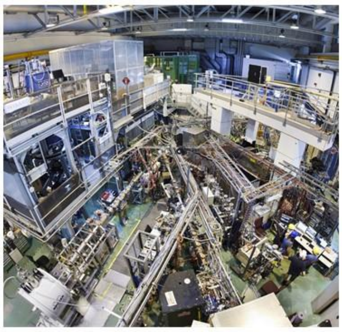
ISOLDE NEWSLETTER 2022



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Introduction

Sean Freeman

It is a great pleasure to be writing my first introduction to the ISOLDE Newsletter as ISOLDE Physics Section Leader and Collaboration Spokesperson, after taking over from Gerda Neyens in late summer 2021.

As Section Leader and Collaboration Spokesperson, Gerda led a period of careful consideration of potential futures for ISOLDE. She facilitated the Collaboration to think about possible paths to improve the Facility, initiating the "Exploiting the Potential of ISOLDE at CERN" (EPIC) Workshops which considered many potential improvements and expansions. This has highlighted a number of medium-term possibilities, such as systems for parallel beam delivery as well as reestablishing the importance of renovating the proton beam dumps and securing the benefits of 2-GeV proton delivery. But perhaps more importantly, she raised the aspirations of the Collaboration by encouraging consideration of more ambitious, longer-terms goals to increase the capability and capacity of ISOLDE by significant expansion. These ideas are currently being written up as a set of EPIC Proceedings to be published in European Physical Journal.

In common with everyone in a leadership position over the past two years, Gerda has had to meet the very many challenges particularly associated with the pandemic, which have ranged from assisting the technical and operations teams in addressing the difficulties of restarting the Facility after Long Shutdown 2 in the face of COVID restrictions, through to supporting the fellows and students in the local group through a very difficult period. Unfortunately, the pandemic limited the opportunities for ISOLDE outreach activities that had been flourishing previously under her watch. She has also been very successful in helping to secure a good stream of highly qualified young scientists taking up CERN Fellowships at ISOLDE.

Gerda is a very hard act to follow - but on behalf of the whole collaboration, I wanted to thank Gerda for all her energetic and influential contributions to ISOLDE over the previous four years.

Although my first visit to ISOLDE was many years ago - CERN IT Systems never forget and they tell me that is was on 5th November 1993 - it is only recently that I've become a more regular ISOLDE User as part of the collaboration that built the ISOLDE Solenoidal Spectrometer (ISS). Whilst I'm not a newcomer to management positions having been Head of Physics and Astronomy in Manchester, the jump to a new organisation is always difficult, perhaps more so when coming afresh to a unique organisation like CERN. I am very grateful to Gerda, with whom I overlapped for a month, for helping to orientate me in this new environment. And Karl and Jenny have been invaluable in helping and supporting me this far. The organisational structures at CERN seem to require a management degree to comprehend, but whoever it was who told me "don't attempt to try to understand it, because by the time you do, they will have reorganised it" seems to have given me sound advice as a more pragmatic approach does seem to work.

Thinking about my first impressions of ISOLDE from the context of the role are overwhelmingly positive. The collaboration between the technical staff from operations, target and ion-source, and RILIS teams is impressive. However, because it works so well, this is often invisible to users who come to the Facility to do science with the delivered radioactive beams. The roles looking after User Support, Technical and Physics Coordination are critical links and are performed adeptly by Jenny, Joachim and Karl, but we need to be a little careful of the risks of single-point failures. The local physics group is very youthful, energetic and impressively talented. It is a privilege to be working with them all. And, finally, the scientific programme driven

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by the Collaboration is inspiring - the range of science and the number of highlights that are produced make the various internal reporting tasks difficult because of the wealth of riches.

The Facility came back online in June 2021 for a productive running period. This is notable as the Long Shutdown was .... well .... long! A period of just over 2.5 years and restarting is always a tricky business. But we can now benefit from several hardware upgrades that were installed during the shutdown including new GPS and HRS front ends, new REX-EBIS electron gun, repaired Cryomodule-4 on HIE-ISOLDE and consolidation of beam instrumentation for high and low energy beam lines. This time the restart was complicated by the strict guidelines imposed by the pandemic, which also made life all the more difficult for those users coming to CERN to perform experiments. Many shifts were backed up by remote users from around the planet who performed key tasks in monitoring online running. More than 30 experiments were performed up to November proceeded by an active winter physics campaign, albeit disturbed by some December power shutdowns. New records were set for the RILIS laser ionisation, which was used for 21 weeks out of 23. The first experiment was run at CRIS, where hyperfine structures of over 20 isotopes were measured. Laser spectroscopy measurements with COLLAPS unravelled the structure of a long chain of lead nuclei. Promising new results were obtained from a search for uv emission from the ^{229}Th isomer. ISS used HIE-ISOLDE beams to probe single-particle states in the Island of Inversion and along $N = 126$. And there were many more interesting experiments.

The 2022 running period has recently started and I hope that we can look forward to another productive year at ISOLDE. One piece of recent good news was the approval of the EUROLABS Project, which is the successor to ENSAR2. We hope that the grant agreement will be signed on time in spring, ready to start the project later in the year that will help support subsistence for some ISOLDE Users. In the meantime, the ISOLDE Collaboration Committee (ISCC) has decided to maintain the scheme to support users from the ISOLDE member states that operated last year.

For those who are visiting ISOLDE in this running period, I would encourage you to think well ahead of time about any necessary training you or your team members need as the administrative arrangements have several weeks lead time. The hostel is busy during the summer, but a small number of rooms that have been reserved for ISOLDE users and information on how to book the reserved rooms has been sent to institutional team leaders. In order to minimise risks to ISOLDE operations, we are asking everyone to please wear masks in Building 508 and in the User Support Office. Due to EU data protection rules, the ISOLDE email list is now a self-subscription list. If new users would like to be added to the ISOLDE mailing list they can subscribe by going to https://e-groups.cern.ch/e-groups/EgroupsSearchForm.do and searching for *isolde*.

Across Europe, Open Access publishing policies are becoming very important. CERN is no exception and the CERN General Conditions require all peer-reviewed primary research articles to be Open Access. But there is plenty of help and support available with many journals having arrangements to do this automatically for CERN authors and collaborations. Even if you are not covered by an automatic arrangement, the CERN Scientific Information Service can provide helpful information and support in ensuring your publications are OA, so please contact them directly before manuscript submission (scientific-info.cern/submit-and-publish). I would also encourage everyone to make use of EP preprints (https://ep-dep.web.cern.ch/content/ep-publishing-policy). For ISOLDE papers there is no additional review, but having an EP preprint will give your publication an additional web presence, increasing its web hit rate and helping with publicity. Importantly, it will also help raise the profile of ISOLDE scientific output within the CERN organisation.

You will be able to find more detailed information on user arrangements and publishing in later sections of the Newsletter and on the ISOLDE or CERN webpages.

At a recent meeting, the ISCC agreed to sign the Diversity Charter that has been drafted jointly by NuPECC, APPEC and ECFA who represent the nuclear, astroparticle and particle-physics communities (ecfa.web.cern.ch/content/diversity-charter). Thanks to those who completed the short survey to monitor diversity in activities related to APPEC, ECFA and NuPECC areas. At the time of writing, the survey is still open, if you would like to contribute: www.survio.com/survey/d/X2C1N9U6B4T6X0H1M
Password 2019JENAS.

The ISOLDE Workshop and Collaboration meeting was a great show case to hear about many interesting new results delivered in a range of very high quality presentations. Participation in the online meeting was again very high with more than 300 registrations from more than 30 countries, illustrating a lot of interest in the Facility and its science. I think everyone is looking forward to the possibility of an in-person meeting, to catch up with colleagues, to profit from the benefits that often arise from an unplanned or incidental conversation over coffee, and perhaps to enjoy a good fondue with old and new friends. But a good challenge is to run an effective hybrid where we can enjoy the benefits of coming together on the CERN site, but allowing virtual participation for participants who may not able to travel for whatever reasons. The two online events have attracted more than twice the registrations of the previous onsite meetings so it would be good to continue to satisfy the same level of interest in the future.

Thanks to everyone in the Collaboration who have helped me settle into my new role. It is a pleasure to be embedded in such a vibrant and diverse scientific and technical endeavour and I look forward to working with you all over the next few years.

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ISOLDE schedule 2022

The physics period in 2022 will run from March 28th until November 28th. Unlike previous years it is unlikely that a winter physics programme will be possible this year due to the lack of services once the proton campaign finishes. Low energy physics started on March 28th and has now been runing for several weeks. HIE ISOLDE is due to start with physics in week 29, around July 20th. Until then, the commissioning of the accelerator will be carried out. This year will see the return of Miniball and will be the first year since 2018 that all three HIE ISOLDE beamlines will be available for experiments.

The first part of the schedule for 2022 can be found online here, and the weekly schedules here. The remaining part of the schedule will be published in the early Summer. A limited amount of financial support from the ISOLDE collaboration will be available for users who need this to attend experiments. The procedure will be simliar to that adopted for ENSAR2 TNA funds. Jenny will contact the spokespeople of scheduled experiments in advance of their experiments running. From September onwards the EUROLABS TNA funding should be available for supporting users, details about how this will be allocated will be communicated in due course.

User Access to CERN in 2022

The majority of restrictions due to Covid-19 have now been lifted at CERN and the site is now in a so-called "level-1" or "green" state. This essentially means that access to the site has now returned to how it was pre-pandemic. However, respecting social distancing where possible and maintaining good habits regarding hand hygiene are encouraged. At ISOLDE, in building 508, the wearing of masks is still mandatory, and also when coming to Jenny's office. The use of a proximeter is no longer mandatory.

In case of a positive test, this must be reported to the medical service and access to the CERN site will be lost for at least 5 days. Close contacts will also be tested, although their access may not be lost. More information for Users about the CERN Covid-19 measures as well as all related rules and regulations is available here.

INTC meetings in 2022

The INTC meetings in 2022 are as follows:

- 70th meeting of the INTC
  - June 22nd and 23rd. The deadline for submission of proposals is May 11th 2022.
- 71st Meeting of the INTC
  - November 8th and 9th. The deadline for submission of proposals is September 27th.

Although the lifting of the majority of Covid restrictions means that meetings can once more take place in person, it has been found that remote presentations to the INTC have worked well, and this policy will remain: this ensures a level playing ground for those who would be unable to travel and will reduce the carbon footprint of such meetings. The open session will still take place on site — either in the Council chamber or the George Charpak room — but presentations will be all via zoom.

User registration for 2022

A full description of the procedure for registering at CERN is given at the end of this newsletter. Visiting teams should use the pre-registration tool (PRT) to register new users. As in 2021: the teamleader and deputy teamleader who sends the information via PRT must have a valid CERN registration. This also applies to paper forms which have been signed at the visiting institute. Please register under "ISOLDE" rather than a specific experiment. If the teamleader or deputy do not

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have a valid registration, the users office will refuse to accept the documents.

Access to ISOLDE

Access to ISOLDE is entirely managed through ADaMS (Access Distribution and Management System). The access permission required for ISOLDE is **ISOHALL**. If the appropriate training ranks have been gained, the access will be granted, it is no longer approved by the physics coordinator.

Required training courses for access to ISOLDE hall and chemical labs

All training is managed via the CERN training hub. There are a variety of training courses required before access to the ISOLDE hall can be granted. These are divided into hands-on courses, which take place at the CERN training centre in Prevessin, and online courses which can be taken via the CERN online training.

- Pre-requisite online training courses (can be followed prior to arrival at CERN)
  - Mandatory courses for everybody at CERN:
    - Emergency evacuation
    - Radiation Protection - Awareness
    - Safety at CERN
    - Computer Security
    - Covid-19 training
  - Additional courses for ISOLDE users:
    - Electrical Safety Awareness - Facilities
    - Electrical Safety Awareness - Fundamentals
- Required hands-on courses
  - EP Electrical safety in EP Experimental areas
    - Course code: STELS03I
  - ISOLDE - Experimental Hall - Radiation Protection - Handling
    - Course code: STIRP06I
  - B. 508 chemical labs: The laboratories on the ground floor of 508 where solid state physics perform chemistry also have their own access. It is required to follow the online LMS course "Chemical Safety Awareness" before requesting the permission **ISOCHEM** for 508 R-002 and **ISOEXP** for 508 R-008 for the measurement area.
  - ISOLDE Traka Box: the ISOLDE TRAKA box is now integrated into Adams. To request access to the box it is necessary for users to ask for the "0508K1-002" permission in Adams.

Please note that the EP electrical course requires the home institute to sign a form prior to registration. This form can be found here. These courses take place on a Tuesday from 0830 until about 1700: electrical safety in the morning and RP training in the afternoon. The registration deadline for the hands-on courses is 15 days prior to their taking place.

Enrollment for courses should take place in advance of coming to CERN; in the event that a user is not yet registered an email can be sent to safety training: safety-training@cern.ch. However, once registered it will be still necessary to register for the hands-on courses in LMS in order to validate the training once the User has arrived at CERN and has completed their User registration.

Visits to ISOLDE

Visits to ISOLDE have resumed. Visits can be arranged by contacting isolde-visits@cern.ch.

A typical visit consists of an overview presentation in the visitors' area in building 508 and – when possible – a tour of the ISOLDE facility itself along the pre-arranged visit path. In the event of a machine intervention or a conflict with physics which happens to be running, the tour of ISOLDE may be cancelled, and visitors remain in the 508 gallery area. Please note that weekend visits of groups are no longer possible and are not advised for individuals except in exceptional circumstances. The possibility of a fully virtual visit also now exisits, which can be particularly attractive for large groups e.g. university students.

More details can be found on the area of the ISOLDE website dedicated to visits.

ISOLDE Publications, open access and CERN EP preprints

ISOLDE should be mentioned in the abstract of articles related to experiments performed at the facility and, if possible, the ISOLDE team should be mentioned in the acknowledgements. Experiments which have benefited from ENSAR2 funding at ISOLDE should also mention this in the acknowledgements of any articles which emerge and which should echo the following: *This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654002*. A simliar wording for EUROLABS support will be communicated in due time.

Please note that under CERN's general conditions, all publications originating from a CERN experiment or featuring a CERN author must be published as open access. Detailed information on open access publishing can be found on this dedicated website, supported by the CERN Scientific Information Service. New agreements have been signed with numerous publishers which facilitate OA publishing with a CERN author. In many cases publication costs will be covered centrally at CERN if there is at least one CERN-affiliated author in the author list. In the cases of the IOP and the APS publication costs can be covered even without a CERN author as long as the ISOLDE collaboration and IS number are mentioned e.g. "CERN, ISOLDE Collaboration, ISXXX" in the collaboration field of the submission form, and this should be added to the paper itself.

In case of any further questions, authors can ask the experts in the CERN library questions via email: open-access-questions@cern.ch.

ISOLDE papers can also be uploaded to the CERN EP preprint server, which will allow them to receive a CERN-EP number as is done for many other experiments at CERN. Details on the submission process can be found here. If there are any questions about this process, please contact the physics coordinator.

Publications on CDS

There is a specific area of the CERN Document Server from which all ISOLDE spokespeople and contacts will be able to upload DOI links (and extra information if required). Once you have signed in with your CERN credentials, you should be able to upload any new articles or theses. The link to use is here. If there are any problems with uploading, please contact the physics coordinator.

Safety in the ISOLDE hall

The wearing of safety helmets and shoes is mandatory inside the ISOLDE hall. It is also mandatory to check yourself on the hand-foot monitor before leaving the ISOHALL zone.

Once within the ISOLDE hall you have at your disposal additional RP protective equipment such as gloves and contamination monitors to ensure your safety. These are located in the cupboard close to the old control room. A new suite of PPE for electrical investigations can now be found close to the IDS setup in the ISOLDE hall.

A variety of "expert" courses are available for those required to perform more demanding operations such as those involving cryogenics, using the crane and lasers. Please ensure that you have followed these courses before performing these tasks.

All experimental setups need to pass safety clearance before they can perform experiments. The first step in obtaining this clearance is to fill out the ISIEC form which can be found here. For any additional questions regarding safety of setups please contact the ISOLDE coordinator for further information.

The mechanical workshop in building 508 is fully operational. If you wish to use it a document will need to be provided which is signed by your teamleader, yourself, and our workshop supervisor, authorising you to use the selected machines in the workshop. For more information, please contact your experiment spokesperson, local contact or the coordinator.

The list of contacts for safety both for local experiments and visiting setups can be found via https://isolde.cern/safety.

ISOLDE facility

News from the technical teams

Simon Stegemann, Sebastian Rothe, Edgar Reis, Reinhard Heinke, Mia Au, Cyril Bernerd, Yago Nel Vila Gracia, Alexandros Koliatos, Stefano Marzari, Răzvan Lică for the SY-STI RBS and LP sections

1 A new target container design

All target developments include the necessity to guarantee durable and efficient behaviour under extreme operating conditions (container temperatures higher than 2000 ℃, high vacuum level of 10^{-7} mbar, high voltage and radiation). To generate these temperatures, various elements are resistively heated (Joule heating). The efficiency of the targets depends on the temperature homogeneity across the target container, ion source and transfer line, and constitutes a key factor for the isotope extraction process. Temperature homogeneity is highly dominated by the container design, while durability depends on engineering design solutions to ensure a robust structure, extending the life span of targets and minimizing heat losses from the container.

Currently, heat screens (consisting of Ta, W and Mo thin foils) are attached to the container surface to reduce heat losses of the container and to protect surrounding materials of the target assembly. Each foil is separated by Ta wires, which provide spacing distance, at the same time reducing contact points. However, they imply additional manual work and varying wrapping techniques induce instabilities which can simultaneously affect the efficiency during heating cycles. At ultra-high temperatures (> 2000 ℃), foils are highly deformed, their spacing distance cannot be guaranteed, resulting in increasing electrical and thermal contact points. During multiple heating tests, it has been demonstrated that the insulation efficiency decreases over time along with a rapid degradation of the container surfaces. Overall, these issues highlighted the need for a system analysis of the target structure and the separation of the thermal insulation from the target container into a new independent sub-system.

Thus, a novel design has been developed to optimize efficiency, at the same time ensuring temperature homogeneity and durability, avoiding current bypass and significant heat losses from the container. A new prototype container with improved features has been tested, demonstrating very promising results. Thinner container extremities and new design of the transfer line connection contributed to a significant reduction of cold spots. Moreover, it has been observed that this solution improved temperature homogeneity, since mass reduction was fundamental to a significant temperature increase on the extremities. Optimization studies are currently being conducted to further decrease cold spots, improving even further the temperature homogeneity of the container.

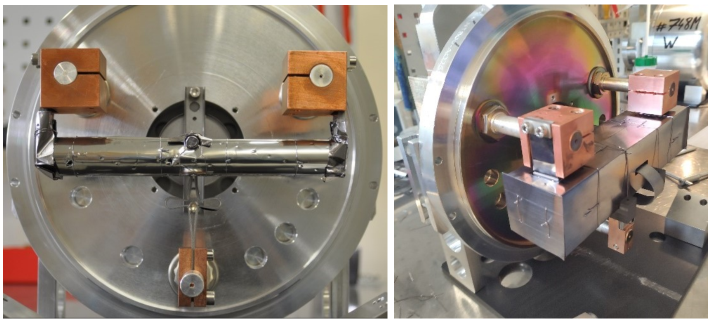


Figure 1: Evolution of the heat shielding: the current thermal screens (left) and the new design with independently supported thermal insulation system (right).

Regarding the new heat shielding, it consists of a layer of graphite soft felt, sandwiched between two layers of Ta foils, designed to provide superior heat insulation, as well as to protect the Ta container from chemical reactions with C. The heat radiates out from the outer layer, enhancing temperature distribution across the target container. It has been demonstrated that with the new design, the target life span has been significantly increased. Figure 1 illustrates the evolution of the heat shielding design.

Initially, the thermal insulation system was massive, complicated and not precise enough to ensure minimum contact points with the container. It was made from two large blocks, held independently in place by two graphite supports, providing mechanical stability. However, using 3D printing, the design was significantly optimized through various design iterations. The massive blocks were broken up into to different simplified components, which were rapidly manufactured and iteratively designed to ensure a faster and more reliable assembly process. The modularity of the current concept is demonstrated in Fig. 2. In order to reduce heat absorption, high reflectivity coatings using advanced UHTCs (Ultra-High-Temperature Ceramics) are under investigation to control further radiative heat transfer, by tailoring surface emissivity and reflecting heat back to the container more efficiently.

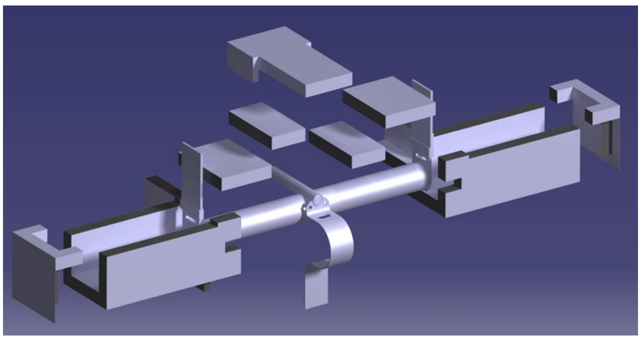


Figure 2: Thermal shielding modularity.

It is envisaged that the new thermal insulation subsystem will be considered as an indispensable part of the target development. Using special assembly jigs, the production of the modular heat shield blocks will be facilitated. The prefabricated modular heat shield blocks will provide a cost-effective solution with new enhanced features including, but not limited to, easy and quick installation, reproducibility, extended life span, lower power consumption and potential reusability.

2 Novel target materials via Electrospinning

At ISOLDE, among the main technical challenges for the production of RIBs is the design of target materials so as to foster in-target production of isotopes via nuclear reactions, while simultaneously allowing for fast diffusion and effusion times to be able to study short-lived radioisotopes. This requires a careful compromise between density and pore structure, while also maintaining the required levels of thermal stability to limit sintering and maintain these properties at higher temperatures of operation. Of particular interest in this area are, on the one hand, nanomaterials with increased surface areas and fine internal microstructure, such as nano uranium carbide (produced from multi-walled carbon nanotubes and in-house produced nano-UO_2) and on the other hand, ceramic fiber-based materials for which yield improvements have been reported by ISOLDE experiments [1]. Aiming to combine the advantages of both, a new development program was launched to produce nanofiber-target materials via electrospinning. In this method, nanofibers are produced by creating a solution of the bulk material precursor with a dispersed polymer and then pushing it through a syringe needle to which a large voltage is applied, leading to the creation of a Taylor cone where the solvent is broken down and the electrically charged nanofibers are projected onto a grounded (or inversely biased) collector surface (see Fig. 3) [2].

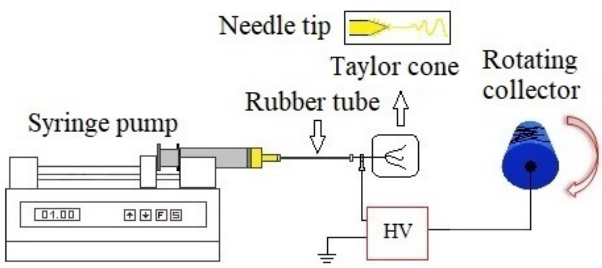


Figure 3: General scheme for an electrospinning setup.

This technique is already used in industry and has proven to be highly versatile, allowing the creation of highly uniform fibers (see Fig. 4), which would otherwise require highly tailored and expensive deposition methods. Moreover, electrospinning is considered to be significantly safer as the nanofibers are created inside a polymer matrix (preventing airborne contamination). Some materials produced by this technique present improved thermal shock resistance, resistance to mechanical stress derived from irradiation and increased stability even in the presence of localized structural defects, allowing for longer runs without significant degradation of the isotope release [3]. Using this method may also increase the number of elements covered and differently structured target materials, helping to improve the viability of experiments that would suffer from low release efficiencies with existing materials, and even potentially open up new radioisotopes for study, which were too short-lived to efficiently extract from similar, but micrometric target materials (ISOLDE has reported online production of around 1000 isotopes from 74 different elements [4]).

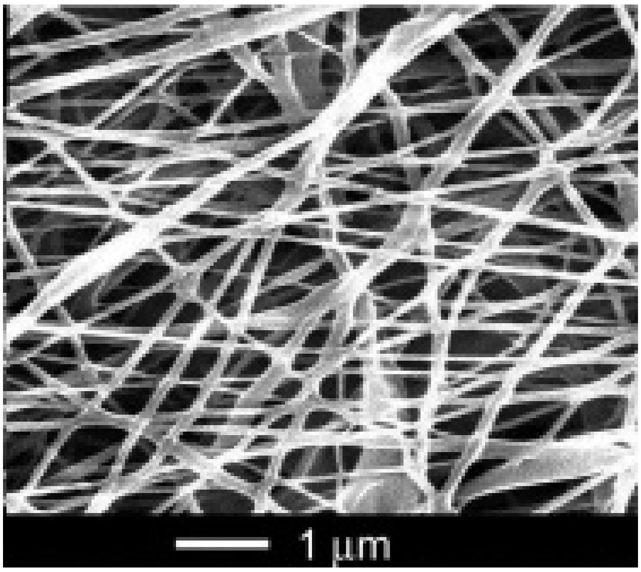


Figure 4: SEM image of Ni acetate + PVA nanofibers after heat treatment [5].

A modular commercial setup has been acquired. Initial plans are focused on the production of ZrO_2 nanofibers, as a micrometric equivalent is occasionally requested by users of ISOLDE. The goal is to optimize the structure and to study, firstly, microstructural changes with increasing operational temperatures and secondly, the structural impact of the polymer pyrolysis on the target material. Analytical techniques such as mass spectroscopy, X-ray diffraction (XRD), He-gas pycnometry, gas adsorption-desorption measurements (BET) and scanning electron microscopy (SEM) will be utilized.

Should viability be established for ZrO_2, there are plans to try HfO_2 and Y_2O_3 (this is currently already a nanomaterial-based target) and investigate the formation of carbides as an alternative to current conventional carburization methods (such as UC_x), or even other applications outside of target materials.

3 News from RILIS

In the 2021 physics campaign, the resonance ionization laser ion source (RILIS) was used in 21 out 23 weeks of operation. A recent upgrade of the observation and stabilization system during LS2 now allows for delivery of RILIS lasers to both HRS and GPS at the same time - a feature that was already used at the end of the year to avoid changing times while running a Dy collection at GLM over night and providing Ac beams to users throughout the day without switching delays. This new mode will e.g. allow RILIS-ionized beams to be used at GLM/GHM and at the central beam line via HRS in parallel.

Investigations on the long-term stability of beam delivery in the deep UV range, being compromised by deposit build-up on transport optics, identified certain dye solvents as the main cause. Replacing these chemicals with respective alternatives during operation led to a substantial increase in operation time without need for manual intervention; previously a RILIS operator had to clean the optics every few hours. In the same project, a new ionization scheme for Pb was developed that projected a 10-fold increase in efficiency compated to the previously used one. The new scheme was employed for a successful COLLAPS beam time a few months later.

A new laser beam shutter system, made from old hard disk drives and Arduino control boards in a cost-efficient and easily reproducible way, was introduced to the users for easy software control via the ISOLDE control PCs. Besides being useful during dual-separator operation, now multiple beams can be blocked individually to monitor their influence on the created ion beam.

3.1 A laser ion source at Offline 2

Comissioning of a dedicated laser lab for the Offline 2 separator was finished this year, with the first laser-ionized beam being samarium. The laser lab itself (see Fig. 5) features the same laser systems as employed at ISOLDE, thus also serving as an emergency back-up system in case of critical failure of RILIS equipment. Closely resembling the ISOLDE frontends, Offline 2 is the main development platform for ISOLDE and MEDICIS laser ion source technology. Additionally, coupling of lasers into the local copy of ISCOOL can be performed. Ongoing projects include the investigation of ion load limitations due to possible excessive contamination, efficiency-preserving ways of improving ion beam purity by exploiting the bunched time structure imprinted by the pulsed laser system and fast ion beam gating (Time-of-flight ion source ToF-LIS).

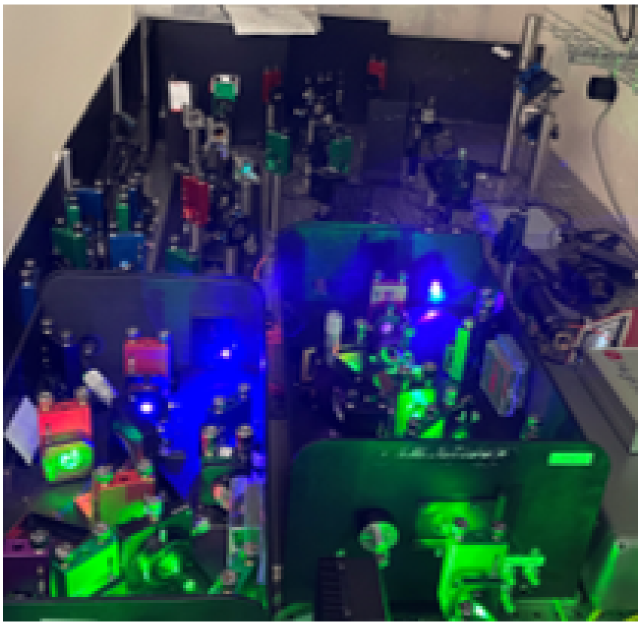


Figure 5: Laser setup at the Offline 2 separator.

The recently developed Raman converters [6, 7], allowing easier access to certain wavelength regimes by shifting a standard laser output, were tested under realistic ion source conditions and are confirmed to be applicable for ISOLDE on-line operation this year.

3.2 The (PI-)LIST for ISOLDE

The Laser Ion Source and Trap (LIST) provides a way of producing clean ion beams at the cost of efficiency decrease [8]. Various proposals request this tool for investigations of isotopes with the same mass as heavily produced and surface-ionized contaminants such as francium or some lanthanides. A new RF voltage supply infrastructure for both frontends was installed, and electrical coupling and functioning of the LIST confirmed with stable beam at the end of last year. Yield and contaminant suppression capability measurements for the envisaged experiments are planned for just before start of the 2022 physics campaign.

An important milestone towards the high resolution operation mode of the LIST using perpendicular illumination (PI-LIST) [9, 10] was reached at the end of last year, when the off-axis beam path through the extraction electrode was tested. Instead of being limited by the Doppler broadening in the hot vapor of the hot cavity, laser linewidth-limited resolution was demonstrated (see Fig. 6). By using a dedicated narrow-bandwidth laser, spectral resolution down to the 100 MHz regime can be achieved, suitable for nuclear structure investigations or isomer-selective ion beam production.

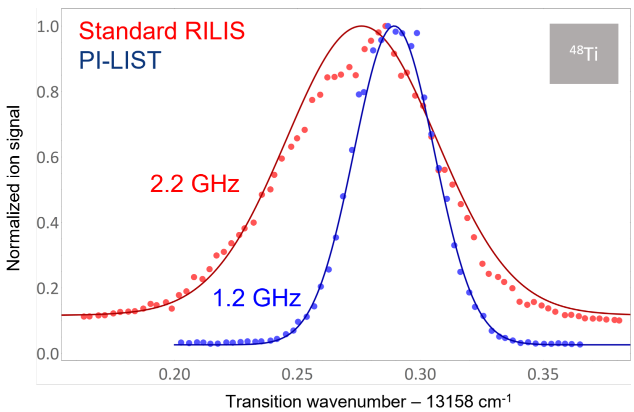


Figure 6: Linewidth comparison of standard RILIS in-source operation and PI-LIST. The spectroscopic linewidth is limited by the available laser instead of the Doppler broadening in the hot cavity. A regime around 100 MHz is possible with a suitable laser system.

The combination of the PI-LIST with a recently developed Raman single mode laser is being tested at Offline 2 in February 2022 to optimize operation parameters and explore limitations of the technique. An application at ISOLDE is foreseen in the LIST yield measurement period before the start of physics and for different experiments throughout the year, where both frontends have been equipped with PI-LIST-compatible extraction electrodes.

4 LISA at ISOLDE

The Laser Ionization and Spectroscopy of the Actinides (LISA) project [11] represents one of many endeavors to develop knowledge in the heavy regions of the nuclear chart. The large community's growing scientific interest in actinide species strongly motivated new developments to facilitate availability of actinide beams at ISOLDE. During the re-commissioning of ISOLDE in June 2021, a previously irradiated target was used to study extraction behaviour of the actinides. ISOLDE RILIS Ti:sapphire lasers were used to provide a series of two-step resonant ionization laser schemes for long-lived species of the light actinides Ac, Pa, U, Np, and Pu from a uranium carbide (UC_x) target with a hot cavity surface source. In combination with resonant laser ionization, the beam composition was studied with the ISOLTRAP Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS) [12], providing identification by Time-of-Flight (ToF) mass measurements. Atomic beams of Ac, U, Np and Pu were identified by laser resonance or ToF. Atomic laser-ionized Pa was not observed, and Th was not attempted. This work has identified the target temperatures at which some of these species start to be released as atoms from UC_x. Out of these, Pu was observed to be the easiest to extract in atomic form. The other actinide species were only visible at high (2000 ℃) target temperatures and were only extracted with low intensities, confirming the challenge of efficiently extracting these refractory elements. The successful production of two new elements at ISOLDE has motivated plans for further laser spectroscopy studies on these elements.

Extracting an isotope of interest as a molecule can give some degree of chemical separation and change the chemical properties of the actinide species, including volatility, vapor pressure and adsorption enthalpy. Molecular beams have been studied for decades at ISOLDE [13, 14, 15, 16] as a way to enhance extraction efficiencies of isotopes of interest, allowing the ISOL target and ion source to provide high-purity beams for otherwise refractory or contaminated beams such as carbon [17] and boron [4]. Fluorine reacts with several of the actinides to form molecules that are stable in the high temperature environments presented by target-ion source systems. This makes fluoride beams a promising potential avenue to get access to light actinides and to study actinide molecules. The in-target volatility of the actinide fluorides is unknown, along with many chemical properties that make the actinide molecules themselves interesting for topics in nuclear chemistry.

In July 2021, a target development campaign was carried out using CF_4 gas as a candidate for molecular sideband extraction of the actinide elements via formation of volatile fluoride molecules. Several surface-ionizable actinide fluoride molecules were stable enough to survive the high-temperature environment of the target-surface ion source system and were identified with ToF mass measurements at the ISOLTRAP MR-ToF MS. These studies give information on some actinide molecules with low ionization potentials and identified some of the surface-ionized background and challenges involved for experiments interested in these beams. The results serve to facilitate delivery of actinide and actinide molecular beams at ISOLDE. The development campaign motivated a similar experimental plan for 2022 in which the actinide fluorides will be revisited with improved mass resolving power at the ISOLTRAP MR-ToF MS and a different ion source to give access to molecular sidebands with higher ionization potential. The aim of the campaign is to study extraction properties and production of the actinide molecules. Some of the actinides may form even heavier fluoride molecules which are of interest for extraction and molecular breakdown studies.

This project has received funding from the European's Union Horizon 2020 Research and Innovation Programme under grant agreement number 861198 project 'LISA' (Laser Ionization and Spectroscopy of Actinides) Marie Sklodowska-Curie Innovative Training Network (ITN).

5 Offline developments for molecular beams

Recent interest in radioactive molecules [18] has pushed developments for specific molecular beams for fundamental physics research [19]. The ISOLDE Offline 1 and 2 mass separator facilities are crucial for these molecular beam developments. Many fragile molecules dissociate in the high temperature environment of the various ISOLDE targets and ion sources, making them difficult to deliver as ion beams. An alternative route to make and deliver specific molecules is to use ion trap environments for low-temperature molecular formation in the ISOLDE beam line, far from the target and ion source. Molecular formation from the primary mass-separated beam has already been observed in both the ISCOOL RFQcb and the ISOLTRAP RFQcb at ISOLDE, likely due to collisions with contaminants in the buffer gas. The use of buffer gas gives a mechanism to deliberately inject species for molecular formation with the radioactive ion beam. Formation of long-lived RaOH+ has already been observed in an ion trap environment [20]. Development of a gas mixing and injection system is ongoing at the ISOLDE Offline 2 facility, along with the design of a mass separation device after the offline RFQcb to identify and systematically study the in-trap formation of the molecules.

6 News from the ISOLDE fast tapestation

The employment of an adequate radioactive decay detector setup is essential for the operation and quality control of radioactive ion beams (RIBs) produced at ISOLDE. Not only is it required as primary asset for the determination of production yields during each physics experiment, it is also used as a diagnostic tool (proton beam alignment, beam composition) during beam commissioning. The new Fast TapeStation (FTS) is an upgrade of the previously installed setup, utilized for more than 40 years until 2018, and represents an optimization in terms of noise and timing. In detail, it consists of a vacuum chamber with four detector positions (P0-P3), where P0 hosts an in-beam β-detector, P1 a 4π β-detector, P2 a HPGe detector for the measurement of γ-radiation and P3 is not yet used (see Fig. 7).

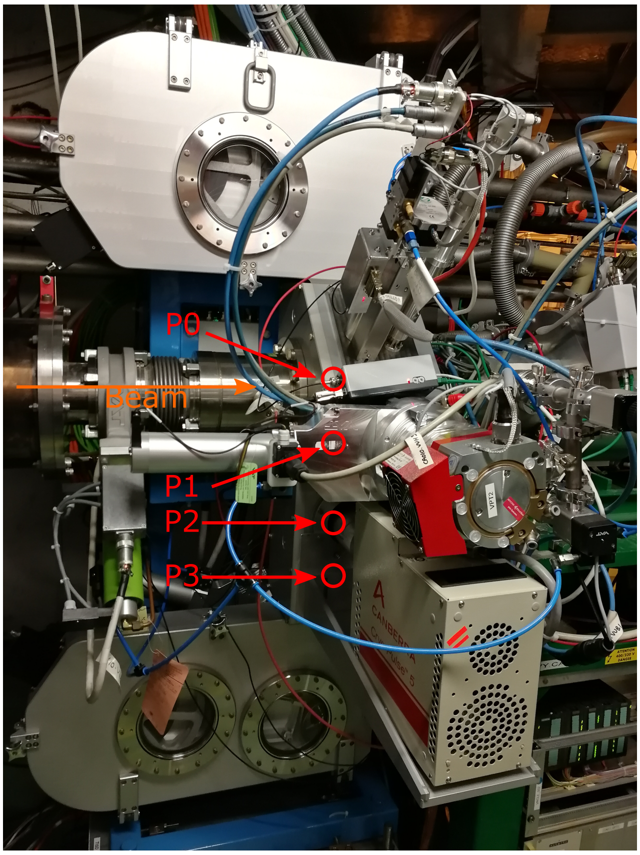


Figure 7: ISOLDE Fast TapeStation installed at CA0. The labels indicate detector positions: P0 in-beam β-detector, P1 4π β-detector, P2 γ-detector, P3 empty (α-detector in the future).

The new FTS reduces transport times to $\sim$ 150 ms compared to $\sim$ 1000 ms in the old design. Furthermore, the in-beam detector enables detection of very short-lived radioisotopes. Noise issues have been improved by employing β-detectors based on silicon photomultiplier (SiPM) 3x3 arrays with integrated Front End

Electronics-preamplifiers, thereby reducing noise pick-up due to passing of short and weak signals through a noisy environment towards the preamplifier. More information concerning the employed β-detectors can be found in [21]. As mentioned in [22], the FTS was first commissioned in 2018 at LA2 and recently transferred to its final location in the central beam line CA0. 2021 was its first operational run where it was routinely used for yield determination and proton beam optimization. The FTS performed smoothly without major complications. Particularly useful was the online visualization of energy spectra and count rate evolution for identification purposes, realized by splitting the slow (energy) and fast (timing) signals and passing one set to a CAEN DTS5725 digitizer. The other set is transferred to a counter that is typically used for yield measurements.

In total, 41 yields have been determined from 19 different isotope-target combinations (some were the same combinations at different temperatures). Some highlights were ^{59}Zn ($T_{1/2}$ = 181 ms), ^{32}Ar ($T_{1/2}$ = 98 ms) and ^{110,113,115}Sb (measured for the first time with the PSB). While a variety of β- and γ-decaying nuclei were successfully measured, limitations at heavy masses (Fr, Ra and Ac) were faced due to the lack of suitable α-detectors. In addition, high background γ-rates, originating from radiogenic gases escaping the target, hampered operation. Therefore, a campaign aiming to expand the FTS capabilities by installing an additional β-detector at P2 to enable background suppression by means of $\beta - \gamma$ coincidences, and installation of a PIPS-detector at P3 for α-detection is ongoing.

7 Beam switching project: feasibility study

Radioactive ion beams can be produced at the ISOLDE experiment at two target stations: at the General-Purpose Separator (GPS) and at the High-Resolution Separator (HRS). Upon creation, the ion beam is controlled by applying different voltage potentials in certain optic devices. Currently, the switch-over between ion beams from the two Front-End (FE) separators to the beam lines is done manually and requires about 10 minutes. The two FEs are usually not able to be operated in parallel, given that they share a beam delivery line (CA0) which causes a bottleneck in production and, thus, a restriction in the number of physics days that ISOLDE can deliver to the users. Under this framework, the beam switching project [23] was proposed (see Fig. 8). This project comprises adding a second pair of voltage supplies in each optical device on CA0 and a high voltage (HV) switch that is able to change between power supplies remotely, automatically and in times below 100 ms.

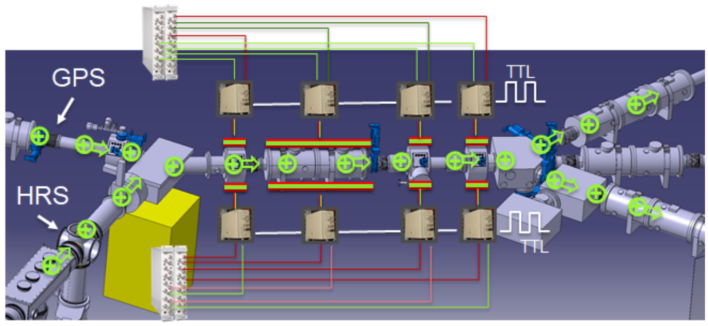
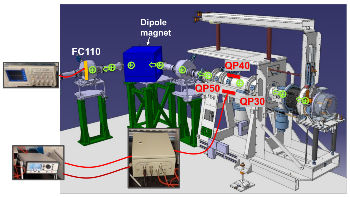


Figure 8: Beam switching technology proposal.

A feasibility study was conducted where the ISOLDE requirements served to build in-house a robust switch box based on relay switching technology. A complete developmental program was conducted, including simulations, material selection and purchasing (counting on a SY-ABT group collaboration), assembly and testing. Subsequently, several tests were performed at the offline 2 facility, and the switch box was compared to existing solid-state switching technology, which offers better results at the expense of higher costs. Both switching devices were connected to the quadrupoles (QP) of offline 2 (QP30, QP40 and QP50) and the switching time was determined. Overall, optimal switching times were deduced for both technologies and the aforementioned QPs (see Fig. 9). It is important to mention that the cable length between the switching device and the QP charging plate relates linearly with the charging time needed. Furthermore, the beam sensitivity to different QPs was noted, obtaining differences in charging times with a factor 6 between the different

QPs. Finally, the solid-state technology showed faster charging times compared with the switch box made in-house (factor 5 faster, shown in Fig. 9).

The next step is to test both technologies at ISOLDE to obtain the lowest charging time within the beam line. This will be an essential parameter to decide whether the switching based on relays can already fulfil the requirements or if the more expensive solid-state switching technology would be needed.



	Time (ms) to transmit 95% of beam	
Quadrupole	Switch Box	Solid State
QP30	10.12	**1.88**
QP40	30.8	**5.56**
QP50	3.16	**1.84**

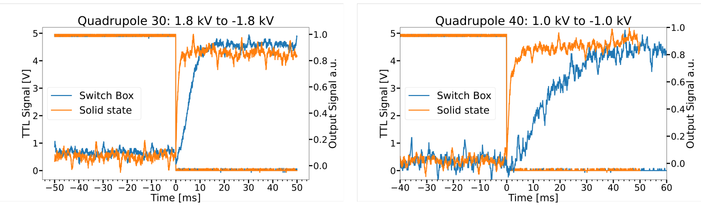


Figure 9: Top left: schematic switching technology test configuration at offline 2. Top right: results obtained for both switching technologies using QP30 and QP40. Bottom: switching time of both technologies using QP30 (left) and QP40 (right) after sending a TTL trigger signal.

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RIB Applications

Major beamline upgrades pushing β-NMR towards applications in biomolecules

Results of experiment IS666

Marcus Jankowski for the BetaDrop NMR Team

The β-NMR beamline at ISOLDE combines spin polarisation using optical pumping and an efficient detection of β particles to reach an ultra high sensitivity compared to conventional NMR. The setup has already generated pioneering results, namely the determination of a magnetic moment of an unstable nucleus, ^{26}Na, with an unprecedented ppm-accuracy [1], which is a hundredfold improvement over what was possible before. Still, the resolution of the setup needed enhancement for the biochemistry applications aimed for in the ongoing experiment IS666: studying the interaction of Na and K with DNA G-quadruplexes [2]. To enable these investigations, several major upgrades were implemented in 2021.

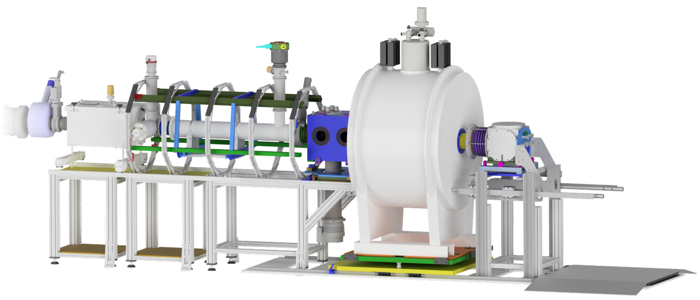

Figure 1: Rendering of the β-NMR beamline (polarisation and detection section) including the superconducting magnet.

The most important advancement is a new superconducting magnet, see Fig. 1, whose 4.7 T magnetic field is fourfold stronger than its predecessor's. It also offers higher stability and sub-ppm homogeneity around the sample. Further upgrades include a dedicated detector array with thin scintillators and silicon photomultipliers placed in front of and behind the sample along the beam axis. To record NMR resonances, visible as the change of β decay asymmetry over frequency, a new FPGA-based data acquisition system was installed that saves characterising properties of each single β event, including its time of arrival, signal amplitude and integral.

First polarisation and β-NMR experiments with the upgraded setup, using ^{26}Na beam and ionic-liquid hosts, took place in July and September 2021. The experimental setup was fully commissioned and highly resolved β-NMR resonances were recorded. The FWHM was reduced to around 70 Hz, see Fig. 2, compared to a few hundred Hz [1] at 1.2 T in the previous setup [3]. In addition to this achievement, ^{37}K was for the first time successfully polarised in November 2021.

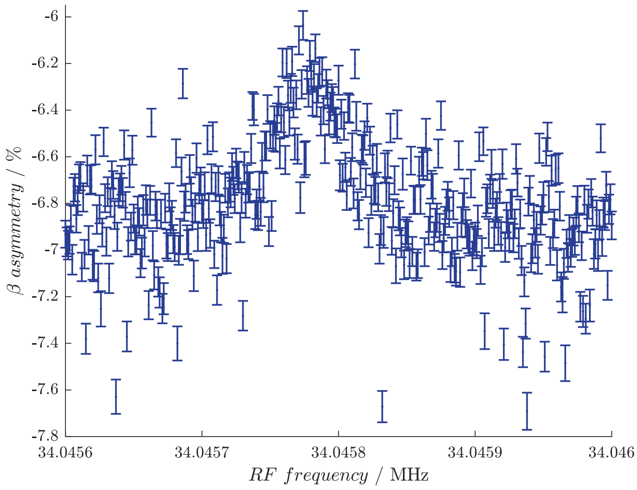

Figure 2: β-NMR resonance of ^{26}Na in an ionic liquid.

The improved resolution and additional advancements based on the upgrades push the boundaries of the β-NMR beamline further, paving the way for exciting investigations of Na and K with DNA in 2022 [2, 4].

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Production of metastable xenon nuclei for gamma-MRI

Results of IS691

Mateusz Chojnacki and Karolina Kulesz
for CERN gamma-MRI team

Gamma-MRI is a project devoted to developing a new imaging modality based on the detection of asymmetric gamma emission from aligned unstable nuclei, and change of this asymmetry upon RF excitation in a gradient magnetic field. It should pave the way to a new medical imaging modality, capable of overcoming the limitations of existing imaging techniques: MRI, SPECT and PET [1].

The study will use $11/2^-$ isomers of three xenon isotopes: ^{129m}Xe ($T_{1/2}$=8.88 d), ^{131m}Xe ($T_{1/2}$=11.84 d) and ^{133m}Xe ($T_{1/2}$=2.19 d). In 2021, three methods of their production were tested [2].

The first method allows to produce ^{129m}Xe and ^{131m}Xe via neutron irradiation of stable xenon isotopes ^{128}Xe and ^{130}Xe enclosed in quartz ampoules inside a reactor core. In 2021, the irradiation took place at the ILL reactor in Grenoble (the strongest thermal neutron flux in the world: $1 \cdot 10^{15}$ n/s·cm^2). The quartz ampoules prepared at ISOLDE were irradiated for 7 days. After returning to CERN, they were opened and transferred to transport vials in a specially prepared setup (Fig. 1) by using an LN_2 trap. Gamma spectroscopy before and after the procedure showed that the transfer efficiency was 84% (the final activities: 170-240 MBq). As the ILL reactor will shut in 2022, the irradiation are now planned at the Maria reactor in Poland, which has the second strongest thermal neutron flux in the world ($2 \cdot 10^{14}$n/s·cm^2).

The second method is based on production from UC_x target and plasma ionization at ISOLDE. This method access to be produced all three ^{m}Xe isotopes. In 2021, we tested online production at GPS (with proton on the target) and offline production (the target was irradiated behind the regular HRS target a few days prior to being placed at the GPS position). The ^{m}Xe isotopes were implanted in gold foils at the GLM collection chamber, extracted after heating the foils to 300-400^{o}C, and collected in transport vials. Gamma spectroscopy of implanted gold foils showed that all three Xe isomers are produced in both modes. However, the extraction in offline mode provides less intensity. The ratios of activities produced for online and offline mode are: 30 for ^{129m}Xe, 40 for ^{131m}Xe and 2 for ^{133m}Xe.

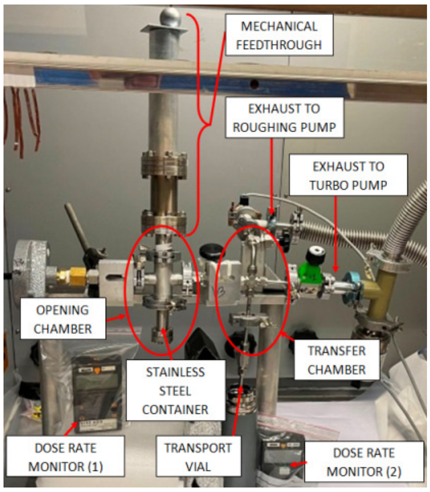

Figure 1: The setup for opening quartz tubes with ^{129m}Xe, ^{131m}Xe .

The last method of production uses ^{131}I ($T_{1/2}$=8 d) which decays to ^{131m}Xe (branching ratio: 0.39%). In 2021, a sodium iodine powder (NaI) was used as a source of ^{131}I, commonly used in nuclear medicine. ^{131}I was decaying to ^{131m}Xe for several days inside a specially prepared setup, then ^{131m}Xe was extracted from the powder by heating it to 100-200^{o}C. Up to 100 kBq were obtained from 50 MBq of ^{131}I. For the GBq sample of ^{131}I, several MBq of ^{131m}Xe should be reached. The main disadvantage of this method of production that during the heating process gaseous chemical contaminants are produced from NaI powder excipitiens (useful in therapeutic applications).

https://gamma-mri.eu/

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First results on lattice location of Mg, Ca and Sr in diamond: evidence for group-II vacancy center formation

Results of experiment IS668

Ulrich Wahl for the EC-SLI collaboration

Mg-vacancy (Mg-V) colour centers in diamond are candidates as single photon emitters for quantum information processing [1, 2], exhibiting a zero-phonon line (ZPL) with a large Debye-Waller factor at 557 nm. It is assumed that this type of defect consists of a Mg atom located on a bond-center (BC) like position inside a double vacancy [2] and that it can be efficiently produced by ion implantation [1]. However, theory has predicted similar energies of formation for Mg on substitutional (S) sites, Mg on BC inside a double vacancy (MgV), but also for Mg inside a triple vacancy, the so-called MgV2 complex (with Mg displaced 0.62 Å from S site along <100>. It is hence of relevance to clarify whether these structures are indeed formed upon ion implantation and to study their formation conditions. During our first emission channeling (EC) beam time following LS2, which took place at the beginning of July 2021, we investigated the lattice sites of ^{27}Mg ($t_{1/2}$=9.5 min) as a function of implantation temperature in single-crystalline CVD diamond. We found that for the whole implantation temperature range from RT up to 800 ℃, Mg was found on substitutional (S) and BC sites (Fig. 1), with the corresponding fractions varying around 12-23% for S and 30-40% for BC sites. It seems possible that the remaining 40-50% of Mg atoms, which contribute only weakly to the angular anisotropy, are, at least partially, located in other vacancy-containing defects. These could be MgV2 or even higher order complexes like MgV3, the structure of which has not yet been predicted in the literature. The optical characterization of diamond implanted with stable Mg isotopes at the University of Turin confirmed the existence of single photon emitters at 557 nm using autocorrelation techniques. Experiments were also performed using the long-lived isotopes ^{45}Ca (164 d) and ^{89}Sr (45 d) of the other group-II elements Ca and Sr. Here RT implantations were followed by emission channeling characterization as a function of annealing temperature. While the detailed outcome is currently being analyzed, first results clearly show the occupancy of BC sites. On the other hand, the anisotropy features relating to the occupation of S sites are considerably less pronounced than in the case of Mg, e.g. axial <100>and planar (110) effects were almost undetectable.

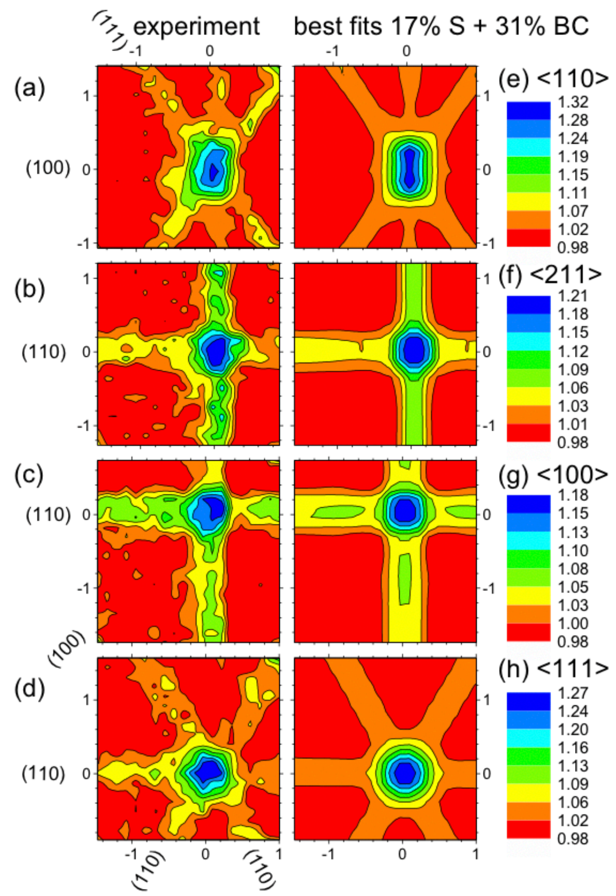

Figure 1: (a)-(d) Experimental β^- EC patterns from ^{27}Mg implanted CVD diamond during implantation at 800 ℃. The plots (e)-(h) are the corresponding fits of theoretical patterns considering ∼17% on ideal substitutional (S) and ∼31% on ideal bond-center (BC) sites.

https://isolde.web.cern.ch

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Local probing of dynamic hyperfine interactions in the $CaMnO_{3-\delta}$ system

Results of experiment IS647

Pedro Rocha-Rodrigues, Armandina Lopes
for the IS647 collaboration

Within the framework of IS647 "Local Probing of Ferroic And Multiferroic Compounds" we have revisited the $CaMnO_3$ perovskite, as recent *ab-initio* molecular dynamics (MD) simulations have shown that the high temperature $CaMnO_3$ cubic $Pm\bar{3}m$ symmetry may arise as a dynamic averaged structure, as the crystal structure fluctuates between equivalent orthorhombic configurations, advancing the nature of the orthorhombic-to-cubic structural transition as of the dynamic order-disorder type and not the previously thought displacive type [1].

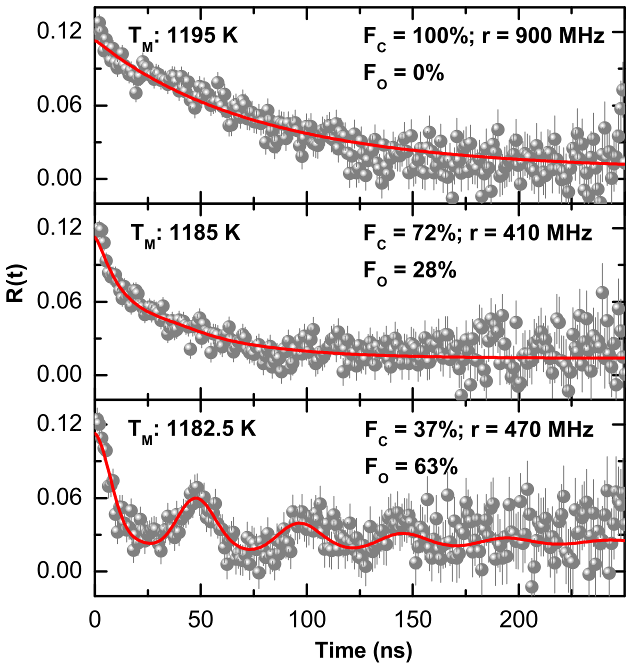

Figure 1: High temperature $R(t)$ functions and corresponding fits (red lines). The $R(t)$ functions were fitted using two fractions, to consider an orthorhombic and a dynamic averaged cubic structure, interaction weighted respectively by the probe distribution in the respective fractions F_O and F_C.

Perturbed γ-γ angular Correlation (PAC) measurements were carried out at the ISOLDE facility during a ^{111m}Cd beamtime to characterize the evolution of the Electric Field Gradient (EFG) distribution at the Ca-sites across the previously reported orthorhombic-cubic structural transition sequence.

A stochastic fluctuating hyperfine field model based on Winkler and Gerdau theory was developed to analyze the experimental data. Admitting a stoichiometric $CaMnO_3$ system, we have studied how the evolution of observable EFG-distribution may provide the experimental evidence for these order-disorder dynamics, and, serve as a tool to measure the characteristic octahedral hopping rates (r), exhibited either by $CaMnO_3$ and/or other analog systems in such transitions. However, in this particular case study, we have observed that the evolution of the observable perturbation function, $R(t)$, across the supposed orthorhombic-to-cubic transition (1180-1190 K), is not described by a smooth increase of the structural hopping rates as previoulsy suggested for this type of dynamic structural transition [2].

Instead, a coexistence of two distinct local environments, labelled as F_C and F_O in Fig. 1, both portraying highly attenuated R(t) profiles, is seen around the critical transition temperature. Above the supposed orthorhombic-to-cubic structural transition, the local probe results can be fitted within the proposed dynamic order-disorder model, where a time-decaying exponentially shaped perturbation function, $R(t)$, is observed around 1195 K. However, the estimated rate for structural hopping events, from the experimental data analysis, is of the order of 900 MHz at 1195 K, which is around 10^3 lower than the characteristic times of fluctuations of octahedra tilting and rotation that have been proposed by the MD simulations in the literature [1]. Further PAC measurements performed under distinct sample environments, such as distinct O_2 (g) partial pressures, suggest that the nature of the observed dynamic hyperfine interactions in the $CaMnO_{3-\delta}$ cubic phase is not related to intrinsic property of the $CaMnO_3$ system, such as the proposed dynamic order-disorder structural transition, but related with the formation of oxygen vacancies in the $CaMnO_{3-\delta}$ system. Furthermore, in both of our temperature/sample environment dependent PAC studies we have obtained evidence for a direct structural transition from the orthorhombic *Pbnm* to the $Pm\bar{3}m$ cubic symmetry, whereas the previously reported intermediate $I4/mcm$ tetragonal symmetry [3] was not detected.

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eMIL meets eMMA soon: Mössbauer set-up for magnetic measurements

Results of experiments IS578

Dmitry Zyabkin, Juliana Schell and Peter Schaaf
for the Mössbauer collaboration at ISOLDE/CERN

The extreme sensitivity of Mössbauer spectroscopy makes it possible to spot even subtle changes and obtain in-depth details on electronic, magnetic and structural properties of materials. The method has been in use at ISOLDE for several decades and has recently got a new life in the form of eMIL. This is a completely new and versatile on-line/offline Mössbauer spectrometer, which utilizes the might of radioactive beams at ISOLDE. Depending on the isotope and its lifetime, Mössbauer measurements may occur simultaneously or can be separated in space and time. The set-up (see Fig. 1) is capable of performing measurements in a broad temperature range, under various external exposures (*e.g.* UV irradiation) and is fully automized, thus it is a solid base for any future extensions [1].

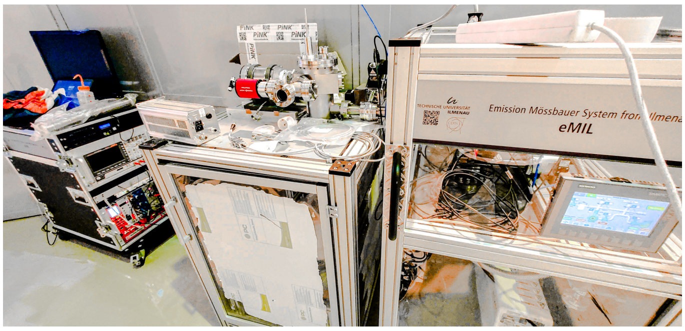

Figure 1: eMIL installed at the GLM area in preparation for offline measurements.

Choosing among several possible directions for further development of Mössbauer spectroscopy at ISOLDE, the collaboration set their eyes on extensive studies of magnetic materials. The attention was mainly sparked by first studies performed with the ^{119}In/Sn isotope on a $Mn_{0.8}Ga$ sample, where one would expect tiny hyperfine fields at Ga sites instead of huge ones, indicating a clear magnetic nature of Ga sites [2].

Taking this into account, construction of a new set-up (eMMA, for Emission Mössbauer Magnetic Analyser) for high field Mössbauer spectroscopy began. During the development and production, there were several important points to address: a) in-situ magnetic environment with variable magnetic fields; b) elevated/cryogenic temperature options; c) fast sample change (interlock chamber); e) eMMA should be able to run standalone.

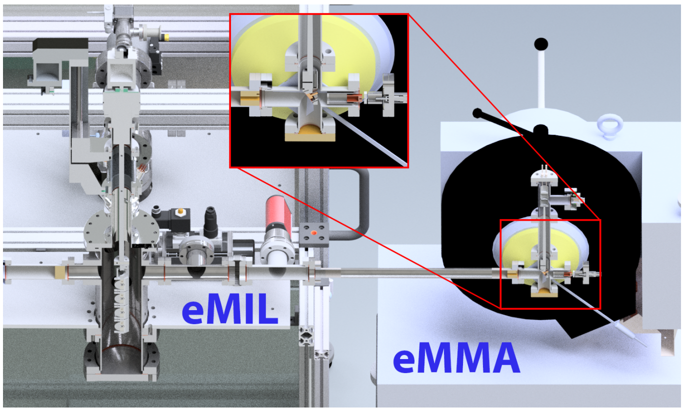

Figure 2: Partial view of both eMIL and eMMA, with special attention paid to the eMMA's implantation chamber.

All aforementioned criteria have been met. eMMA is plugged directly to either the eMIL or GLM implantation branch, and only eMIL's control unit is needed. In order to reach rather high magnetic fields, the implantation chamber is designed to fit between two magnetic cones of the VSM system (see Fig. 2). The latter allows one to get up to 2.3 T at the sample (up to 1×1 cm^2). The special design of the eMMA's chamber allows to implant and collect data simultaneously. The parallel-plate avalanche-counter is placed under the VSM magnets, on a standard electromechanical double-loudspeaker drive, which can be replaced with a piezo drive in the future, in order to decrease the need for frequent recalibration. At the moment, there are two sample holders, with temperatures varying from -196 to 500 ^{0}C. Such a broad range makes it possible to perform and study phase transitions directly in the chamber.

The new setup is expected to be delivered to ISOLDE at the end of this spring and be of great help in the disentangling of magnetic phenomena in solids.

http://e-ms.web.cern.ch/

The authors acknowledge the financial support by the Federal Ministry of Education and Research of Germany (BMBF), contract # 5K19SI1.

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Vacuum-ultraviolet spectroscopy of the ^{229}Ac decay: Towards the first observation of the radiative decay of the low energy isomer ^{229m}Th

Results of experiment IS658

Sandro Kraemer and Janni Moens
for the IS658 collaboration

A unique feature of ^{229}Th is its isomer with an exceptionally low excitation energy. The transition between ground- and isomeric state has been proposed as a candidate for future optical clocks [1]. The small decay width is expected to outperform the accuracy of current state-of-the-art atomic clocks by an order of magnitude [2]. The current best measured values of the excitation energy are 8.28(17)eV and 8.10(17)eV [3, 4]. The first value was obtained using conversion electron spectroscopy and results in a vacuum wavelength of 149.7(31)nm, while the latter has been measured using a microcalorimetric approach and predicts photons at 153.1(33)nm. Vacuum-ultraviolet grating spectroscopy of the isomer's decay allows further reduction of the uncertainty of the isomer's excitation energy, an input urgently needed for the development of powerful lasers to achieve nuclear excitation in a future optical clock.

Photons from the radiative decay of ^{229}Th's isomer have to-date not been observed experimentally. The hyperfine interaction with the crystalline host environment, potentially allowing for a deexcitation of the isomer via the electron conversion channel, and the violent alpha-decay of the precursor nucleus ^{233}U and its induced background challenge the search for the radiative decay in a solid-sate host matrix. An alternative approach based on emission-channeling characterization of the crystalline host material and the population from the beta-decay of ^{229}Ac was developed at ISOLDE [5, 6]. The significantly lower background induced by a beta- compared to an alpha-decay combined with thin-film large-bandgap calcium fluoride crystals reduce the background, masking the isomer's radiative decay, by orders of magnitude.

Preliminary results from emission channeling measurements performed at ISOLDE in 2018 attribute a suitable lattice location to actinium atoms after implantation, expected to block the electron conversion decay channel of the isomer. In beamtimes in autumn 2021, vacuum-ultraviolet spectroscopy of the decay of ^{229}Ac, in which a significant fraction of the decays populates the low-energy isomer of thorium, revealed photon emission from the nucleus at a wavelength comparable with the current knowledge of the isomers' properties. Additionally, the effect of the actinium beta-decay on the lattice position and other host materials was studied in the 2021 beamtime using the emission channeling technique.

The experiments provided evidence for a radiative decay of the low-energy isomer in ^{229}Th embedded in a crystalline host medium with important consequences for the development of a solid-state optical clock. Further analysis is expected to reveal a new value for the excitation energy and limits to the currently unknown half-life of the radiative decay of the isomer.

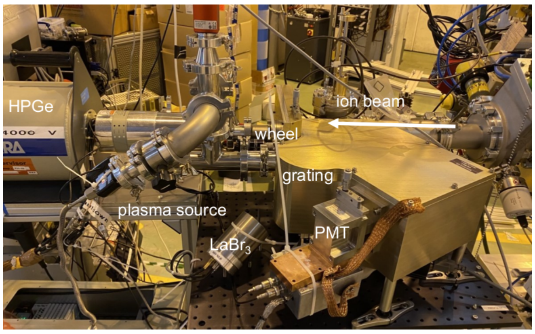

Figure 1: The VUV spectroscopy setup installed at LA1.

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Ground-state properties

CRIS in 2021

Experiments IS657, IS660 and IS663 *Jordan Ray Reilly for the CRIS collaboration*

The CRIS collaboration had another successful year despite the restrictions imposed due to COVID-19. Highlights included publishing our paper in *Physical Review Letters*: 'Isotope Shifts of Radium Monofluoride Molecules'[1], and carrying out two experimental campaigns. The first investigated the isotopic chain of silver (Ag) between the neutron shell closures of $N = 50, 82$; and the second further studied isotopologues of radium monofluoride (RaF).

The publication by Udrescu *et al.* presents the first isotope shift measurements for the isotopologues $^{223-226,228}Ra^{19}F$. Up until 2018, no isotope shift measurements of molecules containing elements that do not occur in sizeable quantities in nature have been achieved. In this work, it is shown that molecular isotope shifts are similarly sensitive to changes in nuclear charge radii as those in atoms. The first set of values presented correspond to four electronic-vibrational transitions between the $X^2\Sigma^{1/2}$ and $A^2\Pi_{1/2}$ electronic states of $^{223-226,228}Ra^{19}F$. These values were then plotted against the changes in mean-square charge radii of Ra^+ isotopes (Figure 1) in order to experimentally determine the molecular analog of the conventional atomic field-shift factor F. This corresponds to the difference in electron density at the Ra nucleus, and are shown to be in excellent agreement with *ab initio* quantum chemistry calculations. These results not only provide a stringent test for current theoretical models of the electron wavefunction, but also confirms that in certain situations, where the atomic form is too reactive or refractory impacting its release from the target, extraction and spectroscopy of a volatile molecule could offer a pathway to extract nuclear observables.

This study of RaF was extended in 2021 with a second campaign to further examine the electronic, vibrational and rotational structure of this molecule, with a focus on high-resolution spectroscopy of ^{226}RaF and the hyperfine structure of $^{225}Ra^{19}F$. This experiment was very successful, yielding a large amount of data addressing the different physics aims. High-resolution measurements of the $0 \leftarrow 0$ Q-branch of $^{223,225}Ra^{19}F$ and the hyperfine structure of the $0 \leftarrow 0$ R-branch of $^{225}Ra^{19}F$ were obtained. Along with this, complete characterisation of the $A^2\Pi_{1/2} \leftarrow X^2\Sigma^+$ transition in $^{226}Ra^{19}F$ was obtained, including spectra of the Q, P and R-branch of the $0 \leftarrow 0$ transition and the Q-branch of the $1 \leftarrow 1$ transition, which is of particular interest when searching for possible laser cooling schemes. Furthermore, measurements of $^{210,212,213,214,223,227,230}Ra^{19}F$ were collected along with new states which were identified as $B^2\Delta_{3/2}$ and $C^2\Sigma^+$. Finally, Rydberg states, autoionising states, life time of the A state and ionisation threshold measurements of $^{226}Ra^{19}F$ were also collected.

The other experimental campaign conducted by the CRIS collaboration in 2021 was an investigation into the isotopic chain of silver. The motivation for this campaign is multifaceted. Due to Ag having 3 proton holes under the $Z = 50$ shell closure, these isotopes are expected to be more deformed than their indium isotones. The purity of nuclear configurations can be studied through measurements of magnetic dipole moments along this chain, while electric quadrupole moments and changes in mean-square charge radii can be used to evaluate the evolution of deformation within this region of the nuclear chart. The particular interest in Ag isotopic chain centres around the evolving character of the $1/2^-$ level which is the ground state around the stable ^{107,109}Ag isotopes but becomes isomeric when going towards the $N = 50$ and $N = 82$ shell closures. Another reason for investigating the isotopic chain of $^{100-123}$Ag is to study the magnetic moments trend of the $I = 1/2^-$ states as they strongly change with neutron number, similarly, but not as drastically, to indium within the same region [2]. However, by using the isotopic chain of Ag, crossing the $N = 50$ shell closure and study how this affects the magnetic moments is made possible.

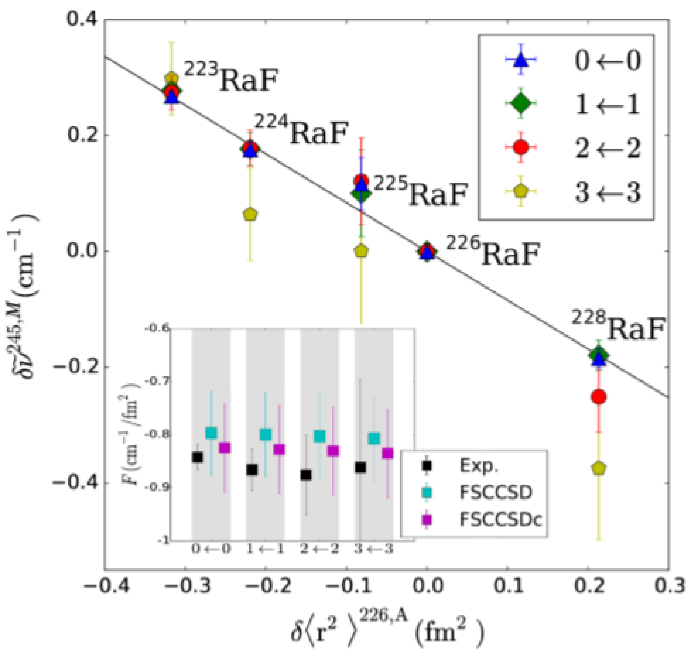

Figure 1: Molecular isotope shifts plotted against the change in mean-square charge radii of radium isotopes obtained through atomic spectroscopy. The solid black line represents the best-fit of the field shift factor (F) for the 0 ← 0 transition. The 'F' values are in excellent agreement with theory.

The experimental run was split into two objectives: measure isomers that had not previously been detected in order to fill gaps within this region, which is vital for isomerically purified beams; and establish the laser ionisation scheme efficiency and perform laser spectroscopy across the $^{100-123}$Ag chain using broadband pulsed lasers. The experiment was very successful as an optimal laser ionisation scheme was discovered (338 nm + 405 nm + 532 nm) that led to strongly suppressed background allowing over 20 isotopes to be measured. A second experimental campaign for Ag is planned for 2022, where the focus is to perform high-resolution spectroscopy and further extend the isotopic chain towards ^{129}Ag.

2021 can be considered a very successful year for the CRIS collaboration. To ensure that 2022 obtains the same level of success, many upgrades are being prepared at CRIS beamline in order to continue pushing the limits of laser spectroscopy. In particular, the upgraded field ionisation unit and the charge exchange cell voltage scanning capabilities which will be available for use during the online period of 2022 [3]. Other improvements that are being prepared beyond 2022 include: a new 34° bend towards the end of the beamline that will allow for energy selection and the separation of field ionised species from collisional ions; a new quadrupole triplet after the bend to allow for greater beam control; and a new decay-spectroscopy station paired with beta and gamma detection. Given the improvements being added and the exciting experiments planned, such as Al, Ag, and AcF, 2022 is expected to be another successful year.

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ISOLTRAP returns to science in 2021

L. Nies, M. Mougeot and D. Lunney
for the ISOLTRAP collaboration

The ISOLTRAP mass spectrometer at ISOLDE at CERN has a long history of science contributions through pioneering developments in mass spectrometry, dating back over 30 years [1, 2].

After an extensive refurbishment during CERN's second long shutdown (LS2), ISOLTRAP is back on line with all guns blazing. In addition to mass measurements made with the classic Time-of-Flight Ion-Cyclotron-Resonance (ToF-ICR) technique, new results were obtained during 2021 beamtimes that exploited the newly developed Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) method as well as measurements with the Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS).

After major repair and testing of the tandem Penning trap system, the PI-ICR technique was again successfully employed to precisely determine the mass of ^{61}Zn, in excellent agreement with a recent measurement from LEBIT at NSCL [3] while reducing the mass uncertainty by a factor of about 30 to reach the sub-keV regime.

In addition, the ISOLTRAP collaboration published results of a very successful experiment in 2018 on neutron-deficient indium masses out to ^{99}In, which is also linked to a Q-value measurement to provide a new mass for the iconic nuclide ^{100}Sn [4].

Further investigating the indium chain in 2021, eleven ground states and seven isomeric states were measured. For the first time the excitation energy of the $(1/2)^-$ isomeric state in ^{99}In was directly measured with only about eighty counts in 48 hours of data-taking (see Figure 1). This was made possible by extensive MR-ToF MS upgrades, including active feedback loops to provide extra voltage stability [5] and synchronizing to the 50 Hz mains voltage, leading to mass resolving powers in excess of 450 000.

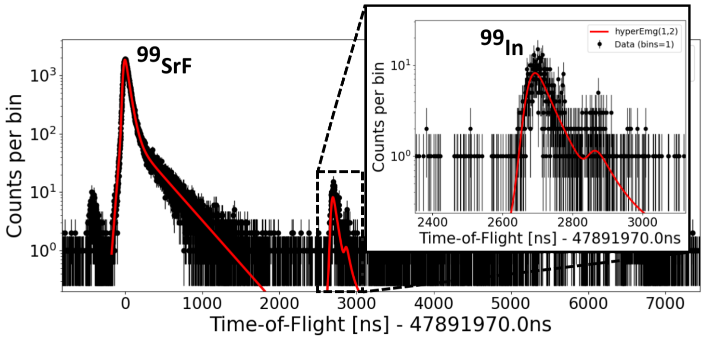

Figure 1: Time-of-Flight spectrum for mass A= 99. The insert shows the separation of ground and isomeric state in ^{99}In. The abundant contaminant, ^{99}SrF, is used to extract a shape reference for fitting the low-statistics ^{99}In while also serving as a well known mass reference for extracting the excitation energy. The hyper-Exponentially-Modified-Gaussian fits [6] are shown in red.

The versatile MR-ToF MS is routinely used in collaboration with ISOLDE target and ion source R&D. During 2021, an extensive test program was launched with the LISA framework for monitoring the production of actinide elements. (For more information on the target team's effort on producing and ionizing actinides in the LISA framework, please refer to the combined RILIS and target team contribution to this newsletter.) These tests were very successful and in addition, to the great surprise of ISOLTRAP and the ISOLDE target teams, they unmasked a *Uranium Flying Object* at A= 273: ^{238}U^{19}F^{16}O and many more complex molecules, forming in the target and the subsequent ion traps.

A new laser-ablation ion-source, described in last year's newsletter [7], has been installed upstream of the ISOLTRAP setup and commissioning began at the end of 2021. Figure 2 shows a first carbon-cluster spectrum obtained using the ISOLTRAP MR-ToF MS.

Laser-ablated carbon cluster ions can be used as reference masses for absolute mass measurements, as they cover the whole nuclear chart, and can be used to study mass-dependent systematic uncertainties of the different mass measurement methods. Laser-ablation

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can also provide ions from long-lived radioactive or stable targets as a source for precision Q-value measurements, not only contributing to nuclear physics but also aiding in the search for the electron-neutrino mass.

With ISOLTRAP fully functional after CERN's Long Shutdown 2 and a busy experimental period in 2021, we look forward to continued experimental activities during 2022, further investigating actinide production at ISOLDE, masses of tin and silver isotopes far from stability, extremely low-lying isomeric states in antimony, and Q_{ec}-value measurements.

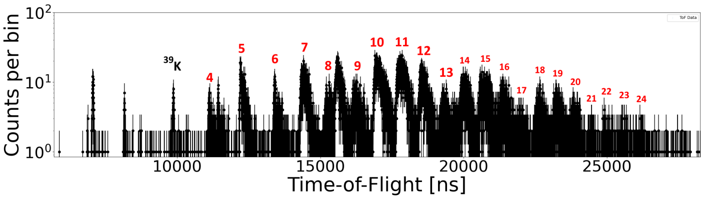

Figure 2: Characteristic ISOLTRAP time-of-flight spectrum of laser-ablated carbon cluster ions. Transmission of heavier cluster sizes is limited by the radio-frequency quadrupole cooler/buncher (see [7] for details of the new setup).

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High-resolution laser spectroscopy of magic lead isotopes

Results of experiment IS701

Liss Vázquez Rodríguez for the COLLAPS collaboration

After a long shutdown period, the high-resolution collinear laser spectroscopy experiment COLLAPS restarted operation with a successful campaign on magic lead isotopes. The IS701 experiment took place in September 2021 and aimed to provide electromagnetic moments and charge radii of 22 isotopes and 10 isomers along the isotopic chain, starting from ^{187}Pb and up to the doubly-magic nucleus ^{208}Pb. Of particular interest were the quadrupole moments of the $\frac{3}{2}^-$ and $\frac{13}{2}^+$ states which together with the isomeric charge radii differences serve as a stringent benchmark for state-of-the-art nuclear theories.

The stable and radioactive isotopes were produced from a uranium carbide target and selectively ionized using the resonance ionization laser ion source (RILIS). The measurements benefited from a recently developed laser scheme which increased the efficiency of laser ionization by a factor of about 10 with respect to the one used in previous years, thus maximizing the suppression of contaminants.

The spectroscopy was performed using the $6s^26p^2\ ^1D_2 \rightarrow 6s^26p7s\ ^3P_1^0$ transition in the neutral atom. This transition, which starts from a metastable state that was efficiently populated in a charge-exchange cell, allowed us to separate the fluorescence wavelength from the laser wavelength and thus considerably reduce the background that originates from the scattered light. In addition, it allowed us to extract the nuclear parameters, quadrupole moments in particular, with higher resolution as compared to previous measurements [1, 2, 3].

Hyperfine structures were observed for all species of interest and isotope shifts were extracted with respect to the stable ^{208}Pb. In Fig. 1 the hyperfine spectrum of ^{197}Pb is shown as an example, together with that of the reference isotope. All expected hyperfine peaks, eight for the ground state of spin $\frac{3}{2}^-$ and nine for the isomeric state of spin $\frac{13}{2}^+$, appear in the spectrum evidencing the high resolution achieved in our measurements. Since both the ground state and isomer were recorded in the same spectrum, the isomer shifts in $^{187\text{-}203}$Pb were also measured. Ground and isomeric state properties, such as spins, electromagnetic moments and charge radii were then determined. Interesting trends are observed, in particular for the quadrupole moments associated with the $i_{13/2}$ unique-parity orbital, which closely resembles those previously observed along the isotopic chain of tin [4] but provide a challenge to nuclear models.

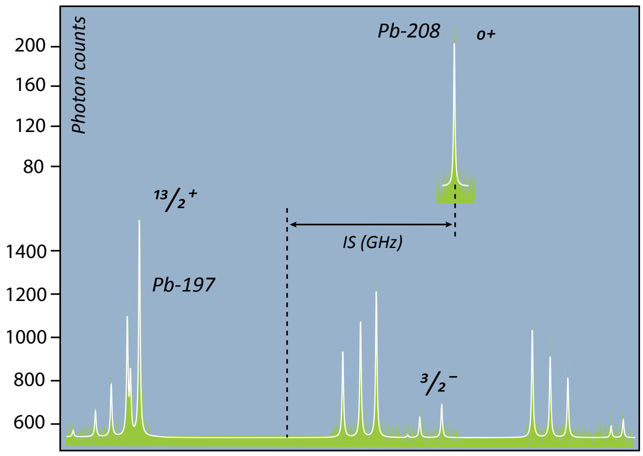

Figure 1: Hyperfine structure of the $\frac{3}{2}^-$ ground and $\frac{13}{2}^+$ isomeric state in ^{197}Pb. The reference isotope ^{208}Pb is also shown in the figure.

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Doppler and sympathetic cooling for the investigation of short-lived ions

Franziska Maier, Simon Sels
for the MIRACLS collaboration

Ever since its introduction in the mid 1970s, laser cooling has become a fundamental technique to prepare and control ions and atoms for a wide range of precision experiments. In the realm of rare isotope science, for instance, specific atom species of short-lived radionuclides have been laser-cooled for fundamental-symmetries studies [1, 2, 3, 4, 5, 6] or for measurements of hyperfine-structure constants [7] and nuclear charge radii [8, 9]. Nevertheless, because of its simplicity and element-universality, buffer-gas cooling in a linear, room-temperature Paul trap cooler-buncher is more commonly used at contemporary radioactive ion beam (RIB) facilities. Recent advances in experimental RIB techniques, especially in laser spectroscopy and mass spectrometry, would however strongly benefit from lower-temperature ion beams provided by laser cooling. In addition, sympathetic ion cooling by co-trapping with a laser-cooled ion species could open a path for a wide range of atomic and molecular sub-Kelvin RIBs.

Recently, we demonstrated that laser cooling is compatible with the timescale imposed by short-lived radionuclides as well as with existing instrumentation at RIB facilities. To this end, a beam of hot $^{24}Mg^{+}$ ions is injected into a linear Paul trap [10] of the MIRACLS proof-of-principle setup [11, 12] in which the ions are cooled by a combination of a low-pressure buffer gas and a 10-mW, cw laser beam of $\approx$ 280 nm. Despite an initial kinetic energy of the incoming ions of a few eV at the trap's entrance, temporal widths of the extracted ion bunch as low as a few ns corresponding to an ion-beam temperature of around 6 K are obtained within a cooling time of $\leq$ 200 ms. Time-of-flight spectra of the stable Mg isotopes as measured after extraction from the Paul trap are shown in the insert of figure Fig. 1, for standard buffer-gas cooling (red) and for Doppler cooling (blue). Moreover, sympathetic cooling of co-trapped K^{+} and O_2^{+} ions was demonstrated. As a first application, a laser-cooled ion bunch is transferred into a multi-reflection time-of-flight mass spectrometer. This improved the mass resolving power by a factor of 4.5 compared to conventional buffer-gas cooling (see figure Fig. 1). More generally, these results open a path to a significant emittance improvement and thus unprecedented ion-beam qualities at RIB facilities, achievable with standard readily available equipment. In a next step, online laser-cooling experiments could be envisioned, for instance in the new MIRACLS Paul trap which features a direct laser access. This will increase the sensitivity in collinear laser spectroscopy and ultimately aims to push the current precision frontier in nuclear structure and beyond-standard-model physics.

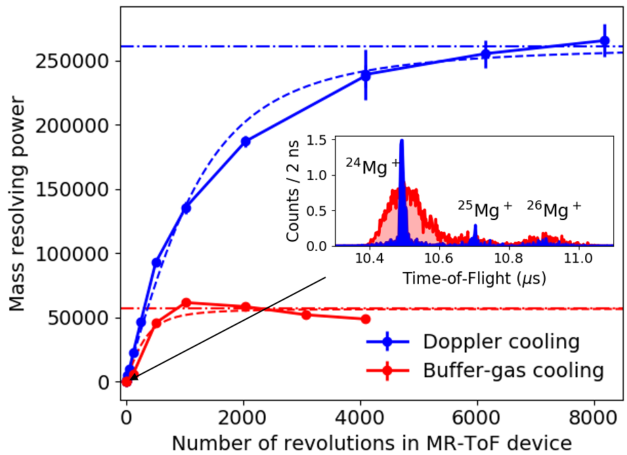

Figure 1: Mass resolving power for $^{24}Mg^{+}$ ions as a function of revolution number in the MR-ToF device for Doppler cooling (blue) and buffer-gas cooling (red) in the Paul trap. The dashed lines are fits to the data, the dashed-dotted lines indicate the saturation resolving power. The insert shows the time-of-flight spectrum of the stable Mg isotopes in single-path operation, i.e. without any revolution in the MR-ToF device for Doppler cooling (blue) and for buffer-gas cooling (red). The data sets are normalized to the number of shots, but a factor 100 more ions are initially loaded into the Paul trap for laser cooling in respect to buffer-gas cooling. This reflects the reduced capturing efficiency for laser cooling within this proof-of-principle Paul trap.

https://miracls.web.cern.ch/

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Beta-decay studies

“What’s in the box?” @ IDS

IDS and IS665 *James Cubiss, on behalf of the IDS collaboration*

A new chamber (see Fig. 1) for the ISOLDE Decay Station (IDS) has been produced by the University of York, and commissioned during the IS665 experiment. The chamber has a box-shaped design, consisting of an aluminium frame onto which custom-made flanges are attached. This flexibility makes it possible to use a wide variety of detectors – one need only design an ‘appropriate’ flange. Inside, the chamber has room to position arrays of charged particle and small volume scintillator detectors around the IDS tape. The box geometry of the chamber allows the IDS Ge clover detectors to be arranged in a cubic array, pointing towards the implantation position, providing an efficient solid angle coverage. The current flanges of the chamber are made from aluminium, and have thin windows ($\approx$ 1 mm) to allow for detection of X rays and low-energy γ transitions.

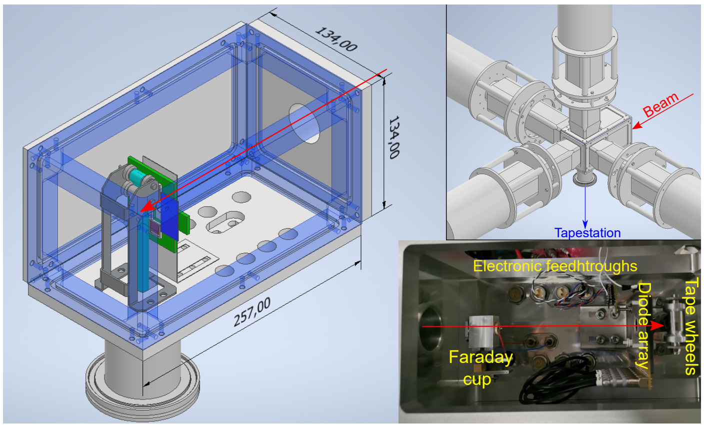

Figure 1: Drawings of the new IDS chamber: the main figure (left) shows an open view of the interior with a Si PIN diode array mounted near the implantation point, the insert (top-right) shows the cubic arrangement of the IDS clovers around the chamber. The photograph (bottom-right) is a birds-eye view of the inside of the chamber with the diode array mounted for IS665. Red arrows are used to indicate the path of the beam.

During the IS665 run, four HPGe clover detectors were used in a cubic configuration (see inset of Fig. 1) – the efficiency curve for which is shown in Fig. 2. In addition a new, modular array of Hammamatsu Si PIN diodes was used to detect α, β, and conversion electron decays, as well as fission fragments. The current array covers a solid angle of $\approx$ 5%, but can be increased to $15-20$%. The Si PIN diodes are cheap compared to conventional Si detectors, and easy to replace, making them well suited for studies where high rates may results in detector damage, or contamination. The Si PINs provided an energy resolution of $\approx$ 20 keV FWHM for α decays, and $\approx$ 7 keV for conversion electrons.

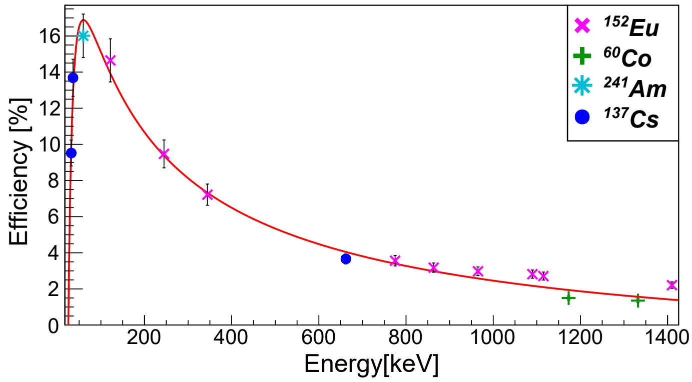

Figure 2: Total efficiency curve measured during IS665 experiment, for the 16 clover crystals (4 crystals per clover detector, no addback) arranged in a cubic geometry around the new IDS chamber.

The successful implementation of the new chamber during IS665 has motivated the design and production of a secondary “decay chamber”. This second chamber will be positioned between the implantation point and tapestation, and will be used to measure the decays of long-lived and daughter activity. Its design will be based on the same frame+flange concept, with a cu-

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bic shape. This will allow four clovers to be positioned in a close geometry around the decay point, whilst leaving enough room for additional ancilliary detectors to be placed inside, such as a nitrogen-cooled silicon-lithium (SiLi, in place of a clover) and detectors for fast-timing measurements.

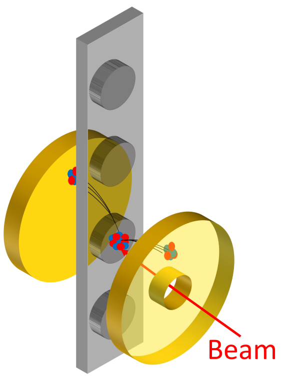
The ASET for β-delayed fission studies

Results of experiment IS665

Boris Andel, Silvia Bara, Jake Johnson
for the IDS and IS665 collaborations

Beta-delayed fission (βDF) studies provide a wealth of information on low-energy fission of exotic isotopes. Previous results obtained by our collaboration in the lead region [1] sparked a high interest in the community of theoretical physicists, followed by a prediction of a whole new region of asymmetric fission below Z = 82 [2]. One of the goals of our experiment, performed in summer 2021, was to identify and investigate βDF in ^{178}Au, that lies deeper in this new region.

For efficient detection of fission fragments (FF) and ability to register FF coincidences, needed for determination of FF mass distribution, the α decay spectroscopy setup (ASET) was installed at LA1. This setup was designed at KU Leuven and commissioned at ISOLDE in 2018 for systematic studies of actinium and radium production for medical purposes (IS637).



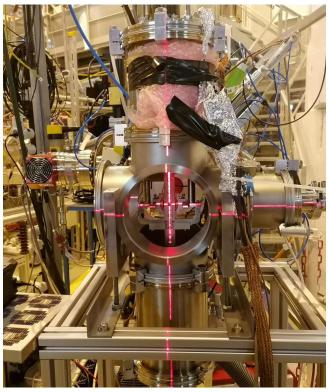


Figure 1: Left: the inside of ASET - the ladder with the thin C-foils placed between an annular and a full Si detector. Right: the opened detection chamber during alignment.

In ASET the beam is implanted on one of the nine thin carbon foils mounted on a ladder. The ladder can move up and down, allowing the users to change implantation foil when needed. Two silicon detectors (an annular, to let the beam through, and a full one) are placed on each side of the ladder at the implantation position (Fig. 1, left). In this arrangement, charged particles emitted by radioactive decay from the implanted species are detected with an overall geometric efficiency of up to 60%. The detectors and the foils are housed within a crosspiece chamber shown in Fig. 1, right. HPGe detectors can be positioned outside two thin recessed γ windows of the crosspiece to measure γ and x rays.

To validate fission detection capabilities of ASET, a test with ^{202}Fr, which has a known βDF branch, was carried out. The test was successful, 8 FFs were detected in total. An example of measured FFs is shown in Fig. 2. The resulting partial half-life of βDF for ^{202}Fr was consistent with our previous work [3], which proves that ASET works properly and is ready for βDF studies.

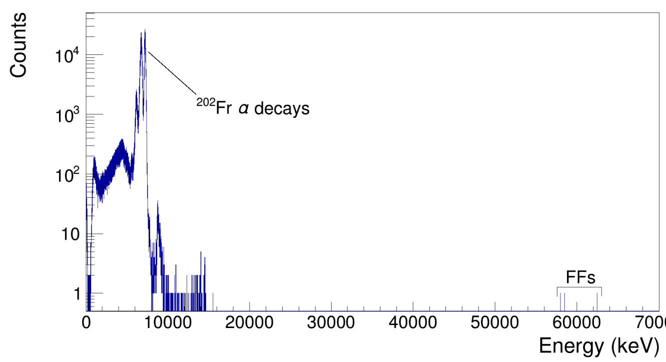


Figure 2: Energy spectrum from the annular Si detector.

In spite of the large amount of implanted ^{178}Au during the main measurement, no fission fragment was observed, which allows very low upper limits of βDF probability for the two β-decaying states in ^{178}Au to be determined. The limits are significantly lower than expectations based on systematics combining experimental βDF probabilities and theoretical fission barriers. Final values will be presented after detailed analysis.

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Observations of beta-delayed multi-particle emission from ^{21}Mg

Results of experiment IS507

Erik A. M. Jensen for the MAGISOL and IDS collaborations

The aim of the IS507 experiment is to carry out detailed studies of the beta decay of ^{20,21}Mg, studying in particular the beta-delayed particle emission branches. The first beam time in 2011 focused on the beta decay of ^{21}Mg, and the second in 2015 on the beta decay of ^{20}Mg. For the measurements in 2015, ^{21}Mg was used as an in-beam calibration source. The data presented here are derived from the ^{21}Mg calibration data, and they therefore constitute just a small fraction of the entire IS507 experiment. Nevertheless, the improved setup and the enhanced statistics of the data acquired during the second run of the experiment provide the following three results:

1. The confirmation of the $\beta p\alpha$ decay channel.
2. Refinements of state assignments in the decay scheme of ^{21}Mg through observations of $\beta p\gamma$.
3. An improved value of 120.2(3) ms for the ^{21}Mg half-life.

When the $\beta p\alpha$ branch of ^{21}Mg was first observed in the earlier stages of the IS507 experiment, this type of decay had only been observed for ^{9}C and ^{17}Ne [1, 2]. The main results of the two runs of the IS507 experiment are presented in [1, 3, 4].

The present data were acquired by utilising 4 ΔE-E silicon detector telescopes of high spatial resolution surrounding (in the polar plane of the beam) a catcher foil in which the radioactive beam particles were stopped. One thick silicon detector was also situated below the polar plane, and outside the chamber the 4 high-purity germanium Clover detectors of the ISOLDE Decay Station (IDS) were positioned.

The thin ΔE detectors allow for the separation of the low-energy proton and alpha lines from noise; see Fig. 1. The order of emission can now be experimentally proven: A relatively sharp peak around a center-of-mass energy matching that expected for the proton at 921 keV (see e.g. the decay scheme in [3]) is revealed by applying corrections for energy losses to the observed energies – the corresponding alpha particle energy of 892 keV is, on the other hand, seen to be smeared over a larger energy interval and is thus emitted from the recoiling ^{20}Ne nucleus.

https://isolde-magisol.web.cern.ch

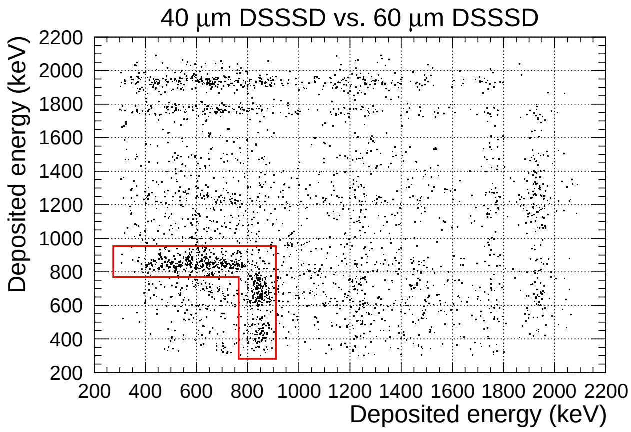

Figure 1: Low-energy spectrum of events of multiplicity two or larger in oppositely situated double-sided silicon strip detectors (DSSSDs). The three most prominent (single) proton peaks in this part of the energy spectrum have, in order of decreasing intensity, energy depositions around 1.9, 1.8 and 1.3 MeV. Roughly 800 events lie within the red-edged polygon, which contains the $\beta p\alpha$ events.

Apart from the confirmation of the $\beta p\alpha$ branch, the direct detection of the emitted gamma rays in coincidence with protons also confirms many of the suggested assignments in [3]. There are, furthermore, some modifications to the state assignments from the present data, and there are currently indications of a new $\beta p\gamma$ channel, as well.

The results are being prepared for publication.

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Beta decay of ^{64}Ga measured with TAS

Results of experiment IS570

S. Parra, E. Nacher, J.A. Briz
for the ISOLDE-TAS collaboration

Nucleosynthesis in Type I X-ray bursts (XRB) proceeds eventually through the rp-process near the proton drip-line. Several N=Z nuclei act as waiting points in the reaction network chain. Astrophysical calculations of XRB light curves depend upon the theoretical modelling of the beta decays of interest, with ^{64}Ge being a key nucleus in this context. Several such theoretical calculations have shown that, in these high-density and high-temperature scenarios, 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.

In the experiment IS570 we applied the Total Absorption Spectroscopy (TAS) technique to measure the beta decay of $^{64-66}$Ge and of their daughters $^{64-66}$Ga, with the main goal of determining the B(GT) distribution for these decays. Preliminary result of ^{64}Ga show a difference from the previously feeding distribution, with the noticeable emergence of feeding above the last known level, at 4713 keV. Our spectrum has a peak at 6081 keV, which was non existent in the evaluated ENSDF data [1], as can be seen in the Fig. 1.

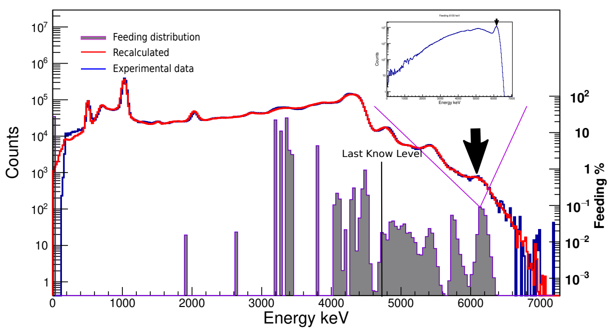

Figure 1: Deconvolution for the ^{64}Ga, in red the recalculated spectrum using the feeding provided by the deconvolution and the response function. The level at 3186 keV is responsible for the peak at 4300 keV due to annihilation of the beta+ particle. The peak at 6081 keV is made by feeding around that energy because this peak is so close to the Q-value that there is only electron capture

The percentage of feeding from ENSDF and the results of the deconvolution by energy level can be seen in Table 1. The results show a difference of 1.6% of feeding at energies above 4000 keV. This difference is very important because, due to the relation between B(GT) and feeding, a small difference in feeding at high energies level means a big difference in the B(GT) distribution.

Table 1: Percentage feeding of ^{64}Ga by energy level

Energy (keV)	ENSDF %	Present results %
0	24.67	27.72
1910	<0.3003	0.015
2609	<0.2132	0.018
3186 3261	32.967	33.442
3321 3366 3425	36.15	31.25
3795	4.031	4.38
4000 - 5000	1.558	2.614
5000 - 6000	0	0.5509

These results are of particular interest for the analysis of ^{64}Ge decay since ^{64}Ga is its daughter, and therefore, appears as a contaminant, so a good understanding of this spectrum means a far cleaner ^{64}Ge spectrum.

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Studies with post-accelerated beams

New silicon array commissioned for ISOLDE Solenoidal Spectrometer

Contributions from experiments IS675, IS680 and IS689

David Sharp for the ISS collaboration

2021 marked the first measurements with the fully commissioned ISOLDE Solenoidal Spectrometer (ISS). During LS2 the new ISS silicon array, constructed by the University of Liverpool, was installed in the ISS magnet, shown in Figure 1. The new array is a $\sim$0.5 m long six-sided device consisting of 24 double-sided silicon strip detectors, four on each side. Each detector has 128 strips along the length of the detector with 0.95 mm pitch and 11 along the back with 2 mm pitch. The large number of strips (3336) requires readout via on-board ASICs.

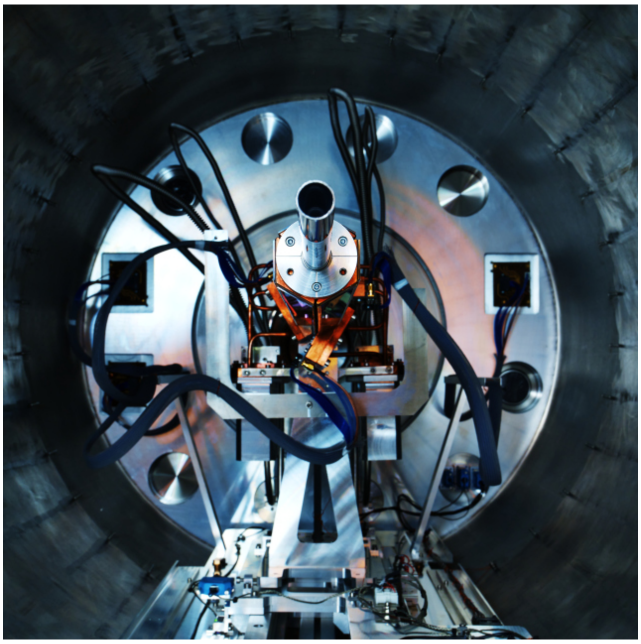

Figure 1: The array mounted inside the magnet. Credit Julien Ordan, CERN.

The device was commissioned using a stable ^{22}Ne beam, with the characteristic kinematic lines shown in Figure 2, before measurements were made using a variety of beams from A = 30 to A = 212, with beam energies of 7.5 – 8.5 MeV/u, addressing a range of different science questions from evolving nuclear shapes through changes in nuclear shell structure to measurements important for producing chemical elements in astrophysical sites in the Universe.

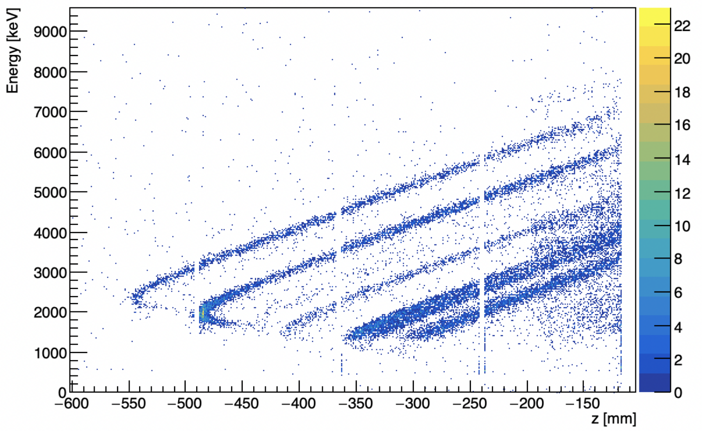

Figure 2: Proton energy as a function of z, the detector-to-target distance for the ^{22}Ne(d,p)^{23}Ne reaction.

A strength of ISS is its flexibility to use a number of different recoil-detection methods, or indeed run in a singles mode. Measurements were made using the device in silicon-recoil mode, with a study of the ^{30}Mg(d,p)^{31}Mg reaction. Experiments also used singles mode, with measurements of the ^{61}Zn(d,p)^{62}Zn and ^{212}Rn(d,p)^{213}Rn reactions. The observed resolution is consistent with that achieved with the HELIOS array in the early exploitation measurements [1, 2] made before LS2 with a FWHM of $\sim$ 140 keV, though there is work still to do to optimise the data collected.

In addition to the array development, a gas ionization chamber was also commissioned in 2021 for recoil detection. Proposals using tritium targets, amongst others, were accepted by the INTC and so reactions induced on tritium will be a future possibility with ISS. Additionally, there are plans to study transfer-induced fission reactions. The first physics measurements with ISS have focused on (d,p) reactions, where the ejectile is predominantly emitted backwards in the lab. Future campaigns will also incorporate measurements where the ejectiles are forward going and so require that the array is positioned downstream.

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Characterisation of the SpecMAT active target and future plans for HIE-ISOLDE

Oleksii Poleshchuk, Andreas Ceulemans, Riccardo Raabe

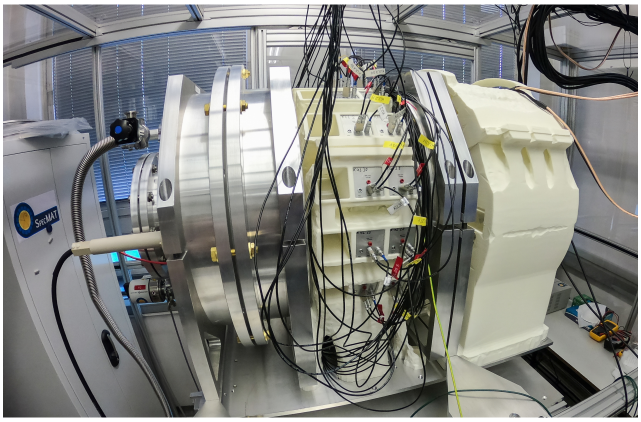

Figure 1: The SpecMAT active target during characterisation at KU Leuven [1].

The SpecMAT active target (see Fig. 1) is a state-of-the-art detector developed for studying direct reactions in inverse kinematics with low-intensity radioactive ion beams (RIB) [1]. This detector will be installed at HIE-ISOLDE in the ISOLDE Solenoidal Spectrometer (ISS). SpecMAT combines a time projection chamber (TPC) [2] for charged-particle detection with an array of $CeBr_3$ scintillation γ-ray detectors capable of operating in a strong magnetic field. The integration of the scintillation detectors with the active target via high-density digital electronics (GET: General Electronics for TPCs) [3]) allows the correlation in time of γ-ray signals with charged particle tracks.

The detector was characterised in a series of off-line measurements at KU Leuven. Details are presented in [4]. The cumulative energy resolution of the scintillation detectors measured at 661.7 keV (^{137}Cs) is ~4.71%. The photo-peak detection efficiency for the same γ-line is 7.8±0.6% (8.6±0.6% after add-back) with a point source and 5.8±0.5% (6.5±0.6% after add-back) with a linear source.

The TPC of the detector is a 323.5 mm-long cylindrical electric field cage with an inner diameter of 220 mm, enclosed between a cathode and a bulk Micro Mesh Gaseous Structure (Micromegas) detector [5].

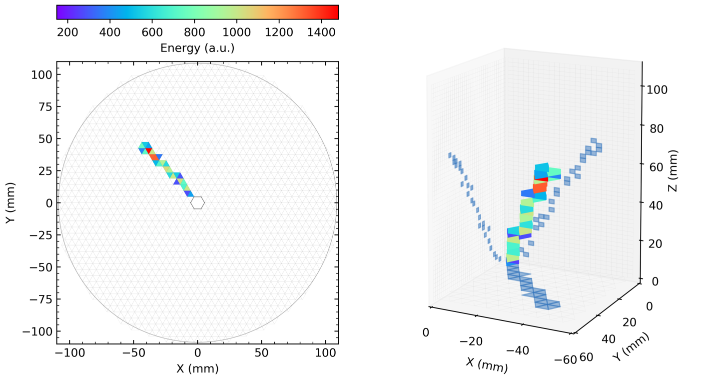

Figure 2: An α-particle track recorded with the SpecMAT active target [1]. Left panel, projection of the track on the plane of the Micromegas detector. Right panel, reconstructed 3D track of the α-particle, Z coordinates were extracted from the timing component of the acquired Micromegas signals.

The Micromegas of SpecMAT is segmented into 2916 triangular pads for fine sampling of the particle tracks. An example of an acquired α-particle track is shown in Fig. 2. The characterisation of the active target was made with a coincidence measurement of the decay products of ^{241}Am: an α particle, and the γ-ray emitted in de-excitation of the 59.5 keV $5/2^-$ state populated in ^{237}Np. This measurement was performed using an Ar(95%)CF_4(5%) gas mixture at a pressure of 400 mbar. The measured (FWHM) energy resolution of the obtained α-particles at ~5.5 MeV is ~180 keV based on the length of the tracks and ~200 keV based on the number of ionisation electrons collected on Micromegas.

All these results can be accurately reproduced by a specifically-developed Geant4 simulation package. The package was further used to demonstrate the feasibility of studying single-particle states populated in ^{69}Cu via a ^{70}Zn(d,^{3}He) transfer reaction [4].

Next, the SpecMAT active target will be installed in ISS for the commissioning of the detector in a magnetic field, using either α or fission sources in gases and gas mixtures commonly used in transfer-reaction experiments with active targets (e.g. He, $HeCF_4$, D_2).

https://isolde-solenoidal-spectrometer.web.cern.ch/specmat

Acknowledgements

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. 617156.

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Transfer reaction with ^{7}Be to study ^{12}C(α,γ)^{16}O

Results of experiment IS554

Kabita Kundalia, Sk Mustak Ali, Dhruba Gupta
for the IS554 collaboration

The $\alpha-$cluster transfer reaction is a potential tool to study nuclear reactions relevant for stellar nucleosynthesis. Direct capture reactions with very small cross-sections at low energies are difficult to measure. An indirect technique to study such reactions involves the investigation of $\alpha-$cluster transfer reactions to populate the relevant states in the residual nuclei. Interestingly the ^{7}Be nucleus, though having an $\alpha-$cluster structure and a low breakup threshold of 1.58 MeV, shows that ^{7}Be-induced $\alpha-$transfer reactions are predominant than breakup [1]. Thus it is a suitable candidate in such studies. We used the $\alpha-$transfer reactions of ^{7}Be to populate states of ^{16}O that dominantly contribute to the reaction ^{12}C(α,γ)^{16}O. This reaction controls the C/O abundance ratio at the end of the helium burning phase where the relevant cross section around stellar temperatures of 300 keV is $\sim 10^{-17}$ b [2, 3]. The reaction predominantly populates the 6.92 MeV state of ^{16}O.

To study this reaction, we carried out an experiment at HIE-ISOLDE, with 35 MeV ^{7}Be beam on a CD_2 target, utilizing the scattering chamber at the third beamline [4]. The beam intensity was $\sim 5 \times 10^{5}$ pps and we used DSSDs covering laboratory angles of 8^{o}-165^{o} [5]. We measured ^{12}C(^{7}Be,^{3}He)^{16}O* to study the ^{12}C(α,γ)^{16}O reaction. The lab energy (E) vs scattering angle (θ) spectrum for ^{3}He and the relevant kinematics are shown in Fig. 1. We could observe the ground state and first two doublets [6.05(0^+), 6.13(3^-)] and [6.92(2^+), 7.12(1^-)] and also the 10.36(4^+) MeV state, as shown in the inset of Fig. 1. The spectroscopic factor (and hence the ANC) of the 6.92 MeV state has been deduced from a FRDWBA analysis using optical model parameters obtained from elastic scattering fits of ^{7}Be + ^{12}C at 35 MeV. The present study is important to further understand the transfer reactions in other loosely bound nuclei like ^{6,7}Li having prominent $\alpha-$cluster structure.

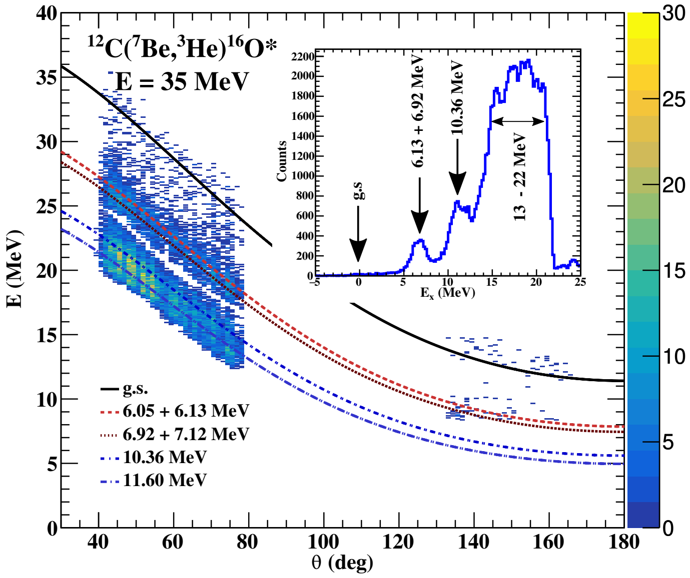

Figure 1: E vs θ plot of ^{3}He from ^{12}C(^{7}Be,^{3}He)^{16}O* at E = 35 MeV. Inset shows the relevant ^{16}O states.

The IS554 collaboration thank the ISOLDE engineers in charge, RILIS team and Target group at CERN for their support. DG acknowledges financial support from ENSAR2 (Grant no. 654002) and ISRO, Govt. of India (Grant no. ISRO/RES/2/378/15−16).

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Rejuvenated Miniball comes back to ISOLDE

Liam Gaffney, Thorsten Kröll, Janne Pakarinen, Peter Reiter for the Miniball collaboration

After the last successful experiments with Miniball performed at HIE-ISOLDE before Long Shut Down II (LS2) the spectrometer was completely dismantled and shipped to Paul-Scherrer-Institute (PSI), Switzerland. At PSI, Miniball provided, together with the other HPGe detectors, unprecedented efficiency for X-rays emitted by the muonic atoms ranging from light element Mg to heavy actinide Ra. The multifaceted experimental program conducted during 2019 included charge radii measurements of heavy unstable actinide ^{248}Cm and ^{226}Ra nuclei and search for forbidden 2s-1s transitions in various elements. Moreover, muon capture rates in ^{130}Xe, ^{82}Kr and ^{24}Mg nuclei, relevant for the understanding of neutrino-nucleus interaction, $0\nu\beta\beta$-decay and chemical analysis employing muonic atoms, were probed.

The next station of Miniball's extended journey during LS2 was RIKEN, Japan where the γ-ray spectrometer was erected at the final focus of the BigRIPS fragment separator in front of the ZeroDegree spectrometer at the turn of the year 2019/20. The beams of exotic nuclei were produced at relativistic energies via fragmentation and in-flight fission reactions of primary beams with highest intensities. For the first time, an efficient high-resolution HPGe detector array was employed for in-beam γ-ray spectroscopy at RIKEN. Nuclei with extreme proton to neutron ratios were studied in eight successful experiments in the HICARI campaign. The physics case focused on the evolution of collectivity in exotic atomic nuclei which is closely linked to shell evolution, magic numbers and the disappearance of classic shell closures in atomic nuclei. However, the campaign at RIKEN was severely delayed due to the COVID-19 pandemic and the spectrometer was shipped back to Europe in mid-2021.

The Miniball spectrometer has been in operation for nearly two decades. The 24 encapsulated six-fold segmented HPGe crystals are comprised in triple-cluster detectors and subject to demanding operation conditions like tight mechanical tolerances, high voltage, low vacuum pressure and liquid nitrogen cooling. The LS2 period was also used for a major hardware revision of the cluster detectors. Starting from the encapsulation technique of the bare HPGe crystal to new preamplifier electronics, all hardware components were overhauled. The design and R&D phase was running in parallel with the two experimental campaigns. The final steps of the new hardware assembly commenced in late summer 2021. A picture of the various components and the final new Miniball triple-cluster detector are shown in Fig. 1.

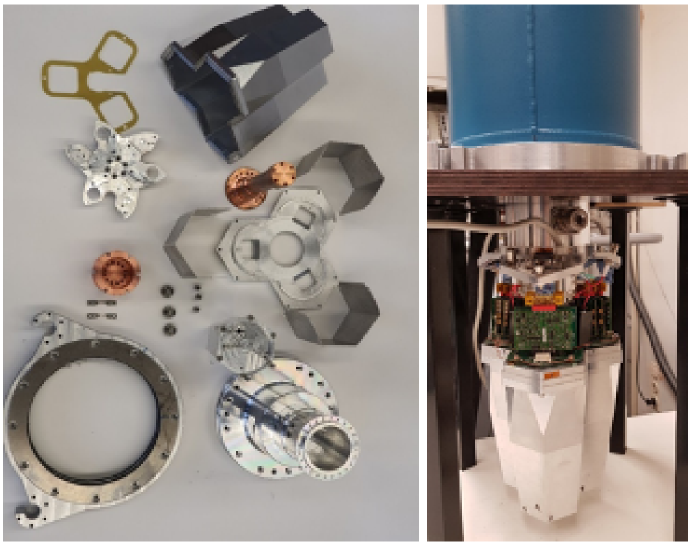

Figure 1: (left) Components of the new Miniball cryostats, designed and manufactured during LS2. (right) A fully constructed Miniball cluster detector.

In parallel to these developments, a new data acquisition system has been constructed based on the FEBEX digitisers from GSI. Firmware and software developments have been performed by the Daresbury group in the UK and the system is currently being tested in Köln with the newly-built cluster detectors.

The Miniball spectrometer will be back at ISOLDE in 2022 for another broad scientific program exploiting the unique HIE-ISOLDE beams.

https://cern.ch/Miniball

Measuring fission barriers with the active target "ACTAR-Demonstrator"

Results of experiment IS581

A. Camaiani for the IS581 collaboration

Since the observation of the Neutron Star Merger (NSM) event through gravitational waves [1], and the confirmation of the associated kilonovae, the investigation of heavy-ion properties has found a renewed interest. Indeed, NSM is one of the main candidates for an efficient r-process site, and in such a neutron-rich environment, neutron-induced fission can become efficient, thus terminating the r-process path via the so-called "fission recycle", yielding the final abundances. Within this scenario, the fission barrier height is expected to be one of the key ingredients to determine the end of the r-process accretion path via the so-called fission recycling mechanism: thus, a test of the actual fission barrier models is mandatory. This could allow discriminating between different proposed astrophysical sites of the r-process [2].

Although the A$\sim$280 mass region is unexplorable at the present facilities, we can test the fission barrier models exploring the poorly-known region between Tl and Ra nuclei [3], in particular moving towards neutron-rich nuclei where larger discrepancies between fission barrier models are present.

The IS581 experiment (performed in November 2021) was the first direct measurement of fission barrier height exploiting the accelerated beams by HIE-ISOLDE. In particular, neutron-induced fission can be "simulated" via a (d,p) transfer reaction in inverse kinematics. The chosen bench test was ^{209}Fr(d,p)^{210}Fr detected with the active target ACTAR-Demonstrator. The ACTAR-Demonstrator works both as a reaction target and as a detection stage, collecting the electrons produced by the ionization of the medium by the incoming beam and reaction products. It is equipped with a 2048-channel MICROMEGAS electron detector located at the bottom plane, where the electrons drift due to an electric field inside the active region. Eventually, with respect to the beam entrance, the downstream and both side flanges were equipped with double-side silicon strip detectors for the detection of the fission fragments and recoil protons, respectively.

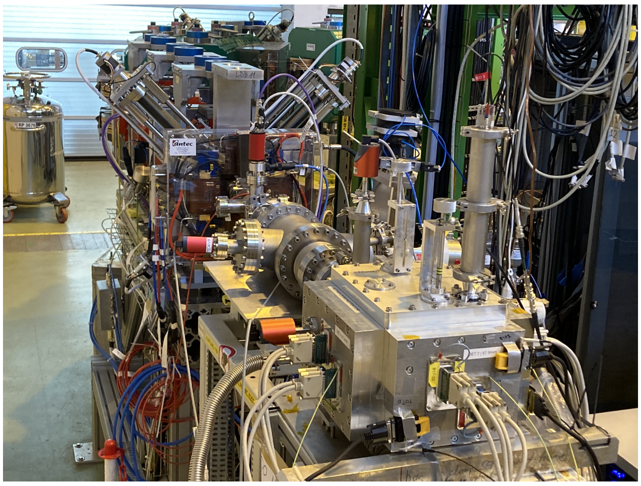

Figure 1: View of the IS581 experimental installation. The active target ACTAR-Demonstrator was installed at the end of the XT03 line and filled with pure deuterium at 800 mbar.

Figure 1 shows the experimental installation of the IS581 experiment, where the ACTAR-Demonstrator detector was connected at the end of the XT03 line. The ACTAR vessel was filled with pure D_2 at 800 mbar and separated from the high-vacuum line (less than 10^{-6} mbar) by a 5 μm-thick Titanium window.

To date, the data analysis of ^{209}Fr is ongoing. Meanwhile, the ACTAR-Demonstrator detector will be upgraded in view of a second run with a neutron-rich ^{227}Fr beam before the end of 2022.

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Acknowledgement

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Design studies of ISOLDE Superconducting Recoil Separator (ISRS)

Results of LoI INTC-I-228

I. Martel, D. Barna, MJG. Borge, I. Bustinduy, J. Cederkäll, G. de Angelis, A. Foussat, C. Guazzoni, A. Haziot, T. Junquera, G. Kirby, O. Kirby, T. Kurtukian-Nieto, LC. Medina, J.L. Muñoz, J. Resta, JA. Rodriguez, V. Rodin, E. Siesling, B. Shepherd, BS. Nara Singh, O. Tengblad, JP. Thermeau and C.P. Welsch, for the ISRS collaboration

The HIE-ISOLDE facility at CERN delivers the largest range of exotic beams with collision energies up to about 8 MeV/A. Structure and dynamics of nuclear systems far from stability are being investigated by means of Coulomb barrier reactions, nucleon transfer, deep inelastic and fusion-evaporation reactions.

The ISRS collaboration [1] has recently proposed the construction of a novel high-resolution recoil separator, the "ISOLDE Superconducting Recoil Separator" (ISRS). The objective is not only to enrich the existing physics program with a zero degree spectrometer, but to expand it with the more exotic isotopes produced in the secondary target by means of focal-plane spectroscopy.

The design of ISRS is based on Non-Scaling Fixed-Field Alternating-Gradient optics (NS-FFAG) and multifunction Cosine-Canted Theta Superconducting Coils (CCT-SC). NS-FFAG optical lattice allows the transportation of an ion beam with large energy and momentum spread using fixed magnetic fields. The technique was first proposed at the end of the 90's [2] for designing neutrino factories, Accelerator Driven Systems and gantries for medical therapy. Due to technical limitations, it was not until a decade later that the proof of principle could be established by building the electron accelerator EMMA at STFC's Daresbury (UK) in 2010 [3].

In multifunction CCT-SC magnets, the magnetic fields are superimposed by nested and tilted solenoids oppositely canted, so that multipolar fields are produced in the same coil. Due to its compactness CCT-SC magnets can reduce the size of the NS-FFAG lattice by an order of magnitude. The team has recently designed a combined-function iron-free 90°-curved CCT-SC magnet, which uses a cancellation coil for stray field suppression [4]. This development has many advantages. In addition to the removal of iron non-linearities, it provides a drastic reduction of solenoid weight, cooling, thermal inertia and energy consumption. First prototypes will be produced at CERN before the end of 2025.

NS-FFAG and SC magnets have been used in the design study of compact gantries [5] and more recently, for the ISRS recoil separator [6]. The present design concept of the ISRS is shown in Fig. 1. The reaction fragments are injected into a ≈ 5 m diameter storage ring composed of four 90° multifunction CCT-SC magnets. The superconducting SuShi septum [7] shown in the figure (*SC septum*) is a possible option for the injection/extraction system. The system can operate in isochronous and "spectrometer" modes. The operation of the ISRS spectrometer as a *recirculating* target, where the reaction target is inserted into the ring, is also under investigation.

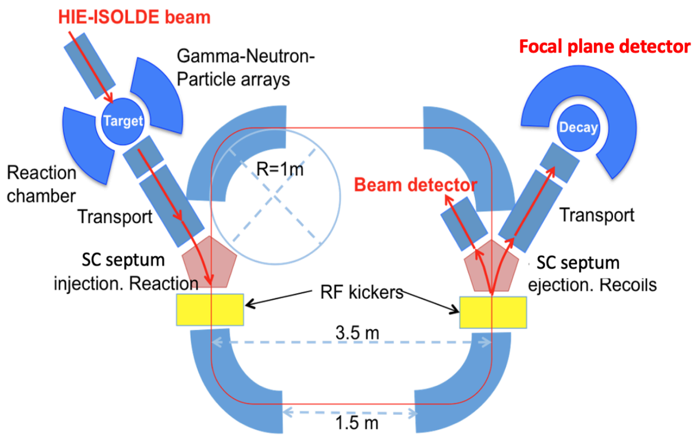

Figure 1: A conceptual design of the ISRS ring showing the main subsystems. See text for explanation.

https://isolde.web.cern.ch

References

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[3] S. Machida et al., *Nat. Phys.* **8**, 243 (2012).

[4] G. Kirby et al., *IEEE Trans. App. Supercond. MT27 Special Issue.* p. 136.R3. (2021).

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[7] D. Barna et al., *Rev. Sci. Inst.* **90**, 053302 (2019).

ISOLDE support

Access and contacts

1. Use the online pre-registration tool[1] which should be launched by your team leader or deputy team leader. You need to attach the following documents to the pre-registration:
   - Home Institution Declaration[2] **signed by your institute's administration (HR).**
   - Passport
2. When your pre-registration is accepted by the CERN users office you will receive an email telling you how to activate your CERN computer account. However, you cannot activate your CERN EDH account until you arrive at CERN and complete the registration process; this means you should register for hands on safety courses via email, see Item 7.
3. Follow the online mandatory CERN safety courses: Safety at CERN, Radioprotection Awareness, Emergency evacuation, Computer Security and Covid-19.
   - If you have activated your CERN account, you can access the mandatory on-line courses at the web page lms.cern.ch, from your computer, inside or outside CERN.
   - If you have not activated your CERN account, there are some computers available for use without the need to log in on the first floor of Building 55 (Your CERN badge will be needed in order to prove your identity).
4. Complete the following online courses available at https://lms.cern.ch:
   - Electrical Safety - Awareness Course - Fundamentals
   - Electrical Safety - Awareness Course - Facilities

   If you have not activated your CERN account see the second part of Item 3.
5. When you arrive at CERN go to the Users Office to complete your registration (Opening hours: 08:30 - 12:30 and 14:00 —- 16:00 but closed Wednesday mornings).
6. Get your CERN access card in Building 55
7. Follow the in-person ISOLDE RP safety course and the "Electrical Safety-Working in EP experiments" course for which you will have to register well in advance[3]. These take place on Tuesdays at the training centre (Building 6959) in Prevessin; the Electrical course takes place on Tuesday morning and the RP course on Tuesday afternoon. If you do not have your own transport, you can take CERN Shuttle 2 from building 500. The timetable for this is here.
8. Obtain a permanent radiation dosimeter at the Dosimetry service, located in Building 55[4] (Opening hours: Mon. to Fri. 08:30 —- 12:00). *If you do not need the dosimeter in the following month, it*

[1] For information see the CERN users' office
[2] The Home Institute Declaration should not be signed by the person nominated as your team leader.
[3] For information about how to register see http://isolde.cern/get-access-isolde-facility
[4] http://cern.ch/service-rp-dosimetry (open only in the mornings 08:30 - 12:00).

should be returned to the Dosimetry service at the end of your visit. The "certificate attesting the suitability to work in CERN's radiation areas" [5] signed by your institute will be required.

9. Apply for access to "ISOHALL" using ADAMS: https://www.cern.ch/adams. (This can be done by any member of your collaboration, typically the contact person, having an EDH account[6]). Access to the hall is from the Jura side via your dosimeter.

   Find more details about CERN User registration see the Users Office website. For the latest updates on how to access the ISOLDE Hall see the ISOLDE website.

   New users are also requested to visit the ISOLDE User Support Office while at CERN. Opening hours: Monday to Friday 08:30 - 12:30

Contacts

ISOLDE User Support
Jennifer.Weterings@cern.ch
+41 22 767 5828

Chair of the ISCC
Gerda.Neyens@kuleuven.be

Chair of the INTC
Marek.Pfutzner@fuw.edu.pl

ISOLDE Physics Section Leader and Collaboration Spokesperson
Sean.Freeman@cern.ch
+41 22 766 5936

ISOLDE Physics Coordinator
Karl.Johnston@cern.ch
+41 22 767 3809

ISOLDE Technical Coordinator
Joachim.Vollaire@cern.ch
+41 22 766 4613

ISOLDE Deputy Technical Coordinator (with special responsibility for HIE-ISOLDE)
Erwin.Siesling@cern.ch
+41 22 767 0926

ISOLDE Operations Section Leader
Alberto.Rodriguez@cern.ch
+41 22 767 2607

More contact information at
ISOLDE contacts and at ISOLDE people.

[5] The certificate can be found via http://isolde.cern/get-access-isolde-facility
[6] Eventually you can contact Jenny or the Physics coordinator.