ISOLDE Workshop and Users meeting 2024

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Book of Abstracts

Contents

75

Welcome

Corresponding Author: brennan.goddard@cern.ch

76

ISOLDE Collaboration News

Corresponding Author: sean.freeman@cern.ch

Operation and developments I / 82

LS3 and MTP Planning

Author: Joachim Vollaire[1]

[1] *CERN*

Corresponding Author: joachim.vollaire@cern.ch

Several projects and activities have been identified under the ISOLDE Improvement Program to enhance the capacity and capabilities of the ISOLDE facility. This presentation will provide a summary of the current status of these initiatives, along with their implementation timelines, taking into account the constraints and opportunities presented by the broader planning of CERN's global accelerators and experimental areas."

Operation and developments I / 64

ISOLDE Beam Dumps Replacement and Sustainability (IBDRS), a step to 2 GeV and 6 uA at ISOLDE

Authors: Ana-Paula Bernardes[1]; Joachim Vollaire[1]; Marco Calviani[1]

[1] *CERN*

Corresponding Author: ana-paula.bernardes@cern.ch

The ISOLDE facility at CERN is pivotal in the field of Radioactive Ion Beams (RIBs) research facilities. Renowned globally for its significant contributions, the facility now faces the challenge of aging infrastructure dating from the early 1990s. To address this, an ISOLDE Improvement Program (IIP) has been launched with the aim of consolidating the facility enhancing its operational efficiency and scientific capabilities. Targeted improvements are scheduled for implementation during the Long Shutdown 3 (LS3) and later.

The ISOLDE Beam Dumps Replacement and Sustainability (IBDRS) project is a core component of this ambitious program. The project focuses on the upgrade of the beam dumps and shielding associated with the GPS and HRS target stations to accommodate operation with higher beam power in the future. The new beam dump systems are designed to safely handle beam energies up to 2 GeV and an averaged beam intensity of 6 uA, compared to the current nominal beam parameters of 1.4 GeV and 2 uA. The higher beam energy and intensity is considered for routine operation of

the facility after the modification of the proton beam line to ISOLDE (foreseen during LS3) and the upgrades of the target stations during LS4.
The IBDRS project will be executed in 3 phases:
- Excavation of the earth above the target area and removal of the shielding blocks, including two uncooled iron blocks that have absorbed most of the beam delivered to ISOLDE since 1992.
- Construction of a new underground technical building above the ISOLDE target area
- Installation of two water-cooled dumps compatible with 2 GeV and 6 uA operation surrounded by a massive iron shielding within the new technical building

In addition to ensuring the long-term radiation safety of the ISOLDE facility, this major upgrade will create new opportunities and keep ISOLDE at the forefront in the fields of nuclear physics research. This contribution will outline the strategic plan to complete this major upgrade within two years during LS3.

Operation and developments I / 70

Development of nano-structured materials for ISOLDE targets

Author: Valentina Berlin[1]

Co-authors: Alexander Schmidt ; Bernard Crepieux [2]; Edgar Miguel Sobral Dos Reis ; Isabel Frank [2]; Line Le ; Matthias Alexander Grasser ; Mia Au [2]; Sebastian Rothe [2]; Serdar Usta ; Simon Thomas Stegemann [2]

[1] *SY group*

[2] *CERN*

Corresponding Author: valentina.berlin@cern.ch

The isotope separation on-line (ISOL) technique consists of on-line extraction, ionization, acceleration, and mass separation of radioisotopes produced in a target material irradiated by a high-energy particle beam. At CERN-ISOLDE, this technique is used to produce a broad variety of radioactive ion beams, enabling the study of exotic isotopes for research in nuclear physics, astrophysics, materials science, and medical applications.
The intensity of a radioactive ion beam at CERN-ISOLDE depends on multiple factors, including the primary beam intensity, target thickness, production cross-section for specific isotopes, as well as the efficiency of isotope extraction, ionization, and purification. To allow a reasonably fast release of the produced nuclei, the target should be tailored to optimize these parameters by selecting materials that are chemically and thermally stable under operational conditions and facilitate rapid diffusion and effusion rates of the elements of interest[1].
ISOLDE targets may be provided in the form of pressed pellets, loose powders, fibres, foils or molten metals, with the target material being carbides, metal/graphite mixtures, refractory metals, eutectic mixtures and oxides[1-2]. Traditionally bulk and micrometric materials have shown significant performance losses during the release process of more exotic radioisotopes, as challenges related to very short half-lives, low production efficiency and difficulties due to certain elements'refractory nature. The latter issue can be addressed by introducing a chemical reactant to enhance the release of the radioisotopes of interest as molecular beams and provide high-purity beams with less contamination compared to atomic beams[3]. The yields of short-lived isotopes can instead be improved by refining the microstructure of target materials as previous experiments at ISOLDE have demonstrated[4-5]. Optimizing these structural characteristics not only improves isotope release but also helps in maintaining the stability of the beam intensity over time[4], which is highly advantageous for users receiving the beam over extended periods of time, making the planning and execution of experimental campaigns more straightforward.
Exploring alternative compositions, testing novel material morphologies, and enhancing key material properties are crucial steps toward improving performance and overcoming current limitations in isotope production, providing stronger and more varied beams to users. In this work, we will examine the potential for employing new materials and nanostructures in ISOLDE target, discuss the challenges related to materials production and characterization, and present recent progress in the development of nanostructured target materials in ISOLDE's chemical laboratories.

Keywords: nanomaterials, porous materials, sintering, ion beam, isotope production, short-lived isotopes.

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5. A. Gottberg, "Target materials for exotic ISOL beams", Nucl. Instrum. Meth. B 376 (2016) 8-15.

Operation and developments II / **80**

In Memory of Bruce Marsh and Mats Lindroos

Operation and developments II / **73**

RILIS in 2024

Author: Jordan Ray Reilly[1]

Co-authors: Anjali Ajayakumar ; Asar A H Jaradat [1]; Cyril Bernerd [2]; Hendrik Buker [3]; Julius Wilhelm Wessolek [1]; Katerina Chrysalidis [2]; Lisa Theresa Gloggler [2]; Manikanta Elle [4]; Mia Au [2]; Mitzi Valeria Urquiza Gonzalez [5]; Ralf Erik Rossel [2]; Ralitsa Ivaylova Mancheva [4]; Reinhard Heinke [1]; Sebastian Rothe [2]; Valentine Fedosseev [2]

[1] *The University of Manchester (GB)*

[2] *CERN*

[3] *KIT - Karlsruhe Institute of Technology (DE)*

[4] *KU Leuven (BE)*

[5] *University of Gothenburg (SE)*

Corresponding Author: jordan.reilly@cern.ch

The Resonance Ionization Laser Ion Source (RILIS) is an essential technique to selectively supply radioactive ion beams to a plethora of experimental arrangements within the ISOLDE facility. Over the past year, RILIS has been involved in supplying laser ionized radioactive ion beams on 22 occasions, producing 60\% of the total beam supplied throughout the online and winter physics periods. This continuous requirement of laser-ionized species demands constant laser developments, ion beam production and selectivity improvements, and Laser Ion Source and Trap (LIST) progression in order to provide purified laser ion beams and rapid switching between elements.
In this talk I will summarize the operation and activities of RILIS and the local group throughout the course of 2024. This will include details on both the technical developments and the scientific output. The technical aspects of this talk will include the first online deployment of the intra-cavity frequency tripling unit, the implementation of the fast-switching 10˜kHz beamgate to provide enhanced laser-ionized beam purity, and the initial investigations to provide refractory beams using in-trap decay performed within the ISCOOL RFQ. On the scientific output component, brief details regarding the LIST experimental campaigns on thulium and lutetium will be presented along with the in-source laser spectroscopy campaign of mercury. The conclusion of this talk will present the planned upgrades and future outlook of RILIS leading into the next running period.

Operation and developments II / 48

Status of PUMA at the new isobar separator beamline RC6

Author: Lukas Nies[1]

[1] *CERN*

Corresponding Author: lukas.nies@cern.ch

The antiProton Unstable Matter Annihilation (PUMA) experiment aims to probe the surface properties of stable and unstable isotopes by annihilating antiprotons with protons and neutrons on the surface of nuclei [1]. The pions generated in the annihilation events are identified and counted using a time-projection chamber and a scintillator trigger barrel surrounding the interaction region. While no facility to date combines radioactive ion beam and antiproton production, PUMA aims to bring antiprotons from the Antiproton Decelerator "across the street"to ISOLDE using a transportable ion trap. The experiment's requirements on isobaric beam purity and vacuum conditions motivate the installation of the new RC6 beamline at ISOLDE, including the Multi-Reflection Time-of-Flight mass spectrometer (MR-ToF MS), currently in operation at the MIRACLS experiment [2]. In this contribution, the status of the PUMA Penning trap, trigger barrel, and TPC are presented, together with the progress on the construction of the new RC6 beamline.
[1] T. Aumann et al., Eur. Phys. J. A (2022) 58: 88
[2] F. Maier et al., NIM A 1048 (2023), 167927

Operation and developments II / 52

The ISOLDE Superconducting Recoil Separator: design, prototypes, and plans for the future.

Authors: Ismael Martel[1]; Ibon Bustinduy[2]; Teresa Kurtukian Nieto[3]; Olof Tengblad[3]

[1] *University of Huelva (ES)*

[2] *ESS Bilbao Initiative*

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

Corresponding Author: ismael.martel.bravo@cern.ch

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The HIE-ISOLDE facility can accelerate a wide variety of radioactive ions, from 6He to 232Ra, up to collision energies close to 10 MeV/A. Present physics program covers a broad range of nuclear structure aspects such as shell-evolution and nuclear shape transitions, unbound systems, reaction dynamics, and astrophysical processes. The ISOLDE Superconducting Recoil Separator (ISRS) [1] aims to extend and develop the HIE-ISOLDE physics programme by combining mass selectivity with target and focal plane spectroscopy. The performance of state-of-the-art linear spectrometers is limited by the length of drifts and dispersive planes, magnetic-field nonlinearities, ohmic losses and mechanical complexity of heavy, room-temperature magnets. ISRS follows a different approach [2]. The spectrometer consists of an array of iron-free superconducting multifunction magnets, cooled by cryocoolers, integrated into a compact particle storage ring that confine the reaction fragments using Fixed Field Alternating Gradient Focussing (FFAG). Unprecedented A/Q selectivity can be achieved by combining ToF with fragment's characteristic cyclotron frequency [3]. During the last year the collaboration has developed an intensive R&D program covering beam dynamics, design studies, and prototypes of critical subsystems. In this contribution we will review recent achievements and planned activities.

References
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[2] ISRS project web site, www.uhu.es/isrs/

[3] J. Resta-López et al., "Design of a compact superconducting recoil separator for HIE-ISOLDE". Proc. of IPAC 2023, TUPA050, 2023.

Operation and developments II / 28

Test bench for the ISOLDE Superconducting Recoil Separator ISRS

Author: Sergio Sanchez Navas[1]

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

Corresponding Author: sergio.sanchez@csic.es

The ISRS is a novel high-resolution recoil separator to be installed at the end of XT03 at HIE-ISOLDE. The design of the ISRS spectrometer exploits the different time-of-flight of the fragments produced in the reaction target to perform the particle separation. Those reaction fragments are injected into a particle storage system, composed of an array of iron-free superconducting multifunction magnets (SCMF) cooled by cryocoolers, and integrated into a compact storage mini-ring using Fixed Field Alternating Gradient focusing (FFAG). This system could allow us to reach resolutions of 1/2000. The present design is compact (3.5 m diameter) with a relatively low magnetic field (< 3T) that should manage to recirculate with 100% efficiency a cocktail beam of heavy mass isotopes (up to mass 234) at 10 MeV/u with a 30% momentum spread.
A prototype of a 90◦ bending magnet composed of a CCT solenoid (FUSILLO) with a pure dipole central field of 3.0 T has been developed by CERN.
The first stage consists of a linear design using one 36◦ compact straight iron-free CCT magnets, called MAGDEM (Magnet Demonstrator), that will be integrated into a dedicated beam transport and focusing system, and assembled into a fully operational ion test bench. The focusing system, target chamber, and focal plane detectors are under study at IEM-CSIC within the MRR-ISRS-Spain project.

Exotic decays / 11

Looking for Beta-Delayed Protons in the Decay of 11Be

Author: Marek Pfutzner[1]

[1] *University of Warsaw*

Corresponding Author: marek.pfutzner@cern.ch

Beta-delayed proton emission is a phenomenon that typically occurs for exotic neutron-deficient nuclei, when the proton binding energy in the beta-daughter nucleus is small and falls well within the Q-beta value. Nevertheless, the energy window for this process is open also for a few light, neutron-rich isotopes. Particularly interesting in this respect is the one-neutron halo nucleus 11Be, for which several channels for beta-delayed particle emission are open, including that for proton decay, with an energy window of 280 keV.
The beta-delayed proton branching ratio is interesting for the determination of the Gamow-Teller strength at high excitation energy and for testing models that predict a direct relation between delayed proton emission and the halo structure. Recent measurements yielded conflicting experimental results for the branching ratio value, triggering even further interest on the problem from the experimental and theoretical communities.

In this work, the Warsaw Optical Time Projection Chamber (OTPC) was used to search for beta-delayed protons in the decay of 11Be. The main experiment was performed at the HIE-ISOLDE facility in CERN, where post-accelerated 11Be ions were implanted into the OTPC and their subsequent decays with the emission of charged particles were recorded. In the talk, our experimental method will be described and the results presented.

Exotic decays / 12

Search for double alpha decay

Authors: Louis Heitz[1]; Elias KHAN[None]; Marine Vandebrouck[2]; Barbara Sulignano[2]; Damien Thisse[2]

[1] *CEA/Irfu/DPhN & IJCLab*

[2] *CEA/Irfu/DPhN*

Corresponding Author: louis.heitz@ijclab.in2p3.fr

Alpha decay is known for more than a century, however a global microscopic description of this process has only been successfully developed recently by Mercier et al. [1]. Within the framework of covariant energy density functional, using a least action principle, the half-life of medium and heavy nuclei are in agreement within one order of magnitude with experimental value [2].

Moreover, a new type of decay was predicted : the double alpha decay, where two alpha particles are emitted simultaneously with a large relative angle. Their typical branching ratio (BR) of ˜10-7 with respect to the single alpha decay, makes it experimentally accessible, these values of BR being those of well-known cluster decays already detected.

A dedicated experiment was held at Isolde in June 2023. A radioactive beam of 220-222Ra has been used to probe for possible double alpha decay of 220-222Ra as well as 216-218Rn. The setup consisted in 4 DSSD, which allows to make accurate spatial (and temporal) coincidences and therefore to drastically reduce the background due to single alpha decays. Preliminary results on this hunt will be shown.

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[2] J. Zhao et al., PRC 107, 034311 (2023)

Exotic decays / 69

Beta-delayed neutron emission at Isolde Decay Station

Author: Robert Kazimierz Grzywacz[1]

Co-authors: IDS Collaboration ; Miguel Madurga Flores [1]; Peter Dyszel [2]; Zhengyu Xu [1]

[1] *University of Tennessee (US)*

[2] *University of Tennessee*

Corresponding Author: robert.grzywack@cern.ch

Beta-delayed (β-n) neutron emitters are a focus of recent ISOLDE [Hei23, Xu23, Xu24], RIKEN [Yok19, Pho22, Yok23], and FRIB/NSCL [Cox24, Neu24] studies. The knowledge of the mechanism of β-delayed neutron emission and its consequences on the decay probabilities contribute to diverse areas of nuclear science, from nuclear reactors to astrophysical nucleosynthesis. Until recently, modeling the β-n process relied on the assumption of Bohr's hypothesis of the compound nucleus (CN) [Boh36, Boh39], in that cause decay of the excited nucleus, populated in β-decay, depends only on its spin, parity, and excitation energy and is independent of the formation process. Our recent experimental work suggested evidence of non-statistical β-n emission near doubly magic 132 Sn [Hei23]. Since then,another clear case has been found in the data [Xu24], and the search for more cases is ongoing using already collected data. These searches aim to verify the limits of the compound nucleus

assumption's applicability and understand the underlying mechanism for non-statistical neutron emission. This is currently attributed to the concept of the doorway state, which is a neutron emitting with a strong mixing with the particle-hole excitations. These are populated in allowed β decay but with very small neutron emission widths. Measurements require access to high-quality beams of β-delayed neutron emitters and a sophisticated detection system, which combines neutron and gamma-ray detectors. To that end, we continue to build new types of neutron detectors. In the recent experiments at Isolde Decay Station, we implemented a recently developed neutron array NEXT [Hei19, Neu22], with interaction tracking capabilities and a new detector, based on new generation material, called an Organic Glass Scintillator (OGS) [War21].
While the analysis is still ongoing, the new results will be presented. I will also discuss some recent β-n results obtained with the FRIB Decay Station Initiator.
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[Yok23] R. Yokoyama et al. Phys. Rev. C 108, 064307 (2023).

Other experiment at CERN / 65

The CERN CLOUD Experiment

Author: Eva Sommer[1]

[1] *University of Vienna (AT)*

Corresponding Author: eva.sommer@cern.ch

This talk will provide an overview of the CERN CLOUD experiment, which explores the formation of atmospheric aerosol particles from trace gas molecules, with a particular focus on the role of cosmic ray-generated ions. Atmospheric aerosols and their interactions with clouds are critical for regulating Earth's radiative balance, making this research essential for understanding anthropogenic climate change. Over more than a decade of operation, CLOUD has made substantial contributions to this field.

The centerpiece of the experiment is the CLOUD chamber, the world's cleanest facility for aerosol formation studies. This 27 m3 stainless steel chamber allows precise control of trace gases at parts-per-trillion levels and simulates a wide range of atmospheric conditions, operating between −70℃ and 100℃ with an accuracy of 0.1℃. Six different light sources are used to trigger various chemical reactions and cosmic rays are simulated using a pion beam from the Proton Synchrotron. The talk will cover the experimental setup, its unique capabilities, the scientific motivation behind the experiment, and key findings that enhance our understanding of atmospheric particle formation and its impact on the global climate.

News from other facilities / 10

The DESIR facility at GANIL/SPIRAL2

Author: Bertram Andreas Blank[1]

[1] *Centre National de la Recherche Scientifique (FR)*

Corresponding Author: bertram.andreas.blank@cern.ch

DESIR, the low-energy facility of GANIL/SPIRAL2 is presently in its construction phase. It will provide users with high-quality exotic beams at energies up of 60 keV. The physics case is centred around three pillars: laser spectroscopy with the LUMIERE facility, ion trapping within DETRAP and the beta-decay experiments grouped in the BESTIOL collaboration. The experiments will address topics in nuclear structure physics, fundamental interactions, nuclear astrophysics and applications of nuclear techniques. One of the main assets of DESIR will be the availability of two complementary production sites for radioactive species (neutron-deficient and heavy nuclei with S3, light fragments with SPIRAL1) and a series of purification devices to provide isotopically pure beams to the users. The future addition of a fission-based production facility at SPIRAL2 will enhance the production capabilities of beams for DESIR significantly.
The paper will present the physics case of the DESIR facility, its general layout and the instrumentation under construction or commissioning.

News from other facilities / 45

Laser spectroscopy of aluminium isotopes at the limits of existence at FRIB

Author: Shane Wilkins[1]

[1] *Massachusetts Institute of Technology*

Corresponding Author: shane.wilkins@cern.ch

Presented on behalf of the BECOLA-RISE Collaboration.

Investigating the properties of atomic nuclei through measuring their influence upon bound electrons is a powerful and well-established approach in modern nuclear physics [Yan23]. By measuring the hyperfine structure and isotope shift in the atomic structure of radioactive nuclei, nuclear spins, magnetic dipole and electric quadrupole moments and changes in mean-square charge radii can be determined in a nuclear model-independent manner. These observables offer critical and complementary insights into the electromagnetic structure of the ground- and isomeric states of atomic nuclei, enabling state-of-the-art models of nuclear theory to be tested.

There is evidence for the existence of a proton halo in the neutron-deficient isotope ^{22}Al. Decay studies suggest that the unbound excited 1+ state possesses a proton halo based on the asymmetry of decays populating it from ^{22}Si compared to its mirror nucleus, ^{22}O [Lee20]. Reaction experiments measure an increased reaction cross-section in ^{23}Al compared to other N=10 isotones, suggesting an increase in nuclear size (both protons and neutrons) near the dripline [Cai02]. Additional experiments measuring the ground-state mass of ^{22}Al reveals an exceptionally low proton-separation energy of around 100 keV, a prerequisite for halo formation [Cam24]. Furthermore, ab initio nuclear theory calculations employing three different nuclear interactions predict an increase in the proton distribution size for the dripline nucleus ^{22}Al, compared to its heavier neighbours [Miy24].

To investigate the charge distribution of ^{22}Al, it was recently studied with laser spectroscopy using the new Resonance Ionization Spectroscopy Experiment, at the Facility for Rare Isotope Beams. This contribution will present the results from this campaign, where the changes in mean-square charge radii were measured all the way the proton dripline nucleus ^{22}Al (N=9).

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News from other facilities / 22

Mass Measurements of Actinides at TRIGA-Trap

Author: Tanvir Sayed[None]

Corresponding Author: tanvir.sayed@mpi-hd.mpg.de

TRIGA-Trap is a high-precision, double Penning trap mass spectrometer located in the reactor hall of the TRIGA (Training, Research, Isotopes, General Atomic) research reactor in Mainz, Germany. Masses of actinides including ^{244}Pu, ^{241}Am, ^{243}Am, ^{248}Cm, and ^{249}Cf have been measured using the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique, achieving uncertainties in the parts-per-billion (ppb) level. These actinides are in the vicinity of the neutron number $N = 152$, a region associated with a deformed sub-shell closure. The precise mass measurements allow the exploration of nuclear structure through trends in mass filters, such as S_{2n} (two-neutron separation energies) and $\delta V_{p,n}$ (average p-n interaction of the most loosely-bound two nucleons), as well as their differentials. Further measurements of actinides are planned to enhance the current dataset and contribute to ongoing nuclear structure studies. In this presentation, an overview of the current status of the experiment, as well as future directions, will be discussed.

News from other facilities / 29

Gaussian process and Bayesian optimization for automatic tuning of the ion source and beam optics of the ISOLDE OFFLINE 2

Author: Santiago Ramos Garces[1]

Co-authors: Dinko Atanasov [2]; Joao Pedro Ramos [3]; Line Le [4]; Lucia Popescu [2]; Marc Dierckx [2]; Maximilian Schuett [4]; Mia Au [4]; Sebastian Rothe [4]; Stijn Derammelaere [1]

[1] *CoSysLab, Department of Electromechanics, University of Antwerp (BE)*

[2] *SCK CEN, Belgian Nuclear Research Center (BE)*

[3] *Belgian Nuclear Research Center (BE)*

[4] *CERN*

Corresponding Author: santiago.ramos.garces@sckcen.be

This contribution presents the results of an experimental test for the automatic tuning of a FEBIAD ion source and electrostatic beamline elements, performed at the OFFLINE 2 facility at ISOLDE. The algorithms were developed for the automatic tuning of the ISOL@MYRRHA facility at the Belgian Nuclear Research Centre and were adapted for testing at the OFFLINE 2 facility. The integration of automatic algorithms to assist in the parameter tuning process of Isotope Separator Online (ISOL) systems is essential due to the time-consuming nature of manual beam tuning and ion source optimization. Optimizing these systems requires adjusting a large number of parameters, while meeting specific performance requirements. As a result, the quality (purity) and quantity (intensity) of the Radioactive Ion Beam (RIB) delivered to the experimental end station are highly dependent on the precise tuning of these parameters and their interactions. In this work, we propose optimization techniques that simultaneously tune the beam optics and ion source parameters, with the goal of extracting a beam with the highest current and optimized beam shape while ensuring efficient transmission through the dipole magnet. Optimizing an ISOL system poses a constrained, multidimensional optimization problem, where evaluating the objective function is time-intensive due to the data acquisition duration of the diagnostic devices.

To address this challenge, we propose using Bayesian optimization (BO), known for its ability to optimize expensive objective functions in relatively few iterations. Furthermore, we employ a Gaussian Process (GP) as a surrogate model to capture parameters effect on the objective function. While the combination of Gaussian Process and Bayesian optimization has been successfully applied in accelerator tuning, in this work we extend its functionality by simultaneously tuning ion source parameters

along with ion beam optics at the ISOLDE OFFLINE 2 facility (YOL2). The beam optics parameters optimized include the voltages of three electrostatic quadrupoles and four voltages from two horizontal and vertical steerers located before the mass separator dipole magnet. For the FEBIAD ion source, the anode voltage and ion source magnet coil current were tuned. The optimization objective was to maximize the beam current, align the beam, and minimize beam size at the entrance focal point of the dipole magnet. Instead of using a Faraday cup to measure the beam current, as is common practice, we computed the objective function using only the wire scanner located before the separator magnet.

Lastly, to accelerate the algorithm's convergence, we utilized archival data by formulating a data-informed Gaussian Process. This approach learns correlations between design parameters, enabling faster convergence toward optimal parameter combinations. This formulation was also tested on the beam optics of YOL2.

Special session / 83

Invisible Diversity Dimensions Poll

Author: Louise Carvalho[1]

[1] *CERN*

Corresponding Author: louise.carvalho@cern.ch

Invisible diversity dimensions refer to aspects of diversity that are not immediately apparent or visible. With this interactive presentation from CERN's Diversity & Inclusion Programme Leader, we gain a better understanding of the invisible diversity dimensions that unite us and their relevance to our daily interactions in the workplace.
Bring your phones and some curiosity, you'll need both

Poster session / 2

Machine Learning Optimization for Beam Steering at TRIUMF's ISAC Facility

Author: Omar Hassan[1]

Co-authors: Chris Ruiz [1]; Oliver Kester [1]; Olivier Shelbaya [2]; Rick Baartman [1]; Thomas Planche [1]; Wojciech Fedorko [2]

[1] *TRIUMF, University of Victoria*

[2] *TRIUMF*

Corresponding Author: ohassan@triumf.ca

TRIUMF's Isotope Separator & ACcelerator (ISAC) facility provides beam to many pivotal nuclear astrophysics experiments. Among these is the Detector of Recoils And Gammas Of Nuclear reactions (DRAGON), which aims to explore the reaction rates of nuclear astrophysical processes by measuring resonances through radiative capture. For this, rare isotope beams delivered to DRAGON are manually tuned by operators in what is a highly variable and inefficient process. This leads to issues as there is high demand for beam time, limiting availability for DRAGON. In particular, the required beam steering cannot be directly modeled as potential sources like alignment errors or magnetic fringe fields are not accurately known. This is a black-box problem where the true functional value can only be accessed by evaluation. Our method uses machine learning to find the optimal steerer values for a given objective. This method has been primarily tested for the single-objective case where our objective is the beam transmission. The multi-objective case considers both the beam

transmission and deviation from the beam axis, where initial testing has been done using simulations to prepare for online testing.

Poster session / **3**

Nuclear magnetic dipole moments of As and Sb isotopes from ab initio NMR shielding calculations and NMR experiments

Author: Andrej Hurajt[1]

Co-authors: Dariusz Kedziera [2]; Anna Kaczmarek-Kedziera [3]; Andrej Antušek [4]

[1] *Department of Physical and Theoretical Chemistry, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina, Ilkovičova 6, 842 15 Bratislava, Slovak republic*

[2] *Faculty of Chemistry, Nicolaus Copernicus University in Toruń, Gagarina 7, 87-100 Toruń, Poland*

[3] *Faculty of Chemistry, Nicolaus Copernicus University in Toruń, ul. Gagarina 7, 87-100 Toruń, Poland*

[4] *Slovak University of Technology in Bratislava, ATRI, Faculty of Materials Science and Technology in Trnava, J. Bottu 25, 917 24 Trnava, Slovak Republic*

Corresponding Author: hurajt3@uniba.sk

Accurate NMR shielding constants for arsenic (As) and antimony (Sb) in the AsF_6^-, AsO_4^{3-}, $SbCl_6^-$, and SbF_6^- complexes were calculated using both non-relativistic coupled cluster methods and relativistic four-component density functional theory (DFT). The magnetic dipole moments of the ^{75}As, ^{121}Sb, and ^{123}Sb nuclei were redetermined, leading to revised recommended reference values. The updated nuclear magnetic dipole moments are $\mu(^{75}\text{As})$ = 1.43711(4) μ_N, $\mu(^{121}\text{Sb})$ = 3.35540(33) μ_N, and $\mu(^{123}\text{Sb})$ = 2.54389(25) μ_N, correcting previous systematic errors of up to 0.008 μ_N in earlier reference data. These magnetic dipole moments provide reliable references in nuclear physics, becoming the reference for magnetic moments in isotopic series of radioactive/exotic nuclei.

Poster session / **9**

PI-LIST at ISOLDE

Authors: Asar A H Jaradat[1]; Collaboration PI-LIST[2]

[1] *The University of Manchester (GB)*

[2] *CERN*

Corresponding Author: asar.a.h.jaradat@cern.ch

Laser resonance ionization spectroscopy in the ion source coupled directly to the isotope production target has been proven to be a highly sensitive tool for nuclear structure investigations on isotopes with low production and extraction yields [1]. While the efficiency of this technique is unrivalled, the spectral resolution is ultimately limited by Doppler broadening. At the ion source temperature of ˜2000 °C typically required for efficient operation, Doppler broadening results in a 1-10 GHz experimental resolution limit whereas precise measurements of nuclear magnetic and quadrupole moments often require resolving hyperfine structure splittings below the GHz regime.
A new laser ion source design has been implemented at ISOLDE recently to provide in-source spectroscopy capabilities down to experimental linewidths of 100 −200 MHz, an order of magnitude below usual limitations. It is based on the high beam purity Laser Ion Source and Trap (LIST) [2, 3], featuring spatial separation of the hot cavity where potential ion beam contamination can arise from non-laser related ionization mechanisms such as surface ionization, and a clean laser-atom interaction region in an RFQ unit directly downstream, where solely element-selective laser ionization takes place. In the so-called Perpendicularly Illuminated LIST (PI-LIST) [4], a crossed laser/atom

beam geometry reduces the effective Doppler broadening by addressing only the transversal velocity components of the effusing atom ensemble.
Following the integration of this device as the standard tool for high-resolution spectroscopy applications at the off-line mass separator facility at Mainz University [5, 6], we present its first on-line application at ISOLDE for nuclear structure investigations. Neutron-rich actinium isotopes in the region of assumed octupole deformation were probed, pinning down predictions of recent Energy Density Functional nuclear theories that incorporate reflection symmetry breaking [7].
The applicability of this technique to ISOL facilities in general, its limits especially in terms of significant efficiency loss, and technical implementation challenges are discussed.

Poster session / 14

Triaxial Nuclear Shapes from Simple Ratios of Electric-Quadrupole Matrix Elements

Authors: Elena Lawrie[1]; Jose Nicolas Orce Gonzalez[2]

[1] *iThemba LABS / University of the Western Cape*

[2] *University of the Western Cape (ZA)*

Corresponding Author: nico.orce@cern.ch

Theoretical models often invoke triaxial nuclear shapes to explain elusive collective phenomena, but such assumptions are usually difficult to confirm experimentally. The only direct measurements of the nuclear axial asymmetry γ is based on rotational invariants of zero-coupled products of the electric-quadrupole (E2) operator, which generally require knowledge of a large number of E2 matrix elements connecting the state of interest. We propose an alternative method to determine γ of even-even deformed nuclei using ratios of two E2 matrix elements only, which are typically well known. While this approach is based on modelling the rotation of a rigid triaxial nucleus following the Davidov and Filippov model, it is applied in such a way that it becomes practically model-independent and parameter-free. The results are in agreement with the Kumar-Cline model-independent values of γ (where measurements are available). The technique was applied to more than 60 deformed even-even nuclei suggesting that deformed nuclei generally exhibit well-defined axially-asymmetric shapes rather than deformation softness as it is commonly presumed.

Poster session / 18

Thermal Release studies from Activated ^{nat}Ti, ^{nat}V and ^{nat}Ta Target Materials - Investigation of Parameters Relevant for Isotope Mass Separation

Author: Patricija Kalnina[1]

Co-authors: Alexandre Dorsival [1]; Bernard Crepieux [1]; Charlotte Duchemin [2]; Chris Theis ; Edgars Mamis ; Elina Pajuste [3]; Francisco Ogallar Ruiz [1]; Helmut Vincke [1]; Laura Lambert [1]; Matthieu Deschamps ; Nadine Conan [1]; Robert Froeschl [1]; Sebastian Rothe [1]; Thierry Stora [1]

[1] *CERN*

[2] *CERN SY/STI/RBS*

[3] *University of Latvia (LV)*

Corresponding Author: patricija.kalnina@cern.ch

Scandium (Sc) and Terbium (Tb) have gained significant interest in nuclear medicine due to their radioactive isotopes being suitable for cancer diagnostics and therapy, offering a promising avenue

for theranostics. However, challenges persist in achieving high molar activity and radiochemical purity for medical applications. The physical isotope mass separation technique presents an interest to increase the purity of such samples for medical applications. Despite recent advancements in mass separation at CERN-MEDICIS and other different facilities, the efficiency for some radionuclides known as "difficult to extract"such as Sc and Tb, remain sub-optimal to produce medically relevant activities.
This study aims to systematically investigate the thermal release kinetics of Sc radionuclides from activated natural titanium and vanadium foils, and of Tb radionuclides in tantalum, all studied in tantalum (Ta) environments of typical ISOL (Isotope Separation On-Line) target units. By elucidating the combination of target material structure and temperature conditions, enhanced release parameters were identified. Maximum Sc release from a non-embossed ^{nat}Ti foil samples was achieved at 1200 ℃, for embossed ^{nat}Ti foil samples at 1450 ℃ and for ^{nat}V foil samples at 1600 ℃, within an hour of reaching the set temperature. However, maximum Tb release from a non-embossed ^{nat}Ta foil samples was achieved at 2300 ℃, for embossed ^{nat}Ta foil samples at 2300 ℃ Tb release reached only 80% and for ^{nat}Ta double folded samples maximum release was achieved at 1900 ℃, within an hour of reaching the set temperature.
Theoretical estimations were done to estimate radionuclide production in target materials and to identify the possible limiting factors during thermal release. A proof of concept for the methodology to study MEDICIS and ISOLDE-produced radionuclide release kinetics and behaviour from various target materials and structures is presented. This work also aims to complement radionuclide release studies in case of fire accidents for radiation protection purposes and provide a way to benchmark theoretical codes.
Additionally, due to the large number of radionuclides that are produced from high-energy proton irradiation of ^{nat}Ta foils, several release curves were obtained for radionuclides, including some of interest in nuclear medicine. These findings offer insights into optimizing the mass separation process to improve the efficiency of radionuclide production by mass-separation both for fundamental physics and for medical applications.

Poster session / 19

Measuring interfacial diffusion of $^{8}Li^{+}$ in solid-state battery materials with β-NMR

Authors: Amy Sparks[1]; Anu Nagpal[2]; Bartholomew Payne[3]; Dalibor Zakoucky[4]; Daniel Paulitsch[5]; Gregory Rees[3]; Ilaria Michelon[6]; Magdalena Kowalska[1]; Mark Bissell[1]; Mateusz Jerzy Chojnacki[6]; Mauro Pasta[3]; Michael Pesek[7]; Mikolaj Hubert Baranowski[8]; Monika Piersa-Silkowska[1]; Nikolay Azaryan[1]; Peter Bruce[3]; Zaher Salman[9]

[1] *CERN*

[2] *University of York (GB)*

[3] *Department of Materials, University of Oxford, Oxford, UK*

[4] *Czech Academy of Sciences (CZ)*

[5] *University of Innsbruck (Universität Innsbruck)*

[6] *Universite de Geneve (CH)*

[7] *Charles University (CZ)*

[8] *Adam Mickiewicz University (PL)*

[9] *Paul Scherrer Institute, Villingen, Switzerland*

Corresponding Author: amy.sparks@cern.ch

Solid-state batteries (SSBs) are considered as a promising solution to address the safety issues and energy density limitations of conventional liquid batteries[1,2]. Although there have been significant breakthroughs in SSB technology in recent years, several challenges still need to be addressed before they reach the commercial market. A key challenge is their slow charge and discharge rates, which arises from poor ion diffusion and conductivity at the interfaces[3,4]. Unfortunately, many standard techniques to study these materials are limited to the bulk, making interface optimization difficult[5−7]. β-NMR, however, offers spatial precision for probing ion transport[8−10]. Using β-NMR relaxometry as a function of temperature, we aim to compare $^{8}Li^{+}$ diffusion in the bulk and anode-electrolyte interface. These experiments, using electrolytes with varying Cl and S content (argyrodites Li_7PS_6, Li_7PS_6Cl, and $Li_{5.5}PS_{4.5}Cl_{1.5}$), will help determine the role of these anions in interfacial conductivity.

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Poster session / 24

To derive the distribution of magnetisation in neutron-rich potassium isotopes

Author: Anu Nagpal[1]

Co-authors: Daniel Havranek [2]; Daniel Paulitsch [3]; Herlik Wibowo [4]; Jacek Dobaczewski ; Magdalena Kowalska [5]; Mark Bissell [5]; Michael Pesek [6]; Mikolaj Hubert Baranowski [7]; Nikolay Azaryan [8]

[1] *University of York (GB)*

[2] *Brno University of Technology (CZ)*

[3] *University of Innsbruck (Universität Innsbruck)*

[4] *University of York, York, Uk*

[5] *CERN*

[6] *Charles University (CZ)*

[7] *Adam Mickiewicz University (PL)*

[8] *Adam Mickiewicz University in Poznan (PL)*

Corresponding Author: anu.nagpal@cern.ch

This study aims to precisely measure the hyperfine structure (HFS) constant *A*, in neutron-rich potassium isotopes [1]. The in-beam laser-rf double-resonance spectroscopy [2] in a collinear geometry will be performed to obtain the relative precision of up to 10-4. This method, which has previously been applied only to stable isotopes, brings significantly enhanced precision through the use of rf excitations between substates of the ground hyperfine structure multiplet. In our experimental setup, an ion beam is optically pumped before it enters a 2-meter-long region, where it propagates collinearly with a traveling rf wave. When the RF frequency is resonant with the energy difference between two adjacent hyperfine sublevels, it allows the population of ions to transition. Then the beam enters the probing zone, where optical photons are monitored and detected.

The *A* factor obtained, will be combined with the magnetic dipole moments measured using β-NMR technique [3] to calculate the magnetisation distribution within the neutron-rich nuclei. The data interpretation will be done with the help of nuclear density functional theory approach with angular momentum symmetry restoration [4] to interpret the variation in these moments across different angular momentum projections and mass. We employ the Hartree-Fock-Bogoliubov formalism to determine the electric quadrupole and magnetic dipole moments of both stable and unstable isotopes using HFODD code [5]. The spectroscopic moments are then compared with experimental data available. These findings will provide valuable benchmarks for refining nuclear models and advancing our understanding of the magnetic properties and structure of neutron-rich isotopes.

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Poster session / 25

Lattice location of implanted 6He in diamond

Authors: Ulrich Wahl[1]; Joao Martins Correia[1]; Angelo Rafael Granadeiro Costa[1]; Brecht Biesmans[2]; Goele Magchiels[2]; Shandirai Malven Tunhuma[2]; André Vantomme[2]; Lino Miguel Da Costa Pereira[2]

[1] *Universidade de Lisboa (PT)*

[2] *KU Leuven (BE)*

Corresponding Author: ulrich.wahl@cern.ch

One of the major scientific interests in the behaviour of He in diamond is due to the belief that the amount of ^{4}He and the ^{3}He /^{4}He ratio found within the material or its inclusions can be used to date terrestrial diamonds [1,2] or learn about the origins of meteoritic nanodiamonds [3]. Recently, He implantation has also been found to create colour centers in diamond that act as single photon emitters [4]. Among the issues of interest are the lattice location of He, which also concerns the one following ion implantation, since part of He is introduced into the material due to the alpha decay from the U and Th decay chains, as well as its diffusion behaviour. The latter is of particular relevance since possible out-diffusion of He at elevated temperatures (typically above 900℃) and on geological time scales (10^9 years) could alter the outcome of dating experiments.
In this contribution we report on the lattice location of the short-lived ion implanted nuclear probe ^{6}He ($t_{1/2}$=807 ms), which was performed using the beta emission channeling method at CERN's ISOLDE facility. ^{6}He was implanted into an artificial diamond sample with 30 keV at room temperature and up to 800℃. By means of comparing the measured emission channeling patterns along different crystallographic directions with simulated yields for a variety of possible lattice sites, we conclude that all of the implanted ^{6}He occupies tetrahedral (T) interstitial sites, in agreement with theoretical predictions that T sites should be the preferred positions of He in diamond [5-8]. Implantation at 800℃ resulted in a drop in the tetrahedral interstitial fraction by ˜20%, which we interpret as the onset of diffusion of ^{6}He, thus being able to reach the surface of the sample or escaping to the bulk during its lifetime. From this we can estimate that the activation energy for interstitial migration of He is around 1.73 eV, which roughly agrees with theoretical predictions of 2.35 eV [5] and 1.97 eV [6]. Activation energies around 2 eV would mean that simple interstitial He cannot be stable in diamond on geological time scales, thus to remain inside it should be bound to some defect in the material or exist in another form such as within inclusions of other minerals or liquids, or possibly small He bubbles.

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Poster session / 26

Coulomb excitation in ^{185g,m}Hg - Shape coexistence in the neutron-deficient lead region

Authors: Hannah Kleis[1]; Peter Reiter[2]; Liam Gaffney[3]; Katarzyna Wrzosek-Lipska[4]; Janne Pakarinen[5]; for the IS699 collaboration[None]

[1] *Universitaet zu Koeln (DE)*

[2] *University Cologne, Nuclear Physics Institut*

[3] *University of Liverpool (GB)*

[4] *University of Warsaw (PL)*

[5] *University of Jyvaskyla (FI)*

Corresponding Author: hannah.kleis@cern.ch

Shape coexistence in the neutron-deficient lead region around N≈104 has been discovered in different nuclei especially in the mercury isotopes, where a staggering effect was found between even- and odd-mass nuclei using charge radii measurements [1,2]. In addition the study of the even-even ^{182,184,186,188}Hg isotopes via Coulomb excitation reactions showed a mixing of weakly deformed oblate and more deformed prolate configurations which coexists at low excitation energies [3].
To investigate collective behavior of low-lying states on top of the ($1/2^-$) ground-state in ^{185g}Hg and the different deformed ($13/2^+$) isomeric state in ^{185m}Hg, a Coulomb excitation experiment was performed at HIE-ISOLDE. The ^{185g,m}Hg beams were accelerated onto ^{120}Sn and ^{48}Ti targets with an energy of 4 MeV/u.
The emitted γ rays were detected utilizing the Miniball array in coincident to the scattered particles measured in the DSSSD detector. Furthermore the SPEDE spectrometer was used to determine distributions from conversion electrons.
Preliminary results of excited states of ^{185g,m}Hg will be shown for both targets. Excited states in ^{185g}Hg up to a spin of $29/2^-$ were observed using the ^{120}Sn target.

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Poster session / 30

Magneto-electric decoupling in bismuth ferrite

Author: Thien Thanh Dang[1]

Co-authors: Adeleh Mokhles Gerami [2]; Astita Dubey [3]; Daniil Lewin [1]; Dmitry Zyabkin [4]; Doru Constantin Lupascu [1]; Ian Chang Jie Yap [1]; João Nuno Gonçalves [5]; Juliana Heiniger-Schell [6]; Marianela Escobar Castillo [1]; Sobhan Mohammadi Fathabad [1]

[1] *Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 45141 Essen, Germany*

[2] *School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM), P.O. Box 19395-5531, Tehran, Iran*

[3] *Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 45141 Essen, Germany; Institute for Advanced Materials and Manufacturing, Department of Materials Science and Engineering, The University of Tennessee Knoxville, Knoxville, TN 37996, USA*

[4] *Chair Materials for Electronics, Institute of Materials Science and Engineering, and Institute of Micro and Nanotechnologies MacroNano®, TU Ilmenau, 98693 Ilmenau, Germany*

[5] *CICECO—Aveiro Institute of Materials and Departamento de Física, Universidade de Aveiro, 3810-193 Aveiro, Portugal*

[6] *Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 45141 Essen, Germany; European Organization for Nuclear Research (CERN), CH-1211 Geneva, Switzerland*

Corresponding Author: thien.dang@uni-due.de

It is still under intensive discussion, how magnetoelectric coupling actually occurs at the atomic scale in multiferroic (BiFeO3 or BFO). Nuclear solid-state techniques monitor local fields at the atomic scale. Using such an approach, we show that, contrary to our own expectation, ferroelectric and magnetic ordering in BFO decouple at the unit-cell level. Time differential perturbed angular correlation (TDPAC) data at temperatures below, close, and above the magnetic Néel temperature show that the coupling of the ferroelectric order to magnetization is completely absent at the bismuth site. It is common understanding that the antiferromagnetic order and the cycloidal ordering due to the Dzyaloshinskii-Moriya interaction generate a net zero magnetization of the sample, cancelling out any magnetoelectric effect at the macroscopic level. Our previous data show that a very large coupling of magnetic moment and electrical distortions arises on the magnetic sub-lattice (Fe site). The oxygen octahedra around the iron site experience a large tilt due to the onset of magnetic ordering. Nevertheless, the Bi-containing complementary sub-lattice carrying the ferroelectric order is practically unaffected by this large structural change in its direct vicinity. The magnetoelectric coupling thus vanishes already at the unit cell level. These experimental results agree well with an ab-initio density functional theory (DFT) calculation.

Poster session / 31

Progress on beam dynamics studies for ISRS

Authors: Jorge Giner Navarro[1]; Rafael Berjillos Morente[2]; Yanis Fontenla[3]; Carlos Garcia Ramos[4]; Domingo Gomez Dominguez[5]; Glyn Kirby[None]; Teresa Kurtukian Nieto[6]; Ismael Martel[5]; Fazel Taft[7]; Javier Resta Lopez[8]

[1] *Instituto de Ciencia de los Materiales Universitat de València (ICMUV)*

[2] *University of Huelva*

[3] *ICMUV - University of Valencia*

[4] *Universidad de Huelva*

[5] *University of Huelva (ES)*

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

[7] *University of Valencia*

[8] *ICMUV-University of Valencia*

Corresponding Author: javier2.resta@uv.es

In order to accommodate an innovative spectrometer within a limited experimental hall space (5x5 meters) for HIE-ISOLDE, a new lattice configuration for the ISRS ring is proposed. This lattice consists of ten combined-function canted cosine-theta (CCT) superconducting magnets, while different approaches are being considered for the injection and extraction subsystems. The challenging integration of these magnets into the lattice considers realistic dimensions, including the cryomodules that house the strongly curved magnets, based on the recent design of a demonstrator (MAG-DEM), which is planned for future fabrication. For the commissioning phase, the separation power

of the spectrometer for various isotope ions has been studied in a linear spectrometer configuration.

Poster session / 33

Laser Spectroscopy of Neutron Deficient Thallium Isotopes

Author: Edward Noel Matthews[1]

[1] *Technische Universitaet Darmstadt (DE) and EP-SME-IS*

Corresponding Author: edward.noel.matthews@cern.ch

This poster will present preliminary analysis of the COLLAPS thallium run from 2023. It will cover the collinear laser spectroscopy technique and detail results from the analysis of this dataset. These results will contain preliminary information on the charge radius, electric dipole moments and magnetic quadrupole moments of the thallium isotopes of interest as well as physics discussion about their relevance to nuclear physics and draw comparisons with the rest of the lead region.

Poster session / 34

Status update on the RFQcb at the ISODLE Offline 2 mass separator

Author: Alexander Schmidt[None]

Co-authors: Justus Berbalk [1]; Maximilian Schuett [2]; Mia Au [2]; Sebastian Rothe [2]

[1] *KU Leuven (BE)*

[2] *CERN*

Corresponding Author: alexander.s@cern.ch

The Offline 2 mass separator [1] is part of the CERN-ISOLDE offline facilities [2], which are required to perform essential quality assurance and benchmarking tests of new target and ion source units prior to their installation and irradiation at CERN-ISODLE. The separator resembles the online CERN-ISOLDE frontend and includes similar services such as the beam instrumentation, the gas mixing system for plasma targets, an adjacent laser laboratory for laser ion source studies or a copy of the control equipment and software. The main purpose of the facility is to perform preparatory offline studies and to benchmark new beam production and manipulation techniques or new beam instrumentation before their online implementation. For these studies, non-radioactive beams with energies up to 60 keV can be produced from surface, plasma as well as laser ion sources, which are separated in a 90° dipole separator magnet with a mass resolving power of $R \approx 500$. After separation, the ion beam can be cooled in bunched in a radiofrequency quadrupole cooler-buncher (RFQcb) with He buffer gas, whose design is similar to the online ISCOOL cooler-buncher. This poster provides an overview of the recent commissioning work on the RFQcb, aiming at reaching a transmission and bunching effect comparable to the ISCOOL cooler-buncher.

While the latter is regularly operated with a transmission of > 80% in DC mode and with slightly lower transmission in bunched mode, systematic measurements at the offline RFQcb indicated that the transmission in DC mode is limited to about 3%, with maximum transmission being reached for a significant vertical offset of the input beam. Following this observation, the RFQcb was removed from the beamline to investigate the origin of the limited transmission. After testing all electrical connections, checking the alignment of the RFQcb with respect to the other beamline elements and replacing malfunctioning components, the cooler-buncher will be reinstalled and further tests will be conducted.

In parallel to the optimization of the transmission through the RFQcb in DC mode, a new gas mixing system, which is similar to the mixing systems of the Offline 2 and online frontends, will be installed for the RFQcb. This system facilitates the addition of traces of reactant gases (e.g. CF4) to the He buffer gas to allow the study of the formation and decay of molecules inside the RFQcb [3]. Following the installation of the new RFQ gas system in November, first tests are foreseen for the start of the next year.

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Poster session / 36

Probing the doubly magic shell closure at ^{132}Sn by Coulomb excitation of neutron-rich ^{130}Sn

Author: Maximilian Paul Droste[1]

Co-authors: Peter Reiter [1]; Thorsten Kröll [2]; for the IS702 collaboration

[1] *Universitaet zu Koeln (DE)*

[2] *IKP, Technical University Darmstadt, Germany*

Corresponding Author: maximilian.paul.droste@cern.ch

Excited states of ^{130}Sn, the even-even neighbour of doubly-magic ^{132}Sn, were populated through safe Coulomb excitation using the recently commissioned, highly efficient MINIBALL array. The ^{130}Sn ions were accelerated to 4.4 MeV/u at the HIE-ISOLDE accelerator and collided with a ^{206}Pb target. Deexciting γ rays from the excited states of both the target and projectile nuclei were detected in coincidence with scattered particles. In addition to γ rays from the first 2^+ state, deexcitation from higher-lying states was observed, attributed to an isomeric $^{130}\mathrm{Sn}_{7-}$ beam component. Reduced transition strengths for the $0^+_{\mathrm{g.s.}} \longrightarrow 2^+_1$ transition will provide insights into the evolution of collectivity and nuclear structure around the magic shell closure in 132Sn. Advanced shell model calculations using realistic interactions predict enhanced collectivity in the neighbouring isotopes of ^{132}Sn [1]. Additionally, a discrepancy between previous measurements of ^{130}Sn and recent theoretical results remains to be resolved [2]. These calculations also indicate a transition from a slightly oblate to a prolate configuration of the first excited 2^+ state across doubly magic ^{132}Sn. The high statistics of the performed experiment will further enable an experimental investigation of the quadrupole moment of the 2^+ state in ^{130}Sn.
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Poster session / 37

Technical study of the MAGDEM ion test bench for the ISOLDE Superconducting Recoil Separator

Authors: Domingo Gomez Dominguez[1]; Luis Armando Acosta Sanchez[2]; Rafael Berjillos Morente[1]; Yanis Fontenla[3]; Maria Del Rocio Fuentes Auden[1]; Jorge Giner Navarro[4]; Carlos Garcia Ramos[1]; Carlos Alejandro Gonzales Cordero[1]; Glyn Kirby[None]; Teresa Kurtukian Nieto[5]; Javier Resta Lopez[6]; Fazel Taft[7]; Olof Tengblad[5]; Jose Sanchez-Segovia[1]; Ismael Martel[1]

[1] *University of Huelva (ES)*

[2] *Universidad Nacional Autonoma (MX)*

[3] *ICMUV - University of Valencia*

[4] *Instituto de Fisica Corpuscular (ES)*

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

[6] *IFIC, Valencia University*

[7] *University of Valencia*

Corresponding Author: domingo.gomez.dominguez@cern.ch

The ISOLDE Superconducting Fragment Separator (ISRS) is composed of a set of multifunction CCT superconducting magnets (MAGDEM) [1, 2], including both dipole and quadrupole functions [3]. A fully operational ion test bench (IONTB) is being developed to test the performance of the MAGDEM units under a realistic in-beam scenario. Despite being limited to a single MAGDEM unit, IONTB can provide enough A/Q selectivity for light fragments and be operated as a linear spectrometer [4, 5] for selected physic cases. The system includes a reaction chamber, beam transport system and diagnostics, a prototype of focal plane detector. The complete system will be assembled into a rotatory platform suitable to analyse forward ejected reaction fragments at user-selected observation angles. The control and data acquisition system plays a critical role and requires a dedicated development.

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Poster session / 38

Design study of a reaction chamber for the ISOLDE Superconducting Recoil Separator

Authors: Carlos Garcia Ramos[1]; Luis Armando Acosta Sanchez[2]; Rafael Berjillos Morente[1]; Maria Del Rocio Fuentes Auden[1]; Domingo Gomez Dominguez[1]; Carlos Alejandro Gonzales Cordero[1]; Teresa Kurtukian Nieto[3]; Olof Tengblad[3]; Ismael Martel[1]

[1] *University of Huelva (ES)*

[2] *Universidad Nacional Autonoma (MX)*

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

Corresponding Author: carlos.garcia.ramos@cern.ch

The ISOLDE Superconducting Fragment Separator (ISRS) [1, 2] is an innovative a high-resolution spectrometer foreseen to study the structure and dynamics of radioactive nuclei at HIE-ISOLDE. The sicentific program requires the use of a variety of nuclear reactions including Coulomb breakup/dissociation, fusion-evaporation, and transfer reactions in direct and inverse kinematics. Part of the foreseen reactions involve the rotation of ISRS to analyse heavy fragments ejected at angles as large as 70 degree. The chamber should be also suitable to be used in combination with neutron and gamma arrays, and for hosting light-ion solid-state detectors. The design of the ISRS scattering chamber is therefore a very challenging part of the project as it has to acomplish several detector constraints as well as those of the ISRS particle spectrometer itself. We present and discuss the design study of an innovative reaction chamber able to rotate and accommodate most of the requirements of the physics program. The reaction chamber will be installed at the MAGDEM ion-test bench for in-beam experiments.

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Poster session / 40

Local Probing of Structural Phase Transitions in Naturally Layered Perovskites: $Li_2SrNb_2O_7$ as a case study

Author: Antonio Duarte Neves Cesario[1]

Co-authors: Pedro Miguel Da Rocha Rodrigues [1]; Neenu Prasannan [2]; Ricardo Manuel Alves Pacheco Moreira [1]; Pedro Alexandre Silva De Sousa [1]; Joao Martins Correia [3]; Lucy Assali [4]; helena petrilli [5]; Araujo Joao Pedro Esteves De Araujo [1]; Armandina Maria Lima Lopes [1]

[1] *Universidade do Porto (PT)*

[2] *IFIMUP, University of Porto*

[3] *Universidade de Lisboa (PT)*

[4] *University of São Paulo (BR)*

[5] *University of São Paulo*

Corresponding Author: antonio.duarte.neves.cesario@cern.ch

Naturally layered perovskites have become an impressive playground for the birth of novel multifunctional devices due to its great electronic tunability aiming at innovative alternatives for improved energy storage devices and electronics. In particular, the search for room temperature ferroelectrics (FE) and magneto electrics has seen a boost in research focused on these structures. However, an accurate structural characterization at a microscopic scale can be notably difficult to establish by conventional scattering experiments [1], leading to conflicting reports in the literature. Our case study is the $n = 2$ pseudo Ruddlesden Popper (pRP) $Li_2SrNb_2O_7$, an interesting anti-FE and weak-FE system where the structural phases for functional applications are not yet fully understood with temperature [2,3].

Through Perturbed Angular Correlation (PAC) Spectroscopy measurements conducted at CERN/ISOLDE using ^{111m}Cd radio-isotopes, we can probe Hyperfine Interactions, in particular the local Electric Field Gradients at the Li and Sr lattice sites, commonly inaccessible to other techniques. With the help of ab-initio Density Functional Theory (DFT) calculations, we can establish the local effects that reproduce our measurements and that allow for the presence of switchable ferroelectric polarizations, granting us the fundamental understanding required to design new and optimal multifunctional materials.

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Poster session / 41

A 3D magnetic field measuring system for the CCT magnet units (MAGDEM) of the ISOLDE Superconducting Recoil Separator

Authors: Rafael Berjillos Morente[1]; Carlos Garcia Ramos[1]; Domingo Gomez Dominguez[1]; Carlos Alejandro Gonzales Cordero[1]; Maria Del Rocio Fuentes Auden[1]; Glyn Kirby[None]; Jose Sanchez-Segovia[2]; Ismael Martel[1]

[1] *University of Huelva (ES)*

[2] *University of Huelva*

Corresponding Author: rafael.berjillos.morente@cern.ch

The design of the ISOLDE Superconducting Fragment Separator (ISRS) [1] is based on a compact particle storage ring that uses a FFAG (Fixed Field Alternating Gradient) beam transport and a set of nested multifunction superconducting magnets (MAGDEM) [2]. Each MAGDEM unit include both dipole and quadrupole functions using a Canted Cosine Theta type (CCT) design, whose winding is inclined with respect to the axis [3]. After fabrication and delivery, MAGDEM magnetic field must be verified against specifications. For this purpose, a dedicated magnetic field-scanner system has been designed and prototyped. The "3D magnetic scanner system"is based on a set of point-by-point Hall probes coupled to a linear/rotary robotic arm with sub-millimetre precision. The development includes the specific software, DAC and control systems, safety magnetic shielding. A fully operative demonstrator of the "3D magnetic scanner system"has been built and tested at the University of Huelva. The assembly of the final system is in progress.

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Poster session / 42

Magnetic Moment Measurement of ^{11}Be with ppm Accuracy

Author: Daniel Paulitsch[1]

Co-authors: Amy Sparks ; Anu Nagpal [2]; Daniel Havranek [3]; Ilaria Michelon [4]; Magdalena Kowalska ; Marcus Jankowski [5]; Mark Bissell [6]; Mateusz Jerzy Chojnacki [4]; Michael Pesek [7]; Mikolaj Hubert Baranowski [8]; Monika Piersa-Silkowska [6]; Nikolay Azaryan [9]

[1] *University of Innsbruck (Universität Innsbruck)*

[2] *University of York (GB)*

[3] *Brno University of Technology (CZ)*

[4] *Universite de Geneve (CH)*

[5] *Technische Universitaet Darmstadt (DE)*

[6] *CERN*

[7] *Charles University (CZ)*

[8] *Adam Mickiewicz University (PL)*

[9] *Adam Mickiewicz University in Poznan (PL)*

Corresponding Author: paulitsch.d@gmail.com

β-detected Nuclear Magnetic Resonance (β-NMR) is a method for measuring the nuclear magnetic moment of unstable nuclei. It allows investigations of short-lived isotopes with a sensitivity inaccessible to conventional NMR. This increased sensitivity is gained by combining hyperpolarization of the nuclear spin generated through optical pumping, and an efficient detection exploiting the

asymmetry in emission of β-particles from the decaying polarized isotopes. A β-NMR experiment to measure the magnetic moment of ^{11}Be is planned in a November 2024 beamtime at VITO. ^{11}Be is of interest because it is a single neutron halo nucleus. Measuring the magnetic moment of ^{11}Be with ppm level accuracy will help to give insights into the nuclear magnetization distribution of ^{11}Be and thus directly confirm its halo structure.
To enable such ppm level accuracy measurements, the VITO beamline has undergone multiple major upgrades and extensions in the past, such as, the installation of a superconducting solenoidal magnet with sub-ppm homogeneity and the ability to measure in liquid samples [1]. The beta detectors are an essential component; their purpose is to detect the asymmetrically emitted β-particles from the hyperpolarized decaying isotopes. For the ^{11}Be beamtime a new detector setup will be used. Unlike the previous setup, this new detector system will be capable of measuring the energies of the detected β-particles. This is useful because in ^{11}Be the two most intense transitions, the transition to the ground state and the first excited state have opposite beta asymmetry parameters and cancel each other out [2]. Measuring only the higher energy decay to the ground state will result in an increased measured β-decay asymmetry. Another upgrade for the ^{11}Be measurement is an optical pumping scheme that aims to achieve a higher degree of nuclear polarization by using two transitions.

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Poster session / 43

β-decay spectroscopy with laser-polarised beams of neutron-rich potassium isotopes at VITO

Author: Ilaria Michelon[1]

Co-author: IS733 Collaboration

[1] *Universite de Geneve (CH)*

Corresponding Author: ilaria.michelon@cern.ch

β-decay spectroscopy is a powerful tool for studying complex phenomena emerging in exotic neutron-rich nuclei, such as β-delayed neutron emission [1-3]. Thanks to the high angular momentum selectivity of the process, β-decay offers unique access to excited states in daughter nuclei having configurations similar to the decaying precursors.

β-decay spectroscopy becomes an even more powerful technique when beams of spin-oriented nuclei are utilized [4,5]. For such nuclei –having a directional orientation of the nuclear spins with respect to the axis of an applied magnetic field - asymmetric emission of β-particles can reveal spins and parities of nuclear states involved in allowed transitions.
This novel approach to β-decay experiments, pioneered by a group from the University of Osaka [4,5], has recently been adopted at the VITO beamline [6] at ISOLDE, where a new decay-spectroscopy station has been integrated with the existing setup for laser-induced spin polarisation. The new station, called "DeVITO", allows measurements of β-particle emission asymmetry in coincidence with γ-rays and/or neutrons. Moreover, the new station also allows the evaluation of the radiation asymmetry nearly free from instrumental asymmetry. This is achieved by reversing the direction of the nuclear spin orientation and comparing measurements performed for these two configurations.
The new setup was recently commissioned with beams of neutron-rich potassium isotopes, including strong β-delayed neutron emitters. In particular, the beam of 47K, with a well-known decay scheme from previous extensive studies [7], was chosen to investigate β-particle emission asymmetry in coincidence with γ-rays. In this contribution, details on the experimental setup, as well as preliminary results from the commissioning runs [8, 9], will be presented.

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Poster session / 44

A Space for Developing New Target Materials –Extension of the Chemical Lab for Development and Production of Non-Radioactive Target Materials

Author: Matthias Alexander Grasser[None]

Co-authors: Bernard Crepieux [1]; Joachim Vollaire [1]; Melania Averna [1]; Sebastian Rothe [1]; Serdar Usta ; Valentina Berlin [2]

[1] *CERN*

[2] *SY group*

Corresponding Author: matthias.alexander.grasser@cern.ch

At CERN-ISOLDE, over a thousand radioactive ion beams (RIBs) are generated from over 70 distinct types of target materials using the Isotope Separation Online Method (ISOL). The target material is bombarded with a high-energy proton beam (around 1.4 GeV) and undergoes nuclear reactions that lead to the production and release of artificially created isotopes, which are then ionised and extracted as ion beams.[1] New materials are needed to improve the release and make even more exotic ion beams accessible, with nanomaterials representing a new class of these target materials.

Even if the first nanomaterial to be operated in ISOL facilities was in 1997, and the first submicrometric (SiC) was tested five years later at ISOLDE and the first nanomaterial in 2011 (CaO), implementation of nanometric target materials meeting the criteria for providing high yields; the need for high cross-sections and high numbers, e.g. density of target nuclei for maximum in-target isotope production contrasts with fast and efficient diffusion and effusion processes of porous materials, remains challenging. As an example, a decade ago only three out of five (CaO, TiC, LaCx or UCx @ MWCNT and MWCNT) nanomaterials have proven to show higher radioisotope intensities than standard targets with longer release characteristics.[2] Nevertheless, the by far most used material is the radioactive uranium carbide (UCx). Consequently, nano structurisation of it is of high importance and will have high impact in present and future ISOL facilities. Even if this low-density nano material showed a 10-fold yield increase for many isotopes due to increased diffusion times, chemical reactions could hinder isotopes from being realeased, in addition to avoid sintering at high operation temperatures, generalised a lot of potential for optimisation and future development is still left. Besides this and additonal advantages, like their highly resistance to radiation damage due to their high ratio of grain boundaries to bulk, they also present additional challenges in terms of safety, e.g. due to reactivity (pyrophoricity of nano-UCx), but more general due to not fully known effects in the human body. Because of this many organizations enforce tight regulations which render difficult the research of nanomaterials, e.g. at CERN, nanomaterials research has been halted until the safety requirements are met or it has been demonstrated that the current facilities are safe enough to avoid airborne nanoparticles, which lead to the construction of a completely new laboratory, the NANOLAB to produce and develop nano-actinide target materials. [1]

With the commissioning of this facility at ISOLDE, a laboratory for further investigations into the tailoring of the microstructure of target materials of non-radioactive, not limited to surrogate materials will improve the ability to develop new target materials in addition to the production of nanometric target materials. Furthermore, the separation of the latter from the development area will streamline the production of established and the implementation of newly developed materials under safe yet efficient conditions and shall be presented.

Keywords: nanomaterial development, ion beams, non-radioactive target material, nanotarget development, laboratory

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Poster session / 47

Design study of the ISRS CCT Magnet Demonstrator MAGDEM

Authors: Carlos Alejandro Gonzales Cordero[1]; Rafael Berjillos[2]; Nikkie Deelen[None]; Carlos Garcia Ramos[2]; Arthur Iziquiel[3]; Tomas Junquera[4]; Glyn Kirby[None]; Teresa Kurtukian Nieto[5]; D. Martins[None]; Ethan Page-Mason[None]; Javier Resta Lopez[6]; Jeroen Van Nugteren[None]; Ismael Martel[1]

[1] *University of Huelva (ES)*

[2] *University of Huelva*

[3] *Accelerator and Cryogenic System*

[4] *ACS*

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

[6] *IFIC, Valencia University*

Corresponding Author: carlos.alejandro.gonzalez.cordero@cern.ch

The ISOLDE Superconducting Recoil Separator (ISRS) at CERN [1-3] is a high-resolution spectrometer for analysing the heavy fragments produced in reactions induced by ISOLDE's exotic beams. ISRS design is based on a compact FFAG particle storage ring composed of short straight multifunction superconducting magnets able to accommodate a wide range of momentum and energy spread. The team has developed a magnet prototype MAGDEM, a very compact, low current, large aperture Nb-Ti CCT superconducting magnet with both dipole and quadrupole functions. It features an innovative cryogen-free cooling system based on GM cryocoolers and a LN2 pre-cooling system [4].

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Poster session / 49

Ab-initio Study on CsNdNb2O7 and CsLaNb2O7 Dion-Jacobson Perovskites

Author: Pedro Alexandre Silva De Sousa[1]

Co-authors: Antonio Duarte Neves Cesario [1]; Neenu Prasannan [2]; Estelina Silva ; Pedro Miguel Da Rocha Rodrigues [1]; Lucy Assali [3]; helena petrilli [4]; Joao Martins Correia [5]; Armandina Maria Lima Lopes [1]; Araujo Joao Pedro Esteves De Araujo [1]

[1] *Universidade do Porto (PT)*

[2] *IFIMUP, University of Porto*

[3] *University of São Paulo (BR)*

[4] *University of São Paulo*

[5] *Universidade de Lisboa (PT)*

Corresponding Author: up201704307@edu.fc.up.pt

In the pursuit of novel and highly efficient multiferroic materials, significant exploration has unfolded during the last decades. These materials, characterized by their ability to exhibit a myriad of intriguing phenomena, hold promise in enabling the electrical manipulation of magnetic degrees of freedom, thus offering numerous potential applications. Our research group focuses on the discovery of new multiferroic materials within the perovskite family, with particular emphasis on naturally layered variants such as Ruddlesden-Popper and Dion-Jacobson (DJ) structures. The complexity of these materials, particularly those within the DJ family, presents challenges in understanding their structural pathways, which is essential to understand due to its correlation with polarization, typical of a highly ionic material. Conventional characterization techniques, like X-ray diffraction (XRD), often fall short in describing these systems transitions driven by rotations and tilts of oxygen octahedra. This limitation emphasizes the need for alternative methods to study these materials effectively. In our study, we employ a local technique known as Perturbed Angular Correlation (PAC), which offers heightened sensitivity to quantum phenomena through the study of the electric field gradient (EFG), an essential property of the ground state. Furthermore, our investigation incorporates ab-initio simulations using Density Functional Theory (DFT). Focusing on CsNdNb2O7 [1,2] and CsLaNb2O7 DJ perovskites, we account for high quantum effects that influence this materials behavior. Our findings highlight the necessity of incorporating Hubbard corrections for specific atoms, such as Nd, to accurately describe the magnetic behavior and hyperfine parameters, thus contributing to a deeper understanding of these complex materials.

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Poster session / 50

New End-Station For In-Beam Laser-RF Double-Resonance Spectroscopy at the VITO Beamline

Authors: Amy Sparks[None]; Anu Nagpal[1]; Daniel Havranek[2]; Daniel Paulitsch[3]; Magdalena Kowalska[4]; Mark Bissell[4]; Nikolay Azaryan[5]

[1] *University of York (GB)*

[2] *Brno University of Technology (CZ)*

[3] *University of Innsbruck (Universität Innsbruck)*

[4] *CERN*

[5] *Adam Mickiewicz University in Poznan (PL)*

Corresponding Author: nikolay.azaryan@cern.ch

One of the upcoming upgrades of VITO beamline is a creation of a new end station for laser-rf double resonance spectroscopy to provide a strongly improved precision in determining the hyperfine structure (HFS) of unstable nuclei. Combined with high-precision measurements of nuclear magnetic moments using liquid beta-NMR at VITO, the new technique will allow determining the hyperfine anomaly in different isotopic chains, starting with potassium.
The apparatus will require a new RF transmission line for direct in-beam excitations within HFS multiplets, in addition to optical pumping. We present here results of an optimised design of microwave excitation region, which will allow efficient coupling and power transmission in L- and S-band, as

well as the magnetic shielding of laser/rf interaction region, and a general integration of this end station into VITO.

Poster session / **55**

Towards King-plot nonlinearity searches with radioactive ion beams

Author: Sandro Kraemer[1]

[1] *KU Leuven (BE)*

Corresponding Author: sandro.kraemer@kuleuven.be

Isotope shift measurements and the King plot are an established method to determine the nuclear charge radius [1]. Nonlinear effects in King plots have recently gained additional interest as probes for higher-order nuclear deformation and beyond-standard-model physics [2]. Methods like the generalized King plot allow to extract multiple effects such as higher-order nuclear deformation and couplings to ultra-light dark matter [3]. For these contributions, high-precision measurements of the isotope shift in multiple narrow transitions between multiple isotope pairs are required and many alkali-earth atoms and singly charged ions show a suitable atomic structure. However, the amount of spinless stable isotopes is a limiting factor.

In oder to overcome this limitation, the idea for deceleration of radioactive ion beams for precision isotope shift spectroscopy is discussed in this contribution. Strontium ions are chosen as proof-of-concept and the implementation of fluorescence spectroscopy of the $S_{1/2} \leftrightarrow D_{3/2}$ and $S_{1/2} \leftrightarrow D_{5/2}$ transitions is propounded.

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Poster session / **57**

First Decay Spectroscopy Measurements of 219,220 Po from IS456 using IDS and PI-LIST

Author: Jack Shaw[1]

[1] *KU Leuven (BE)*

Corresponding Author: jack.shaw@kuleuven.be

The neutron rich isotopes near the $Z = 82$ and $N = 126$ are an area of active research as they display a range of exotic nuclear properties including octupole deformation.

Previously the long lived (>10 minutes) neutron rich isotopes ^{219,220}Po have not been properly investigated as their expected half-lives are too long for fragmentation facilities and until the development of the PI-LIST the present of isobaric Fr contamination it was not possible to study them at ISOLDE.

In 2022 with the use of the double-repeller PI-LIST it was possible to perform both decay spectroscopy and In-source laser spectroscopy. This contribution will discuss the analysis of the decay spectroscopy data and present preliminary results.

Poster session / 60

Reoxidation/Stabilization of pyrophoric ISOLDE targets after irradiation

Author: Serdar Usta[None]

Co-authors: Edgar Miguel Sobral Dos Reis ; Gerald Dumont [1]; Joachim Vollaire [1]; Matthias Alexander Grasser ; Paolo Giunio Pisano [1]; Sebastian Rothe [1]; Sven De Man [1]; Valentina Berlin [2]

[1] *CERN*

[2] *SY group*

Corresponding Author: serdar.usta@cern.ch

Pyrophoric metal carbides such as uranium carbides (UCx), thorium carbides (ThCx) and lanthanum carbides (LaCx) are used as target materials in CERN-ISOLDE to produce radioisotopes due to their high cross-section, thermal stability and porous structure. After irradiating these materials by proton beams, they become pyrophoric radioactive waste and require controlled oxidation prior to disposal to eliminate the risk of thermal runaway or ignition upon contact with oxidants (mainly oxygen). The aim is to develop a controlled oxidation process for these materials in ISOLDE hot cells by taking the necessary safety precautions and considering environmental impacts, for example capturing the formed radioactive volatile species as a result of radionuclei, produced by proton irradiation, and oxygen reactions. Then, they would be ready for long-term disposal in deep geological repositories.

The project started with non-irradiated micro-structured lanthanum carbide to foresee potential safety risks and practice the process development without radioactivity. The oxidation characteristics of core material (metal carbides) and structural materials (graphite sleeve and tantalum container) of ISOLDE target unit are being investigated using characterization techniques such as thermogravimetric analysis (TGA), differential thermal analysis (DTA), X-ray powder diffraction (XRD), X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). Our strategy is to oxidize the core material at the lowest possible temperature under the appropriate oxygen-containing atmosphere to convert it into a thermally stable compound and characterize it by analytical techniques.

Two oxidation pathways were identified for lanthanum carbide in dry and wet atmospheres. In the dry atmosphere (1% O2-Ar mixture), 1074 J/g of heat was generated at 380 oC to reach a thermally stable material (unknown phase). In the moist atmosphere (humid air), the reaction started at room temperature and effectively continued at 50 oC producing 1485 J/g of heat, resulting in a thermally stable lanthanum hydroxide-graphite mixture. Scale-up studies for both methods are ongoing, considering their advantages and disadvantages. Various methods for monitoring the oxidation reaction and determining its completion are also under consideration. The most prominent of these are monitoring of outgases, oxygen concentration, pressure differential and mass change.

Keywords: radioactive waste, pyrophoricity, uranium carbide, thermal runaway, controlled oxidation, dry oxidation, wet oxidation

Poster session / 61

Tailor-made materials for radioactive ion beam production

Author: Edgar Miguel Sobral Dos Reis[None]

Co-authors: Alexander Schmidt ; Doru Constantin Lupascu [1]; Isabel Frank [2]; Jakob Birkner Frederiksen ; Line Le ; Matthias Alexander Grasser ; Mia Au [2]; Sebastian Rothe [2]; Serdar Usta ; Simon Thomas Stegemann [2]; Valentina Berlin [3]; Wiktoria Wojtaczka [4]

[1] *Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 45141 Essen, Germany*

[2] *CERN*

[3] *SY group*

[4] *KU Leuven (BE)*

Corresponding Author: edgar.reis@cern.ch

At CERN-ISOLDE, over a thousand radioactive ion beams (RIBs) are produced from over 70 different types of target materials through the isotope separation online method (ISOL). The material is hit with a 1.4 GeV proton beam and undergoes nuclear reactions leading to the production and extraction of artificially created isotopes which are then ionized and extracted as ion beams.[1]
The design of target materials must therefore balance the need for high cross-sections and high numbers of target nuclei for maximum in-target isotope production versus fast and efficient diffusion and effusion processes. This requires a compromise between density and pore structure, while keeping the required levels of thermal stability to limit sintering and maintain these properties in online operational conditions (which can reach over 2200o C). Additional considerations include power deposition from the incident proton beam, and chemical interactions that can volatilize or bind isotopes of interest, the choice of suitable nuclear reaction pathways to create the desired isotopes, and mechanical, thermal and vacuum conditions required for operation of associated infrastructure such as the ion source.
Recent efforts were made to develop more specialized target materials with microstructure tailored to the application and to test production yields during operation online at ISOLDE to determine their suitability for RIB production, focusing on the production short-lived isotopes and refractory species requiring high temperature target materials.
To fully understand such materials the microstructural stability of the material and the produced RIB yields under different operating conditions were assessed through offline and online studies, and the focus was put on ceramic materials which have proved particularly challenging to employ in the past such as zirconia as it tends to fully sinter when heated inside an ISOLDE target[2] and refractory carbides such as tantalum carbide, a novel type of ISOL material.
First results obtained this year at ISOLDE will be presented demonstrating improvement on existing materials by tailoring the material's structural characteristics to the requested radioisotope beam, providing fast release of isotopes and presenting good stability under online operating conditions even for traditionally difficult lanthanide beams. Future development plans for ISOL target materials will also be discussed.

Keywords: radioisotopes, refractory materials, tantalum carbide, ion beams, lanthanides

Poster session / 62

Beam Switching at CERN-ISOLDE

Author: Line Le[None]

Co-authors: Alexander Schmidt ; Erwin Siesling [1]; Gary Boorman [2]; Jordan Ray Reilly [3]; Lukas Nies [1]; Maximilian Schuett [1]; Mia Au [1]; Reinhard Heinke [3]; Sebastian Rothe [1]; Yago Nel Vila Gracia [1]

[1] *CERN*

[2] *ANGARA Technology*

[3] *The University of Manchester (GB)*

Corresponding Author: line.le@cern.ch

ISOLDE is a world-leading facility for radioactive ion beam (RIB) research using the Isotope Separation Online (ISOL) method, capable of producing over 1300 isotopes of more than 70 elements. It supports a diverse range of experiments in nuclear physics, nuclear astrophysics, laser physics, solid-state physics, and medical applications, with beam energies from 30 keV to 10 MeV/u. Serving

approximately 1500 academic researchers, ISOLDE conducts around 50 experiments annually; however, the demand for beam time consistently exceeds supply, resulting in a backlog of 1,155 shifts awaiting scheduling.

To address this issue, ISOLDE investigates to transition from a single-user to a multi-user facility, enabling parallel experiments. Currently, about 50% of proton pulses from CERN's PS Booster are allocated to ISOLDE, which operates two target stations (frontends) located at the General Purpose Separator (GPS) and the High Resolution Separator (HRS). These produce mass-separated radioactive ion beams delivered to various experimental setups for nuclear spectroscopy, laser spectroscopy, mass measurements, and solid-state research. At present, the switch-over between separators is performed manually by the beam operator and occurs only when a user requests beam from a different separator.

The beam switch project aims to enhance operational efficiency by introducing an automated beam allotment system, allowing automatic switching between separators. This "alternating mode" is expected to increase operational days by 20 to 30 per year, providing up to four additional experiment slots and facilitating test experiments. With the new beam-switching system, ISOLDE could significantly boost total activity and beam time, enabling two experiments to run simultaneously.

Recent studies have investigated beam sharing options at ISOLDE. The primary bottleneck is the CA0 beamline, which merges and switches beams from the two separators to different experiments. While the CERN PS Booster allows pulse-to-pulse switching between the two separators, most experimental installations at ISOLDE receive beams through a single central beamline (CA0). When the HRS beam occupies CA0, the GPS can only deliver beams to upstream beamlines. Similarly, when the GPS beam uses CA0, the HRS cannot run at all.

To resolve this, the proposed solution is to pulse the CA0 beamline. Implementing this solution would require developing a switching system for the electrostatic power supplies, along with new timing hardware and synchronized beam gates. The system would alternate the entire CA0 beamline between inputs from the GPS and HRS separators, directing output to the LA0, CB0, or RA0 beamlines.

Tests at the ISOLDE offline facilities using high-voltage solid-state switches confirmed that switching times were well below the required limits, demonstrating feasibility for integration with existing equipment and infrastructure. Furthermore, ISOLDE features a beam gate system composed of electrostatic plates positioned after the separator magnets. These plates control the passage of secondary RIB beams by managing the enabling and disabling of beam injection into the HRS or GPS. Recent advancements in the beam gates have paved the way for the beam switch project, which focused on upgrading the beam gate control system. This involved implementing an interim solution that improved the control logic and helped understanding the existing limitations.

Poster session / 84

Terbium-149 production and separation: the latest results from IS688

Authors: Anzhelika Moiseeva[1]; Chiara Favaretto[1]; Colin Hillhouse[1]; Cristina Mueller[1]; Hanne Heylen[2]; Karl Johnston[2]; Maryam Mostamand[1]; Nicholas Philip Van Der Meulen[3]; Pascal Grundler[1]; Stuart Warren[1]; Ulli Koester[4]

[1] *PSI*

[2] *CERN-ISOLDE*

[3] *Paul Scherrer Institute (CH)*

[4] *ILL*

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

Terbium-149 was proposed as an attractive candidate for Targeted Alpha Therapy (TAT) in the late 1990's [1], due to its favourable physical decay properties (T1/2 = 4.1 h, Eα = 3.97 MeV, 17%; Eβ+

mean = 720 keV, 7%) [2]. Preclinical studies have demonstrated its therapeutic potential [3-5], however, it was also demonstrated that it can be used for positron emission tomography (PET) [4]. The absence of daughter nuclides emitting relevant quantities of α-particles make it particularly promising, despite its current limited development.
Terbium-149 was produced at ISOLDE/CERN via spallation induced in a tantalum target using high-energy (1.4 GeV) protons, followed by effusion, release and ionization of the spallation products, which were mass-separated online. The mass 149 isobars were collected in zinc-coated gold/platinum/tantalum foils and shipped to PSI for processing. Terbium-149 was chemically separated from its isobaric impurities, as well as the collection material, using cation exchange and extraction chromatography, employing an optimized process as compared to the procedure previously reported [5]. The quality of the radionuclide produced was assessed analytically and by means of radiolabelling experiments.
Up to 1.9 GBq terbium-149 were collected and transported in an experimental campaign in 2024, with ˜850 MBq activity received upon arrival at PSI. The four-hour radiochemical separation process yielded up to 400 MBq final product. The product radiochemical purity was measured by γ-spectrometry and found to be 99.8%. Quality control was performed using DOTATATE, which was successfully labeled at molar activities up to 50 MBq/nmol with >99% radiochemical purity [5]. The chemical purity was further proven by ICP-MS measurements, which showed lead, copper, iron and zinc contaminants at ppb levels.
The collection of mass separated-terbium-149 and radiochemical separation process has steadily improved over the years, such that higher activities can be collected and isolated, while the quality of product can ensure more efficient labelling of tumour-targeting small molecules towards preclinical therapy studies.
The authors thank CERN and PSI radiation safety and logistics teams, as well as Nicole Pereira da Lima (USP - IPEN/CNEN, Brazil) and Wiktoria Wojtaczka (KU Leuven, Belgium) for assistance in collections.

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Poster session / 85

Probing residual nuclei production to optimize ISRS performance

Authors: Fatemeh Torabi[1]; Ismael Martel[2]; Brett Vern Carlson[3]

[1] *University of Huelva*

[2] *University of Huelva (ES)*

[3] *Departamento de Física, Instituto Tecnológico de Aeronáutica, DCTA, 12228-900, São José dos Campos, SP, Brazil*

Corresponding Author: fatemeh.torabi@dci.uhu.es

One main objective of the ISRS project is to investigate residual nuclei production to enhance the ISRS performance and, thereby, guide more precise experimental designs for future research. The analysis in this area has been initiated using different computational codes, namely EMPIRE and PACE4 [1-2]. Our initial examination involves reactions on a CD_2 target induced by a neutron-rich ^{68}Ni beam at a center-of-mass energy of 19.4 MeV. The modified version of the EMPIRE used in our study integrates the post-form distorted wave Born expression of the Ichimura-Austern-Vincent approach (DWBA-IAV) [3-6] for the elastic breakup and nonelastic breakup predictions, as well as the exciton and statistical Hauser-Feshbach models accounting for preequilibrium and compound-nucleus processes. This framework enables precise incorporation of key mechanisms, leading to a reliable estimation of the yields of the residual nuclei produced in the nuclear reaction. The results from EMPIRE were compared with those obtained from PACE4, revealing that EMPIRE predicts a broader range of residual nuclei and a larger total cross section in this reaction. In addition to

general computational differences, the main discrepancy in the predictions arises from the fact that PACE4 focuses on projectile absorption, while EMPIRE incorporates all key processes and predicts the formation of different types of pre-compound/compound nuclei in the reaction, making it a more comprehensive tool for examining the reaction mechanisms and residual nuclei.

In addition to the production yields, we investigated the angular distributions of the residual nuclei using the Monte-Carlo simulation code PACE4. These distributions showed that the yields of nearly all residual nuclei were produced at forward angles of less than 2 degrees. We scaled the cross sections obtained from EMPIRE based on the angular distribution patterns observed in the PACE4 results, ensuring consistency in the cross sections across different angular ranges for each nucleus. Subsequently, using the distributions obtained, precise Gaussian fits were found for each residual nucleus, which will be used in beam dynamic simulations to optimize the design of ISRS.

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Poster session / 86

RIALTO, The laser ion source at ALTO

Author: Anahi Segovia Miranda[None]

Co-authors: Francois Le Blanc [1]; Vladimir Manea [2]

[1] *Inst. Nat. Phys. Nucl. & Particules (IN2P3)-Universite de Paris-*

[2] *Université Paris-Saclay (FR)*

Corresponding Author: segovia@ijclab.in2p3.fr

RIALTO, the Resonant Ionization Laser Ion Source at the ALTO (Accélérateur Linéaire et Tandem d'Orsay) facility, uses a multi-step laser excitation process to produce pure ion beams through the resonance ionization technique. The laser laboratory is equipped with three high-power Nd:YAG operating at 10 kHz and pumping three dye lasers; these lasers are coupled with BBO doubling units and one tripling unit; this laser system allows us to achieve two and three-step ionization schemes with a range of 200–850 nm. An atomic beam unit (ABU) is also integrated to optimize operational parameters for online radioactive beam production.
We present recent upgrades to RIALTO that have improved the laser beam distribution and stabilization system, enhancing reliability and reducing laser scheme switch-over time.
These improvements enable the simultaneous production of ion beams for two different elements, demonstrated by the successful generation of radioactive gallium and silver isotopes during the same run. Notably, this marks the first production of laser-ionized silver isotopes at ALTO. Ongoing developments in generating a Zn beam are also presented.

Recent Experimental Results I / 7

Projectile Breakup of ^{7}Be on ^{12}C at 5 MeV/u

Authors: R Mitra[1]; Dhruba Gupta[2]; S Samanta[1]; S Maity[1]; K Kundalia[1]; Sk M Ali[3]; Olof Tengblad[4]; A Perea[5]; Ismael Martel[6]; Joakim Cederkall[7]; Antonio Moro[8]

[1] *Bose Institute*

[2] *Bose Institute (IN)*

[3] *FRIB, Michigan State University*

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

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

[6] *University of Huelva (ES)*

[7] *Lund University (SE)*

[8] *Universidad de Sevilla, Spain*

Corresponding Author: dhruba.gupta@cern.ch

Breakup reactions involving loosely bound stable nuclei with prominent cluster structures like ^{6,7}Li have been widely studied [1-3]. Similar studies on radioactive nuclei are comparatively lesser in number due to issues of availability and beam intensities. Reaction studies of the ^{7}Be nucleus on ^{12}C target reported very few coincidence events from breakup [4]. Similar results were reported on heavier targets like ^{58}Ni and ^{208}Pb [5-6]. It was concluded that though ^{7}Be has a lower breakup threshold than ^{7}Li, its transfer channels are more prominent than breakup [4]. To make a detailed study of the transfer and breakup channels of ^{7}Be on ^{12}C target, we carried out an experiment at HIE-ISOLDE with a 5 MeV/u ^{7}Be beam [7-8]. The ^{7}Be breakup fragments α and ^{3}He are detected in coincidence, and the plots of relative energy and opening angle of the breakup fragments confirm significant counts from both direct and sequential breakup [9]. The relevant Monte Carlo simulations were carried out with NPTool [10]. Detailed theoretical calculations on the breakup data are in progress. The comparison of the breakup of ^{7}Be with its mirror nucleus ^{7}Li is also important in reaction studies as we move from the line of stability towards the drip lines.

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Recent Experimental Results I / 6

Investigating the deformation of the intruder isomeric 1/2+ state in 79Zn (N=49) via Coulomb excitation

Authors: Andrea Gottardo[1]; Magdalena Zielinska[2]

Co-author: Filippo Angelini [3]

[1] *I*

[2] *CEA Saclay*

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

Corresponding Author: andrea.gottardo@lnl.infn.it

For nuclei with N around 50, several pieces of evidence supporting shape coexistence close to ^{78}Ni have been found. In particular, the ~940-keV $1/2^{+}$ isomeric state in ^{79}Zn has been interpreted as an intruder state, related to neutron excitations across N=50. Laser-spectroscopy measurements found a large isomeric shift for this state with respect to the ^{79}Zn $9/2^{+}$ ground state indicating a signifcantly larger mean squared charge radius. Assuming an axial quadrupole shape, this would

suggest a deformation of β=0.22, considerably larger than β=0.15 of the ground state, and would imply a significant mixing from the $2d_{5/2}$ neutron orbital. Alternatively, the larger radius could be due to the enlarged spherical shape coming from the contribution of the higher major oscillator shell orbital $3s_{1/2}$.
In order to probe the quadrupole deformation of the intruder isomer in ^{79}Zn and to understand the nature of its wave function, we used a post-accelerated ^{79}Zn beam from ISOLDE that consisted of a mixture of nuclei in the 9/2$^+$ ground state and the 1/2$^+$ isomeric state, to populate excited states built on these two different configurations via Coulomb excitation on ^{196}Pt and ^{208}Pb targets. In the experiment, γ rays were detected by the Miniball array, while scattered projectiles and beam recoils by an annular DSSD detector placed at forward angles.
We will present preliminary results of this study, providing evidence for strong Coulomb excitation of states built on the intruder isomer, and for the observation of new transitions that fill the gaps in the known level scheme of ^{79}Zn. We will discuss their possible implications in the context of the deformation of the 1/2$^+$ isomer in ^{79}Zn, and of the 80Zn ground state.

Recent Experimental Results I / 53

Measurement of the quadrupole moment of the first 2$^+$ state in 110Sn

Author: Rafael Antonio Lopez[None]

Co-authors: Joakim Cederkäll [1]; Joochun Park [2]; Jędrek Iwanicki [3]; Katarzyna Wrzosek-Lipska [3]

[1] *Lund University*

[2] *Institute for Basic Science*

[3] *University of Warsaw*

Corresponding Author: rafael.antonio.lopez@cern.ch

The quadrupole moment of the 2⁺₁ state in ¹¹⁰Sn has been determined, along with a more precise determination of the reduced transition probability B(E2;2⁺<sub>1 -> 0⁺₁). The measurement results were obtained through a safe Coulomb excitation experiment at HIE-ISOLDE, using the Miniball setup. Preliminary results yield Q(2⁺<sub>1</su = 0.19(7) eb, and B(E2;2⁺₁⟶0⁺₁) = 462(19) e²fm<sup
A novel analysis approach combining GOSIA and GOSIA2 codes with a DSAM measurement was used to calculate both diagonal and transitional matrix elements. The preliminary results are consistent with recent theoretical predictions, and the reduced transition probability, determined with high precision, aligns with previous experimental studies.

Recent Experimental Results I / 58

Evolution of the one-phonon mixed-symmetry 2+ state in the N=80 isotones

Author: Tim Florian Stetz[1]

Co-authors: Radostina Zidarova ; Volker Werner [2]; Norbert Pietralla

[1] *Technische Universitaet Darmstadt (DE)*

[2] *TU Darmstadt*

Corresponding Author: tstetz@ikp.tu-darmstadt.de

The formation of nuclear quadrupole collectivity and the contributions of valence protons and neutrons to it is a vivid research field in contemporary nuclear structure physics, including activities

at the ISOLDE facility. The excited proton and neutron configurations can couple to predominantly isoscalar and isovector excitations of the nuclear valence shell. The latter are addressed as having mixed symmetry. The simplest mixed-symmetric configuration in vibrational nuclei is the $2^+_{1,\mathrm{ms}}$ state. Its evolution in the N=80 isotones from ^{132}Te to ^{142}Sm has been of great interest for the past two decades [1,2,3,4,5]. Data on the $2^+_{1,\mathrm{ms}}$ state in this isotonic chain is complemented with a recent Coulomb-excitation experiment of ^{142}Sm at HIE-ISOLDE in combination with an angular correlation measurement after two β-decays performed at Heavy Ion Laboratory (HIL), Poland, in order to determine multipole mixing ratios of low-lying $2^+_i \rightarrow 2^+_1$ transitions. From the absolute matrix elements, the isolated $2^+_{\mathrm{ms},1}$ state of ^{142}Sm has been determined for the first time, supporting the concept of valence-shell stabilization as proposed by Rainovski *et al.* [4]. A final account of the recently finished data analysis will be given.

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Recent Experimental Results I / 59

Complementary measurements of octupole collectivity in 146Ce

Author: Ben Rhys Jones[1]

[1] *University of Liverpool (GB)*

Corresponding Author: ben.rhys.jones@cern.ch

I intend to present the preliminary results from the IS708 experiment, which plans to use both ISS and Miniball to study octupole collectivity in ^{146}Ce using the complementary techniques of inelastic scattering and Coulomb excitation, respectively. The ISS experiment will use the Liverpool silicon array to measure the excited 2+ and 3- states populated in a (d,d') reaction. The solenoidal technique will allow for the states to be measured with good separation in the lab, and will overcome sensitivity constraints experienced with γ-ray detectors so far when measuring B(E3) values in the lanthanide region. The measured cross sections will then be used as an input to a coupled channels analysis to determine the $B(E2;0_1\rightarrow 2_1+)$ and $B(E3;0_1\rightarrow 3_1-)$ transition strengths. A nuclear model independent measurement of the $B(E2;0_1\rightarrow 2_1+)$ transition strength at Miniball, will not only serve as a benchmark test of the new method, but will also give access to other E2 and E3 transitions in the nucleus. The complementary measurements will allow for a more comprehensive understanding of octupole collectivity in ^{146}Ce and the broader lanthanide region.

Recent Experimental Results I / 20

Detailed studies of ^{214,216,218}Po via β decay of ^{214,216,218}Bi

Author: Boris Andel[1]

Co-author: on behalf of RILIS-IDS-York-Leuven-Bratislava-Bucharest-Köln-Constantine-IS650 Collaboration

[1] *Comenius University (SK)*

Corresponding Author: boris.andel@cern.ch

The odd-odd bismuth isotopes (Z = 83) and their β-decay polonium daughters ($Z = 84$) are excellent subjects for nuclear structure studies. With only one and two protons, respectively, above the closed shell Z = 82, they provide an outstanding testing ground for shell-model calculations, and in the case of polonium isotopes, also for the seniority scheme. Moreover, both isotopic chains exhibit a wide variety of low-lying isomers. While the neutron-deficient bismuth and polonium isotopes are rather well explored, the information on the neutron-rich side is often scarce because of limitations in available experimental techniques.

In this contribution, results of a high-statistics β-decay experiment aimed at neutron-rich ^{214,216,218}Bi isotopes carried out at ISOLDE Decay Station (IDS) [1] are discussed. The levels populated in daughter nuclei were investigated employing an array of HPGe clover and fast-timing LaBr detectors. A new isomer was identified in ^{214}Bi [2] and complex decay schemes of ^{216g,m}Bi were established [3]. Lifetimes of yrast levels in ^{214,216,218}Po were measured and the deduced transition probabilities $B(E2)$ were confronted with theoretical models [4]. Shell-model calculations based on two different effective interactions, the H208 [5] and the modified Kuo-Herling particle interaction [6], were performed and compared with experimental results. Preferred spin and parity assignments for ^{214m}Bi and ^{216g,m}Bi based on the calculations and observed β-decay feeding intensities will be discussed.

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Special session / 81

New developments for data acquisition systems

Author: Ferdinando Giordano[None]

Corresponding Author: ferdinando.giordano@cern.ch

The aim of this talk is to explore the capabilities of the new CAEN V2730 digitizer, with particular emphasis on the customizable algorithms enabled by the SciCompiler environment. The CAEN V2730 is a state-of-the-art 32-channel, 14-bit, 500 MS/s digitizer designed for high-performance data acquisition and processing, featuring advanced customization options that allow users to tailor its operation for specific experimental requirements. It is based on a high-speed ADC, coupled with a powerful FPGA that provides on-board data processing capabilities, and supports both pulse-height analysis and waveform digitization. Additionally, the V2730 includes multiple programmable I/O channels, USB 3.0 and 1/10 GbE interfaces, as well as a high-speed optical link for data transfer, making it highly adaptable for integration into complex experimental setups.

Using SciCompiler, users can implement sophisticated algorithms for online data analysis, such as custom digital filters, triggering logic, and noise reduction directly on the FPGA, enabling real-time processing and minimizing the need for offline computation. The FPGA resources are accessible through a user-friendly graphical interface, allowing researchers to create and optimize their own algorithms without needing extensive FPGA programming experience. This flexibility allows users to adapt the digitizer's behavior to match the needs of a wide range of applications, including time-of-flight measurements, pulse shape discrimination, and multi-channel coincidence detection.

The discussion in this talk highlight the potential of the CAEN V2730 to revolutionize data acquisition in particle physics by providing researchers with a powerful, flexible platform for developing optimized detection and processing strategies. This talk underscores the value of customizable firmware solutions in advancing detector technology, paving the way for future innovations in real-time data analysis and high-precision measurement systems.

Solid-State Physics / 71

Structure-property correlation from quantum crystallography perspective

Author: Anna Malgorzata Krawczuk[1]

[1] *Georg-August-Universitaet Gottingen (DE)*

Corresponding Author: anna.malgorzata.krawczuk@cern.ch

Understanding the structure-property correlation in molecular materials is crucial for predicting the mechanical, electrical and optical properties of bulk materials. Our primary goal is to elucidate how molecules self-assemble in the crystalline state and to identify which intermolecular interactions determine specific physical properties. Among many possibilities, quantum crystallography (QCr) approach seems perfect for this task, as it combines experimental and theoretical methods to extract essential information. Using this methodology, we integrate high-resolution X-ray diffraction data with quantum chemical calculations to study intermolecular interactions in organic and organometallic crystalline materials.

In this work, we present a set of QCr tools that lead to accurate prediction of molecular and bulk properties. The presented workflow allows us to identify reproducible structural features that are transferable between different systems, which in turn leads to a better understanding of molecular self-assembly processes that promote specific crystal packing and thus prominent material properties.

Solid-State Physics / 74

Particle boundary in agglomerate enhances ferromagnetism in bismuth ferrite nanoparticles

Author: Doru Constantin Lupascu[1]

Co-authors: Astita Dubey [1]; Daniil Lewin [1]; Ian Chang Jie Yap [1]; Joachim Landers [2]; Juliana Heiniger-Schell [3]; Marianela Escobar Castillo [1]; Sobhan Mohammadi Fathabad [1]; Soma Salamon [2]; Thien Thanh Dang [1]

[1] *Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 45141 Essen, Germany*

[2] *Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 47057 Duisburg, Germany*

[3] *Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 45141 Essen, Germany; European Organization for Nuclear Research (CERN), CH-1211 Geneva, Switzerland*

Corresponding Author: doru.lupascu@uni-due.de

The nature of ferromagnetism in multiferroic bismuth ferrite (BiFeO3 or BFO) nanoparticles is still the subject of intense debate. The Time Differential Perturbed Angular Correlation (TDPAC) technique monitors local fields at the atomic scale without altering the structure of the materials under investigation. Using such an approach, we investigate that BFO nanoparticles exhibit strong ferromagnetic order at the unit cell level. Our previous data indicated that the vanishing magnetic order is already contained in the unit cell structure, at the non-magnetic sublattice (Bi site) in bulk BFO. In BFO nanoparticles, however, the temperature dependent magnetic field at the Bi site obeys the Brillouin curve of the ferromagnetic phase transition. Supported by other microscopic techniques, including transmission electron microscopy and X-ray diffraction, it is suggested that the lattice strains induced by the particle boundary in the agglomerate control the ferromagnetism in BFO nanoparticles.

Solid-State Physics / 8

Local effects in vanadia-based compounds

Author: Arnaldo Alves Miranda Filho[1]

Co-authors: Anastasia Burimova [1]; Anderson Souza [2]; Artur Wilson Carbonari [1]; Juliana Schell [3]; Renata Maziviero [2]

[1] *Instituto de Pesquisas Energeticas e Nucleares (BR)*

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

[3] *Institut Fur Materialwissenschaft Universität Duisburg-Essen (DE)*

Corresponding Author: arnaldo.alves.miranda.filho@cern.ch

The current study focuses on the temperature-dependent structural modulation of the local environment of M2+ ions in vanadium bronzes MxV2O5 and vanadates xMnO-V2O5. The growing interest in V2O5-based materials is in view of their potential for cathodes in M ion batteries, as highlighted in recent research [1]. Although the (de)intercalation mechanism of M ions is considered fundamental to charge transfer [2], a detailed description of this process is still lacking. In this regard, it becomes interesting to investigate vanadia-based materials with local methods, such as Time-Differential Perturbed Angular Correlation (TDPAC) spectroscopy to gain deeper insights into the structural dynamics involved. Samples were synthesized using incipient wetness impregnation method and the standard Pechini route. The X-ray diffraction method was employed to control over sample quality. For TDPAC measurements, the radioactive probes were introduced either through ion implantation of 111mCd beam at ISOLDE or directly during synthesis using 111InCl3 sourced from IPEN-Brazil. The behavior of hyperfine parameters indicates a temperature-dependent modulation of the local environment of the Cd probes in both V2O5:Cd and xMnO-V2O5:Cd systems. The observed effect can be associated to either distortions induce by the probe atom; or to intrinsic local structural variation.

Solid-State Physics / 39

PACIFIC2: a cost-effective solution for digital data acquisition and processing in PAC spectroscopy

Author: Pedro Miguel Da Rocha Rodrigues[1]

Co-authors: André Miranda [1]; Antonio Duarte Neves Cesario [1]; Armandina Maria Lima Lopes [1]; Goncalo De Pinho Oliveira [1]; Helena Petrilli [2]; Ivan Miranda [3]; Joao Martins Correia [4]; Joao Pedro Esteves De Araujo [1]; Juliana Schell [5]; Lucy Assali [2]; Neenu Prasannan [1]; Pedro Alexandre Silva De Sousa [1]; Ricardo Manuel Alves Pacheco Moreira [1]; Samuel Santos [2]

[1] *Universidade do Porto (PT)*

[2] *University of São Paulo (BR)*

[3] *Uppsala University (SE)*

[4] *Universidade de Lisboa (PT)*

[5] *Institut Fur Materialwissenschaft Universität Duisburg-Essen (DE)*

Corresponding Author: pedro.miguel.da.rocha.rodrigues@cern.ch

The γ-γ Perturbed Angular Correlation (PAC) spectroscopy's unique ability to probe atomic-scale phenomena makes it an exciting technique for studying structural, magnetic, and orbital phase transitions in solid-state physics, as well as investigating the intrinsic properties of radioactive nuclei. [1-3]
Historically, ISOLDE's PAC setups relied on aging analog equipment, some over 30 years old, or on expensive bulky digital systems. To modernize and streamline our PAC data processing capabilities, we embarked on a series of performance evaluations using the DT5730S desktop digitizer from

CAEN S.p.A. [4] With 8 input channels, a 500 MS/s sampling rate, and a 14-bit ADC, this compact digitizer seamlessly integrates into both 4 and 6-detector PAC configurations. Given the challenge of managing and analyzing vast data sets our team developed the PACIFIC^2 suite—a collection of Python-based tools designed specifically for PAC spectroscopy data acquisition and processing.
In this talk, we will present our latest developments, explore new perspectives for digital data processing in PAC spectroscopy, and highlight key results from the recent ^{111m}Cd beam time. Additionally, we will discuss recent findings on the naturally layered perovskite system $Ca_3Ti_2O_7$, focusing on how the measurement of the Electric Field Gradient (EFG) has helped resolve longstanding controversies regarding the nature of its structural transitions and how the PAC spectroscopy offers a sensitive method for probing anomalous ferroelectric behavior in this system. [5]

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Neutron-rich Nuclei / **17**

Nuclear Astrophysics at n_TOF / CERN

Author: Claudia Lederer-Woods[1]

[1] *The University of Edinburgh (GB)*

Corresponding Author: claudia.lederer@ed.ac.uk

Neutron induced reactions play a key role in stellar nucleosynthesis processes. In particular, neutron reaction cross sections are an important input to predict abundances produced by the slow neutron capture process, responsible for about half of the elemental abundances heavier than iron. Also for some lighter mass isotopes, neutron induced reactions may play a crucial role, for example for the abundance of the cosmic gamma ray emitter 26Al, which is destroyed by 26Al(n,p) and 26Al(n,α) reactions.
Since its inception in 2001, several dozen measurements of neutron induced cross sections have been performed at the neutron time-of-flight facility (n_TOF) at CERN. In this seminar, I will present the facility, methodologies, and recent highlights of neutron induced cross section measurements of interest to astrophysics. I will also discuss future opportunities and plans.

Neutron-rich Nuclei / **67**

Single-Neutron Strength Outside Doubly Magic 132Sn

Author: Benjamin Peter Kay[1]

[1] *Argonne National Laboratory (US)*

Corresponding Author: kay@anl.gov

The pattern of single-particle excitations outside of ¹³²Sn has held a long-standing fascination in the field, being the heaviest short-lived doubly magic nucleus. For over three decades, measurements to explore these excitations have been used as examples to motivate the development of facilities and instrumentation in long-range planning exercises. In a recent experiment at CERN's HIE-ISOLDE facility, the ¹³²Sn(d,p) reaction was carried out at energies above the Coulomb barrier using the ISOLDE Solenoidal Spectrometer. The measurement revealed, for the first time, the energy and strengths of all the valance neutron orbitals outside of 132Sn, including a determination of the long-sought-after 13/2⁺ strength.

Neutron-rich Nuclei / 13

8He beta-delayed neutron emission at IDS

Author: Jeppe Schultz Nielsen[1]

[1] *Aarhus University (DK)*

Corresponding Author: jeppe-schultz@hotmail.com

As part of IS659 a beam of 8He was taken to IDS in May 2022. Here a setup was prepared with double sided silicon strip detectors (DSSDs), plastic detectors with high timing resolution for beta detection, the IDS HPGe Clover array and the IDS neutron detector array (INDiE). With an ADC trace captured for each event in the beta and INDiE detectors, different timing algorithms have been explored to maximize timing resolution for neutron time of flight.

As part of the ongoing analysis, we have been able to use the excellent spatial resolution of DSSDs to do particle identification of charged particles in coincidence with neutrons by conservation of momentum for the first time. Here we have seen neutrons in coincidence with recoiling 7Li nuclei, as well as the alpha-triton-neutron break up of highly excited states of 8Li, of which our first results will be shown.

Neutron-rich Nuclei / 21

First beta-decay spectroscopy experiment at VITO

Author: Monika Piersa-Silkowska[1]

[1] *CERN*

Corresponding Author: monika.piersa@cern.ch

Exciting new opportunities for beta-decay experiments have emerged at the ISOLDE facility with the recently developed spectroscopy station called DeVITO [1]. The novelty of the new setup lies in its integration with the VITO beamline [2] for laser-polarisation of radioactive beams, enabling spectroscopy measurements with spin-oriented nuclei that emit radiation anisotropically. The ability to exploit the directional distribution of radiation represents a significant advance over conventional beta-decay experiments, which greatly benefit from the high angular-momentum selectivity of the process but constantly struggle to unambiguously infer nuclear spins and parities from observed beta-decay feeding intensities [3]. These quantum numbers, essential for discussing complex phenomena observed in nuclei, can be inferred from experimental beta-decay asymmetries measured in coincidence with delayed radiation [4, 5]. This novel approach to beta-decay measurements utilising laser-polarised nuclei was pioneered by a group from the University of Osaka, which successfully applied it to studies of allowed beta transitions [5-7]. It has been shown that the key ingredient for unambiguous spin-parity assignments is the high degree of polarisation in parent nuclei. The VITO beamline, where spin orientation in atoms or ions is induced via optical pumping with laser light, has proven to be an excellent place for implementing this technique and further developing its extension.

The initial configuration of the DeVITO station and the initiated research programme [8] are targeted at studies of very neutron-rich nuclei to gain insight into the mechanism of beta-delayed neutron emission, which is the primary decay mode of exotic nuclei involved in one of the astrophysical processes responsible for the formation of about half of the chemical elements heavier than iron. This contribution highlights key features of the DeVITO station and presents preliminary results from a proof-of-concept run conducted at ISOLDE in April 2024 with laser-polarised beams of neutron-rich potassium isotopes.

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Recent Experimental Results II / 68

Pushing the limits of Collinear Laser Spectroscopy: Advancements in sensitivity and breakthroughs in the study of exotic nuclei at COLLAPS

Author: Peter Plattner[1]

[1] *Max Planck Society (DE)*

Corresponding Author: peter.plattner@cern.ch

Collinear Laser Spectroscopy (CLS) is a powerful tool for investigating nuclear ground state properties such as spin, electromagnetic moments, and the mean-square nuclear charge radius of exotic nuclei [1-3]. Phenomena, like the emergence of new magic numbers and the discovery of proton-emitting nuclei, occur far from stability, requiring researchers to push the limits of their techniques. In 2024, two key areas of investigation at COLLAPS have been the appearance or disappearance of a new magic number at N=32 in calcium and the unknown properties of the proton-emitting nucleus ^{147}Tm. These very exotic nuclei are produced at rates that challenge the capabilities of conventional CLS.

This contribution will present the technical advancements at COLLAPS that have significantly increased sensitivity, achieving detection rates as low as 0.6 ions/s with the recently developed ROC technique. I will also discuss the progress made towards studying the proton-emitting nucleus ^{147}Tm, highlighting efforts to perform spectroscopy on ion configurations with rates lower than 100 ions/s. Overall, this talk will showcase the breakthroughs achieved during a successful year of experiments in 2024.

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Recent Experimental Results II / 35

Measurement of the hyperfine anomaly in short lived radioactive nuclei: progress and outlook

Author: Mark Bissell[1]

Co-authors: Agota Koszorus [1]; Amy Sparks ; Andrej Antušek [2]; Andrej Hurajt ; Anu Nagpal [3]; Benjamin Roberts ; Dalibor Zakoucky [4]; Daniel Paulitsch [5]; Herlik Wibowo [6]; Ilaria Michelon [7]; Jacek Dobaczewski ; Jacinda Ginges ; Magdalena Kowalska [1]; Marcus Jankowski [8]; Markus Kortelainen ; Mateusz Jerzy Chojnacki [7]; Michael Pesek [9]; Mikolaj Hubert Baranowski [10]; Monika Piersa-Silkowska [1]; Nikolay Azaryan [11]; Ruben Pieter De Groote [12]; Rui Han

[1] *CERN*

[2] *Slovak University of Technology in Bratislava, ATRI, Faculty of Materials Science and Technology in Trnava, J. Bottu 25, 917 24 Trnava, Slovak Republic*

[3] *University of York (GB)*

[4] *Czech Academy of Sciences (CZ)*

[5] *University of Innsbruck (Universität Innsbruck)*

[6] *University of York, York, Uk*

[7] *Universite de Geneve (CH)*

[8] *Technische Universitaet Darmstadt (DE)*

[9] *Charles University (CZ)*

[10] *Adam Mickiewicz University (PL)*

[11] *Adam Mickiewicz University in Poznan (PL)*

[12] *KU Leuven (BE)*

Corresponding Author: mark.lloyd.bissell@cern.ch

The hyperfine anomaly in atomic structure is sensitive to both the composition and radial distribution of nuclear magnetisation. Although this observable has been known of and measured since the 1950's, precise measurements have been sporadic and largely limited to stable nuclei [1]. In the last few years, developments in the β-NMR technique have provided a level of precision at which magnetic moments of radioactive nuclei can make meaningful constraints on this observable [2]. However, in all but a few cases, our knowledge of atomic structure hyperfine parameters remains insufficient. At ISOLDE, we are trying to address this problem on two fronts. Firstly, where hyperfine structure parameters are sufficiently well known, ultra-high-resolution β-NMR is being applied to determine the relevant magnetic moments. Secondly, and most significantly, we are developing new apparatus to measure hyperfine parameters of short-lived nuclei with relevant precision.
In parallel to our experimental efforts to provide new information on the atomic nucleus, atomic and nuclear theoretical developments are ongoing. With these developments it has become possible to interpret our experimental observations within a modern theoretical framework. In this contribution, our recent measurement of the hyperfine anomaly in potassium will be presented, along with the developments being undertaken to enable a targeted but wide-ranging investigation of this observable across the nuclear landscape.

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Recent Experimental Results II / 5

Testing the Standard Model with the WISArD Experiment

Author: Samuel Lecanuet[1]

[1] *Centre National de la Recherche Scientifique (FR)*

Corresponding Author: samuel.lecanuet@cern.ch

The objective of the WISArD experiment is to test the existence of new physics in the weak interaction sector of the Standard Model of particle physics using beta decay. The angular correlation parameter a and the Fierz interference term b, which characterize beta decay, are sensitive to the existence of exotic scalar or tensor currents. These currents are not included in the description of the electroweak interaction within the framework of the Standard Model, which only involves vector and axial-vector currents. The goal of the WISArD experiment is to measure these parameters in the decay of 32Ar with a precision of about 0.1%, in order to provide constraints on new physics that are competitive with the direct searches conducted at very high energies at the LHC. The experiment is located in the ISOLDE experimental hall at CERN. The current analysis presents preliminary results on the angular correlation parameter, including a portion of the systematic errors, which account for the experimental setup, analysis fits, and beam contamination.

78

Workshop Dinner

Fundamental Interactions / **1**

Ultra-high precision nuclear mass measurements for fundamental studies

Author: Klaus Blaum[1]

[1] *Max-Planck-Institut für Kernphysik*

Corresponding Author: sekretariat.blaum@mpi-hd.mpg.de

The four fundamental interactions and their symmetries, the fundamental constants as well as the properties of elementary particles like masses and moments, determine the basic structure of the universe and are the basis for our so well tested Standard Model (SM) of physics. Performing stringent tests on these interactions and symmetries in extreme conditions at lowest energies and with highest precision by comparing, e.g., the properties of particles and their counterpart, the antiparticles, will allow us to search for physics beyond the SM. Any improvement of these tests beyond their present limits requires novel experimental techniques.
An overview is given on recent mass measurements with extreme precision on single exotic ions stored in Penning traps. Among others the most stringent test of bound-state quantum electrodynamics could be performed, the accuracy of the electron and proton atomic mass got improved significantly, and precision nuclear masses contributed to neutrino physics research. Most recently even applications in dark matter searches opened up where relative mass uncertainties at the level of 10-11 and below are required.

Fundamental Interactions / **54**

Essential steps towards a nuclear clock: half-life and decay-fraction measurements of the radiative decay of ^{229m}Th

Author: Yens Elskens[1]

Co-authors: André Vantomme [1]; Arno Claessens ; Cyril Bernerd [2]; Fedor Ivandikov [1]; Hilde De Witte [1]; Joao Martins Correia [3]; Katerina Chrysalidis [2]; Lino Miguel Da Costa Pereira [1]; Mia Au [2]; Michail Athanasakis-Kaklamanakis [2]; Mustapha Laatiaoui ; Peter THIROLF [4]; Piet Van Duppen [1]; Premaditya Chhetri [1]; Rafael Ferrer Garcia [1]; Razvan Lica [5]; Reinhard Heinke [6]; Sandro Fabian Kraemer [1]; Sebastian Raeder [7]; Sebastian Rothe [2]; Shandirai Malven Tunhuma [1]; Silvia Bara [1]; Simon Thomas Stegemann [2]; Simone Casci [8]; Skyy Venancio Pineda [1]; Thomas Elias Cocolios [9]; Thorsten Schumm [10]; Ulli Koester [11]; Ulrich Wahl [3]; Zixuan Yue [12]

[1] *KU Leuven (BE)*

[2] *CERN*

[3] *Universidade de Lisboa (PT)*

[4] *Ludwig-Maximilians-Universitaet Muenchen*

[5] *Horia Hulubei National Institute of Physics and Nuclear Engineering (RO)*

[6] *The University of Manchester (GB)*

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

[8] *KU Leuven - Instituut voor Kern- en Stralingsfysica*

[9] *KU Leuven - IKS*

[10] *T*

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

[12] *University of York (GB)*

Corresponding Author: yenselskens@gmail.com

Due to its low excitation energy around 8.3 eV, the unique ^{229}Th isomer is the ideal candidate for developing a nuclear clock [1]. Such a clock would be particularly suited for fundamental physics studies [1]. In the past, measuring the isomer's radiative decay from a large-bandgap crystal with ^{229m}Th embedded, has proven difficult: the commonly used population of the isomer via the ^{233}U α-decay has a limited branching ratio towards the isomer and creates a high-radioluminescence background [2, 3]. However, recently, a new approach to populate the isomer through the β-decay of ^{229}Ac was proposed [2]. This approach made it possible to observe, for the first time, the radiative decay of the ^{229}Th isomer with vacuum-ultraviolet (VUV) spectroscopy, which allowed to successfully determine the resulting photon's wavelength at a value of $\lambda = 148.7 \pm 0.4$ nm ($E = 8.338 \pm 0.024$ eV) and the isomer's radiative half-life in a MgF_2 crystal at a value of $t_{1/2} = 670 \pm 102$ s [4, 5]. Based on this work, the excitation of the nuclear isomer was achieved [6] determining the energy to the 10^{-12} precision, boosting the development of a solid-state nuclear clock. A new measurement campaign in July 2023 took place at ISOLDE, aimed at testing different large-bandgap crystals and accurately determining the half-life of ^{229m}Th, embedded in different crystals. This allowed to (1) observe, for the first time, the radiative decay in a $LiSrAlF_6$ crystal, (2) determine the radiative decay fraction of the isomer in different crystals [7], and (3) study the isomer's time behaviour. Results of these studies will be presented, as well as the plans for future campaigns.

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Theory / **72**

Nuclear Density Functional Theory: general aspects and interpretation of recent experiments

Author: Gianluca Colò[None]

Corresponding Author: gianluca.colo@unimi.it

In this contribution, the nuclear Density Functional Theory (DFT) will be briefly introduced and confronted with other nuclear structure models. This introduction will be tailored for a general audience. Some state-of-the-art Energy Density Functionals (EDFs), as well as their predictive power and their current limitations, will be discussed.
It will be emphasised that one of the main advantages of DFT is the capability to treat excited states, throughout the whole isotope chart. Shell structure evolution, collective nuclear properties and connections with the nuclear Equation of State (EoS) are some of the physics problems that can be addressed. Accordingly, in this contribution, a few applications of DFT and extensions thereof will be highlighted, by focusing on both single-particle and collective spectroscopy. The theoretical results will be compared with the outcome of inelastic scattering and transfer experiments. In particular, a few recent data from ISOLDE, on the evolution of single-particle states, will be also discussed.

Recent Experimental Results III / 16

Nano-strain induced ferromagnetism in epitaxial thin films of bismuth ferrite

Author: Danylo Kviatkovskyi[1]

Co-authors: Thanh Thien Dang [2]; Efe Ipek [3]; Morgan Trassin [3]; Juliana Schell [2]

[1] *Solid State Physics group at ISOLDE-CERN and Faculty of Radio Physics, Electronics and Computer Systems, Taras Shevchenko National University of Kyiv (UA)*

[2] *Institut Fur Materialwissenschaft Universität Duisburg-Essen (DE)*

[3] *Department of Materials, ETH Zurich*

Corresponding Author: danylo.ihorovych.kviatkovskyi@cern.ch

The existence of an uncompensated magnetic order in epitaxial thin films of multiferroic bismuth ferrite (BiFeO3 or BFO) is still the subject of intense debate. The Time Differential Perturbed Angular Correlation (TDPAC) technique monitors local fields at the atomic scale without altering the structure of the investigated materials. Using such an approach, we observed that BFO epitaxial thin films exhibit local ferromagnetic order at the unit cell level. TDPAC data obtained at room temperature with the 111mCd probe show that the strong magnetic field (~ 5 Tesla) exists at the non-magnetic sublattice (Bi site). It is assumed that the nano-strain resulting from the mismatch between the substrate and the BFO thin film produces a non-zero net local magnetisation of the sample.

Recent Experimental Results III / 23

Radiotracer photoluminescence and emission channeling studies of group-IV quantum emitters in diamond

Author: K. Danilov[1]

Co-authors: B. Biesmans [2]; A. Lamelas ; S. M. Tunhuma [2]; A. Costa [3]; E. David-Bosne [4]; K. Johnston ; V. Amaral [5]; A. Vantomme [2]; J. G. Correia [3]; U. Wahl [3]; L. M. C. Pereira [2]

[1] *KU Leuven*

[2] *KU Leuven (BE)*

[3] *Universidade de Lisboa (PT)*

[4] *Czech Technical University in Prague (CZ)*

[5] *University of Aveiro (PT)*

Corresponding Author: kirill.danilov@kuleuven.be

Colour centers based on group-IV impurities (SiV, GeV, SnV, and PbV) in diamond are intensively investigated in the context of quantum nanophotonic applications, with some of their attractive properties stemming from the inversion symmetry of their split-vacancy configuration and their high Debye-Waller factor. Whereas a significant amount of research has been devoted to study their **optical** activation yields after ion implantation and thermal annealing, very little is known about their **structural** formation yields, thermal stability and annealing mechanisms. As part of experiment IS668, we have been studying the lattice location of implanted ^{75}Ge, ^{121}Sn and ^{209}Pb in diamond, using the β^- emission channeling technique. In this talk, we review our previous work [1,2] and present new results from recent beam times, centered around three main findings: (i) contrary to general belief, the GeV, SnV and PbV defects are efficiently formed upon implantation, without the need for annealing-induced diffusion of C vacancies; (ii) while the SnV and PbV defects are stable up to 900 °C, for Ge, annealing or implanting at moderate temperatures (300 °C) significantly reduces the amount of GeV centers, suggesting the existence of two coexisting defect annealing mechanisms; (iii) contrary to recent proposals based on indirect interpretation of optical activation studies, our experiments show that electrical co-doping does not substantially affect the structural formation yields. As part of experiment IS668, we have also developed a radiotracer photoluminescence (rPL) setup specifically optimized for studying colour centers in diamond, located at the newly established **Quantum Photonics Lab** in Building 508. Radiotracer PL is specifically designed to overcome the major limitation of standard PL of not being element specific: using a radioactive isotope and recording the time dependence of the intensity of the rPL lines allows us to correlate them with the half-life of the parent or daughter isotopes. In this talk we will present the first successful rPL experiment on colour centers in diamond performed at ISOLDE, where we recorded the time dependence of GeV$^-$ zero-phonon line (ZPL) and correlated it with the decay of ^{75}Ge. We will also describe our planned rPL experiments within IS668 aimed to determine whether various PL lines observed upon implantation of Sn and Pb are indeed associated with the implanted impurities or instead result from the creation or activation of other defects and impurities.

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Recent Experimental Results III / 46

Molecular Extraction of Terbium and Other Lanthanides: Challenges and Opportunities

Author: Wiktoria Wojtaczka[1]

Co-authors: Christoph Schweiger [2]; Daniel Lange [2]; Edgar Miguel Sobral Dos Reis ; Jake David Johnson [3]; Lukas Nies [4]; Marie Deseyn [1]; Maroua BENHATCHI ; Mia Au [4]; Michael Heines [1]; Paul Fischer [5]; Paul Florian Giesel [6]; Sebastian Rothe [4]; Simon Thomas Stegemann [4]; Thomas Elias Cocolios [7]; Valentina Berlin [8]

[1] *KU Leuven (BE)*

[2] *Max Planck Society (DE)*

[3] *KU Leuven Association*

[4] *CERN*

[5] *University of Greifswald*

[6] *University of Greifswald (DE)*

[7] *KU Leuven - IKS*

[8] *SY group*

Corresponding Author: wiktoria.wojtaczka@cern.ch

Tantalum targets can be used to produce lanthanide beams but in order to extract species with slow release times, such as terbium, the targets have to be pushed to extreme temperatures. This is especially true when it comes to medical isotope production that requires collections in the order of

GBq/day of radionuclides with a minimum half-life of several hours. One way to volatilise the more refractory species is to extract them in the form of their fluoride molecules [1]. Previous studies have explored injecting reactive tetrafluoro-methane (CF4) gas to different target and ion source combinations via calibrated leaks, observing the formation of fluoride molecules and molecular ions of different species [1-4]. Extracting fluoride molecules can also help to purify the beam by collecting on a sideband with fewer contaminants. This makes fluoride beams a promising potential avenue to extract more refractory lanthanides and to increase the experimental yields of more exotic isotopes that have not been accessible to study at ISOLDE so far. For nuclear medicine, this could facilitate more pre-clinical trials with terbium-based radiopharmaceuticals. Additionally, this approach could be advantageous for some other species that cannot be extracted from carbide targets due to their chemistry.

In this work, we report on systematic studies of terbium fluoride beams performed at CERN ISOLDE using a tantalum foil target coupled to a hot plasma ion source with injection of CF4 gas. The ion beam composition was investigated as a function of target, ion source, and gas injection conditions to optimise the terbium fluoride beam delivery for 144-168Tb. The ISOLTRAP MR-ToF MS [5] was the main tool used for the identification of beam composition and yield measurements. Additionally, collections were performed for offline yield measurements with gamma and alpha spectrometry.

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Recent Experimental Results III / 32

Recent results on the beta decay of 152Tb and its relevance in theranostics

Authors: Angie Carolina Fonseca Vargas[1]; Enrique Nacher[2]

[1] *Univ. of Valencia and CSIC (ES)*

[2] *IFIC (CSIC - Univ. of Valencia)*

Corresponding Authors: angie.carolina.fonseca.vargas@cern.ch, enrique.nacher@cern.ch

The use of radionuclides for cancer diagnostics and therapy is extensively recognized and employed across various techniques. The effectiveness of these techniques, along with the minimisation of the doses to healthy tissue in both, therapy and diagnostics, hinges on several factors, one of which is the decay properties of the specific radionuclide used. Specifically, the types of particles, radiation emitted, energies, and their emission probabilities, play a crucial role in accurately calculating the dose administered to patients when using radioisotopes.

High quality/accuracy nuclear decay data is essential for the aforementioned calculations of dose administered to patients. In this case in particular, beta plus-decay data, as positron emission is the preferred decay process when we come to medical imaging (PET). However, one of the main physical quantities relevant to this process is the beta-intensity distribution, which is not easy to measure in medium-mass or heavy nuclei.

A recent report by the IAEA explicitly mentioned the need for measurement of specific isotopes for their relevance in theranostics using Total Absorption Spectroscopy (TAS). Among them, 152Tb, proposed as a theranostic partner of 161Tb and 149Tb, is recommended for a TAS measurement.

In this presentation, we report on the TAS measurement of the beta decay of 152Tb recently carried out at ISOLDE (CERN). The results show clear discrepancies between the measured TAS spectrum and the Geant4 simulation using the ENSDF database. We observed discrepancies in the region from 1.8 MeV to the Q_EC value.

We will present results on the newly measured beta-intensity distribution for this decay, as well as its relevance in the dose administered to different regions of a potential patient undergoing a PET scan with 152Tb.

Recent Experimental Results III / 27

"Nuclear thermometers"reveal the origin of the universal r-process nucleosynthesis

Author: Jose Nicolas Orce Gonzalez[1]

[1] *University of the Western Cape (ZA)*

Corresponding Author: nico.orce@cern.ch

The validity of the Brink-Axel hypothesis is inferred from the resembling behaviour of giant dipole resonances built on ground and excited states, which present similar energy systematics. Together with previous work, this assigns giant dipole resonances as spectroscopic probes or "nuclear thermometers"to explore the cooling of the extremely hot ejecta gas produced in neutron-star mergers, down to the production of elements through the rapid-neutron capture or r-process. Such "thermometers"of nuclear matter show a slight increase in the energy of the giant dipole resonance at the typical temperatures where seed and r-process nuclei are produced, which lowers the nuclear binding energy through the symmetry energy. New data at T=0.5 MeV will be shown, which can provide a solution to the long-sought universality of elemental abundances by narrowing down the reaction network for element production in stellar explosions. Further data for heavy, neutron-rich nuclei are crucial.

Recent Experimental Results IV / 66

Recent results and upgrades from the 2024 CRIS campaign at ISOLDE

Author: Jessica Warbinek[1]

Co-author: CRIS Collaboration

[1] *CERN*

Corresponding Author: jessica.warbinek@cern.ch

For the last decade, the Collinear Resonance Ionization Spectropscopy (CRIS) experiment at ISOLDE has been focussing on performing laser spectroscopy for hyperfine structure studies of exotic nuclei across the nuclear chart. The CRIS technique allows to study atomic, nuclear and molecular properties and stands out with its combination of high-resolution measurements along a high sensitivity and efficiency. In recent years, experiments at CRIS have focussed on studying the atomic and nuclear structure across a range of elements, from as light as aluminium to as heavy as francium, investigating regions of shape coexistence, the island of inversion around $N = 20, 40$, the magicity of shell closures and in recent years also the structure of radioactive molecules such as RaF for beyond-standard-model investigations.

This talk will present the recent highlights from the 2024 CRIS experimental campaign, including the on-line campaigns on neutron-deficient gold isotopes in the "island of deformation" and shape co-existence, as well as the study of neutron-deficient antimony isotopes, with a single valence proton compared to tin ($Z = 50$), towards the $N = 50$ shell closure. Further experiments during the winter physics campaigns focus on studying the atomic structure of francium, in particular the $6D_{3/2,5/2}$ states, which are predicted to share a high sensitivity to new physics. The year at CRIS will end with investigations of negative RaF^-, and its potential for slowing and trapping for future precision measurements. With further on-line and off-line commissioning campaigns for new advancements in the technique, CRIS aims at enhancing its selectivity even further. Newest developments include the upgrade of the CRIS decay station for decay-based laser spectroscopy studies or decay spectroscopy studies after laser purification, and the installation of a field ionization unit for an additionally enhanced sensitivity of the method.

Recent Experimental Results IV / 63

Overview of the 2024 Miniball campaign at ISOLDE

Author: Carlotta Porzio[1]

[1] *CERN*

Corresponding Author: carlotta.porzio@cern.ch

The Miniball gamma-ray spectrometer at ISOLDE-CERN is employed to investigate both collective and single-particle nuclear properties of radioactive isotopes. The spectrometer comprises eight assemblies of three high-purity germanium detectors, and is complemented with ancillary silicon detectors for particle detection. It exploits the re-accelerated radioactive ion beams provided by the HIE-ISOLDE facility to perform Coulomb excitation and nucleon transfer reactions.

The 2024 Miniball campaign at ISOLDE focused on Coulomb excitation reaction experiments to investigate nuclear deformation for medium-mass and heavy nuclei. Highlights of the recent experiments performed at Miniball will be presented.

Recent Experimental Results IV / 15

MIRACLS - Laser spectroscopy of radioactive isotopes in an MR-ToF device

Author: Anthony Roitman[1]

[1] *McGill University, (CA)*

Corresponding Author: anthony.moshe.roitman@cern.ch

The phenomenon of shell closures corresponding to increased stability of nuclei at magic numbers of protons or neutrons (2, 8, 20, 50, etc.) is a key feature of the nuclear shell model. However, conventional shell closures can disappear for radioactive nuclei in several key regions of the nuclear chart known as "islands of inversion."These islands provide ideal testing grounds for modern nuclear theory. In order to make use of them, precise experimental data is necessary for short-lived exotic nuclei. In particular, for the island of inversion in the neutron-rich region around $N = 20$, measurements of the charge radius of the magnesium isotopic chain, especially the ones beyond the shell closure such as ^{33,34}Mg, are crucial to perform accurate theoretical benchmarks.

Collinear Laser Spectroscopy is a highly effective tool for precise measurements of nuclear ground state properties of radionuclides such as the nuclear spin, electromagnetic moments, and charge radius. The Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) is a new experimental setup at ISOLDE which aims to improve the sensitivity of conventional CLS by conducting it in a high-energy (> 10 keV) multi-reflection time-of-flight (MR-ToF) device [1, 2]. This is a type of ion trap which utilizes two electrostatic mirrors to reflect ion bunches back and forth for several thousands of revolutions. Hence, the ion bunches can be probed by the laser multiple times per measurement cycle to obtain higher statistics than with conventional CLS, which can study the ion bunch only once. The resulting improvement in sensitivity allows the exotic magnesium isotopes with yields as low as 100 ions per μC to become accessible.

Earlier this year, MIRACLS had a successful commissioning beamtime, where CLS on the radioactive isotopes ^{28,30,32}Mg was performed for both the D1 and D2 ionic transitions. This data has demonstrated the feasibility of the measurement of ^{34}Mg. In this oral contribution, I will discuss the MIRACLS concept and the latest experimental results, including CLS of short-lived radioactive Mg isotopes.

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Recent Experimental Results IV / 56

Recent mass measurements and developments at ISOLTRAP

Author: Daniel Lange[1]

Co-authors: Burcu Cakirli Mutlu [2]; Christoph Schweiger [1]; David Lunney [3]; Dinko Atanasov [4]; Frank Wienholtz [5]; Klaus Blaum [1]; Lukas Nies [6]; Lutz Christian Schweikhard [7]; Maroua BENHATCHI ; Paul Florian Giesel [7]; Sarah NAIMI ; Vladimir Manea [3]; Yury Litvinov [8]

[1] *Max Planck Society (DE)*

[2] *Istanbul University (TR)*

[3] *Université Paris-Saclay (FR)*

[4] *SCK CEN, Belgian Nuclear Research Center (BE)*

[5] *TU Darmstadt*

[6] *CERN*

[7] *University of Greifswald (DE)*

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

Corresponding Author: daniel.lange@cern.ch

High-precision mass measurements of radioactive ions are used to determine nuclear binding energies, which reflect all forces acting in the nucleus and are used to study among others nuclear structure, nuclear astrophysics and weak interaction.

For this, the ISOLTRAP mass spectrometer [1] uses various ion traps, including a tandem Penning-trap system and a multi-reflection time-of-flight mass spectrometer (MR-ToF MS) [2], where the latter is suitable for both mass separation and fast, precise mass measurements.
In this contribution, the first direct mass measurements of neutron-deficient ^{97}Cd and the excitation energy of the ^{97,n}Cd high-lying isomer along with a precise measurement of ^{98}Cd in the immediate vicinity of the self-conjugate doubly magic N=Z=50 ^{100}Sn will be presented. Furthermore the recent measurements of neutron-rich ^{209,210}Hg will be discussed.
Besides the introduction of ISOLTRAP's current setup, technical developments are presented, in particular the upcoming re-bunching system using a new Mini-RFQ following the MR-ToF MS, which is currently being commissioned. The latter will realize mass-selective re-trapping [3] to enable low-yield experiments with extremely abundant (molecular) isobaric contamination and overcome the limitation of systematic ToF shifts induced by space-charge effects [4].

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79

Closing Remarks and Prizes

Corresponding Author: sean.freeman@cern.ch

Recent Experimental Results II / 51

Collinear Resonance Ionization Spectroscopy of neutron-deficient antimony

Author: Abigail Charlotte Mcglone[1]

[1] *The University of Manchester (GB)*

Corresponding Author: abigail.charlotte.mcglone@cern.ch

Neutron deficient antimony isotopes provide an excellent study of nuclear structure around the doubly magic ^{100}Sn (N=Z=50). With a single valence proton above the Z=50 Sn, Sb can be used as a rigorous test of the single particle shell model around this closed shell. Measuring the neutron deficient Sb isotopes allows for investigation into the robustness of the magic Z=50 core. Significant effort has been invested into this region using a variety of laser spectroscopy techniques studying Cd (Z=47) [1], Ag (Z=48) [2,3], In (Z=49) [4-7], Sn(Z=50) [8] and Sb (Z=51) [9,10], including previous CRIS campaigns.

The Collinear Resonance Ionization Spectroscopy (CRIS) experiment at ISOLDE can measure the electromagnetic moments, spins and changes in mean squared charge radii across an isotopic chain. This allows us to deduce the single particle behaviour of the neutron deficient Sb isotopes and the effect of the additional proton outside of the closed Sn shell.

This contribution aims to introduce this experimental campaign and the CRIS experiment to discuss the recent results measuring $^{111-123}$Sb, which will allow determination of the electromagnetic moments and spins of these nuclei. This work will also discuss the further improvements of the CRIS experiment using field ionization which aims to provide additional background suppression by an order of magnitude [11], granting access to further exotic cases closer to the proton drip line.

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