at ISOLDE in 1995 an intensive discussion on the design and construction of a dedicated γ -ray array started. Due to the low intensity of the radioactive beams high detection efficiency was needed. On the other hand, as the γ -rays are emitted from nuclei moving with 5-10% of the speed of light a high granularity of the array was mandatory in order to limit the Doppler broadening of the γ -lines. The final decision was to extend the technology of the EUROBALL Cluster detectors to segmented Ge detectors and to develop digital electronics for a further enhancement of the position resolution by pulse shape analysis. MINIBALL so far consists of 24 encapsulated, 6-fold segmented Ge detectors which are mounted in 8 cryostats with three detectors each. Thus, it has a granularity of 144 which can be enhanced by one order of magnitude by pulse shape analysis.

A first commissioning experiment at REX-ISOLDE with a MINIBALL triple cluster detector was performed in September 2001 and the full array was installed in May 2002. Thus, we are looking back to 10 years of successful and reliable operation of MINIBALL at CERN and to an impressive list of scientific results.

MINIBALL was an important step in the development of position-sensitive Ge detectors. It has shown that reliable segmented Ge detectors can be produced and that the first interaction point of the γ -rays within the detector can be determined with a two-dimensional position resolution of ~ 5 -8mm by pulse shape analysis in real-time. These results encouraged the development of highly segmented

Ge detectors which are position-sensitive in three dimensions allowing a full tracking of a γ -ray being scattered and finally absorbed in the Ge detector. Two γ -ray tracking arrays, AGATA in Europe and GREY in the USA, started data taking in their demonstration phase. Both spectrometers use encapsulated, 36-fold segmented Ge detectors which are based on the technology developed for EUROBALL and MINIBALL.

Light nuclei / 49

Three-nucleon forces and neutron-rich nuclei

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This talk will discuss three-nucleon forces and their impact on the structure of neutron-rich nuclei, with a focus on the neutron-rich calcium and oxygen isotopes.

Light nuclei / 51

Reactions experiments induced by light exotic nuclei at REX-ISOLDE

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The ability to produce beams of unstable nuclei has changed Nuclear Physics experiments. These beams permit fundamental experiments in order to understand the nuclear structure and processes of astrophysical interest far out from the Valley of Stability.

The REX-ISOLDE facility has allowed us to carry out experiments with exotic nuclei, in an energy range never explored up to date, characterize them and to study the adjacent resonances that can explain how these exotic systems can be formed.

One of the most important and unexpected discoveries of Nuclear Physics during the last decades has been the neutron halo in some nuclei close to or at the drip line. The halo is a threshold phenomenon. A halo state results basically in the presence of bound states close to the continuum. The two neutron halo states situated at the threshold that separates the discrete spectrum from the continuum are maintained bound by forces that in the un-bound, neighbouring nuclei, give rise to resonant states whose break-up gives us information on the final state interactions (FSI).

We began with the characterization of the resonant nucleus ^{10}Li that is one of the binary subsystems of the halo nucleus ^{11}Li and its structure is of capital importance for the theoretical interpretation of the halo. In reactions of ^9Li on a deuterated target we have been able to obtain the excitation energy of ^8Li and to deduce the corresponding spectroscopic factors thanks to the modelling carried out by the group at Seville.

In this presentation we will discuss the experiments we have performed and the results obtained over the last years of REX operation. We will also give an outline for the continuation of these studies taking advantage of the upgrades leading to the HIE-ISOLDE facility.

Light nuclei / 0

Reaction dynamics studies with $6,7\text{Li}$ and 9Be nuclei at Pelletron, Mumbai, India

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The talk will focus on the reaction dynamics studies at Pelletron, Mumbai, India with the three weakly bound stable nuclei : $6,7\text{Li}$ and 9Be . The suppression in fusion cross-sections at above Coulomb barrier energies, the inclusive and exclusive breakup studies and the dipole polarizability studies for 7Li and 9Be will be highlighted.

Light nuclei / 50

LAND-R3B: Experimental Results and Technical Developments

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In this talk I will discuss briefly the experimental concept of the R3B experiment and concentrate on some of its recent results concerning two types of reactions, namely quasi-free scattering and electromagnetic excitation.

Quasi-free scattering aims at a detailed study of the single-particle structure of nuclei, while electromagnetic excitation is being used to study the collective response of nuclei. Our experiments, performed in inverse kinematics, allow exotic nuclei to be investigated in both respects.

The experimental findings for low-lying dipole strength, often referred to as pygmy dipole resonance, for exotic Sn isotopes will be discussed in the context of their possible relation to parameters of the equation of state of asymmetric nuclear matter.

For quasi-free scattering in inverse kinematics, first results from pilot experiments will be presented.

An overview on the further development of the existing setup into the R3B experiment at the FAIR facility will be given.

Heavy nuclei / 11

Recent results on beta-delayed fission from ISOLDE experiments

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Beta-delayed (EC/b^+ , b^-) fission is a rare nuclear decay process in which the beta-decaying parent nuclide populates excited states in its daughter, which may then fission.

The talk will review the results of two ISOLDE experiments performed by our collaboration* in 2011, in which beta-delayed fission of lightest Tl, At and Fr isotopes were investigated. In particular, beta-delayed fission of ^{202}Fr was identified for the first time and a fission fragments mass distribution was measured.

*The work was performed by RILIS-ISOLDE(CERN)-UWS,Paisley (UK)-IKS,KU Leuven (Belgium)-Comenius University, Bratislava (Slovakia)-OLL, University of Liverpool (UK)-JAEA, Tokai (Japan)-Gatchina(Russia) collaboration

Heavy nuclei / 15

Investigating shape coexistence in the lead region with in-source laser spectroscopy at ISOLDE-RILIS

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The competition between spherical and deformed nuclear shapes at low energy gives rise to shape coexistence in the region of the neutron-deficient lead isotopes with $Z\sim 82$ and $N\sim 104$ [1]. In order to determine to which extend the ground-state of those isotopes is affected by this phenomenon, a large campaign of investigation of changes in the mean-square charge radii is on-going at ISOLDE. Using the high-sensitivity of the in-source laser spectroscopy technique, which combines the ISOLDE-RILIS lasers with the Windmill alpha-decay spectroscopy setup, it has been possible to study very exotic isotopes of lead [2-3] and polonium [4-6], down to $N=100$ and $N=107$ respectively, and more recently thallium down to $N=99$. In this contribution, we shall review the experimental observations on lead and polonium and present the first results of the 2011 experiment on thallium.

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- [6] M.D. Seliverstov et al., Letter in preparation

Heavy nuclei / 21

Octupole collectivity in ^{220}Rn and ^{224}Ra

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The notion that nuclei can assume reflection asymmetric shapes, arising from the octupole degree of freedom, has been supported by a considerable amount of theoretical and experimental evidence for some time. The strongest octupole correlations occur near the proton numbers $Z=34$, 56 and 88 and

the neutron numbers $N=34, 56, 88$ and 134 where, for the heaviest nuclei, an octupole deformation can occur in the ground state.

Experiments to quantify the deformation in the region where octupole correlations are strongest, have been too difficult to perform until very recently. The only observable that provides unambiguous and direct evidence for enhanced octupole collectivity is the $E3$ matrix element or more specifically, in the ground state, the $B(E3; 0^+ \rightarrow 3^-)$. Coulomb excitation is the preferred methodology for directly measuring these observables and so far, the $B(E3)$ strength has only been measured in ^{226}Ra , with its comparatively long half life of 1600y . However, with the recent advances in ISOL technology, specifically the post-acceleration of high-intensity radioactive beams, it is now possible to study these nuclei at REX-ISOLDE. Beams of ^{220}Rn (July 2011) and ^{224}Ra (August 2010 and August 2011) have been successfully delivered to MINIBALL at 2.83A.MeV and Coulomb excited on Sn, Cd and Ni targets. The data obtained should now be sufficient to measure the octupole collectivity on these nuclei for the first time.

Heavy nuclei / 17

Status of the CRIS experiment

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The installation of the new Collinear Resonant Ionization Spectroscopy (CRIS) experimental beam line and lasers are now nearing completion. Commissioning tests that started towards the end of 2010 have continued throughout 2011 with beams from both ISOLDE and the newly installed off-line ion source. A new detection chamber that incorporates both ion and alpha detectors has been constructed, tested and installed into the CRIS beam line. Off-line and on-line commissioning experiments have been undertaken to study the non-resonant background, neutralization efficiency, laser ionization and data acquisition. The CRIS technique uses a combination of two techniques: resonant ionization spectroscopy (RIS) and collinear laser spectroscopy. The initial proof of principle of the CRIS experiment has already demonstrated an improvement in efficiency over fluorescence detection by up to 3 orders of magnitude in some cases. The new beam line routinely operates below $5\text{e-}9$ mbar which further suppresses background events by a factor of 50 000. This combination of high detection efficiency and low background counting rates will allow the experiment to study the

rarest isotopes produced at ISOLDE. The first on-line run will look at the neutron deficient and neutron rich Francium isotopes. This work is motivated by the migration of the deformed $(s1/2-1)1/2+$ proton intruder state which is isomeric in $^{201,203}\text{Fr}$ and predicted to invert with the ground state in ^{199}Fr . This talk will present the results from the off-line and on-line commissioning experiments in 2010 and 2011.

Heavy nuclei / 18

Laser assisted decay spectroscopy at the CRIS beam line

Authors: Kara Lynch¹; Mustafa Rajabali²

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The new Collinear Resonant Ionization Spectroscopy (CRIS) experiment at ISOLDE will use 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 also 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, which allows for sensitive secondary experiments to be performed.

A new program aiming to use the CRIS technique to select only nuclear isomeric states for decay spectroscopy has commenced this year. The isomeric ion beam is selected using a resonance of its hyperfine structure. It is then deflected to a spectroscopy station, consisting of a rotating wheel implantation system for alpha and beta decay spectroscopy, and three high purity germanium detectors around the implantation site for gamma-ray detection.

Laser spectroscopy will provide a measurement of the spin of the ground and isomeric states in the parent nucleus, while the level structure of the daughter nucleus will come from the complementary decay spectroscopy.

Here we report the current status of the Laser Assisted Decay Spectroscopy set-up for the CRIS beam line. A case study of ^{204}Fr is presented, along with recent tests carried out on the system.

General interest lecture / 53

Trapped Antihydrogen - Stable, Neutral Antimatter

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Antihydrogen, the bound state of an antiproton and a positron, can be used as a test-bed of fundamental symmetries. In particular, the CPT Theorem requires that hydrogen and antihydrogen have the same spectrum. The current experimental precision of measurements of hydrogen transition frequencies approaches 1 part in 10^{15} . Similarly precise antihydrogen spectroscopy would constitute a unique, model-independent test of CPT symmetry. Antihydrogen atoms have been produced in quantity at CERN since 2002, when the ATHENA collaboration demonstrated [1] how to mix cryogenic plasmas of antiprotons and positrons to produce low energy anti-atoms. In this colloquium I will discuss the newest development along the road to antihydrogen spectroscopy: magnetically trapped antihydrogen. In November of 2010 the ALPHA collaboration reported [2] the first trapping of antihydrogen atoms in a magnetic multipole trap. The atoms must be produced with an energy - in temperature units - of less than 0.5 K in order to be trapped. Shortly afterward, ALPHA demonstrated that it was possible to store trapped antihydrogen atoms for up to 1000 seconds [3]. I will discuss the many developments necessary to realise trapped antihydrogen, the ongoing efforts to resonantly interact with antihydrogen, and the future of antihydrogen physics at CERN.

Spectroscopy techniques / 3

High-precision efficiency calibration of a Germanium detector

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For high-precision gamma-ray measurements (e.g. $0^+ - 0^+$ beta decay) we are about to calibrate a HPGe detector in efficiency. The aim is to obtain an efficiency curve with an uncertainty at the 0.1% level over a range of energy from 100 keV to 6 MeV. Standard source measurement, online source measurement taken at ISOLDE and several scans of the detector are combined to adjust the geometrical parameters of the detector to match it to MC simulations with the GEANT4 and the CYLTRAN codes. The status of this work will be presented.

Spectroscopy techniques / 26

Neutron Wall: recent results and future plans

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The Neutron Wall is a compact 1π neutron detector array consisting of 50 liquid scintillator detectors. The array has been used together with the EUROBALL gamma-ray spectrometer at INFN-LNL in Italy and at IReS in France. Presently it is located at GANIL where it is combined with EXOGAM in experiments with both stable and radioactive ion beams. Recent results obtained with the setup at GANIL will be presented. Future plans of the Neutron Wall and its successor NEDA will be briefly described.

Spectroscopy techniques / 22**Laser Spectroscopy with the Leuven gas cell-based Laser Ion Source****Author:** Rafael Ferrer-Garcia¹**Co-authors:** Amin Hakimi²; Bastin Beyan³; Benoit Osmond³; Deyan Radulov¹; Dieter Pauwels⁴; Herve HSava-jols³; Iain Darby⁵; Iain.D Moore⁵; Jean.C Thomas³; Johannes Rossnagel²; Klaus Wendt²; Lars Ghys¹; Lieve Rens¹; Mark Huyse¹; Mikael. H. T. Reponen⁵; Nathalie Lececsne³; Paul Van den Bergh¹; Piet Van Duppen¹; Sebastian Raeder²; Serge Franchoo⁶; Sergei Zemlyanoy⁷; Sven Richter²; Tetsu Sonoda⁸; Tobias Kron²; Volker. T Sonnenschein⁵; Yuri Kudryavtsev¹¹ IKS-KULeuven² University of Mainz³ GANIL⁴ SCK-CEN⁵ University of Jyväskylä⁶ IPNO⁷ JINR,Dubna⁸ RIKEN

The Leuven Isotope Separator Online (LISOL) facility, located at the Cyclotron Research Center (CRC), Louvain-la-Neuve, is a successful producer of purified rare ion beams using resonant laser ionization of reaction products thermalized in a buffer-gas cell. After almost two decades of operation high purity radioactive ion beams of more than 15 different elements have been obtained exploiting various production mechanism as light- and heavy-fusion evaporation reactions, proton-induced fission, and the spontaneous fission of ²⁵²Cf. Production and thermalization of radioactive species in a cell filled with ultra-pure buffer gas is used in combination with resonant laser radiation for selective ionization of the isotopes of interest by the Leuven gas cell-based laser ion source. These ions are extracted from the cell in a supersonic jet and transported by a radio frequency ion guide up to the mass separator, where they are segregated from non-isobaric contamination. Ion beams of high purity can then be sent to the detector station for the study of their characteristic decay radiation. In addition to the routinely performed nuclear-decay-spectroscopy studies the recent implementation in the LISOL setup of a new concept gas cell [1] has allowed in-source laser spectroscopy studies of neutron-deficient ⁵⁷59Cu [2] and ⁹⁷102Ag [3] isotopes. These measurements have become feasible owing to the enhanced sensitivity of the apparatus, which has allowed spectroscopic studies on exotic species with count rates as low as 6 ions/s for ⁵⁷Cu (T_{1/2} = 200 ms) or 1 ion/s for ⁹⁷Ag, both semimagic nuclei. Online experiments are currently being carried out to pursue similar results on actinium isotopes. In spite of the good results obtained by in gas-cell laser spectroscopy the inherent pressure broadening makes this technique to be inapplicable to those elements with reduced hyperfine parameters and/or high sensitivity to atomic collisions, as observed in practice for instance, in the tin isotopes around A= 100. For the successful study of the atomic properties of these species, and in general, to achieve high resolution laser spectroscopy, a

technique like in-jet laser spectroscopy would be the technique of choice. The proof of principle of in-jet laser spectroscopy has been demonstrated at LISOL [4] and the full benefits of it recently evaluated with a high-repetition laser system [5], making it the best candidate for future studies with the Leuven laser ion source. In this technique laser ionization takes place in the supersonic jet expanding out of the gas cell. Consequently, the isolated atomic beams are obtained by supersonic adiabatic expansion in vacuum, with a significant reduction of the Doppler broadening. In addition, the gas density in the ionization region is too low to contribute to the pressure broadening making the laser line width the main limitation for the final achievable resolution. Two approaches to reduce the laser bandwidth of the LISOL laser system are currently under investigation. On the one hand, single longitudinal mode selection by a thick (14 mm air spaced) etalon placed inside the oscillator of the dye laser, and on the other hand, amplification of single mode cw diode laser light in a pulse dye amplifier. In my presentation I will report on the results obtained in the last online runs performed on the production of Ac beams and in the different tests carried out to accomplish in-jet laser spectroscopy at LISOL in view of a full implementation of this technique in the future low energy branch facility S3, at SPIRAL2.

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Spectroscopy techniques / 40

Tilted-foils setup for nuclear spin polarization of post accelerated beams

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Spin polarized nuclei are of great interest for many applications, for example in nuclear structure, solid state and biological physics. Recently, a project was started at ISOLDE to evaluate the tilted-foils technique applied to post accelerated beams at REX-ISOLDE. Thin tilted foils are introduced

into the beam line which induces nuclear spin polarization and the degree of attained polarization can be measured with Coulomb excitation or more commonly with Beta-NMR. This year, the first online studies took place with a Beta-NMR setup that has been under construction behind REX-ISOLDE for this evaluation project. In this contribution, I will present the setup, the measurement and current results from the analysis, and an outlook for future improvements and extensions to the experiment.

Technical developments / 48

Advances in radioactive ion beam R&D at GANIL

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Since 2001, SPIRAL at GANIL has been delivering radioactive ion beams of gaseous elements of unique intensity and purity for physics experiments.

Recently, a project was formed to upgrade SPIRAL for making use of so far unexploited capabilities for radioactive ion beam production. Neutron deficient beams from condensable elements should soon become available with unequalled intensities for a number of physics cases in nuclear astrophysics, nuclear structure and for precision tests of the Standard Model.

The upgrade relies on the so called 1+ n+ method: singly charged radioactive beams are delivered from a hot plasma source, the ISOLDE VADIS, to an ECR charge breeder, the Phoenix charge breeder, which performs the multi-ionisation required by the post-accelerator.

The association of VADIS with the present SPIRAL target was lately tested on-line. A number of new beams were produced, showing the potential of such association.

The Phoenix charge breeder, which was previously tested at ISOLDE, is being upgraded. So far, modest efficiencies were obtained with the charge breeding of light metallic ion beams in ECRIS. This upgrade is part of a more general program aiming at improving the performances of charge breeding in ECRIS and EBIS for future ISOL facilities: the EMILIE (Enhanced Multi - Ionization of short Lived Isotopes for EURISOL) project.

This contribution will present the latest status of these R&D projects.

Technical developments / 44

Newly Available Beams and Systematic Release Studies at ISOLDE

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ISOLDE is known for the production of very exotic radioactive ion beams far from stability. During the past online period a number of isotopes could be added to that list and are now available for experiments.

Systematic investigations of isotope yields and other release properties promote the understanding of the complex processes of isotope production and extraction and help evaluating future physics proposals making use of exotic ion beams.

Technical developments / 54**Nanostructured Calcium Oxide Targets for the Production of Argon Beams****Author:** Joao Pedro Ramos¹**Co-authors:** Ana Maria Rocha Senos²; Thierry Stora³¹ *University of Aveiro*² *University of Aveiro, PT*³ *CERN***Corresponding Authors:** thierry.stora@cern.ch, joao.pedro.fernandes.ramos@cern.ch

Calcium oxide powder targets have been successfully used at ISOLDE-CERN to produce neutron deficient exotic argon isotopes and carbon isotopes, released as CO and CO₂ molecules. Such targets outperform other related targets used to produce the same beams, such as MgO sintered powder or TiO_x fibers. However, either some CaO target units displayed slow release rates (or low absolute yields) from the beginning or a rapid decrease over time when operated under proton irradiation.[1] We found that the good performance of the ISOLDE historical targets was related to a structure of a nanometric scale.[2,3] Its fast degradation was mainly caused by sintering due to the high operation temperatures and/or high proton intensities being responsible for the fast drop of the yields. Taking this into account, systematic studies of: the synthesis conditions, sintering kinetics and the air reactivity of the nanometric powder were performed; all in order to improve/maintain the target nanostructural properties. A new production and operation methods were proposed and tested at ISOLDE in order to improve the release properties, in terms of diffusion and effusion of isotopes. Improved yields of exotic Ar beams and no sign of degradation were observed during the operation of the CaO #469, target unit of this year.

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Technical developments / 28**Implementation of titanium:sapphire lasers at ISOLDE RILIS****Author:** Sebastian Rothe¹**Co-authors:** Bruce Marsh²; Klaus Wendt¹; Ralf Erik Rossel¹; Valentine Fedosseev²¹ *Johannes-Gutenberg-Universität Mainz (DE)*² *CERN***Corresponding Author:** sebastian.rothe@cern.ch

At ISOLDE RILIS isotopes are resonantly ionized by high pulse repetition rate wavelength-tunable lasers. In recent years the performance of RILIS was substantially improved due to upgrade stages of the laser setup. The dye laser installation has been completely renewed including the replacement of copper vapor pump lasers by solid state Nd:YAG lasers. As part of the RILIS upgrade program, a complementary fully solid state laser system based on 10 kHz repetition rate Titanium Sapphire (Ti:Sa) lasers has been built at CERN in collaboration with Mainz University. On account of their advantages in terms of long-term stability and reliability, Ti:Sa lasers are used or planned to be used at the majority of on-line radioactive ion beam facilities worldwide. In the beginning of 2011 the

new Ti:Sa laser system was installed at ISOLDE RILIS alongside the dye laser system. Since then, the Ti:Sa lasers have been used for a number of on-line experiments and their compatibility with the dye lasers and expected performance was demonstrated. With the implementation of Ti:Sa lasers the range of elements accessible with RILIS is extended. In particular, an efficient ionization scheme of astatine has been developed and the ionization potential of At atoms has been measured for the first time. The improved flexibility offered by the new dual laser system has greatly reduced the switching time from one element to another, making it possible for more physics runs to be scheduled.

Technical developments / 34

The Laser Ion Source and Trap (LIST): Improving the Selectivity of the Resonance Ionization Laser Ion Source

Author: Daniel Fink¹

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Highest ionization efficiency combined with effective isotope selectivity is of utmost importance for most on-line experiments on exotic, short-lived radionuclides, in particular for those with the lowest production rates. At ISOLDE, the ionization technique that most closely meets these requirements is the Resonance Ionization Laser Ion Source (RILIS), where the atoms of a chosen element are step-wise and thus, inherently selectively ionized by simultaneous irradiation with different laser beams, wavelength-tuned to strong optical resonances. Unfortunately, rare isotope beams produced with RILIS at ISOLDE are still often significantly contaminated with surface ionized isobars, which hinder or even prevent foreseen experiments.

In order to fully suppress these isobaric contaminants, the Laser Ion Source and Trap (LIST) has been developed at the University of Mainz and at CERN. An electrostatic electrode positioned at the exit of the isotope transfer line of the target unit stops surface ions from reaching the ion extraction region. Only neutral atoms may diffuse into the two-dimensional radio frequency quadrupole trap located immediately ahead. Resonant laser ionization of the atom of interest takes place within the LIST device, wherein the resulting ions are transversely confined and guided towards the subsequent extraction and acceleration field.

Various preparatory off-line measurements were performed to study the behavior of the LIST with several elements. Characteristics such as transmission, selectivity, and ionization efficiency were determined in full detail under realistic operating conditions.

In May 2011, the LIST was operated successfully at ISOLDE producing ion beams of stable and radioactive Mg isotopes. This is the first time that such a device has been tested in on-line (proton on target) condition at a radioactive ion beam facility. The primary goal was to study the long term behavior of the LIST in a radioactive environment and to study the LIST characteristics under realistic conditions.

A summary of the LIST technique and the results of the off-line and on-line studies will be presented, as well as the latest developments towards further improvements of the LIST performance.

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Highlights of the Radiation Protection Group Activities in 2011 in Support of ISOLDE Operation and Projects

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Several processes and activities carried out in the ISOLDE facility for the production and use of Radioactive Ion Beams present radiological risks. For this reason, the Radiation Protection (RP) Group is involved in the daily operation of the facility to ensure that appropriate mitigation measures are implemented and that the relevant Radiation Protection rules and best practices are followed. For example on the RIB production side, such activities span from the production of actinide targets in dedicated laboratories to the preparation and monitoring of the work performed in the target or separator areas. On the experiment side, the RP Group is providing support to the ISOLDE users in all matters related to Radiation Protection and is also responsible for the monitoring of the radiation levels and personnel exposure to ensure that the applicable legal limits are not exceeded. In addition to the daily operation of the facility, the RP Group is also involved in the preparation of the planned intensity and energy upgrade of ISOLDE (in the frame of the HIE-ISOLDE project), as well as in several other projects related to the facility consolidation. In the context of the HIE-ISOLDE project, a very detailed radiation measurement campaign was conducted in 2010 and 2011 inside the facility and in its vicinity. The measured radiation levels were systematically related to the beam parameters and the radiation levels with the planned primary beam intensity increase could therefore be extrapolated. The measurements were also confronted to calculations performed using the Monte-Carlo code FLUKA. Some areas where some shielding reinforcement is needed were identified and the required additional shielding will be assessed using FLUKA. Finally, another important project for the reliability of the facility and for which the RP constraints must be considered is the replacement of the two robot systems used for the target exchange and which are arriving at the end of their lifetime. For the specification of the new system, the RP Group provided the expected radiological environment in which the system will have to evolve and the consequences of a system failure in terms of access in order to anticipate recovery scenarios.

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Biophysics at ISOLDE

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Due to the complexity of systems in living matter nuclear techniques are not commonly used in biology and biochemistry. By approaching from simple inorganic complexes we aim to elucidate the fundamental chemistry of heavy metal ion integrations with proteins. This furthermore involves studies on de novo designed peptides, naturally occurring proteins, plants and recently also bacteria.

We will present ¹⁹⁹mHg-PAC data on proteins and in vivo systems as well as results from the first beta-NMR experiments on soft matter ever performed.

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A photoluminescence study of Cd, In and Sn in ZnO using radioisotopes

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We report the results of photoluminescence studies of zinc oxide implanted with radioactive ¹¹⁷Ag which decays through Cd and In on to stable Sn. Our results show that two of the so-called I-lines, I9 and I2, both decay away in accordance with the decay of radioactive ¹¹⁷In. This confirms an earlier result that I9 is due to excitons bound to In donors and shows conclusively for the first time that the I2 line is also due to In. We do not observe any photoluminescence due to either Cd or Sn both of which exist at sizeable concentrations during or after the ¹¹⁷Ag decay sequence. It appears that, in contrast to Hg, isoelectronic Cd does not bind an exciton in ZnO, and that Sn, in contrast to another group IV impurity Ge, does not produce a sharp bound exciton line well below the band gap.

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Lattice location of the transition metals Co and Ni in Si

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We have studied the lattice location of the transition metals ⁶¹Co (1.6 h) and ⁶⁵Ni (2.5 h) in Si single crystals of various doping types by means of on-line Emission Channeling using Short-Lived Isotopes (IS453 EC-SLI). ⁶⁵Ni was directly obtained by means of Ni RILIS ionization, while for the ⁶¹Co experiments we implanted the short-lived precursor isotope ⁶¹Mn (4.6 s) which decays via ⁶¹Fe (6 min) to ⁶¹Co, during the Mn RILIS run. In this case only measurements after a waiting period of 30 min were considered.

The samples were low-doped n-Si (7.3-12 Ohm cm, in the following named i-Si), as well as highly p+ (0.0053 Ohm cm) and n+ (0.0030 Ohm cm) doped Si.

While full quantitative analysis of the measured EC-SLI patterns by means of fitting to the results of manybeam simulations of emitter atoms on various lattice sites has not yet been performed, a qualitative inspection gave the following preliminary results.

Directly after room temperature implantation, the major lattice sites occupied by ⁶¹Co and ⁶⁵Ni were substitutional or near-substitutional sites in all doping types studied.

However, after annealing at 500°C ⁶⁵Ni changed to tetrahedral interstitial (T) sites in i-Si and p+-Si, while the majority of ⁶⁵Ni in n+-Si was found on bond-centered (BC) interstitial sites after the same annealing temperature.

Site changes to interstitial T sites were also observed for ^{61}Co in i-Si and p+-Si, while the case of ^{61}Co in n+-Si is still waiting to be measured at next year's Mn beam time.

The behaviour of Co and Ni in Si shows hence some similarities to Fe in i-Si, where site changes from near-S to T sites were already observed in previous experiments. However, there are also clear differences. While the site changes S->T in the case of Ni and Co occurred already after annealing at 475-500°C, in the case of Fe in i-Si around 600°C was required in order to promote the corresponding effect.

Also, while Fe showed considerable resistance against high-temperature annealing, which went along with the occupation of ideal substitutional sites after 900°C annealing, Co and Ni started to show partial out-diffusion from the samples already for annealing temperatures in the 600-850°C range.

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Ab-initio study of the correlation between electric field gradients and electric polarization in ferroelectric oxides

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The hyperfine interaction between the quadrupole moment of atomic nuclei and the electric field gradient (EFG) at the corresponding site provides information related to the near electronic charge distribution. Nuclear techniques such as Perturbed Angular Correlation (PAC) have been used to measure EFGs under temperature or electric field variations, for example, relating them to ferroelectric properties. Macroscopically, the main property in ferroelectrics is the polarization, which also depends on the charge density, but in many cases presents difficulties to be studied due to extrinsic effects. In previous hyperfine studies of ferroelectrics or multiferroics, particularly done at ISOLDE using PAC, a relation between the EFG and the polarization was observed and discussed in a few materials, but without a firm theoretical foundation.

We present first-principles density functional theory calculations for ferroelectric materials such as BaTiO₃, KNbO₃, PbTiO₃, and other oxides with perovskite structures, with a simultaneous calculation and analysis of the two properties as a function of the ferroelectric distortion. The EFG tensor and its properties, including orientation, and correlation between components are examined. A relationship with the electric polarization is found, giving quantitative support to previous works.

The calculations allow a systematic study of this relationship in several compounds, which may help to relate more generally the conventional measurements of polarization and the local EFG experiments, and the added detailed information will potentially increase our understanding of the different mechanisms behind ferroelectrics or multiferroics.

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The TRIUMF-ISAC Radioactive Ion Beam (RIB) Facility: Recent Highlights and Future Plans

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The availability of a wide variety of intense beams of exotic nuclei from the next generation of radioactive ion beam facilities such as the Isotope Separator and Accelerator (ISAC) facility at TRIUMF provides an unprecedented opportunity to address key questions of current interest in nuclear astrophysics, nuclear structure physics, fundamental symmetries and molecular and material science. The short-lived isotopes are produced at ISAC by the ISOL (on-line isotope separation) method using a beam of up to 100 μ A of 500 MeV protons from the TRIUMF H- cyclotron to bombard thick production targets. The targets can be coupled to a wide variety of ion sources including: surface, laser (TRILIS) and plasma (FEBIAD) sources, to produce the world's most intense RIB beams for certain isotopes such as ^{11}Li . A license was obtained in November 2009 to run with uranium targets at $< 2 \mu\text{A}$ for a total of 1000 $\mu\text{A hr}$. The first UCx production target was run in December 2010. This target produced high yields of short-lived neutron-rich and actinide isotopes; one highlight was the development of a TiSa laser ionization scheme for At. We are currently seeking a license upgrade to operate UCx targets at beam currents up to 10 μA for a total of 5000 $\mu\text{A hr}$.

Low-energy ($< 60 \text{ keV}$) RIBs have been available at ISAC since 1999, and over the past decade a large number of state of the art experimental facilities have been developed. Recent research highlights include: high charge state mass measurements of $^{74-76}\text{Rb}$ using the TITAN ion trap facility, co-linear laser spectroscopy of cooled bunched beams including $^{74-78}\text{Rb}$ and $^{206-8}\text{Fr}$, a high-precision branching ratio measurement of the superallowed β -emitter ^{74}Rb using 8π gamma-ray spectrometer, and microscopic investigations by βNMR of proximity effects in metal- superconductor bilayers. Fundamental symmetry studies including a test of time reversal symmetry using polarized ^8Li , the search for a permanent EDM in odd A radon isotopes and PNC in francium isotopes.

An RFQ and variable energy DTL provide reaccelerated radioactive beams at energies from 0.15-1.8 A MeV for nuclear reaction studies of importance in explosive nucleosynthesis environments such as Novae and X-ray bursts. Most recently the DRAGON recoil separator was used to study the $^{33}\text{S}(p,\gamma)^{34}\text{Cl}$ reaction, to determine if ^{33}S abundance in pre-solar grains could indicate nova origin. Since January 2007 a Superconducting LINAC installed at ISAC-II has made nuclear reaction studies possible with radioactive beams at energies up to 5 A MeV for $A < 30$. Recent studies using exotic beams of halo nuclei include, the search for a soft dipole resonance state in ^{11}Li via (p,p) scattering, a study of halo effects in the scattering of ^{11}Li on ^{208}Pb at energies near the Coulomb barrier, and a study of the halo structure of ^{12}Be studied via the $^{11}\text{Be}(d,p)$ reaction. In 2009, the TUDA particle detector array was move to ISAC-II for astrophysically motivated studies of the $^{18}\text{F}(p,\alpha)^{15}\text{O}$ and $^{21}\text{Na}(p,\alpha)^{18}\text{Ne}$ reactions. The potential for nuclear structure studies at ISAC-II was greatly enhanced in the summer of 2010 with the installation of high-beta cavities which when combined with a charge state booster will provide radioactive beams up to 7 A MeV for $A < 150$.

The gamma-ray spectroscopy program at ISAC-II is centered on TIGRESS, a next generation array of high-efficiency segmented HPGe detectors with digital signal processing that is specifically designed to meet the challenges of experiments with high-energy radioactive ion beams. A number of auxiliary detectors are also under development for use with TIGRESS including: a DSSSD barrel for detecting charged particles SHARC, an array of neutron detectors DESCANT, the TIGRESS Integrated Plunger TIP, and a recoil mass spectrometer EMMA. During the past two years, the experimental studies included: the Coulomb excitation of $^{10-11}\text{Be}$ and the first experiments with SHARC including a measurement of the $^{25}\text{Na}(d,p)^{26}\text{Na}$ reaction as part of a program to follow the evolution of shell structure of neutron-rich sd-shell nuclei.

Recent highlights from the research programs at ISAC I and ISAC II will be presented together with an overview of the ARIEL project which includes the construction of a 50 MeV, 500 kW superconducting e-linac to provide intense beams of neutron-rich nuclei via the photo-fission of actinide targets.

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Coulomb excitation of ^{140}Nd - measuring the $B(E2)$ value of the first $2+$ state at REX-ISOLDE

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A radioactive beam of ^{140}Nd was impinging on a 1.40 mg/cm^2 ^{48}Ti as well as a 1.55 mg/cm^2 ^{64}Zn target. Gamma rays were detected by the MINIBALL array and a DSSD was used for particle identification. The transition strength of the first 2^+ to the 0^+ ground state in unstable, neutron-deficient ^{140}Nd was measured to be $30(5)$ W.u. (preliminary). The beam was contaminated by ^{140}Sm , this allows to determine also a limit for the transition strength in that isobar. The result for the $B(E2)$ value in ^{140}Nd deviates from the empirical rules for quadrupole collectivity [1,2] and the predictions of the contemporary microscopic model (QPM for $N=80$ predicts 17 W.u. [3] with parameters as in [4]). This unexpected behavior prompts for new, refined microscopic calculations and potentially can be related to the shell stabilization of the quadrupole isovector valence shell excitations. The result is also important for preparation of the planned HIE-ISOLDE experiment, which aims to identify the one-phonon mixed-symmetry 2^+ state.

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Medium Mass Nuclei II / 2

First High-Resolution Laser Spectroscopy of Cadmium: Recent Results and Perspectives

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We report on the first hyperfine-structure study of cadmium by high-resolution laser spectroscopy. The goal is to determine nuclear spins, electromagnetic moments and root mean square (rms) charge radii of ground and isomeric states along the chain, ultimately reaching the neutron 50 and 82 shell closures.

In the first part of the program we studied the intense beams of $^{106-124,126}\text{Cd}$ by fluorescence spectroscopy, which also covered the β^- isomers in the odd $^{111-123}\text{Cd}$. 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 of the sdgh shell. 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 is sensitive to the changes in the degree of collectivity between the ground states and the isomers, not only from their quadrupole moments, but also through their rms charge radii.

In this contribution we will present the results and their preliminary interpretation. The perspectives for extending the measurements towards the exotic isotopes near the doubly-magic ^{100}Sn and ^{132}Sn will be discussed, as this is expected to shed light on a shell-quenching hypothesis and the stellar nucleosyntheses.

Medium Mass Nuclei II / 12**Probing the Quadrupole Collectivity of ^{128}Cd using Coulomb Excitation****Author:** Sabine Bönig¹**Co-authors:** Marcus Scheck¹; Michael Thürauf¹; Thorsten Kröll¹¹ *Technische Universität Darmstadt (DE)*

^{128}Cd is only two proton and two neutron holes away from the doubly magic nucleus ^{132}Sn . The proximity to this r-process waiting-point nucleus underlines its importance for the understanding of nucleosynthesis. So far, contradicting theoretical predictions for the $B(E2,0^{+}\rightarrow 2^{+})$ value of ^{128}Cd exist. While shell model calculations conclude an almost spherical shape of ^{128}Cd , beyond mean field calculations predict an already considerable quadrupole collectivity. In this contribution the experimental details of the Coulomb excitation of ^{128}Cd at REX-ISOLDE (experiment IS477) will be presented. Furthermore the current status of the analysis to determine the transition strength of the ground state into the first excited 2^{+} state will be shown. This project is supported by BMBF (No. 06 DA 9036I) and EU through ENSAR (No. 262010).

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Preparation, test and commissioning of a molten salt target for noble gases production**Author:** Tania de Melo Mendonca¹**Co-authors:** Daniel Heuer²; Michel Allibert²; Rastilav Hodak³; Thierry Stora⁴; Véronique Ghetta²¹ *IFIMUP and IN, University of Porto, Portugal*² *LPSC-IN2P3-CNRS/UJF/INPG, LPSC 53 Avenue des Martyrs, F-38026 Grenoble Cedex, France*³ *Comenius University, SK-842 15 Bratislava, Slovakia*⁴ *CERN***Corresponding Author:** tania.de.melo.mendonca@cern.ch

A molten NaF-ZrF₄ salt target is produced and tested this year at ISOLDE aiming at collecting data in view of the production of the required rates of ^{18}Ne for the beta beams project[1,2]. The details related to the design of units suited for molten salt target operation are introduced. The release properties of NaF-ZrF₄ associated to a VADIS ion-source are presented. The production, release of gaseous and volatile elements is discussed for F, Ne and Na isotopes.

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