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Book of Abstracts

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A compact gas filled linear Paul trap for CRIS experiments.

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The CRIS technique (Collinear Resonance Ionisation Spectroscopy) has been shown to be an efficient method for accessing fundamental nuclear properties of exotic isotopes [1]. The technique can be applied to stable ion beams produced via laser ablation [2] which are pulsed due to the method of production. However, with radioactive cases produced at the ISOLDE (Isotope separator On-line) facility at CERN, a gas filled linear Paul trap is required for creating ion bunches. Currently, radioactive ion beams are produced via proton impact with a suitable target at ISOLDE. The resulting beam is then trapped, cooled, and bunched using the ISCOOL device following mass separation. The ion bunches are then directed to the CRIS setup where they are prepared for laser spectroscopy experiments. The technique has been shown to reveal properties such as nuclear spins, magnetic and electric quadrupole moments, and isotopic variations in the nuclear mean square charge radii. Measurement of these properties is made possible with ion beams that have been bunched with reduced emittance. The CRIS method has so far measured fundamental nuclear properties of neutron deficient Francium [3], and neutron rich radium [4] isotopes, among others. We envisage significant improvements to the CRIS technique following the installation of an independent gas filled linear Paul trap at ISOLDE as an alternative to the ISCOOL device. This would reduce set up times prior to time constrained experiments at the ISOLDE facility. It would enable constant optimisation of beam transport and quality. It would also trivialise switching from a radioactive beam to a stable reference isotope from our independent offline ion source. We provide an overview of the work completed since the first prototype was constructed and installed at the University of Manchester [5], where tests utilising a Ga ion source are ongoing. These tests include ion transport and gas attenuation within the device. Spatial limitations require that the new device is compact (<80 cm in length). SIMION calculations estimate that a prototype device with a 20 cm rod length could achieve a trapping efficiency of up to ~ 40% with a mean energy spread of ~ 4 eV.

[1]: T.E Cocolios et al. Nucl. Inst, Methods in Phys Res B, 317 (2013) [2]: R.F. Garcia Ruiz et al. Phys. Rev. X 8, 041005 (2018) [3]: K.T. Flanagan et al. Phys rev lett 111, 212501 (2013) [4]: K. M. Lynch et al. Phys. Rev. C 97, 024309 (2018) [5]: B. S. Cooper et al. Hyperfine Interact, 240:52 (2019)

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Actinide beams by light-ion induced fusion-evaporation for mass-, decay- and optical spectroscopy at IGISOL

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The production of actinide ion beams has become a focus of recent efforts at the IGISOL facility of the Accelerator Laboratory, University of Jyväskylä, especially aimed at the measurement of nuclear properties of heavy elements using high-resolution optical spectroscopy [1]. The first successful proof-of-principle on-line experiment for the production of actinides from a light-ion fusion-evaporation reaction has recently been performed with protons on ^{232}Th targets. Several alpha-active reaction products were detected, reaching as neutron deficient as ^{224}Pa through the $^{232}\text{Th}(p, 9n)^{224}\text{Pa}$ with a 60 MeV primary beam. By detection of gamma-rays in coincidence with the alpha-decay, new information on the decay radiation has been obtained on nuclei including ^{226}Pa .

Direct detection of long lived actinides such as ^{229}Th which is of special interest due to the extremely low-energy isomer [2], was not possible due to low alpha-activity as well due to low Q_{EC/β^-} values, rendering separation of isotopes even with high resolution Ramsey cleaning with the Penning trap ineffective. Therefore, the novel Phase-Imaging Ion Cyclotron Resonance (PI-ICR) method [3] at JYFLTRAP is to be used for for a direct yield determination of long-lived isotopes in an upcoming experiment. This will also allow direct high-precision mass measurements creating new anchor points in the mass network calculations which currently rely on long chains of alpha decays in the actinide region of the nuclear chart.

An important aspect of these developments has been related to target manufacturing. In addition to metallic thorium targets, several new ^{232}Th targets manufactured by a novel Drop-on-Demand inkjet printing method [4] were successfully tested. These targets were provided by the Nuclear Chemistry Institute of Johannes Gutenberg-Universität Mainz who will now provide several new targets from other more exotic actinides such as ^{233}U or ^{237}Np . With these new targets we expect to access several new isotopes in the neutron-deficient actinide region for decay and optical spectroscopy as well as for mass measurements.

- [1] A. Voss et al., Phys. Rev. A, 95 (2017) 032506.
- [2] L. von der Wense et al., Nature, 533 (2016) 47.
- [3] D. Nesterenko et al., Eur. Phys. J. A, 54 (2018) 154.
- [4] R. Haas. et al., Nucl. Instr. Meth. A, 874 (2017) 43.

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Addressing the systematics in phase-imaging ion-cyclotron-resonance measurements at the Canadian Penning Trap mass spectrometer

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Phase-imaging ion-cyclotron-resonance (PI-ICR) is a novel technique for determining the cyclotron frequency (ν_c) of an ion trapped in a Penning trap. First developed by the SHIPTRAP group at GSI [1], this technique relies on measuring the radial phase a trapped ion accumulates over a period of time. At the Canadian Penning Trap mass spectrometer (CPT) in Argonne National Laboratory (ANL), PI-ICR is currently employed [2,3]. The measurement campaigns and extensive tests over the last few years have revealed a number of systematics relating to the alignment between the magnetic field and ejection optics, the stability of the Penning trap electric field, and the initial magnetron motion of the ions [4]. These systematics and the efforts to address them will be presented.

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- [1] S. Eliseev *et al.*, Appl. Phys. B 114 (2014) 107.
- [2] R. Orford, N. Vassh *et al.*, Phys. Rev. Lett. 120 (2018) 262702.
- [3] D.J. Hartley, F.G. Kondev, R. Orford *et al.*, Phys. Rev. Lett. 120 (2018) 182502.
- [4] R. Orford, PhD thesis, McGill University, Canada (2018).

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Barium Ion Transport in High Pressure Xenon Gas using RF Carpets

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A background-free measurement of neutrinoless double beta decay can be achieved with the detection of the daughter nucleus. Methods to image the daughter barium ion in the decay of xenon-136 are being developed for use in high pressure gas time projection chambers by the NEXT collaboration. A major remaining challenge is the transport of the barium ion to a small imaging region within the detector. In this talk I will discuss the plans for testing RF carpet performance in high pressure gas, early simulation results, and experimental tests of RF high voltage behavior in high pressure systems. I will also discuss our studies of ion drift properties in DC fields in high pressure gases.

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Barium Tagging in High Pressure Xenon Gas

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The identification of a single barium ion in coincidence with an energy deposit measured with a precision of 1% in xenon is widely recognized as an unambiguous signature of neutrinoless double beta decay. The detection of single ions in tons of gas or liquid xenon, however, is a major experimental challenge. In this talk I will discuss barium tagging methodologies based on single molecule fluorescence imaging adapted to high pressure xenon gas time projection chambers. Recent advances in ion sensing chemistry and gas phase microscopy will be presented, followed by a discussion of the subsequent R&D steps planned by the NEXT collaboration to enable an ultra-low background, barium tagging neutrinoless double beta decay technology.

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Characterization of supersonic jets for in-gas-jet laser ionization spectroscopy at the IGLIS laboratory and of gas flow inside the ion guide at the IGISOL-4 facility

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Noble gases such as argon and helium are utilized within the In-Gas Laser Ionization and Spectroscopy (IGLIS) [1] and Ion Guide Isotope Separation On-Line (IGISOL) [2] techniques to thermalize and transport nuclear reaction products, which often have short lifetimes and small production yields. To facilitate the spectroscopic studies of the properties of nuclear reaction products, thorough understanding and characterization of utilized gas flows are essential. Characterization was performed experimentally at both the IGLIS and IGISOL-4 laboratories and numerically using the Computational Fluid Dynamics (CFD) Module of COMSOL Multiphysics.

With the in-gas-jet method, an extension of the IGLIS technique, the spectral resolution is improved by more than one order of magnitude in comparison to in-gas-cell laser ionization spectroscopy [3], while maintaining a high efficiency. This allows the determination of nuclear properties with higher precision. The flow parameters of such supersonic gas jets were characterized at the IGLIS laboratory at KU Leuven using Planar Laser Induced Fluorescence (PLIF) and will be discussed in the first part of this talk. The projected temperature associated (Doppler) broadening, which can be attained with an upgraded in-gas-jet method, was estimated to be about 140 MHz for the No isotopes. Moreover, the numerical calculations were performed to obtain temperature, velocity and Mach number profiles of supersonic jets formed by a de Laval nozzle. The experimental and numerical in-gas-jet results agreed reasonably well for a range of coordinates after the nozzle's exit [4].

Extraction efficiencies and delay times of subsonic helium and argon flows inside a fission ion guide are being characterized at the IGISOL-4 facility at the University of Jyväskylä using a radioactive ²²³Ra α -recoil source (T_{1/2}=11.4 d). The status of these measurements will be discussed in the second part of this talk. This characterization defines lower limits of production yields and lifetimes of the nuclear reaction products to be studied using gas cells.

[1] Yu. Kudryavtsev et al., Beams of short lived nuclei produced by selective laser ionization in a gas cell, *Nucl. Instrum. Meth. Phys. Res. B*, 114, 350 (1996)

[2] I. D. Moore, P. Dendooven, and J. Ärje, The IGISOL technique—three decades of developments. In: Äystö J., Eronen T., Jokinen A., Kankainen A., Moore I.D., Penttilä H., Three decades of research using IGISOL technique at the University of Jyväskylä. Springer, Dordrecht (2013)

[3] R. Ferrer et al., Towards high-resolution laser ionization spectroscopy of the heaviest elements in supersonic gas jet expansion, *Nat. Commun.* 8, 14520 (2017)

[4] A. Zadvornaya et al., Characterization of Supersonic Gas Jets for High Resolution Laser Ionization Spectroscopy of Heavy Elements, *Phys. Rev. X*, 8, 041008 (2018)

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Design, optimization and commission of a multi-reflection time-of-flight mass analyzer at IMP/CAS

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A multi-reflection time-of-flight mass analyzer is being constructed for isobaric separation and mass measurement at IMP/CAS (Institute of Modern Physics, Chinese Academy Science). A new method including two sub-procedures, global search and local refinement, has been developed for the design of MRTOF mass analyzer. The method can be used to optimize the parameters of MRTOF-MS both operating in mirror-switching mode and in-trap-lift mode. By using this method, an MRTOF mass analyzer, in which each mirror consists of five cylindrical electrodes, has been designed. In the mirror-switching mode, the maximal mass resolving power has been achieved to be 1.3×10^5 with a total time-of-flight of 6.5 ms for the ion species of $^{40}\text{Ar}^{1+}$ [1], and in the in-trap-lift mode, it is 1.6×10^5 with a total time-of-flight of 6.4 ms [2]. The simulation also reveals the relationships between the resolving power and the potentials applied on the mirror electrodes, the lens electrode and the drift tube.

This MRTOF-MS has been constructed and is being commissioning now. The preliminary test results show that it works [2].

In this conference, we will present the design details, optimization method and the test results obtained.

References:

[1] Y.L. Tian, Y.S. Wang, J.Y. Wang, et al., *Int. J. Mass Spectrom.* 408, 28–32 (2016).

[2] Jun-Ying Wang, Yu-Lin Tian, Yong-Sheng Wang, et al., *Nucl. Instrum. Meth. B*, (2019).

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Development of a New Laser Ablation Ion Source

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A new laser ablation ion source is under development at the Institute for Nuclear Physics, TU Darmstadt for high-precision collinear laser spectroscopy. The design will combine the versatility of laser ablation ion production and the non-conservative cooling in Helium buffer gas, to produce a low emittance ion beam of a wide range of elements. It is based on the original idea of an RF-only ion funnel [1] using only the gas jet to transport the ablated ions, which are radially confined by RF electrodes. Additionally, this design will contain a new feature that will allow to further cool and bunch the ion beam. For this purpose, an additional RF electrode stack is placed in the next pumping stage superimposed by a DC gradient towards the exit [2]. The last electrode can be connected to a positive voltage to create a potential barrier and stop the ions to produce a narrow ion bunch. Detailed computer simulations have shown that this ion source [3] will allow us to produce various

high-quality continuous and pulsed ion beams, with low transverse and longitudinal emittance. We will present the current status and first results of this project development.

[1] Victor Varentsov, A new Approach to the Extraction System Design, SHIPTRAP Collaboration Meeting, 19 March, 2001, DOI: <https://doi.org/10.13140/RG.2.2.30119.55200>

[2] Victor Varentsov, Proposal for a new Laser ablation ion source for LaSpec and MATS testing, NUS-TAR Collaboration Meeting, 1 March, 2016, DOI: <https://doi.org/10.13140/RG.2.2.10904.39686>

[3] T. Ratajczyk, V. Varentsov and W. Nörtershäuser, Status of a new laser ablation ion beam source for LASPEC, GSI-FAIR SCIENTIFIC REPORT 2017, DOI: <https://doi.org/10.15120/GR-2018-1>

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Development of offline ion source for collinear laser spectroscopy at the SLOWRI facility in RIKEN

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We have prepared an offline ion source mainly for a planned collinear laser spectroscopy of RI beams at the SLOWRI facility in RIKEN. It was designed to provide low-emittance ion beams including refractory elements such as Zr, by combining laser ablation of a solid target in He gas and RF ion guide system [1]. We have connected the ion source to a test beamline and observed about 10^7 singly charged ions per laser pulse (≤ 10 Hz) extracted at 10 keV. The current situation including tests to evaluate the performance will be presented.

References:

[1] M. Wada *et al.*, Nucl. Instrum. Methods Phys. Res. **B** 204, 570 (2003).

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Efficient Ion Thermalization and Mass Spectrometry of (Super-)Heavy Elements at SHIPTRAP

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The quest for the *island of stability*, a region of nuclides with enhanced stability around proton and neutron numbers $Z \approx 114 - 126$ and $N \approx 184$, respectively, is at the forefront of nuclear physics. The survival of superheavy elements is intimately linked to nuclear shell effects, which can be experimentally probed by mass measurements. Experiments around this region are hampered by extremely low production rates of down to few ions per month. Nonetheless, the Penning-trap mass spectrometer SHIPTRAP, located at the GSI in Darmstadt, Germany, has shown that direct high-precision measurements of atomic masses of ^{102}No and ^{103}Lr isotopes around the deformed shell closure $N = 152$ are feasible and provide indispensable knowledge on binding energies, shell effects and yield important anchor-points on α -decay chains, affecting absolute mass values up to the heaviest elements.

To continue this groundbreaking program and to proceed towards heavier and more exotic nuclides, the drop in production rate has to be accommodated by several improvements. The Penning-trap system was recently relocated, allowing to integrate a second-generation gas-stopping cell, operating at cryogenic temperatures. Its stopping efficiency was optimized using the SRIM simulation software, and its purity was recently investigated using recoil-ion sources. In addition, the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique was developed, increasing the sensitivity of mass measurements. To fully exploit its enhanced mass resolving power required improving the temporal stability of the electric and magnetic fields. Furthermore, its applicability in low-rate measurements, accumulating only few ions in total, yet had to be proven.

In the SHIPTRAP experimental campaign in summer 2018, we extended direct high-precision Penning-trap mass spectrometry into the region of the heaviest elements using the PI-ICR technique. For the first time, direct mass measurements of ^{251}No , ^{254}Lr and the superheavy nuclide ^{257}Rf were performed with rates down to one detected ion per day. Despite lowest rates the PI-ICR technique allowed resolving the isomeric states $^{251m,254m}\text{No}$ and $^{254m,255m}\text{Lr}$ from their respective ground states with mass resolving powers of up to 10.000.000 and to accurately determine their excitation energies, which had previously been derived only indirectly via decay spectroscopy.

In this contribution an overview of the technical developments and the recent results will be given.

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First application of mass selective re-trapping enables mass measurements of neutron-deficient Yb and Tm isotopes despite strong isobaric background

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TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) [1] located at the Isotope Separator and Accelerator (ISAC) facility, TRIUMF, Vancouver, Canada is a multiple ion trap system specialized in performing high-precision mass measurements and in-trap decay spectroscopy of short-lived radioactive ions. Although ISAC can deliver high yields for some of the most exotic species, many measurements suffer from strong isobaric background. In order to overcome this limitation an isobar separator based on the Multiple-Reflection Time-Of-Flight Mass Spectrometry (MR-TOF-MS) technique has been developed and installed at TITAN [2].

Mass selection is achieved using dynamic re-trapping of the ions of interest after a time-of-flight analysis in an electrostatic isochronous reflector system [3]. Re-using the injection trap of the device for the mass-selective re-trapping, the TITAN MR-TOF-MS can operate as its very own high resolution isobar separator prior to mass measurements within the same device. This combination of operation modes boosts the dynamic range and background handling capabilities of the device, enabling high precision mass measurements with ion of interests to contaminant ratios of $1:10^6$.

We will discuss the technical aspects of re-trapping and recent results of mass measurements of neutron-deficient Yb and Tm isotopes investigating the persistence of the N=82 neutron shell closure far from stability made possible by employing for the first time online mass selective re-trapping to suppress strong isobaric background.

References:

[1] J. Dilling et al., NIM B 204, 2003, 492–496

[2] C. Jesch et al., Hyperfine Interact. 235 (1-3), 2015, 97–106

[3] T. Dickel et al. J. Am. Soc. Mass Spectrom. (2017) 28: 1079

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Group Photo

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Improvement of a dc-to-pulse conversion efficiency of FRAC

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At the SCRIT electron scattering facility at RIKEN [1,2], we aim at realizing the world's first electron scattering experiment of unstable nuclei, after succeeding in principle verification experiment using stable nuclei ^{132}Xe [3].

In order to perform electron scattering with unstable nuclei with small production rate, it is important to accumulate and inject ions efficiently into the SCRIT device. For this purpose, it is necessary to convert a continuous ion beam from the ISOL type ion separator ERIS [4] to a pulsed beam with the pulse duration of 300~500 μs .

We developed a dc-to-pulse converter, called FRAC [5], based on RFQ linear ion trap and have attained the dc-to-pulse conversion efficiency of 5.6%.

We modified the FRAC to further improve the efficiency, and enabled cooling of the trapped ions by Xe gas of $\sim 10^{-3}$ Pa. Then an electric field gradient was applied in the longitudinal direction of FRAC.

As a result, the conversion efficiency was improved by more than 10 times compared to that before modification. Details of the modification and its latest performance will be presented.

References:

- [1] M. Wakasugi et al., Nucl. Instrum. Meth. **B317**, 668 (2013).
- [2] T. Ohnishi et al., Physca Scripta **T166**, 014071 (2015).
- [3] K. Tsukada et al., Phys. Rev. Lett. **118**, 262501 (2017).
- [4] T. Ohnishi et al., Nucl. Instrum. Meth. **B317**, 357 (2013).
- [5] M. Wakasugi et al., Rev. Sci. Instrum. **89**, 095107 (2018).

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Laser Resonance Chromatography (LRC): A new methodology in superheavy element research

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Optical spectroscopy constitutes the historical path to accumulate basic knowledge on the atom and its structure. Former work based on fluorescence and resonance ionization spectroscopy enabled identifying optical spectral lines up to element 102, nobelium [1, 2]. Beyond nobelium, solely predictions of the atom's structure exist, which in general are far from sufficient to reliably identify atoms from spectral lines. One of the major difficulties in atomic model calculations arise from the complicated interaction between the numerous electrons in atomic shells, which necessitate conducting experiments on such exotic quantum systems. The experiments, however, face the challenging refractory nature of the elements, which lay ahead, coupled with shorter half-lives and decreasing production yields.

In this contribution, a new concept of laser spectroscopy of the superheavy elements is proposed. To overcome the need for detecting fluorescence light or for neutralization of the fusion products,

which were employed up to date when lacking tabulated spectral lines, the new concept foresees resonant optical excitations to alter the ratio of ions in excited metastable states to ions in the ground state. The excitation process shall be readily measurable using electronic-state chromatography techniques [3, 4] as the ions exhibit distinct ion mobilities at proper conditions and thus drift at different speeds through the apparatus to the detector. The concept offers unparalleled access to laser spectroscopy of many mono-atomic ions across the periodic table of elements, in particular, the transition metals including the high-temperature refractory metals and the elusive superheavy elements like rutherfordium and dubnium at the extremes of nuclear existence.

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (No. 819957)

References

1. J. Reader A. Kramida, Yu. Ralchenko and NIST ASD Team (2018), 2019.
2. M. Laatiaoui et al., Nature, 538 (2016) 495.
3. P. R. Kemper and M. T. Bowers, J. Phys. Chem., 95 (1991) 5134.
4. M. J. Manard and P. R. Kemper, Int. J. Mass Spectrom., 407 (2016) 69.

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MIRACLS: A Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy

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Laser spectroscopy is a well-established technique for studying nuclear ground-state properties in a model-independent way. By observing the isotope shifts and hyperfine structures of the atoms' spectral lines, the technique provides access to the charge radii and electromagnetic moments of the nuclear ground- and isomeric states [1, 2]. While in-source laser spectroscopy in a hot cavity is a very sensitive method that is able to measure rare isotopes with production rates below one particle per second at ISOL facilities [3], the spectral resolution of this method is limited by Doppler broadening to ~5 GHz. Collinear laser spectroscopy (CLS) on the other hand, provides an excellent spectral resolution of ~10 MHz [1] which is of the order of the natural line widths of allowed optical dipole transitions. However, CLS requires yields of more than 100 or even 10,000 ions/s depending on the specific case and spectroscopic transition [4].

The MIRACLS project at CERN aims to develop a laser spectroscopy technique that combines both the high spectral resolution of conventional fluorescence CLS with an enhanced sensitivity factor of 20-600 depending on the mass and lifetime of the studied nuclide. The sensitivity increase is derived from an extended observation time provided by trapping ion bunches in a Multi-Reflection Time-of-Flight device where they can be probed several thousand times [5]. A proof-of-principle

apparatus, operating at 2 keV beam energy, has been assembled at CERN ISOLDE with the goal of demonstrating the MIRACLS concept, benchmark simulations [6] that will be employed to design a future device operating at 30 keV and further technological developments.

Recently, first measurements have been performed with the proof-of-principle apparatus using stable magnesium isotopes as a first test case. Laser spectroscopy has been performed on $24,26\text{Mg}^+$ ions trapped for more than 5000 revolutions in the MR-ToF. Line widths close to the Doppler limit in this 2-keV machine have been achieved. Furthermore, a.o. collinear-anticollinear spectroscopy has been performed on 40Ca^+ ions. Extensive characterizing study of the device is ongoing.

This talk will introduce the MIRACLS concept, present the first results and current status of the project as well as an outlook towards further developments.

[1] K. Blaum, et al., Phys. Scr. T152, 014017 (2013)

[2] P. Campbell et al., Prog. Part. and Nucl. Phys. 86, 127-180 (2016)

[3] B. Marsh et al., Nature Physics 14, 1163-1167 (2018)

[4] R. Neugart, J. Phys. G: Nucl. Part. Phys. 44 (2017)

[5] S. Sels et al., Nucl. Instr. Meth. B, In press (2019) DOI: 10.1016/j.nimb.2019.04.076

[6] F. Maier, et al. Hyperfine Interact (2019) 240:54

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MORA project and optimization of transparent ion trap geometry

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The MORA (Matter's Origin from the RadioActivity of trapped and oriented ions) project [1] is part of the research on CP violation that could explain the matter-antimatter asymmetry observed in the universe, through the measurement of the so-called D correlation. MORA uses an innovative in-trap orientation method which combines the high trapping efficiency of a transparent Paul trap with laser orientation techniques. The MORA setup will permit to reach precision on D down to a few 10^{-5} , which allows to probe the Final State Interactions (FSI) effects for the first time.

Within the framework of this project, a three-dimensional Paul trap (MORATrap) geometry has been optimized to broaden the quadrupolar region, where the contribution of higher order harmonics is reduced. MORATrap is composed of three conic ring pairs with a mid-plane symmetry, its geometry is inspired from the existing transparent Paul trap, LPCTrap [2]. Our trap optimization was carried out by minimizing high order harmonics and maximizing the quadrupolar term in the spherical harmonics expansion of the generated potential in the trap center. Our simulation is based on solving Laplace's equation with the AXIELECTROBEM software developed at LPC Caen coupled to some χ^2 minimization.

[1] P. Delahaye et al., arXiv:1812.02970, proceedings of the TCP 2018 conference, to appear in Hyp. Int.

[2] P.~Delahaye et al., arXiv:1810.09246 [physics.ins-det], submitted to EPJA.

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On the way to a world-competitive fission fragment facility at SARAF

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Combining an Ion Catcher, which is based on the cryogenic stopping cell that is being designed for the Low Energy Branch at the Super-FRS at FAIR [1], with the high-power accelerator SARAF II, currently under construction at Soreq NRC [2], and a liquid lithium target [3] will enable creating a research facility for neutron-rich exotic isotopes based on high-energy neutrons induced fission. I will outline a conceptual design and possible implementation of the Ion Catcher at SARAF, along with rate estimations, which indicate that such a facility will be potent in a world competitive manner, with neutron-rich isotope production rates higher than much larger future facilities such as FRIB.

References:

[1] T. Dickel et al., "Conceptual design of a novel next-generation cryogenic stopping cell for the Low-Energy Branch of the Super-FRS", Nucl. Instr. and Meth. B 376 216-220 (2016)

[2] I. Mardor et al., "The Soreq Applied Research Accelerator Facility (SARAF): Overview, research programs and future plans", Eur. Phys. J. A (2018) 54: 91

[3] S. Halfon et al., "Note: Proton irradiation at kilowatt-power and neutron production from a free-surface liquid-lithium target", Rev. Sci. Inst. 85, 056105 (2014)

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Overview of progress at SMI-2019

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This talk will provide an overview of the field of Stopping and Manipulation of Ions and related topics based on the recent progress presented by the different contributions within SMI-2019. A final focus will aim to look towards the future and the puzzles and possibilities we may face in the coming years which will set the scene for the next conference.

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Particle-in-Cell Simulations for Studies of Space Charge Effects in Ion Trap and Ion Transport Devices

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One of the least intuitive phenomena in ion trap or ion transport devices is the effect of large numbers of charged particles, also known as space charge, on the performance of the device. Space charge can shield applied DC and RF fields, leading to poor transport efficiencies and increased spatial and energy distributions. Robust simulation methods must be employed in order to mitigate these effects and to gain a better understanding of the device in the presence of space charge. However, standard ion optics software, such as SIMION [1], have limited ability to handle space charge, or are not optimized to efficiently study the system of interest. Therefore, other, more specialized, techniques must be used.

The particle-in-cell (PIC) method has been used to study plasmas and gravitational systems for decades, typically employing 2D or 3D coordinate systems. Thorough treatments of the subject can be found in [2, 3]. Modern desktop computing hardware make 3D PIC simulations with millions of super particles possible in a reasonable amount of time without requiring a high-performance computing cluster. The 3DCyPIC package [4] was developed to study devices at FRIB/NSCL, such as RF carpets, gas cells, radiofrequency quadrupole cooler/bunchers, MR-TOFs, etc., that need to operate effectively in the presence of large amounts of space charge. In this talk I will describe how 3DCyPIC operates and present the results of simulations of devices that are currently in use, making comparisons to measurements where possible.

[1] D. A. Dahl, *Int. J. Mass Spectrom.* 200 (2000) 3–25.

[2] C. K. Birdsall, A. B. Langdon, *Plasma physics via computer simulation*, McGraw-Hill, New York, 1985.

[3] R. W. Hockney, J. W. Eastwood, *Computer simulation using particles*, A. Hilger, Bristol [England] ; Philadelphia, 1988.

[4] R. Ringle, *Int. J. Mass Spectrom.* 303 (2011) 42-50.

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Present status and future plans for slow and stopped beams in RIKEN

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The accelerator complex at RIKEN's Nishina Center for Accelerator Based Science offers presently unparalleled intensity and variety of radioactive ion beams. The accelerator complex employs multiple facilities utilizing in-flight fission and fragmentation, fusion, and multi-nucleon transfer reactions to provide radioactive ion beams spanning the table of isotopes from ${}^6\text{He}$ to ${}^{294}\text{Og}$. In order to make these beams viable for low-energy experimental techniques (e.g. ion traps) requires the use of high-pressure gas cells. Several such systems are in various states of readiness.

The SHE-mass gas cell, located after the gas-filled recoil ion separator GARIS-II has been successfully operated since 2016. Recent modifications of the SHE-mass system will be discussed and select results presented.

A medium-size gas cell is nearing construction for use in symbiotic measurements. It will be used as a beam dump for in-beam gamma-ray experiments and in conjunction with a multi-reflection time-of-flight mass spectrograph will enhance the in-beam gamma-ray experiments. The design of the system and its planned usage will be discussed.

To provide access to neutron-rich heavy isotopes which are difficult to access via in-flight fission and fragmentation, the KEK Isotope Separation System (KISS) utilizes multi-nucleon transfer reactions. The transfer products are stopped and neutralized in an argon-filled gas cell. Atoms of a desired element can be selectively re-ionized using a two-color resonance laser ionization scheme. Ions of the selected element are accelerated to 30 keV and isobarically purified via a magnetic dipole prior to being delivered to a measurement station. A new "gas-cell cooler-buncher" has recently been

installed to efficiently convert the 30 keV beam to be compatible with ion traps. The system will be described and its performance reported.

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Recent experimental results of KEK Isotope Separation System (KISS)

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KEK Isotope Separation System (KISS) is a laser ion source with an argon gas cell, we have been developing at RIKEN RIBF facility [1,2]. The KISS project is motivated by the systematic nuclear spectroscopy of neutron-rich nuclei at the north-east part of the nuclear chart, that is from around neutron-magic number 126 to the trans-uranium region. The systematic studies of lifetimes, masses, beta-gamma spectroscopy and laser spectroscopy of those nuclei will provide information of nuclear structures, which is crucial inputs to the theoretical predictions of nuclear parameters included in the the simulation of r-process nucleosynthesis, its astrophysical environments remain unrevealed yet.

KISS has an argon gas cell which is optimized to efficiently collect and extract nuclear products in the multi nucleon transfer (MNT) reactions, which are considered to be appropriate mechanism to produce neutron-rich nuclei of interest [3,4]. The employment of a doughnut-shaped gas cell with high-vacuum condition of the primary beam line improved the extraction efficiency [5]. The laser resonance ionization technique is used to element-selectively ionize the element of interest. Those photo-ions are transported by RF ion guides through the differential pumping area and are finally accelerated by a high voltage to select one species of isotopes with a mass separator. In-gas-cell and in-gas-jet laser ionizations are utilized at KISS.

In this presentation, we will report the present status, the recent experimental results and the future plan of KISS.

[1] Y. Hirayama et al., Nucl. Instrum. and Methods B 353 (2015) 4.

[2] Y. Hirayama et al., Nucl. Instrum. and Methods B 376 (2016) 52.

[3] Y.H. Kim et al., EPJ Web of conferences 66 (2014) 03044.

[4] Y.X. Watanabe et al., Phys. Rev. Lett. 115 (2015) 172503.

[5] Y. Hirayama et al., Nucl. Instrum. and Methods B 412 (2017) 11.

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Recent results from the FRS Ion Catcher

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The FRS Ion Catcher setup [1] is used for thermalization and high-resolution measurements of exotic nuclei produced at relativistic energies of up to 1 GeV/u at the fragment separator (FRS) at GSI. It consists of a cryogenic gas-filled stopping cell (CSC), an RFQ beamline and a multiple-reflection time-of-flight mass-spectrometer (MR-TOF-MS), which can be used for mass measurements with mass accuracies down to $6 \cdot 10^{-8}$ [2] and for the production of isobarically and isomerically clean beams.

Over the last years, several technical improvements and upgrades were implemented to the setup. New techniques for enhancing the selectivity of ion transport based on ion mobility and dissociation of molecular contaminants were developed. The RFQ beamline was expanded and upgraded with improved differential pumping, a mass filter and a laser ablation carbon cluster ion source. The areal density of the CSC was increased to 10 mg/cm². A novel method for half-lives and branching ratios measurements [3] using the CSC as an ion trap for controllable storing of ions was developed and demonstrated.

In addition, the progress on the technical design of the CSC for the Low-Energy Branch of the Super-FRS at FAIR will be reported.

References:

- [1] W. R. Plass et al., Nucl. Instrum. Methods B, 317 (2013)
- [2] S. Ayet et al., accepted to Phys. Rev. C, arXiv:1901.11278 (2019)
- [3] I. Miskun et al., submitted to Eur. Phys. Journal A, arXiv:1902.11195 (2019)

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6

Reviewing the success of radioactive-ion manipulation with RFQ traps and recalling the contributions from McGill

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Ion cooling and trapping techniques have opened new vistas in the physics associated with exotic (short-lived) nuclides and helped cure the ills of isobaric contamination. The ability of condensing ion-beam phase space using soothing cold buffer gas accompanied by electromagnetic confinement has created a new paradigm: beam preparation. The main player in this field is the so-called RFQ cooler-buncher, a segmented linear Paul trap that can capture exotic nuclides hot off the target, reducing emittance by grouping ions into a tight bunch.

Inspired by a 1982 sabbatical leave in Mainz with the group of H.-J. Kluge developing Penning traps for ISOLDE, the late R.B. Moore initiated the first ion-catching developments at McGill with many of details elaborated (at the bar) in Thomson House, the SMI2019 conference venue.

Bunchers are now used for mass measurements and collinear laser spectroscopy of exotic nuclides. Further evolutions have them preceding dipole mass separators to increase resolving power and even inside ISOL target modules combined with laser ionization for beam purification. RFQ bunchers are also necessary preparatory devices for the fabulous multi-reflection time of flight (MRTof) mass spectrometers that are now pervading the radioactive-ion scene.

In this presentation, the (local) history will be briefly told and the rich evolution of cooler-bunchers will be illustrated as exhaustively as time will permit.

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SIMULATION VS. PERFORMAMCE OF THE TRIUMF CANREB RFQ COOLER-BUNCHER

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The CANadian Rare-isotope laboratory with Electron Beam ion source (CANREB) project at TRIUMF [1] produces a large variety of rare radioactive and stable isotope beams for fundamental research. Essential to CANREB is a new radiofrequency quadrupole (RFQ) cooler-buncher [2] operating in grade 5.0 helium gas at 3 MHz, 1.2 kV_{pp} ($q \sim 0.2$) with 60-70 W input RF power. The RFQ is designed to (A) accept beams with <100 pA currents at <60 keV energies, and (B) deliver cooled and bunched beams <10⁶ ions/bunch at 100 Hz with >90% efficiency, <10 eV energy spread, and short <1 us time-spread. Commissioning tests with picoamp beams of 30 keV ¹³³Cs⁺¹ ($r \sim 5$ mm, angular spread ~ 10 mrad) in ~ 5 mtorr helium yield >90% transmission through the RFQ with >80% bunching efficiency. Simulations agree with ¹³³Cs⁺¹ performance characteristics. Here we discuss simulation of beam properties in the RFQ obtained with SIMION to actual performance for ¹³³Cs⁺¹, ⁸⁵Rb⁺¹ and other isotopes of interest, over a range of energies. Preliminary results indicate q-values for RFQ operation with >90% transmission occur for 60 keV: ¹³³Cs⁺¹ = 0.10-0.25, ⁸⁵Rb⁺¹ = 0.09, and ¹³³Cs⁺¹ (18.5 keV) = 0.14-0.30, ⁸⁵Rb⁺¹ (29 keV) = 0.12-0.16.

References:

[1] The CANREB project for charge state breeding at TRIUMF. F. Ames, R. Baartman, B. Barquest, C. Barquest, M. Bleszenohl, J. R. Crespo López-Urrutia, J. Dilling, S. Dobrodey, L. Graham, R. Kanungo, M. Marchetto, M. R. Pearson, and S. Saminathan. Proceedings of the “17th International Conference on Ion Sources”, Oct. 15-20, 2017, Geneva Switzerland, AIP Conf. Proc. 2011, 070010-1–070010-3; (2018).

[2] B.R. Barquest, J.C. Bale, J. Dilling, G. Gwinner, R. Kanungo, R. Krucken, M.R. Pearson. Development of a new RFQ beam cooler and buncher for the CANREB project at TRIUMF. NIMB 376 (2016), 207-210.

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Single Barium Atom Detection in Solid Xenon for the nEXO Experiment

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The proposed nEXO experiment is a tonne-scale liquid xenon time projection chamber, designed to search for neutrinoless double beta decay in xenon-136 [1]. A critical concern for any rare decay search is reducing or eliminating backgrounds that will interfere with the signal [2]. A powerful background discrimination technique is the positive identification (“tagging”) of the decay daughter, in this case barium.

A technique being developed in the nEXO collaboration is the trapping and extraction of the Ba daughter ion in solid xenon on a cryogenic probe, then using fluorescence spectroscopy to tag, i.e., identify the barium atom. Individual barium atoms, implanted into Xe ice as Ba ions, have been imaged in solid xenon, and the 619 nm emission of atomic barium in solid xenon has been assigned to single vacancy trapping sites [3].

1. Al Kharusi et al. (nEXO Collaboration), arXiv:1805.11142 [*physics.ins-det*] (2018).
2. Albert et al. (nEXO Collaboration), *Phys. Rev. C* **97**, 065503 (2018).
3. Chambers et al. (nEXO Collaboration), *Nature* **569**, 203-207 (2019).

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Status of St. Benedict at the Nuclear Science Laboratory

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St. Benedict, the Superallowed Transition Beta-Neutrino Decay-Ion-Coincidence Trap, is in development at the University of Notre Dame's Nuclear Science Laboratory. This ion trapping system will be composed of three main components. The first component will be a large-volume gas cell which will thermalize ions through collisions with a buffer gas, coupled with a RF-funnel-based ion guide system followed by a sextupole ion guide (SPIG) for extraction. Then, a radiofrequency quadrupole (RFQ) will take the continuous beam from the gas catcher and produce a cooled, bunched beam for injection into a linear Paul trap. The Paul trap will hold the ions near rest until they decay, and surrounding detectors will be used to determine the kinematics of the decay particles. The β -decay spectrum can be extracted from this information, and used to determine the β - ν angular correlation coefficient, $a_{\beta\nu}$. This will allow for the determination of the Fermi to Gamow-Teller mixing ratio, ρ , for members of the ensemble of T=1/2 superallowed β decays whom have not had this quantity measured experimentally. The determination of ρ for these decays will allow for the calculation of a precision V_{ud} value complementary to the current precision limit provided by superallowed $0^+ \rightarrow 0^+$ decays. The current status of the project will be presented. This work is funded by the National Science Foundation Major Research Instrumentation grant PHY-1725711.

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Status of the radiofrequency quadrupole cooler/buncher at TRIUMF-CANREB

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The Canadian Rare-isotope facility with Electron Beam ion source (CANREB) is currently being commissioned at TRIUMF in Vancouver, Canada. CANREB will accept rare isotope beams from the Isotope Separator and Accelerator (ISAC) or Advanced Rare Isotope Laboratory (ARIEL) facilities. The ions will be charge bred using an electron beam ion source (EBIS) to $3 \leq m/q \leq 7$ for post-acceleration to medium- and high-energy experiments. For injection into the EBIS, continuous ion beams from the source will be cooled and bunched using a radiofrequency quadrupole (RFQ) cooler/buncher. Results from initial RFQ commissioning tests, as well as an overall status of CANREB, will be presented.

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The Advanced Cryogenic Gas Stopper at NSCL – Progress towards Operations

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The Advanced Cryogenic Gas Stopper (ACGS) has successfully delivered its first rare isotope beam for experiments at the National Superconducting Cyclotron Laboratory (NSCL). The ACGS has shown an increase extraction efficiency, reduce transport time, reduce molecular contamination of the isotope of interest, and the ability to minimize space charge effects. This is achieved by a novel 4-phase Radio Frequency wire-carpet which generates a traveling electrical wave for fast and efficient ion transport, cryogenic cooling of the helium gas chamber reduces unwanted molecular formation, and the new planar geometry with the wire-carpet in the mid-plane of stopper alleviates space charge effects. Offline testing of ACGS has shown wire-carpet transport efficiencies greater than 95% and transport speeds up to 100 m/s. Operating at a temperature of near 80 K, ACGS delivered argon-44 to the ReA3 system reliably for over a week with a beam rate up to twice as much as advertised on the ReA3 Beam List. This presentation will show the most recent online and offline performance of the ACGS and discuss advancements made regarding extraction from the gas stopper.

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The CISE project

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Gas-catchers are widely used in experimental nuclear physics to slow down for precision measurements. Chemical reactions of the ions with impurities in the gas can affect the extraction efficiency. Thus, there is lots of effort to keep the gas inside the catcher as clean as possible. Our aim is to explore the potential of chemical reactions for Chemical Isobaric Separation (CISe). We are currently building a new setup consisting of a gas-catcher and a commercial quadrupole Time-of-Flight mass-spectrometer. First studies in a hexapole collision cell have been performed to investigate the ion chemistry of tin, indium, cadmium and silver. In this contribution, an overview of the project will be presented.

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The ELI-IGISOL radioactive ion beam facility at ELI-NP

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The Extreme Light Infrastructure for Nuclear Physics (ELI-NP) facility will make available in the near future two new photon installations: a high-power laser system and a high-brilliance gamma beam system, which can be used together or separately.

The ELI-IGISOL project [1] will use the primary gamma beam to generate a Radioactive Ion Beam (RIB) via photofission in a stack of Uranium targets placed at the center of a gas cell [2]. The particular technology used for this gas cell is the High Areal Density with Orthogonal extraction Cryogenic Stopping Cell (HADO-CSC) [3] featuring ion extraction orthogonal to the primary beamline. The gas cell is coupled to a radio-frequency quadrupole for beam formation. The exotic neutron-rich nuclei will be separated, and their mass measured, by a high-resolution Multiple-Reflection Time-of-Flight (MR-ToF) mass spectrometer. The isomerically pure RIBs [4] obtained with the MR-ToF will be further measured by a β -decay tape station and a collinear laser spectroscopy station.

The latest developments in the simulation and design of the gas cell are presented. We report benchmark calculations of the production rates and of the extraction time and efficiency from the gas cell. Starting from these studies, the optimal design of the cell and its state-of-the-art technologies is discussed. Various testing units for the HADO-CSC components that are being developed at ELI-NP will be presented.

1. D.L. Balabanski et al., "Photofission Experiments at ELI-NP", *Rom. Rep. Phys.* **68**, S621 (2016).
2. P. Constantin et al., "Design of the gas cell for the IGISOL facility at ELI-NP", *Nucl. Inst. Meth. B* **397**, 1 (2017).
3. T. Dickel et al., "Conceptual design of a novel next-generation cryogenic stopping cell for the Low-Energy Branch of the Super-FRS", *Nucl. Inst. Meth. B* **376**, 216 (2016).
4. T. Dickel et al., "First spatial separation of a heavy ion isomeric beam with a multiple-reflection time-of-flight mass spectrometer", *Phys. Lett. B* **744**, 137 (2015).

The $N=126$ factory at Argonne National Laboratory

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The properties of nuclei near the neutron $N = 126$ shell are critical to the understanding of the production of elements via the astrophysical r -process pathway, particularly for the $A \sim 195$ abundance peak [1]. Unfortunately traditional particle-fragmentation, target-fragmentation, or fission production techniques do not efficiently produce these nuclei. Multi-nucleon transfer (MNT) reactions between two heavy ions, however, can efficiently produce these nuclei [2]. The $N = 126$ factory currently under construction at Argonne National Laboratory's ATLAS facility will make use of these reactions to allow for the study of these nuclei [3]. Because of the difficulty collecting MNT reaction products, this new facility will use a large-volume gas catcher, similar to the one currently in use at CARIBU, to convert these reaction products into a low energy beam that will initially be mass separated with a magnetic dipole of resolving power $R \sim 10^3$. Subsequently, the beam will pass through an RFQ cooler-buncher and MR-TOF system to provide high mass resolving power ($R \sim 10^5$) sufficient to suppress isobaric contaminants. The isotopically separated, bunched low-energy beams will then be available downstream for measurements such as mass measurements using the CPT mass spectrometer or decay studies. The status of the facility under construction will be presented, together with commissioning results of the component devices. This work was supported in part by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357; by NSERC (Canada), Application No. SAPPJ-2018-00028; by the National Science Foundation under Grant No. PHY-1713857; by the University of Notre Dame; and used resources of ANL's ATLAS facility, an Office of Science User Facility.

[1] M. Arnould, S. Goriely, and K. Takahashi, Phys. Rep. **450**, 97 (2007)

[2] V. Zagrebaev and W. Greiner, Phys. Rev. Lett. **101**, 122701 (2008)

[3] G. Savard, M. Brodeur, J.A. Clark and A.A. Valverde, Nucl. Instr. Meth. Phys. Res. B Proceedings of EMIS-2018 (in press)

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