ISOLDE Workshop and Users meeting 2013

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Book of Abstracts

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Welcome

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Direct reactions with exotic nuclei, recent results and future plans at HIE-ISOLDE

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Spectroscopic factors provide unique information on the structure of nuclei, and can be probed by direct reactions. Medium-energy knock-out reactions were the first direct reactions to be applied to the study of exotic nuclei about ten years ago. More recently the availability of post-accelerated ISOL beams has allowed the use of transfer reactions at various facilities like GANIL, TRIUMF, ORNL and ISOLDE. These measurements have provided important information on shell migration and persistency of magic numbers far from stability.
At ISOLDE such studies have been performed successfully in various regions of the chart of nuclei. Keys to this success are the unique range of radioactive species available for post-acceleration, and the coupling of particle and gamma-ray detection at the T-REX/Miniball setup [1,2]. We will review the results, focusing on new ones obtained in the neutron-rich Ni region where theoretical efforts have also been recently produced.
HIE-ISOLDE, with the increase in beam energy, will extend the possibility of direct reaction studies to regions of heavier nuclei.
Several letters of intent and proposals have been presented for measurements around the doubly-magic 132Sn nucleus and in the Pb region.
Proton-transfer reactions with negative Q-values, such as (d,3He), will also be accessible, as well as measurements employing isomeric-pure beams. Plans for new instrumentations include an upgrade of the present T-REX setup, the use of an active target, and possibly a solenoidal spectrometer. On a longer term, the coupling of the post-accelerator to a storage ring could further improve the optical and intensity properties of the ISOLDE beams.
[1] V. Bildstein et al., Eur. Phys. J. A 48 (2012) 85 [2] N. Warr et al., Eur. Phys. J. A 49 (2013) 40

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Charge-particle spectroscopy of exotic nuclei with the Optical TPC

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The Optical TPC detector has been developed to study the very rare and exotic decays with emission of charged particles.
The primary goal was to study in detail the 2p radioactivity, but the device was proven successful also in the beta-delayed particle spectroscopy. In the talk, the main results obtained for beta-delayed proton emission and for 2p radioactivity in the region of the doubly magic 48Ni will be summarized.
The cases where the OTPC chamber has advantages over traditional set-ups based on Si detectors, will be discussed. The examples include multiparticle decays, detection of low energy particles on a

large background of beta radiation, or precise branching ratio measurements.
Finally, some ideas for possible future experiments will be presented.

Structure Light Nuclei / **2**

Properties of low-lying intruder states in 34Al and 34Si populated in the beta-decay of 34Mg

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The results of the IS530 experiment at ISOLDE revealed new information concerning several nuclei close to the N˜20 'Island of Inversion' –34Mg, 34Al, 34Si. The half-life of 34Mg was found to be three times larger than the adopted value (63(1) ms instead of 20(10) ms). The beta-gamma spectroscopy of 34Mg performed in this experiment for the first time led to the first experimental level scheme for 34Al, also showing that the full beta strength goes through the predicted 1+ isomer in 34Al and/or excited states that deexcite towards it. The subsequent beta-decay of the 1+ isomer in 34Al allowed the observation of new gamma lines in 34Si, (tentatively) associated with low-spin high-energy excited states (most probably 1+, 2+) previously unobserved.

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Beta-3p spectroscopy in the decay of 31Ar

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The beta-delayed three-proton decay has so far only been observed in two nuclei: 45Fe [1] and 43Cr [2,3]. Pfützner et al. [4] recently discovered it from 31Ar and it has also been observed now in the analysis of the 31Ar decay-experiment IS476. The IS476 experiment gives the unique possibility to not just identify the decay, but to do spectroscopy on it. This is due to the good energy and angular resolution, given from the setup of 6 Double Sided Silicon Strip Detectors in cube formation.
I will present the latest results of the IS476 experiment, which are currently being prepared for publication, with the focus on the beta-3p decay. The study of the beta-3p decay has revealed decay channels, which previously were not considered significant, and this influences the beta-strength significantly.

[1] K. Miernik et al. Phys. Rev. C 76 (2007) 041304.
[2] M. Pomorski et al. Phys. Rev. C 83 (2011) 014306.
[3] L. Audirac et al. Eur. Phys. J. A 48 (2012) 179.
[4] M. Pfützner et al. GSI Scientific Report (2012) 147.

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Three-nucleon forces and shell structure of neutron-rich calcium isotopes

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Calcium isotopes are ideal to explore the evolution of the nuclear shell structure from stability to the neutron-rich extremes, which have very recently become experimentally available.
From a theoretical point of view, calcium isotopes are also the frontier for calculations consistently including nucleon-nucleon (NN), and three-nucleon (3N) forces. In the framework given by chiral effective field theory (EFT), 3N forces have been shown crucial for a correct description of nuclear structure from the spectra of light nuclei to properties of medium-mass nuclei, such as the neutron dripline of oxygen and the appearance of the shell closure at N=28.
We perform calculations for medium-mass nuclei based on chiral NN+3N forces, employing many body perturbation theory (MBPT) to obtain an effective hamiltonian to be used in a valence-shell model calculations with a 40Ca core. The chiral EFT couplings are adjusted to three- and four-body systems. Single-particle energies and two-body matrix elements are calculated without any further modifications. The NN and 3N forces are included consistently to third order in MBPT.
We study in this framework the neutron-rich calcium isotopes up to 54Ca, calculating the ground state energies, excitation spectra and electromagnetic transitions, and compare to experiment. We find an overall good agreement for the measured properties and provide predictions for the exotic isotopes to be tested by future experiments.
In particular, the calculations show excellent agreement with the two-neutron separation energies (S2n) obtained in recent experiments for the neutron-rich Ca isotopes 51Ca, 52Ca, (measured at TRIUMF) and 53Ca and 54Ca (measured at ISOLTRAP). Of special importance is the S2n at 54Ca, which unambiguously establishes, both in the theoretical calculations and the new ISOLTRAP measurements, the subshell closure at N=32.
The lowest 2+ state in 54Ca, key for the determination of the N=34 subshell closure, is also predicted in reasonable agreement to the very recent experimental determination at RIKEN.

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Ultra-sensitive laser spectroscopy on Ca isotopes

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A program of bunched beam collinear laser spectroscopy at the COLLAPS beam line has recently focussed on the nuclear structure evolution around N = 32, in neutron rich K [1,2], Mn [3] and Ca [4] isotopes. The current results obtained from optical detection of calcium isotopes will be presented, in which hyperfine structures and isotope shifts were measured for the first time in 49,51,52Ca. With these new experimental results, the charge radii, magnetic moments and electrostatic quadrupole moments have been determined.
With a production yield of 52Ca (N=32) estimated at ~ 300 ions/s, optical detection techniques are not suitable for measurements beyond N=32. In order to extend the program up to 53Ca (~ 100 ions/s) and 54Ca (~ 10 ions/s), substantial modifications to the COLLAPS beam line are in progress. With these modifications we will implement an ultra-sensitive particle detection scheme [5]. The current developments towards the design, simulation and implementation of the beam line will be explored.

[1] J. Papuga, et al., Phys. Rev. Lett. 110 (2013) 172503.
[2] K. Kreim et al., Phys. Letters B (2013) submitted
[3] C. Bradley, et al., CERN-INTC-2010-073 INTC-P-286.
[4] M.L. Bissell, et al., CERN-INTC-2011-049 INTC-P-313.
[5] L. Vermeeren, et al., Phys. Rev. Lett. 68 (1992) 1679.

Facilities and Techniques / **48**

The ISAC science program at TRIUMF, status and future plans

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The ISAC program at TRIUMF focuses on nuclear physics, nuclear astrophysics, tests of fundamental symmetries using isotopes, and material science. I will give an overview of the present on-line ISAC system and developments, report on recent science highlights, and present plans and status of the new ARIEL facility. ARIEL is currently being built, and will ultimately provide multi-beam capabilities based on an isotope production facility with photo-fission and a second proton beam line.

Facilities and Techniques / **49**

Nuclear and Applied Research at JYFL Accelerator Laboratory

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Accelerator Laboratory in the Department of Physics, University of Jyväskylä has three disciplines, basic research in nuclear physics, accelerator-based material science and accelerator based commercial services. Those areas are using primary ion beams from three accelerators; K130 heavy ion cyclotron, MCC30 light ion cyclotron and Pelletron accelerator, all of them equipped by in-house produced ion sources. In this presentation I will shortly introduce the present layout and basic instrumentation of the Accelerator Laboratory.
Basic research has mainly concentrated on the research at ion Guide Isotope Separator On Line (IGISOL) and gas-filled recoil spectrometer (RITU). IGISOL facility has recently been moved to a new location. In this presentation, IGISOL program will be highlighted and future prospect with

new IGISOL-4 will be discussed. Similarly, a research highlight from a gas-filled recoil spectrometer RITU will be introduced and future prospects with a new vacuum mode separator MARA will be given.
An increasing amount of beam time at Accelerator Laboratory is devoted to accelerator-based material research and applications. The applied program of the Accelerator laboratory will be summarized and the recent highlights of the research will be demonstrated.

Facilities and Techniques / **22**

WITCH, a Penning Trap Experiment for Weak Interaction Studies

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One of the goals of precision measurements in nuclear beta decay is the search for deviations from the Standard Model that would point to new physics. Within the Standard Model, beta decay is described by the V-A theory but exotic contributions are experimentally not excluded with high precision. The primary aim of the WITCH experiment [1] at the ISOLDE/CERN facility is the precise determination of the beta-neutrino angular correlation coefficient, a, which is in the case of 35 Ar sensitive to a possible scalar contribution. For that purpose, a
scattering-free source consisting of two Penning traps is combined with a MAC-E retardation spectrometer to probe the energy of recoiling daughter nuclei. The first daughter recoil energy spectrum was obtained in June 2011 in the decay of 35 Ar, allowing for a first albeit still crude determination of a [2]. After significant upgrades of the system, an online run in November 2012 resulted in data of much higher quality. Presently, this dataset is being analyzed. This contribution will focus on recent results and outlook of the WITCH experiment.

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Breakup of 7Be in presence of heavy targets

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Production of 7Li is linked to the production of 7Be, which in turn, is related to the reaction 3He + 4He –> 7Be + γ. Measuring this reaction rate is of utmost importance to shed light on 7Li abundance anomaly. A new approach to measuring the reaction rate could be measuring the reverse reaction of Coulomb dissociation of 7Be, preferably in the presence of a heavy target. A related experiment for resonance excitation in 7Be + d reaction, proposed by us, is already approved (INTC–P–350) at HIE-ISOLDE.

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Online TDPAC with digital spectrometers

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The ability of digital TDPAC spectrometers to process high count rates while providing flexible gating and evaluation options provides new opportunities for online measurements. In order to allow for online TDPAC measurements at ISOLDE, a specialized online TDPAC chamber will be build for the GLM branch.
We will present the concept of this chamber alongside first results of an online TDPAC experiment which was conducted at ILL during the ISOLDE shutdown as preparation for future ISOLDE online experiments.

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Numerical studies of the electron beam optics of REXEBIS

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During LS1 an incremental upgrade of the REX-ISOLDE charge breeder along with its regular maintenance is foreseen. The goal is to increase the ion acceptance, pulse frequency and intensity by minor changes in the electron optics and operation settings.
In this contribution we present a complete simulation of the electron beam transport through the entire EBIS. Reliable results can be achieved only with very fine mesh and time step resolving Larmor motion of the electrons (10 µm, 1E-13 sec). In this contribution we demonstrate how such a problem can be reduced to a practical solvable size. Preliminary results on new, modified electron beam optics for REXEBIS are presented.

Poster Session / 21

Lattice location of implanted 59Fe in 3C-SiC

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SiC is a wide band gap semiconductor with an increasing number of applications in high-temperature electronics. Similar to Si, transition metals (TMs) in SiC are the source of deep levels in the band gap, however, the knowledge on structural properties of TMs in SiC, such as possible lattice sites, is much less advanced. In this work we report first results on the lattice site location of implanted 59Fe (45 d) in single-crystalline cubic (3C)-SiC, evaluated by means of the emission channeling effect. Following 40 keV low-fluence (3 × 1013 cm□2) ion implantation, the □□ emission patterns from 59Fe implanted samples were measured with a position-sensitive electron detector around the <100>, <111>, <110> and <211> crystallographic directions. All measurements were performed at room temperature, starting with the as-implanted state and following 10 minute isochronal annealing steps up to 900 ºC in vacuum. While the data analysis is still in progress, so far clearly Fe atoms located on two different lattice sites have been identified. As-implanted, the major fraction of 59Fe (□24-30% before correcting for background from backscattered electrons), sits near tetrahedral interstitial sites with C atoms as nearest neighbours (TC). A smaller fraction (□14%) is located near substitutional Si sites (SSi). In both cases, however, the Fe atoms seem to be displaced roughly 0.1-0.3 Å from the ideal TC and SSi sites. Starting at an annealing temperature of 700℃ a decrease in the number of Fe at interstitial sites became obvious, however, this was not fully reflected in a corresponding increase in the amount of Fe on substitutional sites. The analysis of the experimental data is on-going and the use of three-site fits is likely to reveal further sites of Fe (e.g. TSi, SC) which may be occupied with minor fractions.

Poster Session / 60

The present status of production target development for Isotope Separation On-Line facility in Korea

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Rare Isotope Science Project (RISP) was launched by Institute for Basic Science (IBS) in December 2011 in Korea. We are developing Isotope Separation On-Line (ISOL) target system, which consists of 1.3 mm-thick uranium-carbide multi-disks and cylindrical tantalum heater, to provide various rare isotope beams for the researches in basic science and application. The intense neutron-rich nuclei are produced via the fission process using the uranium carbide targets with a 70 MeV proton beam. The in-target fission rate was estimated to be ˜1013/sec for 10 kW proton beam. The target system has been designed to be operated at a temperature of about 2000 oC so as to reduce the release time. For the uranium-carbide target, we are performing a development of the lanthanum-carbide disk having similar chemical characteristics with those of the uranium carbide owing to the difficulties of handling the radioactive material. The present design of the 10 kW ISOL target and the current status of the development of the lanthanum-carbide disk are briefly introduced.

Poster Session / 64

Testing the magic number N = 32 with multi-reflection time-of-flight mass measurements of the exotic potassium isotopes A = 52 and A = 53

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The mass is a unique property of an atomic nucleus, reflecting its binding energy and thus the sum of all interactions at work in the atom. Precise measurements of nuclear masses, especially of short-lived exotic nuclides with extreme proton-to-neutron imbalance, provide important input for nuclear structure and nuclear astrophysics investigations, for tests of the Standard Model, and for weak interaction studies. The Penning-trap mass spectrometer ISOLTRAP at the on-line isotope separator ISOLDE/CERN was set up and continuously improved for precision mass measurements of more and more exotic nuclides. Currently ISOLTRAP consists of four traps [1]: a linear radio-frequency quadrupole cooler and buncher, a multi-reflection time-of-flight mass separator (MR-ToF MS), and two Penning traps. In the MR-ToF MS, ions of interest are separated from isobaric contaminants within a few ten milliseconds by multiple reflections between two electrostatic mirrors, which allowed the fast selection of, e.g., 82Zn+ [2].
Until recently, ISOLTRAP's precision mass measurements were performed only with the well-established Penning Trap technique. However, the use of the MR-ToF device itself as a precision mass spectrometer has opened the door to nuclides with even shorter half-lives and lower production yields as demonstrated by mass measurements of the calcium isotopes 53,54Ca with sub-ppm uncertainty. These measurements revealed the magic neutron number N = 32 in the calcium isotopes by analysis of mass differences [3].
The investigation of the new magic number has now been continued by the mass determination of the potassium isotopes 52,53K+, neighboring isotones of 53,54Ca+. The N = 32 shell closure is observed again for the potassium chain, i.e. for the element that has one proton less than the closed Z = 20 proton shell of the calcium isotopes. In this contribution, the experimental S2N values for potassium will be presented and compared to HFB calculations.

[1] S. Kreim et al. NIM B, in press, 2013. http://dx.doi.org/10.1016/j.nimb.2013.07.072
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[3] F. Wienholtz et al. Nature, 498, 346-349, 2013. http://dx.doi.org/10.1038/nature12226

Poster Session / 61

Current status of the laser ion source development at RISP

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Development of the hot-cavity laser ion source is planned for the RISP ISOL facility to obtain pure ion beam. Recently, the laser system has been installed, and now the off-line test chamber is being designed. The laser system is composed of four tunable Ti:sapphire lasers (light sources for ionization), and one high power Nd:YAG laser (pump source of Ti:sapphire crystals). In the RISP ISOL facility, Be, Al, Ni, and Sn are planned to be ionized by laser ion source, and Ti:sapphire laser has been known to be available for the ionization of these elements. This presentation will show the plans and the status of the construction of the laser ion source in the RISP ISOL facility.

Poster Session / 9

Can we dope the wide gap Ga2O3 semiconductor? - ion implantation and hyperfine interactions studies

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The interest and study of nanomaterials has grown considerably in recent years due to promising applications in everyday's life technologies. With its relevance depending on tunable properties working at large-scale integration devices, a new battlefield is created since; small scale rules both new properties and new problems. By merging nanostructures with thin film technologies advantageous manufacture is expected where, particularly, ion implantation is investigated as a standard part of the tuning processes. But, ion implantation carries along with the benefits –universal dopant and profile tuning –intrinsic nuisances, i.e., defects created within such poor solubility compounds. A nanoscope tool is necessary, and nuclear hyperfine techniques can provide, at the appropriate scale, an inside view of these problems. When using radioactive elements, produced on-line at ISOLDE-CERN, the number of elements is extended, in particularly with the use of the Perturbed Angular Correlations (γ-γ PAC) technique, to characterize the probe's real environment at the atomic scale.
Moreover, it is also possible to use the e-γ PAC technique - which allows inducing an electronic excitation upon the conversion electron ejection from an atomic orbital - to study the dynamics of the electronic response in the atom neighboring as a function of temperature and time, ranging from the nano to the micro - second time scale. The response depends on the availability of charge carriers and on the intrinsic relationship impurity/dopant- host.
Finally, the experimental results are compared to DFT simulations of different atomic local models and charge configurations.
In the present work, the use of such techniques to study nanostructures of the wide band gap semiconductor Ga2O3 will be demonstrated.

Poster Session / 63

Towards Higher-Precision Mass Spectrometry of Rare Isotopes with ISOLTRAP

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One of the main goals of modern experimental nuclear physics is studying exotic nuclides far from the valley of stability of the nuclear chart. Measuring the mass of these nuclides allows gaining knowledge about the nuclear forces keeping nuclides bounded and about the resulting nuclear structure. ISOLTRAP is the Penning-trap mass spectrometer situated at ISOLDE-CERN used for high-precision measurements of the masses of radioactive ions [1, 2].
The Time-of-Flight Ion-Cyclotron-Resonance (ToF-ICR) technique is used at ISOLTRAP for cyclotron-frequency measurements. It has been successfully used for measuring the mass of ions with yields as low as 102 ions/μC and half-lives as short as tens of milliseconds with relative uncertainties of 10-8 [1]. Exotic nuclides with often lower half-life and minute production rates combined with high ratios of contaminating ions pose enormous challenges. Moreover, studies related to neutrino physics or fundamental interactions often require mass measurements with lower uncertainties than the

ones presently achievable [3, 4]. Different developments are thus ongoing at the ISOLTRAP setup to obtain higher precision.
Recently introduced, the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) method [5] is a promising approach to gain the higher precision. It consists in directly measuring the frequencies of the radial eigenmotions of the trapped ion by determining the evolution of the ions'radial phase, accumulated during a certain amount of time. An enhancement in precision of a factor of 5 and in resolving power of a factor of 40, as compared to the ToF-ICR technique, has already been demonstrated at SHIPTRAP [5]. Also, the PI-ICR technique is up to 25 times faster than the ToF-ICR technique. Thus, it allows investigating more exotic nuclides.
After refurbishment, the systematic uncertainties of the ISOLTRAP setup are being determined. For example, the mapping of the magnetic field has been performed to aim at minimizing its systematic influence. This contribution will briefly report on the current status of the ISOLTRAP setup, present ongoing studies for improving the achievable precision for measurements, and set the stage for an implementation of the PI-ICR detection technique.
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Poster Session / 59

Development of the SPEDE spectrometer

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In-beam spectroscopic techniques have long been one of the most prominent tools in our effort to disentangle and interpret complex nuclear structure phenomena. In heavy nuclei, where internal conversion increasingly competes with γ-ray emission, the simultaneous study of γ rays and conversion electrons can provide a much more complete image than either of them independently.
The SPEDE spectrometer [1] aims to combine a silicon detector, for the detection of electrons, with the MINIBALL γ-ray detection array for in-beam studies employing radioactive ion beams at the HIE-ISOLDE facility at CERN. The setup will be primarily used for octupole collectivity [2] and shape coexistence studies [3, 4] in Coulomb excitation experiments. In the shape coexistence cases the transitions between states of the same spin and parity have enhanced E0 strength [5]. Additionally the 0+à0+ transitions, typically present in nuclei exhibiting shape coexistence [6], can only occur via E0 transitions, i.e. via internal conversion electron emission. SPEDE is one of the first attempts to combine in-beam γ-ray and conversion electron spectroscopy with radioactive ion beams. This poster will present the current status of the setup.
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Isotope Separation On-Line facility for the Rare Isotope Science Project in Korea

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Rare Isotope Science Project (RISP) aims to construct world-class Rare Isotope Facility named "RAON" consisting of both Isotope Separation On-Line (ISOL) and In-flight Fragment (IF) facilities. The main goal of the ISOL facility is to deliver high quality intense neutron-rich beams to the experimental hall with a beam intensity of ˜105–109 particles/sec in the mass range of 80 < A < 160, using high power (>10 kW) direct fission target. Ion sources coupled with the fission target, such as a FEBIAD, a surface ionization, and a resonance ionization Laser ion sources, are being developed so as to produce various element ions. The ISOL facility consists of a RF-Cooler, a High Resolution Mass Separator (HRMS), charge breeders (ECR and EBIS types), and a charge state separator (A/q separator) for the beam purification. A current status of design of the ISOL facility for RISP is briefly introduced with an overview of RAON.

Poster Session / 37

A new neutron time-of-flight array for beta-decay studies

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The LPC Caen, in collaboration with CIEMAT (Madrid), is developing a new neutron time-of-flight array for structure studies, in particular the investigation of beta-delayed neutron emission from neutron-rich nuclei.

Our aim is an array with improved performance compared to existing arrays, with emphasis on better energy resolution, lower neutron energy threshold, and strong background rejection capability. The latter characteristic is crucial for multiple neutron detection, in order to study the most neutron-rich nuclei that can emit two or more delayed neutrons. Our development strategies involve the use of scintillators allowing neutron-gamma discrimination, and of digital DAQ and signal processing, as well as the characterisation of detectors with monoenergetic neutrons to measure intrinsic efficiencies and cross-talk probabilities.

A first version of the array will be used at ISOLDE in an experiment on the coincident detection of 2 neutrons following the decay of 11Li.

This talk will present the status of our development, in particular the performance of neutron-gamma discrimination with digital DAQ and the detector characterisation with monoenergetic neutrons.

Poster Session / 10

CRIS471: Combining laser and decay spectroscopy to study neutron-deficient francium

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The Collinear Resonance Ionization Spectroscopy (CRIS) experiment at ISOLDE uses laser radiation to stepwise excite and ionize an atomic beam for the purpose of ultra-sensitive detection of rare isotopes, and hyperfine structure measurements. The resonance ionization technique offers the ability to purify an ion beam that is heavily contaminated with radioactive isobars (including the ground state of an isotope from its isomer) allowing decay spectroscopy to be performed.

Laser assisted nuclear decay spectroscopy is a novel technique developed at CRIS to selectively ionize nuclear ground or isomeric states present in the ISOLDE beam for radioactive-decay measurements on pure states. The isomeric ion beam is selected using a resonance of its hyperfine structure, where it is deflected to a decay spectroscopy station (DSS). This consists of a rotating wheel implantation system for alpha-decay spectroscopy, and up to three germanium detectors around the carbon-foil implantation site for gamma-ray detection. The ability of CRIS to alpha-tag the hyperfine components of overlapping structures allows the hyperfine structure of two (or more) states to be separated.

Last year, collinear resonance ionization spectroscopy and laser assisted nuclear decay spectroscopy were performed on the neutron-deficient francium isotopes 202-207Fr. This allowed the identification of the hyperfine components of the low-lying states of 202Fr and 204Fr with alpha-spectroscopy. Here, we present the hyperfine-structure and radioactive-decay studies from the IS471 experiment campaign, alongside a brief overview of the CRIS beam line and the DSS.

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Laser spectroscopy of neutron-rich K isotopes

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Collinear laser spectroscopy provides a powerful high-resolution method for the investigation of the nuclear structure of the exotic nuclei. In combination with bunched ion beams a very high sensitivity can be reached. The hyperfine spectra of 48-51K (Z = 19) isotopes were observed at ISOLDE (CERN) for the first time. For this purpose, the CW laser was set to the 4s 2S1/2 ⟶ 4p 2P1/2 transition (769.9 nm) providing power of ˜1 mW into the beam line. In order to study 51K with a production rate of only ˜4000 ions/s, the optical detection system was improved, yielding a considerable reduction in background.
The ground-state nuclear spins of 49K (N = 30) and 51K (N = 32) were measured to be I = 1/2 and I = 3/2 respectively [1]. This points to the re-inversion to the normal order of the π2s1/2 and π1d3/2 orbits when filling the ν2p3/2, after their inversion for a completely filled ν1f7/2 (N = 28). In this way, the role of the monopole interaction in the evolution of the single-particle orbits is revealed. In addition, measured magnetic moments were compared to shell-model calculations performed for two different effective interaction, namely SDPF-NR and SDPF-U. From this comparison, the composition of the ground-state wave function was obtained indicating a strong mixing between and for 48,49K [2].

Additionally, the difference in the mean square charge radii were deduced from the observed isotope shift. There was no indication found for N = 32 being a sub-shell closure [3].

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[2] J. Papuga et al., Physical Review C, in preparation
[3] K. Kreim et al., Physics Letters B, submitted

Poster Session / 34

PIPERADE: A double-Penning trap isobar separator for the low-energy facility DESIR at SPIRAL2

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The next generation of Rare Isotopes facilities, such as SPIRAL2, HIE-ISOLDE, FAIR, RIBF aims to push further the borders of our knowledge about fundamental properties of exotic nuclei. To do so, these facilities require a production of high quality beam that is adapted to the needs of various experiments.
Besides production mechanisms, mass separation techniques are crucial for the improvement of the beam quality by reducing beam impurities.

At DESIR, the low-energy branch of the future facility SPIRAL2, in addition to the High Resolution Separator, a double Penning trap system, PIPERADE, built at MPIK in Heidelberg in close collaboration with CENBG in Bordeaux and CSNSM in Orsay, will be placed upstream the experimental hall as an alternative mass separator. Apart from its higher resolving power, a Penning trap has a high storage capability. Since DESIR will receive beam from different production lines (SPIRAL1, SPIRAL2 and S3), a large variety of exotic nuclei beams will be available to address various questions. The production of the exotic nuclei far from stability (with very low yield) might be accompanied with large amount of unwanted isobars. To allow high precision measurements, in addition to its high storage capacity, PIPERADE is designed to select ions of interest and distribute pure samples to experimental setups installed at the DESIR hall.

As an example, such intense and pure beam is critical for beta-decay spectroscopy and branching ratios measurements of super-allowed transitions in beta-emitters that will be conducted at DESIR. Another experiment that needs such beam is the high-precision measurement of the beta-neutrino angular-correlation parameter in beta-decays that will be performed with the LPCTrap.
It is also foreseen to perform high-precision mass measurements (with MLLTRAP) and laser spectroscopy (with LUMIERE) for nuclear structure and astrophysical r-process studies.

The main challenge of the PIPERADE double Penning trap system is to keep a high resolving power while dealing with large sample that introduces space charge effects. Thus, the traps are designed according to the simulation and tests of new excitation schemes that allow fast separation of ions of interest among a large amount of isobaric contaminants, which is of important for efficient transmission of low yield and extremely short-lived nuclei very far from stability.

The status of the project as well as first experimental tests that address space charge effects will be presented.

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HYPERFINE STUDIES ON GRAPHENE USING ISOLATED AD-ATOM PROBES

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The one-atom-thick crystal - graphene, uniquely combines extreme mechanical strength, exceptionally high electronic and thermal conductivities, as well as many other exotic properties, all of which make it highly interesting for fundamental physics and numerous applications.
The aim of this work is to use radioactive ad-atoms attaching to graphene to investigate several aspects:
The first motivation concerns the investigation of adhesion mechanisms of atoms alone or when forming clusters, their adsorption, migration and interaction with surface defects. Understanding how and if adsorption could be controlled could contribute to the development of innovative devices based on graphene, such as quantum detectors of single molecules with applications in catalysis and nucleation of clusters in nanostructures, ballistic transistors and spintronic devices.
The second motivation of our experimental, concerning the probing of fundamental electronic properties, relies on the type of experimental observables, which are the hyperfine fields measured by ad-atoms on graphene. The experimental method is the nuclear spectroscopy Perturbed Angular Correlations (PAC) technique that allows probing at the atomic scale the ad-atom/graphene interactions without further interference with the graphene electronic structure, other than its atomic bonding. We believe that any electronic perturbation at the level of the graphene intrinsic properties, either electric or magnetic will reveal at the highly sensitive hyperfine parameters, thereby providing unique local, single atom, information, which is impossible to obtain by other techniques like electron spectroscopy and electron microscopy techniques such as, AFM or STM, not exempted from interactions between the tip and the surface test or ad-atoms therein. By PAC measurements it can be determined the electric field gradient (EFG) and magnetic hyperfine field (MHF) at atomic scale, electronic structure and magnetic environment of ad-atoms.
In this brief communication we will present first results of the PAC hyperfine parameters obtained in graphene grown at different substrates as a function of different temperatures and different probing elements, 111mCd and 199mHg. To complement the experimental studies, ab initio simulations, using the software Wien2k and VASP, with the self-consistent LAPW+lo method to solve the Kohn-Sham equations and GGA approximation, have been implemented to simulate the charge density distribution of ad-atoms on graphene for different probe isotopes. This is the first step to attain the next objective that is to understand the Cd, and Hg (our PAC probes) interactions at the graphene layer. Minima of energy for the ideal bond length, the hiperfiines parameters and the charge distributions in the unit cells will be presented.
These are preliminary experimental and simulation results of a large portfolio of experiments and ideas, which are envisaged to come.

Technical HIE_ISOLDE / 0

Status of the HIE-ISOLDE project

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The HIE-ISOLDE project represents a major upgrade of the ISOLDE facility with a mandate to significantly improve the quality and increase the intensity and energy of radioactive nuclear beams produced at CERN. The focus of the upgrade is a 40 MV superconducting linac to increase the beam energy from 3 MeV/u to over 10 MeV/u, and which is based on thirty-two niobium sputter-coated quarter-wave resonators (QWRs) comprising two different families (βg = 6.3% and 10.3%) operating at 101.28 MHz. The project will expand the experimental nuclear physics programme at ISOLDE and permit Coulomb excitation reactions with the heaviest nuclei available at ISOLDE as well as transfer reactions across the nuclear chart. The existing REX linac will be upgraded in stages to first deliver beam energies of up to 5.5 MeV/u, with two high-β cryomodules placed downstream, before the energy variable section of REX is replaced with two low-β cryomodules and two additional high-β cryomodules are installed to attain 10 MeV/u. The superconducting linac will permit energy variation and flexibility never previously available at ISOLDE. It is also foreseen to install a multi-harmonic buncher upstream of the RFQ and a chopper system in the final stage to increase the bunch spacing from 10 ns to approximately 100 ns and allow time-of-flight particle tagging techniques to be exploited by the experiments.

A status report of the different R&D activities will be presented, including the progress of the construction and installation works.

Technical HIE_ISOLDE / 1

Charge breeding for HIE-ISOLDE

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To take full advantage of the HIE-ISOLDE upgrade and to make possible all experiments with TSR@ISOLDE a new charge breeder in the ISOLDE reacceleration branch is required. In this contribution we would like to raise the awareness of the user community on how charge breeding at ISOLDE can affect their experiments, outline the new opportunities and define the limits. The ultimate goals of the new charge breeder are: to increase the extraction repetition rate and therefore lower the instantaneous particle flux at the experiments; give access to higher beam energies in the 10-17 MeV/u range by lowering the A/g ratios down to 3; create the possibility for injecting HCI into the TSR at A/q 3 and provide by request few electron configurations of heavy ions up to Li-like uranium. We would also like to report on our recent experimental progress in our design study of a new generation high performance charge breeder suitable for HIE-ISOLDE and TSR@ISOLDE. The strategy and tentative time planning for the high-performance breeder will be presented as well.

Technical HIE_ISOLDE / 11

The TSR at ISOLDE: status and future prospects

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The goal of TSR@ISOLDE initiative is to place the Test Storage Ring (TSR) from MPI-K, Heidelberg, after the HIE-ISOLDE linac to perform experiments with stored exotic nuclides. With the integration of TSR at HIE-ISOLDE it would become the first storage ring at an isotope separator on-line facility. A substantial fraction of the vast number of radioactive beams produced at the ISOLDE facility could be injected into the ring for storage, beam deceleration or acceleration.

The initiative at its present stage will be summarized, specifically the interfacing of the ring with the HIE-ISOLDE linac and a tentative layout of experimental areas will be introduced. The results from the recently concluded extensive integration study covering the technical aspects of the move and integration into the CERN accelerator environment will be presented, in addition to next steps and future prospects.

Technical HIE_ISOLDE / 45

Status of Beam Dynamics Design Studies for the HIE-ISOLDE Energy Upgrade

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A status report covering recent design and machine development studies for the HIE-ISOLDE linac will be presented. The presentation will be focused on the design and specification of the 10 MHz bunching system to provide beams with an increased bunch spacing of ~100 ns. The feasibility of chopping the 'unbunched' background created during the bunching process will be demonstrated. Other studies will be introduced in the HIE-ISOLDE context: development of an automatic cavity tuning algorithm, studies of the REX A/q-separator, 3D electromagnetic simulations of the RFQ and the effects of stray magnetic fields on beam delivery in the experimental hall (HEBT).

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An Introduction to the HIE-ISOLDE Design Study

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The On-Line Isotope Mass Separator ISOLDE [1] is a facility dedicated to the production of a large variety of radioactive ion beams (RIB) for a great number of different experiments. Over 1000 radioactive nuclides from 70 elements can be produced in thick high-temperature targets via spallation, fission or fragmentation reactions with the PS-Booster pulsed proton-beam. With the arrival of CERN's new linear accelerator Linac 4 [2,3], ISOLDE will have the possibility to exploit a factor of 3 increase in proton-beam intensity and a possible proton-beam energy increase from 1.4 GeV to 2 GeV [4].
After 20 years of successful ISOLDE operation at the PS-Booster, a major upgrade of the facility, the HIE-ISOLDE (High Intensity and Energy ISOLDE) project was launched in 2010. It is divided into three parts; a staged upgrade of the REX post-accelerator to increase the beam energy from 3.3 MeV/u to 10 MeV/u using a super-conducting Linac, an evaluation of the critical issues associated with an increase in proton-beam intensity and a machine design for an improvement in RIB quality. The latter two will be addressed within the HIE-ISOLDE Design Study.

Protons/pulse	Intensity(μA)	Energy(GeV)	Cycle(s)	Power(kW)
3.3x10ˆ13	2.2	1.4	1.2	3.1
1x10ˆ14	6.7	1.4	1.2	9.3
1x10ˆ14	6.7	2.0	1.2	13.3

Table 1. Projected beam parameters considered within the HIE- ISOLDE Design study. Based on ISOLDE receiving 50% of available proton pulses from the PS-Booster.
This presentation will review the progress of the Design Study by outlining the critical issues being addressed concerning the intensity upgrade and beam quality.
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The RILIS and LIST status and prospects

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The Resonance Ionization Laser Ion Source (RILIS) is the most frequently used ion source at ISOLDE because it offers unmatched selectivity and high reliability without compromising the yield of the isotope of interest. Additional benefits such as isomer selectivity, laser on/off based beam diagnostics and low emittance have proven essential for many experiments. To date, ionization schemes for 31 elements have been developed for the ISOLDE RILIS and 27 of these have been used for on-line radioactive ion beam production. The RILIS operating time in 2012 exceeded 3000 h and ion beams of 13 elements were provided for 24 different experiments. This included the first on-line physics experiment to use the newly established Laser Ion Source Trap (LIST) for active suppression of surface ionized isobars.
In addition to routine maintenance and minor improvements to the RILIS installation, during the CERN long shutdown (LS1) period, a many-sided approach to improving the RILIS performance, reliability and operating conditions has been initiated. This includes the RILIS cabin extension; a machine protection and automation system to enable on-call operation; off-line ionization scheme development; high resistance cavity tests for improved selectivity by beam micro-gating; new laser beam launch system and reference area. Further optimization and characterization of the LIST has been performed at Mainz University and a new LIST design is being tested. A status report of these developments and an outlook towards the planned 2014 RILIS system will be presented.

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Status and progress of the target and ion source group activities.

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The presentation will give an overview of the status of current activities and developments in the ISOLDE target and ion source group. Besides the characterisation of widely used target materials, activities focus on the improvement of such in order to provide high yields of desired isotopes over extended periods. Moreover the work on new target designs such as the molten salt targets will be presented.

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Update of the ISOLDE DAQ

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An overview of the Data Acquisition Systems available for non-permanent experiments will be presented.

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First report on the inventory of radionuclides in 1.4 GeV proton irradiated thick Lead-Bismuth Eutectic (LBE) target

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In the planning of the EURISOL (European Isotope Separation On-Line) facility at CERN, the use of liquid Hg or Lead Bismuth Eutectic (LBE) was proposed as proton to neutron converter. The study on the impact of high energy protons (˜1-1.5 GeV) on the liquid Hg has already been carried out; however, handling of tons of liquid Hg has some practical difficulty, which may be overcome using LBE target. Hence, it is important to have a detailed knowledge on the production of radioisotopes in the LBE targets induced by the impact of high energy (1.4 GeV) protons. A target prototype phase, the so-called LIEBE (Liquid lEad Bismuth eutectic loop target for EURISOL) project with participation of CEA, CERN, IPUL, PSI, SCK-CEN and SINP is ongoing and foresees the operation of a direct LBE target at ISOLDE in 2015. In this framework, we have started a systematic program to investigate the impact of the target thickness on the production of radioisotopes, and more particularly addressing the highly radiotoxic Po and At known to occur through secondary particle reaction channels.

Eight cylindrical LBE targets having a fixed diameter of 6 mm with varying lengths from 1 to 8 mm weighing between 0.43 and 2.83 g were irradiated by 1-3 pulse of 1.4 GeV protons using the rabbit irradiation facility at CERN-ISOLDE. The intensity of the proton beam was 3.18×1012 protons/pulse for 1 and 2 mm length target and 3.22×1013 protons/pulse for the rest. We have analyzed two samples (2mm and 8mm) till date.

The impact of 1.4 GeV protons produced radionuclides of mainly 4th, 5th and 6thperiod elements of the Periodic Table. Most of the radioisotopes identified in sample length 2 mm are also present in sample length 8 mm. Additionally some more radioisotope production is seen in sample length 8 mm. The radioisotopes identified in both the samples ranged from 7Be (53.12 d) to 207Po (5.8 h). The list of produced radionuclides includes 206,207Po, 203-207Bi, 200,201,203Pb and other elements. The total number of radioisotopes identified in sample length 2 and 8 mm are 54 and 103 respectively. Apart from this, there are some radionuclides in both the samples which could not be confirmed due to overlap of photo-peaks and similar half life for different radionuclides. The modes of production of the radionuclides are mainly fission, electron capture decay of the fission products, fragmentation, spallation, etc. Also, typical reactions can be found in thick targets like 209Bi(p, pi-xn)210-xPo or 206Pb(alpha,xn)210-xPo. The highest activity observed in sample length 2 was for 172Lu (6.70 d) (˜610 Bq) and in 8 mm for 205Bi (15.31 d) (˜2800 Bq) at End Of Beam (EOB) in the experimental condition. It has been difficult to calculate the activity of short lived radionuclides, because of high Compton background in the initial spectra.

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The GRETINA science campaign at NSCL and FRIB status

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The US gamma-ray tracking array GRETINA just completed its first science campaign at the NSCL(MSU). An overview will be presented, showing selected results covering broad topics from nuclear structure physics and nuclear astrophysics. A brief summary of the FRIB status will be given.

Structure Medium Mass Nuclei / 39

Overview of Miniball results combined with decay spectroscopy studies for middle-mass nuclei

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Studying the region around the doubly magic nucleus 78Ni with the Z=28 and N=50 shell closures is particularly interesting for testing the validity of the contemporary nuclear models and for unraveling new aspects of the interactions used in these models. Especially the evolution of single-particle and collective phenomena between the harmonic oscillator shell closure at N=40 and the shell closure at N=50 challenges our understanding of the nuclear structure. In recent years, intense experimental and theoretical work has resulted in a substantial progress in our understanding of the nuclear structure in this region, but still several questions remain. A large part of the experimental data available has been obtained at ISOLDE exploiting Coulomb Excitation reactions at safe energies with the Miniball setup. In recent years the availability of a system for measuring transfer reactions has extended the possibilities of Miniball. With this setup it is even possible to perform transfer reactions using a radioactive beam and a radioactive tritium target. These results have been complemented by the data coming from decay spectroscopy, like the beta-decay studies of neutron-rich Mn isotopes.

In this contribution we will highlight some of the physics results from several experimental campaigns. An outlook to the opportunities in decay spectroscopy with the new Isolde Decay Stations (IDS) and in nuclear reactions at HIE-ISOLDE will be presented.

Elisa Rapisarda for the Miniball Collaboration

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Collectivity of 4+ states in heavy Zn isotopes

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Shell evolution in the vicinity of 68Ni 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 1g9/2 and 2d5/2 neutron orbital induces collectivity by pair excitations from the fp shell into the g9/2 orbital, the parity change hinders quadrupole excitations and therefore mimics the properties of a doubly magic nucleus in 68Ni, 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 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. Coulomb excitation studies at ISOLDE (74,76Zn [1]) as well as a DSAM lifetime measurement in 70Zn [2] suggested an important increase of collectivity of the 4+ state for heavy Zn isotopes with a maximum at N=40. However, a recent RDDS lifetime measurement performed with AGATA Demonstrator in Legnaro [3] yielded lifetimes of the 4+ states in 70-74Zn that are considerably longer and correspond again to B(E2; 4+ ⟶ 2+)/ B(E2; 2+ ⟶ 0+) ratio lower than 1. The observed discrepancy between lifetime and Coulex data triggered further measurements of transition probabilities in heavy Zn isotopes. In order to decide between the two experimental values of B(E2; 4+ ⟶ 2+) in 70Zn, a dedicated Coulomb excitation measurement was performed at HIL Warsaw. Coulomb excitation studies of neutron-rich Zn isotopes will be continued at HIE-ISOLDE (IS557).

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Multiple Coulomb Excitation of 72Zn with MINIBALL at ISOLDE using a new Coulex silicon geometry

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The standard Coulomb Excitation setup at MINIBALL uses a forward CD at fixed distance to the target, only. We built a new setup, based on the T-REX design, to allow a variable distance of the forward CD as well as to cover backward angles in the laboratory frame. This allows to use high intense beams and gives better insight into multiple coulomb excitation studies. Multiple coulomb excitation studies will be performed intensively at HIE-ISOLDE at 5 MeV/u and more.
The new setup was used for a couple of experiments in autumn 2012 at ISOLDE. We here present this new setup and show spectra of 72Zn after multiple coulomb excitation using intensities of more then 10ˆ8 pps. The good statistics for the 4+1 gamma decay will contribute to the ongoing discussion on diverging data from experiments using AGATA and MINIBALL on 4+1 states in the neutron-rich zinc isotopes.

Structure Medium Mass Nuclei / 33

Fast timing studies of collective and single-particle features near 78Ni

Authors: Alfredo Poves[1]; Bruno Olaizola[2]; Dan Gabriel Ghita[3]; Gary Simpson[4]; Henryk Mach[5]; Ioana Gheorghe[3]; Luis Mario Fraile[2]; Nicolae Marginean[3]; Razvan Lica[3]; Ulli Koester[6]; Vadym Paziy[2]

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There is a strong interest in the properties of the exotic doubly magic 78Ni. 78Ni itself is at the edge of the experimental reach, thus most of the experiments concentrate on its very close neighbors located North and North-East, as well as South-West, which can be studied in some detail. This presentation provides an overview of the current status of the fast timing experiments IS441 and IS474 recently performed at ISOLDE. They are part of wider research effort on this region using different experimental probes.

In the IS441 we have studied the levels in heavy Ga nuclei populated in the beta decay of Zn. The current analysis is focused on the decays of 80, 81 and 82Zn. This region shows very small collectivity and reveals the single particle features. The experiment IS474 probes the heavy Fe nuclei at the neutron number ˜40 which show a strong increase in the quadrupole collectivity with an increase of the neutron number. The current analysis includes 63,65 and 66Fe.

The Fast Timing probe is particularly effective on the odd-A and odd-odd nuclei where sub-nanosecond lifetimes allow to clarify the nature of the observed excited states. Results will be presented on these nuclei.

Structure Medium Mass Nuclei / 7

Search for tetrahedral states in Yb nuclei with N˜90 through Coulomb excitation using HIE-ISOLDE and Miniball

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The 160Yb nucleus (Z=70 and N=90) is double-magic with respect to the predicted Tetrahedral symmetry. Even if already studied in heavy-ion induced reactions, neutron spallation and β+-decay, the non-yrast low-spin states and their properties are not well known. In particular it is not clear if a 3- state exists in 160Yb, which could belong to the tetrahedral band. We propose to study the properties of the low-spin states in the radioactive nucleus 160Yb by Coulomb excitation using the HIE-ISOLDE facility and the Miniball array. We we also like to study for the first time through Coulomb excitation the 162,164,166,Yb isotopes.The information acquired from the experiment will give important insights into the X(5) symmetry predicted for the N˜90 nuclei, into the CBS (confined β-soft) rotor model which describes the transition between X(5) and the rigid rotor limit, and the existence of mixed symmetry states.These different phenomena and their manifestation in the Yb nuclei will be discussed.

Astrophysics / 53

Exotic nuclei and explosive nucleosynthesis

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In this talk I will review recent advances in the description of the structure of exotic nuclei and their impact in supernova evolution and explosive nucleosynthesis.

Astrophysics / 54

Towards a nuclear explanation for the large amount of 44Ti produced in Core Collapse Supernovae

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The most massive stars of the Universe suffer the fate of core collapse. Despite much recent progress, the underlying mechanism that allows such stars to subsequently explode is still not fully understood. A satellite based gamma-ray observation of the isotope 44Ti may hold the key to resolving

this problem. The amount of this isotope in stellar ejecta, available for detection, is thought to depend on the explosion mechanism. However, to enable such a deduction the 44Ti(a, p)47V nuclear reaction rate must be better known as it contributes a significant uncertainty to the quantity of 44Ti produced.
A direct measurement of this reaction has been performed at the ISOLDE facility, CERN, at energies within the Gamow window of core collapse supernovae. The experiment employed a beam of 44Ti derived from highly irradiated components of the SINQ spallation neutrons source of the Paul Sherrer Institute. Results will be presented.

Astrophysics / 52

General Interest Talk - Nuclear Astrophysics at n-TOF

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After a brief description of the n_TOF facility and of the experimental setups employed for capture and fission measurements, an overview of the most notable results obtained so far in the first experimental area (EAR1) - especially focused on nuclear astrophysics - will be presented in the seminar. The capability of the facility and the extent of the experimental program will be significantly expanded with the new vertical experimental area (EAR2), presently under construction and ready by mid-2014. This upgrade will open the possibility to measure neutron-induced cross-section on low mass samples and drastically increase the measurement sensitivity.
A report on the future measurements proposed by the n_TOF Collaboration over the course of the next few years will also be given.

Applications I / 55

2-dimensional electron gases in oxide heterostructures

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Oxide materials display within the same family of compounds a variety of exciting electronic properties ranging from ferroelectricity to ferromagnetism and superconductivity. These systems are often characterized by strong electronic correlations, complex phase diagrams and competing ground states. This competition makes these materials very sensitive to external parameters such as pressure or magnetic field. An interface, which naturally breaks inversion symmetry, is a major perturbation and one may thus expect that electronic systems with unusual properties can be generated at oxide interfaces. A striking example is the interface between LaAlO3 and SrTiO3, two good band insulators, which was found in 2004 to be conducting [1], and, in some doping range, superconducting with a maximum critical temperature of about 200 mK [2]. The characteristics observed in the normal and superconducting states are consistent with a two-dimensional electronic system.
In this presentation, I will briefly motivate the search for novel properties at oxide interfaces before to focus on the 2-dimensional electron gas observed in at the LaAlO3/SrTiO3 interface. The thickness of the electron gas is found to be a few nanometers at low temperatures. This electron gas with low electronic density, typically 5 10ˆ13 electrons/cm2, and naturally sandwiched between two insulators is ideal for performing electric field effect experiments allowing the carrier density to be tuned. I will discuss the origin of the electron gas [3]; field effect experiments and the phase diagram of the system [4]; superconductivity and the role of spin orbit [5,6]; and if time allows the physics of high mobility samples that display Shubnikov de Haas oscillations [7].

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Applications I / 5

Defect annealing in TiO2 (rutile)

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TiO2 has a wide range of applications. It is used as pigments in paints, sunscreen and food products, and as a photocatalyst, where doping by ion-implantation has been found useful to tailor the photocatalytic properties. TiO2 is used as a host for the upconversion process and in recent years there have been reports on dilute magnetism in this system, where the charge state of Fe is of importance.

A study of the annealing processes and charge state of dilute Fe in rutile TiO2 single-crystals was performed in the temperature range 143-662 K, utilizing on-line 57Fe emission Mössbauer spectroscopy following low concentrations (<10-3 at.%) implantation of 57Mn (T½ = 1.5 min.). Both Fe3+ and Fe2+ were detected in the entire temperature range. Three annealing stages were distinguished:
i) A broad annealing stage below room temperature leading to an increased Fe3+ fraction.
ii) A sharp annealing stage at ˜330 K characterized by conversion of Fe3+ to Fe2+ and changes in the hyperfine parameters of Fe2+, attributed to the annealing of Ti vacancies in the vicinity of the probe atoms.
iii) An annealing stage in the temperature range 550 to 600 K, where all Fe ions are transformed to Fe3+, attributed to the annealing of the nearby O vacancies.

The dissociation energy of MnTi-VO pairs was estimated and Fe3+ found in a paramagnetic state with slow spin-lattice relaxation which does not follow the expected T2 dependence expected for a Raman process.

Applications I / 15

Dynamic off-centering of Cr3+ ions and short-range magneto-electric clusters in CdCr2S4

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Magnetoelectric materials experience a renewed interest due to its enhanced multifunctional properties, which are extremely appealing for technological applications into memories that could be written electrically and read magnetically or vice-versa [1,2]. Such properties can be affected by local distortions at the atomic scale, therefore requiring understanding the role of the local, polar and magnetic clusters3. Local distortions are of special importance on a class of disordered materials, the relaxor-like ferroelectrics, where in many cases we find the competition/coexistence between short-range and long-range order. Among these relaxor-like systems appears CdCr2S4 chalcogenide4.
Our experimental findings, based on complementary Pair Distribution Function (PDF), Perturbed Angular Correlations (PAC), Magnetization [M(T)] and Dielectric ε(T) measurements, address the presence of a new dynamic state caused by the presence of simultaneous polar and magnetic clusters, "multiferroic clusters". The nature of the effects described in the recent literature is set to arise from the atomic displacement of Cr3+ well above the ferromagnetic ordering temperature. These new insights directly prove the existence of Cr3+ ion off-center displacements, to happen with the onset of local polar distortions. PDF analysis shows small displacement of the Cr3+ site (Δrmax≈0.015 Å) explaining the low polarization values obtained. Additionally, Electric Filed Gradient (EFG) measurements evidence the dynamic character of the off-centering which leads to the formation of local electric dipoles, which are also responsible for the observed magnetic correlations between Cr3+ neighbors. This correlation between electric and magnetic orders is shown to justify the peculiar low-field χ−1 (T) measurements. Additionally, upon considering the Landau theory of phase transitions with an expansion of the free energy of a multiferroic system including a bi-linear magnetoelectric coupling term, the simulated results match the experimental ones.5

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Applications I / 18

Lattice location and thermal stability of the implanted transition metals Fe, Co and Ni in silicon of different doping types

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Although vacancy-type defects are known to getter transition metals (TMs) in silicon, detailed information on their interaction, e.g. the lattice sites occupied by the TM trapped in the defects, is still poor. Emission Channeling (EC) is a technique that allows us to obtain the preferred sites of the TMs inside these vacancy-type complexes by implanting single crystals with radioactive probe atoms that decay by the emission of beta particles. On their way out of the crystal, beta particles experience channeling effects along crystallographic directions, depending on the lattice site occupied by the probe atom. In this work, we have studied the lattice location of the transition metals 59Fe (t1/2 = 45 d), 61Co (t1/2 = 1.6 h) and 65Ni (t1/2 = 2.5 h) in Si single crystals of various doping types (i, n+, p+) by means of EC at the ISOLDE facility/CERN.

By comparing our two-dimensional experimental patterns with simulations we obtained direct evidence of Fe [1,2], Co and Ni occupying at least three different lattice sites: ideal substitutional (S), displaced bond-center (near-BC) and displaced tetrahedral interstitial sites (near-T). We show that the stability of some sites depends on the doping of the material, e.g. near-BC sites are more stable in n+-type than in p+-type Si. Although we observed the same lattice sites for the three transition metals, some differences can also be found. In particular, while Ni is trapped in near-T sites only after high temperature anneals for all the doping types of silicon, Fe and Co seem to prefer near-T sites in p+-type Si even at room temperature. This can be partially explained by the pairing of Co and Fe with the dopant B in near-T sites, while Ni seems not to respond to the negatively charged dopant. Also, while Fe and Co show considerable stability against annealing even at 900℃, Ni starts to show partial out-diffusion from the samples already in the 600-700℃ range, indicating that vacancy-type defects are less stable gettering centers for Ni than for Fe and Co.

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Applications II / 43

CERN-MEDICIS (MEDical Isotopes Collected from ISOLDE): A new facility

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About 50% of the 1.4GeV CERN's protons are sent onto targets to produce radioactive beams by online mass separation at ISOLDE, for a wide range of studies. As reported at the last Isolde users workshop, CERN-MEDICIS is a spin-off dedicated specifically to R&D in life sciences and medical applications. It is located in an extension of the Class A building presently under construction. It will comprise laboratories to receive the irradiated targets from a new station located at the dump position behind the ISOLDE production targets. An increasing range of innovative isotopes will thus progressively become accessible from the start-up of the facility in 2015 onward, for fundamental studies in cancer research, for new imaging and therapy protocols in cell and animal models, and possibly extended to specific pre-clinical studies. 500MBq isotope batches purified by electromagnetic mass separation combined with chemical methods will be collected on a weekly basis. Progresses witnessed since the last workshop will be reported here, with a milestone met with civil-engineering-related activities started already this summer and a groundbreaking ceremony that took place in September. The scientific scope has also been further elaborated. Finally, future upgrades and links to facilities where GBq pharmaceutical-grade (i.e., cGMP) batches can be produced will also be reported.

Applications II / 41

199mHg AND 111mCd-PAC SPECTROSCOPY: APPLICATIONS IN COORDINATION CHEMISTRY AND BIOCHEMISTRY

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Application of perturbed angular correlation (PAC) of γ-rays spectroscopy in coordination chemistry and biochemistry is well established [1]. Over the past few years we and our collaborators have applied this technique to elucidate structure and dynamics at metal sites in proteins. In addition, we have applied quantum chemical methods to explore how the spectroscopic properties are affected by change of molecular structure and of type of coordinating ligand. Recent results will be presented [2,3].

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Applications II / 27

Metal ion interaction of peptides imitating the metal binding domain of CueR metalloregulatory proteins

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Metalloregulatory proteins are key elements of bacterial metal homeostasis and resistance regulating the metal ion transport/storage/detoxification systems at a transcriptional level. The copper-efflux

regulator CueR belongs to the MerR protein family the members of which are dimers and all possess a characteristic short metal binding domain close to the C-terminus of each monomer. The sequential/structural diversity found in this Cys-Xn-Cys (n = 6-10) loop is a key factor in allowing the sensing of a variety of metal ions [1] and in many cases, the selection of the cognate ones. CueR exhibits an outstanding selectivity for monovalent group 11 metal ions but no transcriptional regulation activity for Hg(II) or Zn(II).[2] It was shown that the thiolate donor groups of the metal binding loop restricts the metal ions into a linear coordination geometry, but besides this, other factors were also suggested to play a role in distinguishing between divalent and monovalent ions.
To have a better understanding of this metal ion selectivity we have synthesized oligopeptides comprising fully or with slight modifications the metal binding loop of various CueR proteins and investigated their interaction with the group 12 metal ions Zn(II), Cd(II) and Hg(II). pH-potentiometry, UV-titrations, SRCD, NMR and 199mHg PAC spectroscopy (performed in the ISOLDE Facility at the CERN) have all been applied to monitor whether Asp or His residues, besides the Cys units of the ligands, or the flexibility of the sequences may significantly influence the metal binding features. We have found that while Hg(II)-binding takes place via the sulfur donors of the Cys-thiolates only, side chains of His and/or Asp also play a role in coordinating Cd(II) and Zn(II).[3] Preliminary results on the Ag(I)-binding of one of the peptides suggests surprising differences in the binding modes of Ag(I) and Hg(II). While further experiments with the peptides and monovalent metal ions (studies with Cu(I) are also planned) are in progress, we are also working on the synthesis of the native CueR of E. coli. Comparison of the metal binding features of the macromolecule and the related peptides is likely to provide answers for the question: on what level the metal ion recognition really occurs.

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Applications II / 30

Origin of unusual Ag diffusion profiles in CdTe

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Radiotracer experiments are the most sensitive tool for the study of diffusion phenomena in solids. At ISOLDE/CERN diffusion experiments have been performed using 111-Ag delivered for implantation by ISOLDE.
It has been shown that in CdTe 111-Ag exhibits the phenomenon of uphill diffusion, which under suitable conditions (800 K, 60 min, Cd-pressure) results in the formation of symmetric concentration-depth profiles that are strongly peaked about the center of a several 100 µm thick crystal [1,2]. The phenomenon of uphill diffusion is quantitatively understood and successfully described by a theoretical model [3,4] leading to the conclusion that the dopant profile essentially images the profile of the deviation of stoichiometry generated by the diffusion of Cd-interstitials into the initially Te-rich CdTe crystal.
Uphill diffusion can be observed also at significantly lower diffusion temperatures down to 450 K, if metal layers are evaporated onto the implanted surface of an initially Te-rich CdTe crystal [5]. We assume that a Cd-rich layer between the metal and the CdTe crystal is formed, which is responsible for the in-diffusion of Cd-interstitials into the Te-rich material. This creates a deviation of stoichiometry, which is imaged by the dopant, leading to the uphill profiles.

In addition, it is possible to image a profile of the deviation of stoichiometry generated before the implantation of the radiotracer. For this purpose a metal layer was evaporated onto the surface of a CdTe crystal, which subsequently was annealed at a temperature of 470 K. After removing the metal layer by etching, 111-Ag was implanted followed by annealing at 550 K in order to diffuse the dopant. The 111-Ag dopant showed an uphill diffusion profile as expected.
The experimental data indicates that the composition of the surface present during the annealing process influences the diffusion of the 111-Ag dopants significantly. This is further supported by experiments showing that uphill diffusion can be initialized also by an etching procedure leaving behind a Cd-rich surface. In contrast, this seems not to be the case if an etching procedure creates a Te-rich surface.

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Versatile Ion-polarized Techniques Online (VITO) at ISOLDE

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The planned upgrade of the RB0 line at ISOLDE, currently hosting the ASPIC apparatus, will be presented. The newly designed UHV beam line –reborn as the VITO experiment –will have three end stations allowing for carrying out versatile and multidisciplinary experiments: the ASPIC end station, the β -NMR end station and at a later stage an open station for traveling experiments. The major enhancement of the new line will be the introduction of laser-based nuclear spin polarization of the isotope beams, which will allow for establishing laser and β-NMR spectroscopies in a wide range of sample environments realized in all end-stations.
The new project has been positively evaluated by the INCC committee and the work on the beam line has started. The scientific program presented the INTC committee in Summer 2013 has been endorsed.

Medium towards Heavy Nuclei I / 8

Pear-shaped nuclei

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In this talk I will describe how recent experiments carried out at REX-ISOLDE at CERN have found new examples of reflection asymmetry in heavy nuclei. I will discuss how the new measurements are constraining nuclear theory and how they can contribute to tests of extensions of the Standard Model.

Medium towards Heavy Nuclei I / 56

EDM experiments with Nuclear Probes

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Searches for violations of the fundamental discrete symmetries parity (P), time reversal (T) and charge conjugation (C) are of outmost importance for the model building in physics and looking beyond the Standard Model of the electroweak interactions (SM). Permanent electric dipole moments (EDMs) are particularly sensitive probes to look for minute violations with a robust discovery potential. The EDMs are strongly suppressed in the SM to a level far below the experimentally reachable sensitivity. However, different experiments have provides limits to possible extensions to the SM.
The effects of symmetry violations are strongly enhanced in heavy atomic systems. This permits to derive stringent limits from precision atomic physics experiment. The sensitivity of a particular experimental approach depends on several parameters. Such are: i) possible intrinsic enhancement factors due to atomic and nuclear structure [1] which are particularly large for short lived elements around the nuclear charge 86-88 (Rn, Fr, Ra) which exhibit nuclear deformations [2]; ii) the number of available particles for the experiment which are available e.g. at the ISOLDE facility for the production of heavy elements [3]; and iii) the experimental procedure. The experimental work toward an EDM measurement with heavy nuclear probes [3] and the prospects for a sensitive EDM search at ISOLDE will be discussed. Furthermore, atomic parity violation (APV) is enhanced in the same type of heavy nuclei. A measurement of the weak mixing angle with a five-fold improvement over existing experimental results is reachable with a single trapped radium ion [4].
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Cluster-transfer reactions with radioactive 98Rb and 98Sr beams on a 7Li target

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We report on an exploratory experiment performed with MINIBALL coupled to T-REX [1-2], to investigate neutron-rich Sr and Y nuclei around mass A = 100, by cluster transfer reactions of neutron-rich 98Rb/98Sr beams on a 7Li target. The aim of the experiment was on one hand to perform a gamma-spectroscopy study by transfer reactions of
neutron-rich Sr and Y nuclei beyond N=60 populated, so far, only via beta-decay and spontaneous fission experiments[3]. On the other hand we wanted to acquire experience in using cluster transfer reactions with the weakly bound 7Li target, in order to perform, at a later stage with HIE-ISOLDE, similar measurements induced by neutron-rich
radioactive beams of Sn and Hg, for which at least 5 MeV/nucleon are needed to overcome the Coulomb barrier. The present experiment is therefore meant as a first step of a research program aiming at
gamma-spectroscopy studies of the low-lying structures in Sb and Tl isotopes located close to 132Sn and 208Pb, respectively.
In the experiment, a 98Rb beam, and a strong component of its beta-daughter 98Sr, were accelerated at 2.85 MeV/A on a 1.5 mg/cm2 thick LiF target. The experiment lasted 3 days, with an average beam current of 2·10ˆ4 pps. 7Li nuclei are particularly suited to study cluster transfer reactions since they can be described as an alpha and a t cluster that easily break up due to a small binding energy of 2.5 MeV, with a sizeable probability of one of the two fragments to
be captured [4]. The MINIBALL/T-REX [1-2] set-up allowed to detect the complementary charged particle emitted in coincidence with the
gamma-cascade of the excited system created by the transfer, giving a very clean trigger on the final populated residues.
gamma-rays have been detected after two or three evaporated neutrons and levels with spin up to 6 hbar have been observed. The reaction mechanism has been investigated by studying the cross section for both t and alpha transfer as a function of the excitation energy of the final nucleus and of the scattering angle. The experimental results have been compared with theoretical calculations, performed by the FRESCO code [5], considering a DWBA transfer of a cluster-like particle in 7Li to the continuum, showing that the model can predict with qualitative agreement the excitation energy distribution of the final products. Furthermore, the calculated angular distributions can reproduce the ratio between t and alpha cross sections measured experimentally, suggesting a proper description of the direct nature
of the process.
In conclusion, the present study shows that cluster transfer reactions can be consider as a valuable tool to study nuclear
structure far from stability, encouraging their future application with heavier neutron-rich HIE-ISOLDE beams.

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Coulomb excitation of 140Sm

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The open-shell nuclei with Z>50 and N<82 are known to have some of the largest ground- state deformations in the nuclear chart. The shape of the nuclei in this region are expected to be prolate, except for a small island of nuclei with Z>62 and N≈78, which are predicted to be oblate. Nuclei near 140Sm are therefore expected to be located in a transitional region between deformed and spherical shapes (as a function of neutron number) and between prolate and oblate shapes (as a function of proton number), and shape coexistence may be expected to occur. Indeed, a low-lying excited 0+ state was tentatively assigned in 140Sm, which could be interpreted as a sign for shape coexistence. The measurement of spectroscopic quadrupole moments and transition strengths represents a sensitive test for theoretical predictions in this region. Due to the occurrence of two isomeric 10+ states of \pi(h_{11/2})^2 *and*\nu(h_{11/2})^{-2} $ configuration the lifetimes of low-lying states are completely unknown. A Coulomb excitation experiment with a 140Sm beam on a 94Mo target was performed at ISOLDE with the typical setup comprising Miniball and a DSSD in June/July 2012. The laser- ionized beam of 140Sm was quasi-pure with an average intensity of 2*10^5 particles per second. At least three excited states in 140Sm were populated during the experiment: the 2+ and 4+ states of the ground-state band and the tentatively assigned 0+ state at 990 keV excitation energy. The statistics collected during the experiment allows the analysis of differential Coulomb excitation cross sections as a function of scattering angle. Experimental details and first preliminary results obtained in the analysis with GOSIA2 will be discussed.

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Studies of nuclear structure using the ISOLTRAP mass spectrometer

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The ISOLDE Penning-trap mass spectrometer ISOLTRAP has constantly been subject to state-of-the-art upgrades pertaining to one of the world's leading Penning-trap mass spectrometers. The current setup of ISOLTRAP consists of four ion traps [1]. The linear segmented radio-frequency quadrupole is used for ion-beam accumulation, cooling and bunching. Afterwards, the ion bunch is transferred to a multi-reflection time-of-flight mass separator (MR-ToF MS), where ions of interest are separated from isobaric contaminants within a few ten ms after multiple oscillations between two electrostatic mirrors (resolving power on the order of m/Δm ≈ 1.0E5). The MR-ToF MS has been employed not only as a purifier [2], but also as a mass spectrometer, measuring masses of short-lived nuclei [3]. In the subsequent preparation Penning trap, the buffer-gas cooling technique is used for further beam purification reaching similar resolving powers. In the last step, the purified ion sample is stored in the precision Penning trap, where the time-of-flight ion-cyclotron-resonance technique is used for mass determination, routinely reaching relative uncertainties on the order of 1.0E−8.

The evolution of nuclear structure far away from the valley of beta stability can be studied through different observables. Measurements of the mass of an atom yield its binding energy and thus information on nuclear interactions determining its structure. We will present recent mass measurements of exotic nuclei addressing various topics of nuclear structure. First, the emergence of a new magic number in asymmetric systems through the recent mass measurements of 52−54Ca and 51−53K will be discussed. In the case of Ca, we could investigate, through dedicated calculations, the contributions due to three-nucleon (3N) forces. The microscopic calculations showed an excellent agreement with our obtained values of the two neutron separation energies [3]. Secondly, new mass measurements of nuclei around A ~ 100 will be shown. The experimental observables suggest a sudden onset of deformation in this region. We have carried out a theoretical study exploring nuclear deformation by employing the newly measured 99,100Rb masses. The studied nuclei in our investigation exhibit a variety of intrinsic shapes, with stable prolate and oblate configurations lying close in energy [4]. Finally, we will present a study of the isomerism in neutron-deficient 190,194Tl isotopes. Mass measurements led to the determination of the excitation energies of isomers in Tl nuclei. Furthermore, by coupling mass spectrometry to nuclear spectroscopy, the spin-state ordering in those nuclei could be unambiguously assigned [5].

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Fundamental properties of heavy nuclei studied with laser spectroscopy

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High-resolution optical measurements of unstable atoms provides some of the most fundamental nuclear properties: spin, nuclear moments, mean-square charge radii. The simple fact that an observation of an optical resonance has been made, confirms the existence of a new nuclide or long-lived nuclear state. By performing systematic measurements across isotope chains it is possible to elucidate structural changes and the onset of new phenomena. These measurements are compelling since they do not rely on the assumptions of any particular nuclear model and rather provide a rigorous test of existing models. There has been considerable attention focused onto the heaviest nuclei in the last 10 years, with many exciting new measurements made at the very limits of stability. This talk will present a summary of the latest achievements and future developments in this region of the chart.

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On Line Nuclear Orientation (OLNO) in Europe

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Low temperature on-line nuclear orientation is a technique dedicated to the study of the decay of polarized exotic nuclei. A He3-He4 dilution refrigerator provides very low temperature (˜10 mK) allowing nuclei to reach a large degree of polarization in the hyperfine field which exists at nuclei implanted into a ferromagnetic metal host. The decay products can be observed using proton, alpha or beta-particle detectors fitted within the cryostat and/or external gamma or neutron detectors, providing a very versatile instrument.

Oriented nuclei give access to a wide range of experiments. These include a precise measurement of nuclear moments using the NMR technique and the observation of beta-decay to, and gamma emission from, excited states in the daughter nucleus to study aspects of nuclear structure. As a special feature of LTNO, far-reaching studies of fundamental weak interactions and associated symmetries can be made as well as investigations into parity nonconservation.

The worldwide situation is that the only existing on-line system is the NICOLE experiment at ISOLDE/CERN. Another is being installed at ALTO: PolarEx. A common physics program is being built based on the complementarity of the two installations. We will present the most recent result obtained at ISOLDE with NICOLE, namely the measurement of the magnetic moment of 49Sc [Phys.Rev.Lett. 109 (2012) 032504] and will outline new proposals, in particular the study of beta-delayed neutrons from oriented 137,139I and 87,89Br.

The current status of the program at ALTO will be reported.

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Collinear resonance ionization spectroscopy of neutron rich 218m,219,229,23 isotopes

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The physics results on the neutron rich 218m,219,229,231Fr isotopes from the Collinear Resonance Ionization Spectroscopy (CRIS) experimental run in October 2012 at ISOLDE, will be presented. These isotopes are located on the borders of the actinide region in which nuclei are known to posses reflection asymmetric shapes. 218g,219Fr have previously been interpreted as octupole vibrational nuclei in the transitional region between nuclei possessing stable octupole deformation and nuclei with spherical shapes. 229,231Fr are located on the neutron rich side of this region of reflection asymmetry and have not been studied in detail before.
The magnetic dipole moment values as well as the relative mean square charge radii of these isotopes were extracted from the measured hyperfine spectra. This allows conclusions to be presented based on the general trend of the relative mean square charge radii of Fr isotopes. Additionally, the relation of the odd-even staggering effect of the isotope shift and presence of reflection asymmetric shapes will be discussed for the case of Fr. Finally, information on the valence nucleon orbital occupation for 219,229,231Fr and its implication on the spin values of 229,231Fr will be presented.

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Welcome

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