ISOLDE Workshop and Users meeting 2017

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Book of Abstracts

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Welcome

Corresponding Author: gerda.neyens@cern.ch

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Thirty years with ISOLTRAP at ISOLDE

Author: David Lunney[1]

[1] *Université Paris-Saclay (FR)*

Corresponding Author: lunney@csnsm.in2p3.fr

Proposed by Heinz-Juergen Kluge in 1980 and installed in 1986, ISOLTRAP was the world's first Penning trap connected to a radioactive beam facility. Since then, ISOLTRAP has pioneered most of the techniques now associated with on-line ion trapping and manipulation for precision measurements of atomic masses. After an introduction of physics motivation, a brief history and description of the ISOLTRAP spectrometer is given, followed by an overview of the numerous developments and scientific results achieved since Juergen's presentation at this workshop 10 years ago. Plans for the next 10 years will also be addressed.

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Progress of mass measurements of short-lived nuclides at the heavy-ion storage ring in Lanzhou

Author: Yuhu Zhang[1]

[1] *Institute of Modern Physics, CAS, Lanzhou*

Corresponding Author: yhzhang@impcas.ac.cn

Recent commissioning of the Cooler Storage Ring at the Heavy Ion Research Facility in Lanzhou enabled us to conduct high-precision mass measurements at the Institute of Modern Physics in Lanzhou (IMP). In the past few years, mass measurements were performed using the CSRe-based isochronous mass spectrometry employing the fragmentation of the energetic beams of 36Ar, 58Ni, 78Kr, 86Kr, and 112Sn projectiles. Masses of short-lived nuclides of on both sides of the stability valley were measured. Relative mass precision of down to 10^{-6} -10^{-7} is routinely achieved and some issues in nuclear structure and nuclear astrophysics have been addressed. In this talk, the experimental details are presented and the progress and some typical results are briefly introduced. We also outline the plans for future experiments.

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Structure and beta decay properties of medium-heavy nuclei from the relativistic nuclear field theory

Author: Elena Litvinova[1]

[1] *Western Michigan University*

Corresponding Author: elena.litvinova@wmich.edu

The relativistic nuclear field theory (RNFT) developed throughout the last decade will be featured as an approach to the nuclear many-body problem, which is based on meson-nucleon Lagrangian and connects consistently the high-energy scale of heavy mesons, the medium-energy range of the pion, and the low-energy domain of emergent collective vibrations (phonons). Mesons and phonons build up the effective interaction in various channels, in particular, the phonon-exchange part takes care of the retardation effects, which are of great importance for the fragmentation of single-particle states, spreading of collective giant resonances and soft modes, quenching and beta-decay rates with significant consequences for astrophysics and theory of weak processes in nuclei.

Recent progress on the response theory in the proton-neutron channel has allowed for a very good description of spin-isospin-flip excitations. Spectra of such excitations can serve for probing the nucleon-nucleon interaction in the isovector sector caused by the exchange of pion and rho-meson between nucleons in the strongly-correlated medium. At the same time, such excitations as, for instance, Gamow-Teller and spin-dipole resonances in medium-mass nuclei are of a high astrophysical importance as they are in the direct relation to beta-decay and electron capture rates. Some more exotic isospin-flip excitations studied lately at NSCL facility have been also described very reasonably by the RNFT. Recent developments consider excitation modes in the deuteron transfer channel in view of their role in mediating the proton-neutron pairing and in constraining the delta-meson contribution to the nuclear forces.

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Perturbed Angular Correlations at ISOLDE: a 40 years young technique

Authors: Juliana Schell[1]; Doru C. Lupascu[1]; Peter Schaaf[2]

[1] *Universität Duisburg-Essen*

[2] *TU Ilmenau*

Corresponding Author: juliana.schell@cern.ch

The idea that "new-is-small"is a paradigm propelling industries and research: **new materials for new applications and new technologies**. Precise and efficient characterization techniques are, therefore, required to make the "new"and the "small", understandable, applicable, and reliable. Within this concept, **Time Differential Perturbed Angular Correlations**, TDPAC, appears as one of the most exotic and efficient techniques to characterize materials and **is celebrating 40 years at ISOLDE, CERN [1].** In this overview we explore the TDPAC measurement possibilities at ISOLDE-CERN for solid state physics research with a rich potential due to the wide number of available radioactive probe elements, delivered with great purity and high yield.

[1] Juliana Schell, Peter Schaaf and Doru C. Lupascu, **Perturbed Angular Correlations at ISOLDE: a 40 years young technique**, AIP Advances, Accepted October (2017).

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Overview of ISOLTRAP's mass measurements (the 2017 edition)

Author: Dinko Atanasov[1]

Co-authors: Pauline Ascher [2]; Klaus Blaum [3]; Thomas Elias Cocolios [4]; Sebastian George [5]; Alexander Herlert [6]; Frank HERFURTH ; Wenjia Huang [7]; Jonas Karthein [3]; Yuri Litvinov [8]; David Lunney [9]; Vladimir Manea [3]; Maxime

Mougeot [9]; Dennis Neidherr [10]; Antoine de Roubin [11]; Lutz Christian Schweikhard [12]; Andree Welker [1]; Frank Wienholtz [12]; Robert Wolf [3]; Kai Zuber [13]

[1] *Technische Universitaet Dresden (DE)*

[2] *CENBG*

[3] *Max-Planck-Gesellschaft (DE)*

[4] *KU Leuven - IKS*

[5] *Institut fuer Kernphysik*

[6] *Facility for Antiproton and Ion Research (DE)*

[7] *CSNSM IN2P3-CNRS, Université Paris-Sud, Orsay, France*

[8] *GSI, Darmstadt*

[9] *Université Paris-Saclay (FR)*

[10] *GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE)*

[11] *Department of Physics, University of Jyvskyl*

[12] *Ernst-Moritz-Arndt-Universitaet (DE)*

[13] *Technische Universitaet Dresden*

Corresponding Author: dinko.atanasov@cern.ch

This presentation will focus on the experiments carried out during 2017 with ISOLTRAP, the versatile mass spectrometer situated at ISOLDE/CERN. Highlights of this year's campaign were the precision mass measurements of neutron-rich krypton (^{98,99}Kr), argon (^{48}Ar) and cadmium (^{127,129,131,132}Cd) isotopes addressing, respectively, the onset of deformation in the $A \approx 100$ region and the quenching of the neutron shell gaps at $N = 28$ and 82 far from stability. Over the course of the year ISOLTRAP performed several tests with ISOLDE beams, including the implementation of the Phase-Imaging Ion-Cyclotron-Resonance Mass Spectrometry to study the ^{88}Rb - ^{88}Sr Q-value. The value was determined to better then 200 eV precision. Furthermore, by using Multi-Reflection Time-Of-Flight Mass Spectrometry the ISOLTRAP team together with the RILIS and the ISOLDE target and ion-source groups performed a yield study of neutron-rich titanium and scandium. The outcome of these tests as well as preliminary results from the mass measurements will be discussed.

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Isomeric decays of N ˜ Z nuclei in the vicinity of 100Sn

Author: Joochun Park[1]

[1] *Lund University (SE)*

Corresponding Author: joochun.park@cern.ch

(On behalf of the EURICA collaboration)

The structure of nuclei in the vicinity of doubly magic ^{100}Sn offer insight to the interplay between the seniority scheme in closed-shell nuclei and isoscalar proton-neutron interactions which are prevalent in $N \sim Z$ nuclei. Below ^{100}Sn, information on the excited states of $N \sim Z$ nuclei is accessible by isomeric decays and β-delayed γ-ray spectroscopy with limited production rates.

A decay spectroscopy experiment was performed at the RI Beam Factory of RIKEN Nishina Center. A 345-MeV/u ^{124}Xe beam was fragmented on a ^{9}Be target, producing record quantities of ^{100}Sn and other proton-rich isotopes in its vicinity. Ion implantation and β decays were measured with the Wide-

range Active Silicon-Strip Stopper Array for Beta and ion detection (WAS3ABi), and γ rays were measured with the EUroball-RIKEN Cluster Array (EURICA).

Half-lives and transition strengths of many γ-decaying isomeric states were measured. New isomeric decay information was obtained in ^{92}Rh, ^{96}Ag and ^{98}Cd, consistent with shell-model calculations.

As one of the highlights of the experiment, the low-spin structure ^{96}Cd was revealed for the first time.

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Coulomb excitation of doubly-magic 132Sn at HIE-ISOLDE

Authors: Dawid Rosiak[1]; Peter Reiter[2]

Co-authors: Georgi Ivanov Rainovski [3]; Joakim Cederkall [4]; Liam Gaffney [5]; Maria Jose Garcia Borge [5]; Michael Seidlitz [6]; Piet Van Duppen [7]; Thorsten Kroell [8]

[1] *University of Cologne*

[2] *University Cologne, Nuclear Physics Institut*

[3] *University of Sofia (BG)*

[4] *Lund University (SE)*

[5] *CERN*

[6] *Universitaet zu Koeln (DE)*

[7] *KU Leuven (BE)*

[8] *Technische Universitaet Darmstadt (DE)*

Corresponding Author: drosiak@ikp.uni-koeln.de

The vibrational first 2^+ and 3^- states of the doubly-magic nucleus ^{132}Sn were excited via safe Coulomb excitation (CE) employing the recently commissioned HIE-ISOLDE accelerator at CERN in conjunction with the highly efficient MINIBALL array. The ^{132}Sn ions were accelerated to an energy of 5.5 MeV/nucleon and impinged on a ^{206}Pb target. Dexciting γ rays from the first excited states of the target and the projectile nucleus were recorded in coincidence with scattered particles. The optimized beam energy, the high-energy resolution and good efficiency of the HPGe spectrometer provide a favourable combination to master the demanding measurement characterized by small CE cross sections of the high lying states with excitation energies above 4 MeV. The reduced transition strengths were determined for the transitions $0^+ \rightarrow 2^+_1$, $0^+ \rightarrow 3^-_1$, and $2^+_1 \rightarrow 3^-_1$ in ^{132}Sn. In the past first preliminary results for the $B(E2; 0^+ \rightarrow 2^+_1)$ value were obtained with an efficient BaF2 array at ORNL [1]. The results on excited collective states in ^{132}Sn provide crucial information on cross shell configurations that are expected to be dominated by a strong proton contribution. Large-scale shell model calculations and new mean field calculations are on its way.

[1] R.L. Varner, et al.; Eur. Phys. J. A 25, s01, 391 (2005)

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Collinear Resonance Ionization Spectroscopy (CRIS) studies of neutron-rich Indium isotopes

Author: Adam Robert Vernon[1]

[1] *University of Manchester (GB)*

Corresponding Author: adam.vernon@cern.ch

With a proton hole in the Z = 50 shell closure, the indium isotopic chain (Z = 49) offers a compelling scenario to explore the evolution of nuclear-structure properties in the neighbourhood of the doubly-magic isotopes 100Sn (Z, N = 50) and 132Sn (N = 82).

This contribution will present recent measurements of the hyperfine spectra of the neutronrich indium isotopes 113-131In using the Collinear Resonance Ionization Spectroscopy

(CRIS) experiment. From these measurements, the spins, electromagnetic moments, and changes in root-mean-squared charge radii of several ground and isomeric states have been determined for the first time, extending our experimental knowledge up to N = 82. The importance of these results, in connection with modern developments of nuclear theory, will be discussed.

The development of the ionization schemes used during the experiment was enabled by the creation of an ablation ion-source setup, which will also be discussed

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PHYSICS AVENUE WITH THE SUPER SEPARATOR SPECTROMETER (S3) AT THE SPIRAL2 FACILITY

Author: Herve Savajols[1]

Co-authors: A. Drouart [2]; J.A. Nolen [3]

[1] *GANIL*

[2] *CEA Saclay*

[3] *Argonne National Laboratory*

Corresponding Author: savajols@ganil.fr

The LINAG superconducting linear accelerator of the SPIRAL2 project in GANIL (Caen) will produce stable heavy ion beams with very high currents. Their energy ranges from from 2 to 14MeV/u. These stable ion beams will enable us to observe rare events in the fields of nuclear physics, like very heavy and superheavy elements studies, neutron deficient nuclei at the proton drip line, as well as of atomic physics, like beam-beam ion interactions. S3 (Super Separator Spectrometer [1]) is a device designed to handle these high beam currents, combining a high selectivity of the reaction products with a high transmission of the nuclei of interest. The primary target is a fast rotating wheel, able to sustain the high beam current. The S3 line is a two-step, low energy fragment separator. The first step is a momentum achromat for rough rejection of the primary beam and the second step is a mass spectrometer. The backbone of S3 is composed of seven large aperture (r=150mm) superconducting quadrupole triplets. They are combined with sextupole and octupole correctors, in order to ensure a high mass resolution at the final focal plane. It can be equipped with different detection setups. Notably, the SIRIUS [2] spectroscopy station is designed to study proton alpha, electron and gamma decays of the nuclei of interest. Conversely, the REGLIS3 [3] low energy branch can be installed to stop the products in a gas cell for in-gas-jet laser ionisation and spectroscopy and, if required, transmission to other detection systems. In the present contribution, we will present the design and the latest progresses in the construction of the spectrometer. We will show the expected performances for some highlight physics cases.

[1] F. Dechery al., Eur. Phys. J. A 51, 56 (2015).
[2]J. Piot and the S3 collaboration, Acta Phys. Pol. B 43, 285 (2012).
[3]R. Ferrer al., Nucl. Inst. and Meth. B 317, 570 (2013).

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Exploring the extremes with NUSTAR at FAIR

Author: Alexander Herlert[1]

[1] *Facility for Antiproton and Ion Research (FAIR)*

Corresponding Author: alexander.herlert@cern.ch

With the ground breaking in July 2017, the construction of FAIR, the Facility for Antiproton and Ion Research, has officially started. Besides the adaption of the existing SIS18 synchrotron for FAIR operation, the ground works for the new SIS100 synchrotron tunnel is presently pursued. FAIR will host four scientific pillars: APPA, CBM, NUSTAR and PANDA. NUSTAR comprises several experiments aiming at the exploration of nuclear structure, astrophysics and reactions at extremes. The exotic ions of interest will be produced by impinging a primary beam of heavy ions (for example uranium) on a target and will be selected by use of the high resolving power of the Super-FRS fragment separator and distributed to three branches: low-energy, high-energy, and the ring branch.

The low energy branch will house the HISPEC/DESPEC experiments dedicated to high-resolution gamma spectroscopy and decay spectroscopy as well as the stopped-beam experiments MATS and LaSpec, which aim at measuring the masses and perform laser spectroscopy on short-lived ions. In the high-energy branch, the R3B collaboration will perform studies on nuclear reactions at high energy and intensity, employing inverse kinematics. The ring branch couples the Super-FRS with the collector ring CR, where the ILIMA collaboration will mount their detectors for mass and lifetime measurements on stored highly-charged short-lived ions. Furthermore, the Super-FRS itself can be employed as a setup for an experiment by adding supplemental detectors at the focal planes of the separator.

Many of the future detectors and equipment are already available and will be used in a precursor phase prior to the operation at FAIR. This program –called Phase 0 –will take place at GSI but also at other facilities, where NUSTAR experimental equipment can be employed for first tests and physics runs.

An overview of the present status of the FAIR facility and the NUSTAR experiments will be given as well as an outlook on the next years of the project.

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HELIOS: New Results and Future Developments

Author: Benjamin Kay[1]

[1] *Argonne National Laboratory*

Corresponding Author: kay@anl.gov

The HELIOS spectrometer was developed to study of light-ion transfer reactions in inverse kinematics, where outgoing ions are transported through a solenoidal field removing the effects of kinematic compression. It operates at ATLAS at Argonne National Laboratory where it can be used with stable beams, light radioactive ion beams produced by the in-flight technique, and fission-fragment beams from CARIBU. HELIOS has been in use for approximately ten years, demonstrating excellent Q-value resolution for studies with beams from mass 10 to 140. I will discuss recent results, including the measurement of transfer reactions induced by an isomer beam, and comment on future developments for HELIOS, and new solenoidal-spectrometer projects.

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An update on the chemical separation of 152Tb and its subsequent application for PET imaging

Authors: Nicholas Philip Van Der Meulen[1]; Ulli Koester[2]; Karl Johnston[3]; Christoph Umbricht[4]; Martina Benesova[4]; Roger Hasler[4]; Nadezda Gracheva[4]; Christiaan Vermeulen[1]; Cristina Mueller[4]

[1] *Paul Scherrer Institut (CH)*

[2] *Institut Laue-Langevin*

[3] *CERN*

[4] *Paul Scherrer Institute*

Corresponding Author: nicholas.philip.van.der.meulen@cern.ch

Terbium is a unique element, as it provides a quadruplet of radionuclides suited for diagnostics and therapy in nuclear medicine [1]. Much success has been gained from the PSI-ISOLDE collaboration, with the collection and purification of 149Tb (α-emitter, T1/2 = 4.1 h –for potential therapy), used for preclinical therapy studies [2] and PET imaging [3], and 152Tb (β+-emitter, T1/2 = 17.5 h –for use in PET imaging), for preclinical [4] and clinical [5] PET imaging, respectively.

Following this success, further upgrades were required for the chemical separation system, as the ALARA (As Low As Reasonably Achievable) radiation safety principle should be adhered to –thereby, minimizing direct manipulation of the nuclides.

In 2017, mass-separated beams of 152Tb were implanted at ISOLDE-CERN into Zn-coated Au foils, using new shielded collection chamber. Collections of 152Tb lasted 4 to 6 hours and up to 600 MBq 152Tb could be shipped to PSI.

At PSI, the chemical separation system was performed using a new set up and manipulators in a hot cell. The foil containing the 152Tb was extracted from the Zn foils by dissolving them in HNO3/NH4NO3. The dissolved nuclides were loaded on to a macroporous strongly acidic cation exchange resin and 152Tb eluted using dilute α-hydroxyisobutyric acid (α-HIBA). As an addition, the product eluent was passed through a second resin, to ensure formulation of the product in chloride form.

152Tb was directly employed for radiolabeling of PSMA-617. PET/CT scans were performed with PC-3 PIP (PSMA-positive) tumor-bearing mice at different time points after injection of 152Tb-PSMA-617.

The successful experimental runs with the updated system has prepared the collaboration well for proposed extended preclinical imaging and therapy experiments in 2018, in the hope of finalizing the preclinical therapy study with 149Tb.
Support by ENSAR2 (EU H2020 project Nr. 654002) is gratefully acknowledged.

The authors thank the ISOLDE RILIS team for efficient Dy ionization and the ISOLTRAP-MR-TOF-MS team for beam characterisation.

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[3] C. Müller et al., EJNMMI Radiopharmacy and Chemistry 1,5 (2016).
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[5] R. Baum et al., Dalton Transactions, in press (2017).

Technical Session / 50

Target Developments

Authors: Jochen Ballof[1]; Ferran Boix Pamies[2]; David Leimbach[3]; Yisel Martinez Palenzuela[4]; Joao Pedro Ramos[5]; Sebastian Rothe[5]; Thierry Stora[5]

[1] *Johannes Gutenberg Universitaet Mainz (DE)*

[2] *Centro de Investigaciones Energéti cas Medioambientales y Tecno*

[3] *Gothenburg University (SE)*

[4] *KU Leuven (BE)*

[5] *CERN*

Corresponding Author: jochen.ballof@cern.ch

As in the previous years, the target and ion source development group (TISD) has been working to push the limits of beam intensity and purity of available beams, and to develop new beams of elements, which are not yet available at any other ISOL facility. Important progress has been made on the LIEBE project, which exploits the forced circulation of a hot Pb-Bi eutectic melt. Here, the prototype is nearing completion and commissioning is planned. We have launched a material development campaign to synthesize and characterize novel low work function materials to increase the efficiency of negative ion sources. The work on an improved proton to neutron converter is progressing fast, as well as the detailed study and optimization of the VADLIS cavity. The status of molecular beam developments as well as an overview of target operation in 2017 will finally be presented.

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RILIS developments 2017

Author: Katerina Chrysalidis[1]

Co-authors: Valentine Fedosseev [2]; Bruce Marsh [2]; Reinhard Matthias Heinke [1]; Dominik Studer [3]; Dmitry Fedorov [4]; Shane Wilkins [5]; Pierre Bruno Larmonier [6]; Camilo Andres Granados Buitrago [7]; Maxim Seliverstov [8]; Pavel Molkanov [4]; Klaus Wendt [1]

[1] *Johannes Gutenberg Universitaet Mainz (DE)*

[2] *CERN*

[3] *Johannes-Gutenberg-Universitaet Mainz (DE)*

[4] *Petersburg Nuclear Physics Institut (RU)*

[5] *University of Manchester (GB)*

[6] *Ministere des affaires etrangeres et europeennes (FR)*

[7] *KU Leuven (BE)*

[8] *B.P. Konstantinov Petersburg Nuclear Physics Institute - PNPI (*

Corresponding Author: katerina.chrysalidis@cern.ch

The Resonance Ionization Laser Ion Source (RILIS) at ISOLDE is the most frequently used ion source, providing 60% of the ion beams in 2017, and more than 85% in 2016. The ionization mechanism, based on stepwise resonance excitation of an outer electron of the atom, is element selective. For certain elements even isomer-selective ionization can be achieved, enabling the delivery of beams with an enhanced isomer- or ground-state abundance. This year isomeric indium beams were delivered for IDS and CRIS experiments. In the reduced laser linewidth mode, Doppler-broadening becomes the limiting factor in terms of spectral resolution but, for certain atomic transitions, the isotope shifts or hyperfine structures can be resolved. Our ongoing campaign to study these for the lead-region continued this year with bismuth –together with our first use of the ISOLDE Decay Station for this purpose.

The 2017 technical developments and new laser hardware will be presented, along with the resonance ionization scheme developments that have been performed in an attempt to reduce the dependence on dye lasers during standard operation. The generation of high-power blue laser beams by intracavity frequency doubling inside the Ti:Sapphire lasers is now routine operation, resulting in an improved laser beam shape and higher power for the blue and deep-UV range. RILIS ionized radiogenic Sc was measured for the first time, representing a new beam to the ISOLDE user's community. Further attempts to extract laser-ionized Se were made, although suitably efficient and selective Se beam production needs further development. The technical developments of the VADLIS: RILIS ionization inside the ISOLDE FEBIAD have been continuing at the ISOLDE offline separator, with promising progress towards optimizing the RILIS-mode of operation. The advances towards the goal of high-resolution, Doppler-free RILIS ionization making use of two-photon excitation will be presented. If successful, this approach may not only provide the means for high-resolution in-source spectroscopy of exotic nuclei, but also enable selective resonance ionization of elements with high ionization potentials that can so far only be ionized with a plasma ion source.

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Progress towards the commissioning of first stable beams at CERN-MEDICIS

Author: Yisel Martinez Palenzuela[1]

[1] *KU Leuven (BE)*

Corresponding Author: yisel.martinez@cern.ch

The CERN-MEDICIS laboratory is located in an extension of the CERN-ISOLDE radioactive ion beam facility in Geneva, Switzerland. ISOLDE is able to provide more than 1000 different isotopes by irradiating a thick target with a 1.4 GeV proton beam from the CERN Proton Synchrotron Booster. Since more than 90 % of the proton beam passes through the ISOLDE targets, the MEDICIS targets will be placed immediately behind the HRS one on a dedicated station to produce radioactive isotopes and benefit from the otherwise lost proton beam. The isotope batches will be extracted in the new laboratory thanks to a dedicated electromagnetic isotope mass separator.
With the development of the facility, many innovative radioisotopes will become available. Applications in fundamental studies in cancer research and new imaging and treatment protocols in cell and animal models will follow, possibly extended to pilot trials. On a weekly basis, 500 MBq isotope batches, purified by mass separation combined with chemical methods can be collected.
In this talk we will offer an overview on the current status of the facility and the progress towards the commissioning of the first stable beams at MEDICIS. We will discuss the main requirements for the production of radioactive beams in terms of efficiency, chemical selectivity and reliability/feasibility when dealing with high beam currents.
By joining forces with leading institutes in life and medical sciences within a newly formed translational collaboration, CERN-MEDICIS offers an exciting prospect with its scientific program in the coming years.

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Current progress on Offline 2 and the RFQcb ISCOOL.

Author: Stuart Warren[1]

[1] *CERN*

Corresponding Author: stuart.warren@cern.ch

For many years the RFQcb (Radio-Frequency Quadrupole cooler buncher) has been a vital part of ISOLDE experiments and it has improved the beam optics of the HRS line significantly downstream. However, there is very little time and infrastructure available to test and quantify improvements made to the RFQcb's structure, tuning and bunching methods. The Offline 2 separator was proposed to allow for proper analysis of the RFQcb and many other areas of the ISOLDE beam, such as: target development, laser scheme testing and new beam optics methods. All of these are vital in keeping ISOLDE competitive in the ISOL facilities field. The current status of the ISOLDE RFQcb and progress on the construction of Offline 2 will be presented.

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CRIS: A Toolbox for Exploring Quantum Many-body Problems

Authors: Ronald Fernando Garcia Ruiz[1]; CRIS Collaboration [None]

[1] *The University of Manchester*

Corresponding Author: ronald.fernando.garcia.ruiz@cern.ch

The Collinear Resonance Ionization Spectroscopy (CRIS) apparatus at ISOLDE-CERN [1] provides a powerful tool to perform highly-efficient and precise hyperfine structure measurements on isotopes produced at rates lower than 100 ions/s [2]. Such measurements allow the extraction of observables that are key for our understanding of the nuclear many-body problem: nuclear ground-state spins, electromagnetic moments, and changes in the root-mean square charge radii. Moreover, a precise knowledge of the interaction between the atomic nucleus and the surrounding electrons offers an important benchmark to test the validity of atomic many-body methods and weak interaction Hamiltonians used in studies of fundamental symmetries [3].

This contribution will present the recent developments that have allowed the extension of collinear resonance ionization spectroscopy in the potassium, copper and indium isotopic chains at extreme regions in the nuclear chart. The relevance of these results in connection with the recent advances in nuclear and atomic theory will be discussed. Future experimental programs focused on studying exotic isotopes around doubly-magic nuclei will be presented.

[1] K.T. Flanagan et al. Phys. Rev. Lett. 111, 212501 (2013).
[2] R.P. de Groote et al. Phys. Rev. C 96, 041302(R) (2017).
[3] R.F. Garcia Ruiz et al. Submitted (2017).

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HIE-ISOLDE physics campaign in 2017

Author: Liam Gaffney[1]

[1] *CERN*

Corresponding Author: liam.gaffney@cern.ch

HIE-ISOLDE experiments have been focused on two experimental setups in 2017, with the Miniball HPGe array [2] taking most of the beam time alongside experiments at the third beam line. The ISOLDE Solenoidal Spectrometer (ISS) [3] is currently being commissioned on the second beam line with the aim of performing few-nucleon transfer reactions in the magnetic field of a former MRI magnet. As HIE-ISOLDE operation becomes routine, the number of experiments per year is increasing and this year there were 12 experiments in a campaign running from July until November. In addition to Coulomb excitation, this year we have also performed multi-nucleon transfer reactions, utilising the maximum energy of the linac.

In this talk I will present the preliminary status of experiments from the 2017 campaign at Miniball.

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Collectivity of the 4+ states in heavy Zn isotopes and the first HIE-ISOLDE experiment

Authors: Andres Illana Sison[1]; Magdalena Zielinska[2]; Piet Van Duppen[3]; Elisa Rapisarda[4]

[1] *Universita e INFN, Legnaro (IT)*

[2] *CEA Saclay*

[3] *KU Leuven (BE)*

[4] *Paul Scherrer Institut (CH)*

Corresponding Author: magda@slcj.uw.edu.pl

Shell evolution in the vicinity of ^{68}Ni has recently attracted many theoretical and experimental investigations. By now it has been clearly established that the presumed subshell closure at N=40 is not very pronounced. While the intruder character of the $1g_{9/2}$ and $2d_{5/2}$ neutron orbital induces collectivity by pair excitations from the fp shell into the $g_{9/2}$ orbital, the parity change hinders quadrupole excitations and therefore mimics the properties of a doubly magic nucleus in ^{68}Ni, i.e. a high 2^+_1 energy and a low B(E2; $2^+ \rightarrow 0^+$) 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; $2^+ \rightarrow 0^+$) 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; $4^+ \rightarrow 2^+$)/B(E2; $2^+ \rightarrow 0^+$) ratio of 1 or less, which is normally observed only around closed shells. Coulomb excitation studies at REX-ISOLDE (^{74,76}Zn [1]) as well as a DSAM lifetime measurement in ^{70}Zn [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 $^{70-74}$Zn that are considerably longer and correspond again to B(E2; $4^+ \rightarrow 2^+$)/B(E2; $2^+ \rightarrow 0^+$) ratio lower than 1. This has been confirmed by the results of another RDDS measurement performed at GANIL [4] for ^{70,72}Zn.

The ISOLDE facility finished in 2016 the first phase of a major upgrade in terms of the energy of post-accelerated exotic beams, bringing it up from 3 MeV/u to 5.5 MeV/u. The increased beam energy strongly enhances the probability of multi-step Coulomb excitation, giving experimental access to new excited states and bringing in-depth information on their structure. The very first HIE-ISOLDE experiment in October 2015 and its continuation in 2016 have been dedicated to the study of the evolution of the nuclear structure along the zinc isotopic chain. The results discriminate between the two experimental values of B(E2; $4^+ \rightarrow 2^+$) in ^{74}Zn, and the B(E2; $4^+ \rightarrow 2^+$) value in ^{78}Zn has been obtained for the first time.

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Session 3 / 26

High precision laser spectroscopy of Nickel isotopes

Authors: Anastasios Kanellakopoulos[1]; Bernhard Maass[2]; Bradley Cheal[3]; Calvin Wraith[4]; Christian Gorges[2]; Deyan Yordanov[5]; Gerda Neyens[6]; Hanne Heylen[6]; Joerg Kraemer[7]; Jonathan Billowes[3]; Klaus Blaum[8]; Kristian Lars Koenig[2]; Liang Xie[3]; Liss Vazquez Rodriguez[9]; Magdalena Kowalska[6]; Mark Bissell[3]; Rainer Neugart[8]; Rodolfo Sanchez[10]; Ronald Fernando Garcia Ruiz[1]; Simon Kaufmann[2]; Stephan Malbrunot[6]; Tim Ratajczyk[2]; Wilfried Noertershaeuser[2]; Wouter Anton M Gins[1]; Xiaofei Yang[1]; Zhengyu Xu[1]

[1] *KU Leuven (BE)*

[2] *Technische Universitaet Darmstadt (DE)*

[3] *University of Manchester (GB)*

[4] *University of Liverpool (GB)*

[5] *Universite de Paris-Sud 11 (FR)*

[6] *CERN*

[7] *University Mainz, Germany*

[8] *Max-Planck-Gesellschaft (DE)*

[9] *Université Paris-Saclay (FR)*

[10] *TU Darmstadt*

Corresponding Author: s.kaufmann@uni-mainz.de

Nickel isotopes $^{58-68,70}$Ni were measured using collinear laser spectroscopy at the COLLAPS setup at CERN-ISOLDE. Nickel has magic proton number 28, the first magic number that is caused by the spin-orbit interaction and the isotope chain is state-of-the-art in nuclear structure research. One of these is the sub-shell closure at N=40, which has been intensively studied by various experimental methods [1-5]. In the whole region, ^{68}Ni is expected to exhibit the strongest sub-shell closures and this is visible in the behavior of the now measured mean-square charge radii crossing N=40.
Furthermore, a tight correlation between neutron-radii, the electric dipole polarizability α_D and the neutron equation of state (EOS) has been intensively discussed first based on Skyrme Hartree-Fock models, linking nuclear properties with the structure of neutron stars. Of particular interest in this respect are also recent ab initio calculations entering into the medium mass region and demonstrating a clear correlation between the charge radius, the neutron radius and α_D in the case of ^{48}Ca [6]. Indeed, this correlation was exploited to predict α_D based on ^{48}Ca's experimental charge radius in reasonable agreement with a recent measurement [7]. Ab initio calculations now become feasible in the Nickel mass region as well. Recent α_D measurements in ^{68}Ni [8] are now backed up by our experimental value for the mean-square charge radius making this a rare case where both observables are experimentally known and will therefore provide an important new benchmark for ab initio as well as density functional theory.

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Session 3 / 39

Coulomb excitation of 66Ge

Author: Kenzo Abrahams[1]

[1] *The University of the Western Cape*

Corresponding Author: kenzoabrahams@gmail.com

This work pertains to determining the spectroscopic quadrupole moment for the first 2+ state in 66Ge using "safe"Coulomb excitation measurements. Motivation to study 66Ge arises from the anomalous rotational behaviour of the high-lying first 2+ state observed in even-even isotopes in the A ˜ 70 region [1]. Low-lying 0+ excited states have been suggested for even-even neutron-deficient nuclei Se [2] and Kr [3] which may be an indication of shape coexistence [4]. The same trend was observed in 198Pt and is interpreted as the result of the presence of an intruder state [4]. The A ˜ 70 region near the N = Z line is a region of rapidly changing nuclear shapes due to the shell gaps at proton and neutron number 34 and 36, making this region an excellent testing ground to study the phenomenom of shape coexistence. In addition, macroscopic-microscopic models suggest gamma-softness for 64Ge through oblate-prolate shape coexistence in 68Se and 72Kr to some of the most deformed nuclei at 76Sr and 80Zr.

Our experiment was performed at HIE-ISOLDE during July 2017. A 4 mg/cm2 target of 196Pt was bombarded with 66Ge beams at 4.395 MeV/u. This was the first experiment carried out using accelerated unstable Ge beams. The initial aim was to study 70Se, but the beam was contaminated with 66Ge. At first it was thought not to be a problem, but it became clear that the ratio between 70Se and 66Ge grew in favour of 66Ge. The beam was then tuned to run 66Ge for the rest of the experiement. The gamma rays were detected using the MINIBALL array containing 8 cluster of HPGe detectors. Scattered particles were detected using an annular CD detector placed a distance of 25.74 mm, covering scattering angles from 21 to 57 degrees. Studying the shape of 66Ge may shed light on some of the systematics in this rapidly changing region of nuclear shapes. Preliminary results for the spectroscopic quadrupole moment of the first 2+ state in 66Ge will be presented during the ISOLDE Workshop.

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Session 4 / 56

Recent developments in gravitational wave science

Author: Jo van den Brand[1]

[1] *Nikhef*

Corresponding Author: jo@nikhef.nl

Recently, the LIGO Virgo Collaboration achieved the first detections of a gravitational waves. A century after the fundamental predictions of Einstein, we report the first direct observations of binary black hole systems merging to form single black holes. The detected waveforms match the predictions of general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. These observations demonstrate the existence of binary stellar-mass black hole systems. Our observations provide unique access to the properties of space-time at extreme curvatures: the strong-field, and high velocity regime. It allows unprecedented tests of general relativity for the nonlinear dynamics of highly disturbed black holes. Last month, the first detection of gravitational waves from the merger of a binary neutron star was reported. This event was also observed by thousands of scientists by using conventional astronomy. We now have realized a global gravitational wave network that allows interdisciplinary studies in (fundamental) physics, astrophysics, astronomy, cosmology and nuclear physics.

The scientific impact of the recent detections will be explained. In addition key technological aspects will be addressed. Attention is paid to Advanced Virgo, the European detector near Pisa, which recently come on-line. The lecture will close with a discussion of the largest challenges in the field, including plans for a detector in space (LISA), and Einstein Telescope (ET), a large underground observatory for gravitational waves science.

Session 4 / 17

First Observation of the Low-Spin Structure of 213Fr Populated in the EC/β+ Decay of 213Ra

Author: Cristina CLISU[1]

[1] *IFIN-HH*

Corresponding Author: cristina.clisu@cern.ch

The level scheme of 213Fr was investigated for the first time through γ-ray spectroscopy at ISOLDE, CERN. An A=232 molecular beam of 213Ra+19F was sent to the ISOLDE Decay Station setup, where

γ-rays and charged particles were detected using HPGe clover detectors and DSSSDs, respectively. Low-spin excited states in the semi-magic 213Fr (N=126) were populated in the EC/β+ decay of the 1/2- ground state of 213Ra and the level scheme was constructed starting from the previously reported 498 keV γ-ray depopulating the (7/2-) first excited state and contains over 10 new levels and 20 new transitions. The results will be discussed and compared with neighboring N=126 nuclei.

Session 4 / 40

Study of shell evolution around the doubly magic ^{208}Pb, via a multi-nucleon transfer reaction at MINIBALL

Authors: Andres Illana Sison[1]; Jose Javier Valiente Dobon[2]; Suzana Szilner[3]

[1] *Universita e INFN, Legnaro (IT)*

[2] *LNL (INFN)*

[3] *Ruder Boskovic Institute*

Corresponding Author: andres.illana@cern.ch

Study the east region around the doubly magic ^{208}Pb, represents an ideal testing ground to understand the effects related to the effective three-body forces, i.e., if the large calculations are feasible and the seniority scheme provides useful guidance. However, this region of the Segrè chart has been traditionally difficult to access experimentally due to its neutron richness and low cross sections. Even with the new improvements and the new facilities, we still have lack of information around this region.
On the other hand, multi-nucleon transfer reaction has been proved for many years an important tool in order to investigate exotic nuclei with stable beams. With this technique it is possible to excite high spins states, to find new isomers and to understand the band structure of a nucleus. In addition, in one experiment you will be able to investigate different isotopes at the same time.
The aim of this experiment is twofold: i) firstly, it will represent the proof of principle that multi-nucleon transfer reactions with unstable beams is efficient to populate neutron-rich heavy binary partners, and represents a competitive method to cold fragmentation ii) secondly, we aim at populating medium- to high-spin states in ^{212,214}Pb and ^{208,210}Hg to elucidate the existence of the 16^+ isomer in the lead isotopes, and at the same time to disentangle the puzzling case of a very low energy 3^- state in ^{210}Hg not described by any nuclear model.
On this way, the first multi-nucleon transfer experiment with radioactive beam (RIB) was carried out in September of this year. Very preliminary results will be presented.

Session 4 / 5

Investigation of octupole excitations in 207Tl using gamma-gamma angular correlations at the ISOLDE Decay Station

Author: Thomas Andrew Berry[1]

Co-authors: Zsolt Podolyak [1]; Robert John Carroll [1]; Razvan Lica [2]; Christophe Sotty [2]; B. Alex Brown [3]

[1] *University of Surrey (GB)*

[2] *IFIN-HH (RO)*

[3] *NSCL-MSU*

Corresponding Author: thomas.andrew.berry@cern.ch

^{208}Pb is the heaviest stable doubly-magic nucleus and has been studied in great detail. Its first excited state occurs at 2.6 MeV and corresponds to an octupole vibration, resulting from the collective

behaviour of a number of E3 ($\Delta l = \Delta j = 3$) particle excitations across the closed shell. This octupole transition has been observed in several other nuclei around ^{208}Pb, including the single proton-hole ^{207}Tl[1]. This nucleus has a number of known states; however, below the core-breaking limit[2] only the four states below 2 MeV ($s^{-1}_{1/2}, d^{-1}_{3/2}, h^{-1}_{11/2}, d^{-1}_{5/2}$) are well-known from previous experiments[3]. It is expected that, given a $\frac{9}{2}^+$ ground state in ^{207}Hg and a Q-value of 4.8 MeV, β decay from ^{207}Hg should populate many of the states consisting of one of these proton-hole states coupled to the octupole 3^- vibration.

One experiment took place in 2014 and a second in 2016, both at the ISOLDE Decay Station (IDS) at CERN. Using the molten lead target on the General Purpose Separator (GPS), ^{207}Hg was produced at a rate of up to 5×10^4 pps in 2014, and 2×10^5 pps in 2016. This was deposited on the tape at IDS and observed by an array of five HPGe detectors.

A new level scheme, including 9 new levels and 73 new transitions, has been established in this analysis. Using relative transition strengths, $\gamma\gamma$ angular correlations, $\log ft$ values and electron conversion coefficients, spin-parities have been deduced for the majority of observed states. Angular correlations of successive gamma rays have been performed successfully for a small number of transitions, and used where possible to guide the assignments. This study has motivated the improvement of the IDS setup for angular correlation studies in the future. The KHM3Y shell model calculation - which gives the most accurate replication of the octupole excitation in this region[4] - was performed, and a good agreement was observed between the predicted and experimental level schemes. The majority of the states correspond to three-particle excitations breaking the neutron core. Six collective octupole-coupled states have been observed: the two states corresponding to $\pi \mathrm{s}^{-1}_{1/2} \times 3^-$, three of the four $\pi \mathrm{d}^{-1}_{3/2} \times 3^-$ states and, tentatively, the $\frac{7}{2}^+$ $\pi \mathrm{h}^{-1}_{11/2} \times 3^-$ state.

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Facilities Session 2 / **27**

MARA – from commissioning to experiments

Authors: Jan Saren[1]; Juha Uusitalo[1]; Jari Partanen[1]

[1] *University of Jyväskylä*

Corresponding Author: jan.saren@jyu.fi

MARA is a new in-flight recoil separator mainly for studies of the exotic isotopes close to the N˜Z line and close to the proton-drip line produced in fusion evaporation reactions. MARA consists of a quadrupole triplet followed by an electrostatic deflector and a magnetic dipole. It has two main functions: separate a primary beam from products and give additional mass over charge selectivity among the products. The mass resolving power is roughly from 100 to 300 depending on the experiment. MARA is a complementary device to the gas-filled RITU separator and enables the continuation of the nuclear spectroscopy research program in Jyväskylä to lighter masses.

In this presentation the basic properties of MARA will be presented and compared to RITU. The commissioning campaign and the accomplished experiments will be reviewed and an overview of the experimental conditions based on the reactions performed with MARA will be given. Some of the physics cases will be discussed alongside the spectrum of the accepted proposals.

Facilities Session 2 / **47**

New possibilities for nuclear spectroscopy at ILL: the FIPPS instrument and its first experimental campaign

Author: Caterina Michelagnoli[1]

[1] *ILL*

Corresponding Author: michelagnolic@ill.fr

Thermal neutron capture gamma-ray spectroscopy and prompt gamma-ray spectroscopy of fission fragments are powerful tools to obtain detailed nuclear structure information for nuclides close to stability and medium mass neutron-rich isotopes. This nuclear structure information can be used for the test of nuclear models, as well as for the extraction of quantities important for nuclear applications. The power of coupling a high-efficiency Ge detector array with an intense pencil-like neutron beam provided by the ILL reactor, has been recently demonstrated by the success of the EXILL (EXogam at ILL) campaign. This success led to the installation of permanent setup at ILL, the new instrument FIPPS (FIssion Product Prompt Spectrometer). In its first phase, it consists of a halo-free pencil neutron beam incident on a target surrounded by an array of 8 Ge clovers. This setup has been commissioned in Dec. 2016 and it has recently been exploited for a variety of (n,gamma) experiments. Also fissile and radioactive targets will be used. In a second phase it will be complemented with a recoil spectrometer based on a gas filled magnet. This will increase the sensitivity and selectivity for nuclear spectroscopy of fission products and enable fission studies of the correlation between excitation energy, angular momentum and kinetic energy.
After a review of the most significant physics output of the EXILL campaign, the FIPPS instrument will be described. The present performance of the setup will be shown, together with a summary of the results of the first experimental campaign. Future perspectives and physics opportunities will be discussed.

Facilities Session 2 / 1

Ion beam analysis of materials with MeV beams at the Ruhr University Bochum

Author: Hans-Werner Becker Becker[1]

[1] *Ruhr-University Bochum*

Corresponding Author: hans-werner.becker@rub.de

The opportunities and features of the analytical techniques such as Rutherford Backscattering Spectrometry (RBS) or Nuclear Reaction Analysis (NRA) available at the 4MV Dynamitron Tandem accelerator in Bochum will be presented and illustrated with examples from the ongoing research programs. In particular diffusion studies in geological systems will be discussed in more detail. Since such diffusion is strongly correlated to defects in the crystal the potential of future studies of minerals with Perturbed Angular Correlation needs to be explored.

Facilities Session 2 / 31

Reactions with 9Li at HIE-ISOLDE

Authors: Jesper Halkjaer Jensen[1]; Karsten Riisager[1]

[1] *Aarhus University (DK)*

Corresponding Author: jesper.halkjaer.jensen@cern.ch

The increase of energy of the ISOLDE radioactive beams made possible through the HIE-ISOLDE project has opened new possibilities for reactions studies with exotic beams. A particular challenge is presented by the light nuclei where unbound final states play an important role and the role of the continuum is by now known to be important. Theoretical work on the reaction mechanisms involved aiming for a detailed description of the reaction processes is ongoing and evolves as new experimental data appear.

I shall report on results from two experiments performed in the Scattering Experimens Chamber (SEC), both using 9Li as reaccelerated radioactive beam. The first experiment ran November 2016 at XT02 at a beam energy of 6.8 MeV/u on a deuterated polyethylene target. The second experiment takes place late October 2017 at XT03 with a beam energy close to 8 MeV/u on a tritium-containing Ti target. Many reaction channels are open at these energies, but the major ones of interest are one- and two-neutron transfer reactions to the isotopes 8Li to 11Li. Particularly interesting are the final channels leading to 10Li and 11Li where knowledge on the detailed structure is still lacking in spite of many earlier experiments at widely different beam energies.

The presentation will give an overview of the experimental set-up used and report on the results that have been extracted so far. A comparison will also be given between the current results and the 9Li+2H experiments carried out earlier at REX-ISOLDE at beam energies of 2.3 MeV/u and 2.8 MeV/u.

HIE-ISOLDE Technical Session / **4**

Operations of the REX/HIE-ISOLDE linac during the 2017 Physics Campaign

Author: Jose Alberto Rodriguez[1]

[1] *CERN*

Corresponding Author: alberto.rodriguez@cern.ch

The High Intensity and Energy ISOLDE project (HIE-ISOLDE) is a major upgrade of the ISOLDE post-accelerator at CERN. Phase 2A of the project was completed in June 2017 when an additional cryomodule and the third High Energy Beam Transfer line (HEBT) were installed and commissioned. The 2017 Physics campaign started immediately after. Multiple stable and Radioactive Ion Beams (RIBs) were delivered to two different experimental stations and a total of twelve experiments were completed. The main issues and the operational highlights for each of the experiments as well as the reliability of the different subsystems of the linac and possible future improvements and upgrades of the machine will be discussed in this presentation.

HIE-ISOLDE Technical Session / **23**

The HIE-ISOLDE Cryogenic System, its Infrastructure and Considerations for Phase 3

Author: Olivier Pirotte[1]

[1] *CERN*

Corresponding Author: olivier.pirotte@cern.ch

The cryogenic system for the project phases 1 & 2 of HIE-ISOLDE is based on a refurbished helium cryo-plant previously used to cool the ALEPH magnet during the operation of the LEP accelerator from 1989 to 2000. The helium refrigerator is connected to a new cryogenic distribution line, supplying a 2000-liter storage dewar and six interconnecting valve boxes (i.e jumper boxes). Since its implementation, the cryogenic system has been operated with first one cryo-module in 2015, then two in 2016 and three in 2017. During each year the operation of the cryo-plant has required significant technical enhancements and tunings for the compressor station, the cold-box and the cryogenic distribution system in order to reach nominal and stable operational conditions. The commissioning results and the lessons learnt during these three years of operation are presented and the preparatory work for the installation of the fourth cryo-module in early 2018 discussed. Finally, preliminary considerations on a new cryogenic system in view of a potential phase 3 implementation is reported.

HIE-ISOLDE Technical Session / 2

Performance of the HIE-ISOLDE seamless cavity compared with welded series productions

Authors: Akira Miyazaki[1]; Walter Venturini Delsolaro[2]; Yacine Kadi[2]; Karl-Martin Schirm[2]; Alban Rene Maurice Sublet[2]; Silvia Teixeira Lopez[2]; Mathieu Therasse[2]

[1] *University of Manchester (GB)*

[2] *CERN*

Corresponding Author: akira.miyazaki@cern.ch

The test result of the newly developed seamless cavity is compared with the series cavities already installed and operated in the cryomodules.
Slow and uniform cool down has been preferred by the series cavities; thus optimized cool-down procedure has achieved performance better than the nominal design.
The off-line test in a dedicated cryostat showed that the seamless cavity did not depend on the cooling down, and resulted in the best performance even without a special care during the cooling down.
Instead, this new cavity was relatively sensitive to the ambient magnetic field such as the earth field.
Comparison between series and seamless cavities will provide information about the thermodynamic environment inside the cryomodule during the RF commissioning 2018.
Also, in order to use the seamless cavity as a spare in the lower energy cryomodules, i.e. CM1 and CM2, a possible modification will be proposed by correcting the beam steering effect.
Finally, possible cavity designs for the low-beta section in Phase3 will be discussed.

HIE-ISOLDE Technical Session / 44

Beam dynamics studies for 10 MHz post-accelerated RIBs in Phase 3 of the HIE-ISOLDE linac upgrade

Author: Matthew Alexander Fraser[1]

[1] *CERN*

Corresponding Author: matthew.alexander.fraser@cern.ch

A ten-fold increase in the bunch spacing of post-accelerated radioactive ion beams has been requested by several research groups at ISOLDE, CERN in order for experiments to use time-of-flight particle identification and background suppression techniques. It is proposed to bunch externally into the existing REX-RFQ at a frequency of 10.128 MHz using a multi-harmonic buncher to produce the desired ˜100 ns bunch separation with minimal loss in transmission and, in certain installation scenarios, a significantly reduced longitudinal emittance. A review of the beam dynamics studies, carried out until 2014, will be presented in the framework of the HIE-ISOLDE linac upgrade at CERN.

Session 5 / 48

Engineering defects in diamond

Author: Mark Newton[1]

[1] *University of Warwick*

Corresponding Author: m.e.newton@warwick.ac.uk

Defects in diamond have great potential for use as quantum sensors and qubits. The negatively-charged nitrogen-vacancy (NV–) center in diamond is established as a leading platform in solid state quantum applications, with potential technologies in sensing, computation and communication enabled by its long spin-coherence time and optical spin polarization. However, NV's poor photonic properties (Debye-Waller factor ˜0.04) have resulted in significant efforts on optical cavities to enhance its coherent emission, and search for alternate color centers with comparable spin properties and superior optical properties.
Currently, the vacancy-impurity family of defects is most promising, with major interest in group IV centers SiV–[1,2], GeV–[3] and SnV–[4,5]. Of these, SiV–is the most-studied, with T2 > 10 ms and single-shot readout demonstrated at 100 mK. Nonetheless, the onerous experimental requirements and low quantum efficiency (˜10% [6]) motivate further research on alternative centers. In this presentation, I will discuss recent work alternative color centers, including the neutrally-charged silicon vacancy, SiV0 [7,8], its spin physics and electronic structure.
Full exploitation of their optical and spin properties necessitates that we control the position, orientation and environment of the chose colour centre to optimise all of the desirable properties simultaneously. I will review our understanding of the production of intrinsic defect complexes and present new data on the production of preferentially orientated defect complexes by electron irradiation and/or annealing whilst the sample is subjected to a large uniaxial stress. I will show that near 100 % preferential orientation can be achieved for a number of different defects.

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Session 5 / 14

Influence of Fermi-level on the lattice location of 27Mg in GaN

Authors: Ulrich Wahl[1]; Angelo Rafael Granadeiro Costa[2]; Eric David Bosne[1]; Tiago Abel De Lemos Lima[3]; Gertjan Lippertz[4]; Joao Martins Correia[1]; Manuel Castro Ribeiro Da Silva[5]; Kristiaan Temst[6]; André Vantomme[7]; Lino Miguel Da Costa Pereira[3]; Menno Kappers[8]

[1] *Universidade de Lisboa (PT)*

[2] *Instituto Superior Tecnico (PT)*

[3] *KU Leuven (BE)*

[4] *Katholieke Universiteit Leuven (BE)*

[5] *Instituto Superior Tecnico IST*

[6] *IKS, Leuven*

[7] *IKS, KU Leuven*

[8] *Cambridge Center for GaN, U Cambridge*

Corresponding Author: ulrich.wahl@cern.ch

During 2017 we focused on investigating the lattice location of 27Mg as a detailed function of implantation temperature, implanted fluence, and fluence rate in different doping types of GaN: undoped GaN, as well as Si-doped n-type, Mg-doped p-type, and Mg-doped as grown.
The amphoteric nature of Mg, i.e. the simultaneous occupation of substitutional Ga and interstitial sites previously reported [1], was fully confirmed: following ultra-low fluence (˜2E10 cm-2) room temperature (RT) implantation, the interstitial fraction of Mg was highest (20-25%) in the two samples that were pre-doped with 2E19 cm-3 stable Mg during epilayer growth, and lowest (˜8%) in Si-doped n-GaN, while undoped GaN showed an intermediate interstitial fraction of ˜12%. However, while for implanted fluences up to 4E12 cm-2 hardly any change at all was observed in the interstitial fraction in undoped and in n-GaN, in p-type GaN following implantation of 1E12 cm-2 of 27Mg it decreased to the ˜12% level found for undoped GaN; in as-grown Mg-doped GaN, a similar decrease occurred but already at a fluence of 2.5E11 cm-2, i.e. around four times faster.
Raising the implantation temperature above RT, the amount of interstitial 27Mg initially increased in all types of samples, most pronounced in both Mg pre-doped samples, where interstitial fractions around 30% were reached for ultra-low fluence implantation at 400℃.
Finally, implanting at temperatures above 400℃ progressively converted interstitial 27Mg to substitutional Ga sites in all doping types; detailed Arrhenius curves were measured, from which for all four sample types the activation energy for migration of interstitial Mg was estimated between 1.3 and 2.1 eV.
These results are being interpreted within the framework of Fermi-level dependence of the formation of interstitial vs substitutional Mg. The amount of interstitial Mg formed is highest when the Fermi level is low in the band gap, i.e. in p-type material. However, with increasing fluence the implantation-related defects push the Fermi level towards the middle of the band gap, which reduces the amount of interstitial Mg to levels which are identical to undoped material. The fact that this also happens in Mg-predoped samples that were not previously activated indicates that these were actually also p-type, however, with smaller hole concentration since the effect was faster. The observation that the amount of interstitial Mg initially increases with temperature can be explained by the fact that implantation at elevated temperatures creates less defects so that damage-related shifts of the Fermi level are less pronounced. We also have indications that the amount of interstitial Mg is influenced by changes in the Fermi level due to positive charges building up on the GaN surface during implantation.

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Session 5 / 8

Insight into the amorphous-to-crystalline phase transition in GeTe thin films

Author: Roberto Mantovan[1]

Co-authors: Roberto Fallica ; Adeleh Mokhles Gerami [2]; Torben Esmann Molholt [3]; Claudia Wiemer ; Massimo Longo ; H. P. Gunnlaugsson ; Karl Johnston [3]; Hilary Masenda [4]; Deena Naidoo [5]; Mehuli Ncube ; Krish Bharuth-Ram ; Marco FANCIULLI [6]; Haflidi Gislason [7]; Guido LANGOUCHE [8]; Sveinn Olafsson [9]; Gerd Weyer

[1] *CNR-IMM Agrate Unit (IT)*

[2] *K.N Toosi University of Technology (IR)*

[3] *CERN*

[4] *University of Witwatersrand*

[5] *University of the Witwatersrand (ZA)*

[6] *CNR-INFM MDM National Laboratory*

[7] *University of Iceland*

[8] *Katholieke Universiteit Leuven*

[9] *University of Iceland (IS)*

Corresponding Author: roberto.mantovan@cern.ch

The unique method of 57Fe emission Mössbauer spectroscopy (eMS), as performed at the large-scale facility of ISOLDE at CERN, was employed to reveal, at the most atomic-scale, important aspects governing the amorphous-to-crystalline phase transition in GeTe thin films, of importance for phase change memory (PCM) applications. By following dilute implantation of 57Mn (T½ = 1.5 min) decaying to 57Fe, we investigated the changes of the electronic charge distribution and local environment occurring around Fe probe substituting Ge (Fe@Ge), across the phase transition. The local structure of as-sputtered amorphous GeTe turned out to be a combination of tetrahedral and defect-octahedral sites. Upon crystallization a large conversion from tetrahedral to defect-free octahedral sites occurred. We discovered that only the tetrahedral fraction in amorphous GeTe participates to the change of the Fe@Ge-Te chemical bonds, with a net electronic charge density transfer of ~ 1.6 e/a0 between Fe@Ge and neighboring Te atoms. The observed atomic-scale chemical-structural changes resulted to be directly connected to the macroscopic phase transition and resistivity switch of GeTe thin films.

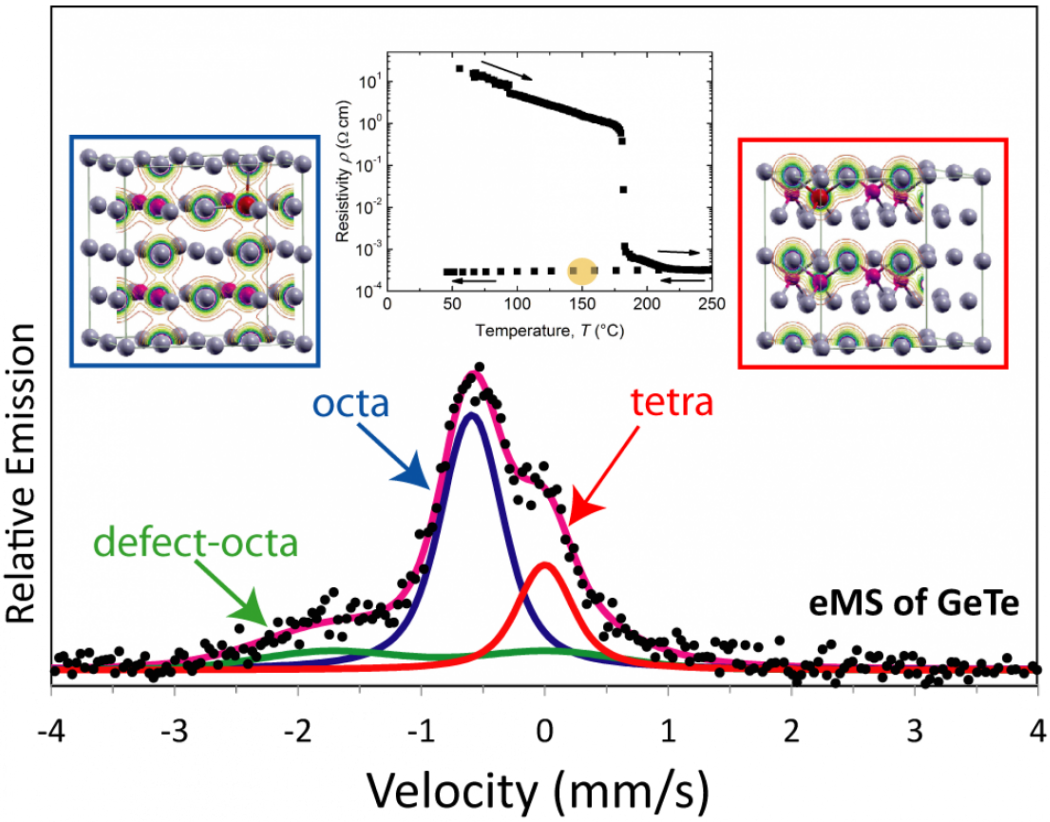

Figure 1: 57-Fe emission Mössbauer spectra obtained of GeTe at 150 ℃, following the amorphous-to-ccrystalline phase transition. Middle inset shows the corresponding resistivity state. Left (right) inset show the local structure around Fe@Ge in a 2x2x2 supercell of GeTe in c-GeTe (a-GeTe), with the red spheres indicating the Fe impurity substituting Ge (purple spheres) in the two configurations, and the grey spheres representing the Te atoms.

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Results of IS601: β-asymmetry and relaxation time of 35Ar

Author: Wouter Anton M Gins[1]

Co-authors: Abhilash Javaji [2]; Anastasios Kanellakopoulos [1]; Bertram Blank [3]; Dalibor Zakoucky [4]; Frank Wienholtz [5]; Fredrik Parnefjord Gustafsson [6]; Gerda Neyens [7]; Hanne Heylen [7]; Magdalena Kowalska [7]; Marcus Jankowski [8]; Mark Bissell [9]; Michal Walczak [10]; Miguel Madurga Flores [11]; Mik Baranowski [12]; Nathal Severijns [1]; Phillip Wagenknecht [8]; Robert Dale Harding [13]; Robin Yoel Engel [2]; Stavroula Pallada [7]; Victoria Isabel Araujo Escalona [1]; Xiaofei Yang [1]; Zhengyu Xu [1]

[1] *KU Leuven (BE)*

[2] *Universitaet Oldenburg (DE)*

[3] *CEN Bordeaux-Gradignan*

[4] *Acad. of Sciences of the Czech Rep. (CZ)*

[5] *Ernst-Moritz-Arndt-Universitaet (DE)*

[6] *KU Leuven, Instituut voor Kern- en Stralingsfysica, BE-3001 Leuven, Belgium*

[7] *CERN*

[8] *Carl von Ossietzky Universität Oldenburg, Ammerländer Heerstr. Germany*

[9] *University of Manchester (GB)*

[10] *Poznań University of Technology*

[11] *University of Tennessee (US)*

[12] *Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznan, Poland*

[13] *University of York (GB)*

Corresponding Author: wouter.anton.m.gins@cern.ch

Within the Standard model, the CKM matrix is predicted to be unitary. Testing this unitarity is therefore important to put limits on Beyond Standard Model physics contributions. The dominant matrix element for this test, Vud, is traditionally obtained from the corrected ft-values of superallowed pure Fermi beta transitions 1. Another sensitive way to address Vud is through measuring the β-asymmetry parameter of the decay of 35Ar (Z=18) [2] which would help to further decrease the experimental uncertainty. To this end, a campaign (IS601) is ongoing at the VITO beamline at ISOLDE-CERN to determine this parameter.
For the first phase of the project, 35Ar was optically polarized and implanted in different stopper hosts (crystals). This phase functions as a design study for the final setup, detailing the efficiency of the laser polarization scheme and studying the performance of several crystal hosts for maintaining the ensemble polarization. This is done by verifying the accuracy of the optical pumping simulations and determining the relaxation time of the implanted polarized ensemble in the different crystals used.
This contribution will focus on the results obtained for the behavior of the relaxation time, including temperature and magnetic field dependency of the host crystals.

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Study of β-delayed proton decays at IDS: the cases of 33Ar and 31Ar

Author: Irene Marroquin Alonso[1]

Co-authors: Maria Jose Garcia Borge [2]; Hans Fynbo [3]; Alan Michael Howard [3]; Oliver Soelund Kirsebom [3]; Morten Vinther Lund [3]; Michael Kulmback Munch ; Enrique Nacher Gonzalez [1]; Angel Perea Martinez [1]; Jonas Refsgaard [4]; Karsten Riisager [3]; Olof Tengblad [1]

[1] *Consejo Superior de Investigaciones Cientificas (CSIC) (ES)*

[2] *CERN*

[3] *Aarhus University (DK)*

[4] *Aarhus University*

Corresponding Author: i.m.alonso@cern.ch

^{31}Ar isotope is one of the most exotic β-delayed particle precursors, near the proton drip-line, with high Q-value and low proton separation energy. Due to these two factors, many channels are opened and β-delayed protons are emitted in the decay of this nucleus (one-proton, two-proton and even three-proton emission) 1.

Taking advance of the ISOLDE Decay Station (IDS) [2], the decay of ^{31}Ar was measured in the IS577 experiment, becoming the first of its kind (multi-particle emission) performed successfully at this installation. The aims of this experiment were the study of β2p and β3p channels, the identification of the β3pγ-decay, as well as to provide important information on the resonances of 30S and 29P (proton daughters), important for the astrophysical rp-process [3].

The set-up used consisted of 5 Double Sided Si Strip Detectors (DSSSD) backed by un-segmented Si-pad detectors in ΔE-E telescope configuration (Fig. 1). This Si-array is located inside the new *MAGISOL Si-Plugin Chamber*, installed by our collaboration at the permanent station IDS, devoted to β-decay measurements. In addition, there are 4 HPGe clover-detectors surrounding the chamber

for gamma detection.
This set-up is very compact with both high efficiency (47% of 4π) and good energy resolution (25 keV) over a wide energy range for particle emission.

The decay of ^{33}Ar was also measured in the experiment, since this isotope is well suited for the energy calibration of the silicon detectors; it emitts β-delayed protons and their energies are well known. However, new low energy proton peaks are seen for the first time in this kind of β-decay works [4]. Thanks to the possibility of detecting p-ϒ coincidences with this set-up, the identification of these new peaks in the level scheme has been done.

Finally, new results in ^{31}Ar will be presented here too, such us the identification of proton emission from levels near the threshold in ^{30}S (β2p channel). These levels show competition between gamma and proton emission and their study is really important to understand some astrophysical processes.

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Closing Remarks

Corresponding Author: gerda.neyens@cern.ch

Poster Session / 7

On the automation of the chemical experiments with radionuclides at ISOLDE (SSP)

Author: Sergey Dedushenko[None]

Corresponding Author: dedushenko@mail.ru

First wet-chemical experiments with Mn-57 were successfully conducted at ISOLDE in June 2017. These experiments comprised multiple steps: placement of a piece of metallic foil in the implantation chamber followed by its evacuation, accumulation of Mn-57 by ion-implantation into the foil, vacuum release and removal of the foil from the chamber, package and transportation of the foil to the chemical lab, unpackage the foil, dissolution of manganese in acid followed by the additions of chemicals to transform manganese into the desired chemical form, preparation of a sample for Moessbauer measurement including freezing of a solution, measurement, radioactivity waste and preparations for the repetition. Thus, the experiments required concerted efforts of several men. But the critical problem was the time necessary for the manipulations, because the live-time of Mn-57 is very short (85s) and most of the accumulated activity was lost before it was involved into a chemical reaction.
To constrict the time lost, to improve the radiation safety, and to increase the efficiency of the experiments, we consider the automation of all steps of the experimental procedure.
The fast insertion and removal of the sample (substrate) into/from the implantation space without vacuum release can be performed by a valve mechanism, which animated sketch is presented at www.happysloth.ru/ISOLDE.
All manipulation with the liquid chemicals can be realized based on standard automated laboratory dosing equipment. (We are realizing this step on the base of laboratory devices of Metrohm AG (Switzerland), including 730 Sample Changer, 800 Dosinos driven by 809 Titrando, and operated by Tiamo software.) This equipment is also responsible for the transfer of the ready-to-measure liquid sample to desired place for freezing, for sucking-out the unfrozen sample after the measurement, and for rinsing as well.

The described set-up can be enclosed into a thick-wall plastic aquarium ensuring protection from ionizing radiation and any liquid leakages.

Poster Session / 9

A novel experiment for search of physics beyond the standard model

Authors: Michael Hass[1]; Ish Mukul[2]; Oded Heber[2]; Michael Rappaport[2]; Yigal Shachar[2]; Guy Ron[3]; Sergey Vaintraub[4]; Yonatan Mishnayot[4]; Tsviki Hirsh[4]

[1] *Weizmann Institute of Science (IL)*

[2] *The Weizmann Institute*

[3] *Hebrew University of Jerusalem*

[4] *Soreq Nuclear Research Center*

Corresponding Author: michael.hass@weizmann.ac.il

We present the details and status of a new experiment commissioned at Weizmann Institute of Science, Israel for a high precision study of the Weak Interaction via the beta-neutrino correlation in radioactive decay of short lived 6He. The facility consists of a 14 MeV d + t neutron generator to produce atomic 6He via the 9Be(n,alpha)6He reaction. The Be target was in the form of 40 porous BeO discs of 2 mm thickness and 80 mm diameter 1. After extraction from the target, the 6He atoms are to be ionized and bunched in an electron beam ion source, and subsequently injected into an electrostatic ion beam trap. The ion storage time inside the trap for stable ions was found to be about 1.2 s at the chamber pressure of 7 x 10-10 mbar. This provides sufficient time for the measurement of the angular correlation coefficient of beta decay from trapped 6He ions. electrons are measure in a plastic position sensitive detectors and the recoiling 6Li in an annular position sensitive microchannel-plate (MCP) detector. The present results yield the production probability of 6He atoms to be 1.5x10-44 per 14 MeV neutron and the transport efficiency to be about 4%, in good agreement to simulations, demonstrating that most of the 6He atoms emerged from the BeO disc assembly in a time considerably shorter than the 0.8 s half-life of 6He. The test results of the facility demonstrate a novel method for production of light radioactive atoms for the precision measurement. This is an important result for the present scale-up of the earlier ISOLDE experiment 1 and bodes well for even larger scale-ups of such production set up.
The entire system is being presently transferred to the newly constructed target room at the SARAF accelerator at the Soreq Research Center, Israel [2]. At the SARAF, an orders-of-magnitude improvement in the 6He yield is expected due to a much higher n flux from the 7Li(d,n)4He reaction on the LiLiT liquid lithium target [3], larger number of BeO discs and improved transportation efficiency.
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Poster Session / 10

The phase-imaging ion-cyclotron-resonance detection technique using ISOLTRAP/CERN

Authors: Jonas Karthein[1]; Pauline Ascher[2]; Dinko Atanasov[3]; Klaus Blaum[1]; Thomas Elias Cocolios[4]; Sergey Eliseev[5]; Frank Herfurth[6]; Alexander Herlert[7]; Wenjia Huang[8]; Magdalena Kowalska[9]; Yuri Litvinov[10]; David Lunney[11]; Vladimir Manea[1]; Maxime Mougeot[11]; Dennis Neidherr[6]; Marco Rosenbusch[12]; Lutz Christian Schweikhard[12]; Andree Welker[3]; Frank Wienholtz[12]; Robert Wolf[1]; Kai Zuber[13]

[1] *Max-Planck-Gesellschaft (DE)*

[2] *CENBG*

[3] *Technische Universitaet Dresden (DE)*

[4] *KU Leuven - IKS*

[5] *Max-Planck-Institute for Nuclear Physics*

[6] *GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE)*

[7] *Facility for Antiproton and Ion Research (DE)*

[8] *CSNSM IN2P3-CNRS, Université Paris-Sud, Orsay, France*

[9] *CERN*

[10] *GSI, Darmstadt*

[11] *Université Paris-Saclay (FR)*

[12] *Ernst-Moritz-Arndt-Universitaet (DE)*

[13] *Technische Universitaet Dresden*

Corresponding Author: jonas.karthein@cern.ch

For three decades, the ISOLTRAP experiment at ISOLDE/CERN has performed high-precision mass measurements of short-lived nuclides using the time-of-flight ion-cyclotron-resonance (ToF-ICR) detection method, which is reaching its limits for accessible half-lives and relative uncertainties. With the new phase-imaging ion-cyclotron-resonance (PI-ICR) [S. Eliseev et al., Phys. Rev. Lett. 110, 082501 (2013)] detection technique, experiments can be performed with fewer ions and higher resolving power, providing access to new areas of the nuclear chart. This poster will present the ion-optical and data-acquisition improvements required for the implementation of the PI-ICR detection technique at ISOLTRAP, as well as results from first on-line measurements in both the high-precision and high-resolution regimes. During a systematic on-line-study the Q-value of the ^{88}Sr-^{88}Rb beta-decay was determined as a validation of the successful implementation of the PI-ICR detection technique with ISOLTRAP. Furthermore, the new detection technique allowed spatial separation of the close-lying isomeric states in ^{127}Cd and ^{129}Cd from which their excitation energy was derived. A mass resolving power $\frac{m}{\Delta m} > 10^6$ was reached in both cases for only 200 ms phase-accumulation time.

Poster Session / 12

WISArD: Status and perspectives

Authors: Victoria Isabel Araujo Escalona[1]; Bertram Blank[2]; Nathal Severijns[1]

[1] *KU Leuven (BE)*

[2] *CEN Bordeaux-Gradignan*

Corresponding Author: victoria.isabel.araujo.escalona@cern.ch

The new WISArD (Weak Interaction Studies with 32Argon Decay) experiment reutilises the former WITCH superconducting magnet at ISOLDE to measure the beta-neutrino angular correlation coefficient. 32Ar decays by beta-delayed proton emission. The protons emitted from the recoiling 32Cl daughter nuclei experience thus a Doppler effect, which shifts their energy. The proton and positron detection in the same or in opposite hemispheres of the superconducting magnet will allow the determination of the Doppler shift of the protons emitted. This will be more or less pronounced as a function of the strength of a possible scalar current component in the weak interaction relative to the dominant vector current responsible for "Fermi-type"decay.
The present work gives an overview of the experimental technique and a general description of the new set up.

Poster Session / 16

Laser spectroscopic studies along the Al isotopic chain and the isomer-shift of the self-conjugate 26Al nucleus

Authors: Agota Koszorus[1]; Anastasios Kanellakopoulos[1]; Bradley Cheal[2]; Christian Gorges[3]; Deyan Yordanov[4]; Gerda Neyens[5]; Hanne Heylen[5]; Joerg Kraemer[6]; Klaus Blaum[7]; Kristian Koenig[None]; Liang Xie[8]; Liss Vazquez Rodriguez[9]; Livio Filippin[10]; Mark Bissell[8]; Rainer Neugart[7]; Rodolfo Sanchez[11]; Ronald Fernando Garcia Ruiz[1]; Simon Kaufmann[3]; Sommer Felix[11]; Stephan Malbrunot[5]; Wilfried Noertershaeuser[3]; Wouter Anton M Gins[1]; Xiaofei Yang[1]; Zhengyu Xu[1]

[1] *KU Leuven (BE)*

[2] *University of Liverpool*

[3] *Technische Universitaet Darmstadt (DE)*

[4] *Universite de Paris-Sud 11 (FR)*

[5] *CERN*

[6] *University Mainz, Germany*

[7] *Max-Planck-Gesellschaft (DE)*

[8] *University of Manchester (GB)*

[9] *Université Paris-Saclay (FR)*

[10] *ULB, BE*

[11] *TU Darmstadt*

Corresponding Author: hanne.heylen@cern.ch

H. Heylen for the COLLAPS - IS613 collaboration

Collinear laser spectroscopy was performed on $^{26-32}$Al ($Z = 13$) at the COLLAPS experiment in ISOLDE-CERN. From the measured isotope shifts in combination with multiconfiguration Dirac–Hartree–Fock calculations of the atomic mass and field shift factor 1, the differences in mean-square charge radii along the Al isotopic chain could be extracted. These results will be compared to IM-SRG calculations, providing an interesting benchmark for charge radii of odd-Z, open shell nuclei in an ab-initio framework [2]. Additionally, our experiment allowed filling up the gap of missing nuclear moments of ^{29}Al and ^{30}Al.

During the experiment, special attention was paid to measurement of the hyperfine spectrum of the 0+ isomer in ^{26}Al. Despite the low isomeric production yields and fully overlapping structure with the ground state, for the first time an experimental value (and uncertainty) of its mean-square charge radius could be established. This is necessary to put the uncertainty assessment on the isospin-symmetry breaking correction used in the extraction of V_{ud} from the $0^+ \to 0^+$ superallowed beta-decay data on solid experimental grounds. Furthermore, the difference in radius between the $T = 0$ (ground) state and $T = 1$ (isomeric) state in $N = Z$ nuclei has been shown to be a sensitive probe for proton-neutron pairing correlations [3]. ^{26}Al is only the fourth case (and lightest one so far) for which this quantity is measured, and knowledge of its magnitude is important to better understand the phenomenon across the nuclear chart.

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Poster Session / 18

Investigation of isovector valence-shell excitations in nuclei around the N=82 shell closure

Authors: Ralph Otto Kern[1]; Robert Stegmann[1]; Georgi Ivanov Rainovski[2]; Norbert Pietralla[3]

Co-authors: James Gerald Cubiss [4]; Liam Gaffney [5]; Kalin Gladnishki [2]; Vasil Karayonchev [6]; Par-Anders Soderstrom [1]; Pietro Nicola Spagnoletti [7]; Andreas Vogt [6]; Nigel Victor Warr [6]; Andree Welker [8]; Volker Ralph Werner [1]; Johannes Christoph Wiederhold [1]; Radostina Zidarova

[1] *Technische Universitaet Darmstadt (DE)*

[2] *University of Sofia (BG)*

[3] *IKP, Technische Universität Darmstadt*

[4] *University of York (GB)*

[5] *CERN*

[6] *Universitaet zu Koeln (DE)*

[7] *UWS - Univ. of West of Scotland (GB)*

[8] *Technische Universitaet Dresden (DE)*

Corresponding Author: ralph.otto.kern@cern.ch

A particular interest in contemporary nuclear structure research is the impact of the local shell structure on the proton-neutron mixing in low-energy quadrupole states at the onset of collectivity near neutron shell closures. In near-spherical nuclei, the two simplest quadrupole-collective excitations can be understood as a mixture of the collective 2^+ proton and 2^+ neutron excitations. The symmetric (isoscalar) coupling appears as the 2^+_1 state while the antisymmetric (isovector) one forms the so-called $2^+_{1,ms}$ state with mixed proton-neutron symmetry. Based on the evolution of these states in the $N = 80$ isotonic chain it has been suggested that the properties of the mixed-symmetry states are sensitive to the underlying subshell structure. In particular, the observed fragmentation of the $2^+_{1,ms}$ of ^{138}Ce has been explained as due to the absence of a mechanism dubbed shell stabilization 1. This then requires contributions from active proton configuration in both, the $1g_{7/2}$ and $2d_{5/2}$ proton orbitals, and thus leads to fragmentation of low-lying quadrupole phonon excitations at $Z = 58$.

In order to examine further the effect of shell stbailization of the MSSs it is necessary to quantitaively identify and study the properties of these states in the next heavy $N = 80$ isotones beyond $Z = 58$ - ^{140}Nd and ^{142}Sm. This was the main goal of the IS546 experiment run in October 2017. Preliminary results from the experiment for both isotones will be shown and discussed.

Poster Session / 19

Alpha decay of ^{180}Tl

Author: Boris Andel[1]

[1] *Comenius University in Bratislava*

Corresponding Author: boris.andel@fmph.uniba.sk

Alpha-decay measurement is an important source of information on nuclear structure of exotic isotopes, especially when coincident γ rays are registered as well. Respective fine-structure α decays can be disentangled from complicated α-decay spectrum and excited states in daughter nucleus can be established. This is particularly valuable for investigation of odd-odd isotopes, where coupling of unpaired proton and neutron leads to high density of relatively low-lying states in daughter nuclides. Since α decay is very sensitive to changes of spin, parity or configuration, it provides an insight into structural differences between initial and final states.

A typical example of odd-odd nucleus decaying via multiple fine-structure transitions is ^{180}Tl. Its α decay was previously studied in Argonne National Laboratory [1,2], while β decay and β-delayed fission were investigated at the ISOLDE facility [3] with the Windmill decay-spectroscopy set-up [4]. This contribution will report on a detailed α-decay study of ^{180}Tl [5] performed in the same experiment at ISOLDE. High statistics collected during the measurement allowed us to analyze α-γ

and α-γ-γ coincidences. We identified many new excited states in daughter nucleus ^{176}Au, determined multipolarities for some of the γ decays de-exciting these states and established an extended decay scheme.

Reduced α-decay widths for ^{180}Tl transitions were evaluated and compared to values for unhindered decays in this region. It was found out that all decays of ^{180}Tl are hindered, which leads us to conclusion that daughter states are of different character than the ground state in ^{180}Tl. Alpha-decay properties of ^{180}Tl will be discussed in connection to decay characteristics of neighboring odd-odd Tl isotopes.

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Poster Session / 22

Towards beta-detected Nuclear Magnetic Resonance in Liquids: Recent Technical Developments at the VITO Beamline

Author: Robert Dale Harding[1]

Co-authors: Abhilash Javaji [2]; Anastasios Kanellakopoulos [3]; Bertram Blank [4]; Dalibor Zakoucky [5]; Frank Wienholtz [6]; Fredrik Parnefjord Gustafsson [7]; Gerda Neyens [8]; Hanne Heylen [8]; Joanna Wolak [9]; Magdalena Kowalska [8]; Marcus Jankowski [10]; Mark Bissell [11]; Michal Walczak [12]; Miguel Madurga Flores [13]; Mik Baranowski [9]; Nathal Severijns [3]; Phillip Wagenknecht [10]; Robin Yoel Engel [2]; Stavroula Pallada [8]; Victoria Isabel Araujo Escalona [3]; Voigt Kocman [14]; Wouter Anton M Gins [3]; Xiaofei Yang [3]; Zhengyu Xu [3]

[1] *University of York (GB)*

[2] *Universitaet Oldenburg (DE)*

[3] *KU Leuven (BE)*

[4] *CEN Bordeaux-Gradignan*

[5] *Acad. of Sciences of the Czech Rep. (CZ)*

[6] *Ernst-Moritz-Arndt-Universitaet (DE)*

[7] *KU Leuven, Instituut voor Kern- en Stralingsfysica, BE-3001 Leuven, Belgium*

[8] *CERN*

[9] *Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznan, Poland*

[10] *Carl von Ossietzky Universität Oldenburg, Ammerländer Heerstr. Germany*

[11] *University of Manchester (GB)*

[12] *Poznań University of Technology*

[13] *University of Tennessee (US)*

[14] *Slovenian NMR Center, National Institute of Chemistry, Ljubljana, Slovenia*

Corresponding Author: robert.harding@cern.ch

β-NMR is powerful tool which takes advantage of the anisotropic nature of beta decay to measure a range of nuclear properties. Nuclei are first polarised, then implanted into a crystal or sample of interest from which beta decay intensities are measured in opposing directions. The nuclear structure information is extracted from the excitation radio-frequency which resonantly destroys the polarization. The new VITO beamline has been developed over the last year to provide beams of spin polarised nuclei for study. This culminated in a successful commissioning experiment measuring the beta decay asymmetry in 26Na and 28Na, the results of which were published in March this year 1.

A recent proposal has been submitted to apply this powerful technique to study biological systems. One such example is to observe how Na+ cations interact with DNA G-quadruplex structures in solution, the subject of campaign IS645 [2]. To achieve this, the DNA sample would need to be kept in a low vacuum environment (on the order of a few mbar). Therefore, a new differential pumping system was designed to optimise the transport of the polarised ion beam from the high vacuum of the VITO beamline to the low vacuum of the detection chamber whilst preserving the polarisation properties of the beam essential for β-NMR. In addition, a new transitional magnetic field system and detection chamber featuring a liquid delivery mechanism were installed at the beamline. This contribution will focus on the development, testing and installation of these new systems at the VITO beamline.

1 M. Kowalska et al. J. Phys. G: Nucl. Part. Phys. 44 (2017)
[2] M. Kowalska, V. Kocman et al. Interaction of Na ions with DNA G-quadruplex structures studied directly with Na b-NMR spectroscopy. INTC Proposal IS645. (2017)

Poster Session / 29

111mCd in vanadium oxides: investigation of doping influence on local structure and phase transitions by time-differential perturbed angular correlations

Authors: Anastasia Burimova[1]; Artur Wilson Carbonari[1]; Brianna Bosch dos Santos[1]; Diego Richard[2]; Dru C. Lupascu[3]; Gabriel Adolfo Cabrera Pasca[4]; João Guilherme Martins Correia[5]; Juliana Schell[6]; Luciano Fabricio Dias Pereira[1]; Peter Schaaf[7]; Rafael Sá de Freitas[8]; Rajendra Narain Saxena[1]; Robinson Alves dos Santos[1]

[1] *Instituto de Pesquisas Energéticas e Nucleares - IPEN*

[2] *4Departamento de Física, Facultad de Ciencias Exactas, Universidad Nacional de La Plata, La Plata, Argentina*

[3] *Institute for Materials Science and Center for Nanointegration, Duisburg-Essen (CENIDE), University of Duisburg-Essen*

[4] *2Universidade Federal do Pará, Campus de Abaetetuba, Pará, Brazil*

[5] *EP Department, ISOLDE-CERN; Centro de Ciências e Tecnologias Nucleares (CCTN), Instituto Superior Técnico, Universidade de Lisboa, Portugal*

[6] *EP Department, ISOLDE-CERN; Institute for Materials Science and Center for Nanointegration, Duisburg-Essen (CENIDE), University of Duisburg-Essen*

[7] *Chair of Department of Materials for Electronics, Technische Universität Ilmenau, Institute of Materials Science and Engineering*

[8] *3Instituto de Física da Universidade de São Paulo-IFUSP*

Corresponding Author: rasantos@ipen.br

Extending the work started with LOI144, we present preliminary perturbed angular correlations results of vanadium oxides. The goal of this work is to understand, along with first-principles calculations, the effects of doping on the local structure in the dopant neighboring and its consequence on the electric and magnetic properties of the host oxides. Vanadium oxides are particularly attractive due to the phase transitions and to the capacity of the vanadium ion to change its oxidation state, being such properties well adequate for applications on, e.g., electrochemical energy storage via the intercalation of Li-ions, catalytic and optoelectronic devices. At ISOLDE-CERN, we started studying the incorporation of 111mCd by ion implantation as a function of temperature. In this presentation, we show promising preliminary results.

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LIST 2.0 - New features and ongoing developments for ISOLDE's Laser Ion Source and Trap LIST

Author: Reinhard Matthias Heinke[1]

Co-authors: Katerina Chrysalidis [1]; Dominik Studer [2]; Valentine Fedosseev [3]; Tom Kieck [1]; Tobias Kron [2]; Bruce Marsh [3]; Sebastian Raeder [4]; Sebastian Rothe [3]; Marcel Truemper [1]; Elise Verstraelen [5]; Klaus Wendt [1]

[1] *Johannes Gutenberg Universitaet Mainz (DE)*

[2] *Johannes-Gutenberg-Universitaet Mainz (DE)*

[3] *CERN*

[4] *Helmholtz-Insitut Mainz (DE)*

[5] *IKS, KU Leuven (BEL)*

Corresponding Author: reinhard.heinke@cern.ch

Today ion sources based on laser resonance ionization are well-established core techniques at the worldwide leading radioactive ion beam facilities such as CERN-ISOLDE or ISAC-TRIUMF. Ensuring both, highly efficient and element-selective ion beam production to the users, these devices in addition allow for direct laser spectroscopic investigations on exotic nuclei far off stability with lowest production yields. Further developments comprise preeminent suppression of isobaric contaminants by spatially separating the hot atomization cavity from a clean laser –atom interaction volume. This Laser Ion Source and Trap (LIST) design permits experimental access to nuclides such as neutron-rich Po, which were formerly inaccessible due to overwhelming contamination by easily surface ionized alkaline elements [1, 2].
Derived from operation experience and systematic studies, several changes have been implemented for the next generation of the LIST, intended to be run at ISOLDE in 2018. A dual repelling electrode design allows for simultaneous suppression of surface ionized contamination as well as electrons from the hot cavity, inhibiting electron impact induced ionization inside the LIST's RFQ structure [3]. Also, based on atom beam divergence investigations, the overall length was decreased, potentially yielding additional space for a chemically selective quartz transfer line.
By matching the field-free drift length in the LIST to the hot cavity dimensions, a time-of-flight based operation mode can be established, creating very short ion bunches. This effect is enhanced by using a higher voltage gradient over the cavity via high resistance materials and/or pulsed heating with higher currents. A fast and robust high current switch is being developed to allow for both laser repetition rate synchronized heating and quick in-situ polarity switching to select between additional suppression and ion guiding operation.
A perpendicular laser irradiation mode has been developed to perform Doppler-free high resolution spectroscopy in the LIST. Experimental linewidths below 100 MHz FWHM allow for hyperfine structure investigations of isotopes with highly dense spectra, as well as isomer-pure ion beam production. In off-line experiments, valuable nuclear data from minuscule samples of 10 day half-life Ac-229 could be extracted.
The presentation will give an overview of the described developments and discuss future directions.

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Poster Session / 32

Paving the way towards gamma-MRI

Author: Robin Yoel Engel[1]

Co-authors: Magdalena Kowalska [2]; Jean-Noël Hyacinthe [3]; Stavroula Pallada [2]; Walter Neu [4]; Karolina Kulesz [5]; Thierry Stora [2]; Renaud Blaise Jolivet [6]

[1] *Universitaet Oldenburg (DE)*

[2] *CERN*

[3] *Radiology Clinic, Geneva University Hospital and Faculty of Medicine, University of Geneva*

[4] *Faculty of Technology, Department of Natural Sciences, Photonics, University of Applied Sciences, Fachhochschule Oldenburg/Ostfriesland/Wilhelmshaven, Emden, Germany*

[5] *Warsaw University of Technology (PL)*

[6] *CERN and University of Geneva*

Corresponding Author: robin.yoel.engel@cern.ch

A 2016 publication in Nature 1 presented a proof of principle experiment for a new method of medical imaging. The new technique uses many elements of traditional Magnetic Resonant Imaging (MRI), but replaces the measurement of RF signals from 1H nuclei with the detection of anisotropic gamma-emission from a hyperpolarized radioactive tracer, in this case 131mXe.
Since gamma-radiation is far easier to detect than RF-photons, this method is sensitive to sample concentrations that are orders of magnitudes lower than those needed for conventional MRI. Therefore, it has the perspective of combining the advantages of nuclear tracers, as they are used in SPECT for their selective chemical properties, with the much higher spatial resolution of MRI.
The method as presented in Nature has only been realized with a relatively low-resolution 2d-projection image in gas phase, recorded over many hours.
We have therefore created a collaboration to further develop the method towards a new medical imaging modality. In this poster, we present the planned configuration of our first setup, as well as the imaging algorithm and simulation results for the upcoming experiments.

1: Y. Zheng et al, Nature, 537 (2016) 652-655

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Negative ion source development at ISOLDE –towards the electron affinity measurement of astatine

Author: David Leimbach[1]

Co-authors: Bruce Marsh [2]; Dag Hanstorp [1]; Joao Pedro Ramos [2]; Jochen Ballof [3]; Katerina Chrysalidis [3]; Klaus Wendt [3]; Reinhard Matthias Heinke [3]; Richard Catherall [2]; Sebastian Rothe [2]; Thierry Stora [2]; Tim Giles [2]

[1] *Gothenburg University (SE)*

[2] *CERN*

[3] *Johannes Gutenberg Universitaet Mainz (DE)*

Corresponding Author: david.leimbach@cern.ch

Most commonly, ISOLDE uses positively charged ion beams produced by a variety of ion sources such as the positive surface ion source, the Resonance Ionization Laser Ion Source (RILIS) or the Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source. In recent years, the availability of negative ion beams at ISOLDE was re-established and the development program for negative ion sources was revitalized. Recently, the first measurement of the electron affinity of the isotope iodine-128 using the GANDALPH experimental beam line marked a milestone on the way to a first experimental determination of the electron affinity (EA) of the radioactive element astatine. During the first campaigns, it was evident that the astatine experiment would not be successful under the current conditions. The development program, presented here, addresses the issues from both sides: increasing the production efficiency of low affinity elements and improving the experimental setup. To accelerate the negative ion source development, a dedicated ion source test stand was conceived and constructed. The two main features are an ion extraction system that allows measuring the total ion beam current, and a residual gas analyzer that allows us to monitor source degradation and outgassing. A data acquisition and control system facilitates the automation of repeated measurement tasks, thereby also enabling long-term performance tests, rigorous quality control and stress testing. Eventually we will perform destructive tests, which will give insight in to failure modes and

operational limits, the lack of knowledge of which is often a limiting factor in achieving optimal ion source performance under on-line conditions.
The GANDALPH experimental setup is undergoing several upgrades in order to improve its suitability for the study of low intensity beams of negative radioactive astatine ions that are expected at ISOLDE. A dedicated off-line negative ion source has been designed which is to be coupled to the GANDALPH beamline. This will facilitate testing and fine-tuning of the neutral atom detector and the new electrostatic elements in the beam-line.

We will introduce the general concept of the GANDALPH experimental beam line and the envisioned measurements at ISOLDE. A detailed description of the ion source and its parameters will be given in addition to a summary of the first results obtained from the work at the new ion source test stand.

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Absolute standardisation of ^{155}Tb and precision nuclear data determination: accelerating clinical uptake of novel radioisotopes

Authors: Andrew Robinson[1]; Sean Collins[1]; David Cullen[2]; Andrew Fenwick[1]; Kelley Ferreria[1]; Peter Ivanov[3]; John Keightley[1]; Ulli Koester[4]; Andy Pearce[1]; Ben Pietras[2]; Emlyn Price[2]; The MEDICIS collaboration[None]

[1] *National Physical Laboratory, UK*

[2] *The University of Manchester, UK*

[3] *National Physical Laboratory*

[4] *Institut Laue-Langevin (FR)*

Corresponding Author: andrew.robinson@npl.co.uk

Introduction:

Interest in the element terbium (Tb) for medical application has grown recently 1. Four Tb isotopes have been identified with the potential to provide unique theragnostic treatment strategies which combine cancer therapy with diagnostic imaging. The isotopes ^{155}Tb and ^{152}Tb can provide SPECT and PET imaging respectively [2], whilst ^{161}Tb can be used for beta– therapy [3] and ^{149}Tb for alpha therapy [4][5]. Using a combination of these isotopes as labels for radio-pharmaceuticals can provide both pre-therapy diagnostic imaging and post-therapy dosimetry and treatment optimisation using the same delivery vector. In order to validate the use of these isotopes for patient treatments extensive pre-clinical studies 1 are required to provide the foundation for future clinical trials.

The determination of administered activity, traceable to a primary standard of radioactivity is essential for all radio-pharmaceuticals. Accurate nuclear data measurements combined with a primary activity standardisation underpin the clinical use of any radioisotopes.

Methods:
Samples of ^{155}Tb were collected with the prototype MEDICIS collection chamber at ISOLDE. At NPL, pseudo-isobaric ^{139}Ce impurities have removed from the dissolved target using ion-exchange and extraction chromatography separation procedures. A new primary activity standardisation was performed using digital coincidence counting [6] and liquid scintillation techniques. Calibration factors for the NPL secondary standard ionisation chamber were also determined. Gamma spectrometry measurements of the ^{155}Tb decay scheme and half-life were also performed.

Results:
After purification of the sample a detection limit for ^{139}Ce of < 0.021 % is reported. An absolute activity standardisation for ^{155}Tb will be reported. Revised gamma-ray intensities for transitions in ^{155}Tb are reported with significant variations from the ENSDF evaluation [7]. A new half-life measurement is also reported.

The impact of these revised measurements on the clinical use of ^{155}Tb will be highlighted.

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Poster Session / 38

New shielded collection chamber for medical isotope collections

Authors: Fabien Lafont[1]; Ulli Köster[2]; Elodie Aubert[3]; Alexandre Dorsival[3]; Karl Johnston[3]; Joachim Vollaire[3]; Nick van der Meulen[4]; Etienne Vermeulen[5]

[1] *Institut Laue-Langevin*

[2] *Institut Laue-Langevin (FR)*

[3] *CERN*

[4] *PSI*

[5] *Paul Scherrer Institut (CH)*

Corresponding Author: lafont@ill.fr

Recent preclinical experiments using Tb isotopes produced at ISOLDE enabled significant progress in the field, including the first demonstration of PET imaging with an alpha emitter 1 and the demonstration of 152Tb as theranostic match for the clinically used 177Lu therapeutic isotope [2]. These successes enormously raised the interest of the medical community and a first clinical application using 152Tb could be performed in 2016 [3]. The activities required for this and future work are of the order of several hundred MBq and result in consequent dose rates. Thus, to follow the ALARA rules, manual manipulation should be minimized and a dedicated shielded collection chamber is required for such collections. Different concepts for such a shielded collection chamber were developed in the frame of the ENSAR2-TECHIBA-RITMI project and discussed with the Swiss Federal Office of Public Health (the radiation protection supervisory body of CERN). The newly designed collection chamber was constructed and tested at ILL, then installed at ISOLDE. A first commissioning run was successfully performed in September 2017 and two high activity collections of 152Tb were made for preclinical experiments at PSI.

Support by ENSAR2 (EU H2020 project Nr. 654002) is gratefully acknowledged.

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[3] RP Baum et al. Dalton Trans 2017; in press. DOI 10.1039/C7DT01936J

Poster Session / 57

Laser spectroscopy of tin across N=82

Author: Liss Vazquez Rodriguez[1]

Co-authors: Bradley Cheal [2]; Calvin Wraith [3]; Christian Gorges [4]; D. L Balabanski [5]; Deyan Yordanov [6]; Georgi Georgiev [7]; Gerda Neyens [8]; Hanne Heylen [8]; J. Krämer [9]; Klaus Blaum [10]; Liang Xie [2]; Magdalena Kowalska [8]; Mark Bissell [2]; R. Sanchez [11]; Rainer Neugart [10]; Ronald Fernando Garcia Ruiz [12]; Simon Kaufmann [4]; Simon Lechner [13]; Stephan Malbrunot [8]; T. Kanellakopoulos [14]; Varvara Lagaki [15]; W. Nörtershäuser [9]; Wouter Anton M Gins [12]; Xiaofei Yang [12]; Z. Y. Xu [14]

[1] *Université Paris-Saclay (FR)*

[2] *University of Manchester (GB)*

[3] *University of Liverpool (GB)*

[4] *Technische Universitaet Darmstadt (DE)*

[5] *ELI-NP, Horia Hulubei National Institute for R&D in Physics and Nuclear Eng., 077125 Magurele, Romania*

[6] *Universite de Paris-Sud 11 (FR)*

[7] *CSNSM*

[8] *CERN*

[9] *Institut für Kernphysik, TU Darmstadt, D-64289 Darmstadt, Germany*

[10] *Max-Planck-Gesellschaft (DE)*

[11] *GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany*

[12] *KU Leuven (BE)*

[13] *University of Vienna (AT)*

[14] *KU Leuven, Instituut voor Kern-en Stralingsfysica, B-3001 Leuven, Belgium*

[15] *Ernst Moritz Arndt Universitaet (DE)*

Corresponding Author: liss.vazquez.rodriguez@cern.ch

The hyperfine structure and isotope shift of the neutron-rich tin isotopes have been measured across the *N*=82 shell closure for the very first time. The work has been carried out at ISOLDE, CERN by high-resolution collinear laser spectroscopy. The charge radii and electromagnetic moments of ground and isomeric states along 107-134Sn show regularities which can be explained within the framework of "simple structure in complex nuclei" 1. The quadrupole moments of the 11/2- states, determined with much higher precision than previous studies, have been found to follow a characteristic trend similar to the one observed in the neighbouring cadmium isotopes [2]. The charge radius of the doubly magic plus one neutron nucleus 133Sn together with the one of 134Sn enable a conclusion on the expected "kink" in the radii trend at the *N*=82 shell closure.

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Reinforcing the participation and contribution of the Portuguese team @ HIE-ISOLDE

Author: Daniel Galaviz Redondo[1]

Co-authors: João Guilherme Martins Correia [2]; Luis Peralta [3]; R. Honorio [3]; P. Teubig [3]; A. Henriques [3]

[1] *LIP Laboratorio de Instrumentacao e Fisica Experimental de Part*

[2] *EP Department, ISOLDE-CERN; Centro de Ciências e Tecnologias Nucleares (CCTN), Instituto Superior Técnico, Universidade de Lisboa, Portugal*

[3] *LIP*

Corresponding Author: daniel.galaviz.redondo@cern.ch

The experimental nuclear physics group of the Faculty of Science of the University of Lisbon has recently joined the consortium of groups traditionally working at ISOLDE in fundamental nuclear physics. Nowadays, integrated at the LIP laboratory, our group has increased its presence and participation at various levels at the ISOLDE laboratory and is looking forward to the promising future of HIE-ISOLDE.

The group normally focuses on the study of nuclear reactions at relativistic energies in experiments performed at the GSI laboratory (Darmstadt, Germany), as well as on the study of properties of

interest for nuclear astrophysics of stable and exotic nuclei. The group has a solid background in the preparation, execution and analysis of complex nuclear reaction experiments.

Complementary to this, and thanks to the refurbishment of a Balzer's ultra-high vacuum thermal evaporator, the group has recently initiated a line of work devoted to the production of high quality thin films aimed to be used as targets in nuclear physics reaction experiments. A newly developed technique 1 resulted in a first batch of films isotopically enriched in 208Pb. The produced targets were used during the recent experiment IS619, in the study of the elastic scattering of 15C nuclei at energies close to the Coulomb barrier at the SEC line of HIE-ISOLDE.

Considering the higher energies available at HIE-ISOLDE, the group is working on a proposal to study the interaction of proton-rich nuclei in inverse kinematic reactions with Helium targets. These studies aim at improving the knowledge of basic nuclear physics properties that would reduce present associated uncertainties in nuclear reaction networks for nuclear astrophysics.

The present contribution provides an overview of the recent participation and future goals of the group at the ISOLDE/CERN laboratory.

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Coulomb Excitation of 206Hg using HIE-ISOLDE and Miniball

Author: Lisa Morrison[1]

[1] *University of Surrey*

My poster will summarise the experimental methods, simulations and results for the coulomb excitation of the singly magic two-proton-hole nucleus 206Hg. Doing so will provide information on both quadrupole and octupole collectivity of this nucleus and as a result provide an insight into its shape.

Poster Session / 60

MIRACLS- the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy

Author: Simon Lechner[1]

Co-authors: Klaus Blaum [2]; Laurin Fischer [3]; Hanne Heylen [3]; Varvara Lagaki [4]; Franziska Maria Maier ; Wilfried Noertershaeuser [5]; Marco Rosenbusch [6]; Stefan Sailer [7]; Lutz Christian Schweikhard [6]; Frank Wienholtz [6]; Stephan Malbrunot-Ettenauer [3]

[1] *Vienna University of Technology (AT)*

[2] *Max-Planck-Gesellschaft (DE)*

[3] *CERN*

[4] *Ernst Moritz Arndt Universitaet (DE)*

[5] *Technische Universitaet Darmstadt (DE)*

[6] *Ernst-Moritz-Arndt-Universitaet (DE)*

[7] *Technische Universitaet Muenchen (DE)*

Corresponding Author: simon.lechner@cern.ch

Collinear laser spectroscopy (CLS) is a powerful tool, with a long and successful history at COLLAPS/ISOLDE, to access nuclear ground state properties such as spin, charge radius, and electromagnetic moments with high precision and accuracy 1. Conventional CLS is based on the optical

detection of fluorescence photons from laser-excited ions or atoms. It is limited to radioactive ion beams with yields of more than 100 to 10,000 ions/s, depending on the specific case and spectroscopic transition. The study of the most exotic nuclides synthesised at ISOLDE consequently demands for more sensitive experimental methods.

Complementary to Collinear Resonance Ionization Spectroscopy (CRIS) [2] or more specialised techniques, e.g. [3], we are currently developing the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS). Supported by an ERC Starting Grant, this novel approach is determined to enhance the sensitivity of CLS by a factor of 20-600. It is centred on an a multi-reflection time-of-flight (MR-ToF) apparatus in which the ions bounce back and forth between electrostatic mirrors [4]. This scheme allows extended observation times and hence higher experimental sensitivity while preserving the high resolution of conventional CLS.

This poster contribution will introduce the MIRACLS concept and will present the current status of the project.

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