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# Book of Abstracts

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## ISOLDE Collaboration News

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## RILIS operation and development in 2023

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In line with the previous years, RILIS has been the favored ion source at ISOLDE in 2023, with more than 65% of the ion beams produced from April to November, including the winter physics program. In that period of time, more than 20 different elements were ionized using lasers at ISOLDE.

The stable operation of RILIS and fast switching in-between the elements was possible thanks to the constant effort in consolidating and developing the laser ionization technique. These developments concern both the laser capabilities and the ion source itself.

Concerning laser developments, the main axis of improvement aims to improve stability, output power, spectral coverage, and linewidth capabilities. Multiple projects have been conducted throughout the year, including the permanent installation of crystal ovens (stability), intra-cavity tripling (power/beamshape improvement in the UV range), Raman laser (spectral coverage –linewidth)⋯ These developments were possible thanks to the refurbishment of a dedicated laser laboratory called LARIS.

Regarding the ion source, two main developments have been followed over the year. First, the LIST ion source is now a standard source at ISOLDE and has been used for several experiments over the year. Multiple improvements are ongoing to make it an even more versatile source in the future, especially for High-resolution Spectroscopy with the PI-LIST configuration. Secondly, developments toward a high-throughput laser ion source are ongoing in collaboration with SPES and SCK, with a common objective of tackling the ion load effect occurring in high-throughput operation configuration.

In terms of atomic and nuclear research, the team has dedicated 3 weeks of experiments at the beginning of the year to the spectroscopy and yield measurements of several Lanthanides (Dy, Pm, Tm, Er, Yb, Gd) and Actinides (Pu, Np), and finalized the development of a new laser ionization scheme for Cr.

This presentation will give an overview of operation, developments and research introduced above.

**Operation and New Developments I / 33**

## MIRACLS - A novel laser spectroscopy technique for observing the most exotic nuclei

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The assumption of universal magic numbers, i.e. closed nuclear shells, all across the nuclear chart has been a fundamental paradigm of the nuclear shell model. However, when exploring nuclides far away from stability, a disappearance of well-established shell closures can be encountered, which, for instance, manifests itself in the island of inversion around N = 20 [1].
Describing this shell evolution from first principles is a formidable task for nuclear theory. Recently, nuclear ab-initio methods have been able to expand their reach also into open shell nuclei. This advance now allows for ab-initio calculations of nuclear observables within the N = 20 island of inversion [2]. In order to deepen our understanding of this region of nuclides and challenge the predictive power of modern nuclear theory, experimental knowledge about the nuclear charge radii of neutron-rich magnesium (Z = 12) isotopes is crucial.
A powerful tool to access nuclear charge radii is collinear laser spectroscopy (CLS) [3]. However, to extend previous measurements [4] and explore the most exotic nuclides like $^{33,34}$Mg with very low production yields at radioactive ion beam facilities, more sensitive methods have to be envisioned.
The novel Multi-Ion-Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) at ISOLDE/CERN [5] combines the high spectral resolution of conventional fluorescence-based CLS with high experimental sensitivity. This is achieved by trapping ion bunches in a Multi-Reflection Time of Flight (MR-ToF) device, in which the ions bounce back and forth between two electrostatic mirrors. Hence, the laser-ion interaction time is increased with each revolution in the MR-ToF apparatus, while retaining the high resolution of CLS.
The new experimental setup consists of a buffer-gas filled Paul trap for providing cooled ion bunches, an offline ion source and an MR-ToF device, with built-in optical detection region and laser access. Besides its use for CLS, MIRACLS'MR-ToF device will enable advanced MR-ToF mass separation with increased ion capacity [6]. At the next stage, this device will thus be able to deliver purified radioactive ion beams to PUMA and other (traveling) experiments at ISOLDE.
This oral contribution will introduce the MIRACLS concept, present results from a proof-of-principle experiment, show the new experimental setup as well as the first commissioning measurements and outline upcoming plans with the setup.

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[3] K. Blaum, et al., Phys. Scr. T152, 014017 (2013)
P. Campbell et al., Prog. Part. and Nucl. Phys. 86, 127-180 (2016)
[4] D. T. Yordanov et al., Phys. Rev. Lett. 108, 042504 (2012)
[5] S. Sels et al., Nucl. Inst. Meth. Phys. Res. Sec. B, 463, 310–314 (2020)
V. Lagaki et al., Nucl. Inst. Meth. Phys. Res. Sec. A, 165663 (2021)
F. Maier et al., Nucl. Inst. Meth. Phys. Res. Sec. A, 167927 (2023)
[6] F. Maier et al., Nucl. Inst. Meth. Phys. Res. Sec. A, 168545 (2023)

**Operation and New Developments I / 24**

## Status of the HIE-ISOLDE Superconducting Recoil Separator (LOI-INTC-I-228)

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The Isotope mass Separator On-Line facility (ISOLDE) [1] at CERN provides the largest variety of low-energy radioactive beams available worldwide, including some of the most exotic nuclear species. The beams can be post-accelerated by the HIE-ISOLDE LINAC [2] up to ˜ 10 MeV/nucleon, and delivered for experiments at the Miniball detector system for gamma spectroscopy studies, the ISOLDE Solenoid Spectrometer (ISS) for transfer reactions studies in inverse kinematics, and the Scattering Experiments Chamber (SEC) for general reaction experiments. About 1300 isotopes of more than 70 elements are produced to develop a cutting-edge nuclear structure and reactions research program [3], that can be largely extended by the installation of a Recoil Separator.
The aim of the ISRS Collaboration [4] is to develop a Proof-of-Concept study of a Superconducting Recoil Separator, as described in the LOI-INTC-228 (2021) [5]. The aim of this contribution is to report on the present status of the R&D program including organization and funding, as well as the latest developments in the physics program, beam dynamics, magnets, focal plane detectors, and the buncher system.

**Medical Applications / 14**

## CERN-MEDICIS: a unique facility for the production of non-conventional radionuclides for medical research

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The MEDICIS facility is a unique facility located at CERN dedicated to the production of non-conventional radionuclides for research and development in medical imaging, diagnostics and radiation therapy. Located in a laboratory equipped to safely handle unsealed radioactive samples, it comprises a dedicated isotope separator beam line, a target irradiation station at the 1.4 GeV Proton Synchroton Booster (PSB), or alternatively receives activated targets from external institutes e.g. during CERN Long Shut-Downs. The target is heated up at high temperatures to allow for the diffusion and effusion of the produced atoms out of the target that are subsequently ionized. The ions are accelerated and sent through an off-line mass separator. The radionuclide of interest is mass-separated and implanted into a thin metallic collection foil. After collection, followed by a radiochemistry process when necessary, the batch is prepared to be dispatched to a research center for further processing and usage. Since its commissioning in December 2017, the facility has provided novel radionuclides including, but not limited to, Ba-128/Cs-128, Cs-129, Tb-149, Sm-153, Tb-155, Tm-165/Er-165, Tm-167 Er-169, Yb-175, Ra-224/225, Ac-225 with high specific activity values, some for the first time, to research institutes part of the collaboration. CERN-MEDICIS'research and development around the topics of production, extraction and mass-separation is in constant evolution. The facility also contributes in the education and training of young researchers. Moreover, MEDICIS is one of the pillars of PRISMAP, a network of world-leading European facilities including nuclear reactors, medium- and high-energy accelerators, radiochemical laboratories and biomedical facilities. PRISMAP acts as a European platform for medical radionuclides and supports the ongoing research on nuclear therapy and molecular imaging by providing immediate access to novel radionuclides. This presentation will

provide a general overview of the facility and its operation as well as address recent achievements and developments together with the challenges that such a facility faces.

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## Total Absorption Spectroscopy of isotopes with medical interest at ISOLDE

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The therapeutic and diagnostic use of radionuclides is well known and widely applied in different techniques and pathologies. The efficacy of the treatments, as well as the off-target dose minimisation in both treatment and diagnosis depend, among other things, on the decay characteristics of the radionuclide in use. In particular, the different particles and radiation emitted, the emission energies and the emission probabilities, are of paramount importance in the calculations of the dose administered to the patient in medical imaging or therapeutic treatment with radioisotopes.

In this contribution we will present a series of TAS measurements carried out at ISOLDE (CERN) since July-2022 aimed at the detection of all the beta strength missing in previous studies of some nuclei of medical interest. The advantage of the TAS technique over the high-resolution one, lies in the high sensitivity of the former, since it allows the measurement of weak beta decay branches to levels at high excitation energy in the daughter nucleus, where HPGe-detector arrays tend to have lower sensitivity.

Our results on the beta-intensity distribution within the Q window of the selected isotopes will be useful to calculate the distribution of energy per decay that goes as gamma rays or as kinetic energy of emitted particles, and therefore to calculate the dose administered to a patient subject to a PET scan or theranostic treatment. We will show results on 66Ga and comparisons of recent TAS data vs evaluated ENSDF data on 128Ba/128Cs, 76Br and 152Tb.

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## Polarisation of longer-lived isotopes and Zero to Ultra low Field Radiation Detected NMR

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Radiation detected (RD) NMR is a sensitive and versatile experimental technique. It relies on the detection of asymmetric nuclear decay. For that, a high degree of nuclear polarisation beyond thermal equilibrium is required and multiple techniques are commonly used to achieve it. One specific case is the optical pumping method that works very well for alkali metals which is used at the VITO beam-line at ISOLDE and successfully used to polarise short-lived nuclei like $^{26}$Na or $^{47}$K with half-life of seconds. However, other approaches are not all easily applicable to short-lived unstable nuclei due to the time required to build up the polarisation, which can in the order of minutes up to several

hours using e.g. Signal amplification by reversible exchange (SABRE) or Dynamic nuclear polarisation (DNP). These approaches would be suitable for isotopes like $^{11}C$, $^{13}N$, $^{18}F$ which are being used as PET tracers, since they have longer half-lives (10-110 min) and are readily available from hospital cyclotrons. In this contribution we will present the work towards application of the SABRE polarisation technique on the PET isotope 13N combined with zero to ultra low field (ZULF) NMR. The latter is a novel type of conventional NMR which does not require high magnetic fields and is performed in a magnetic shield at field $\leq$1 $\mu$T. The method provides a very compact setup and allows for e.g. study of metallic samples. We will present the current status of the RD ZULF NMR project (funded by CERN Medical Applications Fund) and outlook for near future.

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## Towards a high-throughput laser ion source for MEDICIS

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Resonance laser ionization is an efficient and highly selective method for producing radioisotopes. In the laser ion source of the ISOLDE –RILIS (Resonance Ionization Laser Ion Source), the laser interaction region is inside a metal tube, the so-called "hot cavity"which is heated to temperatures >2000 degrees Celsius. In addition to providing a longitudinally confining electrostatic potential due to electron emission from the cavity material, this heating also induces surface ionization of elements with low (< 6 eV) ionization potential. If the overall ion load of laser and surface ionized species reaches a certain threshold the confining potential breaks down and the efficient extraction of laser ionized particles is compromised. In concrete terms this means that the extraction efficiency of laser ions which have a distinct and short time structure induced by the pulsed lasers reduces drastically whereas the surface ions, which have a constant mode of creation, remain unaffected (if the half-life is long enough). This effect is especially prevalent in facilities like MEDICIS which demand a high ion throughput and fast extraction for quick and efficient delivery of radioisotopes (or their precursors) for medical applications (half-lives of ˜ 5 days). This work aims to highlight the different ion source requirements for MEDICIS compared to ISOLDE and show the development work performed over the last year towards an improved ion source design for MEDICIS. Measurements with ion sources from three different facilities were performed at ISOLDE's OFFLINE2 facility and their results will be discussed.

**Investigation of magic numbers / 48**

## From thallium to calcium: Pushing the limits of CLS at COLLAPS in 2023

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*On behalf of the COLLAPS collaboration*

Collinear laser spectroscopy (CLS) has been a cornerstone of low energy nuclear physics since its conception in the 1970s, providing access to nuclear charge radii and moments of nuclear ground states and long-lived isomers. The COLLAPS setup at ISOLDE hosted the very first online CLS measurement in which the nuclear structure of barium isotopes, produced at yields of 10<sup>7</sup> ions/s, was investigated. In this talk, I will give an overview of the 2023 experimental campaign at COLLAPS and the efforts to improve the sensitivity of the setup down to 1 ion/s.

Neutron deficient thallium (Z=81) isotopes were studied at the beginning of the running period. Nuclear properties of more than 25 isotopes and 15 isomers where successfully measured. The physics output of this run, closely linked to a measurement campaign on lead isotopes in 2021, will be discussed. A novel detection scheme to push closer towards the drip-line in future runs will also be presented.

Following the thallium measurements, a feasibility study on thulium (Z=69) isotopes was carried out in cooperation with ISOLTRAP. The main goal was to check the production/contamination rates of the <sup>147</sup>Tm proton emitter nuclei for a future exploration of his nuclear structure at COLLAPS. The efficiency of the setup for this specific case was also quantified to 1000 ions/s.

Finally, neutron-rich calcium isotopes were studied with a new implementation of the ROC technique (radioactive detection after optical pumping and state selective charge exchange). An enhanced sensitivity of 1 ion/s was expected and needed to reach the physics case which included the first laser spectroscopy measurement of <sup>53</sup>Ca and <sup>54</sup>Ca. The preliminary results will be shown and discussed.

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## In-source laser spectroscopy at ISOLDE –revealing peaks and plateaus in nuclear charge radii in the lead region

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Laser spectroscopy is a powerful tool for studying fundamental nuclear properties. By observing small changes in atomic transitions, we can deduce the spins, changes in mean-squared charge radii and the electromagnetic moments of ground and isomeric states across long chains of isotopes. This allows for wide ranging studies to be conducted of how structures evolve across the nuclear chart.

The in-source resonance ionisation technique is a highly efficient method, which when combined with the sensitivity of radiation detection systems such as the ISOLDE Decay Station (IDS) and mass spectrometry devices like the MR TOF MS of ISOLTRAP, allows access to exotic nuclides with extremely low production rates. Over the past decade an extensive campaign has been conducted studying the structures of neutron-deficient isotopes near Z=82 –a region that has proven to be a hotbed of nuclear shape phenomena. Highlights will be given from recent studies of gold and bismuth isotopes, along with prospects for future in-source studies exploiting recent developments in ion source design.

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

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First excited states of 130Sn, the even-even neighbour of the doubly-magic nucleus 132Sn, were populated via safe Coulomb excitation (CE) employing the recently commissioned, highly efficient MINIBALL array. The 130Sn ions were accelerated by the HIE-ISOLDE accelerator to an energy of 4.4 MeV/u and impinged onto a 206Pb target. The de-exciting ⊠ rays from excited states of the target and projectile nuclei have been recorded in coincidence with scattered particles. Sufficient statistics was obtained to observe ⊠ rays from the first 2+ and 4+ states. The ongoing data analysis aims for reduced transition strengths for the 0+g.s. ⟶ 2+1 and 2+1 ⟶ 4+1 transitions in 130Sn in order to understand the evolution of collectivity and nuclear structure around the magic shell closure at N=82, Z=50 tin isotopes. Advanced shell model calculations using realistic interactions predict enhanced collectivity in the neighbouring isotopes of 132Sn [1]. Moreover, a puzzling discrepancy between previous measurements in 130Sn and latest theoretical results [2] awaits to be resolved.
[1] D. Rosiak et al. Phys. Rev. Lett. 121, 252501 (2018)
[2] T. Togashi et al. Phys. Rev. Lett. 121, 062501 (2018)
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## Single-neutron transfer on 68Ni

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The application of one-nucleon transfer reactions is one way to investigate nuclear structure. 68Ni is an interesting case because of the collectivity present in the region around this nucleus. In particular the neutron d5/2 orbital plays an essential role in this. One-neutron transfer was performed with a 6 MeV/u postaccelerated beam of 68Ni at ISOLDE using the Isolde Solenoidal Spectrometer (ISS) setup.

In this talk the (preliminary) results of the IS587 experiment, held in November 2022, will be discussed.

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## Unlocking Precision Mass Measurements with the Rare-RI Ring

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The Rare-RI Ring, located at the RI Beam Factory within RIKEN, represents a breakthrough in the field of Isochronous Mass Spectrometry. Specifically designed to cater to the high-precision mass measurement needs of rare isotopes characterized by low production yields and exceedingly short half-lives, the Rare-RI Ring distinguishes itself as a cyclotron-like storage ring. Its unique capability allows for the selective acceptance of pre-identified rare isotopes on an event-by-event basis,

ensuring the attainment of precise mass measurements for the rarest of isotopes within a broad momentum acceptance range.
This novel operational mode has successfully surmounted the challenge of achieving mass measurements at the parts-per-million (ppm) level for the rarest isotopes. The recent accomplishment in determining the new mass of a palladium isotope, situated 15 neutrons away from stability revealed the impact on precision mass measurements in the modeling of the r-process abundance.
In this presentation, the technological accomplishments will be highlighted, and the forthcoming rich scientific program intended for the Rare-RI Ring will be discussed.

[1] H.F. Li et al., Phys. Rev. Lett. 128 (2022)
[2] S. Naimi et al., Eur. Phys. Jour. A, 59 (2023)

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# First results from ATLANTIS - A new collinear laser spectroscopy setup at Argonne National Laboratory

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The region of refractory metals, below the magic number Z=50 is of particular interest for nuclear physics studies and exhibits phenomena such as deformations, shape coexistence, and hints of triaxial nuclei. Laser spectroscopy has provided valuable and complementary input, providing information about the shape, size, and electromagnetic moments of radioactive isotopes and isomers in this region. The CARIBU californium-252 fission source at Argonne National Laboratory can uniquely produce sufficiently intense low-energy ion beams of neutron-rich isotopes in this part of the nuclear chart. Therefore, the new collinear laser spectroscopy setup, ATLANTIS –the Argonne Tandem hall LAser beamliNe for aTom and Ion Spectroscopy–was installed at the low-energy branch of CARIBU.

The setup includes a dedicated open-gate cooler-buncher that prepares and delivers cooled ion beams with minimal energy and time spread and a laser ablation source to produce stable isotope beams. The laser spectroscopy beamline is fitted with a low-energy charge exchange cell suited for high-temperature application to also allow spectroscopy on atomic beams and a highly efficient 4-pi mirror system to collect fluorescence ions.

In this talk, the results of the first measurements of short-lived isotopes of palladium and ruthenium obtained at ATLANTIS will be discussed, and an outlook of future laser spectroscopy endeavors at Argonne National Laboratory will be given.

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## ISOL-like beams of 22Al and 26P at FRIB

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The Facility for Rare Isotope Beams (FRIB) in the United States, with its superconducting radio frequency linac slated to deliver 400 kW of beam power at up to 200 MeV/u [1], is beginning —already at 1-5 kW of beam power —to open new avenues of in-flight beam production and, hence, of new experimental insights across the chart of nuclides [2].

The FRIB experiment E21010, carried out in June 2023, is the 10th scientific user experiment carried out at FRIB, and it is the first experiment to utilise the Gas Stoppers available at FRIB [3] to first thermalise the 130 MeV/u in-flight-separated beams and then to re-accelerate the beams to 30 keV. In this way, fast radioactive beams of $^{22}$Al and $^{26}$P, which can currently only feasibly be produced at in-flight facilities, are slowed down to low-energy beams of ISOL quality. In the experiment, the high-quality, low-energy beams of $^{22}$Al and $^{26}$P are stopped in a thin catcher foil in order to study the subsequent beta decays of the beam particles; the yields of beta-decaying $^{22}$Al and $^{26}$P from the present experiment are at least an order of magnitude larger than previously seen in experiments which utilised implantation of fast beams in stacks of detectors [4,5].

The remarkable improvement in yield and beam quality is complemented by silicon detector telescopes of high spatial and energy resolution which cover roughly 40% of 4π around the thin catcher foil in which the beam particles are stopped. The silicon detector telescopes enable detailed studies of the β-delayed proton (βp) emission and of the β-delayed two-proton (β2p) emission from the parent nuclides.

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The distribution of individual proton energies $E_i$ for a given energy release in two-proton emission $Q_{2p}$ reveal the nature of the particle break-up —sequential vs. direct. The above figure shows the 8000 β2p events recorded from $^{26}$P during the E21010 experiment at FRIB.

For both $^{22}$Al and $^{26}$P, previously only two β2p branches, both via the IAS, were known. Based on this recent experiment, it is possible to identify many more decay channels, and to properly separate β2p and βp events; it is possible to map the level distributions of the exotic daughter nuclides by identifying gamma transitions in coincidence with emitted protons (utilising the germanium detectors also available during the experiment); and it is even possible to make all-new, unambiguous spin and parity assignments based on hitherto unobserved cases of β-delayed α emission.

[1] B.M. Sherrill, EPJ Web Conf. 178 (2018) 01001.
[2] H.L. Crawford et al., Phys. Rev. Lett. 129 (2022) 212501.
[3] A.C.C. Villari et al., Nucl. Instrum. Methods Phys. Res. B 541 (2023) 350-354.
[4] C.G. Wu et al., Phys. Rev. C 104 (2021) 044311.
[5] P.F. Liang et al., Phys. Rev. C 101 (2020) 024305.

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## In-gas-jet laser spectroscopy with S3-LEB, status and perspectives

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The Superconducting Linear Accelerator (SPIRAL2-LINAC) facility of GANIL is designed to deliver heavy-ion beams with highest intensities ever achieved [1,2]. The Super Separator Spectrometer ($S^3$), a high-resolution recoil separator coupled to the LINAC, will use these high-intensity beams to produce neutron-deficient nuclei close to the proton dripline and super heavy nuclei via fusion–evaporation reactions . It is designed to separate the reaction products from the intense primary beams [3]. The Low Energy Branch of $S^3$ ($S^3$-LEB) [4,5], currently under commissioning at LPC Caen, will be installed at the focal plane of $S^3$ and aims to study ground state and isomeric state properties of the produced neutron-deficient species using the in-gas laser ionization and spectroscopy technique. This technique allows the determination of isotope shifts and hyperfine constants of exotic isotopes and thus nuclear properties such as spin, moments and difference in mean-square charge radii.
The reaction products will be stopped and neutralized in a buffer gas cell filled with argon gas. After extraction through a "de-Laval nozzle"of Mach number M ˜ 8, the atoms of interest are ionized a two or three step laser scheme. The use of the de-Laval nozzle creates a homogeneous hypersonic gas jet of low temperature and pressure. Probing and ionizing the atoms by lasers in the gas jet will reduce the Doppler and pressure broadening by at least an order of magnitude compared to the gas cell [6]. An improved spectral resolution (≤300 MHz) can thus be achieved in laser spectroscopy studies with $S^3$-LEB while maintaining high efficiency and selectivity. The $S^3$-LEB set-up will allow for further mass and decay spectroscopy experiments.
In this contribution, the status of the $S^3$-LEB experiment will be presented, results from the most recent in-gas-cell and in-gas-jet laser spectroscopy measurements performed off-line will be discussed and the upgrate program to allow for the study of short-lived isotopes addressed. The goal of the off-line measurements is to identify suitable atomic transition schemes for erbium, the first study case at $S^3$. Determination of the isotope shift and hyperfine structure parameters in the hypersonic gas jet, a comparison with literature values and characterization of the pressure broadening effects in gas cell will be reported. With the upgrade program (FRIENDS3 [7]), the extraction time of the current $S^3$-LEB gas cell that is on the order of a few hundred milliseconds, will be reduced substantially, allowing to study isotopes with half lives well below 100 ms. An important condition to reach this goal is the presence of a fast neutralization process. The neutralization efficiency is contingent upon the number of electrons created by the incident beam during the stopping process in the buffer gas. The latter heavily relies on the beam intensity. The FRIENDS$^3$ project [7] aims to design a fast gas cell with an independent neutralization technique in order to enable nuclear-structure studies by laser spectroscopy on short-lived isotopes. A status of the simulation, design and experimental work performed in this project will also be given.

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**News from other facilities / 66**

## Extremely large oblate deformation of the first excitation in $^{12}$C: a new challenge to modern nuclear theory

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A high-statistics Coulomb-excitation (CE) study of $^{12}$C onto an enriched $^{208}$Pb target has been carried out at safe energies using the high-resolution {\sc Q3D} magnetic spectrometer at the Maier-Leibnitz Laboratory (MLL) in Munich (Germany). Measurements at different scattering angles and beam currents of approximately $10^{11}$ pps allowed the determination of the spectroscopic quadrupole moment for the first excitation at 4.439 MeV in $^{12}$C, $\mathrm{Q}_S(2_1^+)$, with unprecedented accuracy. The effect of the nuclear electric dipole (E1) polarizability on the $\mathrm{Q}_S(2_1^+)$ measurement has been investigated using the no-core shell model (NCSM) with the N$^4$LO500-srg2.4 chiral effective-field-theory ($\chi$EFT) interaction, where the Lanczos continued fraction algorithm was applied for the first time to sum up contributions of all excited states and allow the calculation of hundreds of E1 transitions up to 70 MeV; a huge improvement compared to previous NCSM calculations [1,2]. The NCSM calculation predicts $\kappa(2_1^+) = 1.40(5)$. Using this result and the weighted average $B(E2; 0_1^+ \to 2_1^+) = 39.1(8)$ e$^2$fm$^4$ from all previous measurements (excluding CE measurements) we get a large $\mathrm{Q}_S(2_1^+) = 10.5(10)$ efm$^2$, confirming the oblate but enhanced deformation for the $2_1^+$ state, in agreement with a recent Coulomb-excitation measurement using particle-$\gamma$ coincidences with a double-sided silicon detector at backward angles [3]. Such a large $\mathrm{Q}_S(2_1^+)$ value challenges modern theoretical calculations which generally predict $\mathrm{Q}_S(2_1^+) \approx 6$ efm$^2$; independent of the interaction in the case of NCSM calculations. The most likely explanation for the larger oblate deformation found in this work concerns $\alpha$-cluster effects that are not properly included in the NCSM [4,5,6]. Finally, this work emphasizes the need of dedicated measurements of the E1 polarizability using stable and radioactive-ion beams, which will also be briefly discussed.

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**Poster Session / 5**

## Synthesis and TDPAC Characterization of Multiferroics: The HoMnO3 Case

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Materials of the $RMnO_3$ (R is a rare-earth) multiferroic perovskite family show an extraordinary number of applications in technology, e.g., spintronic devices, data storage equipment, and sensors, thanks to properties like magnetically induced ferroelectricity. According to the literature, the Perturbed $\gamma - \gamma$ Angular Correlation (PAC) method is an available technique to study hyperfine interactions in material with such properties and can be used to identify phase transition due to its non-dependence on temperature variation, for instance. In addition, the orthorhombic $HoMnO_3$ is a promising multiferroic, but this material possesses a nonperovskite hexagonal phase. The synthesis of the orthorhombic phase requires high-pressure or soft chemistry routes that are hard to perform in any synthesis Lab. By considering this matter, we propose a sol-gel synthesis route for orthorhombic $HoMnO_3$ using different Cd and La percentage doping. Sample crystalline structures are then characterized by X-ray diffraction to determine hexagonal/orthorhombic phase proportion. After structural characterization, we analyze samples employing PAC spectroscopy using $^{111}$Cd probes that are implanted and analyzed at the ISOLDE/CERN facility or during synthesis with $^{111}$In at the Hyperfine Interaction Group - HIG laboratory at the Nuclear and Energy Research Institute - IPEN.

**Poster Session / 7**

# Coulomb excitation of 79,80Zn

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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, hinting at its quadrupole deformation of $\beta$=0.22, considerably larger than $\beta$=0.15 of the ground state. In order to probe the quadrupole deformation of the intruder isomer in $^{79}$Zn, 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.
During the same campaign a beam of $^{80}$Zn (with a magic neutron number N=50) was used to to probe via the same experimental technique the B(E2) transition probabilities from the 4$^+$ and 2$^+$ states and to possibly identify non-yrast states in this nucleus. The results will serve as a benchmark for large scale shell-model calculations in the doubly closed-shell $^{78}$Ni region.
In both experiments, $\gamma$ 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 Coulomb excitation of states built on the intruder isomer, and discuss their possible implications in the context of the deformation of the 1/2$^+$ isomer in $^{79}$Zn, and of the $^{80}$Zn ground state.

**Poster Session / 8**

# Intracavity generation of tripled Ti:Sa laser pulses

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To efficiently laser-ionize many different elements, the spectral range of the Ti:Sa lasers at ISOLDE RILIS is extended with nonlinear processes of second-, third- and fourth harmonic generation (SHG, THG and FHG).
We present a technique to intracavity generate ns pulses in the tripled Ti:Sa range (˜ 230nm –310nm) with a Gaussian beam shape and a size comparable to that of the fundamental Ti:Sa output. By generating the 3rd harmonic inside the cavity of the Ti:Sa, the need for tedious beam shaping, which is required in single-pass THG outside the laser cavity, is eliminated.
The setup is less complex than the usual single-pass THG and requires less space since it is located inside the Ti:Sa cavity. Similar performance to that of external frequency conversion has been achieved and a direct comparison of the technique will be presented.
We discuss long-term stability, wavelength tuning behaviour and linewidth, as well as future potential with bespoke optics.

**Poster Session / 10**

# Diamond-based Raman laser technology for RILIS

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The Raman nonlinear process consists in a scattering interaction between light and a crystal. Through the process, light losses energy to a phonon of the crystal, leading to an up-shift in the laser wavelength. This wavelength shift can be used extend the laser frequency covered by the RILIS system, and hence improve its versatility.
During the past years, different laser designs have been tested, and characterized.
Particularly, a Z-fold diamond laser has been implemented which conserves the pump laser's linewidth, making it suitable for regular RILIS operation. Recently, the use of this design has been validated in MEDICIS with the ionization of Radium, for which the first step frequency of the laser scheme is difficult to achieve with TiSa lasers.
A second design provides narrow linewidth, suitable for high-resolution spectroscopy, for example with PI-LIST or other high-resolution laser spectroscopy experiments. Characterization is ongoing to study the most suitable configuration for on-line application in the near future.

**Poster Session / 16**

# MULTIPAC, a versatile TDPAC spectrometer

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Abstract for MULTIPAC draft for Users Meeting

MULTIPAC is a spectrometer that can perform γ-γ time-differential perturbed angular correlation (γ-γ TDPAC) experiments under controlled conditions such as an applied external magnetic field up to 8.5 T and temperatures ranging between 3 to 375 K. MULTIPAC differs from conventional γ-γ TDPAC spectrometers in the use of modern multi-pixel photon counters (MPPC), which offers advantage over the standard photomultiplier tubes, due to its compact size (allowing for the MPPC-detector combo to be fitted into bore of the superconducting solenoid magnet), resistance to magnetic fields, ease of maintenance, and requiring only low voltage. Additionally, the MPPC maintains a low quantum efficiency (< 25%) and the high gain ( $10^{5-6}$) comparable to that of a photo multiplier tube.

MULTIPAC uses a cryogen-free helium-based system to cool down both the sample space environment and the superconducting magnet (separately), thus preserving helium gas as an expensive and scarce natural resource and is safer to operate (no massive amount of helium released in the event of a magnetic quench) as opposed to the more commonly used liquid helium as a coolant.

In addition, MULTIPAC also features a vibrating sample magnetometer (VSM) to leverage upon the field provided by its inbuilt superconducting magnet. In sum, MULTIPAC is an all-in-one package that allows users to explore the multiferroic properties of compatible materials by probing its microscopic hyperfine structure using suitable probes from the TDPAC spectroscopy, and its macroscopic properties using VSM, while allowing for external influences from the external magnetic and electric field.

**Poster Session / 19**

## Shell model calculations of the electric dipole polarizability

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The electric dipole (E1) polarizability has recently been used to explain the universality of elemental abundances [1]. Here, we present shell-model (SM) calculations of the E1 polarizability for the ground- and first-excited states of selected p- and sd-shell nuclei, substantially advancing previous knowledge. Our results for ground states [2] are slightly larger compared with the somewhat more scattered photo-absorption cross-section data, albeit agreeing with *ab initio* calculations at shell closures and presenting a smooth trend that follows the leptodermus approximation from the finite-range droplet model (FRDM). The total E1 strengths also show an increasing trend proportional to the mass number which follows from the classical oscillator strength (TRK) sum rule for the E1 operator. The enhancement of the energy-weighted sum over E1 excitations with respect to the TRK sum rule arises from the use of experimental single-particle energies and the residual particle-hole interaction. Furthermore, following the original work of Hausser, Barker and collaborators together with basic quantum mechanics, novel equations for the E1 polarizability of low-lying excited states in atomic nuclei are inferred in terms of electric dipole and quadrupole matrix elements [3]. These equations are valid for arbitrary angular momenta of the initial/ground and final/excited states. Consequently, new SM calculations of the E1 polarizability for excited states will be presented during the ISOLDE workshop, which are part of the effective quadrupole interaction and relevant to the analysis of Coulomb-excitation measurements in RIB facilities.

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[3] José Nicolás Orce, Electric dipole polarizability of low-lying excited states in atomic nuclei, submitted to PRC (2023).

**Poster Session** / **20**

## Emission Mössbauer spectrometer from ILmenau (eMIL): An update

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The advanced emission Mössbauer spectrometer, eMiL (Emission Mössbauer from Ilmenau) was built for the emission Mössbauer (eMS) collaboration at ISOLDE/CERN. The set-up is based on the emission geometry and combines on-line and off-line isotope implantation used to measure hyperfine interactions in solids. Using radioactive Mössbauer probes that are ion-implanted to the sample by the GLM setup, eMiL has multiple advantages over the more common transmission or electron conversion setups. The versatility of the set-up is epitomized through five different lids: rotation, magnetic, powder, hot and cold lid. These lids can be easily interchanged, without the need for realignment, which makes eMiL extremely flexible during beam time. eMiL had its first successful run this year, which marked the first beam time for the Mössbauer collaboration since 2018. During this beam time it was proven that the set-up makes probe handling easy, while providing the flexibility needed by the eMS collaboration.

**Poster Session** / **25**

## A New Beamline for Very Clean Beams at ISOLDE

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With the advent of nuclear structure studies using antiproton annihilations on the surface of unstable nuclei at the PUMA experiment [1], isobaric beam purity and vacuum requirements with < 1e-10 mbar motivate the installation of a new beamline at ISOLDE. A Multi-Reflection Time-of-Flight mass spectrometer (MR-ToF MS) is currently in commissioning at the MIRACLS experiment [2], promising up to a factor hundred higher throughput compared to other multi-reflection devices and features mass separation powers in excess of 100,000 within only a few milliseconds of storage time [3]. In this contribution, the current status for the new transfer beamline at RC6, incorporating the MIRACLS Paul trap and MR-ToF MS, will be presented.
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[2] F. Maier et al., NIM A 1048 (2023), 167927
[3] F. Maier et al., NIM A 1056 (2023), 168545

**Poster Session / 28**

# Transfer reactions with $^{7}$Be + $^{12}$C at 5 MeV/u

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We studied the transfer reactions with $^{7}$Be + $^{12}$C at 5 MeV/u. The measurements were carried out in the scattering chamber at HIE-ISOLDE using the pentagon detector array. Interestingly, for the $^{7}$Be nucleus having an $\alpha-$cluster structure and a low breakup threshold, transfer reactions are predominant than breakup[1].The transfer data leading to $^{16}$O* excited states are useful in studying the $^{12}$C($\alpha$,$\gamma$)$^{16}$O capture reaction. This is a key reaction in the helium-burning phase of stars, affecting the C/O abundance ratio. This ratio is crucial for stellar nucleosynthesis of elements heavier than carbon and the evolution of life in the universe. The present study is also important to further understand the transfer reactions in other loosely bound nuclei like $^{6,7}$Li having prominent $\alpha-$cluster structure. The required optical potential parameters for the analysis have been obtained from the elastic scattering measurements in the same experiment[1]. The Asymptotic Normalization Constant (ANC) of the ground state of $^{16}$O has been measured in this reaction for the first time. The ANCs of other subthreshold states of $^{16}$O particularly 6.92 MeV ($2^+$) and 7.12 MeV ($1^-$) have also been obtained and the implications will be discussed.

[1]K. Kundalia *et al.*, Phys. Lett. B 833, 137294 (2022)

**Poster Session / 29**

# Data Acquisition at MIRACLS

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The Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) is a new experiment in the ISOLDE facility at CERN which aims to conduct collinear laser spectroscopy (CLS) on exotic nuclei with low production yields by exploiting a 30-keV multi-reflection time-of-flight (MR-ToF) device [1]. Ions bunches prepared by MIRACLS'Paul trap are sent into the MR-ToF instrument, where they are reflected back and forth between two electrostatic mirrors. Hence, the ion bunch interacts with a laser beam thousands of times before leaving the device, which yields a significant boost in sensitivity over conventional,single-passage CLS.

Data acquisition for MIRACLS comes with its own unique set of challenges, such as processing larger amounts of raw data (compared to single-passage CLS) from the photo-multiplier tubes used for photon detection (up to a few gigabytes per frequency scan), building an intuitive graphical user interface (GUI) for data collection, and integration with the MIRACLS experiment's EPICS-based control system.

In this poster contribution, I will present how we faced these challenges. For the data processing, we aggregate the data into bins, which facilitates fast and efficient online analysis, e.g. during the experiment itself, while saving the full data files (containing every detected photon event) to an external hard drive. For building the data acquisition GUI, we utilized "spinmob,"a Python package developed at McGill University based on the Qt framework [2]. Finally, we used the pyepics Python package to control and monitor EPICS process variables from within the data acquisition GUI, allowing us to integrate the GUI into our control system.

[1] F. Maier et al., NIM A 1056 (2023), 168545
[2] Spinmob GitHub repository. https://github.com/Spinmob/spinmob.

**Poster Session / 31**

## Characterization of the INDiE array

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The β-decay of 8He and 9Li are observed as background in neutrino detectors where the detection mechanism is inverse β-decay by the reaction ν + p ⟶ e+ + n. Both nuclei have decay-branches that mimic this signal by emission of an electron and a neutron, which in addition to decay-decay branches of interest for pure nuclear physic motivates their study at the ISOLDE decay station, IDS.

At IDS a setup capable of measuring neutron, charged particles and gamma rays in coincidence has been developed. The neutrons are measured with the time of flight array INDiE, where the start signal comes from β-particles impinging on plastic scintillators near the collection point. 8He decay was collected in May 2022, while measurement of 9Li is foreseen for 2024.

In this contribution focus will be on improvement of the resolution of the neutron spectra from the INDiE array. The array consists of flat bars of extended length, and different points of interaction correspond therefore to different flight paths. The point of interaction can be determined by the time difference of signals from photomultiplier tubes in either end of an INDiE bar, which then provides input to the geometric correction to the time of flight. This correction, however, is disturbed by timing jitter on all detectors, leading to an under estimation of TOF and decreased resolution since the correction is asymmetric. In my work, I present a new method of correction, which mitigates this effect.

**Poster Session / 32**

# Improving the precision of β spectrum shape measurements at WISArD

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Measurements of the shape of the β energy spectrum are interesting to study, e.g., nuclear structure [1] and, when high precision is reached, allow to test for exotic scalar and/or tensor currents in the weak interaction [2].

However, the experimental precision reached is limited by the incomplete energy deposition caused by backscattering. In the WISArD set-up, this problem is alleviated using two detectors placed in a high magnetic field. This configuration ensures a 4π solid angle and guides backscattered β particles towards the opposite detector. In December 2020 the InESS@WISArD [3] proof-of-principle experiment measured the β spectrum shape of $^{114}_{49}$In using two plastic scintillators, which led to the first determination of weak magnetism in the fission fragment region. While these results are very promising, the data analysis showed several opportunities for further improvement.

For subsequent experiments, we are investigating the possibility of replacing the scintillators with lithium doped silicon (Si(Li)) detectors. These have a superior energy resolution, i.e., an improvement of about a factor of 50 [3,4], and a significantly lower energy threshold, i.e., around 1.5 keV [4], compared to 65 keV [3]. Such detector characteristics can drastically improve the situation for of the systematic effects encountered with the scintillators, thus making the installation of these Si(Li) detectors a promising path for further advances in β spectrum shape studies.

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[4] C. Knapen. Characterisation of Si(Li) Detectors for β Spectrum Shape Measurements. Master's thesis, KU Leuven, 2023.

**Poster Session / 34**

# Collinear resonant ionization spectroscopy of RaF

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The use of table-top high-precision measurements for studying physics beyond the standard model has become an alternative window to physical phenomena that are currently probed only by large-scale colliders like the LHC [1]. Among them, studies on diatomic molecules have become a promising quatum systems for diverse fields [2]. Even though most of these studies have been primarily with stable species, the advances in laser spectroscopy techniques have allowed the study of radioactive species at ISOLDE (CERN) using the Collinear Resonance Ionization Spectroscopy (CRIS) experiment [3].
Due to the rich electronic, vibrational, and rotational structure inherent in molecules, the sensitivity to different observables, such as the electron's electric dipole moment (eEDM) and nuclear Schiff moments, is expected to be enhanced in radioactive polar molecules [4]. However, their molecular structure is poorly known, requiring preparatory spectroscopic studies of their electronic structure. So far, RaF and AcF are the only short-lived radioactive polar molecules whose structure has been studied. After two experimental campaigns at CRIS (2018, 2021), many electronic levels in RaF have been studied with broadband laser spectroscopy [5], as well as one optical transition in high resolution [6]. This has shown the capacity of collinear laser spectroscopy at radioactive ion beam facilities for the study of radioactive molecules, as well as benchmarking the predictive power of state-of-the-art quantum chemistry.
This poster will present why molecules are ideal probes for eEDM studies, along with the basic principles of molecular spectroscopy. An overview of the CRIS technique and results from RaF [7], revealing most of the predicted electronic excited states up to 30.000 cm-1, will also be presented.
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**Poster Session / 40**

# Development of a new β Detector Setup for the VITO Beamline

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β detected NMR is a method to determine the magnetic moments of short-lived isotopes with a sensitivity inaccessible to conventional NMR. One of the isotopes scheduled to be investigated with β detected NMR at VITO is $^{11}$Be. It is of interest because it is a single neutron halo nucleus. Measuring the magnetic moment of $^{11}$Be with greater accuracy will help to give insight into the nuclear magnetisation distribution of $^{11}$Be and thus directly confirm its halo structure.
To enable such measurements, the VITO beamline has undergone multiple major upgrades and extensions in the past, including the installation of a superconducting solenoidal magnet with sub-ppm homogeneity and the ability to measure in liquid samples [1]. The β-detectors are a critical aspect; their purpose is to detect the asymmetrically emitted β-particles from the hyperpolarized decaying isotopes. The detector setup that is currently being developed will consist of two plastic scintillators with silicon photomultipliers. This setup will be able to measure the energies of the detected β particles. For $^{11}$Be this is important because the two most intense transitions have opposite β 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.
The trajectory of the β-particles in the magnetic field and their energy defines the minimum dimensions of the detector. Consequently, the two scintillators must be significant in volume. Collecting the scintillation light with good energy resolution poses challenges. Simulations of the light transport within the scintillator volume were performed. Numerous silicon photomultiplier arrangements and geometries were simulated in Geant4. The objective of this optimization is to find a configuration with sufficient energy resolution.

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**Poster Session / 47**

# NMR shielding calculations –from accurate nuclear magnetic moments to interpretation of NMR spectra

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Beta-detected nuclear magnetic resonance (β-NMR) is a sensitive technique, which has gained widespread recognition in the fields of nuclear physics [1] and materials science [2]. The recent utilization of ionic liquid targets has unlocked fresh opportunities for incorporating β-NMR spectroscopy into the domain of chemistry [3]. Precise determinations of the nuclear magnetic moments of β-NMR probes enable the direct evaluation of NMR shielding in β-NMR experiments [4]. Nevertheless, the successful execution of these experiments relies also on robust ab initio modeling support. In this study, we present a computational methodology for ascertaining the NMR shielding of β-NMR probe nuclei in ionic liquids and water environment. Our approach entails the use of force-field molecular dynamics to simulate the solvation shell structure, subsequently employing approximate models for NMR shielding. These models are based on non-relativistic coupled cluster and four-component Dirac-Kohn-Sham methods. Through benchmark calculations,we have observed that the proposed NMR shielding models can accurately predict the NMR shielding of alkali metal ions (Li+, Na+, K+) within ionic liquids and water with an accuracy of just a few parts per million (ppm). The calculated NMR shieldings can be used in re-derivation of nuclear magnetic moments or could serve as a computational support for interpretation of measured β-NMR spectra.

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**Poster Session / 51**

## Local Probing of Structural Phase Transitions in Naturally Layered Perovskite Oxides

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Naturally layered perovskites have been subject of great interest for novel technological applications, guiding, in particular, the extensive search for room-temperature (RT) magneto-electrics (ME). We aim to enhance the magneto and photo-induced effects in systems displaying Hybrid Improper Ferroelectricity (HIF) to achieve maximum energy conversion efficiencies in ME systems, thus exploring innovative alternatives for improved energy storage devices and electronics.

Our case study is the structural phases adopted by $n = 2$ pseudo Ruddlesden-Popper (pRP) $Li_2SrNb_2O_7$. Determining the system's structural symmetries is key to understand its functionalities, but its structural phase diagram can be notably difficult to establish by conventional diffraction measurements [1,2].

Perturbed Angular Correlation (PAC) Spectroscopy has recently played a pivotal role in clarifying complex structural debates on systems alike, as with $Ca_3(Mn,Ti)_2O_7$ multiferroics [3]. The sensitivity of the measured Electric Field Gradient at $^{111m}$Cd probes to the structural symmetry makes PAC Spectroscopy an invaluable tool for the problem at hand, possibly able to reconcile conflicting perspectives within the literature on the $Li_2SrNb_2O_7$ system [1,2].

Our research at ISOLDE/CERN serves a dual purpose: to address conflicting structural reports regarding the FE phase transition at $T_C = 217$K in $Li_2SrNb_2O_7$, and to unveil previously documented [2] but yet ambiguous phase transitions in the same system at higher temperatures; both to grant us the fundamental understanding required to design optimal multifunctional materials.

**Aknowledgments**
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**Poster Session / 50**

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

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According to Benedek et. al [1], the $CsNdNb_2O_7$ system undergoes two phase transitions, one at 625 K and another at 800 K. Our objective is to investigate those three distinct phases: $P2_1am$ (\# 26), $C2/m$ (\# 12) and $P4/mmm$ (\# 123) [1].

There is no existing literature discussing the magnetic state of $CsNdNb_2O_7$. Nevertheless, due to the presence of three unpaired electrons in the $4f$ orbital of the Nd atoms, this material is expected to exhibit magnetic properties.

Benedek and her research group simulated the system by freezing the *4f*$^3$ electrons in the core [2], employing a non-polarized simulation.
We initiated our study with an investigation into the optimal approach for simulating the $CsNdNb_2O_7$ system. To accomplish this, we conducted a thorough analysis by comparing spin-polarized with Hubbard correction and non-polarized models. We demonstrated the necessity of a Hubbard correction for the spin-polarized model, wherein we obtained an *ab-initio* estimate of the Hubbard parameter as 4.15 eV for the $P4/mmm$ (aristotype) phase. This value is in our spin-polarized simulations, although further investigation is being held to obtain an accurate estimate for the ground state. Additionally, we expanded our investigation to include the $CsLaNb_2O_7$ system, which exhibits non-magnetic characteristics, thereby offering a valuable point of comparison in our study.
Thus, through the analysis of the Density of States (DOS) and the Electrical Field Gradients (EFG)

of the different models, we will determine the optimal approach for simulating $CsNdNb_2O_7$ and potentially other members of the Dion-Jacobson family of naturally layered perovskites.

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**Poster Session / 52**

## Tick-Tock on the Nuclear Clock: Time for an Upgrade

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Due to its low excitation energy around 8.3 eV, the unique $^{229}$Th isomer is, for now, the only candidate for developing a nuclear clock for, amongst others, fundamental physics studies~\cite{peik2015nuclear,thirolf2019improving
In the past, measuring the isomer's radiative decay from a large-bandgap crystal with $^{229\text{m}}$Th embedded, has proven difficult: the commonly used population of the isomer via the $^{233}$U $\alpha$-decay has a limited branching ratio towards the isomer and creates a high-radioluminescence background \cite{verlinde2019,beeks2022nuclear}. However, recently, a new approach to populate the isomer through the $\beta$-decay of $^{229}$Ac was proposed \cite{verlinde2019}. 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)\cite{kraemer2023observation,thesis_sandro}. Building on this work, a new measurement campaign in July 2023 took place at ISOLDE, aimed at, amongst others, reducing the systematic uncertainty on the energy and accurately determining the half-life of $^{229\text{m}}$Th, embedded in different crystals. Dedicated on-line measurement sequences of the VUV spectrometer were performed to reduce the systematic uncertainty reported in~\cite{kraemer2023observation,thesis_sandro}. We will report the results of these studies, as well as the plans to upgrade the VUV spectrometer that are implemented to further investigate the isomer's time behaviour in different crystals, and under different conditions.

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author = {M. Verlinde et al.},
title = {Alternative approach to populate and study the $^{229}${T}h nuclear clock isomer},
year = {2019},
journal = {Phys. Rev. C100},
pages = {024315}
}

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author = {S. Kraemer et al.},
title = {Observation of the radiative decay of the $^{229}${T}h nuclear clock isomer},
year = {2022},
journal={arXiv},
pages={2209.10276}
}

@phdthesis{thesis_sandro,
author = {S. Kraemer},
title = {Vacuum-ultraviolet spectroscopy of the radiative decay of the low-energy isomer in $^{229}${T}h},
school = {KU Leuven - Instituut voor Kern- en Stralingsfysica},

year = {2022}
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number={7962},
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}

**Poster Session / 54**

# Investigation of $^{182}$Pt via $\beta$ decay of $^{182}$Au

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On behalf of IS665 and IDS Collaboration.

Shape coexistence is a well-established phenomenon in which two or more different types of deformation coexist at low excitation energy within the same nucleus [1]. One of the most extensive manifestations of shape coexistence can be found in the neutron-deficient isotopes near the closed proton shell of lead (Z = 82). Exotic nuclei in this region have been extensively studied using various experimental methods, one of which is $\beta$-delayed $\gamma$-ray spectroscopy. This method is valuable for

studying such nuclei because it allows us to identify and study levels in the daughter nucleus up to relatively high excitation energy. Since $\beta$ decay is sensitive to the change of nuclear structure between the mother nucleus and the populated state, this method can be used for the determination of properties of excited levels, such as nuclear spin.
One of the nuclei from this part of the nuclear chart is $^{182}$Pt, the daughter nucleus after the EC/$\beta^+$ decay of $^{182}$Au, which was studied at the ISOLDE Decay Station (IDS) [2]. The $\gamma$ rays originating from the de-excitation of states in $^{182}$Pt populated in this $\beta$ decay were measured using four HPGe Clover detectors. In comparison to the previous study [3], we collected over an order of magnitude higher statistics. This increase in data allowed us to significantly expand the currently known level scheme of $^{182}$Pt by the use of the prompt $\gamma$-$\gamma$ coincidence technique. We observed all previously known transitions and about 200 new transitions and 80 new levels up to the excitation energy of ~ 3.7 MeV were placed in the level scheme. Additionally, we evaluated the $\beta$-decay feeding intensities into levels in $^{182}$Pt and calculated corresponding log *ft* values for the first time for this $\beta$ decay. The log *ft* values for several already known $2^+$ and $3^+$ states are consistent with the allowed decay of $2^+$ ground state in $^{182}$Au [4]. Moreover, the obtained log *ft* values will be used to hint at the spin and parity of levels for which they are not yet known.

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**Poster Session / 58**

## Establishing the deformation characteristics and decay spectroscopy of $^{66}$Ge

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The presence of both well-deformed prolate and oblate deformations are expected in the $A \approx 70$ mass region because of the stabilisingly large single-particle energy gaps at $N = 34$. Nonetheless, oblate deformations in this region has mostly been inferred from rotational bands ($^{68}$Se [1])

or model-dependent decay measurements ($^{72}$Kr [2]). Only recently, Coulomb-excitation measurements have been able to determine the sign of the quadrupole moment in a few proton-rich nuclei in this region; conclusively prolate in $^{74,76}$Kr [3] and slightly oblate in $^{70}$Se [4,5], although with large uncertainties. As inferred for $^{68}$Se, the $N = 34$ isotone $^{66}$Ge is another candidate to possess a large oblate deformation in its ground state. The measurement of the spectroscopic quadrupole moment for the first $2^+_1$ excitation, $Q_S(2^+_1)$ and shape coexistence in the neutron-deficient isotope of $^{66}$Ge have been investigated using the $^{196}$Pt($^{66}$Ge,$^{66}$Ge)$^{196}$*Pt* Coulomb-excitation reaction at 4.395 MeV/u with the MINIBALL spectrometer and double-sided silicon detectors. In order to accurately determine the beam purity, the beam was implanted on an aluminium foil and let to decay. Here, we present results from the analysis of the Coulomb-excitation and $\beta$-decay data sets, which suggest a strong oblate collectivity with a large $E2$ strength and a potentially large oblate deformation. As found in previous work [3,6], the triaxial degree of freedom seems to be relevant, as also inferred in this work from beyond mean-field calculations where the collective wave functions go from soft in the ground state to a well-defined minimum as the angular momentum increases.

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**Poster Session / 61**

## Onset of deformation in the neutron-rich krypton isotopes via transfer reactions with the ISOLDE Solenoidal Spectrometer

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In the A = 100 region, the dramatic shape change observed for Zr [1-3] and Sr [4-7] (Z = 40 and 38, respectively) is not present in Kr (Z = 36) isotopes [8-10]. The $2^+_1$ energies and the B(E2;$2^+_1 \rightarrow 0^+_1$) values vary smoothly across the Kr isotopes. This is in contrast to the Sr and Zr isotopes which display a large jump at N = 60, indicating a significant increase in the ground state deformation of these isotopes. The $\nu g_{7/2}$ orbital is filled in the ground states of krypton isotopes around N = 59 and is thought to lower the energy of the $\pi g_{9/2}$ orbital and help to drive deformation in this region.

Previous studies in this region have shown a smooth onset of deformation in Kr isotopes at N = 60 [9,10], and evidence of a new oblate structure coexisting with the prolate ground state [11]. Accurately predicting ground-state spins and parities of odd-mass isotopes in this region is challenging due to the large valence space, and lack of ESPE data and accurate shell-model interactions. The single-particle energy differences and spectroscopic factors extracted from neutron adding reactions will provide a more complete experimental picture of the underlying single-particle configurations allowing for comparison to modern shell-model calculations [12] that try to describe the onset of deformation around A = 100.

The transfer reactions $^{92,94}$Kr*(d,p)* were carried out in inverse kinematics at an energy of 7.35 MeV/u using the ISOLDE Solenoidal Spectrometer at ISOLDE, CERN. However, due to the low yield obtained for the $^{94}$Kr beam, only the $^{92}$Kr*(d,p)* reaction has been performed so far. Spectroscopic factors of the low-lying states of $^{93}$Kr have been determined. Preliminary results obtained in the October 2022 experiment will be presented.

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**Poster Session** / **62**

## Magnetic moments of 47K, 49K, and 51K and new horizons for β-NMR at VITO

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β-NMR is a powerful method that exploits the asymmetry in the emission of β particles from spin-polarised, unstable nuclei. Combining a high degree of nuclear spin polarisation achieved through laser-induced optical pumping with an efficient detection yields a sensitivity up to ten orders of magnitude greater than conventional NMR. Its applications range from biochemistry to solid-state, atomic, and nuclear physics.

One major forerunner of this technique is the VITO beamline. Recent upgrades pushed the boundaries of this setup, including installing a superconducting magnet to improve the resolution and a state-of-the-art data acquisition system. This was followed by commissioning experiments with the implantation of $^{47}$K, $^{49}$K, and $^{51}$K in liquid samples.

These studies yielded improved nuclear magnetic moments that are, in fact, precise enough to calculate the Bohr-Weisskopf effect for these isotopes, which describes a perturbation of the hyperfine structure due to the finite size of the nucleus. As such, the effect provides information on the distribution of nuclear magnetisation and, in return, the distribution of neutrons. The results of these measurements are presented in this poster.

They will also benefit the next major project at VITO. Several upgrades to the experimental setup are currently in preparation to measure magnetic moments and hyperfine $A$ factors with greater precision to determine the Bohr-Weisskopf effect and, thus, the nuclear magnetisation distribution for a broader range of isotopes.

**Poster Session / 63**

## $\beta$-decay spectroscopy studies of $^{128}$In

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Simple systems near the doubly-magic shell closures offer optimal scenarios for assessing the accuracy of shell-model predictions. While near the stability path, the predictions are consistent with experimental data; the nuclide properties change as we move away towards the neutron-rich nuclide. In this context, a comprehensive understanding of nuclear structure in the immediate vicinity of the doubly-magic nucleus $^{132}$Sn is crucial before making projections regarding nuclear properties in more neutron-rich isotopes.
Some of the theoretical models predict that in the region to the southeast of $^{132}$Sn, nuclear structure plays a significant role in influencing the competition between neutron and $\gamma$-ray emissions in the decay of neutron-unbound states. The results of our recent experiments at ISOLDE Decay Station (IDS) confirm this and point to a significant contribution from the electromagnetic decay of unbound excited states, which are populated in the $\beta$-decay of isotopes $^{133,134,135}$In [1,2]
Moreover, these nuclei and the competition between neutron and $\gamma$-ray emissions that occurs during their $\beta$ decay are also significant within the context of the astrophysical
r-process.

Emission of delayed neutrons in $^{128}$Sn was not observed in previous studies, but it cannot be ruled out. The existing experimental information about excited states populated in
$\beta$-decay comes from the decay of the ground state ($3^+$) and the isomeric state ($8^-$) of the isotope $^{128}$In [3].
The recent mass measurement [4] allowed the observation of a new $16^+$ isomeric state in $^{128}$Sn, and the observed $\beta$-delayed $\gamma$ transitions corresponding to its decay indicate the necessity for a revision of the current decay scheme. Furthermore, the excitation energy of the new $16^+$ isomeric state enables the feeding of unbound levels in the $^{128}$Sn nucleus.

Excited states in $^{128}$Sn were investigated through the $\beta$-decay of $^{128}$In at the IDS. The implementation of $\beta$-$\gamma$ and $\gamma$-$\gamma$ coincidences in the preliminary analysis of $^{128}$In data revealed six previously unknown transitions and two excited levels in $^{128}$Sn.

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**Poster Session / 44**

## Upgrades to the VITO beamline to study solid-state battery materials

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All-solid-state batteries (SSBs) present a potential route to address the poor range, slow charge, small temperature range of operation, and safety issues associated with traditional lithium-ion batteries.[1] However, one of the major limitations preventing SSBs to commercial market is the poor ionic conductivity of SSB materials, determined mostly by ion diffusion. Unlike other techniques to study these materials, such as impedance spectroscopy, pulsed-field gradient resonance (PFG-NMR), and NMR relaxometry, $\beta$-NMR can monitor ion dynamics at the interfaces, which is where the lower limit for diffusion expected to arise.[2–4]

This poster presents the proposed experiments using the VITO beamline for an exploratory study of $^{8}Li^{+}$ diffusion across the anode and electrolyte interface of three SSB materials. These experiments aim to utilise the correlation between relaxation and diffusion in solid state materials, in addition to the well-known characteristics of $^{8}$Li $\beta$-decay asymmetry.

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**Poster Session / 67**

## Efficient production routes of 129m,131m,133mXe for a novel medical imaging technique, gamma-MRI

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The future gamma-MRI imaging modality will allow the simultaneous exploitation the advantages of SPECT –sensitivity of gamma-ray detection, and MRI –spatial resolution and flexibility. The combination of these technique requires use gamma-emitting nuclei (like in SPECT) with highly polarized spins, leading to anisotropic emission of gamma-ray, and allowing spin manipulation with rf pulses (like in MRI).

An efficient production of 11/2 spin isomers $^{129m}$Xe ($T_{1/2}$=8.9 days), $^{131m}$Xe ($T_{1/2}$=11.8 days) and $^{133m}$Xe ($T_{1/2}$=2.2 days) is an important aspect of the gamma-MRI project. This contribution will present results of systematic studies of two production routes: at ISOLDE and in nuclear reactors. At ISOLDE, during four beamtimes in 2022 and 2023, we investigated the best production and implantation conditions. We used a UCx with plasma ion source and a cooled transfer line and implanted beams of different Xe isotopes inside the GLM chamber into aluminium and gold foils with and without beam sweeping for seconds and hours. We then compared the number of implanted ions and the activity of the samples determined with ISOLDE gamma detectors to our simulations based on the ISOLDE in-target yields [Michelon master thesis]. As a result, we could determine the isomeric ratio for 11/2 to 3/2 states and the total efficiency of xenon extraction from the target. The study will allow us to determine the best conditions to collect high-activity samples (> 10MBq) of $^{129m,131m,133m}$Xe.

The second method that we investigated in several campaigns between 2020 and 2023 to the production of $^{129m}$Xe and $^{131m}$Xe is based on neutron irradiation of highly enriched stable $^{128}$Xe and $^{130}$Xe samples in the high-flux nuclear reactors: RHF reactor at Institute Laue-Langevin (ILL, Grenoble, France) and MARIA reactor in the National Centre for Nuclear Research (NCBJ, Swierk, Poland). We developed and optimised experimental setups for efficient enclosure of stable Xe, extraction and characterisation of the produced xenon isomers. The results show that both reactors provide isomer activities sufficient for the project (> 50 MBq) with few unstable contaminants [M.Chojnacki et al, Applied Radiation and Isotopes –submitted 04/09/2023] .

The presentation will give a brief introduction to the gamma-MRI technique and will provide experimental details as well as results of xenon-isomer production at ISOLDE and at ILL and MARIA reactors.

**Poster Session / 56**

## Recent upgrade of the VITO beamline for beta-decay spectroscopy with laser-polarised beams

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The new research programme at VITO combines the strengths of β-decay spectroscopy and collinear laser spectroscopy. The design of an experimental station for studying the asymmetry of beta particle emission in coincidence with delayed radiation emitted from laser-polarised beams of neutron-rich nuclei involved technical solutions that balance the requirements of these two powerful techniques. The central part of the new setup at VITO is a magnet built at CERN, made of a hollow conductor cooled by water, which provides a magnetic field up to 0.1 T to decouple the atomic and nuclear spins and to maintain the nuclear spin polarisation following the beam implantation into a crystal. A significant challenge in the magnet development was to ensure its compact size so that gamma-ray and neutron detectors could be placed around it to allow spectroscopy studies. The measurement of neutron energy by the time-of-flight technique imposes the demand to minimise the amount of material used in constructing the mechanical structure holding the magnet and detector frame. The new magnet hosts the main chamber with two SiPM-based plastic scintillators with a central hole, allowing the laser-polarised beam to be implanted into the centre of the chamber. In this contribution, I will discuss the technical details of the key components of the new spectroscopy station - magnet, beta detectors and implantation system, which were successfully commissioned in July 2023 with laser-polarised beams of neutron-rich potassium isotopes.

**Poster Session / 69**

## Structural transitions in Mn vanadates tackled with local characterization techniques

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We present original high quality TDPAC data for Mn vanadates obtained during the last Cd run at ISOLDE together with possible interpretations and the discussion of related ambiguities.

**Poster Session / 64**

## Investigation of the properties of $^{124}$Sn populated in $\beta^-$ decay

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The investigation of nuclei surrounding doubly-magic isotopes, such as $^{132}$Sn, represents a fundamental approach for gaining deeper insights into the nuclear structure. However, the region

of neutron-rich tin isotopes remains relatively unexplored, and experimental information is limited.

The only $\beta$-decay study of $^{124}$In to the excited states in $^{124}$Sn have been performed in the 1970s at the Studsvik laboratory [1]. This work was a basis for the $1^+$ spin-parity assignment of the $^{124}$In ground state. However, since then, the $3^+$ assigment was, first, proposed in the $\beta$-decay study of $^{124}$Cd [2] and later confirmed by laser spectroscopy [4]. In a recent mass measurement study, the excitation energy of the $^{124m}$In was reported for the first time [3]. In addition, a reversed order of the two long-lived states, with $8^-$ being assigned as the ground state, was proposed [3]. These studies encouraged us to revise the existing $\beta$-decay scheme of $^{124}$In.

The excited states in $^{124}$Sn populated via $\beta$-decay of $^{124}$In were studied at the ISOLDE Decay Station. A pure beam of $^{124}$In was delivered by means of laser ionization provided by RILIS. The $\beta\gamma\gamma$ coincidence analysis of the collected data points to identification of new $\gamma$-ray transitions. The preliminary results also suggest significant discrepancies between this work and the previous study [1].

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**Poster Session / 23**

## Commissioning of a beta-decay spectroscopy station at VITO

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Beta-decay spectroscopy is a powerful technique for studying the properties of exotic nuclei. Thanks to the high angular momentum selectivity of the process, beta decay offers unique access to states in daughter nuclei having configurations similar to the decaying precursors. However, the one major drawback of conventional beta-decay experiments is the limited ability to firmly assign spins and parities of states involved in the decay [1]. This difficulty can be overcome by employing beams of spin-oriented nuclei decaying with the asymmetric emission of beta particles. The degree of experimental beta-asymmetry reveals spins and parities of nuclear states involved in allowed transitions, yielding a particular value and not just a tentative range of spin values, as inferred from experimental logft.

A novel approach to beta-decay spectroscopy, developed by a group from the University of Osaka [2,3], has been recently adopted at the VITO beamline at ISOLDE [4]. A new experimental station has been here developed and integrated with the existing setup for spin polarisation. The recent upgrades at VITO include the installation of a new, compact magnet that provides a field strong enough to maintain beam polarisation and to decouple atomic and nuclear spins, and, at the same time, it enables easy access for detectors around the chamber located inside and hosting implantation crystals or foils.

The new decay station at VITO (DeVITO) accommodates three Clovers, a set of neutron time-of-flight detectors –the VANDLE array from the University of Tennessee [5], as well as beta-particle detectors with SiPM readout. The chosen configuration allows for the coincident measurements of beta-delayed radiation emitted from laser-polarised nuclei and, thus, for the selection of the levels of interest for unambiguous assignment of spins and parities from measured beta-decay asymmetry in coincidence with gamma rays or neutrons. The recently built DeVITO station was commissioned in July 2023, with polarised beams of 47K and 49K [6]. Details on the commissioning set-up and preliminary results from online tests will be presented. The feasibility of the method and its possible extensions will also be discussed.

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**Poster Session / 81**

## Fine-structured designer materials for Radioisotope Production at CERN-ISOLDE

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Fine-structured designer materials for Radioisotope Production at CERN-ISOLDE

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At CERN-ISOLDE, over a thousand radioactive ion beams (RIBs) are produced from over 70 different types of target materials through the online isotope separation method (ISOL). The material is hit with a 1.4 GeV proton beam and undergoes nuclear reactions leading to the production and release of artificially created isotopes which are then ionized and extracted as ion beams.[1]
The design of target materials must therefore balance materials with high cross-sections for in-target isotope production and fast diffusion and effusion times for the produced and often short-lived species for delivery to ISOLDE experiments. 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 upwards of 2000 C) accounting for power deposition from the incident proton beam, while avoiding chemical interactions which would prevent the isotopes of interest from being volatilized and extracted from the target, and suitable nuclear reaction pathways to create the desired isotopes.
Recent efforts were made to develop target materials with tailored microstructure and to study their characteristics with respect to isotope release, RIB yields and microstructural stability, focusing on ceramic materials which have proved particularly challenging to employ in the past such as zirconia and hafnia as they tend to fully sinter when heated inside an ISOLDE target[2]. and lanthanum or uranium carbides with improved isotope release properties. They are now being developed in-house by exploring different top-down and bottom-up techniques such as ball-milling, high-pressure precipitation and electrospinning [3] so that we can create materials with fewer contact points that are predicted to exhibit better resistance to sintering effects and continue to provide fast effusion paths

for optimized extraction of difficult RIBs. In this contribution, we will give an overview over the past and on-going development efforts and present first results.

Keywords: radioisotopes, nanomaterials, electrospinning, nanofibers, ion beam production

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**Poster Session / 80**

## Characterizations of a modified VD7 ion source

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In a Forced-Electron Beam Induced Arc-Discharge Ion Source (FEBIAD) ion source [1], at ISOLDE called VADIS (VD), electrons are produced by resistively heating a cathode up to 2000 ℃. Afterwards, they are accelerated towards an anode volume, by passing through a grid biased to an adjustable voltage. Atoms within the anode volume can then be ionized by electron impact or plasma ionization. In a standard VADIS ion source, the grid is connected to the anode body [2,3], whereas in the modified ion source discussed in this poster, the grid is isolated, and a separate voltage can be applied. Additionally, another voltage difference can be applied to the cathode.

By having the possibility of applying different voltages across the ion source, including a difference between isolated grid and anode body, it is possible to investigate the ionization process taking place within the target in more detail. With the aim of studying ionization and dissociation processes in molecules, it will be possible to vary the grid voltage and to apply a voltage in the cathode, allowing a potential difference between the grid, anode body and cathode with respect to the extraction voltage. By studying the total and mass separated ion beam, as well as the electron drain current, it is possible to characterize the ionization processes and their efficiencies. This in turn allows us to investigate and test the production of a wider range of atomic and molecular species.

Here, we present the first results obtained from several tests performed on this target at the Offline 2 separator [4, 5] with this ion source.

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**Poster Session / 79**

## Negative ion spectroscopy at CRIS-ISOLDE

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Negative ion spectroscopy at CRIS-ISOLDE

Dag Hanstorp for the GANDALPH and CRIS collaboration

Negative ions are unique quantum systems to probe electron correlation effects: since the Coulomb potential of the nucleus is almost entirely screened, the binding of the additional electron is primarily due to many body interactions between electrons. Consequently, negative ions are sensitive probes for electron correlation theories that go beyond the independent particle approximation. However, due to the weak binding potential, the energy gained by attaching an electron to a neutral atom, referred to as electron affinity (EA), is typically only of the order of one eV. For the same reason, negative ions typically lack bound excited states with opposite parity. Consequently, the EA is the only parameter which can be probed with high precision, typically via laser photodetachment threshold spectroscopy.

In order to study radiogenic elements, in particular those with short half-lifes, an on-line facility such as CERN-ISOLDE is needed, where elements with half-lifes larger than 30ms can be produced and delivered to experimental setups. A program to study EAs and isotope shifts utilizing radiogenic negative ions at ISOLDE was established by the GANDALPH collaboration, reaching a major milestone with the determination of the electron affinity of astatine utilizing the GANDALPH detector in 2018 [1].
Most commonly, ISOLDE uses positively charged ion beams produced by a variety of ion sources, thereby requiring considerable time and effort for the production of negative ion beams. Furthermore, the existing negative ion source only produces the halogen elements efficiently. Hence, in order to widen the scope of negative ions available at ISOLDE, efforts to convert positive ions delivered by ISOLDE to negative ions using the charge-exchange process were initiated. Initial yields of the production of uranium from charge exchange reactions by injecting a 40keV ion beam into a sodium filled charge exchange cell were performed in 2022 using the CRIS setup [2].

Following the successful tests, a beamline dedicated for negative ion beam spectroscopy, utilizing the GANDALPH detector connected to the CRIS setup was designed, expected to be commissioned for experiments by the end of 2024.

Here, we will present the status and developments of the negative ion program at ISOLDE utilizing the charge exchange production at CRIS as well as future activities including the isotope shift in the EA of chlorine, the EAs of Po, Fr and the actinide elements.

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**Poster Session / 88**

# Mapping the lanthanide region of the nuclear chart: Clean beams and high-resolution laser spectroscopy with ISOLDE's PI-LIST ion source

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The lanthanide elements, being located around the Z = 64 "sub-magic"proton subshell closure and all crossing the N = 82 neutron shell gap, offer a unique testing ground for nuclear theory. Benchmark cases range from strongly pronounced odd-even-staggering of charge radii vanishing in isomers (around Sm-141) [1], abrupt transitions from spherical to strongly deformed nuclei (for N < 75) [2], to possible octupole deformation (around Eu-154) [3]. Additionally, pushing towards the proton drip line will elucidate the phenomenon of proton emission amongst others in the thulium and lutetium isotopic chains [4,5].

Extensive studies in this region at ISOL facilities are heavily jeopardized by strong prevalent ion beam contamination. This is due to significant surface ionization rate of the lanthanides themselves and the neighboring cesium and barium isobars, often even presenting radiation protection issues in the experimental hall. Fast beam collinear high resolution laser spectroscopy additionally suffers from thinning of level population if charge exchange to atomic form is employed, due to the large quantity of atomic states in the complex electronic structure with open f shells. The latter also effectuates rich and dense hyperfine structure spectra caused by high angular momenta of the involved states, necessitating sufficient experimental resolution.

ISOLDE's novel specialized laser ion source PI-LIST (Perpendicularly illuminated Laser Ion Source and Trap) [6] tackles these obstacles by utilizing surface ionization contamination suppression in the ion source in combination with strongly reduced Doppler broadening in a crossed laser / atom beam interaction geometry. Its first-time experimental utilization in 2022 on actinium proved achievable resolution in the order of 100 MHz, while extensive off-line work on lanthanide laser ionization schemes in the community [7,8] paves the way to its broad application in this region.

This year, a campaign to measure extractable yields of lanthanides from a tantalum foil target with a PI-LIST was launched [9]. Follow-up experimental proposals entail, e.g., nuclear structure investigations on the praseodymium isotope chain which to date exhibits the scarcest experimental data in this part of the nuclear chart [10]. Additionally, a tailored resonance ionization laser scheme is being developed for this purpose.

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# Design of coaxial RF line for VITO beamline

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The design and simulation of an rf-atom/ion beam interaction region will be presented. The development of this region is needed to perform rf spectroscopy of short-lived radioactive atom or ion beams. In order to obtain the largest possible signal strength from rf spectroscopy, the field strength must be uniform across the atom/ion beam. In order to obtain this uniformity a vacuum spaced stripline geometry was employed. Detailed simulations of the transition from coaxial geometry to stripline geometry will be presented along with the optimised design of the rf interaction region.

**Operation and New Developments II / 74**

# ISOLDE Consolidation and Improvements programme until LS3 and beyond

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Since the relocation of the On-Line Isotope Mass Separator ISOLDE at the PS Booster more than 30 years ago, the facility has benefitted from several upgrades and from a very rich target and ion source development program. Over 1000 radioactive nuclides from 70 elements can now be produced in thick targets via different nuclear reactions induced the PS-Booster 1.4 GeV proton-beam and delivered in the form of radioactive ion beams for different experiments. The installation of the REX-ISOLDE Linac in 2001 and the addition of a superconducting Linac starting in 2015 have allowed to increase the maximum energy of the ion beam above the Coulomb barrier and open possibilities for new experiments on top of the ones performed in the low energy beam lines. Considering the leading role of ISOLDE worldwide and the backlog of experiments, a proposal for target consolidations and improvements is proposed in the coming years with the objective of enhancing the capacity and capabilities of the facility. For the beam production system, the consolidation and improvement program includes the upgrade of the proton transfer-line, the replacement of the beam dumps as well as the re-enforcement of the shielding to fully exploit the potential of the Linca4 and PS Booster energy upgrade to 2.0 GeV that was implemented during LS2. As safety of and the protection of the environment are paramount, another major consolidation concerns the modernization of the target area ventilation process with the installation of charcoal filters and the improvement of the fire compartmentation of the facility. For the post-accelerator, a consolidation plan and several upgrades are proposed to ensure the availability and increase the performances of the REXTRAP and REXEBIS. For the superconducting Linac, improvements of the cryogenics process and the production of an additional cryomodule during LS3 are considered to reduce the Linac's thermal cycles and to improve the availability of post-accelerated beams.
The presentation will review the consolidation and improvement proposed until the Long Shutdown 3 and beyond and the status of the different activities.

**Operation and New Developments II / 42**

# Highly-sensitive photodetachment spectroscopy in an MR-ToF device

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The electron affinity (EA) is the energy released when an electron is attached to a neutral atom. An experimental determination of this quantity serves as an important benchmark for atomic models describing electron correlation [1]. Several atomic spectroscopy studies aiming to answer questions in quantum chemistry, nuclear structure and fundamental symmetries rely on atomic theories of complex many-body systems. Unfortunately, the EA of several radioactive elements is still unknown and detailed information about isotope shifts or hyperfine splittings of EAs are only available for a handful of cases, all with modest precision.

A precise determination of EAs is possible via laser photodetachment threshold spectroscopy. The photon energy is scanned to find the minimal value necessary to detach the additional electron from a negatively charged ion. Since the photodetachment probabilities around this threshold are very low, this technique has so far been limited to mostly stable species which are available in large quantities. Up to now, pulsed high-power lasers are used to increase the photodetachment probability, which are, however, broadband and hence limit the measurement precision.
Employing the low-energy version of the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) at ISOLDE/CERN [4], we have performed a highly-sensitive photodetachment measurement on 35Cl. By trapping ion bunches between the two electrostatic mirrors of MIRACLS'multi-reflection time-of-flight (MR-ToF) device, the same ion bunch is repeatedly probed by the spectroscopy laser. As a result, the signal sensitivity is increased by 3 orders of magnitude while maintaining the high resolution of the collinear geometry. Additionally, we use a narrow-band continuous-wave laser.

Possible systematic effects of the new technique were carefully studied via dedicated measurements and ion-optical simulations. Finally, the EA of 35Cl was determined, which is in perfect agreement with the literature value [2,3]. Even though a factor ˜280,000 smaller ion sample was employed in our measurements compared to the previous single-passage measurement [3], we achieved a comparable precision thanks to the use of narrow-band continuous wave lasers and the repeated probing of the ion bunch in the MR-ToF device.

In addition to the present physics result itself, this advancement in photodetachment measurements at MIRACLS has opened a path for high-precision EA measurements with unprecedented sensitivity for various radioactive species.

I will present our measurement results on 35Cl and discuss the analysis methods, possible systematic effects as well as future application of the new technique for rare isotope sciences.

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**Operation and New Developments II / 59**

# Towards the Nuclear Magnetization Distribution with Laser-rf Double-Resonance Spectroscopy

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Over the past few decades, laser spectroscopy has provided a wealth of information on the nuclear charge distribution and how it evolves away from the valley of nuclear stability. Conversely, very little information is available for the distribution of nuclear magnetization. The study of this nuclear property for the exotic isotopes produced at ISOLDE, could provide significant new insight into the evolution of nuclear structure.
In order to perform these measurements, two ingredients are required: Nuclear magnetic moments with extremely high precision and atomic hyperfine splitting with two orders of magnitude better precision than obtained with collinear laser spectroscopy. The first of these requirements has already been achieved using liquid state β-NMR at the VITO beamline[1].
Here, the ongoing development of a new setup which employs radio frequency excitation of the atomic hyperfine structure will be presented. The laser-rf double resonance technique will be introduced and our progress towards the study of the nuclear magnetization distribution will be reviewed.

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**Operation and New Developments II / 27**

# The PUMA experiment at ELENA and ISOLDE

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PUMA (antiProton Unstable Matter Annihilation) is a new experiment at CERN since 2021. It aims to utilize antiprotons' unique properties to probe the nucleonic composition of the tail of the nuclear density distribution of both stable and exotic nuclei. After formation of antiprotonic atoms with the isotope of interest, antiprotons will annihilate on the nucleus's surface. This process yields annihilation products whose total electric charge allows to reconstruct the isospin distribution and thus grants access to a new observable: the neutral-to-proton ratio. These insights can provide a new perspective for investigating quantum phenomena such as nuclear halos and neutron skins. In order

to trap antiprotons with exotic nuclei, PUMA aims to transport up to one billion antiprotons from the AD (Antiproton Decelerator) to the ISOLDE (Isotope Separator On-Line Device) facility.

In this presentation the motivations and objectives of PUMA will be presented. Additionally, an overview of the current progress in the installation of PUMA at AD and ISOLDE will be provided, together with first physics cases. Furthermore, we give a detailed description of the main components of the apparatus necessary to bring PUMA to life.

**Special Topics / 82**

## Determination of the neutron skin of Pb-208 from ultrarelativistic nuclear collisions

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The more diffusive skin of neutrons in Pb-208 has a wide range of implications ranging from nuclear structure to heavy ion collisions to neutron stars. In this talk I will present the first determination from relativistic heavy ion collisions at the LHC, which is complementary to dedicated studies such as by the PREX collaboration at JLab. In particular I will show that the larger size of the Pb nucleus due to the skin characteristically changes the number, average momenta and angular distributions of outgoing particles. Using a state-of-the-art global analysis this constrains the size of the neutron skin to be $0.217\pm0.058$ fm.

**Rare Decays I / 30**

## Laser-polarisation assisted beta-decay spectroscopy at VITO

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Experimental $\beta$-decay studies contribute significantly to improving our understanding of exciting nuclear phenomena emerging far from stability, such as $\beta$-delayed multiple-particle emission [1–3], evolution of the shell structure [4], and the appearance of so-called "islands of inversion"[5]. The great success of $\beta$-decay experiments in probing ground- and excited-state properties is due to the high angular-momentum selectivity of the $\beta$ decay that populates states with particular "allowed" configurations in the daughter nuclei.

$\beta$-decay spectroscopy becomes even more powerful when spin-polarised nuclei are utilised, i.e. when the nuclear spin of the $\beta$-decay emitter has a directional orientation with respect to the axis of an applied magnetic field. In this way, one can benefit from the parity non-conserving nature of the weak interaction and exploit the anisotropy of the $\beta$-particle emission from spin-oriented nuclei to unambiguously assign spins and parities of states populated in daughter nuclei via allowed transitions [6, 7].

This novel approach to $\beta$-decay measurements, pioneered by a group from the University of Osaka [8-11], has recently been adopted at the VITO beamline [12], which is a permanent setup at the ISOLDE facility devoted to versatile studies with laser-polarised radioactive beams. In this contribution,

a new experimental station that accommodates $\beta$-particle, $\gamma$-ray, and neutron detection following the $\beta$ decay of laser-polarised nuclei will be presented. The research program focused on strong $\beta$-delayed neutron ($\beta n$) emitters will be discussed. $\beta$-decay studies with spin-polarised beams can provide a robust experimental dataset to test $\beta n$ emission models and answer critical questions about the mechanism of $\beta$n decay, being a prevalent decay branch of exotic nuclides, with great relevance to the *r*-process nucleosynthesis. Preliminary results from the commissioning experiment with laser-polarised beams of neutron-rich potassium isotopes will be presented [13].

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**Rare Decays I / 17**

## First determination of weak magnetism in the fission fragment region.

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High-precision measurements of the beta spectrum shape and beta-neutrino angular correlation parameter allow to test for exotic scalar and/or tensor currents in the weak interaction. These measurements are the goal of the WISArD collaboration at ISOLDE [1]. When aiming for the highest precision in the description of the shape of the beta energy spectrum, even small Standard Model effects, usually called corrections, become important [2]. The present work focuses on one such effect, i.e., the recoil-order or hadronic correction, on the beta spectrum shape. This determination of the recoil-order correction for $^{114}$In is the first within an uncharted part of the nuclear chart as, previously, weak magnetism had only been experimentally determined for specific isotopes up to $A = 75$ [3]. The determination of the weak magnetism form factor in the mass region of the fission fragments is interesting for the evaluation of the reactor neutrino anomaly [4].

This experiment has been performed by two face-to-face detectors in a high magnetic field. This effectively forms a closed system with a 4π solid angle thus mitigating the effect of backscattering, an important intrinsic limitation for other spectrum shape measurements. We will present the details

of the experimental approach and report the first determination of the recoil-order correction, which is dominated by the weak magnetism form factor, on the beta energy spectrum of $^{114}$In.

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**Rare Decays I / 4**

## Search for double alpha decay

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Alpha decay is known for more than a century, however a global microscopic description has only been developed recently by Mercier al. [1]. With 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 values [2].

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

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

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**Rare Decays I / 55**

## The 229Th nuclear-clock isomer: half-life and energy determination in several different crystals

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The thorium-229 nucleus contains an isomeric state with a low excitation energy, making it accessible to laser excitation. It is presently the only known candidate for the development of a nuclear clock [1,2,3,4] which will enable testing fundamental principles in physics, such as e.g. potential variations of fundamental constants [5] or the search for ultralight dark matter candidates [6]. Moreover, practical applications like relativistic geodesy are possible [7].
The radiative decay of the thorium-229 isomer was observed at ISOLDE in a previous experiment

by populating it via the beta decay of actinium-229, implanting its shorter-lived decay precursors in large bandgap crystals and observing the isomer's VUV photons in a dedicated spectrometer. A reduced uncertainty of the isomer's excitation energy (8.338±0.024 eV) and a first determination of the ionic half-life (670±102 s) in $MgF_2$ was reported [8]. During the July 2023 campaign seven crystals (including $SiO_2$, AlN, $LiSrAlF_6$) were tested, the energy was determined with better precision, and the half-life behavior of the VUV signal in the different crystals was studied. Preliminary results and ongoing analysis as well as future prospects will be discussed.

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**Ground state properties / 83**

# Nuclear DFT electromagnetic moments in heavy deformed open-shell odd nuclei

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About half of the nuclei in nature have odd particle numbers; however, in the past nuclear-DFT applications, odd nuclei were considered much less frequently than even-even ones. As a result, in building the nuclear-DFT functionals, the existing wealth of experimental information on odd systems was virtually unused.

Nuclear electromagnetic moments provide essential information in our understanding of nuclear structure. Observables such as electric quadrupole moments are highly sensitive to collective nuclear phenomena, whereas magnetic dipole moments offer sensitive probes to test our description of microscopic properties such as those of valence nucleons. Although great progress was achieved in the description of electromagnetic properties of light nuclei and experimental trends in certain isotopic chains, a unified and consistent description across the Segré chart of nuclear electromagnetic properties remains an open challenge for nuclear theory.

In our nuclear-DFT methodology, we align angular momenta along the intrinsic axial-symmetry axis with broken spherical and time-reversal symmetries. We fully account for the self-consistent charge, spin, and current polarizations, in particular through the inclusion of the crucial time-odd mean-field components of the functional. Spectroscopic moments are then determined for symmetry-restored wave functions without using effective charges or effective $g$-factors and compared with available experimental data.

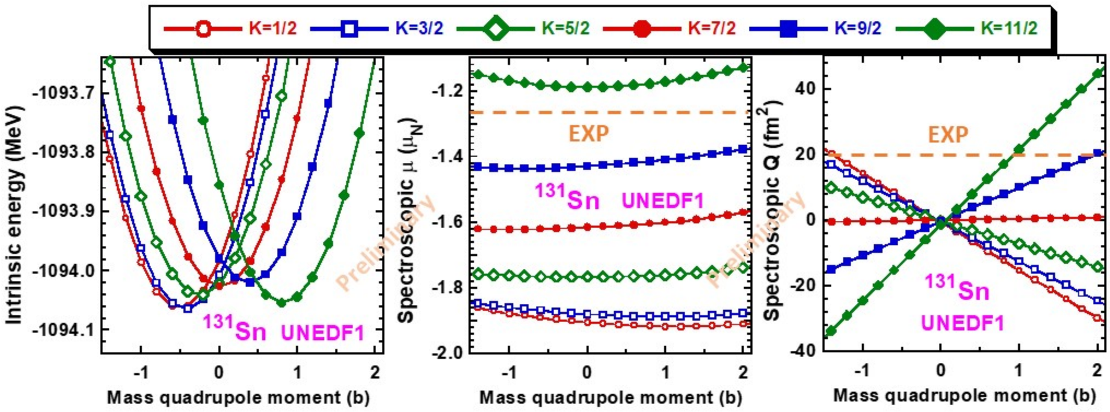


Figure 1: Properties of the the $1h_{11/2}$ hole state in $^{131}$Sn

In this talk, I will review the DFT description of nuclear electromagnetic moments and illustrate it with the results obtained in the unpaired odd near doubly magic nuclei [1], heavy paired odd open-shell nuclei [2,3], and in indium [4], silver [5], tin [6], dysprosium [7], and potassium [8] isotopes. In particular, as shown in the Figure for the $1h_{11/2}$ hole state in $^{131}$Sn, I will discuss different aspects of occupying and mixing the deformed sub-orbitals (Nilsson states) characterised by the projections $K$ of the angular momentum on the intrinsic axial-symmetry axis.

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[7] J. Dobaczewski *et al.*, to be published
[8] A. Nagpal *et al.*, to be published

**Ground state properties / 12**

# ISOLTRAP in 2023: Masses, Molecules, and Future Developments

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Since ISOLDE's return to science in 2021, the ISOLTRAP mass spectrometer has mainly focused on mass measurements of rare isotopes for the study of nuclear structure near doubly-magic nuclei and acted as one of the key tools in the development of various radioactive molecule beams, identifying hundreds of different ions and molecules from different target and ions source combinations.
In this contribution, key scientific achievements of the last three years will be presented, focusing on

shape coexistence near the doubly-magic nuclei 78Ni [1] and shell evolution near 100Sn [2-4]. This will be followed by an overview of beam composition studies for target and ion source developments and for the production of medical isotopes. Finally, technical improvements and an outlook for the next two years until the Long Shutdown 3 will be given.
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Lukas Nies for the ISOLTRAP collaboration

**Ground state properties / 38**

# New results and upgrades from the CRIS experiment at ISOLDE

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The Collinear Resonance Ionization Spectroscopy (CRIS) experiment is a laser spectroscopy setup that allows hyperfine structure measurements to be performed in high resolution, efficiency and sensitivity. This technic established itself as a versatile tool for the study of nuclear, atomic and molecular properties.
2023 has been a fruitful a year for the CRIS experiment with four online runs and two major upgrades of the setup. The year started by assembling and commissioning the new end of the CRIS beam line that allowed to greatly improve the beam transport efficiency towards the detection setup. Then, CRIS successfully studied neutron rich Aluminium, Chromium and Zinc isotopes, probing the evolution of ground state properties entering the N=20 and N=40 islands of inversion and across N=50 in the 78Ni vicinity, respectively. For the Chromium beam time, a decay spectroscopy station (DSS) has been installed to supress background arising from stable contaminants in the radioactive beam. For the Zinc beam time, this DSS was further upgraded using a tape system to perform decay spectroscopy of isomericaly purified Zn beams using the CRIS technique. CRIS performed its last experiment of the year during winter physics, studying the rotational and hyperfine structure of the RaF radioactive molecules.
In this talk, the CRIS experiment will be introduced and the 2023 year at CRIS will be reviewed. The upgrades of the setup will be presented together with new results from the 2023 experimental campaign. The focus will be on the study of the evolution of the ground state properties of Chromium isotopes from the magical N=28 into the N=40 island of inversion.

**Ground state properties / 15**

# Nuclear properties and exotic structure of $^{81,82}$Zn isotopes beyond $N = 50$

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Rich nuclear structure phenomena, such as shape coexistence and shell evolution, have been observed in the neutron rich region up to $N$ = 50 around $^{78}$Ni [1-4]. Moving to more neutron-rich nuclei, theoretical calculation shows that the shell evolution and deformation will also appear in the ground states of isotopes beyond $N$ = 50 [4-6]. Nuclear spins, electromagnetic moments and charge radii of the ground states of these neutron-rich nuclei, which are accessed by laser spectroscopy techniques, would provide important information on theoretically-predicted exotic structure. However, due to the low production yield of neutron-rich isotopes in the northeast of $^{78}$Ni, as well as the accompanying large isobaric contamination, measurement of ground-state properties in this region using laser spectroscopy has been limited till now.

Recently, thanks to the strong rubidium suppression by using a quartz transfer line in the ISOLDE target, and the high sensitivity and selectivity of the Collinear Laser Spectroscopy (CRIS) technique [7,8], measurements of $^{81,82}$Zn ($N$ = 51,52) close to the $^{78}$Ni have been performed successfully. This leads to the first determination of the nuclear spin and electromagnetic moments of $^{81}$Zn and the charge radii of $^{81,82}$Zn. In this talk, the details of the CRIS experiment as well as the extracted nuclear properties of the $^{81,82}$Zn isotopes will be presented. The experimental results will be further discussed based on the on-going shell model and ab-initio calculations.

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**HIE-ISOLDE I / 2**

## Recent results from the Miniball spectrometer

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Over the last two years, a revamped Miniball has been conducting physics experiments across the nuclear chart. Comprising eight assemblies of three electronically-segmented high-purity germanium crystals, the spectrometer measures gamma-rays emitted from fast-moving nuclei following various nuclear reactions. As well as being refurbished with new endcaps, cryostats, and AGATA-like pre-amplifiers, a new digital data acquisition for Miniball has been successfully installed to allow for a triggerless readout and to easily integrate ancillary detectors.

Recent developments, such as the first uses of a novel conversion electron spectrometer and the data acquisition readout scheme, will be discussed alongside selected results over the last two years of operation. Finally, future prospects of experiments and other developments will be presented.

**HIE-ISOLDE I / 21**

## Gamma-ray spectroscopy of neutron-rich Sb isotopes by cluster transfer reactions

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We present recent online results obtained in the IS595 experiment performed in October 2023. Aim of this work is the investigation of excited states in $^{133,134}$Sb and, possibly, $^{134,135}$Te, by employing a cluster transfer reaction of a $^{132}$Sn beam (at 3.9 MeV/A) on a $^{7}$LiF target (1.5 mg/cm$^{2}$ thick). The experiment ran for 7 days very smoothly, with a very pure and stable $^{132}$Sn beam, with an intensity of ˜5×10$^{6}$ pps. The experimental setup consisted in the MINIBALL array coupled to the CD and PAD Si detectors of T-REX. Alpha particles and tritons emitted in the transfer processes, leading to the population of $^{133,134}$Sb and $^{134,135}$Te isotopes, respectively, could be well identified using the Si array. A total number of ˜ 10$^{6}$ $\alpha-\gamma$ coincidences was measured, which will allow us to perform $\alpha-\gamma-\gamma$ studies with rather high statistics. In one single shift, online, it was already possible to

identify $\gamma$ transitions from $^{133}$Sb and $^{134}$Sb. The main aim of the experiment is to locate states arising from the coupling of the valence proton of $^{133}$Sb to the collective low-lying phonon excitations of $^{132}$Sn (in particular the $3^-$) via $\gamma$-ray spectroscopy. In addition, for the case of $^{134}$Sb, multiplets arising from the coupling of the one-valence proton and one-valence neutron will be searched for, to test effective proton-neutron interactions above $Z$=50 and $N$=82 employed in realistic shell-model calculations.

**HIE-ISOLDE I / 73**

## The first TDRIV g-factor measurement on a radioactive ion beam: $^{28}$Mg

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The Island of Inversion in the neutron-rich $N = 20$ region arises in part due to a significant reduction in the energy gap between the sd and fp shells. Recent theoretical calculations [1] and experimental results in $^{30}$Mg [2] favor a much smoother transition towards the Island of Inversion than previously thought, with considerable fp admixtures in the ground state of $^{30}$Mg and small fp admixtures down to $^{28}$Mg. The gyromagnetic factors of nuclear states are very sensitive to the underlying single-particle structure. The predictions for the g factors of the $2_1^+$ states in even-even Mg isotopes in the sd and sdpf valence spaces begin to diverge approaching $^{32}$Mg under the influence of the np-nh excitations to the fp shell.

An experiment to measure the g factor of the first $2_1^+$ state in $^{28}$Mg was performed at HIE-ISOLDE using the MINIBALL array and the newly installed MINIBALL plunger device. The state of interest was populated via Coulomb excitation of the $^{28}$Mg beam and the technique used to obtain the g factor was the Time Differential Recoil In Vacuum (TDRIV) method in its modified version for radioactive ion beam experiments [3,4]. The TDRIV method is based on observing the Larmor frequency, proportional to the g factor, at which the nuclear and atomic spins precess around the total spin of the projectile as it recoils between the target and a secondary foil within a plunger device. In the same experiment a TDRIV measurement of the supposedly well-known g factor of the $2_1^+$ state in $^{22}$Ne was also performed as a test of the system and in order to determine the plunger zero-offset distance, needed for the $^{28}$Mg TDRIV analysis.

The results obtained from the $^{22}$Ne measurement showed a surprising disagreement with the adopted g-factor value which impacts the $^{28}$Mg g-factor result. The obtained g factors for both isotopes will be presented and compared to shell-model calculations.

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**HIE-ISOLDE I / 53**

## Combined conversion electron and gamma-ray spectroscopy of neutron-deficient Hg isotopes utilising the SPEDE spectrometer

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The shape coexistence phenomenon close to the midshell N=104 in the lead region has been under study for several decades. The E0 transitions can be used to study this phenomenon. These transitions can be detected mainly through internal conversion in this region. To investigate this phenomenon, the combined conversion electron and gamma-ray spectroscopy experiments IS563 and IS699 were performed for $^{182,184,185}$Hg using Coulomb excitation reaction. The experiments were done in November 2022 and July 2023 utilising the MINIBALL [1] and SPEDE spectrometer [2]. This experimental setup allows sensitivity for E0 transition. Additionally, these were the first radioactive beam experiments conducted with the SPEDE spectrometer at the MINIBALL setup.

The SPEDE spectrometer is a 24-pixel silicon detector located upstream from respect to the target to detect conversion electrons. The MINIBALL germanium detector array surrounds the target chamber to detect gamma rays, and the CD detector is located downstream for particle identification. This setup allows us to detect gamma rays and conversion electrons simultaneously. The results of these experiments are still under analysis.

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*On behalf of the IS563 and IS699 collaboration

**HIE-ISOLDE I / 77**

## Scattering Studies at the SEC (XT03) beamline at HIE-ISOLDE

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The SEC (Scattering Experiments Chamber) at the XT03 Beamline of HIE-ISOLDE is an experimental station to facilitate diversified reaction experiments. The chamber is sufficiently big to accumulate a variety of charge particle detectors as well as scintillator detectors for gamma detection. It is equipped with a rotational disc of 50 cm radius radially graduated and supplied with Al-bars for precise support and positioning of detectors. This makes SEC a versatile station for reaction experiments either to study the structure via the dynamics of the reaction or to study low-lying resonances in light nuclei via transfer reactions.

In this contribution I will present the results of some of the experiments realised at SEC as well as the planned upgrade and future experiments.

The discovery of halo nuclei and the coupling of these weakly bound systems to the continuum have brought renewed interest in the study of nuclear reactions. The presence of halos in the loosely bound system have been highlighted in inverse kinematic studies of relativistic radioactive beams. At the same time, reaction studies of weakly bound systems at energies close to the Coulomb barrier are of great interest due to the interplay between the reaction process and the structure of the projectile. In elastic scattering at low energies the nucleus has time to adapt during the collision,

giving rise to unique polarization effects. The Coulomb interaction dominates the reaction process with heavy targets. This manifests in the differential elastic cross section by a strong reduction of the interference pattern. What happen when the target is light or we study a p-halo nuclei?
At SEC, we have studied the elastic scattering of the 1p-halo 8B with a middle mass 64Zn target at energies 1.5 the Coulomb barrier and the debated 1n-halo 15C on a 208Pb target at energies around the Coulomb barrier [1]. In the 8B+64Zn reaction contrary to the 11Be+64Zn case the analysis of the elastic scattering angular distribution shows little suppression of the Coulomb-nuclear interference peak, with no enhancement of the total reaction cross-section [2]. Further, the 7Be(d,p)8Be* transfer-reaction at an high energy of 35 MeV was studied to address a possible increase in the disappearance of 7Be that could help to understand the 7Li abundance anomaly. The higher beam energy, for the first time, allowed the population of high excited states in 8Be up to 22 MeV. The contribution of the 16,63 MeV state to the previously determine S-factor, based only on the gs+3.03+11.35 states, in the Gamow window of 67%. However, this is far from enough to account for the Li abondance discrepancy [3].

I present here on behalf of my colleagues the highlights of these experiments, the setup upgrade and future plans.
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## Workshop Dinner

**Solid State Physics / 26**

## Development of large-area topological insulators for spintronics

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Topological insulators (TIs) represent a state of matter in which the material bulk has insulating properties while the surface hosts highly conducting states [1]. In TIs, the presence of Dirac-like dispersed surface states jointly with the large spin–orbit coupling provides the so-called spin-momentum locking and generates topologically protected surface states [1]. Within this talk I will first present the basics of TIs with particular focus on the properties making them appealing from a technological perspective [2,3]. I will then present our strategies to develop epitaxial quality chalcogenide-based 3D-TIs over large area (up to 4") Si substrates by means of Metal Organic Chemical Vapour Deposition [4-7]. Following the validation of their topological character [7], I will present how we built simple spin-charge converters by interfacing the TIs with ferromagnetic layers (FM=Fe,Co). In such TI/FM systems, we report a large spin-charge conversion efficiency, as measured by spin pumping ferromagnetic resonance (SP-FMR) [8,9]. More recently, we developed combined Sb2Te3/Bi2Te3 heterostructures, where the top Bi2Te3 layer displays a remarkable shift of the Fermi level towards the Dirac point, as visualized by angular resolved photoemission spectroscopy [10]. This led to an almost total suppression of bulk states'contribution resulting in the emergence of ideal topologically-protected surfaces states, which are successfully exploited to enhance the spin-charge conversion efficiency when compared to single layer-TIs [10]. Our results open interesting routes toward the use of chemical methods to produce TIs over large area Si substrates, which may bring them closer to the future technology-transfer of spintronic devices based on them.

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**Solid State Physics / 13**

## Application of PAC spectroscopy to metalloproteins

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Time differential Perturbed Angular Correlation (PAC) of γ-rays spectroscopy may be applied to study the coordination geometry and dynamics at metal ion binding sites of proteins [1-2]. Selected examples relating to recent $^{199m}$Hg and $^{111}$Ag PAC experiments will be presented, such as 1) Ag(I) binding to human serum albumin - the major transport protein in blood; 2) A potential $^{111}$Ag reference sample (Ag-benzoate(s)); 3) Modelling the effect of recoil energy on local structure upon the $\beta$-decay of $^{111}$Ag [4]; 4) Hg(II) binding to an arsenic(III) biosensor - As(III) is one of the most important ubiquitous toxic elements in the environment.

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Dynamics of nuclear recoil: QM-BOMD simulations of model systems following β-decay
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**Solid State Physics / 35**

## Structural formation yield of GeV centers from implanted Ge in diamond

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*emphasized text*Group-IV vacancy centers in the so-called "split-vacancy configuration"in diamond are of high interest as spin-photon interfaces for a number of quantum applications, such as quantum information processing and quantum communication, with a particular focus on quantum networks [1-3]. However, the reliable and reproducible fabrication of germanium-vacancy centers has remained a key challenge for practical development of GeV-based devices.
In order to study the structural formation yield of GeV from implanted Ge in diamond, we have investigated its lattice location by using the beta emission channeling technique from the radioactive isotope 75Ge (t1/2=83 min) produced at the ISOLDE/CERN facility. 75Ge was introduced via recoil implantation following 30 keV ion implantation of the precursor isotope 75Ga (126 s) with fluences around 2E12–5E13 cm-2. While for room temperature implantation fractions around 20% in split vacancy configuration and 45% substitutional Ge were observed, following implantation or annealing up to 900℃, the split vacancy fraction dropped to 6-9% and the substitutional fraction reached 85-96%. GeV complexes thus show a lower structural formation yield than other impurities, e.g. Sn or Mg, with substitutional Ge being the dominant configuration. Moreover, annealing or high-temperature implantation seem to favour the formation of substitutional Ge over GeV. Our results strongly suggest that GeV complexes are thermally unstable, which is likely to contribute to the difficulties in achieving high formation yields of these optically active centers. We note, though, that the ***structural*** formation yields of 6-9% are still a factor of 3-10 higher than the reported formation yield of ***optically active*** GeV-, which were reported to be 0.4-0.7% [4] and 1.9% [5].

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**Solid State Physics / 43**

# A study of the local fields in bismuth ferrite by using different radioactive tracer ions

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This work presents the study of the local electric and magnetic fields in multiferroic bismuth ferrite (BiFeO3: BFO) using Time Differential Perturbed Angular Correlation (TDPAC) spectroscopy. The measurements were carried out at a wide range of temperatures up to 850oC, after the implantation of various radioactive tracer ions: 181Hf, 111In and 111mCd. The experimental results reflect the obedience to the Landau theory and the Brillouin-Weiss equation of local electric polarization and magnetization, respectively. Particularly, a huge coupling between local electric and magnetic fields has been investigated in anti-ferromagnetic order. With the support of ab-initio DFT simulations, we are able to discuss the site-assignment for the probe nucleus, and conclude that under our experimental conditions, the 111mCd is located at the Bi-atom at the A-site, 181Hf and 111In probes substitute the Fe-atom at the B-site.

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## Local Probing Energy Efficient Perovskites

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Naturally layered perovskite phases such as the Ruddlesden-Popper present an inspiring route to achieve unique magneto-electric, ferroelectric–photovoltaic or negative thermal expansion effects, among others. In these structures, the rotations of the disconnected perovskite octahedra can lead to different symmetry groups, polar and non-polar, and different magnetic orders adding extra pathways to engineer novel and efficient perovskite materials. Here, nanoscopic probing with local selective electrical and magnetic output information, is fundamental, as lattice distortions at the origin of the functional properties, do not always show clear macroscopic signatures. Of particular interest is to understand how the individual lattice modes evolve across phase transitions and within a particular symmetry. These symmetry-related fine details can be monitored via precise hyperfine Perturbed Angular Correlation γ-γ (PAC) measurements as recently reported [1, 2]. In these perovskites, specifically in $Ca_{3-y}Cd_yMn_{2-x}Ti_xO_7$, the $MnO_6$ octahedra rotation and tilting modes couple to polar cation displacement modes, inducing a ferroelectric polarization in a mechanism known as hybrid improper ferroelectricity [3-5]. Also, the negative thermal expansion observed in the lower dimension layered perovskite, e.g. $Ca_2MnO_4$, is associated with a $MnO_6$ antiphase rotation mode. PAC experiments performed in perovskite paradigmatic examples in a wide temperature range and obtained at ISOLDE-CERN will be presented. The evolution of the electric field gradient, EFG, combined with ab-initio electronic structure calculations are presented to show the EFG sensibility to distinct MnO6 distortion modes and how it can inform about the local details that govern macroscopic effects.

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**Rare Decays II / 68**

# Fast-timing in the $^{128}$Cd→$^{128}$In→$^{128}$Sn $\beta$-decay chain

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Isotopic chains close to the magic proton number \textit{Z}=50 have motivated extensive experimental and theoretical efforts in the last decades, since they provide an excellent ground to study shell-evolution and to investigate the interplay between single-particle and collective degrees of freedom. The systematic study of excited structure of nuclei in the region, and specifically the measurement of excited-state lifetimes, provide key observables to get a deeper insight on nuclear structure.\\

The presentation will discuss results obtained during the experimental campaign performed at ISOLDE Decay Station (IDS) nuclei populated in the $\beta$ decay of Cd isotopes. High purity Cd (Z=48) beams were produced after the fission of a thick UC$_x$ target, selectively ionized by the ISOLDE Resonance Ionization Laser Ion Source (RILIS) and separated in mass using the General Purpose Separator (GPS) ISOLDE mass separator.
High resolution gamma spectroscopy using 6 highly efficient clover-type HPGe detectors was used to build level schemes, while the Advanced Time-Delayed $\beta\gamma\gamma$(t) [1,2] method was employed to

access lifetimes down to the 10 ps range. The method relied on the use of a compact fast-timing setup with 2 $\gamma$-LaBr$_3$(Ce) detectors and 3 fast $\beta$-detectors around the IDS implantation point and it is deemed well suited to measure lifetimes in the sub-nanosecond range from low-lying isomers that are common in this region.

In this work we focus on the $\beta$-decay chain $^{128}$Cd$\rightarrow$$^{128}$In$\rightarrow$$^{128}$Sn [3-5]. The level scheme for both $^{128}$In and $^{128}$Sn has been expanded and completed. In the case of $^{128}$In we preliminarily propose 18 new transitions given rise to 6 new levels, while for $^{128}$Sn a completely new level scheme is proposed, with 28 new preliminary transitions and 10 new excited levels. The first lifetime measurements in the subnanosecond range are reported for $^{128}$In and $^{128}$Sn. The experimental $B(XL)$ results obtained derived from the analysis are discussed in the context of shell-model calculations and the seniority symmetry.

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**Rare Decays II / 45**

# Accurate characterization of the 2+ isospin doublet of 8Be in beta -decay

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In this contribution, an accurate characterization of the $2^+$ isospin mixed doublet of $^8Be$ is provided. The excitation spectrum of $^8Be$ populated in the beta decay of $^8B$ is analysed via two methods; an R-matrix approach and an alternative approach based on the beta recoil. Through this complementary analysis, the isospin mixing in the doublet and the variation with excitation energy of the Fermi and Gamow-Teller components have been established.

The existence of a $2^+$ isospin doublet in $^8Be$ formed by its 16,6 and 16,9 MeV excited levels has been known since the mid-60s [1-3]. This is the only known case of an expected full isospin mixing between two nuclear states where the 16.6 MeV ($^7Li + p$) and 16.9 MeV ($^7Be + n$) levels can be factorized into two pure isospin levels [4]. While their isospin composition has been hinted by R-Matrix fits to reaction data [5], it has never been directly confirmed. The beta decay feeding of $^8B$ to the $^8Be$'s doublet is a good tool to probe the isospin mixing by analysing the Fermi and Gamow-Teller components. However, the difficulty is to resolve the $2^+$ doublet since in the $Q_{EC}$ window ($Q_{EC}$ = 17,9798(1) MeV) the dominant (>88%) decay mode is the feeding to a broad $2^+$ state at 3 MeV [6], and the broad tail of the feeding to this level interferes in the region of the doublet.

Experiment IS633 was performed by the MAGISOL collaboration at the IDS beamline with the ambition of having enough statistics to resolve the $2^+$ doublet of $^8Be$ populated through beta decay [9,10]. A mass-separated 50 keV $^8BF_2$ beam was stopped in a 30 $mg/cm^2$ carbon foil. The $^8B$ feed via $EC/^+$ decays the excited states of $^8Be$. All excited states of 8Be are unbound, they break up into two alpha particles that are detected through a system of four particle telescopes, each formed by a Double-Sided Silicon Strip Detector (DSSD) with thicknesses of 40 and 60 µm stacked with thick

Si-PAD detectors of 1500 µm. The detected alpha spectra are then used to reconstruct the excitation spectrum.

IS633 represents a significant improvement in comparison to previous experimental attempts, obtaining two orders of magnitude more statistics than our previous benchmark experiment at Jyväskylä (JYFL08). Due to the high statistics, the continuum spectrum off 8Be has been determined from 1 MeV up to 17 MeV, within this spectrum the 16,6 MeV 16,9 MeV doublet has been resolved for the first time in a beta decay study. This allows the determination of the Fermi and Gamow-teller contributions following the different methods that will be presented in this contribution.

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**Rare Decays II / 41**

# Analysis of experiment IS570: Beta decay of $^{64-66}$Ge and $^{64-66}$Ga

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Nucleosynthesis in explosive hydrogen burning at high temperatures (T $> 10^8$ K) is characterized mainly by the rapid proton capture rp-process. One of the possible sites for the rp-process are Type I X-ray bursts (XRBs). Several N=Z nuclei, such as $^{64}$Ge, act as waiting points in the nuclear flow. The beta decays of these waiting points are needed in theoretical modeling for astrophysical calculations of XRBs light curves. Several such theoretical calculations have shown that, in the conditions of XBRs, continuum electron capture and decay rates from excited states play an important role, in particular for nuclear species at and around the waiting-point nuclei.

We applied the Total Absorption Spectroscopy (TAS) technique to measure the beta decay of $^{64-66}$Ge and of their daughters $^{64-66}$Ga, because for every Ge analysis we need to performed an analysis on its isobar Ga daughter since they did appears on the Ge measurements. The preliminary results of N=64 for $^{64}$Ga show that the largest difference between the existing data and our new measurement is the noticeable emergence of feeding at around 6080 keV, relatively close to the Q-value of 7171 keV, while for $^{64}$Ge revealed a considerably large amount of beta intensity above the last known level at 817 keV up to the Q-value of 4517 keV. The N=65 case, $^{65}$Ga the analysis shown that it was contaminated and it cannot be analyzed any further but due to how the measurement was performed it still can be used to analyze the parent isotope, $^{65}$Ge reveal feeding above 2000 keV not seen before on the ENSDF data. Lastly for the N=66 case the $^{66}$Ga decay shows a difference in feeding distribution but a overall good agreement with ENSDF data, and in the case of $^{66}$Ge the analysis shown that it was contaminated so a further analysis was no possible.

In this contribution we will present our results on the beta decay of $^{64,66}$Ga and will discuss their relevance in the context of isospin mixing of the ground state and our results on the beta decay of $^{64,65}$Ge as for the B(GT) of this new results and its relevance in rp-process calculations.

**Rare Decays II / 22**

# Total absorption gamma-ray spectroscopy at ISOLDE for isospin mirror asymmetry studies

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The isospin mirror asymmetry parameter in mirror systems is evaluated based on the $\beta$-decay data of the mirror partners. In particular, $\beta$ decay intensities are traditionally obtained from $\gamma$-ray spectroscopy experiments with HPGe detectors. However, due to the limited efficiency of such detectors, this approach is known to be potentially affected by the Pandemonium effect [1], specially when high excitation-energy levels are fed and de-excitation cascades are very fragmented. A well consolidated tool to avoid this bias and determine the complete $\beta$-intensity distributions is the total absorption $\gamma$-ray spectroscopy technique [2].

In this contribution we will focus on a recent experiment with the Lucrecia total absorption spectrometer at ISOLDE [3] aimed at investigating the $\beta$ decay of $^{27}$Na, studied in the past with germanium detectors [4]. Our preliminary results point to previously unseen $\beta$ intensity populating excited states in $^{27}$Mg, including the observation of competition between neutron emission and $\gamma$ de-excitation above the neutron separation energy. This would be the first confirmation of Pandemonium effect for such a light system and it would reduce the isospin mirror asymmetry of the $^{27}$Na - $^{27}$S pair, suggested to be an evidence of a proton halo structure in $^{27}$S [5]. The $\gamma$ emission from neutron-unbound states, observed so far in heavier nuclei, can be interpreted as a nuclear structure effect by means of Hauser-Feshbach statistical model calculations [6].

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**Special Topics / 6**

# FERS-5200: a distributed Front-End Readout System for multidetector arrays

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Modern physics experiments usually rely on big experimental setup where it is possible to find a wide variety of detectors: silicon microstrip trackers or other solid state detectors, plastic scintillator calorimeters, LAr cryostats readout by a Time Projection Chamber, spectrometers composed of several drift tubes and resistive plate chambers. Moreover, detector granularity and precision

measurements are paramount all across the physics field and often hundreds or thousands of detector channels need to be read out. Nowadays, waveform digitizers and/or ASIC-based front-end cards are well-established readout electronics to build a reliable system hosting many readout channels.

The FERS-5200 is the new CAEN Front-End Readout System, answering the challenging requirement to provide flexibility and cost-effectiveness in the readout of large detector arrays. FERS-5200 is a distributed and easy-scalable platform integrating the whole readout chain of the experiment, from detector front-end to DAQ. It is based on compact ASIC-based front-end cards integrating A/D conversion and data processing, which can be ideally spread over a large detector volume without drawbacks on the readout performance. Synchronization, event building and DAQ is managed by a single Concentrator board, capable of sustaining thousands of readout channels.

Using the appropriate Front-End, the solution perfectly fits a wide range of detectors such as SiPMs, multianode PMTs, GEMs, Silicon detectors, Wire Chambers, Gas Tubes, etc, thus matching the requirements of different applications.

**Special Topics / 3**

## Gamma-Factory@CERN - status and perspectives

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In this talk, I shall discuss a project that may significantly broaden the present CERN research program by including a new component —the novel-type light source. The proposed, partially-stripped-ion-beam-driven light source is the backbone of the Gamma Factory project being presently studied within the PBC framework. It could be realized at CERN by re-using the infrastructure of the already existing accelerators and by profiting from the recent progress in laser technology. It could extend the scientific life of the LHC storage rings beyond its HL-LHC phase. Gamma Factory could push the intensity limits of the presently operating light sources by at least 7 orders of magnitude, reaching the flux of up to 10ˆ18 photons/s, in the particularly interesting gamma-ray energy domain of 0.1 —400 MeV, which is presently not accessible to the FEL photon sources. The partially stripped ion beams, the unprecedented-intensity energy-tuned gamma beams, together with the gamma-beam-driven secondary beams of polarized positrons, polarized muons, neutrinos, neutrons, and radioactive ions constitute the basic research tools of the Gamma Factory. A broad spectrum of new research opportunities, in a vast domain of uncharted fundamental and applied physics territories, could be opened by the Gamma Factory. Examples of new research opportunities and the status of the Gamma Factory project development will be presented in this talk.

**HIE-ISOLDE II / 18**

## Advances in the theoretical description of transfer reactions

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Transfer reactions are often used to infer structure information of nuclei. In particular, the new ISS at ISOLDE provides an excellent experimental setup to measure (d,p) reactions with exotic beams. To properly analyse measurements, its is important to have a good understanding of the reaction process and to which structure observable the transfer reaction is sensitive. In this short talk, I will review recent developments in the analysis of transfer reactions.
First I will review a systematic analysis of transfer reactions on halo nuclei. In particular, I will focus

on the 10Be(d,p) reaction that populates the halo nucleus 11Be. I will show how the magnitude of the halo can be probed reliably by selecting data at low energies and forward angles [1].
Second, I will illustrate the importance that optical potentials exhibit in the analysis of transfer reactions. This is particularly well illustrated in the recent paper of Catacora-Rios et al. [2], where the authors perform a very systematic analysis of (nearly) all the potentials entering the usual ADWA model of transfer using a Bayesian approach.
Finally, I will present the recent development of the model of transfer reaction that includes core excitation [3]. This model should enable us to go beyond the simplified few-body model of the nuclei, and hence give us access to more reliable structure information than the usual ADWA.

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**HIE-ISOLDE II / 1**

## Updates from the ISOLDE Solenoidal Spectrometer

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The ISOLDE Solenoidal Spectrometer specialises in the study of transfer reactions in inverse kinematics, using the solenoid spectrometer technique pioneered at Argonne National Laboratory [1]. It was fully commissioned in 2021 with a new silicon array, and has since undergone three successful physics campaigns focusing on measurements of the $(d, p)$ reaction to probe single-neutron properties in a number of nuclear systems.

This talk will outline the solenoidal spectrometer technique and highlight some of the physics results from these campaigns.

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**HIE-ISOLDE II / 70**

## Evolution of Single Particle Trends Outside the N = 16 Isotones: The 27Na(d,p) Reaction at ISS.

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Single-particle structure has been observed to evolve away from the valley of beta-stability. In exotic nuclei, the ordering and separation between energy levels vary to the extent that nuclear magic numbers change. For example, in the neutron-rich region with Z = 8-20, the N = 20 shell closure weakens, and a new shell closure emerges at N = 16 in $^{24}$O [1]. The behaviour of the negative-parity intruder states from above N = 20 are of particular interest here. The difference in the effective single particle energies (ESPE) between negative-parity orbitals and the positive-parity $d_{3/2}$ orbital defines the N = 20 shell closure. The increasing presence of negative-parity states at low excitation towards Z = 8 indicates a lowering in the ESPE of the $f_{7/2}$ and p orbitals, and therefore a weakening of the N = 20 shell closure. The proton-neutron cross-shell interactions that govern these changes in ESPE have been poorly constrained by experimental data thus far. To understand the evolution of these shell closures, and to test new shell-model interactions better tuned to the cross-shell interactions and properties of the negative-parity states, it is crucial to measure the single-particle properties of nuclei in this region.

Single-nucleon transfer reactions provide a suitable means to study single particle properties, as they selectively populate single particle states. For exotic nuclei, it is necessary to perform such reactions in inverse kinematics using radioactive ion beams. A measurement of the d($^{27}$Na,p)$^{28}$Na reaction has been performed, using the ISODLE Solenoidal Spectrometer, to investigate the single-particle properties of the single-neutron states outside N = 16 in $^{28}$Na. From this measurement, positive- and negative-parity states have been identified and a preliminary distribution of the single-particle strength in 28Na has been produced. The results can then be compared to new shell-model interactions, such as the FSU interaction [2], and further characterise the single-particle trends across the N = 17 isotones, when combined with existing data on the N=17 isotones.

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**HIE-ISOLDE II / 49**

## The $(d,p)$ reaction on $^{11}$Be using ISS: Bringing clarity to the structure of $^{12}$Be

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The available data on $^{12}$Be are ambiguous and limited despite numerous attempts via direct and indirect reactions. For the three previous (d,p) reactions[1-3], their reaction energies and angular

coverage were not optimized so the data could not be easily interpreted in terms of well-tested reaction mechanisms. For another, these measurements provided limited information on the unbound excited states and did not achieve good enough Q-value resolution to isolate the $0_2^+$ and $2_1^+$ states which are just 150 keV part. To resolve this situation, a new $^{11}$Be$(d,p)$ measurement has been carried out using ISS at ISOLDE at an energy of 9.78 MeV/u. The $0_2^+$ and $2_1^+$ states have been isolated owing to the good resolution of ISS. The neutron $1s_{1/2}$ spectroscopic factor of the $0_2^+$ level has been determined, which will allow for its matter radius extraction, and hence, if it has a two-neutron halo structure, similar to the $^{11}$Li ground state. The recently observed $0^-$ state [4] has been confirmed and its width and excitation energy have been precisely determined, located just 40 keV above Sn. The spectroscopic factors of states below 5 MeV have also been determined and suggestions of the spin-parities of the unbound states will been made. In particular, a new resonance at ˜4.2 MeV has been observed for the first time in $^{12}$Be. The new results will be compared with shell model calculations incorporating effective interactions, Gamow shell model (GSM) calculations [5] and Gamow coupled-channel method (GCC) calculations [6] incorporating the continuum coupling effects.

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## Closing Remarks and Prizes

**News from other facilities / 60**

## Octupole correlations in the neutron-deficient $^{110}$Xe nucleus

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Octupole correlations near $N = Z = 56$ are unique in sense that they occur between particles in the same orbitals for both neutrons and protons. In this region just above $^{100}$Sn, it is expected that enhanced octupole correlations will take place at low and medium spins in the light Te ($Z = 52$), I ($Z = 53$) and Xe ($Z = 54$) nuclei [1]. In this region of the nuclear chart, the Fermi surface for both neutrons and protons lies close to orbitals from the $d_{5/2}$ and $h_{11/2}$ subshells; octupole correlations emerge from the interactions of particles in these orbitals with valence neutrons and protons outside the $^{100}$Sn core [2, 3]. As a result of the octupole correlations, an enhancement of octupole collectivity is expected to appear. Close to N = Z = 56, a level structure characteristic of octupole correlations, consisting of negative-parity states and enhanced E1 transitions, has been observed in a number of cases including $^{112}$Xe [4], $^{114}$Xe [5, 6, 7] and $^{118}$Ba [8].
With the aim to observe for the first time the octupole band in the neutron-deficient ($N = Z + 2$) $^{110}$Xe nucleus, an in-beam experiment was performed at the Accelerator Laboratory of the University of Jyv\"askyl\"a, Finland. The $^{110}$Xe nuclei were produced via the $^{54}$Fe($^{58}$Ni,2n) fusion-evaporation reaction. The emitted $\gamma$ rays were detected using the JUROGAM3 $\gamma$-ray spectrometer [9], while the fusion-evaporation residues were separated with the MARA separator [10]. In this experiment, we were able to prove the existence of the octupole band via the identification of the low-lying $3^-$ and $5^-$ states and the inter-band E1 transitions between the ground-state band and the octupole band. These new experimental data combined with a discussion using state-of-the-art theoretical calculations will be presented.

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## Welcome