INTERNATIONAL CONFERENCE ON ELECTROMAGNETIC ISOTOPE SEPARATORS AND RELATED TOPICS

EMIS XVIII

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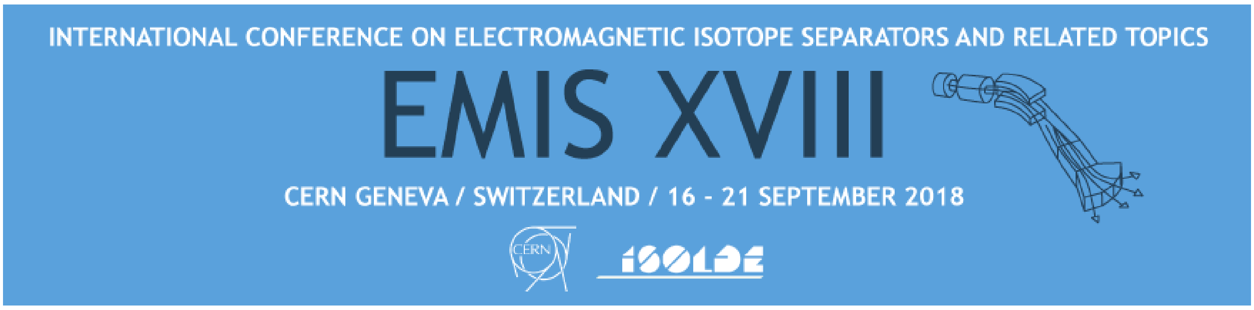

Sunday 16 September 2018 - Friday 21 September 2018

CERN

Book of Abstracts

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Sponsors

Exhibitors

Monday 17th September

TARGET & ION SOURCE TECHNIQUES I

Main auditorium *Chair: Richard Catherall*
09:00 Welcome
09:10 New exotic beams from the SPIRAL1 upgrade *Pierre Delahaye*
09:40 Thick solid targets for the production and online release of radioisotopes: the importance of the material characteristics *Joao Pedro Ramos*
10:10 Nuclear spectroscopy of r-process nuclei using KEK isotope separation system *Yoshikazu Hirayama*

TARGET & ION SOURCE TECHNIQUES II
Main auditorium *Chair: Thierry Stora*
11:00 High-intensity highly charged ion beam production by superconducting ECR ion sources at IMP *Hongwei Zhao*
11:30 Radioactive Beam Production at TRIUMF – Present and Future *Alexander Gottberg*
11:50 Research and development for the SPES target ion source system *Alberto Monetti*
12:10 Isolde V *Tim Giles*
12:30 High efficiency ISOL system to produce neutron deficient short-lived alkali RIBs on GANIL/SPIRAL 1 facility *Venkateswarlu Kuchi*
12:45 On-line results from ISOLDE's Laser Ion Source and Trap LIST *Reinhard Matthias Heinke*

TARGET & ION SOURCE TECHNIQUES III

Main auditorium *Chair: Hanna Franberg*
14:15 The laser ionisation toolkit for ion beam production at thick-target ISOL facilities *Bruce Marsh*
14:35 TRIUMF resonance ionization laser ion source operation lessons & highlights *Jens Lassen*
14:55 EBIS debuncher performances *Predrag Ujic*
15:10 Molecular beams in the ISOL process *Jochen Ballof*

INSTRUMENTATION FOR RADIOACTIVE ION BEAM EXPERIMENTS
Main auditorium *Chair: Navin Alahiri*
16:00 Status of the Super-FRS project at FAIR *Haik Simon*
16:30 The SECAR System for Nuclear Astrophysics Measurements at FRIB *Couder Manoel*
16:50 Development of a multi-segmented proportional gas counter for beta-decay spectroscopy at KISS *Momo Mukai*
17:05 Current Status of Experimental Facilities at RAON *Young Jin Kim*

17:30 Poster Session 1 in *Pas perdus*

Tuesday 18th September

INSTRUMENTATION FOR RADIOACTIVE ION BEAM EXPERIMENTS II
Main auditorium *Chair: Hideyuki Sakai*
09:00 Recent progress and developments for experimental studies with the SAMURAI spectrometer *Yosuke Kondo*
09:30 Study of spin-isospin responses of radioactive nuclei with background free neutron spectrometer, *PANDORA Laszlo Stuhl*
09:50 New energy-degrading beam line for in-flight RI beams, OEDO *Shin'ichiro Michimasa*
10:10 Status and future plans for MRTOF mass measurements at RIKEN-RIBF *M. Rosenbusch*

ION TRAPS AND LASER TECHNIQUES
Main auditorium *Chair: Georg Bollen*
11:00 The elusive 229-Thorium isomer: On the road towards a nuclear clock *Peter Thirolf*
11:30 Phase-Imaging Ion-Cyclotron-Resonance measurements at JYFLTRAP *Dmitrii Nesterenko*
11:50 First application of TITAN's newly installed MR-TOF-MS: Investigating the N = 32 neutron shell closure *Moritz Pascal Reiter*
12:10 Penning-Trap Mass Spectrometry of the Heaviest Elements with SHIPTRAP *Oliver Kaleja*
12:30 New program for measuring masses of silver isotopes near the N=82 shell closure with MLLTRAP at ALTO *E. Minaya Ramirez*
12:45 Improving the sensitivity of the Canadian Penning Trap mass spectrometer with PI-ICR *Rodney Orford*

INSTRUMENTATION FOR RADIOACTIVE ION BEAM EXPERIMENTS III
Main auditorium *Chair: Christoph Scheidenberger*
14:15 Gamma-ray tracking with AGATA: A new perspective for spectroscopy at RIB facilities *Peter Reiter*
14:45 The ISOLDE Decay Station - a Swiss Army knife for nuclear physics *James Cubiss*
15:05 Advanced scintillators for fast-timing applications *Luis Fraile*

ION GUIDE, GAS CATCHER, AND BEAM MANIPULATION TECHNIQUES
Main auditorium *Chair: Wilfried Northershauser*
16:00 Ionic, atomic and optical manipulation techniques at radioactive ion beam facilities *Iain Moore*
16:30 Accurate High Voltage measurements based on laser spectroscopy *Jorg Kramer*

16:45 Poster Session 2 in *Pas perdus*

20:00 Public lecture in the *Globe*

Wednesday 19th September

LOW-ENERGY AND IN-FLIGHT SEPARATOR
Main auditorium *Chair: Dave Morrissey*
9:00 MARA and RITU, in-flight separators for nuclear structure studies at JYFL *Juha Uusitalo*
9:15 Status of the new Fragment Separator ACCULINNA-2 and first experiments *G. Kaminski*
09:30 New control method of slowed-down RI beam and new particle-identification method of secondary-reaction fragments at RIKEN RI beam factory *Toshiyuki Sumikama*
09:45 Recent Results from the FIONA Separator at LBNL *Jacklyn Gates*

LASER TECHNIQUES

Main auditorium *Chair: Michael Bloch*
10:30 High-resolution Laser Ionization Spectroscopy of Heavy Elements in Supersonic Gas Jet Expansion *Rafael Ferrer Garcia*
11:00 Resonance ionization schemes for high resolution and high efficiency study of exotic nuclei at the CRIS experiment *Agota Koszorus*
11:20 Laser Spectroscopy of the Heaviest Elements at SHIP / GSI *Sebastian Raeder*
11:40 MIRACLS: Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy *Simon Sels*
11:55 Collinear laser spectroscopy at the IGISOL facility: upgrades and new opportunities *Ruben Pieter De Groote*
12:10 First demonstration of Doppler-free two-photon in-source laser spectroscopy at the ISOLDE-RILIS *Katerina Chrysalidis*

13:45 Excursions – Buses leave from CERN: Globe car park

19:00 back at CERN

Thursday 20th September

STORAGE RINGS
Main auditorium *Chair: Jens Dilling*
9:00 Status of the low energy storage ring CRYRING@ESR *Frank HERFURTH*
9:30 Rare-RI Ring in cyclotron facility RIBF *Yoshitaka Yamaguchi*
10:00 Application of In-ring Slit on Isochronous Mass Spectrometery *Xing XU*
10:15 Design, optimization and construction of multi-reflection time-of-flight mass analyzer for Lanzhou Penning Trap *Yulin TIAN*

ION GUIDE, GAS CATCHER, AND BEAM MANIPULATION TECHNIQUES
Main auditorium *Chair: Piet Van Duppen*
11:00 Re-acceleration of Rare Isotope Beams at Heavy-Ion Fragmentation Facilities *Antonio Villari*
11:30 The N=126 factory: a new facility to produce the very-heavy neutron-rich isotopes *Guy Savard*
11:50 Ba-ion extraction from high pressure Xe gas for double-beta decay studies with EXO *Thomas Brunner*
12:10 Beam Thermalization at the National Superconducting Cyclotron Laboratory *Chandana Sumitrarachchi*
12:25 Actinide ion beams by in-gas-cell laser resonance ionization, recoil sources, and on-line production at IGISOL *Ilkka Pohjalainen*
12:40 Online Tests of the Advanced Cryogenic Gas Stopper at NSCL *Kasey Lund*

APPLICATIONS OF RADIOACTIVE ION BEAMS I
Main auditorium *Chair: Magda Kowalska*
14:15 EMIS for Health *Ulli Koester*
14:45 Beta-detected Nuclear Magnetic Resonance: From nuclear physics to biology *Robert Dale Harding*
15:00 Production of intense mass separated 11C beams for PET-aided hadron therapy *Simon Thomas Stegemann*
15:15 Very high specific activity Er-169 production *Roberto Formento Cavaier*

APPLICATIONS OF RADIOACTIVE ION BEAMS II
Main auditorium *Chair: Valentine Fedosseev*
16:00 Laser Isotope Separation revisited – radioisotope purification by resonance ionization mass spectrometry at Mainz University *Klaus Wendt*
16:20 Applications of β-radiation detected NMR in wet chemistry, biochemistry and medicine *Monika Stachura*

17:30: Buses leave from CERN – Globe car park

Be aware that the boat leaves for conference dinner at 19:00 (from Paquis.pier. Outside the Beau Rivage Hotel)

Friday 21st September

TECHNIQUES RELATED TO HIGH-POWER RADIOACTIVE ION BEAM PRODUCTION
Main auditorium *Chair: Carmen Angulo*
9:00 High-power target development for the next-generation of ISOL facilities *Lucia Popescu*
9:30 Towards 100 kW targets for electron driver beams at the TRIUMF-ARIEL Facility *Thomas Day Goodacre*
9:50 BRIF: from the first proton beam to RIB production *Tianjue Zhang*
10:10 Current status of Isotope Separation On-Line (ISOL) facility at RAON *BH KANG*

ION OPTICS AND SPECTROMETERS
Main auditorium *Chair: Hans Geissel*
11:00 The Magnex spectrometer for double charge exchange reactions *Manuela Cavallaro*
11:30 New ion-optical modes of the BigRIPS and ZeroDegree Spectrometer for the production of high-quality RI beams *Hiroyuki Takeda*
11:45 ISLA, an Isochronous Separator with Large Acceptance for Experiments with Reaccelerated Beams at FRIB *A Matthew Amthor*
12:00 New high-resolution and high-transmission modes of the FRS open up new perspectives for FAIR phase-0 experiments *Emma Haettner*
12:15 Status of the CANREB high resolution separator at TRIUMF *Jens Lassen*

12:30 Prize Presentations and Closing remarks

14:00 Visit to ISOLDE and SC

ORAL PRESENTATIONS

New exotic beams from the SPIRAL 1 upgrade

Presenter: Pierre Delahaye (Grand Accelerateur National d'Ions Lourds (FR))

Since 2001, the SPIRAL 1 facility has been one of the pioneering facilities in ISOL techniques for reaccelerating radioactive ion beam: the fragmentation of the heavy ion beams of GANIL on graphite targets and subsequent ionization in the Nanogan ECR ion source has permitted to deliver beams of gaseous elements (He, N, O, F, Ne, Ar, Kr) to numerous experiments. Thanks to the CIME cyclotron, energies up to 20 MeV/u could be obtained. In 2014, the facility was stopped to undertake a major upgrade, with the aim to extend the production capabilities of SPIRAL 1 to a number of new elements. This upgrade, which will become operational this year, consists in the integration of an ECR booster in the SPIRAL 1 beam line to charge breed the beam of different 1+ sources. A FEBIAD source (the so-called VADIS from ISOLDE) was chosen to be the future workhorse for producing many metallic ion beams. This source was coupled to the SPIRAL 1 graphite targets and tested on-line with different beams at GANIL. The charge breeder is an upgraded version of the Phoenix booster which was previously tested in ISOLDE. It was lately commissioned at LPSC and more recently in the SPIRAL 1 beam lines with stable beams. The upgrade will additionally permit at longer term the use of other target material than graphite. In particular, the use of fragmentation targets will permit to produce higher intensities than from projectile fragmentation, and thin targets of high Z will be used for producing beams by fusion-evaporation [1]. The performances of the aforementioned ingredients of the upgrade (targets, 1+ source and charge breeder), have been and are still being optimized in the frame of different European projects (EMILIE, ENSAR and ENSAR2). This year, the upgraded SPIRAL 1 facility will provide its first new beams for physics and further beam development will be undertaken to prepare for the next AGATA campaign. This invited contribution will describe the R&D which was undertaken for the upgrade, focusing on the radioactive ion beam and ion source R&D, and the results obtained during the on-line commissioning period.

[1]: see contributions of V. Kuchi and of P. Jardin to this conference.

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Thick solid targets for the production and online release of radioisotopes: the importance of the material characteristics

Presenter: Joao Pedro Ramos (CERN)

In ISOL (Isotope Separator OnLine) facilities around the world, high-energy particle beams are accelerated towards a thick target to produce radioactive isotopes through nuclear reactions. Though different driver beam particles and energies can be used or converter targets (e.g. proton to neutron, electron to gamma) once the isotope of interest is produced in the main target, it has to be extracted from the target bulk. After thermalization the release from the target consists on diffusion out of the material crystal structure, through the material porosity and finally from the target material envelope to the ion-source. This phenomenon is highly dependent on the combination of matrix-element to be released, chemistry, microstructure and surfaces properties, which are all influenced by the operation temperature.

The chemical reactivity of the element of interest with the target material (contaminations or reactive gas introduced intentionally) and respective formed compounds play a substantial role. This created compound can either be a volatile molecule, which promotes release but might distribute the isotopes over different masses, or form a refractory compound, which can partially or totally hinder the release. The surface properties, namely adsorption, play an important role after the isotope leaves the material bulk. The isotope atoms or molecules have to diffuse through the material porosity by colliding with the material pore surfaces and then the target structural materials until they reach the ion source, where sticking times and possible re-diffusion into the bulk are critical.
The microstructure characteristics (grain and pore size distributions, agglomeration factor, pore volume and resulting specific surface area) will have a large impact on the discussed phenomena, where the macrostructure is of relatively low importance. As such, the engineering and high temperature stability (sintering, sublimation, phase change phenomena) of micro and nanostructures is of vital importance to any ISOL facility for the deliver exotic beams. To add to the complexity, these phenomena are in the presence of a high radiation environment where impurity and crystalline defect creation and annealing are a constant, where both have can change by orders of magnitude bulk diffusion rates (and implicitly sintering).

This talk will focus on the latest target related material developments mostly in terms of microstructure. It will also review and discuss the complex release phenomena and the influence of the material characteristics on it. The complexity of the release phenomenon make it nearly impossible to predict isotope yields through modeling, where the community highly depends on empirical data and extrapolations.

Nuclear spectroscopy of r-process nuclei using KEK isotope separation system

Presenter: Yoshikazu HIRAYAMA(KEK, WNSC)

The study of the β-decay half-lives of waiting-point nuclei with N= 126 is crucial to understand the explosive astrophysical environment for the formation of the third peak in the observed solar abundance pattern, which is produced by a rapid neutron capture process (r-process). However, the half-life measurements of the waiting-point nuclei remain impracticable due to the difficulty in the production of the nuclei. Therefore, accurate theoretical predictions for the half-lives are required for investigations of astrophysical environments. In order to improve and establish nuclear theoretical models, it is essential to perform nuclear spectroscopy for investigating β-decay schemes including spin-parity values, nuclear wave-functions and interactions, and nuclear masses in this heavy region.

For the nuclear spectroscopy, we have developed KEK Isotope Separation System (KISS), which is an argon-gas-cell-based laser ion source combined with an on-line isotope separator, installed in the RIKEN Nishina center [1-2]. The nuclei around N= 126 are produced by multi-nucleon transfer reactions (MNT) [3] of ^{136}Xe beam (10.75 MeV/A) impinging upon a 198Pt target. Thanks to newly developed doughnut-shaped gas cell [2], the extraction yields of the reaction products increased by more than one order of magnitude. This enabled us to successfully perform in-gas-cell laser ionization spectroscopy of ^{199g,199m}Pt [4] and ^{196,197,198}Ir for evaluating the magnetic moments and the trend of the charge-radii (deformation parameters), and β-γ spectroscopy of ^{195,196,197,198}Os for the half-life measurements and study of β-decay schemes.

For further nuclear spectroscopy, we have been developing a new narrow-band laser system for the precise in-gas-jet laser ionization spectroscopy, an MR-TOF system for mass measurement, and high-efficiency and low-background 3D tracking gas counters for β-decay spectroscopy.

In the presentation, we will report the present status of KISS, experimental results of nuclear spectroscopy in the heavy region, and future plan of KISS activities.

[1] Y. Hirayama et al., Nucl. Instrum. Methods B 353 (2015) 4.; B 376 (2016) 52.
[2] Y. Hirayama et al., Nucl. Instrum. Methods Phys. Res. B 412 (2017) 11.
[3] Y.X. Watanabe et al., Phys. Rev. Lett. 115 (2015) 172503.
[4] Y. Hirayama et al., Phys. Rev. C 96 (2017) 014307.

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High Intensity highly charged ion beam production by superconducting ECR ion sources at IMP

Presenter: Hongwei Zhao (Institute of Modern Physics (IMP),CAS)

Accelerator facility for rare isotope beam production requests high power primary ion beam which actually very much depends on performance of the front-end ion source. Superconducting ECR ion source with higher magnetic fields and higher microwave frequency is the most straight forward path to achieve high beam intensity and high charge state in the past years. SECRAL is a superconducting-magnet-based ECRIS (Electron Cyclotron Resonance Ion Source) for the production of intense highly-charged heavy ion beams. It is one of the best performing ECRISs worldwide and the first superconducting ECRIS built with an innovative magnet to generate a high strength Minimum-B field for operation with heating microwaves up to 24-28 GHz. SECRAL has so far produced a good number of CW (Continuous Wave) intensity records of highly-charged ion beams, in which the beam intensities of $^{40}Ar^{12\text{-}14+}$, $^{86}Kr^{18+}$, $^{129}Xe^{26+}$ have exceeded 1 emA for the first time by an ion source.

SECRAL source has run into operation to deliver highly charged ion beams for HIRFL accelerator for more than 9 years and total beam time more than 30000 hours, which has demonstrated its excellent stability and reliability. SECRAL-II, an upgraded version of SECRAL, was built successfully in less than 3 years, and has recently been commissioned at full power of a 28 GHz gyrotron and three frequency heating (28+45+18 GHz) . New record beam intensities for highly charged ion production have been achieved by SECRAL-II, such as 620 eμA $^{40}Ar^{16+}$, 15 eμA $^{40}Ar^{18+}$, 53 eμA $^{129}Xe^{38+}$ and 17 eμA $^{129}Xe^{42+}$. A 45 GHz superconducting ECR ion source FECR (a first Fourth generation ECR ion source) is being built at IMP. FECR will be the world first Nb_3Sn superconducting-magnet-based ECR ion source with 6.5 Tesla axial mirror field, 3.5 Tesla sextupole field on the plasma chamber inner wall and 20 kW@45 GHz microwave coupling system. This talk will focus on high-intensity highly- charged ion beam production by SECRAL and SECRAL-II at 24-28 GHz and technical design of 45 GHz FECR, which demonstrates a technical path for highly charged ion beam production from 24-28 GHz SECRAL to 45 GHz FECR.

Co-author: Liang ting Sun (Institute of Modern Physics (IMP),CAS)

Radioactive Beam Production at TRIUMF – Present and Future

Presenter: Alexander Gottberg (TRIUMF)

ISAC-TRIUMF is the only ISOL facility worldwide that is routinely operating targets under particle irradiation in the high-power regime in excess of 10 kW. TRIUMF's current flagship project ARIEL, Advanced Rare IsotopE Laboratory, will add two new target stations providing isotopes to the existing experimental stations in ISAC I and ISAC II at keV and MeV energies, respectively. In addition to the operating 500 MeV, 50 kW proton driver from TRIUMF's cyclotron, ARIEL will make use of a 35 MeV, 100 kW electron beam from a newly installed superconducting linear accelerator. Together with additional 200 m of RIB beamlines within the radioisotope distribution complex, this will put TRIUMF in the unprecedented capability of delivering three RIB beams to different experiments, while producing radioisotopes for medical applications simultaneously – enhancing the scientific output of the laboratory significantly. General characteristics of the high-power target stations, remote handling and beam production technology at ISAC and ARIEL will be presented, showing the opportunities and limitations. Moreover, the current status of the facilities as well as the path to completion and ramp-up of ARIEL will be discussed.

Research and development for the SPES target ion source system

Presenter Alberto Monetti (INFN, LNL)

In the facilities for the production of radioactive ion beams based on the isotope separation on line (ISOL) technique, the target ion source (TIS) system is surely the most critical object. In the specific case of the selective production of exotic species (SPES) facility, a multifoil uranium carbide target is impinged by a 40 MeV, 200 µA proton beam produced by a cyclotron proton driver. Under these conditions, a fission rate of approximately 10^{13} fissions per second is expected in the target. The radioactive isotopes produced by the ^{238}U fissions are delivered to the 1^+ ion source by means of a tubular transfer line. Here they can be ionized and subsequently accelerated toward the facility experimental areas. In ISOL facilities the target system can be combined with different types of ion sources in order to optimize the production of specific ion beams. In this work the SPES target and the related 1+ ion sources are accurately described, presenting their characterization and testing, together with the main research and development activities. A detailed electrical-thermal-structural study is also reported, with some considerations on long term operation at high temperature.

Co-authors: Mattia Manzolaro, Michele Ballan (INFN), Alberto Andrighetto Andrighetto, Giovanni Meneghetti (University of Padova), Daniele Scarpa, Fabio D'Agostini (INFN-LNL), Massimo Rossignoli (INFN-LNL),
Stefano Corradetti (INFN - National Institute for Nuclear Physics), Francesca Borgna (INFN-LNL

Session 2- Target and Ion Source Techniques / 53

Isolde V

Presenter : Tim Giles (CERN)

The Isolde facility was established in 1967 and since then has been rebuilt three times, in 1976, 1983 and in 1992. The fourth and current incarnation is 26 years old, and there is now a strong case for another major upgrade to address increasing demands on the targets, the isotope separators, and the experimental hall.

The existing target areas are well designed and have already been upgraded with new frontends in 2010 and 2011. The beam-dumps and surrounding concrete are at the end of their lives and will be replaced in 2024, and the frontends will be upgraded once again at the same time. However the geometry of the building, the beam-lines and the surrounding services limits how much can be changed. Furthermore the radiation levels and the schedule requirements make large modifications difficult and risky, even during the long shutdown periods. Even with upgrades the target stations are reaching the limits of their capabilities in terms of proton beam capacity, maintainability, and compatibility with prototype targets.

The performance of the isotope separators is largely determined by their geometry. Upgrade of their performance -- to improve isobar separation, to improve acceptance of beams from new ion-sources, or to improve background suppression for ultra-sensitive experiments -- is not possible without moving the permanent shielding and the downstream beam-lines, which is not practical.

The current ion beam delivery system has a severe bottle-neck, in that beam from only one target at a time may be delivered into the experimental hall. There are ideas to switch rapidly between the two target stations, but this is of limited usefulness.

Thus there is a strong case to build new target stations and a new beam preparation system to circumvent these limitations and to expand and modernise Isolde's capabilities. Constructing a new isotope production area would minimise perturbation of the running facility, whilst simultaneously permitting radically improved designs.

This paper explores the possibilities and makes a proposal for two new target stations, new isotope separators, and a beam transport system designed along modern principles. Connection of the new beam-lines to the existing facility is discussed, as well as a layout for a completely new experimental area. The layout of the proton beam-lines, radiation shielding, and the impact on the surrounding infrastructure is considered.

A possible layout will be presented with two new target areas, pre-separators, and a beam-switching system which can deliver multiple beams into the existing experimental hall. Design concepts for the new target areas and beam-lines will be shown, compatible with up-to-date handling techniques. The integration of beam preparation systems will be considered, including beam cooling and bunching and isobar separation. Finally a possible the expansion of the facility with a new experimental hall will be shown, with space for new experiments and a sophisticated and flexible beam delivery system.

High efficiency ISOL system to produce neutron deficient short-lived alkali RIBs on GANIL/SPIRAL 1 facility

Presenter: Venkateswarlu Kuchi(GANIL)

SPIRAL1 (Système de Production d'Ions Radioactifs Accélérés en Ligne) facility at GANIL (Grand Accélérateur National d'Ions Lourds) is developing new techniques to access nuclei in the neutron deficient isotope region far from the stability-valley, with Z ranging from 30 to 60. The availability of different primary beams, ranging from carbon to uranium with energies up to 100 MeV/A, gives an opportunity to produce a large variety of radioactive ion beams. The production of neutron deficient short-lived alkalis by fusion-evaporation reactions is the focus of this work. A design of simple and compact target ion source system is developed to produce isotopes of ^{74}Rb (τ_(1⁄2) = 65 ms) and ^{114}Cs (τ_(1⁄2) = 570 ms). The radioactive recoils are produced by interaction of heavy-ion beams, respectively ^{20}Ne@10^{13} pps and ^{58}Ni@10^{12} pps, with a thin ^{58}Ni target and are subsequently stopped in a catcher. The implanted recoils diffuse and effuse into the target ion source cavity, where they are ionized by surface ionization process. By applying an electric field in the cavity, the ions are guided towards the exit hole.

This system should offer an enhanced atom-to-ion transformation efficiency (e.g. higher than 75% and 95% for the ^{74}Rb and ^{114}Cs nuclei respectively). The intensity of RIBs is estimated to attain about 104 pps. The different aspects of the design and of the technical principles will be described: effusion, thermal, electrical and mechanical studies. The first off-line measurements of the thermal properties and response time will finally be presented.

Co-authors: Pascal JARDIN (CNRS) Clément MICHEL (CNRS) Laurent Maunoury (GANIL) Dubois Mickael (GANIL - CNRS) Pierre Delahaye (Grand Accelerateur National d'Ions Lourds (FR)) Olivier BAJEAT (CNRS) Stephane HORMIGOS (CNRS) Vincent METAYER (CEA)

On-line results from ISOLDE's Laser Ion Source and Trap LIST

Presenter: Reinhard Matthias Heinke (Mainz)

The method of laser resonance ionization [1] today is a well-established core technique for efficient and chemically selective radioactive ion beam production at the worldwide leading ISOL facilities such as ISAC-TRIUMF or CERN-ISOLDE. In addition, these devices allow for direct in-source laser spectroscopic investigations of exotic nuclei with lowest production yields. Nevertheless, in experiments demanding highest beam purity, suppression of beam contamination arising from competing ionization processes inside the hot cavity is essential. Correspondent techniques therefore comprise spatial separation of high temperature atomization from a clean and cold laser ionization volume inside an RFQ ion guiding structure. Namely, these are TRIUMF's IG-LIS [2] or ISOLDE's LIST, which was used for hyperfine structure spectroscopy on neutron-rich polonium previously inaccessible due to an overwhelming fraction of surface-ionized francium [3, 4].

Derived from operation experience, systematic off-line studies and simulations, a next generation of the LIST has been developed to go on-line at ISOLDE in 2018, providing highly pure 22Mg beams for measurements on its super-allowed branching ratio and half-life (IS614). The overall geometric design has been adapted to minimize deposition, while a second repelling electrode ensures additional suppression by inhibiting electron impact ionization inside the RFQ structure. Moreover, the unit undergoes additional tests to eventually further increase its performance: A DC voltage offset mode shifts the produced ions to a different mass regime, sidestepping isobaric contamination. Using high-resistance cavity materials and the LIST of matched length as field-free drift volume also enables a time-of-flight based operation mode for shortest ion bunches and subsequent purification methods by laser pulse synchronized ion beam gating [5, 6].

The presentation will show results and operation characteristics from the on-line application of the "LIST 2.0", as well as the status of ongoing developments and future directions.

References
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The laser ionisation toolkit for ion beam production at thick-target ISOL facilities

Presenter: Bruce Marsh (CERN)

Multi-step resonance photo-ionisation is an essential component of radioactive ion beam production at most of the existing and planned thick-target ISOL facilities. At ISOLDE, the Resonance Ionisation Laser Ion Source (RILIS) is capable of ionising 40 elements. Its unmatched combination of selectivity and efficiency ensures its place as the most commonly used ion source for ISOLDE physics.

Since its initial implementation the RILIS has developed from the original copper-vapour laser pumped dye laser system into a much more versatile dual Dye and Ti:Sapphire system pumped by modern industrial solid-state lasers. Furthermore, the RILIS technique, originally exclusively applied within the hot cavity surface ion source, has been further developed to enable specific modes of operation or to exploit alternative laser atom interaction regions. The performance can now be tailored to prioritise efficiency, selectivity or versatility, depending on the requirements of the experiment. This is thanks to the multitude of laser ionisation options at our disposal: the Laser Ion Source Trap (LIST) and low work-function cavity for enhanced selectivity; and the Versatile Arc Discharge and Laser Ion Source (VADLIS), which is a multi-functional ion source for a variety of applications.

A status update on the ISOLDE-RILIS installation will be presented, including a selection of 'use case' highlights for each of the laser ion source configurations mentioned here.

Finally, an outlook towards the planned next stages of laser ion source R&D (such as the PI-LIST, ToFLIS and next-generation VADLIS), with a view to the possible interest for existing and next-generation ISOL facilities will be provided.

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TRIUMF resonance ionization laser ion source operation lessons & highlights

Presenter: Jens Lassen(TRIUMF)

TRIUMF's isotope separator and accelerator facility is an ISOL facility based on a 500MeV proton driver beam with a beam intensity of up to 100microA on target. The ion sources in use are TRIUMF's FEBIAD, surface ion source and resonance ionization laser ion source (TRILIS). The TRILIS operational experience – delivering more than 50% of all beams and scheduled shifts - with all solid state laser based laser systems, operated by a small operations team will be critically discussed and analyzed and the achievements of the past years presented.

This analysis is essential to the ongoing facility upgrade to the advanced rare isotope laboratory (ARIEL). ARIEL is going to add two additional RIB target stations, one based on an additional 500MeV, up to 100microA proton driver beam, and one based on photo-fission from a 30MeV, up to 10mA electron driver beam, to simultaneously deliver RIB to the ISAC experimental infrastructure, that can be separated into "low energy", "medium energy" and "high energy" experimental areas, with the "medium" and "high energy" areas using post-accelerated RIB.

In this scenario, it is envisioned to operate the two additional RILIS alongside TRILIS – without major resource increases - to provide the RIB for the experimental nuclear and particle physics programs.

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EBIS debuncher performances

Presenter : Predrag Ujic (GANIL, Caen, France)

Charge breeding by Electron Beam Ion Source (EBIS) is an important technique for preparation of radioactive beams for further post-acceleration. The most efficient mode of the EBIS is pulsed mode. Depending on different parameters the characteristic time of the charge breeding process is of order of ~10 ms to ~100 ms, while the extraction time is 10 µs – 100 µs.

However, from the experimental point of view, continuous wave (CW) beams are preferred since bunched beams of the same average intensity tends to have larger pile-up probability, dead-times, and random coincidences in the detectors due to the higher instantaneous counting rate at the moment of the beam bunch arrival. One of the goals of the Innovative Charge Breeding Task (ICBT) of the EURISOL JRA within ENSAR2 is the development of a debuncher device for CW ion beam formation at future ISOL facilities using the EBIS charge breeding technique.

The EBIS debuncher was developed and commissioned at LPC Caen within the EMILIE project [1]. It has been lately tested, thoroughly and successfully, with stable 7Li+1 beam on the LPC Caen test bench. Trapping lifetimes well beyond 1 s could be measured, and continuous extracted beams with intensity variations of ±20% could be obtained for extraction times as long as 800 ms. Projections for the use of such device with an operational EBIS, i.e. for HIE-ISOLDE or for a future EBIS at GANIL, are therefore encouraging. This contribution will describe the results of the test and the possible opportunities it offers for future EBIS setups.

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Molecular beams in the ISOL process

Presenter : Jochen Ballof (Johannes Gutenberg Universitaet Mainz (DE))

Radioactive ion beam facilities exploiting thick targets, which are irradiated by a high-energy driver beam, allow the production of intense beams of many chemical elements. For example at CERN-ISOLDE more than 1000 isotopes of 73 different chemical elements are available for delivery to a large spectrum of experimental setups for investigations in nuclear physics, structure and applications.

While thick targets benefit from high in-target production rates, the release of the generated nuclides strongly depends on the chemical and physical nature of the element. Some elements (like Li, Na, K) are easily released. In contrast, it is still not possible to release many elements with high boiling points, the refractory metals (e.g. Mo, W, Os). The in-situ volatilization by molecule formation has proven to be a key concept for the extraction of such difficult elements [1].

Recently exotic boron beams could be newly produced upon injection of sulphur hexafluoride gas into a carbon nanotubes target [2]. Besides helping the volatilization of the isotope of interest , molecular beams can be used as a mean to purify from isobaric contaminations, as already shown for example for selenium beams, extracted as SeCO ions [3] or more recently also with germanium sulphide ions.

Within this contribution, we summarize novel developments in molecular beam formation and show an original target concept based on the fission recoil effect for the release and ionization of the most challenging refractory elements, which are still not available in any ISOL facility, despite of the long history of the technique. Detailed numerical and experimental data will be presented to prepare for an online prototype test.

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Status of the Super-FRS project at FAIR

Presenter: Haik Simon (GSI Darmstadt, Germany)

The Super-FRS will serve as a separator for a wide range of secondary beams at relativistic velocities as well as a experimental device in the future FAIR facility. The system is based on large aperture superconducting magnets in conjunction with a high rate detection system, serving both for identification at high rates and as integral part of running experiments at the separator or experiments in the different branches of the Super-FRS.

In my talk, I will discuss the status of the project and will also put some focus on the interspersed use of equipment in a campus wide large detection system.

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The SECAR System for Nuclear Astrophysics Measurements at FRIB

Presenter: Couder Manoel (University of Notre Dame)

The Separator for Capture Reactions (SECAR), under construction at Michigan State University, is a next-generation recoil separator system optimized for nuclear astrophysics measurements with radioactive ion beams at the National Superconducting Cyclotron Laboratory (NSCL) and at the Facility for Rare Isotope Beams (FRIB). SECAR will enable the measurement of critical proton and alpha radiative capture reactions on proton-rich unstable nuclei that are needed to improve our understanding of stellar explosions such as novae, supernovae, and X-ray bursts. Two +/-300 kV Wien filters with carefully matched electric and magnetic effective field length are used to achieve beam rejection compatible with the high radioactive beam intensities expected from FRIB/ReA

The design philosophy, status of SECAR construction, the early commissioning plans and the first commissioning measurements at MSU NSCL/FRIB will be presented

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Development of a multi-segmented proportional gas counter for β-decay spectroscopy at KISS

Presenter: Momo Muka (University of Tsukuba)

We have developed a new multi-segmented proportional gas counter (MSPGC) [1] for β-decay spectroscopy of nuclei with neutron number N∼126 relevant to the 3rd peak in the r-process. These nuclei are produced by multi-nucleon transfer (MNT) reactions of 136Xe beam and 198Pt target [2], and can be extracted from KEK Isotope Separation System (KISS) [3]. KISS is an argon-gas-cell based laser ion source combined with an on-line isotope separator, and therefore it can select mass and atomic numbers. The extracted nuclei are implanted into a tape in the KISS detector system. In order to perform the β-decay spectroscopy precisely and efficiently, the background event rate of a β-ray detector should be less than 0.1 cps considering the typical extraction yield of neutron-rich nuclei of a few pps, and detection efficiency should be as high as possible.

The MSPGC comprises a pair of 16-segmented proportional gas counters in 2-cylindrical layers (total 32 ch) in order to identify β-ray events with high-efficiency and eliminate background events such as cosmic-rays by two-dimensional tracking effectively. The small energy losses in detector gas of argon (90%) + CH4 (10%) and the cathode made of aluminized Mylar foils have allowed us to realize an absolute detection efficiency of 45% at Qβ=1 MeV along with detection of low-energy conversion electrons. We successfully achieved our desired background event rate of 0.1 cps. We performed the hyperfine structure measurements of neutron-rich nuclei by in-gas-cell laser ionization spectroscopy and β-γ spectroscopy including identification of isomeric states through the detection of conversion electrons. In the presentation, we will discuss the properties of the MSPGC and the experimental results. We will also present the current status of three-dimensional tracking in the MSPGC to realize the background event rate of 0.01 cps by applying resistive carbon wire anodes.

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Current Status of Experimental Facilities at RAON

Presenter: Young Jin Kim (Institute for Basic Science/Rare Isotope Science Project)

The Rare Isotope Science Project (RISP) was established in December 2011 for the accomplishment of the accelerator complex (Rare isotope Accelerator complex for ON-line experiments; RAON) for the rare isotope science in Korea. The rare isotope accelerator at RAON will provide both stable and rare isotope (RI) beams with the energy ranges from a few KeV to a few hundreds of MeV per nucleon for the researches in fields of basic and applied science.

At the moment, there are 7 experimental facilities considered at RAON: KOrea Broad acceptance Recoil spectrometer and Apparatus (KOBRA) and Large Acceptance Multi-Purpose Spectrometer (LAMPS) for nuclear physics, High Precision Mass Measurement System (HPMMS) with Multi-Reflection Time-of-Flight (MR-ToF) and Collinear Laser Spectroscopy (CLS) for atomic physics, Nuclear Data Production System (NDPS) for nuclear reaction data, Muon Spin Rotation/Relaxation/Resonance (muSR) for material science, Beam Irradiation System (BIS) for bio-medical science.

In this talk, current status including detail design and research goal of 7 experimental facilities at RAON will be discussed.

Recent progress and developments for experimental studies with the SAMURAI spectrometer

Presenter: Yosuke Kondo (RIKEN)

The SAMURAI spectrometer has been designed for various types of experimental studies using high intense beams of exotic nuclei provided by the BigRIPS fragment separator at RI Beam Factory (RIBF). SAMURAI consists of a large-gap superconducting dipole magnet equipped with heavy ion detectors, a large-volume neutron detector array NEBULA, and proton detectors. Since the construction was completed, many experimental studies and developments have been done so far. In addition to the standard detectors, several other experimental devices have been installed. For instance, a prototype of the large neutron detector array NeuLAND developed at GSI, called NeuLAND demonstrator, had been installed at the SAMURAI experimental area to improve the neutron detection efficiency by combining with NEBULA. Thanks to the high neutron detection efficiency with the intense RI beams at RIBF, the setup enabled us to carry out several pioneering studies such as invariant-mass spectroscopy of the unbound nucleus 28O (Z=8, N=20), which requires detection of four neutrons in coincidence. Developments of other detectors have also been done. In the presentation, recent progress of the SAMURAI spectrometer, developments of experimental devices, and future prospects will be shown and discussed.

Study of spin-isospin responses of radioactive nuclei with background free neutron spectrometer, PANDORA

Presenter: Laszlo Stuhl (Center for Nuclear Study, University of Tokyo)

The (p,n) reactions in inverse kinematics provide uniqe tool to study the spin-isospin responses of radioactive nuclei, including their giant resonances, in a wide excitation energy region. In particular, high luminosity can be achieved using thick hydrogen target without losing information on recoil neutron momentum applied for the missing mass reconstruction [1]. As a side effect in this measurements, a background of gamma rays overlaps with the low-energy neurons, this makes difficult the separate an efficiently tag the reaction channel. The existing neutron spectrometers used for measuring the Time-of-Flight (ToF) of recoil neutrons are not able to provide online particle identification. A new, digital readout based low-energy neutron spectrometer, PANDORA (Particle Analyzer Neutron Detector Of Real-time Acquisition) was developed [2] for real time neutron-gamma discrimination. PANDORA consists of a plastic scintillator bars with pulse shape discrimination capability coupled to photomultiplier tubes.

After an overview of the pulse shape discrimination method, the evaluation of our programmed digital pulse processing mode will be presented. The quality (Figure-of-Merit) of the neutron and gamma peak separation of PANDORA will also be discussed. Using PANDORA the gamma-ray background is reduced by one order of magnitude.

PANDORA and the digital data acquisition were commissioned in 2017 December, at HIMAC facility in Chiba. We successfully identified the Gamow-Teller transitions of 6He in inverse kinematical (p,n)reactions at 123 MeV/nucleon incident energy using polyethylene target. In this talk, properties of PANDORA, details of experimental setup and the intelligent triggering will be reported as well as a brief overview of our whole experimental program [3] at RIKEN RIBF aiming to study the spin-isospin responses of light nuclei along the neutron drip line.

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New energy-degrading beam line for in-flight RI beams, OEDO

Presenter: Shin'ichiro Michimasa (Center for Nuclear Study, the Univ. of Tokyo)

The OEDO system was proposed to produce focused slow-down radioactive-ion (RI) beams in RIBF, and has been installed in the High-Resolution Beamline (HRB) in the end of fiscal year 2016. Generally, the momentum dispersive focal plane has a strong correlation property between the pass point and the timing of the beam. The OEDO system was designed to tune separately energy degrading and beam focusing of the RI beams by using such a property of the dispersive focus. To obtain a mono-energetic beam, a wedge-shaped degrader on a dispersive focus is efficient tool. However a wide beam size at the dispersive focus become a defect to produce a small spot at a downstream focus for experimental measurements. We developed a new ion-optical scheme where the time-of-flight difference at the dispersive focus can be utilized for the beam focusing in parallel with use of a mono-energetic degrader for the beam-energy condensation.

The main components of the OEDO system are a Radio-Frequency deflector (RFD) synchronized with the accelerator cyclotron's RF and 2 sets of superconducting triplet quadrupole (STQ) magnets. The OEDO configures STQ-RFD-STQ on the straight beamline. At the entrance of the OEDO, the ion optics of HRB is tuned to be a momentum dispersive focus of approximately 10 mm/%, and a mono-energetic Al degrader is located there to slow down RIs to less than 50 MeV/u. The first STQ provides point-to-parallel transport, resulting in a strong correlation between the angular and time components of the beam. The second STQ works as inverse transformation of the first one. The RFD, locating in the middle of the two STQs, periodically changes the RI's horizontal angles in order to align them into parallel. The aligned RI's make a focus at the exit of the OEDO system through the parallel-to-point optics of the second half of the system.

The commissioning of the OEDO beamline has been performed in June, 2017 and we have successfully confirmed energy-degraded RI beams focused by the OEDO scheme.
In the commissioning run, we have produced long-lived fission products ^{79}Se and ^{107}Pd at around 40 MeV/u from a 345-MeV/u ^{238}U beam. The slow-down ^{79}Se beam obtained by the OEDO was at 45±2 MeV/u, and its spot size at the secondary target position was 15 mm in FWHM.

In this presentation, we will show the details about the ion-optical design and about achieved performance of the OEDO system. We are also going to discuss upcoming physics experiments and physics plans developed at the OEDO beamline.

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Status and future plans for MRTOF mass measurements at RIKEN-RIBF

Presenter: M. Rosenbusch (RIKEN)

The Wako nuclear science center (WNSC), a collaboration between RIKEN and KEK, has directly measured the masses of more than 80 isotopes. We have recently performed the first mass measurements of several Md isotopes [1] along with other rare species such as Ac/Ra isotopes [2] using a multi-reflection time-of-flight spectrograph (MRTOF-MS) coupled to the gas-filled recoil ion separator GARIS-II [3]. With the MRTOF-MS coupled to GARIS-II at a new location (RRC accelerator) we will next aim to directly determine atomic numbers and masses of ^{284}Nh and ^{288}Mc. Additionally, we are developing several more MRTOF-MS devices to perform mass measurements of the most exotic species. As part of the SLOWRI facility we will implement MRTOF for both mass measurement and beta-delayed neutron multiplicity studies of value to r-process studies. As part of the KEK Isotope Separation System we are implementing a miniature MRTOF-MS for mass measurements of $N \approx 162$ isotopes below Pt. A new MRTOF-MS behind the zero-degree spectrometer at RIBF is also being planned for use in symbiotic operation with other experiments focussing on neutron-rich nuclides. In this contribution an overview of the status and the future plans for low-energy precision mass measurements by WNSC will be provided.

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The elusive 229-Thorium isomer: On the road towards a nuclear clock

Presenter: Peter Thirolf (Ludwig-Maximilians-Universität München)

Today's most precise time and frequency measurements are performed with optical atomic clocks. However, it has been proposed that they could potentially be outperformed by a nuclear clock, which employs a nuclear transition instead of an atomic shell transition. There is only one known nuclear state that could serve as a nuclear frequency standard using currently available technology, namely, the isomeric first excited state of 229Th. Since more than 40 years nuclear physicists have targeted the identification and characterization of the elusive isomeric ground state transition of 229mTh. Evidence for its existence until recently could only be inferred from indirect measurements, suggesting an excitation energy of 7.8(5) eV. Thus the first excited state in 229Th represents the lowest nuclear excitation so far reported in the whole landscape of known isotopes. Recently, the first direct detection of this nuclear state could be realized via its internal conversion decay branch [1], which confirms the isomer's existence and lays the foundation for precise studies of its properties. Subsequently, the half-life of neutral 229mTh could be measured [2] and its hyperfine structure was resolved via collinear laser spectroscopy [3]. An optical excitation scheme based on existing laser technology [4] as well as a measurement scheme for the isomeric excitation energy [5] have been developed. This would pave the way towards an all-optical control and thus the development of an ultra-precise nuclear frequency standard. Moreover, a nuclear clock promises intriguing applications in applied as well as fundamental physics, ranging from geodesy and seismology to the investigation of possible time variations of fundamental constants.

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Phase-Imaging Ion-Cyclotron-Resonance measurements at JYFLTRAP

Presenter: Dmitrii Nesterenko (University of Jyväskylä)

The studies of short-lived nuclides,far from the valley of stability, require fast and precise mass measurements to elucidate fundamental nuclear properties related to the nuclear mass and binding energy. Many exotic nuclides have isomeric states, therefore, it is necessary to have a high resolving power, sufficient for their separation. The Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique, where the radial ion motion in a Penning trap is projected onto a position-sensitive detector [1], can be used for the separation of states with an energy difference of a few tens of keV in singly-charged ions with half-lives of several 100 ms. The PI-ICR method, implemented at the Penning-trap mass spectrometer JYFLTRAP [2], in combination with the conventional Time-of-Flight Ion-Cyclotron-Resonance (ToF-ICR) technique, allows the exploration of short-lived nuclides for the purposes of nuclear physics, astrophysics, fundamental tests for physics beyond the Standard Model and for rare or weak decays. The PI-ICR method has been used for the identification of isomeric states in 88Tc and 76Cu, and for mass measurements of ^{88m}Tc and ^{48}Mn at JYFLTRAP. The phase dependent cleaning method for preparing isomerically pure beams was developed at JYFLTRAP and demonstrated for the ions $^{127m}Cd^{+}$ and $^{127}Cd^{+}$. This newly developed technique provides new opportunities for post-trap decay spectroscopy measurements. Isotopic yield ratio (IYR) measurements in proton-induced fission of natural uranium using PI-ICR technique at JYFLTRAP have been performed for the first time. The advantage of the PI-ICR method in the IYR determination is that the measurement is done through direct ion counting, which makes it chemically independent and independent of the knowledge of the decay scheme.

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First application of TITAN's newly installed MR-TOF-MS: Investigating the N = 32 neutron shell closure

Presenter: Moritz Pascal Reiter (TRIUMF, JLU-Giessen)

TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) located at the Isotope Separator and Accelerator (ISAC) facility, TRIUMF, Vancouver, Canada is a multiple ion trap system capable of performing high-precision mass measurements and in-trap decay spectroscopy. In particular TITAN has specialised in fast Penning trap mass spectrometry of singly-charged, short-lived exotic nuclei using its Measurement Penning Trap (MPET). 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 recently installed at TITAN. 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.

After a first commissioning with stable beam from ISAC in mid-2017 the MR-TOF-MS was employed in a measurement campaign aiming to investigate the evolution of the N = 32 neutron shell closure. This shell closure forms several neutrons away from stability and had been established in neutron-rich K, Ca and Sc isotopes, where as in V and Cr, no shell effects can be found. Thus leaving the intermediate Ti isotopes as the ideal test case for state-of-the-art ab-initio shell model calculations. High-precision mass measurements with TITAN's MPET and for the first time with the MR-TOF-MS were able to prove the existence of a weak shell closure in Ti and quenching of the shell in V. These findings challenge modern ab initio theories, which over predicted the strength and extent of this weak N = 32 shell closure.

Being able to resolve all isobars at the same time, the new MR-TOF-MS has become a routine device during TITAN beam times, being used for real-time determination of the radioactive beam composition and optimization of the ISAC mass separator, for precision mass measurements and soon for isobar separation.

We will discuss our recent mass measurements of singly charged ions making use of MPET and the new MR-TOF-MS as well as technical and operational details of the new device and perspectives for future mass measurements of short-lived isotopes at TITAN.

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Penning-Trap Mass Spectrometry of the Heaviest Elements with SHIPTRAP

Presenter: Oliver Kaleja (MPIK Heidelberg; JGU Mainz; GSI Darmstadt)

The quest for the heaviest element is at the forefront of nuclear physics. Superheavy elements (SHE), with 104 protons (*Z*) or more, owe their very existence to an enhanced stability resulting from nuclear shell effects. High-precision Penning-trap mass spectrometry (PTMS) is an established tool for investigations of nuclear structure-related properties, reflected in binding energy differences, for example two-nucleon separation energies [1]. Although elements up to oganesson ($Z = 118$) have been discovered, detailed studies of the elements with $Z > 110$ are hampered by low statistics due to low production cross sections in the order of picobarn. However, the use of PTMS in the region of $Z > 100$ provide indispensable knowledge on single-particle orbitals and pairing correlations affecting the properties of the heaviest elements. Furthermore, masses of anchor points for alpha-decay chains and benchmarks for theoretical models are obtained.

Pioneering experiments with SHIPTRAP, located behind the velocity filter SHIP at GSI in Darmstadt, Germany, have demonstrated that direct measurements of the heaviest elements are feasible for lowest yields [2,3], in the case of ^{256}Lr ($Z = 103$) with a cross section of 60 nb only about one ^{256}Lr ion every two hours was detected behind the trap. Recent developments of the setup allow pushing these limits to even heavier and more exotic nuclei in the upcoming beam time periods at GSI in 2018/19. The implementation of a cryogenic gas-catcher [4] increases the stopping, thermalization and extraction efficiency by almost one order of magnitude and was recently integrated in the relocated experimental setup. This will allow directly measuring ^{254}Lr and the SHE isotope ^{257}Rf ($Z = 104$) for the first time and extend the nuclear shell evolution studies at $N = 152$ [3]. In addition, anchor points in odd-*A* and odd-odd nuclides in this mass region will be obtained, affecting the masses of elements up to darmstadtium ($Z = 110$).

The development of the Phase-Imaging Ion-Cyclotron-Resonance technique at SHIPTRAP [5], the new standard in online PTMS worldwide, increases the mass resolving power, precision and detection sensitivity compared to the previously used techniques significantly. This will allow simultaneous measurements of ground and low-lying isomeric states of the heaviest elements that are difficult to access by any other method. The precise determination of their excitation energy allows studying pairing correlations and single-particle energies that are responsible for the spherical shell gap at $Z = 114$ and thus give significant input to nuclear models predicting the so-called island of stability.

To reach the ultimate goal to perform direct mass spectrometry on heavier elements for which the yields are smaller and only single ions are available, a second dedicated setup is being developed in parallel to the ongoing online mass measurement activities to adapt the non-destructive Fourier-Transform Ion-Cyclotron detection technique to this mass region.

Recent results and the status of the technical developments will be presented.

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New program for measuring masses of silver isotopes near the N=82 shell closure with MLLTRAP at ALTO

Presenter : E. Minaya Ramirez (Institut de Physique nucléaire Orsay, 91406 Orsay, France)

The ISOL facility ALTO, located at Orsay in France, provides stable ion beams from a 15 MV tandem accelerator and neutron-rich radioactive ion beams from the interaction of a γ-flux induced by a 50 MeV 10 µA electron beam in a uranium carbide target. A magnetic dipole mass separator and a resonance ionization laser ion source allow selecting the ions of interest. New setups are under preparation to extend the fundamental properties measured at ALTO of ground and excited states of exotic nuclei. For example, high-precision mass measurements for an accurate determination of the nuclear binding energy. To perform these measurements two devices will be hosted at ALTO: a radiofrequency quadrupole to cool and bunch the continuous radioactive beam and the double Penning trap mass spectrometer MLLTRAP, commissioned off-line at the Maier-Leibnitz Laboratory (MLL) in Garching, Germany. The unique production mechanism using photo-fission at the ALTO facility allows mass measurements in a neutron rich area of major interest around 132Sn with less isobaric contamination than using proton drivers. In this context, we plan to measure neutron-rich silver isotopes ($Z = 47$, $A > 121$) to explore the possible weakening of the shell gap for $Z < 50$ and its impact on the $A = 130$ r-process nucleosynthesis. The well-known silver masses ($A < 121$) will be used for the on-line commissioning of MLLTRAP and to characterize the performance of the detection system. The status and timeline of the novel setup will be presented.

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Improving the sensitivity of the Canadian Penning Trap mass spectrometer with PI-ICR

Presenter: Rodney Orford (McGill University)

Nuclear masses provide a direct probe of nuclear structure effects and are necessary inputs for studies of nuclear astrophysics. Measuring the masses of neutron-rich nuclei far from stability, which are relevant to heavy element nucleosynthesis, is difficult due to low production rates in the laboratory, and short lifetimes. Over the past three decades, Penning trap mass spectrometry has been the preferred mass measurement method due to its proven accuracy and precision, and is employed at several rare isotope beam facilities around the world. At CARIBU, intense beams of radioactive neutron-rich nuclei are produced from the spontaneous fission of ^{252}Cf. Using the MR-TOF, high-purity beams ($R=m/\Delta m>100{,}000$) are rapidly prepared and efficiently btransported to the experimental area where the Canadian Penning Trap mass spectrometer (CPT) resides. To take advantage of these clean beams, the CPT has pivoted from using TOF-ICR to a phase-imaging measurement technique (PI-ICR), which has improved the overall sensitivity of the device by more than two orders of magnitude. In the PI-ICR method, masses can be determined with fewer ions and with a shorter measurement cycle without loss in precision, making it well-suited for studying the most weakly produced isotopes at CARIBU. I will present details of the PI-ICR technique used by the CPT and highlight several recent results.

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Gamma-ray tracking with AGATA: A new perspective for spectroscopy at RIB facilities

Presenter: Peter Reiter (University Cologne, Nuclear Physics Institut)

The Advanced GAmma Tracking Array is a next generation high-resolution gamma-ray spectrometer for nuclear structure studies based on the novel principle of gamma-ray tracking. It is built from a novel type of high-fold segmented germanium detectors which will operate in position-sensitive mode by employing digital electronics and pulse-shape decomposition algorithms. The unique combination of highest detection efficiency and position sensitivity allows sensitive spectroscopy studies with instable beams of lowest intensity. The first implementation of the array consisted of five AGATA modules; it was operated at INFN Legnaro. A larger array of AGATA modules was used at GSI for experiments with unstable ion beams at relativistic energies. At the moment the spectrometer is hosted by GANIL. In the near future AGATA will be employed at the leading infrastructures for nuclear structure studies in Europe. The presentation will illustrate the potential of the novel gamma-ray tracking method by physics cases from the different exploitation sites. Perspectives and opportunities for future RIB facilities given by the new spectrometer will be presented.

The ISOLDE Decay Station - a Swiss Army knife for nuclear physics

Presenter: James Cubiss (University of York (GB))

The ISOLDE Decay Station (IDS) [1] has been a permanent experiment used for studies of low-energy nuclear physics at the CERN-ISOLDE facility, since 2014. The core of the setup consists of four, high-efficiency, clover-type germanium detectors and a tape transportation system. These can be coupled to a number of ancillary detector arrays, used for alpha/beta/gamma spectroscopy, neutron time-of-flight studies, or fast-timing measurements, making IDS a powerful and versatile tool for studying the wide range of radioactive species that are readily produced at ISOLDE.

In this contribution, an overview the IDS system and its detectors will be presented, along with preliminary results from recent experiments performed at IDS [2]. In particular, results from an in-source laser spectroscopy study of bismuth isotopes [3] will be shown, in which a new high-spin isomer was identified and studied in 214Bi, thanks to the high gamma-ray detection efficiency of IDS. Plans for studying the low-lying excited states in 182,184,186Hg, and the incorporation of a new SPEDE conversion electron detector [4] at IDS, will also be revealed [5].

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Co-authors: (On behalf of the IDS-Windmill-RILIS collaboration)

Advanced scintillators for fast-timing applications

Presenter: Luis Mario Fraile (Universidad Complutense (ES))

Fast scintillator detectors such as $LaBr_3$(Ce) are changing the landscape in several research fields including experimental nuclear physics and medical imaging systems. This is due to the combination of excellent time response, good energy resolution and high effective Z. Advanced instrumentation for radioactive ion beam experiments takes advantage of these novel scintillator crystals and enables fast-timing experiments that allow the measurement of nuclear state lifetimes down to tens of picoseconds. On the other hand faster scintillators allow replacing the present generation of LSO or LYSO-based PET scanners, and improving the achievable time resolution for TOF-PET. Moreover, short decays times will be able to sustain higher rates enhancing the sensitivity of modern preclinical scanners.

In this contribution we report on the experimental investigation of the time and energy response of detectors based on inorganic scintillators with strong potential for fast timing and imaging applications. The selected crystals are $LaBr_3$(Ce), $CeBr_3$ and co-doped $LaBr_3$(Ce+Sr) scintillators. An intercomparison of the energy resolution and time response of cylindrical 1-inch in height and 1-inch in diameter crystals coupled to optimized photomultiplier tubes, is provided. The performance of custom crystals, specially designed for timing measurements, is also described.

Secondly, alternative readouts based on Silicon Photomultipliers (SiPMs) are discussed. These photosensors exhibit high photon detection efficiency, are insensitive to magnetic fields, have a small size and are relatively easy to use with simple read-outs. They are also intrinsically fast. In this work we investigate the time and energy resolution achieved with the relatively large scintillator crystals coupled to suited SiPMs and compare them to those obtained with photomultiplier-tube readout.

Finally, we discuss digital signal processing for the fast signals from the scintillator detectors. Digital processing has become a standard in data acquisition for multi-parameter set-ups, since it provides good performance in terms of energy resolution, dead time and flexibility. Nevertheless digital methods able to recover the excellent intrinsic time resolution of fast scintillators are still not widely available. We present results of digital acquisition and processing strategies, and compare them to analogue electronics. We show that digital processing is a competitive technique for fast scintillators and holds a strong potential for its implementation in standard set-ups.

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Ionic,atomic and optical manipulation techniques at radioactive ion beam facilities

Presenter: Iain Moore (University of Jyväskylä)

This contribution will present an overview of some of the most recent developments at radioactive ion beam facilities including methods to enhance the purity of ion beams both at the ion source, whether this be at an ISOL-type hot cavity facility or gas-cell-based facility, as well as the manipulation of beams prior to delivery to experimental setups. I will focus primarily on the application of laser techniques applied for purification (in-source, laser ion source trap methods, in-gas jet), but also how they may be used to gain an understanding of recently identified limitations in efficiency when one compares the application of similar resonant laser ionization schemes in gas cells vs hot cavity ion sources. This latter aspect becomes relevant in atomic systems with a high density of atomic levels, and I will use studies on the actinide elements and beyond as an example.

Further manipulation and "cleaning" of the ion beam is done using a combination of radiofrequency cooler-bunchers and traps. Other contributions to this conference include a variety of tools for low-energy purification, from Multi-Reflection Time-of-Flight devices, to novel phase-imaging cleaning applied in Penning traps. Optical manipulation in cooler-bunchers serves to move electronic state population into ionic levels which are more suited for laser spectroscopy, and such methods may be extended to resonantly ionize singly-charged ions for additional Z-selectivity. Extensions to optical manipulation may be found via polarization techniques, and in the near future this will be applied in combination with ion trapping for tests of Physics beyond the Standard Model. I will also present the status of new atom trapping applications at JYFL, which combine the selectivity of laser cooling and magneto-optical trapping to uniquely study isomeric or ground states. Such "cold atom" techniques are well known however are now being applied on-line to fission fragments for future applications.

Accurate High Voltage measurements based on laser spectroscopy

Presenter : Jörg Krämer (Institut für Kernphysik, TU Darmstadt)

The ALIVE experiment at the TU Darmstadt is a collinear laser spectroscopy setup that has been developed for the measurement of high voltages in the range of 10 to 100 kV with highest precision and accuracy. Here, ions with a well-known mass and transition frequency are accelerated with the voltage that has to be measured and their Doppler shift is examined precisely with laser spectroscopic methods. An accuracy of at least 1 ppm is targeted which is of interest for metrology as well as scientific applications like, e.g. the KATRIN experiment. Furthermore, this opens the opportunity to define a quantum standard for the absolute high voltage determination since only direct frequency measurements are involved.

Earlier attempts with this technique were limited by the uncertainty of the optical frequency measurement [1] or the uncertainty of the real starting potential of the ions in the ion source [2]. In the ALIVE (Accurate Laser Involved Voltage Evaluation) experiment a two-stage laser interaction for optical pumping and probing is combined with a highly accurate frequency determination with a frequency comb [3] to overcome these limitations.

We will present the results we achieved with 40Ca+ ions where the well-known 4s1/2 → 4p3/2 and the 3d3/2 → 4p3/2 transitions were used to identify the ion velocities before and after the acceleration. We have performed a measurement series with voltages between -5 kV and -19 kV in parallel to two high precision voltage dividers and were able to demonstrate a 20-fold improvement compared to the previous approaches to an accuracy almost comparable to the best state-of-art high voltage dividers. To further improve this, indium ions from a liquid metal ion source and an alternative pump-and-probe approach will be used in the next stage of the experiment. With these improvements we think that we will be able to reach a sub-ppm accuracy.

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MARA and RITU, in-flight separators for nuclear structure studies at JYFL

Presenter: Juha Uusitalo (University of Jyväskylä)

A new separator, MARA (Mass Analyzing Recoil Apparatus) [1], has recently been constructed at Jyväskylä University ACCLAB. MARA is a vacuum-mode double focusing mass separator. The ion-optical configuration is QQQDEDM. MARA went through an extensive commissioning program during 2016 and already during 2017 MARA was used in spectroscopic studies at and beyond the proton drip line. In these studies, for example, three new isotopes have been identified which is a strong proof itself that MARA fulfills the needed performance.

RITU (Recoil Ion Transport Unit) [2, 3] is a gas-filled recoil separator used to preferentially select recoiling nuclei from primary beam like products after fusion evaporation reactions. RITU is based on a standard DMQQ magnetic configuration, with an extra vertically focusing quadrupole magnet in front of the dispersive element added, thus giving it a QDMQQ configuration. RITU has already been in operation for almost 25 years and a wide-ranging experimental program has been performed during these years.

MARA and RITU represents two different kind of separators having they own pros and cons. They are complementary devices and together they give a freedom to extend substantially the experimental program performed by the Nuclear Spectroscopy Group.

In this work a status report of the JYFL in-flight separators RITU and MARA will be given.

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Status of the new Fragment Separator ACCULINNA-2 and first experiments

Presenter: G. Kaminski (Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia)

In 2017 the first set of radioactive ion beams (RIBs) was obtained from the new in-flight fragment separator ACCULINNA-2 [1] operating at the primary beam line of the U-400M cyclotron [2]. Observed RIB characteristics (intensity, purity, beam spots in all focal planes) were in agreement with estimations. The new separator provides high quality secondary beams and it opens new opportunities for experiments with RIBs in the intermediate energy range 10÷50 AMeV [3].

The ^{6}He + d experiment, aimed at the study of elastic and inelastic scattering in a wide angular range, was chosen for the first run. The data obtained on the ^{6}He + d scattering, and in the subsequent measurements of the ^{8}He + d scattering, are necessary to complete MC simulation of the flagship experiment: search of the enigmatic nucleus ^{7}H in the reactions d(^{8}He,^{3}He) H and p(^{8}He,pp)^{7}H.

Opportunities of day-two experiments with RIBs using additional heavy equipment (radio frequency filter, zero angle spectrometer, cryogenic tritium target) will be also reported. In particular, the study of several exotic nuclei ^{16}Be, ^{24}O, ^{17}Ne, ^{26}S and its decay schemes are foreseen.

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ACCULINNA-2 (1 Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia; 2 Institute of Physics, Silesian University in Opava, Czech Republic; 3 Bogolyubov Laboratory of Theoretical Physics, JINR, Dubna, Russia; 4 GSI Helmholtzzentrum fur Schwerionenforschung, Darmstadt, Germany; 5 National Research Center “Kurchatov Institute”, Moscow, Russia; 6Heavy Ion Laboratory, University of Warsaw, 02-093 Warszawa, Poland; 7 Faculty of Physics, University of Warsaw, Warsaw, Poland; 8 Fundamental Physics, Chalmers University of Technology, Goteborg, Sweden; 9 All-Russian Research Institute of Experimental Physics, Sarov, Russia; 10 Ioffe Physical Technical Institute, St. Petersburg, Russia; 11 NSCL, Michigan State University, East Lansing, Michigan, USA)

New control method of slowed-down RI beam and new particle-identification method of secondary-reaction fragments at RIKEN RI beam factory

Presenter: Toshiyuki Sumikama (RIKEN)

The energy of the RI beam is one of the most important parameter for reaction studies.At RIKEN RI beam factory (RIBF), the energy around 200 MeV/u is easily available because the primary-beam energy is 345 MeV/u. Spectrometers and beam-line detectors are optimized to this energy region. On the other hand, for the transfer reaction, the multi-nucleon transfer reaction, and the fusion reaction, the energy around the Coulomb barrier is required. The lower energy is also awaited to determine the energy dependence of the spallation cross sections for the long-lived fission products (LLFPs) to search for a nuclear transmutation scheme of LLFPs [1].

The first experiment with ^{82}Ge beam was demonstrated to produce the slowed-down RI beam using the BigRIPS fragment separator at RIBF [2]. The beam energy with 13 MeV/u was successfully achieved. However, a control method about the absolute beam energy and the distributions of the energy, position, and angle was not established. The particle identification method designed for the higher energy couldn't be applied to the fragments with such low energy.

In the present study, we established new control methods by changing the material thickness, momentum selection, slit setting coupled with new ion optics mode. For example, the beam energy of 20.2 MeV/u was obtained for the 20 MeV/u setting of the ^{93} beam. A new particle-identification (PID) method was also developed. The combination of Bρ-TOF-ΔE-E-Range was obtained by using the momentum dispersive mode of the ZeroDegree spectrometer coupled with the multi sampling ionization chamber. The demonstration of PID with the 50 MeV/u ^{93}Zr beam will be presented. The capability to the lower energy will be discussed.

This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

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Recent Results from the FIONA Separator at LBNL

Presenter: Jacklyn Gates (Lawrence Berkeley National Laboratory)

Recently, the Berkeley Gas-filled Separator (BGS) at the Lawrence Berkeley National Laboratory (LBNL) was coupled to a new mass analyzer, FIONA. The goal of BGS+FIONA is to provide a M/deltaM separation of ~300 and transport nuclear reaction products to a shielded detector station on the tens of milliseconds timescale. These upgrades will allow for direct A and Z identification of ii) new actinide and transactinide isotopes with ambiguous decay signatures such as electron capture or spontaneous fission decay and i) superheavy nuclei such as those produced in the ^{48}Ca + actinide reactions.

Nuclear reaction products recoil from the target and are separated from the beam and unwanted reaction products in the BGS. There they pass through a window and into a radio-frequency gas catcher where they are thermalized and extracted into a radio-frequency quadrupole (RFQ) trap. The nuclear reaction products are cooled and bunched in the RFQ trap, where they maintain a +1 or +2 charge, and are injected into the mass analyzer. The mass analyzer consists of crossed electric and magnetic fields such that the ions take trochoidal trajectories. Here we will present recently results from the FIONA commissioning experiments.

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High-resolution Laser Ionization Spectroscopy of Heavy Elements in Supersonic Gas Jet Expansion

Presenter Rafael Ferrer Garcia (KU Leuven (BE))

Resonant laser ionization and spectroscopy are widely used techniques at radioactive ion beam facilities to produce pure beams of exotic nuclei and measure the shape, size, spin and electromagnetic multipole moments of these nuclei. In such measurements, however, it is difficult to combine a high efficiency with a high spectral resolution. A significant improvement in the spectral resolution by more than one order of magnitude has recently been demonstrated without loss in efficiency by performing laser ionization spectroscopy of actinium isotopes in a supersonic gas jet [1], a new spectroscopic method [2] that is suited for high-precision studies of the ground- and isomeric-state properties of nuclei located at the extremes of stability.

Spatial constraints and limitations of the pumping system in the present setup prevented the formation of a high quality jet and, as a consequence, an optimal spatial and temporal laser-atom overlap. Offline characterization studies at the In-Gas Laser Ionization and Spectroscopy (IGLIS) laboratory at KU Leuven [3] are being carried to overcome these limitations in future experiments when dedicated IGLIS setups are in operation at new generation radioactive beam facilities [4]. These characterization studies include: the flow dynamics and the formation of supersonic jets produced by different gas-cell exit nozzles using the Planar Laser Induced Fluorescence (PLIF) technique on copper isotopes, gas-cell designs with better transport and extraction characteristics, an ion guide system for efficient transport of the photo-ions and a high-power, high-repetition rate laser system.

Extrapolation of the online results on the actinium isotopes show that the performance of the technique under optimum conditions can reach a final spectral resolution of about 100 MHz (FWHM) and an overall efficiency of 10% when applied in the actinide region.

In this presentation, I will summarize a number of on-line results and mainly will focus on the characterization studies and future prospects of the in-gas-jet resonance ionization method applied on very-heavy elements.

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Resonance ionization schemes for high resolution and high efficiency study of exotic nuclei at the CRIS experiment

Presenter: Agota Koszorus (KU Leuven (BE))

Laser spectroscopy of exotic isotopes requires a technique that combines high spectral resolution with high efficiency. At the Collinear Resonance Ionization Spectroscopy (CRIS) ISOLDE [1], significant effort has been invested in improving both aspects. These developments resulted in e.g. linewidths of 20 MHz in radioactive Francium [2], and in the successful high-resolution measurements on beams with yields as low as 20 pps [3]. This contribution presents an in-depth study on how to achieve high-resolution and high-efficiency RIS on radioactive ion beams. These developments will pave the way for current and future experiments on radioactive beams, with many different groups exploring ways to achieve high resolution RIS [4,5].

Resonance ionization scheme developments have been performed for a number of elements (19K, 29Cu, 31Ga, 49In, 50Sn, 87Fr, 88Ra). The significance of these studies lies in achieving high resolution without introducing efficiency losses and line shape distortion in the observed hyperfine spectra. Interesting and unexpected effects have been identified related to the role of laser powers, temporal laser pulse lengths and relative firing delay of pulsed lasers. In particular, the use of "chopped" continuous light [2,6] as the first excitation step has been investigated in comparison with the use of an injection-locked laser [3,7]. The complementarity of these two approaches is such that both will continue to see use at CRIS.

In this contribution, the laser systems installed at CRIS will be presented, along with experimental results, demonstrating the advantages and opportunities that come with having such a versatile laser system, and the necessity of a solid understanding of the interaction of lasers and atoms for high resolution resonance ionization laser spectroscopy.

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Laser Spectroscopy of the Heaviest Elements at SHIP / GSI

Presenter: Sebastian Raeder (Helmholtz Institut Mainz, GSI Darmstadt)

Laser spectroscopy is a versatile tool to unveil fundamental atomic properties of an element and information on the atomic nucleus. The heaviest elements are of particular interest as their electron shell is strongly influenced by electron-electron correlations and relativistic effects changing the electron configuration and thus, the chemical behavior [1,2]. The elements beyond fermium (Z>100) are only accessible through fusion-evaporation reactions at minute quantities and at high energies, hampering so far their optical spectroscopy. Only recently we were able to identify optical transitions in nobelium (Z=102) in a pioneering experiment employing the RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) technique [3,4]. Nobelium ions are produced in the fusion-evaporation reaction by a 48Ca beam impinging on a lead target. The primary beam is deflected by the velocity filter SHIP and the transmitted recoils are stopped in high-purity argon gas and collected onto a thin tantalum filament. After re-evaporation the neutral atoms were probed by two-step resonance ionization. The so the created photo-ions were then guided to a detector where they were identified by their characteristic α-decay. With this technique a first identification and characterization of a strong 1S0→1P1 ground state transition in nobelium was possible. The resonances for the isotopes 252−254No were measured as well as the hyperfine splitting in 253No. In combination with atomic calculations, we determined the evolution of the deformation of the nobelium isotopes in the vicinity of the deformed shell closure at neutron number N=152 and extracted the magnetic moment and the spectroscopic quadrupole moment of 253No.

Next steps include the extension of the RADRIS method to more exotic nobelium isotopes and to the next heavier element lawrencium (Z=103) as well as developments for higher resolution spectroscopy. For the latter a dedicated setup is being developed combining the efficient stopping and neutralization from the RADRIS experiment with the high resolution of in-gas-jet spectroscopy [5]. Here, the stopped ions are guided by electric fields to a heated filament, which efficiently neutralizes the nobelium ions, as demonstrated in the RADRIS experiment. The neutral atoms are then extracted through a de Laval nozzle forming a collimated gas jet. Laser spectroscopy in this low density and low temperature regime will enable an improved resolution in laser spectroscopy and furthermore will allow us to address shorter-lived isotopes and isomers as, e.g., the K-isomer in 254No.

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MIRACLS: Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy

Presenter : Simon Mark C Sels (CERN)

Laser spectroscopy is a powerful tool for studying nuclear ground-state properties in a model-independent way. It provides access to the charge radii and electromagnetic moments of the nuclear ground state as well as of isomers by observing the isotope shifts and hyperfine structures of the atoms' spectral lines [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 [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].

Complementary to the Collinear Resonance Ionization Spectroscopy (CRIS) technique [5], 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. The sensitivity increase is derived from an extended observation time provided by trapping ion bunches in an Electrostatic Ion Beam Trap / Multi-Reflection Time-of-Flight device [6] where they can be probed several hundred of thousand times.

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

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Collinear laser spectroscopy at the IGISOL facility: upgrades and new opportunities

Presenter: Ruben Pieter De Groote (University of Jyvaskyla (FI))

Collinear laser spectroscopy is an established tool for the study of electromagnetic moments, charge radii and nuclear spins. With a history that now spans 4 decades, the technique has been successfully applied in laboratories all over the world. Recently, several upgrades were performed at the Ion Guide Isotope Separator On-Line (IGISOL) facility, Jyväskylä. Chief among these upgrades are a new event-by-event data acquisition system, and a new charge exchange cell. These developments will expand the applicability of the method significantly, and will in particular enable studies of the late d-shell species like Tc-Pd. No measurements on radioactive isotopes of these elements have been reported so far which reflects the challenge of producing such refractory species at ISOL-based facilities

In parallel to the developments at the collinear laser spectroscopy station, modifications of the radiofrequency cooler-buncher at the IGISOL are underway. The goal of these upgrades is to reduce the temporal length of the ion bunches. This is required to reach optimal mass-resolving power with the new Multi-Reflection Time-of-Flight (MR-TOF) device which is also currently being built and commissioned. Since an increase in the energy spread of the ions will result in a broadening of the resonance lines in collinear laser spectroscopy, collinear laser spectroscopy presents a unique tool to investigate the time- and energy spread of the bunches produced with this upgraded cooler-buncher.

In this contribution, the aforementioned upgrades will be discussed in detail. The performance of the upgraded cooler-buncher, evaluated using collinear laser spectroscopy, will be summarized. The implications of all these upgrades for the future physics program will be explored

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First demonstration of Doppler-free two-photon in-source laser spectroscopy at the ISOLDE-RILIS

Presenter: Katerina Chrysalidis (Johannes Gutenberg Universitaet Mainz (DE))

The ISOLDE on-line mass separator facility at CERN has offered radiogenic beams of a multitude of elements for over 50 years [1]. Fundamental research on nuclear structure, masses and decay modes are carried out by the various experimental installations inside the hall. To complement these, several measurement campaigns throughout the past years have been conducted by the in-source laser ionization spectroscopy collaboration between teams of the Resonance Ionization Laser Ion Source (RILIS), the Windmill alpha-detector setup, ISOLTRAP and, more recently, the Isolde Decay Station (IDS). Studies performed by this collaboration have made a great impact on our knowledge of nuclear shape evolution along isotopic chains in the gold-astatine region [2]. The high sensitivity of the in-source resonance laser ionization method has enabled us to extend our reach towards the most exotic isotopes ever studied at ISOLDE, close to the proton drip line.

Doppler-broadening inside the hot cavity ion source environment remains the biggest drawback of this method, limiting the achievable resolution and thereby restricting its use to the study of the heavier isotopes, or to specific cases where the isotope shift or hyperfine structures are sufficiently large. A Doppler-free approach has been tested for the first time at ISOLDE, making use of two counter propagating laser beams, which are both required to excite a two-photon transition. The resolution is then limited by the laser linewidth because the Doppler-shifts seen by two photons are of equal magnitude and opposite direction, thereby summing to zero. This approach will open the door to high-resolution and high sensitivity in-source laser spectroscopy studies across the nuclear chart. Since we are restricted to ionization pathways involving two-photon transitions, this technique is complementary to the other laser spectroscopy experiments at ISOLDE.

Here we report on the first demonstration of this method inside the ISOLDE target-ion-source assembly using a newly developed injection seeded ring Ti:Sa laser cavity for reduced laser linewidth. The Doppler-free spectra of silicon stable isotopes have been obtained, repeating a historical study that was carried out inside an independent atomic beam apparatus [3]. By making use of the same ionization scheme, we were able to provide a benchmark for comparison of the resolution and extracted nuclear data. Based on this initial feasibility study the scope of applicability of the Doppler-free two-photon spectroscopy technique at the ISOL facilities will be discussed and presented.

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Status of the low energy storage ring CRYRING@ESR

Presenter: Frank HERFURTH (GSI Helmholtzzentrum für Schwerionenforschung GmbH)

Heavy, highly charged ions stored at low energy are ideal probes for various questions of modern physics that range from tests of QED especially at high fields to detailed investigations of nuclear reactions. An early installation of the low-energy storage ring LSR, a Swedish in kind contribution to the FAIR project in Darmstadt/Germany, provides the necessary environment for precise experiments with slow, highly charged ions. During the last years, the immensely successful storage ring CRYRING has been connected to the powerful source of heavy, highly charged ions that is GSI/FAIR to form the CRYRING@ESR facility.

The ring can store ions ranging from a few 100 keV/nucleon to a few MeV/nucleon. Heavy, highly charged ions up to bare or hydrogen like uranium are produced at the GSI accelerator facility at about 400 MeV/nucleon, decelerated and cooled in the experimental storage ring ESR to about 4 MeV/nucleon, and then transported into CRYRING@ESR. There the ion beam can be decelerated further, cooled with an electron cooler, and stored for experiments, or extracted. An in ring gas target will be setup as well as a number of single particle detectors and laser – ion beam interaction zones. Three experiments have already been accepted by the GSI/FAIR general program advisory committee for beams from ESR and from the local source for the running period 2018/19. Additionally, 17 letters of intent have been received for experiments and tests with the local injector.

The ring installation has been finished. The local injector produced successfully H2+ ions accelerated to 300 keV/nucleon that were injected into the ring, stored, accelerated and cooled. Hence, all basic functions have been demonstrated. The remaining commissioning is dedicated to transfer first signals into routine operation and to get ready to accept ESR beam.

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Rare-RI Ring in cyclotron facility RIBF

Presenter: Yoshitaka Yamaguchi (RIKEN)

The Rare-RI Ring (R3) is located at RIKEN RI Beam Factory for the purpose of the systematically measurement for the basic properties of nuclei such as mass and lifetime including the r-process region. The R3 is an isochronous ring of an unprecedented concept that can inject, circulate, and quick extract an ion one-by-one. An isochronous field can be formed precisely in a wide momentum range by trim-coils attached to R3 like a cyclotron. This mechanism makes it possible the precise mass measurements of extremely short-lived (~1ms) Radioactive Isotopes (RIs) that are rarely produced (several particles/day). In the commissioning using RIs which masses are well-known, we demonstrated that the masses of several RIs within a wide range of m/q (~5%) can be derived relatively from one reference RI by measuring the flight time under a precise isochronous optics. The accuracy can be reached to an order of 10^{-6} by performing beta- or rigidity-correction. In the presentation, the features of R3 will be described with the results of commissioning, and the future prospects will be mentioned.

Application of In-ring Slit on Isochronous Mass Spectrometery

Presenter: Xing XU (Institute of Modern Physics)

Nuclear mass measurements provide valuable information on the nuclear binding energy which reflects the summed result of all interactions among its constituent protons and neutrons. The systematic and accurate knowledge of nuclear masses have wide application in many areas of subatomic physics ranging from nuclear structure and astrophysics to the fundamental interactions and symmetries depending on the achieved mass precision [1].

A storage ring coupled with a radioactive beam line has been proven to be a powerful tool for mass measurement of exotic nuclide. This kind of mass spectrometry was inventively pioneered at ESR-GSI in Darmstadt in the 1990s and then successfully established at CSRe-IMP in Lanzhou. For the ions stored in the CSRe, their revolution times T are a function of their mass-over-charge ratios m/q and their momentum p in the first order as follows:

$$\frac{\Delta T}{T} = \frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} - \left(\frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}\right)\frac{\Delta p}{p}$$

where γt is the so-called transition point of the ring and γ is the the relativistic Lorentz factor.

Numerous efforts based on this principle have been made to improve the mass resolving power of the storage-ring-based mass spectrometry. According to the equation, the mass resolving power m/Δm ∝ T/ΔT for a specific nuclide are inversely proportional to two parameters. One is the phase-slip factor η, defined as η=1γ2−1γ2t, representing how much the isochronous condition is fulfilled for this nuclide. The other one is the momentum spread Δpp, in other words, the magnetic rigidity acceptance of a storage ring, which is almost the same for all nuclides. In this contribution, we will report on the recent development for the Isochronous Mass Spectrometry(IMS) based on the storage ring CSRe.

In the experiment, the transition point γt of CSRe was found to be about 1.396 after 12-hours data accumulation. Nuclides with revolution time around 616ns were under the best isochronous condition, while the revolution time of 52Co27+ is about 614ns. This deviation from the anticipatory setting was mainly caused by the the imperfections of the electromagnetic field. Based on such conditions, the first order isochronicity optimization was made via the modifications of the quadrupole and sextupole magnetic field strengths [2], and thus, the transition point γt of CSRe was corrected to be 1.400. In this way the phase-slip factor of 52Co27+ was significantly reduced. The success of this isochronicity optimization was confirmed via 8-hours data accumulation.

To make a further improvement on separating 52Co from its low-lying isomer 52mCo (excitation energy is about 380 keV inferring its mirror nucleus 52Mn regardless of isospin symmetry breaking, and the corresponding difference of revolution time is about 2.4 ps), the momentum acceptance Δppwas limited via a slit installed at the dispersion section of the straight part of storage ring CSRe. The slit opening was 60 mm corresponding to the momentum acceptance of the CSRe of Δpp ∼ 4×10−4(sigma), while in previous experiments under the same optical setting but without the slit was Δpp ∼ 8×10−4(sigma) [2]. With the help of the slit, mass resolving powers for all nuclides were notably improved step by step. Despite of the decrease of statistic, a high resolution revolution time spectrum for 52Co and 52mCo was finally obtained, and the mass resolving power of IMS have touched 4×105 (sigma) region for the first time [3].

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Design, optimization and construction of multi-reflection time-of-flight mass analyzer for Lanzhou Penning Trap

Presenter: Yulin TIAN (Institute of Modern Physics, Chinese Academy of Sciences)

The multi-reflection time-of-flight mass spectrometer (MRTOF-MS) was first proposed by Wollnik and Przewloka. It has been developed as a new device in recent years for nuclear mass spectrometry and isobaric separation with ion bunches with kinetic energies ranged from a few hundreds of electron-Volts to a few kilo-electron-Volts. By extending the flight path using multi-reflection between electrostatic ion mirrors, an MRTOF-MS can reach a very high mass resolving power of >100,000 in a compact structure. Moreover, it also has other unique advantages, such as extremely short measurement time, a large mass range, very high sensitivity and non-scanning operation. Up to now, many MRTOF-MSs for mass measurements and isobaric separations have been commissioned or under construction.

A multi-reflection time-of-flight mass analyzer is being constructed for isobaric separation for the Lanzhou Penning Trap (LPT). A new method including two sub-procedures, global search and local refinement, has been developed for the design of MRTOF-MS. The method can be used to optimize the parameters of MRTOF-MS both operating in mirror-switching mode and in in-trap-lift mode. By using this method, an MRTOF mass analyzer, in which each mirror consists of five cylindrical electrodes, has been designed. The optimal potential parameters of the electrodes have been obtained and compared directly for our MRTOF mass analyzer operating in both modes. In the mirror-switching mode, the maximal resolving power has been achieved 1.3×105 with a total time-of-flight of 6.5 ms for the ion species of 40Ar1+, and 7.3×104 with a total time-of-flight of 4.3 ms in the in-trap-lift mode. 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.

In this conference, we will present the design details, optimization method and the results obtained. The status and progress of MRTOF mass analyzer for LPT will also be reported.

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Re-acceleration of Rare Isotope Beams at Heavy-Ion Fragmentation Facilities

Presenter: Antonio Villari (Facility for Rare Isotope Beams)

Heavy-ion fragmentation facilities provide a wide range of rare isotope beams of most chemical elements, as the in-flight production is fast and chemistry independent. Rare isotopes are delivered at half the speed of light are used for a wide set of nuclear science experiments. In order to leverage the advantages of the production mechanism for experiments that require lower energies and high-quality beams, beam stopping and reacceleration needs to be employed. The first re-acceleration system at a heavy-ion fragmentation facility in the world is ReA3 at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. Beams of rare isotopes are produced and separated in-flight in NSCL's Coupled Cyclotron Facility (CCF) at energies of typically 100 MeV/U and subsequently stopped in a gas cell. The rare isotopes are then continuously extracted as 1+ ions and transported into a beam cooler and buncher, followed by a charge breeder based on an Electron Beam Ion Trap (EBIT). In the charge breeder, the ions are ionized to a charge state suitable for acceleration in a superconducting radiofrequency (SRF) linac and then extracted in a pulsed mode and mass analyzed. The extracted beam is bunched to 80.5 MHz and then accelerated to energies ranging from 300 keV/u up to 6 MeV/u, depending on their charge-to-mass ratio. This contribution will present the state of art of this technique, advantages and disadvantages, results obtained so far and discuss developments.

The N=126 factory: a new facility to produce the very-heavy neutron-rich isotopes

Presenter: Guy Savard (Argonne National Laboratory)

A new facililty, the N=126 factory, is currently under construction at Argonne National Laboratory. It will use multi-nucleon transfer reactions to create neutron-rich isotopes of the heaviest elements for studies of interest to the formation of the last abundance peak in the r-process. This region of the nuclear chart is difficult to access by standard fragmentation or spallation reactions and as a result has remained mostly unexplored. The nuclei of interest, very neutron-rich isotopes around Z=70-95, will be produced by multi-nucleon exchange of a high intensity 10 MeV/u heavy-ion beam on the most neutron-rich stable isotopes of heavy elements such as 198Pt and 238U. This reaction mechanism can transfer a large number of neutrons and create with larger than mb cross-section very neutron-rich isotopes. The reaction mechanism is a nuclear surface process and the reaction products come out at around the grazing angle which makes them very difficult to collect. The N=126 factory circumvents this difficulty by using a unique large high-intensity gas catcher, similar to the one currently in operation at CARIBU, to collect the target-like reaction products and turn them into a low-energy beam that will then be mass separated with a medium resolution electromagnetic separator (DM/M ~ 1/1500), followed by an RFQ buncher and an MR-TOF (DM/M ~ 1/100000) system. The extracted radioactive beams will be essentially pure and be available at low-energy for mass measurements with the CPT mass spectrometer or decay study with the X-array. Status of the overall facility construction will be presented, together with commissioning results of the novel front end and the observed yield.

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Ba-ion extraction from high pressure Xe gas for double-beta decay studies with EXO

Presenter: Thomas Brunner (McGill and TRIUMF) for the nEXO collaboration

An RF-only ion funnel has been developed to efficiently extract single Ba ions from a high-pressure (10 bar) xenon gas into vacuum. Gas is injected into the funnel where ions are radially confined by an RF field while the neutral gas escapes. Residual gas flow alone (without any DC drag potential) transports the ions longitudinally through the funnel. In the downstream chamber the ions are captured by ion guides and delivered to an ion identification device. The xenon gas is captured by a cryopump and then recovered back into storage cylinders for future use.

With the current setup ions were extracted from xenon gas of up to 10 bar. This was one of the highest gas pressures ions have been extracted from so far. The ions were produced by a 252Cf-ion source placed in the high-pressure gas. The ion transmission has been studied in detail for various operating parameters and initial ion-identification has been achieved with a commercial mass spectrometer. An improved mass-to-charge identification via a multi-reflection time-of-flight mass spectrometer is currently being developed to further investigate the properties of the funnel and to measure the Ba-ion extraction efficiency of this setup.

This approach of ion extraction is intended for application in a future large-scale ^{136}Xe neutrinoless double-beta decay (0nbb) experiment. The technique aims to extract the bb-decay product, ^{136}Ba, from the xenon volume of a gaseous time-projection chamber and detect it unambiguously and efficiently. This individual identification of the decay product allows for an ideally background-free measurement of 0nbb by vetoing natural occurring backgrounds. This identification enables a higher level of sensitivity to the 0nbb decay half-life and thus is a more sensitive probe of the nature of the neutrino.

Beamv Thermalization at the National Superconducting Cyclotron Laboratory

Presenter: Chandana Sumitrarachchi (National Superconducting Cyclotron Laboratory)

Thermalization of projectile fragment beams provides access to a wide range of low-energy rare isotope beams at projectile fragmentation facilities. The thermalization process includes slowing down the fast exotic beams in solid degraders combined with momentum compression and removal of the remaining kinetic energy by collision with helium buffer gas. The second-generation National Superconducting Cyclotron Laboratory (NSCL) beam thermalization facility includes a momentum compression beam line with degraders, a large radio-frequency gas catcher constructed by Argonne National Laboratory and a low energy transport system. A number of experiments have been carried out to characterize the behaviour of the gas catcher for capturing and extracting a variety of fast beams.The stopping and extraction efficiency as a function of incoming particle rates, the effect of range focusing on extracted beam rates, the drift time in gas catcher and the chemical forms of extracted ions have been studied for a variety of chemical elements. The combined stopping and extraction efficiencies were found to vary from 0.05% to 40% for fragments ranging from O-14 to Ga-76. Careful selection of degraders and dispersion matching of the fast beam to the wedge angle increases the extracted beam rate significantly. Since different rare ion beams require different angle wedges, a variable wedge angle device has been constructed. The properties of the gas catcher, techniques used to thermalize radioactive beams and the performance of the whole system will be presented.

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Actinide ion beams by in-gas-cell laser resonance ionization, recoil sources, and on-line production at IGISOL

Presenter: Ilkka Pohjalainen (University of Jyväskylä)

The production of actinide ion beams has become a focus of recent efforts at the IGISOL facility of the Accelerator Laboratory, University of Jyväskylä, aimed at the measurement of nuclear properties of heavy elements using high-resolution optical spectroscopy [1]. Recently, off-line ion beam production of plutonium and thorium using laser resonance ionization combined with filament dispensers in a gas cell has been the subject of extensive studies. Additionally for thorium, which is of interest mainly because of the 229Th isotope and its extremely low-lying isomeric state [2], development of a ^{233}U alpha-recoil source and on-line production activities have now commenced.

Both plutonium [3] and thorium [4] show unexpected phenomena during laser resonance ionization in a gaseous environment. A plutonium ionization scheme that has been reported to have high efficiency in vacuum (hot cavity) performed poorly in the gas cell due to significant collisional quenching of states. The high density of atomic states in actinide elements has also complicated the understanding of the laser ionization process. Therefore, the selective ionization of plutonium was investigated further with a tunable, grating-based Ti:sapphire laser developed by the Applied Quantum Beam Engineering group from Nagoya University [5]. For the filament dispensers of ^{229}Th, an additional challenge has been the low volatility of thorium, contaminants and scarcity of ^{229}Th material.

A gas cell with ^{233}U alpha-recoil sources is also a viable approach towards the production of a low-energy ^{229}Th ion beam. Two different sources have been characterized at IGISOL with gamma- and alpha-ray spectroscopy by taking measurements from the sources directly and via implantation foils. The Rutherford back scattering spectrometer of the local ion beam analysis facility was also used to characterize the sources. The findings of these studies emphasize the importance of having control over the source quality, thickness and contaminants.

The first on-line experiment for the production of ^{229}Th from a light-ion fusion-evaporation reaction on ^{232}Th targets has also been performed. Although the identification of ^{229}Th was not directly possible due to the long half-life (7932 years), several alpha-active reaction products were detected and a yield of about 400 ions/s/μA for ^{229}Th was deduced from the ^{227}Pa yield, known detection efficiency and cross section estimates. The challenge of on-line production is in the competing (and overwhelming) fission channel which produces a large number of fission fragments that are expected to cause strong ionization of the buffer gas. Also, significant target damage was seen to be a problem because the targets were kept as thin as possible. This has prompted new target manufacturing concepts which are current being considered.

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Online Tests of the Advanced Cryogenic Gas Stopper at NSCL

Presenter: Kasey Lund (NSCL/MSU)

Linear gas stoppers filled with helium have become a common tool to convert high energy rare isotope beams into low-energy beams. The National Superconducting Cyclotron Laboratory (NSCL) has designed and fabricated a new cryogenic gas stopper to maximize efficiency and beam rate capability in order to increase scientific reach at the facility. Compared to earlier designs, the Advanced Cryogenic Gas Stopper (ACGS) is expected to have increased extraction efficiency, reduced transport time, reduced molecular contamination of the isotope of interest, and minimized space charge effects. A novel 4-phase Radio Frequency wire-carpet generates a traveling electrical wave for fast ion transport, cryogenic cooling of the helium gas chamber reduces unwanted molecular formation, and a new planar geometry with a bare wire-carpet in the mid-plane of the stopper alleviates space charge effects. Prototype testing of the ACGS components have shown wire-carpet transport efficiencies greater than 95% and transport speeds up to 100 m/s. First online tests of the ACGS with radioactive beams have been performed and the results will be presented.

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EMIS for Health

Presenter: Ulli Köster (Institut Laue-Langevin)

Electromagnetic isotope separation is an essential technology for the production of radionuclides with high radionuclidic purity, also those that are the “fuel” for nuclear medicine applications. Radionuclides for imaging and therapy are produced by charged particle induced reactions at accelerators or by neutron induced reactions in nuclear reactors. Yet, both methods require as prior step the preparation of a suitable target that often has to be isotopically enriched. I will discuss present needs and methods for isotope enrichment and possible synergies with new techniques that had initially been developed for nuclear physics experiments.

Beta-detected Nuclear Magnetic Resonance: From nuclear physics to biology

Presenter: Robert Dale Harding (University of York (GB))

β-NMR is a powerful tool which takes advantage of the anisotropic nature of β decay, to obtain information about the environment in which the radioisotope is implanted or to study the properties of the radioisotope itself. Nuclei are first polarized, then implanted into a crystal or sample of interest from which β-decay intensities are measured in opposing directions. The relevant information is extracted from an excitation radio-frequency applied to the system, which resonantly destroys the nuclear polarization. This technique has the advantage of being significantly more sensitive (up to 10 orders of magnitude) than traditional NMR. The new VITO beamline has been developed over the last two years at the ISOLDE facility (CERN) to provide beams of spin polarized radioactive nuclei for study. This culminated in a successful commissioning experiment measuring the β-decay asymmetry of 26Na and 28Na in a crystal of NaF, the results of which were published in March of 2017 [1].

A recent proposal is to apply this powerful technique to study biological systems. One such example is to observe how Na+ cations interact with DNA G-quadruplex structures in solution, the subject of campaign IS645 [2]. This contribution will focus on the results from these initial studies.

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Production of intense mass separated ^{11}C beams for PET-aided hadron therapy

Presenter: Simon Thomas Stegemann (KU Leuven)

We will present a novel production system based on the ISOL method (Isotope Separation On-Line) for intense mass separated 11C beams for PET-aided hadron therapy. Hadron therapy, and particularly carbon therapy, is a very precise treatment for localized tumors where the tumor is irradiated with a pure, monoenergetic and high intensity particle beam. Carbon therapy significantly reduces the dose exposure to healthy tissue compared to conventional photon therapy. However, the verification of the actual dose deposition in the human body remains difficult. Complex treatment planning systems are required that simulate the beam trajectory, and thus, calculate the dose distribution of the particle beam to the human body. Such treatment planning systems suffer from uncertainties that originate for instance from range deviations and from moving organs due to the patient's breathing. Therefore, within the Marie Skłodowska-Curie innovative training network MEDICIS-Promed, a 11C based carbon therapy protocol is being developed. 11C is a β+-emitter (T1/2= 20.4 min) widely used in PET-imaging. Consequently, by replacing the stable 12C beam with its radioactive isotope 11C, therapy can be combined with on-line PET-imaging. The PET-images that are recorded simultaneous with the treatment, represent a 3D dose distribution map of the irradiation field, and thus, provide an on-line dose verification. While the advantages of a 11C based hadron therapy are obvious, the challenge remains to produce a radioactive particle beam of sufficient intensity. Effective treatments require 4· 108 ions/spill delivered to the patient. As a result, this implies a radioactive ion beam production system that is capable to produce a 11C beam of high intensity. Therefore, we propose a production system based on the ISOL method, which is capable to produce pure and intense radioactive ion beams. This technique includes the irradiation of a solid target with a particle beam. The isotope of interest is produced, among many others isotopes, via a nuclear reaction inside the target. The isotopes then have to be released from the target and effuse to an ion source, where the atoms are ionized. Subsequently, the ions can be accelerated and mass separated by a deflecting magnet that bends the ions on trajectories according to their mass-over-charge ratio, producing (radioactive) ion beams. To ensure highest intensity as possible, optimization of the different steps from target irradiation until mass separation and beam formation is essential. We present our proposed production system, consisting of a solid boron nitride target, a cyclotron for low-energy proton irradiation and an ECR ion source. Optimization of important aspects, such as isotope release, transport and ionization efficiency will be discussed.

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Very high specific activity Er-169 production

Presenter: Roberto Formento Cavaier (Advanced Accelerator Application, GIP Arronax, Subatech, CERN)

The new facility CERN-MEDICIS produces isotopes using the CERN proton beam at 1.4 GeV coming from the CERN Proton Booster. The produced radioisotopes are dedicated for medical applications. A wide range of innovative radionuclides can be produced through its off-line mass separator. Indeed the mass separation allows the production of radionuclides which are not available at sufficient specific activity using conventional chemical separation methods only, in particular in the lanthanides region.

One radiolanthanide with very promising decay properties for targeted radionuclide therapy is Er-169. It shows favorable nuclear decay characteristics among β- emitters with about one week half-life, as it has the lowest beta energy and no disturbing gamma rays. More elaborated dosimetry calculations have validated that Er-169 would provide one of the best ratio of absorbed dose to the tumor versus normal tissue [1]. Unfortunately, Er-169 cannot be produced directly with high specific activity. Reactor irradiation of highly enriched Er-168 leads to specific activities of 0.4–4 GBq/mg (for thermal neutron fluxes of 1014–1015 cm-2s-1 and irradiation for one half-life). This corresponds to a “dilution” of the radioactive Er-169 with 8000 or 800 times more stable Er-168 respectively. This low specific activity carrier-added Er-169 is actually in clinical use, but only for radiosynovectomy of finger joints in the therapeutic management of arthritis [2,3], where the low specific activity is acceptable. Therefore higher specific activities could allow no-carrier-added Er-169 being considered for receptor targeted therapies.

The production of Er-169 with the off-line mass separator, allows to significantly increase the specific activity and to spread the potential applications of this radionuclide in medicine. For this reason in the spring 2018 a highly enriched Er-168 target will be irradiated in ILL reactor and shipped to CERN where the mass separation will be performed. We will present the experimental results of the irradiation and separation in comparison to the yields estimated from off-line experiments. Future improvements of the overall process efficiency will be discussed.

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Laser Isotope Separation revisited – radio isotope purification by resonance ionization mass spectrometry at Mainz University

Presenter: Klaus Wendt (Johannes Gutenberg Universitaet Mainz (DE))

As a spin-off of the on-going development of on-line laser ion sources and based on the suitability and reliability of present days laser systems for this specific task, resonance ionization mass spectrometry has demonstrated its great versatility in the field of radioisotope separation and ion beam purification. This application primarily profits from the universality of the technique, the high overall efficiency of the process and the unrivaled suppression of isobaric and other background in the final sample. For elimination of disturbances from neighboring isotopes specific techniques of ion source operation or ion-beam gating have been developed.

In the field of long-lived radioisotopes, as accessible at the ion source development set-up and off-line radioactive ion beam facility of the RISIKO laser mass separator at Mainz University, a number of applications in the field of fundamental and applied research are carried out, adding to spectroscopic activities e.g. in preparation of nuclear-medical species for CERN-Medicis [1].

One example of specific radioisotope purification concerns the isotope 163-Ho and its efficient implantation into the magnetic metallic calorimeter chips of the ECHo collaboration for investigation of the neutrino mass [2]. Purification of the isotope 53-Mn, delivered from beam dump recovery as part of the Meancorn project of PSI [3], is carried out for supporting lifetime measurements. A further activity concerns a radiometrical clean implantation of the isotope 225-Ra as standard for the PTB.

Advances and limitations of the technique, as realized at the Mainz University RISIKO mass separator, concerning the spectroscopic background, the laser and ion source optimization and finally, the optimization of the collection and implantation unit will be discussed.

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Applications of β-radiation detected NMR in wet chemistry, biochemistry and medicine

Presenter: Monika Stachura (TRIUMF)

Many processes in nature are governed by the interaction of biomolecules with metal ions. Some biologically highly relevant metal ions, such as Mg2+, Cu+ and Zn2+, are silent in most spectroscopic techniques, rendering characterization of their biological function difficult. Therefore, there is a demand for new experimental approaches to directly study these metal ions.

Recently, β-radiation detected nuclear magnetic resonance (β-NMR) spectroscopy was successfully applied to liquid samples at the ISAC facility at TRIUMF [1], Canada's particle accelerator center. In contrast to any previously reported measurements, the resonance spectra recorded for 31Mg+ implanted into solutions of different ionic liquids displayed well-resolved resonances originating from oxygen and nitrogen coordinating Mg2+ ions in typical Mg2+ complexes, illustrating that β-NMR can in fact discriminate between different structures. Furthermore, the recorded resonance line widths are very narrow, and in some cases exceed the ones reported for conventional NMR spectroscopy on similar systems, underlining the complementary advantages of β-NMR. This achievement marks a milestone in applications of β-NMR in liquid samples and opens new opportunities in the fields of wet chemistry, biochemistry and medicine.

Results from the recent β-NMR experiments with 31Mg+ ions performed at TRIUMF [1,2] and the future plans will be presented and discussed.

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High-power target development for the next-generation of ISOL facilities

Presenter: Lucia Popescu (SCK-CEN, Mol, Belgium)

The production of high purity radioactive ion beams (RIB) through the isotope separation online (ISOL) method makes possible unique research programmes in several fields of science. The demand for beam time continues to be high, while the study of more and more exotic isotopes, difficult to produce in sufficient quantities, is of primary interest for many of the currently defined research projects. At the same time, the growing interest from the medical field cannot pass unnoticed, the ISOL technique giving access to the most innovative medical isotopes, with extremely-high specific activity. Increasing the RIBs intensity is therefore of primary interest, and it is carefully addressed through several R&D programmes worldwide.

One of methods to increase the RIB intensity is by increasing the intensity of the primary beam on target. The ISAC facility at TRIUMF is capable to operate with high-intensity (up to 0.1 mA) 500-MeV proton beams, being the highest power ISOL facility under operation worldwide. To reach this level, composite target materials have been developed and integrated in a high-power target container capable of dissipating up to 20 kW through radiative cooling. Next-generation ISOL facilities plan to increase this power even further, which calls for innovative target designs. Such example is the LIEBE target (LIquid lEad Bismuth eutectic loop target for EURISOL), where, for the first time, the concept of a liquid target material circulating in a loop is being put forward. This loop-type target allows incorporation of a heat-exchanger for the necessary heat removal.

Similar or even exceeding heat-management challenges are to be faced by ISOL targets at high-intensity but lower-energy primary beam facilities. Examples are SPES and ISOL@MYRRHA-phase1, where, even if the primary-beam power doesn’t exceed the level of the ISAC facility, the lower energy of the protons (40/70 MeV and 100 MeV, respectively) increases the power deposited into the target. The concept of these targets, therefore, departs from the concept of the high-power targets of ISAC.

Finally, the presentation will discuss high-power converter targets, used to produce secondary particles (e.g., neutrons) irradiating a fissile material. Dealing with the power deposition in the converter instead of the ISOL target represents an advantage. However, the design of this target system requires a detailed R&D for optimized RIB production.

Towards 100 kW targets for electron driver beams at the TRIUMF-ARIEL Facility

Presenter: Thomas Day Goodacre (TRIUMF)

The TRIUMF ARIEL Facility will add two new target stations for Radioactive Ion Beam (RIB) production at TRIUMF, one of which will be capable of accepting a 100 kW electron “driver beam”. TRIUMF is already a world leader in the operation of “high power” (50 kW) targets for proton driver beams, however, in many aspects and particularly for the target, the exploitation of an electron driver beam presents a fresh set of challenges.

An electron-gamma (e-γ) converter is required upstream of the target, with the resulting γ-rays used to irradiate target materials. The spatial profile of the γ-rays necessitates significant changes to the dimensions and the orientation of the target with respect to the driver beam, compared to targets on the proton stations. The resulting asymmetric power deposition from irradiation and the proximity to the converter, results in new requirements for both the target heating and methods for increasing the effective emissivity to facilitate power dissipation. The ARIEL era will also introduce hermetic target vessels at TRIUMF, enabling the use of new types of target materials. In addition to the significant opportunities this may bring in the range and the yield of RIB production, there is also the potential for a significant increase in the ion/neutral load on the ion sources coupled to the targets.

The latest results from the developments to meet the heating and thermal dissipation requirements for targets for use with 100 kW electron driver beams will be presented, together with options to mitigate the effects of increased ion/neutral loads on the ion sources.

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BRIF: from the first proton beam to RIB production

Presenter: Tianjue Zhang (China Institute of Atomic Energy)

Various technologies for high current compact H- cyclotron have been developed since 1990s [1,2]. The energy of compact style machines was firstly elevated up to 100 MeV for Radioactive Ion Beam production[3,4]. The project, BRIF, Beijing Radioactive Ion-beam Facility was approved to start the construction in 2011, and the first proton beam was extracted from the 100 MeV compact cyclotron CYCIAE-100 on July 4, 2014[5]. This paper will present the progress on the BRIF after the first proton beam, including the cyclotron improvements for the stable operation and mA beam acceleration efforts, the RIB production and the implementation for mass resolution of 20000, and the future development etc.

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Current status of Isotope Separation On-Line (ISOL) facility at RAON

Presenter: BH KANG (Institute for Basic Science)

The two types of advanced high power Rare Isotope production facilities, Isotope Separation On-Line (ISOL) and In-Flight (IF) Fragment separator, are being developed by Rare Isotope Science Project (RISP). The installation of ISOL facility is going to start from year 2019 and its commissioning will be finished by 2021 at Rare Isotope Accelerator complex for ON-line experiments, RAON, in Korea. The main systems of ISOL comprise (or consist) of 70 MeV proton cyclotron driver, Target/Ion Source (TIS) including remote handling system, beam separation and transportation system and EBIS type charge breeder. The first goal of TIS development in RISP is providing about 10^8 pps of Sn isotope using high power U target to very low energy experimental hall. Here, the current status of development of ISOL facility will be presented.

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The Magnex spectrometer for double charge exchange reactions

Presenter: Manuela Cavallaro (INFN - National Institute for Nuclear Physics)

The physics of neutrinoless double beta decay has tremendous implications on particle physics, cosmology and fundamental physics. In particular, the nuclear matrix elements entering in the expression of the half-life of this process play a crucial role.

The possibility to use heavy-ion induced reactions and in particular double charge exchange reactions as tools for extracting information on matrix elements will be presented at the conference. The basic point is that the initial and final state wave functions in the two processes are the same and the transition operators are similar. The strengths and the limits of the proposed methodology will be discussed. The experimental difficulties that limited in the past the exploration of such kind of reactions and the advantages of using the MAGNEX large acceptance spectrometer at INFN - LNS (Italy) will be stressed.

New experimental data regarding the 40Ca(18O,18Ne)40Ar and 116Cd(20Ne,20O)116Sn double charge exchange reactions and competing channels involving same projectiles and targets at 15 MeV/u incident energy will be shown.

New ion-optical modes of the BigRIPS and ZeroDegree Spectrometer for the production of high-quality RI beams

Presenter: Hiroyuki Takeda (RIKEN Nishina Center)

The BigRIPS projectile fragment separator1,2 is presently the most powerful device for the research of exotic nuclei separated in flight. The scientific merits and potential of the BigRIPS and its combination with the ZeroDegree spectrometer2 have been demonstrated in many dif-ferent experiments since more than 10 years3.

The intensity of the primary beam provided by the Superconducting Ring Cyclotron (SRC)4 has been increased in the recent years by more than 2 orders of magnitudes which directly yields higher intensities of spatially separated exotic nuclei at the final focal plane of BigRIPS, but inevitably it causes also higher background. The spatial separation of fragments is per-formed by a two-fold $B\rho-\Delta E-B\rho$ method using two wedge-shaped degraders placed at the central focal planes of the first-stage (F0 to F2) and second-stage (F3 to F7). In the standard operating mode of BigRIPS, the 2 $B\rho-\Delta E-B\rho$ spatial separations are subtractive in resolving power, we present here an additive mode which has been developed and realized in first machine tests. The calculated significantly increased spatial separation power has been demonstrated in measurements and examples of experiments will be presented in this contribution where the additive mode is essential. In addition to the higher separation power, the additive mode has a favorable image condition at F6 which allows for a back-ground reduction via application of slits and diagnostics. Higher ion-optical resolving power modes at dispense of slightly lower transmission are also investigated and discussed. The lat-ter will give access to heavier elements. The coupling of BigRIPS and ZeroDegree is presently realized via two independent achromatic systems. A dispersion-matched mode and also a higher angular acceptance of the ZeroDegree are also presented in this report.

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Yoshiyuki Yanagisawa (RIKEN Nishina Center), Koichi Yoshida (RIKEN Nishina Center)

ISLA, an Isochronous Separator with Large Acceptance for Experiments with Reaccelerated Beams at FRIB

Presenter: A Matthew Amthor (Bucknell University)

The Isochronous Separator with Large Acceptance (ISLA) has been identified by the ReA12 Recoil Separator working group of the FRIB Users Organization as the single device that meets the needs of all the physics cases proposed by the community for studies with reaccelerated rare isotope beams from ReA at FRIB. ReA will reaccelerate stopped FRIB beams to energies ideal for transfer reactions, multiple Coulomb excitation, fusion, and deep inelastic scattering. ISLA will provide efficient rejection of unreacted beam; large acceptances in momentum (±10%), angle (64 msr), and charge state (±10%) distributions; and high M/Q resolving power (>400) for reaction products. This purely magnetic system will accept magnetic rigidities up to 2.6 Tm, to match incoming rigidities expected from the fully upgraded ReA12, and will not be limited by electric rigidity. M/Q separation in time-of-flight and a long preceding drift will allow efficient detection at ISLA's compact focal plane, facilitating multi-physics measurements (e.g. implantation-decay coupled to γ-ray spectroscopy). Space at the target is sufficient for coupled operation with GRETA, and a beam swinger will allow incoming beam angles up to 50 degrees. Recent work will be presented on the magnetostatic design of ISLA's four large dipoles and the results of updated ion optical models.

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New high-resolution and high-transmission modes of the FRS open up new perspectives for FAIR phase-0 experiments

Presenter: Emma Haettner (GSI Helmholtzzentrum für Schwerionenforschung GmbH)

The FRagment Separator FRS at GSI is primarily a powerful in-flight separator for short-lived exotic nuclei based on multiple magnetic rigidity analysis ($B\rho max=18$ Tm) and atomic energy loss in shaped matter. The quadrupole magnets determine the focal-plane conditions and the hexapole magnets can be used to correct aberrations, which play a crucial role for projectile fragments characterized by a large phase space. The ion-optical system of the FRS can also be operated as a high-resolution spectrometer for precise momentum measurements. For example, the investigation of the influence of the tensor force as a part of the nuclear force has been performed with the addition of the resolving powers of the four dispersive dipole magnet stages. Dispersion-matched ion-optical settings, specially shaped degraders and tools to reduce the fragment energy spread are methods applied in high-resolution experiments. – Other experiments have their preference for high rates which is enabled through thick targets and high optical transmission. In this contribution, we report on new ion-optical developments which are essential for the planned FAIR phase-0 experiments.

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Status of the CANREB high resolution separator at TRIUMF

Presenter: Marco Marchetto (TRIUMF)

A new ISOL rare isotope beam production facility, ARIEL, is under construction at TRIUMF. ARIEL aims at increasing the delivery of radioactive beams three fold with respect to the present capability of the ISAC facility. Part of ARIEL is the new CANREB equipment that can be described by the two main functionalities: a charge breeding system that includes RFQ cooler, EBIS and Nier separator, and a high resolution mass separator system. The latter is designed to achieve a resolving power of twenty thousand for a transmitted emittance of three micrometer. The separator optics has been designed with symmetry in order to minimize high order aberrations. The dispersion of the system is created by two identical ninety degrees magnetic dipoles with a field flatness of one part in one hundred thousand. The dipoles are tested and the magnetic field characterized before being installed on line for operation. High order aberrations can also be corrected by an electrostatic multipole; this features a novel design as well as a new tuning technique. In this paper we will present the latest results from the field characterization and discuss the high level application to tune the multipole.

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Closing Remarks

Poster session I

Development of gas filled dipole magnet for FIPPS phase 2

Presenter: Yung Hee Kim (Institut Laue-Langevin)

FIPPS (FIssion Product Prompt gamma-ray Spectrometer) is a new instrument of ILL for the gamma-ray spectroscopy of nuclei produced by thermal neutron induced reactions. In the current stage, FIPPS consists of an array of 8 HPGe clover detectors and a pencil-like intense thermal neutron beam.

The next phase of FIPPS aims to study i) Nuclear structure of neutron-rich nuclei far from stability produced in neutron induced fission. ii) Fission of heavy elements to explore the dynamics of the fission process. To study these under optimum conditions, ancillary devices are required to increase the sensitivity and selectivity of fission fragment detection with a good efficiency.

In FIPPS phase 2 the existing FIPPS HPGe-array will be complemented by an anti-Compton shield. Moreover, a Gas-Filled-Magnet (GFM) with a moderate mass separation (< 4 amu) [1] and a large acceptance (> 50 msr) of fission fragments will be installed. The conventional homogenous field magnet has been compared with an innovative design based on 1/r magnetic field with arc-shaped pole edges to assure point-to-point focusing of fission fragments over very wide acceptance. Thus requirements for tracking of ions are strongly relaxed.

The design of the GFM spectrometer with magnetic field calculation of the dipole magnet will be presented. Characteristics of the GFM for detecting fission fragments were studied by Monte-Carlo simulation using GEANT4, based on test experiments at LOHENGRIN [2], will be presented.

[1] H. Lawin et al., Nucl. Inst. and Meth. 137 (1976) 103-117
[2] A. Chebboubi et al., Nucl. Inst. and Meth. B 376 (2017) 120-124

Co-authors: Abdelhazize Chebboubi (CEA, DEN, DER, SPRC, Cadarache), Herbert Faust (Institut Laue Langevin), Emmanuel Froidefond (LPSC Grenoble), Michael Jentschel (Institut Laue-Langevin), Gregoire Kessedjian (LPSC Grenoble) Ulli Köster (Institut Laue-Langevin), Olivier Meplan (LPSC Grenoble), Caterina Michelagnoli (Institut Laue-Langevin), Paolo Mutti (Institut Laue-Langevin), Emilio Ruiz-Martinez (Institute Laue-Langevin), Michel Thomas (Institut Laue-Langevin)

Tuning of an 81.25 MHz Four-vane RFQ with a Lamped Field Profile at RISP

Presenter: Bum-Sik Park (IBS)

A radio frequency quadrupole (RFQ) linear accelerator has been developed and tuned for the heavy ion accelerator facility at RISP (Rare Isotope Science Project). The RISP RFQ has the 81.25 MHz operational frequency and a four-vane structure for a continuous wave (CW) operation despite the fabrication difficulties of the huge cavity due to the brazing technology. The cavity is inherently insensitive to perturbations due to low frequency and a short cavity length. The linearly increasing profile of the inter-vane voltage has been tuned for all quadrants through not only the movable slug tuners but also the modification of the end plate. In this study, a low-frequency RFQ with a novel ramped field profile has been tuned and the commissioning tests have been conducted with a new tuning method compatible with the modification of end region geometry.

Co-authors: • Hong In-Seok (Institute fo Basic Science), Ji-Ho Jang (Institute of Basic Science), • Kyungtae Seol (IBS (Institute of Basic Science))

Poster Session 1 / 15

Isotope Production by the High Current Proton Beam of CYCIAE-100

Presenter: Tianjue Zhang (China Institute of Atomic Energy)

CYCIAE-100, a 100 MeV high current compact cyclotron has been constructed and first beams were extracted in 2014. The machine has 7 beam lines for multi-application purposes. N1, one of the beam lines, is designed for high current beam transportation, beam dump tests and isotope production. In 2016, a mA proton beam was tested on the internal target. In 2017, 200 micro-ampere proton beam was extracted and transported to the beam dump. This paper will present the simultaneous Dual-beam extraction from CYCIAE-100 and the improvement of the uniformity of the beam on the target.

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Poster Session 1 / 22

Improvement of the β-ion correlation efficiency in decay spectroscopy

Presenter: Jeongsu Ha (Seoul National University)

β-decay spectroscopy is a useful method for understanding physics of nuclear structure. In decay spectroscopy experiments, Double-Sided Silicon Strip Detectors (DSSSDs) have often been used because of their detection capability on ions and β-rays. In order to identify β-ray events in the DSSSDs, it is necessary to correlate a β-ray and a corresponding, implanted ion using time and position information.

This process of the β-ion correlation should be carried out carefully, because the correlation efficiency depends on the positions and the energy losses of the implanted ions and the emitted β-rays in the DSSSDs. In this analysis, a new algorithm has been introduced to improve the β-ion correlation efficiency with the DSSSD, WAS3ABi [1]. In the new approach, hit patterns of β-rays recorded in the WAS3ABi are categorized to determine the initial position of the β-rays. When the β-rays were detected by the plastic scintillators installed at upstream/downstream of the WAS3ABi, the directions of the β-rays were also deduced. Furthermore, some ions stopped at the surface of the DSSSD layers have also been analyzed [2], finally improving the β-ion correlation efficiency. We demonstrate that this method can successfully reduce the background from random β-ion correlations while collecting more correlated β-ion events, thus improving signal to background ratio.

[1] P. -A. Söderström et al., Nucl. Instrum. Methods Phys. Res. B 317, 649 (2013)
[2] I. Nishizuka et al., JPS Conf. Proc. 6, 030062 (2015)

Co-authors: Toshiyuki Sumikama (RIKEN Nishina Center), Seonho Choi (Seoul National University)

A novel method for in-trap nuclear decay spectroscopy and level lifetime measurement using a double Penning trap

Presenter: Pierre Chauveau (CSNSM)

MLL-Trap is a double Penning-Trap for high precision mass measurement of exotic nuclei, built and commissioned off-line at the Maier-Leibnitz Laboratory in Garching, Germany [1] and currently installed at the ALTO facility at IPN in Orsay. A new double trap geometry is being studied, in which the central electrode of the second trap has been replaced by an arrangement of four silicon strip detectors [2]. An ion cloud stored in a Penning Trap is indeed an ideal source for decay spectroscopy, since it is very well localized and backing free. Moreover, the ion bunch can be purified from contaminants and in the case of alpha emitters, the strong magnetic field spatially separates the alpha particles and coincident conversion electrons, allowing a clean spectroscopy of both. Such a setup enables direct in-situ observation of decaying very heavy alpha emitters.

In addition, once coupled with a position-sensitive electron detector, this spectroscopic trap will allow for indirect measurement of lifetimes of first excited states or 0+ states in the region of heavy and super heavy nuclei, via a recoil-distance measurement [2]. Measuring the lifetime of the 2+ level in very-heavy even-even nuclei can lead to the derivation of the corresponding quadrupole moment and gives insight into its deformation and degree of collectivity. Also, the lifetime measurement of a low-lying 0+ state could allow to quantify the shape mixing with the ground state.

Simulations performed with SIMION8.1 confirm the feasibility of the method, while the expected uncertainties are still being investigated. Candidate nuclei for both offline and on-line commissioning at ALTO have been identified.

[1] V.S. Kolhinen et al., NIM A 600 (2009) 391-397
[2] C. Weber et al., IJMS 349-350 (2013) 270-276

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Velocity filter SHELS: performance and experimental results.

Presenter: Alexander Yeremin (FLNR JINR)

In recent years α-, β- and γ- spectroscopy of heavy nuclei at the focal plane of recoil separators ("decay spectroscopy") has been very intensively developed. The mixing of α decay with γ and β decay spectroscopy allows to investigate single particle states behavior as well as the structure of little known elements in the Z = 100-104 and N = 152-162 region.

In the past using the GABRIELA (Gamma Alpha Beta Recoil Invetsigations with the ELectromagnetic Analyser) set-up and VASSILISSA electrostatic separator the experiments aimed to the gamma and electron spectroscopy of the Fm – Lr isotopes, formed at the complete fusion reactions 48Ca+207,208Pb→ 255,256No*, 48Ca+209Bi→ 257Lr*, 22Ne + 238U → 260No *were performed.*

Accumulated experience allowed us to perform ion optical calculations and to design the new experimental set up, which will collect the base and best parameters of the existing separators and complex detector systems used at the focal planes of these installations. New experimental set up SHELS (Separator for Heavy ELement Spectroscopy) on the basis of existing VASSILISSA separator was developed for synthesis and studies of the decay properties of heavy nuclei [1,2]. The ion optical scheme of the new separator can be described as Q-Q-Q-E-D-D-E-Q-Q-Q-D, where Q denotes Quadrupole lenses, E - Electrostatic deflectors, D – Dipole magnets. Test experiments showed that transmission efficiency for slow evaporation residues formed in asymmetric target projectile combinations (22Ne induced reactions) increased by factor of 3 – 4, for more symmetric combinations (48Ca and 50Ti induced reactions) background condition at the focal plane became more comfortable

.

During the last experimental campaigns (years 2016 – 2018) the new double sided silicon detector (DSSD) was used at the focal plane of the SHELS separator (128x128 strips, 100x100 mm2). The detector demonstrated high stability and ensured a high resolution (0.2 %) of alpha particle registration. GABRIELA detector set up was modernized too, now it consists of 5 Ge gamma detectors (1 Clover and 4 single crystal)

.

At the last 2 years we performed experiments to study decay properties of 255,257Rf and 256,257Db in the reactions 50Ti + 207,208Pb → 256,357Rf *and 50Ti + 209Bi → 259Db*.*

[1] A.V. Yeremin et. al., PEPAN Letters, 12, 35 (2015)
[2] A.V. Yeremin et. al., PEPAN Letters, 12, 43 (2015)

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An optimized plasma ion source for difficult ISOL beams

Presenter: Ailin ZHANG (Institut de Physique Nucléaire Orsay, CNRS-IN2P3)

The ionization by radial electron neat adaptation (IRENA) ion source has been designed to operate under extreme radiation conditions. Based on the electron beam generated plasma concept, the ion source is specifically adapted for thick target exploitation under intense irradiation. A validation prototype has already been designed and tested offline. The design of a new optimized prototype for online difficult beams production with ISOL facilities will be presented. In particular, simulation constructions for thermionic emission, ions confinement and extraction will be presented and results discussed

.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 654002.

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Production of theranostic Tb isotopes: electromagnetic isotope separation before or after irradiation?

Presenter: Ulli Köster (Institut Laue-Langevin)

Terbium has a quadruplet of so-called theranostic isotopes useful for the preparation of radiopharmaceuticals: ^{152}Tb (PET imaging), ^{155}Tb (SPECT imaging), ^{161}Tb (beta-therapy) and ^{149}Tb (alpha therapy). All isotopes belong to the same element, thus assuring identical pharmacokinetics, an essential requirement for theranostics. ^{149,152,155}Tb with high radioisotopic purity is so far only available from spallation of Ta targets combined with on-line mass separation at CERN-ISOLDE or TRIUMF-ISAC.

Additional production at cyclotrons is urgently required to satisfy the great demand for medical applications. These isotopes could in principle also be produced by ^{155}Gd(p,n)^{155}Tb, ^{152}Gd(p,n)^{152}Tb and ^{152}Gd(p,4n)^{149}Tb reactions respectively, provided targets of sufficient isotopic enrichment become available. Commercially available ^{152}Gd reaches only 30% enrichment, but >>90% enrichment is required to minimize co-production of longer-lived Tb isotopes in (p,n) reactions
.
We present a demo experiment performed at the tandem accelerator of the MLL Garching where ^{152}Tb was produced by irradiating a unique ion-implanted ^{152}Gd target (>99% enriched) with 8 MeV and 12 MeV protons respectively. At these energies only ^{152}Tb was observed while upper limits are derived for co-production of other Tb isotopes. This radioisotopic purity would enable direct use for human applications, only requiring a chemical Tb/Gd separation from the target material.

We will discuss prospects to efficiently separate more ^{152}Gd and ^{155}Gd with the SIDONIE mass separator at CSNSM Orsay and thus prepare cyclotron targets suited for high current irradiations.

We thank the MLL staff for smooth operation of the tandem accelerator.

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SIPT - An Ultrasensitive Mass Spectrometer for Rare Isotopes

Presenter: Ryan Ringle (Michigan State University)

Over the last few decades, advances in radioactive beam facilities like the Coupled Cyclotron Facility at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) have made short-lived, rare-isotope beams available for study in various science areas, and new facilities, like the Facility for Rare Isotope Beams (FRIB) under construction at MSU, will provide even more exotic rare isotopes. The determination of the masses of these rare isotopes is of utmost importance since it provides a direct measurement of the binding energy of the nucleons in the atomic nucleus. For this purpose we are currently developing a dedicated Single-Ion Penning Trap (SIPT) mass spectrometer at NSCL to handle the specific challenges posed by rare isotopes. These challenges, which include short half-lives and extremely low production rates, are dealt with by employing the narrowband FT-ICR detection method under cryogenic conditions. Used in concert with the 9.4-T time-of-flight mass spectrometer, the 7-T SIPT system will ensure that the LEBIT mass measurement program at MSU will make optimal use of the wide range of rare isotope beams provided by the future FRIB facility, addressing such topics as nuclear structure, nuclear astrophysics, and fundamental interactions.

Co-authors: Georg Bollen (Michigan State University), Alec Hamaker (MSU/NSCL), Chris Izzo (MSU/NSCL), Daniel Puentes (MSU/NSCL), Stefan Schwarz (NSCL/MSU), Isaac Yandow (MSU/NSCL)

Poster Session 1 / 56

Current Status of Rare Isotope Science Project (RISP) of IBS

Presenter Taeksu Shin (RISP/IBS)

The construction of the heavy ion accelerate complex, RAON (Rare isotope Accelerator complex for ON-line experiments), has been carried out under RISP of IBS since 2011. The major accelerator systems, QWR(quarter-wave resonator) and HWR(half-wave resonator) of low energy LINAC system, are in the process of mass production after demonstrating of functional readiness through SCL(super–conducting linac) Demo runs in 2016 including superconducting ECR-IS(electron cyclotron resonance ion source) and RFQ(radio-frequency quadrupole) of injection system. Also, KOBRA (Korea broad acceptance recoil spectrometer and apparatus), the low energy experimental system for the day-1 experiment of early phase runs, is being successfully in the stage of construction with RISP rare isotope production systems, ISOL(Isotope Separation On-Line) and IF(in-flight) fragmentation system and others. Therefore, the current integrated RISP effort and status of the construction of RAON will be reported.

TITAN’s Next Generation of Experimental Setup for Mass Spectrometry of Highly Charged Ions

Presenter: Erich Leistenschneider (TRIUMF, UBC)

Atomic masses are key tools to understand the nature of nuclear forces and structure, fundamental symmetries and astrophysical processes if known with sufficient precision. With the availability of beams of increasingly exotic species, mass spectroscopy techniques have become more challenging. They need to be faster for shorter lifetimes, more sensitive for lower intensities, and sufficiently precise for scientific interest.

The TITAN facility at TRIUMF has been successfully performing precision mass measurements of radioactive nuclei for over a decade. Its mass Measurement Penning Trap (MPET) is designed to probe atomic masses of ions living as short as 10 ms, with low production yields, in the 10^{-7} - 10^{-9}precision range. A powerful way to boost this precision is to charge breed the inspected ion, which is done at TITAN through electron impact ionization in an Electron Beam Ion Trap (EBIT).

The implementation of TITAN's next generation capabilities of performing mass spectrometry on highly charged ions (HCIs) is currently on its final stages. The EBIT has been upgraded to deliver electron beam energies up to 60 keV, which can provide access to bare ions up to Z=65. On the other hand, MPET is being redesigned to perform mass measurements of ions at charge states well beyond +20. It will be integrated into a new cryogenic vacuum system to prevent electron recombination due to ion's interaction with background gas.

We will present our most recent mass spectrometry results employing highly charged ions, as well as details of TITAN's new CryoMPET and EBIT high voltage upgrades, their design concepts, status and future plans.

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Development of Direct Temperature Measurements of ISAC and ARIEL Targets at TRIUMF

Presenter: Aurelia Laxdal (TRIUMF)

To improve the thermal model of high power Isotope Separation On-Line (ISOL) targets at TRIUMF, an optical technique is being developed which allows for direct off-line and on-line temperature measurements of targets for radioactive isotope production. In this set-up the light coming from a hot target through the ionizer opening is collected via a set of optics in a spectrometer. Thus, from the emission spectrum and Stefan-Boltzmann distribution the target temperature is deduced. In off-line tests, tantalum targets were heated up to vacuum pressure limited temperature (2700K) - corresponding to minimum black body radiation peaks at wavelengths down to 1.07 μm. These preliminary temperature measurements confirm the correlation between the spectrum of the radiation emitted from the target and the currents used to resistively heat the targets. The final goal is to apply this technique to on-line targets and correlate the isotope releases with the target temperatures - for a better understanding of the diffusion and effusion processes happening in the target and for optimizing the delivery of short-lived species

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New gamma-ray detector CATANA for in-beam gamma-ray spectroscopy with fast RI beams

Presenter: Yasuhiro Togano (Rikkyo University)

The γ-ray detector CATANA (Caesium iodide Array for γ-ray Transitions in Atomic Nuclei at high isospin Asymmetry) is designed to detect inflight γ-rays from fast RI beams of RIBF at RIKEN Nishina Center. CATANA consists of 200 square frustum-shaped CsI(Na) crystals coupled with the photomultiplier tubes. Total active weight of the scintillator material is 270 kg. The scintillator positions are arranged to minimize the distance between the scintillators so as to have better calorimetric property.

The 50% of total detectors has been constructed and commissioned in 2016. We have performed several experiments by combining CATANA and the SAMURAI spectrometer [1]. The talk will give an overview of CATANA and results from experiments.

[1] T. Kobayashi et al., Nucl. Instr. Meth. B 317, 294 (2013).

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Development of a prototype ion source for RIB production in reactor

Baoqun Cui (China Institute of Atomic Energy)

A prototype ion source for RIB production in reactor has been developed at China Institute of Atomic Energy(CIAE) to demonstrate the feasibility. The ion source has to be compact enough to fit into the neutron tunnel of the reactor. Also the ion source has to withstand the tens of kW heat from target fission. A electric heater is uesd to simulate the fission heat, at the same time the cathode of the ion source is heated to emit electrons which are energized between anode and cathode to ionize the fission product. The details of the ion source and its preliminary test results will be presented.

Co-authors: Lihua Chen (China Institute of Atomic Energy), Yingjun Ma (China Institute of Atomic Energy), Bing Tang (China Institute of Atomic Energy), Ruigang Ma (China Institute of Atomic Energy)

Using Genetic Algorithm for Characterization of Neutron Spectrum at KIRAMS MC-50 Cyclotron

Presenter: Sy Minh Tuan Hoang (Institute of Fundamental and Applied Sciences, Duy Tan University)

The genetic algorithm (GA) method, which is a solution method emulating natural evolution for global optimization and search problems, has been successfully applied to adjust the neutron spectrum of the MC-50 cyclotron (KIRAMS) in this study. The comparison between resulting unfolded spectra from the GA method and STAY'SL PNNL code has confirmed the correctness of the performance of the GA. In addition, applying the GA unfolded neutron spectrum has released the dependence on an initial guess spectrum and available cross-section data, which are inherent characteristics of other unfolding codes, for improving the exactness and accuracy of the unfolded spectrum. Especially, the GA is able to unfold the emerging neutron spectrum from an accelerator-based neutron source that is an outstanding problem with other unfolding codes due to missing the cross-section data and the existence of large uncertainties above 20 MeV. The resulting unfolded spectrum from the GA can be used as a reference neutron spectrum in experiments at the MC-50 cyclotron.

Co-authors: Gwang Min Sun (Korea Atomic Energy Research Institute), Hoai-Nam Tran (Institute of Fundamental and Applied Sciences, Duy Tan University)

Recent developments of ISOLTRAP's MR-ToF MS

Presenter: Timo Pascal Steinsberger (Max-Planck-Gesellschaft (DE))

The Multi Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS) of ISOLTRAP has been used successfully for several years for precision mass measurements and ion purification. Nevertheless, further improvements are still possible concerning, e.g. the ion optics, beam preparation and stability of the system. All these issues were addressed in a series of systematic studies reported here. High-precision mass measurements require a pulsed ion beam with a narrow spread in time and energy. Therefore, the ions are cooled and bunched in a gas-filled radiofrequency linear quadrupole trap. The effect of the buncher radiofrequency field on the beam quality and time-of-flight was studied with simulations and experimentally using an off-line alkali source. The energy width of the ion bunch was studied in different experimental conditions. This led to a reduction of the systematic mass dependent shifts and to more symmetric peak shapes. The stability of the MR-ToF MS was addressed in order to determine and reduce the impact of voltage fluctuations and to compensate for voltage drifts during data analysis. This allowed to improve and estimate the accuracy of MR-ToF MS measurements using off-line references. In addition, a new einzel lens was simulated, designed and implemented in order to improve the injection efficiency into the MR-ToF MS..

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Database of radioactive isotopes produced at the BigRIPS separator

Presenter: Yohei Shimizu (RIKEN)

A new-generation radioactive isotope (RI) beam facility called the RI Beam Factory (RIBF) has been operating at the RIKEN Nishina Center since 2007. A wide variety of RI beams have been produced using the BigRIPS in-flight separator to perform various studies of exotic nuclei far from stability. Not only the projectile fragmentation of heavy-ion beams, such as 14N, 18O, 48Ca, 70Zn 78Kr, and 124Xe beams, but also the in-flight fission of a 238U beam has been employed for the production of RI beams.

A total of 159 experiments using RI beams at the BigRIPS separator have been performed so far. The number of RI beams produced amounted to approximately 1600, and the number of new isotopes reached 132. Production cross sections for more than 1000 isotopes were obtained. In order to gather and manage of a lot of experimental data we have been developing a database of RI beams produced at the BigRIPS separator. The RI database includes the production cross sections and yields together with detailed experimental conditions. The information of isomeric nucleus, such as gamma ray energy half life and sample of gamma ray energy spectrum is also included. The RI database is synchronized with a web site.

The RI database system is powerful tool to make the RI beam setting quickly and exactly. During the BigRIPS tuning, we can obtain the production cross sections and gamma ray energy quickly and easily. In comparison with these values, we can confirm whether present measurement is carried out with success. The RI database system helps us to confirm the validity of the setting and to shorten the tuning time. Furthermore, this system assists on RIBF user to design RI beam experiments using the BigRIPS separator

Co-authors: Naoki Fukuda (RIKEN), Hiroyuki TAKEDA (RIKEN Nishina Center), Ahn Deuk Soon (RIKEN), Hiroshi Suzuki (RIKEN), Naohito Inabe (RIKEN), Kensuke Kusaka (RIKEN Nishina Center), Masao Ohtake (RIKEN Nishina Center), Yoshiyuki Yanagisawa (RIKEN Nishina Center)
Koichi Yoshida (RIKEN Nishina Center)

Study on laser resonance photoionization of Molybdenum atoms

Presenter: Alberto Monetti (INFN, LNL)

In the framework of the research and development activities of the SPES project,and regarding the optimization of the radioactive beam production the Hollow Cathode Lamp Spectroscopic technique, is nowadays a solid based application to study resonant laser ionization.

By means of this instrument, it is possible to test resonant laser ionization processes of stable species, and in this work, the study is applied to Molybdenum atoms.

The three-step, two color ionization schemes have been tested. The “slow” and the “fast” optogalvanic signals were detected and averaged by an oscilloscope as a proof of the laser ionization inside the lamp.

As results, several wavelength scans across the resonances of ionization schemes were collected with the “fast” optogalvanic signal. Some comparisons were made of ionization efficiency for different ionization schemes. Furthermore, saturation curves of the first excitation levels have been obtained.

Molybdenum, in its isotope 99 it is used to produce 99Tc, which is the paramount radionuclide for diagnostic and cure in modern nuclear medicine; thus the interest of the study even if not a real SPES element.

In this framework, MOLAS project (Molybdenum production with Laser technique at SPES) has recently been introduced and this study will be the first milestone for the project.

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alberto andrighetto (INFN-LNL)

The development of a FEBIAD ion source for BRISOL

Presenter: Bing Tang (China Institute of Atomic Energy)

The Beijing Radioactive ion beam facility Isotope Separator On-Line（BRISOL, is a radioactive ion beam facility based on a 100MeV cyclotron providing a 100μA proton beam bombarding the thick target to produce radioactive nuclei, which produces singly charged ions using an ion source. A new FEBIAD ion source has been developed to fulfil the requirements of the BRISOL for producing radioactive ion beam. A series of structural optimization have been adopted to make the maintenance of the ion source model easier. The results from this ion source will be presented in this paper.

Co-authors: Baoqun Cui (China Institute of Atomic Energy), Lihua Chen (China Institute of Atomic Energy), Yingjun Ma (China Institute of Atomic Energy), Xie MA, Ruigang Ma (China Institute of Atomic Energy)

Media Board – Low-cost interface for remote handling of beam instrumentation devices at the Super-FRS

Presenter: Haik Simon (GSI)

At the Super-FRS, the new in-flight separator under construction at FAIR [1] many beam instrumentation devices like detector drives, degrader and slit systems, etc. have to be implemented. These devices are installed as insertions in the diagnostic vacuum chambers at the various focal planes of Super-FRS. The insertions have to be remote handled due to the highly activated environment by means of a fully autonomous industrial robot system.

In order to connect and disconnect automatically utilities like electrical power, cooling water, compressed air, electrical signals, etc. a low-cost mechanical interface called media board was developed at GSI. In this contribution we will present this development.

[1] https://www.gsi.de/en/research/fair.htm

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The NSCL Cyclotron Gas Stopper - preparing to go “on- line”

Presenter: Stefan Schwarz (NSCL/MSU)

Rare isotopes are produced at the NSCL by projectile fragmentation at energies of ~100 MeV/u. The NSCL has successfully used linear gas stopping cells for more than a decade to thermalize projectile fragments and extract them at 10's of keV energies; first for experiments at low energy and later for reacceleration to Coulomb barrier energies. In order to stop and rapidly extract light and medium-mass ions, which are difficult to efficiently thermalize in linear gas cells, a gas-filled, reverse cyclotron has been constructed [1]. The device uses a ≤2.6T field superconducting cyclotron-type magnet and helium gas in a LN-cooled stopping chamber to confine and slow down the injected beam. The thermalized beam is transported to the center of the magnet by a traveling-wave RF-carpet system [2], extracted through the central bore with an ion conveyor [3] and accelerated to <60 keV energy for delivery to the users.

For magnet commissioning and low-energy ion tests, the cyclotron gas stopper has been constructed in a location not connected to NSCL high-energy beamlines. The magnet has been energized to its nominal strength and the measured field is in excellent agreement with predictions. The RF ion-guiding components have been installed inside the magnet. Efficient ion transport has been demonstrated with ions from a movable alkali source with the magnet off. The tests are currently being repeated with the magnet energized and preparations are underway to cool the gas to LN temperature.

With offline tests coming to an end, an experimental vault is being prepared to allow connecting the cyclotron gas stopper to the NSCL beamline. The design for a dedicated momentum-compression beam line, similar to the ones feeding the linear gas cells, is essentially complete and the components are under construction. A summary of the offline tests, the layout of the cyc-stopper's new online location, the ion-optical design of the beamline and plans for the move of the device will be presented.

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Antonio Villari (Michigan State University)

The thermal finite element analysis of the high-power rotating target for BigRIPS separator

Presenter: Zeren Korkulu (RIKEN Nishina Center)

The RIKEN RI Beam Factory (RIBF) cyclotrons can accelerate very heavy ions up to 345 MeV/nucleon, such as uranium. The goal beam intensity is as high as 1 pμA (6.2 × 1012 particles/s), which corresponds to a beam power of 82 kW in the case of 238U. An important aspect in increasing beam intensity is to limit the maximal temperature due to the beam energy loss in the material. The control of this absorbed power is proving to be one of the key challenges. Therefore, the water-cooled rotational disk targets and ladder-shaped fixed targets were designed and constructed for the BigRIPS separator [1,2,3]. For low power deposition and low power density, the fixed ladder-shaped target is sufficient to dissipate the heat. For high power density, the rotating disk target is used for all primary beams up to uranium.

Although the present primary beam intensity is lower than the goal value, the beam spot temperature at various conditions was measured and compared with thermal simulations to examine the beam power tolerance and evaluate the cooling capacity of the high-power rotating disk target. The finite element thermal analysis code, ANSYS was used to model thermal distributions in targets. The calculations of the beam spot temperature on the rotating disk target were done for the different primary beams. The design of the high-power rotating disk target and the detail of ANSYS simulation will be reported as well as the calculated beam spot temperature will be presented.

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Position sensitive resonant Schottky cavities

Presenter: Ivan Kulikov (GSI)

Resonant Schottky pick-up cavities are sensitive beam monitors. They are indispensable for the beam diagnostics in storage rings. Apart from their applications in the measurements of beam parameters, they can be used in non-destructive in-ring decay studies of radioactive ion beams [1]. In addition, position sensitive Schottky pick-up cavities enhance precision in the isochronous mass measurement technique. The goal of this work is to construct and test such a position sensitive cavity (Schottky detector) based on previous theoretical calculations and simulations. These cavities will allow measurement of a particle‘s horizontal position using the monopole mode in a non-circular(elliptic) geometry [2]. This information can be further analyzed to increase the performance in isochronous mass spectrometry [3-4]. A brief description of the detector and its application in mass and lifetime measurements will be provided in this contribution.

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Co-authors: Dmytro Dmytriiev(GSI) (GSI), Shahab Sanjari (GSI), Yuri Litvinov (GSI, Darmstadt), Thomas Stoehlker (GSI)

Exploratory study for the production of Sc beams at the ISOL facility of MYRRHA

Presenter: Martin Ashford (SCK•CEN)

The design of high-power targets for production of Radioactive Ion Beams (RIBs) at an Isotope Separation On-Line (ISOL) facility requires a full overview of the physical processes occurring in the target: nuclear reactions, thermal effects, isotope diffusion and effusion. Such high-power targets are nowadays a requisite as they constitute one of the means to significantly increase the yields of certain RIBs to the levels required by the users. In the first phase of the MYRRHA project, the ISOL@MYRRHA facility will make use of a high-power proton beam (100-MeV & 0.5 mA) in combination with high-power targets in order to produce high intensity RIBs of various isotopes. These high power targets require specific R&D to tackle engineering challenges like heat dissipation issues while maintaining the high isotope yields that are obtained with thick targets.

For this, an algorithmic method is in development that will combine the particle transport calculations, thermo-mechanical simulations, and an isotope release model, in order to determine the optimal target design for the production of a specific isotope. In this contribution, the exploratory study for the production of Sc beams at the ISOL facility of MYRRHA will be presented. The short lived isotopes like 41Sc would be of interest for beta-decay spectroscopy while the long lived ones like 44,47Sc are useful for medical applications.

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ToF and molecular beam studies of the on-line beam with the ISOLDE RFQ beam-cooler

Presenter: Annie Ringvall Moberg (CERN)

A new high-sensitivity time-of-flight detector has been designed and installed in the Isolde beamline, permitting study of the time structure of the on-line beam for the first time. The detector uses secondary electron emission and an MCP read-out to create a robust but highly-sensitive detector with a response time of 0.5 ns.

The detector is 10 m downstream of the RFQ extraction point, allowing us to measure the mass composition of the RFQ beam. This allows us to study cooled molecular beams, which may suffer collisional decomposition during the cooling process. We present the results of the first systematic study of the effects of the RFQ on molecular beams under varying conditions.

The new detector also allows us to adapt the RFQ bunching to the particular needs of the downstream user. We present the effects of different RFQ tunes, optimised for low energy-spread or for short bunch widths.

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Measurement of spallation cross sections for the production of terbium radioisotopes for medical applications from tantalum targets

Presenter: Thomas Elias Cocolios (KU Leuven - IKS)

Terbium has 4 interesting isotopes for usage in the context of nuclear medicine: 149Tb, 152Tb, 155Tb and 161Tb, sometimes referred to as the Swiss army knife of nuclear medicine [1]. Their chemical identity means that radiopharmaceuticals for imaging and therapy respectively will have identical pharmacokinetics and pharmacodynamics, an important advantage for so-called theranostics applications.

161Tb is best produced by irradiating 160Gd with thermal neutrons to form 161Gd which quickly decays into 161Tb. For the neutron deficient isotopes mentioned above, one of the most promising production methods is high-energy proton-induced spallation of tantalum foil targets, coupled with isotope separation on-line or off-line [2]. However, the collection of isobaric contaminants is unavoidable, which includes pseudo-isobars such as monoxide ions with the same total mass [3]. For example for 155Tb, it was found that the main impurity was 139Ce in the form of 139CeO+ [4]. Often these byproducts need to be chemically removed before the terbium isotopes can be used. It is therefore beneficial to optimize the production protocol such that these isobaric contaminants are minimized. One way is to select the most appropriate proton energy for the isotopes of interest, while minimizing molecular sidebands. Indeed a lower proton energy reduces the number of nucleons evaporated in the spallation process and limits production of Ce isotopes with respect to Tb isotopes. Unfortunately the cumulative spallation cross sections for some of the isotopes of interest are not well known or conflicting data exist in literature, e.g. for 149Tb [5,6] and 152Tb [6,7].

Here we present new measurements of cumulative cross sections for production of 149Tb, 152Tb, 155Tb and other nuclides from A=100 to 180 by proton-induced spallation of tantalum foil targets at different proton energies between 300 and 1700 MeV, using the COSY synchrotron at FZ Jülich.

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Ulli Koester (Institut Laue-Langevin (FR))

A NEW OFF-LINE ION SOURCE FACILITY AT IGISOL

Presenter: Markus Vilen (University of Jyväskylä)

A new beamline for off-line ion sources has been commissioned at the IGISOL [1] (Ion Guide Isotope Separator On-Line) facility at the University of Jyväskylä, Finland. It allows parallel operation of off-line ion sources and production of radioactive ion beams while offering a flexible platform for producing a variety of stable ion beams. Parallel operation opens up a range of new possibilities for measurements at IGISOL. The new system has been used to provide doubly charged 89Y2+ ions for laser spectroscopy measurements during on-line operations [2] and singly charged 133Cs+ ions for off-line testing of a magneto-optical trap under development at IGISOL [3]. Ions for these measurements were produced using a glow discharge ion source and a surface ion source, respectively. The system will also be used to provide reference ions for on-line Penning trap mass measurements with JYFLTRAP [4] in the near future.

While the off-line ion source station is operational and has been used in several measurements, technical development of the system is still ongoing with the aim of increasing ion yields and the number of ion species available for experiments. The development effort has been mainly focused on the glow discharge ion source with the construction of a buffer gas purification system and presently ongoing design work of a new vacuum system.

In this contribution, the layout and technical details of the offline ion source facility at IGISOL will be given together with examples of its applications and future prospects.

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Electron beam ion source for the re-acceleration of rare isotope ion beams at TRIUMF

Presenter: Leigh Graham (TRIUMF)

TRIUMF is enhancing its rare isotope production capabilities by creating a new scientific infrastructure known as the Advanced Rare IsotopE Laboratory (ARIEL). A critical part of this expansion is the CANadian Rare-isotope facility with Electron-Beam ion source (CANREB) project which combines a high-resolution separator, a gas-filled radiofrequency quadrupole (RFQ) cooler and buncher, a pulsed drift tube (PDT), an electron beam ion source (EBIS) charge-breeder, and a Nier-type magnetic spectrometer to deliver pure rare isotope beam for post-acceleration.

The CANREB-EBIS was developed at the Max Planck-Institut fur Kernphysik (MPIK) in Heidelberg and uses electron beam driven ionisation to produce highly charged ions (HCI) in a few, well-defined charge states. Singly charged ions from the RFQ are injected into a longitudinal electrostatic trap and are then tightly, radially confined by the spacecharge potential of a maximally focussed electron beam current. To date, the maximum electron beam current achieved is 1 A with a density in excess of 5000 Acm−2 by means of a 6 T axial magnetic field. It is expected that during operation HCI bunches of up to 107 ions are extracted at a repetition rate of 100 Hz with an A/Q in the range 4-7 which is required for re-acceleration at the ARIEL or ISAC facility. We present here the CANREB-EBIS design and results from the commissioning runs at MPIK and TRIUMF, including X-ray diagnostics of the electron beam and charge-breeding process, as well as ion injection and HCI-extraction measurements.

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First success of RI-beam separation and particle identification for nuclei with atomic number Z>82 at RIKEN RI beamfactory

Presenter: Toshiyuki Sumikama (RIKEN)

A wide variety of RI beams can be produced from the ^{238}U primary beam with 345 MeV/u at RIBF. The RI beam production of heavy isotope, especially Z > 82, becomes complicate and difficult, because the charge state can change in any beam-line materials at this energy. The RI beam separation in the fragment separator is affected not only by Z and A, but also by the charge state in the separator. The purification of the RI beam becomes worse because a different RI beam is selected for a different charge state, i.e. fully stripped or hydrogen-like ion etc.

We considered the RI beam separation in case many charge state combinations are possible. It was found that the RI beam can be well purified against main contaminants of the fission fragments and the primary beam when the proper charge state combination is selected.

The RI beams around ^{208}Rn were produced from the ^{238}U primary beam to verify our consideration. The main contaminants were surprisingly well eliminated. The particle identification was also succeeded by the measured information without a total kinetic-energy detector, thus the RI beam is ready for the use of secondary reaction studies. In this conference, the considered principle of RI beam separation and the experimental details will be presented.

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Control systems for the CRIS experiment

Presenter: Ruben Pieter De Groote (University of Jyvaskyla (FI))

The collinear resonance ionization spectroscopy (CRIS) experiment at ISOLDE has grown over the years to include a multitude of devices and hardware. Control of these devices, and logging of the data that they produce, requires software that communicates across several computers, in different locations (beam line, laser laboratory, data center). In this poster, a schematic overview of the CRISTAL (CRIS Tuning, Acquisition and Logging) software will be presented.

The CRISTAL software is responsible for tuning and recording of the laser wavelengths, recording of transmission fringes produced by Fabry-Perot interferometers, control of high voltages for ion optics, logging of information regarding the proton-synchrotron booster, readout of Faraday cups and other charged-particle detectors, etc. Since these various activities are performed by different computers, the CRISTAL software is built upon a network communication protocol that ensures time synchronization and centralized data storage. Furthermore it features rich graphical user interfaces that allow for e.g. on-the-fly configuration and control.

New hardware is added easily with small plugin scripts, which means the CRIS experiment can be continuously upgraded. For example, a recent addition to CRIS was a new time discrimination card with a 500 ps resolution. Using this card, the precise arrival time of laser-ionized ions can be recorded. This has added a new dimension to datasets produced by CRIS. By exploiting this new information dramatic improvements in resolution, when using the (also new) laser ablation source were obtained. Examples of these time-of-flight lineshape reconstructions will be presented.

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Poster Session 1 / 124

Characterization of the AstroBox2 detector in online conditions

Presenter: Antti Saastamoinen (Cyclotron Insitute, Texas A&M University)

The AstroBox2 detector [1] is a gas-filled calorimetric detector for almost background free low-energy beta-delayed particle spectroscopy. It is an upgraded version of the original AstroBox proof-of-concept detector [2] based on Micro Pattern Gas Amplifier Detector (MPGAD) technology. After the initial commissioning described in [1] some extensive upgrades have been made in conjunction with the first physics experiments. A new gating grid covering the whole detector has been built and instrumented with a dedicated fast HV switch. The setup has been instrumented further with two different high-purity Ge detector setups for particle-delayed gamma detection. So far beta-decays of 20Na, 23Al, 25Si, 31Cl, 32Cl, and 35K have been studied with the setup. The diverse chemical nature of the studied isotopes, beam rates, and the laboratory environment stability has been observed to have influence on the measured decay spectra. The physics results will be discussed elsewhere and here we present some of the results that can have an influence on other similar experiments with stopped rare isotope beams and detectors relying on gas amplification.

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Control Systems for improved Laser Ion Sources

Presenter: Kristof Dockx (KU Leuven)

Over the past decades, laser ion sources have proven to be a selective and efficient ion source for high purity radioactive isotope and isomer beam research. Advanced control systems are a necessary tool for high resolution measurements and easy control of the laser ion source. In this framework, a new control and data acquisition system has been developed at KU Leuven. Furthermore, accurate control of the frequency selective elements in the laser are a requirement for a reproducible and reliable laser ion source.

The Heavy Elements Laser Ionization and Spectroscopy (HELIOS) project at KU Leuven has the goal of performing In-Gas Laser Ionization and Spectroscopy (IGLIS) measurements on the actinide and superheavy (transfermium) elements and around the 100Sn region. These studies will allow to deduce atomic properties and nuclear properties with high precision owing to an improved spectral resolution down to 150 MHz (FWHM) for these elements. In these spectroscopic measurements, step-wise laser ionization of the involved isotopes takes place in the supersonic jet formed by a de Laval nozzle installed at the gas cell exit.1,2,3 These include isomeric beams making use of the laser ionization mechanism.

A complete characterization of the in-gas-jet method can only be achieved when factors such as frequency and power instabilities of the lasers as well as the spectral linewidths are minimized and the timing for data acquisition of multiple systematic measurements can be synchronized. Therefore, a dedicated control system, IGLIS Control System, has been developed at KU Leuven. The program enables the stabilization of the laser wavelength, reducing the laser frequency fluctuations from 50 MHz down to 7 MHz, only limited by the precision of the employed wavelength meter. This reduction in frequency fluctuations is necessary to accurately perform spectroscopy on resonance peaks with a Full Width at Half Maximum (FWHM) in the order of tens of MHz. Furthermore, the control program synchronizes the full command to several types of data acquisitions e.g. Time-of-Flight measurements for isotope separation in an Atomic Beam Unit (ABU), image acquisitions for Planar Laser Induced Fluorescence (PLIF) spectroscopy of the seeded atoms in the supersonic jet and beam line diagnostics. This synchronization makes it possible to increase the signal-to-noise ratio and to study systematic effects by comparing the results of PLIF spectroscopy with those obtained in the ABU. Recently, the IGLIS Control Software allowed us to perform a first preliminary In-Gas Jet Laser Ionization Spectroscopic measurements on 63,65Cu.

In the Laser Ion Source, the stability of the frequency selective elements, e.g. ethalons, in the laser will strongly influence their reliability. Therefore, a full characterization of different types of motorized mounts for these frequency selective elements is performed at RILIS $^{4}, CERN, comparing a stepper motor, Galvanometer motor, an indirect piezo controlled mount and a closed-loop direct drive piezo mount. The presence of hysteresis in the movement of such mounts can result in non-reproducibility of the laser ion source. Therefore, it has been found that the closed-loop direct drive piezo mount ensures the most reliable and reproducible control of the frequency selective elements, contributing to a more stable and reliable laser ion source.In this presentation we discuss the improvements in reliability and accuracy that were achieved with the IGLIS Control software for the In-Gas Jet Laser Ion Source. Furthermore, the characterization of the improved mounts for the frequency selective elements in lasers is discussed.

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Narrow band pulsed dye amplification system for nuclear structure studies.

Presenter: Camilo Andres Granados Buitrago (KU Leuven (BE))

Laser spectroscopy is a powerful and versatile technique for the study of nuclear ground-state properties [1]. The precision with which these nuclear properties can be extracted from the isotopic shifts and hyperfine structure of optical transitions is defined by the observable spectral line width. The latter depends on different line broadening mechanisms existing due to the conditions of the experiment, as well as the laser line width. Lasers with extremely narrow width of emission light are often required for spectroscopic techniques used to study exotic nuclei [2] Pulsed Ti:Sapphire (Ti:Sa) lasers with ring-cavity design [3] and seeded by a continuous-wave (cw) single-mode laser are able to fulfill those requirements. However, the tunable range of the Ti:Sa lasing medium is limited to ~ 700-950 nm which can be extended to blue and UV wavelengths using common higher-harmonic generation techniques. Complementing this are dye lasers whose emission spectra, when pumped with 532-nm laser light, can cover the range of 540-900 nm and can also be extended to UV ranges in a similar fashion to Ti:Sa lasers but with higher power. Pulsed amplification of a cw single frequency dye laser in a dye cell pumped by a copper vapor laser has been demonstrated and successfully applied for resonance photoionization spectroscopy of radioisotopes in [4]. In this approach, the pulse length of pumping laser determines the spectral width of the amplified radiation according to the Heisenberg uncertainty principle. Preliminary studies performed with Nd:YAG laser pumping suggest that narrowband pulsed-dye amplification suffers from the existence of sidebands in the amplified light due to the amplitude modulation nature of the multimode pumping light. The characteristics of the system in terms of design, power and spectral width as well as the application to the in-gas-jet laser ionization and spectroscopy technique [5] will be discussed. Future applications for two-photon spectroscopy and electronic-affinity measurements will be presented.

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TOF/FFT Hybrid Mass Analysers

Presenter: Vyacheslav Shchepunov (Shimadzu Research Laboratory (Europe) Ltd)

As it is well known isochronous periodic structures (electric or magnetic) are used for mass measurements either as Time of Flight (TOF) mass analysers (MA) or Fast Fourier Transform (FFT) mass analysers with image charge detection. In this study we demonstrate that both the operational modes can be implemented in a single and compact hybrid mass analyser. Such an instrument can be run in one of the two complimentary modes - multi-pass TOF with lower m/dm, but faster mass analysis, or FFT mode with higher m/dm and slower analysis. Two examples are presented: (i) a multi-reflection coaxial mirror analyser, and (ii) a rotationally symmetric multi-turn sector field analyser.

Analysers of the 1st type are widely used in nuclear physic experiments as MR-TOF instruments [1-5]. Many authors have also used similar systems as electrostatic ion traps with image charge detection and FFT analysis [6-9]. In this work we describe a 400 mm long MR-TOF, which can work in two complimentary modes - as a MR-TOF instrument with m/dm~100 k (fwhm), or an electrostatic ion trap with m/dm>600 k (fwhm).

Analysers of the 2nd type [10] comprise a pair of polar-toroidal sectors S1 and S3, a toroidal sector S2 located at the mid-plane of the system, lens electrodes for longitudinal and lateral focusing, each set of the electrodes being mirror symmetric with respect to the mid-plane. In the multi-turn TOF operational mode drift focusing segments are additionally used to provide focusing in the drift direction. It was demonstrated earlier that in the multi-turn TOF mode the analyser achieves at least ~200 k (fwhm) of m/dm [11]. In this work we present three similar analysers - with 500 mm, 250 mm and 120 mm diameter of the external electrode. The largest of the three is the most appropriate for the use in the multi-turn TOF mode. Its simulated m/dm for 5 keV 400 Th ions is~400 k (fwhm) at typical flight times of about 2.2 ms. The large size, however, makes it rather slow for running in the FFT mode. On the contrary, the smallest analyser is the fastest of the three and the most appropriate for the use in the FFT only mode. The 5th harmonic of the FFT signal provides m/dm of~ 800 k (fwhm) after ~1 sec of measurement time. In the multi-turn TOF mode its estimated m/dm is only ~15-20 k. The intermediate size (hybrid) analyser demonstrates m/dm~100k (fwhm) in the multi-turn TOF mode and m/dm of~800 k (fwhm) after~2.1 s measurement time. It can be used in one of the two complimentary modes - multi-turn TOF or FFT.

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First tests of a stabilised cw Ti:sapphire laser and new charge-exchange cell for collinear laser spectroscopy at IGISOL

Presenter: Sarina Geldhof (University of Jyvaskyla (FI))

Collinear laser spectroscopy is a powerful tool for the study of fundamental properties of exotic nuclei via the measurement of the hyperfine structure and isotope shift of electronic transitions. This technique has been in use at the IGISOL facility, University of Jyväskylä, for over 20 years [1]. During this time, spectroscopic studies where primarily focused on singly-charged ions and laser radiation was generated using a continuous wave (cw) dye laser. To expand the region of elements that can be accessed, a new charge-exchange cell and cw Ti:sapphire Matisse laser have recently been taken into use. This will allow access to atomic transitions, and wavelengths not easily accessible to the cw dye laser.

To find the best way for long-term frequency stabilisation of the cw Matisse laser, a saturated absorption spectroscopy setup using Rb or Cs as a reference frequency standard, a scanning Fabry-Perot interferometer (FPI) and a new WSU10 wavemeter (precision of 10 MHz) have been used. The setup was originally built to precisely determine the Free Spectral Range (FSR) of several FPIs [2]. This was motivated by the need to address systematic uncertainties in wavelength determination, initially identified in earlier resonance ionization spectroscopy studies of stable copper isotopes [3]. Stabilisation of the cw laser to a Rb hyperfine component and, separately, to the wavemeter have been done and will be presented in this contribution. The results from saturated absorption spectroscopy on Rb and Cs will also be compared to the first collinear laser spectroscopy tests using the charge-exchange cell on these alkali elements.

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New Central module for the Modular Total Absorption Spectrometer

Presenter: Marek Karny (University of Warsaw)

The Modular Total Absorption Spectrometer (MTAS) has been used in Oak Ridge since 2012. It consists of 18 NaI(Tl) hexagonal modules. Each of the 18 modules is 21" long and 6.93" wide (side-to-side). There is also one central module of the same length and cross section, but with a 2.5" hole drilled through. The crystals are arranged in a honeycomb like structure. Radioactive samples, to be measured, are placed between two 1mm thick silicon detectors in the geometrical center of the detector. The total active NaI(Tl) mass is approximately one ton, making MTAS the largest and most efficient detector of this type currently in use [1].

Apart from its large efficiency the main advantage of the MTAS is its modularity, which allows accounting not only the summed gamma energy signals (standard total absorption data evaluation [2,3]), but also the study the intensities of the individual gamma rays to confirm decay schema assumptions made. Most of the individual gamma ray analysis is based on the signals from all, but central detector. Unfortunately, this functionality is only efficient for higher energy gamma transitions. The low energy gamma rays are efficiently absorbed in the central detector and do not reach other modules. Due to the almost 4π geometry of the central module, energy deposited by multiple gammas in the cascade are summed up, creating TAS like spectrum.

In order to overcome this feature of MTAS a new central detector has been designed. The new module will be optically segmented into 6 independent pieces to allow for more efficient analysis of low energy gammas. This presentation will discus the simulated impact of the new module on the efficiency of the detector as well as on the data analysis. If available, real performance data from the completed new central module will also be presented.

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Application of the PyCAMFT code for the multi-component ion beam separation modeling

Presenter: Helen Barminova (NRNU MEPhI)

The ion beams extracted from modern ion sources are usually characterized by complicated charge and mass state distributions of the particles. To predict accurately the behavior of the ion bunch with complicated structure in magnetic field of the separator the PyCAMFT code is developed. The 3D-code realized with Python allows to treat various particle density and charge distributions, various geometry of the bunches, arbitrary initial bunch phase volumes, various field geometry. To provide the high accuracy and high calculation rate the parallel computing is implemented based on CUDA technology. The code peculiarities allow to apply it in the experiment automation system too. The code has different built-in tools of 2D and 3D visualization. In the report the simulation of the multi-component beam separation with the PyCAMFT is discussed, the calculated bunch parameters as well as integral radiation dose distributions are presented.

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On-line and off-line EMIS for production of medical and industrial radionuclide and radiotracer generators

Presenter: Sunniva Siem (University of Oslo)

Radionuclides are extensively used in the medical field both for diagnostic (tracer) and therapeutic purposes. The requirements concerning half-life vary from a few seconds to a few days, and the desired radiation properties range from simple low-energy gamma emitters and positron emitters for diagnostic purposes to beta, auger electron and alpha emitters for therapy.

Industrial use includes both beta and gamma emitters mainly for tracing purposes. Half-lives and radiation characteristics may be different from those of the medical nuclides: Some applications require half-lives of months to years (extended reservoir examinations) while other applications can only utilize short-lived radiotracers with half-lives of minutes to hours (industrial process monitoring). Further in industrial applications, higher-energy gamma radiation (> 1 MeV) as well as multi-gamma emission is useful, especially in process monitoring.

Some of the interesting radionuclides can be produced in reactors and small-size particle accelerators in low-energy fission, simple absorption, transfer or knock-on reactions while others will require high-energy fission, spallation and fragmentation reactions. To extend the region of use outside the immediate surrounding of such production facilities (due to half-life limitations), the application of radionuclide and radiotracer generators based on a long-lived mother and a shorter-lived daughter is now in extensive development. The short-lived radiotracer can thereby be produced on site and on demand.
Both the medical and industrial application area require high radiochemical purity. One of the best ways to avoid cumbersome work-up and purification procedures is to make use of EMIS after (or during) irradiation of a suitable target material. In the best cases, isotopically pure products may be collected for direct labelling of various defined chemical or biochemical compounds.

This presentation will describe mother-daughter nuclear relationships of interest to these two application areas. Additionally, examples are given on how these may be produced in an affordable way by selecting a proper target material and involving EMIS in the process. Furthermore, examples are sketched of some possible generator types and systems and how they may be operated.

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Low energy nuclear structure spectrometer specific to multinucleon transfer reactions at HIAF

Presenter: Wenxue Huang (Institute of Modern Physics, Chinese Academy of Sciences)

The study of the nuclear structure and exotic decay property of neutron-rich isotopes is nowadays an important subject in nuclear physics research. To date, by using nuclear fusion-evaporation reaction, projectile fragmentation, proton (neutron)-induced fission, and spontaneous fission, we can only produce neutron-rich isotopes with a small charge number Z. For significantly more neutron-rich isotopes with higher Z>70, there is no appropriate method to production except multinucleon transfer reaction, which is believed to be the most possible way to produce those neutron-rich isotopes.

At the ongoing large-scale scientific project HIAF (High Intensity heavy-ion Accelerator Facility), a low energy nuclear structure spectrometer specific to the multinucleon transfer reactions is being designed and constructed. In this spectrometer, the research will be concentrated on synthesis and the identification of new neutron-rich nuclides, and on the study of their nuclear structure and decay properties. Unlike the fusion evaporation and projectile fragmentation products which are emitted near 0∘ in the forward direction in a laboratory frame, the outgoing angles of the products from multinucleon transfer reactions cover a wide range of 25∘ - 80∘ , thus it is very difficult to collect and separate the products of interest.

In the conference, the motivation, conceptual design and working principle of this spectrometer will be introduced. Computer simulation results and mechanical considerations will also be presented.

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Prospects for the production of ^{100}Sn ISOL beams at HIE- ISOLDE

Presenter: Thierry Stora (CERN)

The region around doubly magic isotopes, such as 100Sn and 132Sn, has attracted a large interest in nuclear structure and physics studies, and for which intense and high quality beams are still required, as documented in the Long Range Plan published by NuPECC [1]. While 132Sn beams and beyond have been available at ISOL facilities for many years at low energy and as post-accelerated beams, 100Sn has shown to be much more challenging with only a few 101Sn/min being produced at GSI-ISOL [2]. Inflight beam fragmentation facilities at GANIL, GSI and RIKEN provide relativistic 100Sn beams at a rate comprised between less than one and a few ions per hour. In the future, up to a few ions/s is foreseen at FRIB [3]. ISOLDE has been limited so far to 104Sn, produced from LaCx targets and RILIS ionization, measured at a rate of 2000 ions/s in 2017.

The production of 100Sn beams by the ISOL technique has not been possible due to the lack of a suitable primary beam driver and target-ion source unit for any of the present-day facilities. We review here the techniques suitable for the production of 100Sn beams at HIE-ISOLDE and propose an option based on a high power molten lanthanum target combined with molecular tin formation and a FEBIAD ion source. The envisaged options take into consideration upgrade scenarios of the primary beam at HIE-ISOLDE, going from a 1.4 GeV - 2 µA to a 2 GeV - 6 µA pulsed proton beam [4]. Details on achievable 100Sn beam intensities and purities will be provided, based on in-target production rates simulated with ABRABLA and FLUKA, tin release characteristics and molecular tin compound formation available from past experimental investigations. Progresses in the development of a high power molten metal target for the production of ISOL beams will finally be described and complete the set of data required to trigger the development of an ISOL beam of 100Sn [5].

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The LIEBE high-power target: Offline commissioning results

Presenter : Ferran Boix Pamies (Centro de Investigaciones Energéti cas Medioambientales y Tecno)

With the aim of increasing the primary beam intensity in the next generation of Radioactive Ion Beam facilities, a major challenge is the production of targets capable of dissipating the high deposited beam power. In that context, LIEBE is a high-power target dedicated to the production of short-lived isotopes.

The design consists of a loop of molten lead-bismuth eutectic, in which the deposited primary beam power is dissipated by a water-cooled heat exchanger. The circulation of the liquid metal is achieved by an electromagnetic pump coupled to the loop. Additionally, the target includes a diffusion chamber next to the irradiation chamber to promote the creation of droplets through a grid. The extraction of short-lived isotopes is then enhanced by the shorter diffusion paths of the droplets compared to the ones of a liquid bath.

The LIEBE prototype is now fully assembled and before operating the target online at ISOLDE, the safety and operation conditions have to be reviewed. An offline commissioning phase has started, in which several non-conformities could be identified and solved. The flow established by the electromagnetic pump has been evaluated in a LIEBE replica, the stability of the target/pump coupling has been assessed through alignment and vibration measurements and the thermal control system has been tested. The final test will foresee the full operation of the prototype on the offline isotope separator.

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Target materials for the ARIEL era at TRIUMF

Presenter: Marla Cervantes (UVIC/TRIUMF)

The Advanced Rare IsotopE Laboratory (ARIEL) is under construction at TRIUMF. ARIEL will include two ISOL target stations, one will accept a 100 kW electron driver beam the other a 50 kW proton beam. These target stations are in addition to the two that are currently operated at TRIUMF's ISAC facility. Once ARIEL is fully operational an estimated 9000 Radioactive Ion Beam hours will be available to experimental users at TRIUMF each year.

To meet the demands of the ARIEL era, a fourfold increase in target material production is required. Additionally, a target material development program is needed to optimize the target materials for photofission at the target station for the electron driver beam.

Tests have been performed using a modified methodology to accelerate the current uranium carbide target material production. The resultant target material has been characterized by XRD and SEM. From these analyses, we have found that the composition and morphology of the target material obtained with the new methodology are in agreement with those of the targets used on-line. Additional tests are ongoing, with a planned on-line test at the end of this year. The latest results from these developments will be presented.

Micro-structured uranium carbide pellets are planned to be developed for the photofission target material. Lanthanum carbide pellets were produced to investigate production methods, the next step is to perform tests with uranium carbide to characterize the resultant material. The development plan will be outlined together with the results from the pellet tests with lanthanum carbide.

FRS Ion Catcher: Results and Perspectives

Presenter: Emma Haettner (GSI Darmstadt)

The FRS Ion Catcher experiment at GSI enables precision experiments with projectile and fission fragments. The fragments are produced at relativistic energies in the target at the entrance of the fragment separator FRS, spatially separated and energy-bunched in the FRS, slowed-down and thermalized in a cryogenic stopping cell (CSC). A versatile RFQ beamline and diagnostics unit and a high-performance multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) enable a variety of experiments, including high-precision mass measurements, isomer measurements and mass-selected decay spectroscopy. At the same time the FRS Ion Catcher serves as test facility for the Low-Energy Branch of the Super-FRS at FAIR.

In five experiments with 238U and 124Xe projectile and fission fragments produced at energies in the range from 300 to 1000 MeV/u the performance of the CSC has been characterized. The stopping and extraction efficiencies, the extraction times and the rate capability have been determined, and the charge states and the purity of the extracted ions have been investigated. Based on these studies, a novel concept for the CSC for the LEB has been developed. High-accuracy mass measurements of more than 40 projectile and fission fragments have been performed at mass resolving powers up to 450,000 with production cross-sections down to the microbarn-level and at rates down to a few ions per hour. A novel data analysis method for MR-TOF-MS measurements on rare nuclides has been developed, achieving mass accuracies as good as 6· 10−8. Access to millisecond nuclides has been demonstrated by the first direct mass measurement and mass-selected half-life measurement of 215Po (half-life: 1.78 ms). The versatility of the MR-TOF-MS for isomer research has been demonstrated by the measurements of 15 isomers, determination of excitation energies and the production of an isomeric beam. The isotope-dependence of proton-rich indium isomers has been measured. The determination of isomeric ratios gives access to the study of the mechanisms of projectile fragmentation and fission.

An overview of the latest results and proposed experiments to be carried out with the FRS Ion Catcher during the upcoming beam time period 2018 - 2019 covering mass measurements, beta-delayed neutron emission probabilities and reaction studies with multi-nucleon transfer will be presented.

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Poster Session 1 / 183

Development of an Ba^{++} ion source for the Barium Tagging Program of the NEXT experiment

Presenter: Juan Jose Gomez Cadenas (DIPC)

Double beta decays in Xe-136 result in the production of a Barium ion. In gas phase it is expected that a Ba^{++} ions is produced. Tagging Ba^{++} becomes thus, an unmistakable signature of the decay and can lead to a background-free neutrinoless double beta decay experiment. In this poster a Ba^{++} ion source based on a fs laser is presented. Such a source can be used as a part of the Barium Tagging program of the NEXT experiment.

Co-authors: Francesc Monrabal (U. Texas at Arlington), Alvaro Peralta, Marina Sanchez (CLPU)

Poster Session II

Poster Session 2 / 4

Benchtop Isolation of Radioactive and Stable Isotopes by ICP-MS

Presenter: Michael P. Dion (Pacific Northwest National Laboratory)

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) has become a routine instrument for elemental/isotopic analysis. PNNL has made simple modifications to such instruments to collect single or multiple isotopes. Commercial instruments are now widely available and the latest benchtop systems offer high level isotope isolation performance >99.999%. While mass selected ion currents are still relatively low ~10-100 nA, the approach is perfect for preparing ultra-pure isotopes on the ng-µg scale and may be easily adapted to collect single or multiple isotopes. The atmospheric pressure RF Ar Plasma readily accommodates source materials in any form (gas, liquid or solid) and will ionize most elements quite efficiently with little or no changes to the ICP ion source. We will present experimental results illustrating the application of ICP-MS isotope purification utilizing quadrupole and magnetic sector based systems. This will include examples of the excellent isotopic purity that can be obtained for stable and radioactive isotopes. Additionally, benefits to α, γ and β spectrometry will be presented where very low ion energy deposition, and isotopic purity improve the subsequent radiometric measurements.

Co-authors: Martin Liezers (Pacific Northwest National Laboratory), May-Lin Thomas (Pacific Northwest National Laboratory), Gregory C. Eiden (Pacific Northwest National Laboratory)

Ongoing progress of the MARA low-energy branch

Presenter: Iain Moore (University of Jyväskylä)

The MARA low-energy branch (MARA-LEB) [1,2] is a novel facility currently under development at the University of Jyväskylä. Its main focus will be the study of ground-state properties of exotic proton-rich nuclei employing in-gas-cell and in-gas-jet resonance ionisation spectroscopy, and mass measurements of nuclei at the N=Z line of particular interest to the astrophysical rp process.

MARA-LEB will combine the MARA vacuum-mode mass separator [3] with a gas cell, an ion guide system and a dipole mass separator for stopping, thermalising and transporting reaction products to the experimental stations. The gas cell is based on a concept developed at KU Leuven [4] and designed for the REGLIS facility, GANIL. It will be able to use both Ar and He buffer gases to allow for more efficient neutralisation or faster extraction times respectively.

Laser ionisation will be possible either in the gas cell or in the gas jet using a dedicated Ti:Sapphire laser system. Following extraction from the cell the ions will be transferred by radiofrequency ion guides and accelerated towards a magnetic dipole for further mass separation before transportation to the experimental setups. The mass selectivity of MARA, combined with the elemental selectivity achieved through laser ionisation, will open the way to the study of nuclei with production cross-sections several orders of magnitude smaller than isobars produced in the same nuclear reaction. For example, isotopes at or close to the N=Z line, e.g. light Ag and Sn isotopes, will be of key interest.

A radiofrequency quadrupole cooler and buncher and an MR-TOF-MS [5] will be combined with the facility. These devices, which will be developed in Jyväskylä, will allow for mass measurements of several isotopes close to the N=Z line, and will provide significant information on the rp process and will be used as test grounds for nuclear models.

In this presentation, we will give an update of the current status of the MARA-LEB facility.

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Poster Session 2 / 11

Using radioactive beams to unravel local phenomena in ferroic and multi ferroic materials

Presenter: Juliana Schell (Institut Für Materialwissenschaft Universität Duisburg-Essen (D)

The increasing interest of using ferroic and multiferroic materials in high-tech applications requires that the underlying physical phenomena are studied on an atomic scale. Time-differential perturbed correlation (TDPAC) measurements have a local character and can provide important information concerning combined magnetic dipole and electric quadrupole interactions in ferroic and multiferroic systems. With the application of characterization techniques and radioactive beams, this method has become very powerful, especially for the determination of the temperature dependence of the hyperfine parameters even at elevated-temperatures. Such measurements lead to a better understanding of phase transitions, including observations of local environments in low fractions of different phases. Several facilities are used at ISOLDE-CERN benefiting from the multitude of available beams adequate to the use and development of the TDPAC technique. Moreover, the concentration of required TDPAC probes is so small that the probes negligibly affect the observed transition temperatures. The polarization of the TDPAC probe nucleus during the measurements of ferroics systems is due to the transferred spin density. This phenomenon gives rise to the so called "super transference" of the magnetic hyperfine field in perovskites. An overview of prior literature intercalated with a discussion of measurement conditions and isotopes is presented. Particular emphasis is given to the important case of measurements carried out at ISOLDE-CERN employing the 111mCd as a probe.

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Long-term research and development for the SPIRAL1 facility

Presenter: Pascal JARDIN (CNRS)

After 4 years of upgrade, the SPIRAL1 (Système de Production d'Ions Radioactifs Accélérés en Ligne) facility situated at GANIL (Grand Accélérateur National d'Ions Lourds) is again on-line. Its capabilities of hosting target ion-source systems using other ionization techniques than electron cyclotron resonance allows the extension of the production of radioactive ion beams (RIBs) to sticky chemical species. The in-target production variety will in the future be further enlarged owing to the panel of primary beams in terms of elements and energies, and to a new license authorizing other targets than graphite. The increased number of target-primary beam combinations gives the possibility to optimize the yields using the best reaction among fusion-evaporation, transfer or fragmentation. Optimized TISS must be developed to make the most of these new possibilities. The list of the most interesting RIBs for the nuclear community, which will guide the short and long-term R&D plan, will therefore have to be enriched taking into account these new possibilities. So far, the efforts have mainly been focusing on the nuclide chart region of "light isotopes" with masses lower than Nb for target fragmentation induced by carbon@ 95MeV/A beam, and of isotopes with masses up to U for beam fragmentation on graphite target. Neutron deficient isotopes ranging from A~70 to ~130 produced by fusion-evaporation reactions is our next objective. A new principle developed over the last 3 years aims at producing high yields of alkali elements by optimizing the atom-to-ion transformation efficiency within the TISS to balance low in-target productions. Parameters involved in the efficiency, i.e. target structure, stickiness, diffusion and effusion release, and thermal properties of materials are under study. Estimates give yields rarely obtained previously in this region, which is hard to explore at other facilities. If the principle of the first prototype is validated, the technical principle will be transposed to the production of neutron-deficient metallic isotopes within the next 3 years.

The status of these developments are presented.

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Development of new Ti:sapphire based laser sources for selective ionization and spectroscopy applications

Presenter: Volker Sonnenschein (University of Nagoya)

Laser spectroscopy and ionization are already well established tools for the analysis or production of radioactive ion beams. However, to best suit the needs of specific applications, new or modified laser systems are required. We present our recent progress and several applications of these new systems.

Two-photon transitions require high pulse energy and short pulse duration for efficient excitation. A simple approach for generation of such pulses is the use of a reduced laser cavity length. A 3.5cm Ti:sa laser cavity with a two-prism tuner for wavelength selection is demonstrated. Pulses of > 1mJ energy with pulse durations below 3ns at 905nm were produced using an old flashlamp-pumped YAG laser as pump source. In a recent experiment (2018) at the J-PARC facility the system was used for fluorescence studies in He2∗ excimer clusters, which were generated by recoils of the neutron induced 3He(n,p)3T reaction[1]. The fluorescence from these clusters may in the future allow 3D particle tracking velocimetry to investigate the superfluid phase in liquid helium.

Multi-element studies require either multiple expensive laser systems or the ability to quickly switch the wavelength of the laser system from one element of interest to another. A widely-tunable grating Ti:sapphire laser system with intra-cavity frequency doubling and motorized wavelength selection was developed. The system was applied to Secondary Neutral Mass Spectrometry (SNMS)[2] of Zr and Cs.

High resolution resonance ionization spectroscopy for the analysis of isotope shifts and hyperfine structure is possible with an injection-locked Ti:sapphire laser [3]. For increased wavelength flexibility we have started development of a continuous-wave direct diode pumped Ti:sapphire (DDPTS) laser to be used as master-laser source for generating the seed radiation. The use of inexpensive diodes as compared to frequency doubled YAG lasers as pump source will make this solution very cost-efficient.

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Design and commissioning of an RFQ ion guide device for in-gas-laser-ionization studies at KU Leuven

Presenter: Simon Mark C Sels (KU Leuven (BE))

At the SPIRAL2 facility (GANIL) the LEB-REGLIS3 set-up [1] is being developed and will allow to perform laser spectroscopy studies of rare, unstable nuclei using the "In Gas Laser Ionization and Spectroscopy" (IGLIS) technique [2,3]. After separation with the S3-spectrometer, the fusion-evaporation reaction products are thermalized in a buffer gas cell, transported towards a de Laval type nozzle where they are embedded in a cold, homogeneous gas jet. Laser resonant ionization is subsequently performed and the photo ions are captured in a radiofrequency quadrupole structure, efficiently transported from a high to a low pressure region and subsequently transferred towards different detection systems.

In this contribution we report on the preparatory work that is being performed at the IGLIS laboratory at KU Leuven [4]. As part of this laboratory, an ion-guide system consisting of three RFQ-structures has been simulated using the software packages SIMION [5] and IonCool [6].

A prototype has been constructed and commissioned. An overview of the commissioning tests will be discussed.

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A compact linear Paul trap cooler buncher for CRIS

Presenter: Christopher Malden Ricketts (University of Manchester (GB))

Collinear resonance ionisation spectroscopy (CRIS) combines ionisation spectroscopy with a collinear geometry to provide Doppler-free measurements of atomic hyperfine structure, used to determine changes in root mean square charge radii, nuclear ground state spins and nuclear ground state electromagnetic moments. In the technique, an atomic beam is collinearly overlapped with multiple laser fields to resonantly excite then ionise the atoms of interest for deflection and detection.

As the high-power pulsed-lasers required are only available with relatively low repetition rates (<200 Hz), the ion beam must arrive in bunches to avoid duty-cycle losses [1]. This requirement for a bunched beam necessitates the use of an ion trap. The CRIS experiment at ISOLDE, CERN currently makes use of the shared linear Paul trap, ISCOOL [2]. Installing a cooler buncher after the independent ion source at CRIS would allow for continual optimisation of the beam transport and quality. This would reduce the setup times needed before time-pressured experimental runs studying radioactive isotopes and would simplify rapid switching to a stable reference isotope.

This poster presents the work completed towards a compact linear Paul trap cooler buncher for CRIS measurements with the Artemis project at The University of Manchester. The project also acts as an initial prototype for a future ion trap at CRIS, ISOLDE. The design incorporates many 3D printed and PCB based DC optics and mounting pieces, greatly increasing the speed of manufacture. Initial vacuum tests have demonstrated the vacuum compatibility of these plastics, reaching pressures below 1 x 10^{-8} mbar.

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An RFQ Cooler-Buncher for the N=126 factory at Argonne National Laboratory

Presenter: Adrian Valverde (University of Notre Dame)

The properties of nuclei near the neutron N=126 shell, in particular their atomic masses, are critical to the understanding of the production of elements via the astrophysical r-process pathway [1]. Unfortunately, such nuclei cannot be produced in sufficient quantities using common particle-fragmentation, target-fragmentation, or fission production techniques. However, multi-nucleon transfer reactions between two heavy ions provide a method to access and study these nuclei [2]. The N=126factory currently under construction at Argonne National Laboratory's ATLAS facility will make use of these reactions to allow for the study of these nuclei through, for example, high-precision mass measurements through Penning trap mass spectrometry. This new facility will include a large-volume gas catcher to stop reaction products, followed by a mass analyzing magnet of resolution R∼103 to provide initial separation, a radio frequency quadrupole (RFQ) buncher to cool and accumulate the beam and injection into a multi-reflection time-of-flight mass spectrometer (MR-ToF) to provide high mass resolution (R∼105) and suppress isobaric contaminants. The construction and commissioning of the RFQ buncher, based on the design used at the National Superconducting Cyclotron Laboratory's BECOLA [3] and EBIT cooler-bunchers, will be presented.

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Co-authors: Maxime Brodeur (University of Notre Dame), Jason Clark (Argonne National Laboratory), Daniel Lascar (Argonne National Laboratory), Guy Savard (Argonne National Laborator/University of Chicago)

Developments of the Collinear Resonance Ionisation Spectroscopy (CRIS) experiment at CERN-ISOLDE

Presenter: Adam Robert Vernon (University of Manchester (GB))

Significant improvements have been made to the Collinear Resonance Ionization Spectroscopy (CRIS) experiment at CERN-ISOLDE in recent years.

A versatile ion source setup has been developed to support the range of ionization properties of the elements under investigation at CRIS. This has required combining surface, plasma and laser ablation sources with compatible ion optics and has allowed atomic studies independent of the ISOL facility's limited beamtime.

The beamline itself has also been upgraded on the road towards truly collisional-free background conditions, needed for measurements of the lowest isotopic yield cases. The vacuum in the interaction region now reaches 1x10-10 mbar, a factor of 200 improvement from the previous years.

This was achieved by additional vacuum pumping technologies, adjustable differential pumping apertures, as well as a 3-axis adjustable charge-exchange cell, which has mutually improved the atom-laser beam overlap. Remote actuation of systems such as valves and Faraday cups and automation of beam-tune optimization have also been incorporated.

These developments and relevant results will be presented in the talk, in addition to future prospects such as field-ionisation, ion-ionisation and anion-neutralisation.

Co-authors: Ronald Fernando Garcia Ruiz (CERN), Gerda Neyens (KU Leuven (BE)), Agota Koszorus (KU Leuven (BE)), Kieran Flanagan (University of Manchester (GB)), Thomas Elias Cocolios (KU Leuven - IKS), Ruben Pieter De Groote (University of Jyvaskyla (FI)), Wouter Anton M Gins (KU Leuven (BE)), Cory Binnersley (University of Manchester (GB)) Gregory James Farooq-Smith (KU Leuven (BE)), Christopher Malden Ricketts (University of Manchester (GB)), Jonathan Billowes (University of Manchester (GB)), Xiaofei Yang (Peking University (CN)), Mark Bissell (University of Manchester (GB)), Fredrik Olof Andre Parnefjord Gustafsson (KU Leuven (BE))

Poster Session 2 / 49

Beam Cooling and Bunching for the CANREB Project at TRIUMF

Presenter: Leigh Graham (TRIUMF)

The CANadian Rare isotope facility with Electron Beam ion source (CANREB) will aid in the delivery of pure, intense rare isotope beams (RIBs) from ISAC and ARIEL to further the nuclear science research programs at TRIUMF. CANREB will include a high resolution magnetic spectrometer (HRS) for beam purification, and a charge breeding system consisting of an ion beam cooler and buncher (BCB), a pulsed drift tube (PDT), an electron beam ion source (EBIS), and a Nier-type magnetic spectrometer to charge breed the RIB for post-acceleration. The BCB will accept continuous RIB beam and efficiently deliver bunched beam to the EBIS with intensities of up to 107 ions per bunch, with bunch frequencies of up to 100 Hz. The PDT will be used to match the energy of the bunched beam from the BCB to that of the EBIS acceptance in the range of 10-14 keV. The EBIS, developed at MPIK in Heidelberg, has been delivered to TRIUMF, and installation of CANREB equipment is underway. Design features of the BCB and PDT will be described, and a summary of installation and testing progress will be given.

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Polarization dependent laser resonance ionization of beryllium and cadmium for optimized laser ion source performance

Presenter: Ruohong Li (TRIUMF)

In a multistep photoexcitation process, the excitation efficiency from the ground state to a final state depends on the polarization of the excitation photons, the angular momentum of the intermediate state and of the final state. Most experimental work on the polarization dependence in resonance ionization has been performed in atomic beams, where polarization relaxation due to collisional interaction is negligible. For ISOL type hot cavity laser ion sources however these ideal conditions do not necessarily exist.

Using TRIUMF's off-line laser ion source test stand with a system of tunable titanium sapphire lasers, we investigated the polarization-dependence of laser resonance ionization in Be and Cd – using our preferred laser ionization schemes. A significant polarization dependence of the ion signal was confirmed in the typical excitation ladder 1S0→1P1→1S0 for alkaline and alkaline-like elements. Polarization as an important parameter in optimizing laser ion source operation will be discussed. The use of polarization spectroscopy to determine the J values of the newly found states in the spectra of elements with complex electronic structure or only radioactive isotopes, e.g., Ra, Sm, Yb, Pu and No will be explained.

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Direct mass measurements of heavy/superheavy nuclei with an MRTOF-MS coupled with the GARIS-II

Presenter: Yuta Ito (RIKEN)

The initial phase of the SHE-Mass project -- precision mass measurements of superheavy nuclei with a multi-reflection time-of-flight mass spectrograph (MRTOF-MS) coupled with the gas-filled recoil ion separator GARIS-II -- has successfully been carried out. In a series of the experiments, masses of a wide variety of heavy/superheavy nuclei have been measured [1,2,3]. In particular, masses of mendelevium (Z=101) isotopes in the vicinity of the N=152 deformed neutron shell closure have been directly measured for the first time [3]. For the project, dedicated experimental devices to produce low-energy ion beams such as a cryogenic gas catcher and ion traps and sophisticated measurement scheme for the MRTOF-MS have also been developed. The details for the measurements and developments will be presented.

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Co-authors: Peter SCHURY (KEK, WNSC), Michiharu WADA (KEK, WNSC), Fumiya Arai (Univ. of Tsukuba), Hiromitsu Haba (RIKEN), Yoshikazu HIRAYAMA (KEK, WNSC), Satoshi Ishizawa (Yamagata Univ.), Daiya Kaji (RIKEN), Sota KIMURA (RIKEN), Hiroyuki Koura (JAEA), Marion MacCORMICK (IN3P3), Hiroari MIYATAKE (KEK, WNSC), JunYoung MOON (IBS), Koji Morimoto (RIKEN), Kosuke Morita (Kyushu Univ.), Momo MUKAI (Univ. of Tsukuba), Ian Murray (RIKEN), Toshitaka Niwase (Kyushu Univ.), Kunihiro Okada (Sophia Univ.), Akira Ozawa (Univ. of Tsukuba), Marco Rosenbusch (RIKEN), Aiko Takamine (RIKEN), Taiki Tanaka (Kyushu Univ.), Yutaka WATANABE (KEK, WNSC), Hermann Wollnik (New Mexico State Univ.), Sayaka Yamaki (Saitama Univ.)

Poster Session 2 / 63

Rotating Proton Beam onto TRIUMF ISAC Targets for Higher RIB Yields' Releases

Presenter: Aurelia Laxdal (TRIUMF)

A raster magnet was installed to rotate the 500 MeV proton beam onto the TRIUMF ISAC target. Rotating the proton beam produces a more uniform average power deposition, which increases the amount of beam power that targets can take. The magnet system is a pair of two ferrite AC magnets which rotates the proton beam at a frequency up to 400 Hz, for various deflection angles. A new tune was developed to produce a controllable spot size, while having an approximate parallel beam on target and a 90 degrees phase advance between the raster magnets and the target. A set of diagnostics was developed to monitor the rotating beam. Online tests have shown that we can increase the RIB yields from a target for the same maximum temperature. In addition this method simplifies beam delivery by making beam size adjustments more predictable and straightforward.

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Present status of ERIS (Electron-beam-driven RI separator for SCRIT) at the SCRIT electron scattering facility

Presenter: Tetsuya Ohnishi (RIKEN)

ERIS (Electron-beam-driven RI separator for SCRIT) [1] at the SCRIT (Self-Confined Radioactive isotope Ion Target) electron scattering facility [2] is an online isotope separator system to produce low energy radioactive isotope (RI) beams, used for electron scattering experiments of short-lived unstable nuclei. ERIS consists of a production target, a forced electron beam induced arc discharge (FEBIAD) ion source [3], and a beam-analyzing transport line. In ERIS, RIs are produced in photo fission reaction of uranium and we prepared our own uranium carbide disks as the production target. The produced RIs are ionized in the FEBIAD ion source. They are extracted and transported to the SCRIT system [2] through FRAC (Fringing-RF-field-activated ion beam compressor) [4]. In FRAC, continuous beams are converted into pulsed beams with an appropriate stacking time.

In the commissioning experiment of the RI production, 23 uranium carbide target disks of 0.8 mm thickness and 18 mm diameter were used and the total amount of uranium was about 15g. They were irradiated with the 10-W electron beam. The observed rates for 132Sn and 138Xe were 2.6×105 and 3.9×106 atoms s−1, respectively. Details are reported in Ref. [5].

Recently, ion stacking and pulse extraction at ERIS were developed to shorten the opening period of the FRAC's entrance and inject the same number of ions as in the continuous injection. In order to stack ions inside the ionization chamber, entrance and exit grids are connected to the ionization chamber through an insulator, and the applied voltages of these grids are slightly higher than that of the ionization chamber. Then, ions are trapped in the longitudinal direction.

As a result, with a 1-ms stacking time and 300-μs pulse width, the measured pulse height is about 5 times larger than that of the continuous beam and the total number of ions in the pulsed beam is the same as those of the continuous injection with a 1-ms injection. Using this scheme, a number of the accumulated ions inside FRAC is 2--3 times larger than using the continuous injection.

As a further development, the surface ionization system will be introduced in order to extend the variety of ion beams, and the commissioning experiment will be performed soon.
In this paper, we would like to report the present status of ERIS and recent results.

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High-power converters for RIB production

Presenter: Luca Egoriti (TRIUMF)

TRIUMF is developing two target assemblies for radioisotope production based on the conversion of primary charged particle beams into neutral particle fluxes, which consequently induce fission in a uranium carbide (UCx) target.

One is a proton-to-neutron converter made out of a 2 cm thick tungsten core clamped by copper brackets to dissipate up to 7.5 kW deposited by a 500 MeV, 100 uA proton beam. The high-energy isotropic neutrons will then induce cold fission in an annular UCx target material upstream of the converter.
The other is an electron-to-gamma converter made out of a thin tantalum layer deposited on awater-cooled aluminum backing. A 35 MeV electron beam of up to 100 kW will impinge on the tantalum surface and produce a gamma-ray flux, principally in the forward direction of a downstream UCx target.
This contribution focuses on some of the design challenges resulting from the extreme conditions in terms of power density, temperature and radiation.

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A New Approach to Obtain a Precise SOBP Profile in the Thyroid Cancer Therapy using SDTrimDP Code

Presenter: Sy Minh Tuan Hoang (Institute of Fundamental and Applied Sciences, Duy Tan University)

In radiotherapy, proton beams are still being studied to obtain optimal therapeutic results, which provide a lethal effect on tumor tissue but safe for the surrounding healthy tissue. The way to obtain the dose profile named Spread Out Bragg Peak (SOBP), a condition where the radiotherapy dose is high and flat in the area of the tumor and lower in areas outside the tumor, was always based on conventional codes such as SRIM/TRIM, MCNP, FLUKA, PHITS, etc. The drawback of the calculation based on these conventional codes is the change of thickness and composition of the tumor tissue during high-dose proton irradiation that yield imprecise results. With the 2D/3D extension of the dynamical version of the binary collision code SDTrimSP (Static and Dynamic Trim for Sequential and Parallel computer), dynamical changes of surface composition and structure of the tumor can be studied, resolving the drawback of getting the precise results of the SOBP profile. The calculation has been carried out with the geometric model of tissues from the skin to the thyroid gland by determining the energy and the number of protons in each beam of the proton. The SOBP profile obtained from this study is flatter on the region of the tumor compared to previous results by other researchers so that the tumor tissue receives a uniform high dose, while other normal tissues surrounding receive safer doses. From SOBP profile that has been generated, the maximum dose received by healthy tissue closest to the tumor relative to the dose received by the tumor tissue was 10% lower. On average, the area outside the tumor tissue receives a much lower dose, which is about 60% relative to the dose received by the tumor tissue. The results show that the best proton energy interval is around 40 to 54 MeV to cover thyroid layer completely, where the 14 mm thick thyroid gland is located 11.2 mm below the skin surface, and a large percentage of stored energy is around 53.5 MeV and 78% of the proton beam energy.

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Poster Session 2 / 74

Thermal modelling and analysis of high temperature target and ion sources for the production of radioactive beams

Presenter: Lihua Chen (China institute of atomic energy)

At the facilities of radioactive nuclear beams based on ISOL technique, where the exotic nuclear atoms are produced in a thick target, then transported to an ion source, ionized, and extracted from the ion source to form an ion beam,the target and ion source (TIS) are one of the most important components. Their high temperature performance has an important effect on the life-span of TIS and the production efficiency of radioactive nuclear beams. To gain further knowledge for design of more dedicated TIS, the TIS components used in BIRIF are modelled and studied. And their high temperature performance are analyzed under different conditions, such as the temperature of TIS and its structural components, the influence of primary beam power on target temperature, etc. The results are compared with experimental measurements.

Co-authors: Baoqun Cui (China Institue of Atomic Energy), Bing Tang (China Institute of Atomic Energy)

The design and tests for the new CERN-ISOLDE spallation source: an integrated tungsten converter surrounded by an annular UCx target operated at 2000 °C

Presenter: Joao Pedro Ramos (CERN)

Neutron-rich fission fragments are currently of great interest for the physics community. These neutron-rich fission fragments are readily available at CERN-ISOLDE using the ISOL (Isotope Separator OnLine) method. However, if produced by direct irradiation (1.4 GeV protons) of uranium carbide (UCx) targets, commonly used at ISOLDE, the desired isotopes come with very high isobaric contaminations – neutron-deficient fission fragments. Since the year 2000 at ISOLDE, a tungsten/tantalum spallation source is positioned close to the UCx target and irradiated instead. The spallation neutrons produced irradiate isotropically and interact with the target producing very high purity neutron-rich fission fragments. However, scattered protons from the bombardment of the W bar still hit the target causing the non-desired impurities.

An ISOLDE-CERN converter design optimization has been proposed before [1,2] and a simplified version has been tested under proton beam irradiation. In both, current and tested, prototype designs, the converter is put just below the target. In order to use the full solid angle of the emitted neutrons and have the highest possible neutron flux a solution is being studied where the W converter is positioned inside of the target. While this solution present large gains in both production rates and purity of the desired beams, it presents many engineering challenges. By positioning the W converter in the center of the UCx target, normally operated at 2000°C or higher, a larger diameter target oven has to be developed. Furthermore the chemical compatibility between all the target/converter components has to be guaranteed. In addition from the 1.4 GeV pulsed proton beam – 2.8 kW (1.2 GW instantaneous, 2.4 μs pulse length) – up to 700 W are deposited in the target, while submitting the W to large power depositions in very short times. Since the W converter sits inside of the target oven, it acts as an internal heat source for the target, which needs to be controlled with some precision to avoid target degradation and promote isotope release. To do such optimization studies simulations on isotope production, power deposited (FLUKA) and thermo-mechanical aspects (ANSYS) of the target oven have been done.

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Co-authors : Ricardo Manuel Dos Santos Augusto (Ludwig Maximilians Universitat (DE)), Michele Ballan (INFN), Marc Dierckx (SCK-CEN), Luca Egoriti (TRIUMF), Alexander Gottberg (TRIUMF), Donald Houngbo (SCK-CEN), Stefano Marzari (CERN), Lucia Popescu (Belgian Nuclear Research Center (BE)), Sebastian Rothe (CERN), Thierry Stora (CERN)

Development and applications of tunable solid-state laser techniques for the CERN-ISOLDE-RILIS

Presenter: Katerina Chrysalidis (Johannes Gutenberg Universitaet Mainz (DE))

The Resonance Ionization Laser Ion Source (RILIS) relies on a versatile, reliable and easy to use laser system to enable selective and efficient multi-step resonance photo-ionization of radioisotopes, for the majority of experiments at CERN-ISOLDE. A set of titanium sapphire (Ti:Sa) lasers complements the dye laser system of the ISOLDE RILIS installation [1], providing convenient access to the near infrared and blue parts of the optical spectrum.

Since their first use at ISOLDE [2], the Ti:Sa lasers have been under continuous development, extending their performance in terms of ease of use, spectral resolution, output power and beam quality. Intra-cavity frequency doubling has been achieved by introducing a non-linear BiBO crystal at the phase matching angle into the cavity. High efficiency and output power, together with a Gaussian profile of the generated second harmonic beam, have enabled us to easily saturate atomic transitions used for resonance ionization of elements of interest. A technique for scanning the frequency-doubled laser wavelength without additional beam steering has been developed. Subsequent frequency conversions to third and fourth harmonics have become more efficient due to the improved beam shape quality, leading to generation of high power UV laser light.

Here we report on the advanced performance of the RILIS Ti:Sa lasers as well as their applications in resonance ionization spectroscopy of stable and radioactive isotopes. An outlook for continued development activities, aiming at closing the existing gap in spectral range between dye and Ti:Sa lasers, will be presented.

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Helium-Jet Ion-Source development for commensal operation at NSCL/FRIB.

Presenter: Jiban Jyoti Das (National Superconducting Cyclotron Laboratory)

NSCL is a national user facility with a mission to provide beams of rare isotopes for researchers from around the world. Presently, a rare-isotope beam can only be delivered to one experimental end station. The Helium-Jet Ion Guide System (HJ-IGS) project is aimed at delivering a second radioactive ion beam to another end station by collecting rare isotopes that are not delivered to the primary user. This will be done by thermalizing rare isotopes in a stopping cell placed at suitable focal plane(s) off the ion-optical axis of the A1900 fragment separator. The cell is filled with high pressure helium gas mixed with aerosols. The gas/aerosol mixture is then transported through a capillary to a high temperature plasma ion source, where rare isotopes are separated from Helium, then ionized and accelerated to produce low energy ion beams. Subsequently, these beams will be mass-separated using an isotope separator and delivered to various experimental systems. Essential for the implementation of this concept is that the thermalizing cell and the extraction mechanisms are compact and compatible with existing fragment separator infrastructure.

A unique feature of the HeJet stopping technique compared to other techniques is the absence of space charge limitations, as stopping and ionization regions are physically separate. Stopping efficiencies that are independent of the incident ion rate are expected even at the highest rates to be available at FRIB.

The proof of principle of this concept was tested using 252Cf fission fragments at HRIBF, ORNL. Several dozen n-rich isotopes were thermalized, extracted from the cell and identified from decay gamma rays after transporting to a distance of about 100 ft. Subsequently, a high voltage system and optics was developed and neutron-rich rare isotopes were identified in the extracted as low energy ion beam.

At NSCL, a new isotope separator with matching optics will be added for producing mass separated ion beams. The eventual goal is to then cool these beams using a RFQ cooler and transport the rare isotopes to one of the low-energy experimental end stations or the NSCL re-accelerator. The installation and the initial testing of stopping and transport efficiencies have been completed and preparation for a beam test is in progress.

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Molybdenum production with Laser technique at SPES: MO- LAS Project

Presenter: Alberto Monetti (INFN, LNL)

The MOLAS project (Molybdenum production with Laser technique at SPES) calls for the production of 99Mo radioactive ions by means of the method that has being employed for the generation of ion beams studied in nuclear physics experiments.

The hypothetical system includes a commercial cyclotron with energy in the range 10 MeV to 20 MeV and a production target.

The target is a Molybdenum disk or a multi-foil structure, like the UCx SPES target, activated by the highly energetic protons coming from the cyclotron.

Once activated, the target undergoes a laser ablation process and the evaporated atoms are then available for subsequent ionization, which is necessary to select 99Mo through a mass spectrometer and collect the selected atoms.

The laser ablation, laser photoionization and mass separation process chain is the paramount aspect of the MOLAS idea that allows to avoid several problems:

Laser ablation solves the refractory element high evaporation temperature problem; Laser photoionization is the perfect technique to couple with Time of Flight mass separation system, together they solve the delivery of an isotopic pure beam of element of interest possibly without any request of an isotopic pure Mo target at the beginning.

Furthermore, laser resonant photoionization could be itself the starting point for isotope separation using different excitation and ionization levels for different isotopes.

The MOLAS project could be thus a cost-convenient method to produce high pure 99Mo to be used in the actual 99Tc chain of production.

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Laser ion source development for the CERN-MEDICIS facility

Presenter: Vadim Gadelshin (Johannes Gutenberg University of Mainz (DE))

The new CERN-MEDICIS facility aims for production of medical radioisotopes. It is foreseen to use two production routes. The first one implies the use of the 1.4 GeV proton beam coming from the CERN Proton Booster for irradiation of a target material with subsequent radionuclide extraction at the dedicated off-line MEDICIS Mass Separator. However, during short and long shutdowns, this production route is not available. The second way is based on the extraction of radioisotopes from targets pre-irradiated and provided by external institutions: nuclear reactors, medical accelerators and cyclotrons, nuclear waste depositaries. This unique feature guarantees a continuous radionuclides supply to the end users, as well as the work of the Mass Separator independently from the CERN shutdowns.

The MEDICIS facility is designed on the ISOL technology. The off-line Mass Separator uses the conventional electromagnetic separation technology. It requires the ionic state of a work substance. A traditional surface ionization method does not possess enough efficiency in the ionization of MEDICIS targeted radionuclides, and is accompanied by undesired isobaric contamination. The presence of isobaric or other radionuclide impurities is not acceptable for the personalized nuclear medicine, because it can cause an unintended irradiation of living tissues as well as a contamination with long-lived radioisotopes.

Using the laser resonant ionization method, we are able to ionize only radioisotopes of a desired chemical element. Therefore, the resonance ionization laser ion source (RILIS technology) allows us to combine the benefit of element selectivity with mass selectivity of electromagnetic separation. As a result, we can produce a pure desired radionuclide. Moreover, the high ionization efficiency of the laser ion source ensures a high radioisotope production rate.

The MEDICIS Laser Ion Source Setup (MELISSA) will use a solid-state laser system. It is based on tuneable Ti:Sapphire lasers as the most reliable and flexible for continuous operation of a separation facility. The use of Ti:Sapphire lasers requires spectroscopic development of a suitable multi-step laser ionization scheme for every chemical element of interest. In the report, the current status of the laser ion source development for the CERN-MEDICIS facility is going to be presented. The newest results of laser resonant ionization spectroscopy will be demonstrated for several lanthanides, which medical radioisotopes are the most interesting for the theranostic approach. In particular, various laser ionization schemes will be considered to define the most optimal for the efficient production of innovative radiopharmaceuticals.

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An injection-locked Titanium:Sapphire laser system for a high-resolution resonance ionization spectroscopy.

Presenter: Mikael Reponen (University of Jyväskylä)

Hyperfine structures and isotope shifts in electronic transitions contain readily available model-free information on the single-particle and bulk properties of exotic nuclei, namely the nuclear spin, magnetic dipole and electric quadrupole moments as well as changes in root-mean-square charge radii [1]. Recently, resonance ionization spectroscopy (RIS) in a low-temperature supersonic gas jet utilizing a narrowband first step excitation [2] has been demonstrated to be a powerful tool for probing exotic nuclei [3]. An optimal solution to combine high pulse powers, required for efficient RIS, with a narrow bandwidth is the pulsed amplification of a narrow-band continuous wave (CW) laser. In a regenerative Titanium:Sapphire amplifier, the cavity length is locked to a multiple of the seed wavelength allowing lasers to reach a final output power of several kW (during the pulse) from the few mW of CW input.
We present a pulsed injection-locked Titanium:Sapphire laser [5] designed with an emphasis on stability and reproducibility. The laser design couples low vibration sensitivity with stability via FEM simulation optimized feet positions and by integrating the injection and cavity optic mounts onto the baseplate. In addition, the laser can be configured for different cavity round-trip lengths and intra-cavity second harmonic generation.

The laser has been commissioned in the PALIS laser laboratory [4] in the RIKEN Nishina Center with a laser spectroscopy of ^{93}Nb with the interest to study the possibility to separate the ^{93m}Nb isomer from the ground state [6, 7]. These measurements yielded a total FWHM of ~ 400 MHz and hyperfine A coefficient of 1866 ± 8 MHz for the ground state and 1536 ± 7 MHz for the first excited state in a good agreement with the literature values [8].

In conclusion, the laser has been demonstrated to perform as expected and ready to be applied to in-gas-jet spectroscopy at PALIS. Furthermore, a similar laser is under construction at the University of Jyväskylä to be utilized at the IGISOL and MARA facilities.

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The new Offline-2 laboratory for Isolde

Presenter: Stuart Warren (CERN)

Offline-2 is an entirely new laboratory for the Isolde facility, to serve a wide range of R&D needs. Whilst the existing off-line lab is sufficient for target conditioning and for limited ion-source developments, it is now rather old and not always suitable for testing and development of more sophisticated target units. In addition there is an increasing need for beam dynamics studies, which the older off-line separator is entirely unsuitable for. Including infrastructure the new laboratory represents an investment of roughly 1M CHF.

The new separator comprises a standard Isolde frontend (target handling and beam-preparation system), so beam conditions are extremely realistic. After the separator magnet there is a matching section and an RFQ beam-cooler. The cooler is similar to the on-line cooler, and will permit a wide range of cooler upgrades to be studied including longitudinal emittance studies, alternative beam-capture schemes, and improved buffer-gas distribution inside the RFQ volume. After the RFQ there is a transverse emittance meter, and space for other advanced beam instrumentation including time profiling detectors and energy spread measurement (see abstract #104).

In general modifications to the on-line facility are difficult and risky, and with Offline-2 for the first time we will have a general-purpose test-bed to validate new equipment and new designs under realistic conditions prior to installation. A major project which will benefit from this is the planned replacement and upgrade of the Isolde GPS and HRS frontends.

Offline-2 will be ideal for development of ambitious new targets and ion-sources. It will allow for much more comprehensive testing before taking a prototype on-line, reducing failure risks and minimising the proton beam-time needed. A dedicated laser laboratory will allow far more laser-ionisation studies to be carried out, including work that currently has to be done with the on-line facility.

The infrastructure of the Offline-2 lab is now complete and commissioning of the source, separator and RFQ has started. We will present the measurements of the first beams, the construction status, and discuss plans for the exploitation of this new laboratory.

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A novel setup to develop Chemical Isobaric SEparation (CISE)

Presenter: A. Mollaebrahini (KVI-Center for Advanced Radiation Technology, University of Groningen)

Gas catchers are widely used to slow down nuclear reaction products and extract them for precision measurements. However, it is known that impurities in the inert stopping gas can chemically react with the ions and thus influence the extraction efficiency. So far, chemical reactions in the gas catcher have not been investigated in details. We want to understand the chemistry inside the gas-catcher and explore its potential as a new technique for separation of isobars. Therefore, we are currently building a new setup to develop Chemical Isobaric SEparation (CISE).

The CISE-Setup consists of a gas-catcher which can either be used in online experiments or in combination with a laser ablation source, for chemical studies with stable nuclides. It is coupled to an octupole ion-guide and a quadrupole mass filter combined with a linear Time-Of-Flight (TOF) spectrometer. Different chemical reactions for separation of isobars will be tested inside the gas-catcher filled by helium and reactive gases. An overview of the CISE-Setup, ion-optical simulations and technical design together with the status of the project will be presented in this contribution.

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Poster Session 2 / 110

Laser ionization scheme development and high resolution spectroscopy of promethium

Presenter: Dominik Studer (Johannes Gutenberg Universitaet Mainz (DE))

Promethium (Z = 61) is an exclusively radioactive element with short half-lives of up to 17 years. Consequently, Pm sample amounts that can be safely handled in off-line laboratories are small and data on atomic transitions is scarce.

In order to access Pm for RIB facilities, extensive laser ionization scheme development was carried out at JGU Mainz. More than 1000 new optical transitions were recorded in the spectral ranges from 415 - 470 nm and 800 - 910 nm using pulsed Ti:sapphire lasers. From the obtained spectra several two- and three-step ionization schemes were identified. In this course the ionization potential of Pm could be experimentally determined for the first time via field ionization of weakly bound states. The precision of the ionization potential could be improved by three orders of magnitude [1].

For high-resolution spectroscopy of Pm isotopes first tests on 147Pm were carried out within the PI-LIST ion source unit, a RF quadrupole structure separating the hot atomizer region from a cold laser interaction region. Like this surface ions can be suppressed while the species of interest is resonantly ionized in crossed laser beam geometry, significantly reducing spectral Doppler broadening. Hyperfine spectra for two subsequent transitions in a newly developed RIS scheme were measured with linewidths of ≈ 120 MHz. Off-line spectroscopy of the isotopes 143,144,145,146Pm at JGU Mainz is envisaged for 2018.

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Testing the Weak Interaction using the NSLtrap of the University of Notre Dame

Presenter: Patrick O'Malley (University of Notre Dame)

The standard model of physics provides a description of matter in the universe. However, it fails to reproduce many unexplained features and so there has been search for physics beyond the standard model. One avenue is via the precise determination of the Vud matrix element of the Cabibbo-Kobayashi-Maskaka (CKM) matrix from the ft-value of superallowed mixed beta-decay transitions. A violation of the CKM matrix unitarity could be the consequence of a missing quarkgeneration, new bosons, or even supersymmetry. However, the determination of Vud from mirror transitions requires the measurement of the Fermi-to-Gamow Teller mixing ratio ρ. At the Nuclear Science Lab (NSL) within the University of Notre Dame a project is underway to develop a Paul trap devoted to the measurement of this elusive quantity. It will receive radioactive ion beams produced in-flight with TwinSol, a coupled pair of superconducting solenoids. The NSLtrap will consist of a gas catcher to stop the 1-3 MeV/A secondary beams from TwinSol . This will be followed by a radio-frequency quadrapole to cool and bunch the thermalized ions before their injection into a Paul trap. The design will be presented and the planned initial measurements will be discussed.

Project supported by NSF MRI: PHY-1725711

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Lessons learned from the success of ISOLTRAP's MRTOF for a future general-purpose device

Presenter: Frank Wienholtz (CERN)

The multi-reflection time-of-flight mass separator/spectrometer (MR-ToF MS) [1, 2] installed at the ISOLTRAP experiment [3] at ISOLDE at CERN has proven to be a valuable asset, allowing fast identification of the incoming ion beams [4] and selection and transfer of only a certain species to either the Penning-trap section [5], or to other experimental components [6]. The time-of-flight information can also be used to determine the masses of the beam constituents with sufficient precision for many physics topics, such as nuclear structure [7,8,9,10] and astrophysics [5, 11]. In addition to mass spectrometry, the MR-ToF can also provide purified samples for decay spectroscopy [6] or, in combination with the Resonant Ionization Laser Ion Source (RILIS) of ISOLDE, for measurements of nuclear moments and charge radii with background suppression [12, 13]. The fast-identification capabilities also make the MR-ToF a very attractive tool for target and ion source optimization and ion yield determination [14].

The ISOLTRAP MR-ToF MS will be discussed in detail and the idea of a future 30-kV general-purpose MR-ToF MS at ISOLDE will be presented.

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Co-authors: On behalf of the ISOLTRAP and the ISOLDE collaboration.

Ion Source Research and Development on Behalf of the TRIUMF ARIEL Development Team

Presenter: Fernando Maldonado (University of Victoria/TRIUMF)

TRIUMF's flagship is the Advanced Rare IsotopE Laboratory (ARIEL), which will operate the existing ISOL facility, ISAC, to increase the number of shifts available to experimental users by a factor of three. In order to not only deliver more experimental hours but also better beams, a dedicated research and development program is required. There is scope for significant improvements to the performance of the target ion source systems currently used. The ion sources used at TRIUMF such as surface ion sources, and especially the FEBIAD (Forced Electron Beam Induced Arc Discharge) ion source will benefit for the dedicated research and development. ISAC will serve as a starting point to validate simulations and experimental methodology that will be applied to the ARIEL design.

Experimental characterization and calibration of the ion source parameters has been performed to gain more understanding of the ion source performance. Additionally, the simulations are capable of coupling different physics aspects of the source. This information allows a visualization of ionization maps that serve for a more realistic ion generation. Finally, the software tracks the ion extraction and exports data from which observables, such as the emittance are obtained. Preliminary simulation results show a similar behavior to the experimental ion current as a function of the varying magnetic field. Through the multiphysics approach of the simulations, and the experimental validation, it is hoped a better understanding will lead to possibilities for the optimization of the current ion sources used at TRIUMF.

Commissioning a Multi-Reflection Time-of-Flight Mass Spectrometer at the University of Notre Dame

Presenter: Maxime Brodeur (University of Notre Dame)

A multi-reflection time-of-flight mass spectrometer (MR-TOF) will be a critical component for quickly removing radioactive contaminants produced at the future "N = 126 beam factory" addition to ATLAS at Argonne National Laboratory. This unique thermalized ion beam facility will employ deep-inelastic reactions to produce very neutron-rich isotopes relevant to the astrophysical r-process. This production method entails high levels of isobaric contaminants, but precision measurements of such rare isotopes typically require highly purified samples. With this problem in mind, an MR-TOF has been built and commissioned in an off-line test setup at the University of Notre Dame. These devices can accommodate low production yields and short half-lives of desired radionuclides, and can separate isobars with resolving powers > 10^5 with a non-scanning operation. A series of simulations done in symphony with the off-line commissioning, as well as a summary of the MR-TOFs performance, will be presented. This work is supported by the National Science Foundation and the University of Notre Dame.

Co-authors: Maxime Brodeur (University of Notre Dame)

State-of-the-art industrial laser technology for laser ion source applications at ISOL facilities

Presenter: Shane Wilkins (University of Manchester (GB))

The unrivaled combination of efficiency and selectivity of the resonance-ionization process has made laser ion sources a mainstay of Isotope Separator On-Line (ISOL) facilities. The growing demand for laser-ionized beams has necessitated the use of increasingly robust laser systems, which are capable of operating continuously, and possess a long mean time between failures.

Such stringent reliability requirements are commonplace in the industrial sector, where lasers used for machining applications typically operate around-the-clock. To meet our industrial-level demand, we have therefore taken advantage of the range of machining lasers that have emerged in recent years [1][2]. Whilst these systems typically satisfy the reliability requirements, only a few satisfy the particular performance characteristics needed for laser-ion-source applications. At ISOL facilities, the industry-grade lasers are extensively used for tunable-laser pumping and non-resonant ionization [3]. Laser-induced breakup of molecular species released from targets is currently under investigation. Optimal performance for each foreseeable ISOL application requires a range of specific sets of laser-pulse characteristics: pulse width, energy, repetition rate, beam quality, and linewidth. This contribution will present an overview of our current practical experience of industrial lasers used for laser-ion-source applications.

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Preliminary design of the new FRAgment In-flight SEparator (FRAISE)

Presenter: Antonio Domenico Russo (INFN - National Institute for Nuclear Physics)

In the perspective of the LNS-INFN plan that provides to increase the ion beam power delivered by the existing superconducting cyclotron up to 10 kW, a new FRAgment In-flight SEparator (FRAISE) has been proposed. Due to the constraint of the experimental hall and despite an increasing of the thickness of the shielding walls we expect to run the facility with power no higher than 3 kW. The mass of the ion used as primary beam will be lower than 70 amu.

FRAISE consist of 4 bending magnets arranged in the symmetry configuration to produce an achromatic transport beam line with a momentum acceptance of ±1%.

Although, the room available for FRAISE is limited, in the symmetry point of the system where a degrader will be installed we achieved a maximum dispersion value of 5.2 m.

FRAISE could deliver radioactive ion beam at three experimental rooms where the magnetic spectrometer MAGNEX, the multi detector CHIMERA and the general purpose scattering chamber CICLOPE are respectively installed. Moreover, the superconducting solenoid SOLE will be moved to take advantage to use the new RIB.

The features and the performances of FRAISE will be presented.

Poster Session 2 / 143

Laser resonance ionization scheme development and laser spectroscopy with Ti:Sa lasers on Tm

Presenter: Maryam Mostamand (TRIUMF, University of Manitoba)

Spectroscopic studies to develop laser ionization schemes suitable for titanium:sapphire (Ti:Sa) lasers were carried out in Tm. While efficient ionization schemes exist for dye laser based RILIS, development is needed for Ti:Sa laser based RILIS. The spectroscopic studies were performed at TRIUMF's off-line laser ion source test stand with a system of tunable Ti:Sa lasers with the focus on developing simple, two-step resonant laser ionization schemes utilizing auto-ionizing (AI) states. Three different two-step resonance ionization schemes were developed using strong AI resonances which were determined with a measurement accuracy of about ±0.05 cm-1. The resulting laser ionization schemes for Tm are well suited for Ti:Sa laser based RILIS and will be used for on-line yield measurements in August 2018.

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Offline Target Studies for the ARIEL Facility

Presenter: Carla Babcock (TRIUMF)

The ARIEL facility, currently under construction at TRIUMF, brings two new target stations and a new electron driver beam from ARIEL's e-linac to the TRIUMF facility. With these upgrades comes a suite of new technologies and new methodologies specific to the challenges posed by the ARIEL target station design. Several offline test stands, becoming increasingly integrated as the tests progress, have been designed and constructed. They will validate the new concepts and designs, and facilitate studies of particular aspects of the ARIEL design. The use of an electron driver beam necessitates a redesign of the typical ISOL target and target vessel geometry used with a proton driver beam. Increased air activation also imposes stringent requirements on the system for remotely coupling and decoupling the target vessel. In addition, the target vessel must be coupled to both the driver and RIB beam lines, unlike the case for a proton driver beam. ARIEL target stations will also deliver a large number of services through the target vessel, and the TRIUMF facility as a whole faces unique coupling and alignment challenges by inserting and removing parts of the target station vertically. Investigations into the performance and reliability of these enhancements are crucial to successful online operation and studies focusing on the main challenges are underway. The results from these ongoing tests will be presented with an emphasis on the unique features present in the ARIEL era.

Co-authors: ARIEL Development Team (TRIUMF)

Upgrades of the GANDALPH photodetachment detector towards the determination of the electron affinity of Astatine

Presenter: David Leimbach (Johannes Gutenberg Universitaet Mainz (DE))

The Gothenburg ANion Detector for Affinity measurements by Laser PHotodetachment (GANDALPH) has been designed to determine electron affinities (EA) of radioisotopes. A first goal is the determination of the EA of astatine, the rarest naturally occurring element on earth [1]. The EA of astatine, together with the previously measured first ionization potential (IP) [2] gives valuable benchmarks for quantum chemical calculations predicting the chemical properties of this element and its compounds. As a milestone, the first ever photodetachment measurement of a radioisotope was successfully conducted with a negative 128-iodine beam produced at CERN-ISOLDE [3].
In order to improve the suitability to study ion beams with low intensity (<1pA), we have upgraded GANDALPH in several aspects. First, a dedicated off-line negative ion source has been constructed and attached to GANDALPH. This will facilitate off-line tests and fine tuning of the neutral atom detector as well as the electrostatic elements in the beam-line. Second, a new particle detector has been installed, which will be used to measure the ion beam currents that are expected to be very small. Finally, we have installed segmented apertures that will allow a more efficient beam tuning through GANDALPH.

In this paper the GANDALPH beam-line and its upgrades will be presented. Further, the off-line ion source will be introduced and off- and on-line results will be discussed.

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Co-authors: Sebastian Rothe (CERN), Klaus Wendt (Johannes Gutenberg Universitaet Mainz (DE)), Dag Hanstorp (Gothenburg University (SE))

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High beam intensities and long trapping times of molecular beams in the REX/HIE-ISOLDE charge breeding system

Presenter: Johanna Pitters (CERN)

Within the framework of MEDICIS-Promed, possibilities for hadron therapy with radioactive ion beams are investigated. For preparation of a radioactive 11C treatment beam, the use of an ISOL-production stage followed by a charge breeding system is considered. In order to better understand the limitations of the charge breeding system, we have performed tests with stable high-intensity CO beams at the REX/HIE-ISOLDE low energy system, consisting of a Penning trap and an Electron Beam Ion Source. Efficiencies for high current throughput are presented along with data on molecular breakup in the buffer gas and ion losses for long holding times of the CO beam in the Penning trap.

Co-authors: Martin Breitenfeldt (CERN), Fredrik John Carl Wenander (CERN)

Monte Carlo shielding calculations for the SPES target handling system

Presenter: Antonietta Donzella (University of Brescia)

The Selective Production of Exotic Species (SPES) is a nuclear facility currently under construction at the National Laboratories of Legnaro (LNL) of the Italian Institute of Nuclear Physics (INFN), aiming at the production of Radioactive Ion Beams.

In the first SPES production phase, low energy and low intensity ion beams are planned to be produced using different targets. A continuous proton beam of 40 MeV of energy and 20 µA of current will impinge on SiC and UCx targets, whose operational temperature is 2000 °C. The life-cycle of the Target and Ion Source (TIS) unit is 15-day long. After this time, the TIS unit will be removed from the Front-End.

A semi-automatic handling system for this kind of target units is being designed at the SPES laboratories. Such a system picks up the TIS unit and takes it to a temporary storage, where it will be hosted until the final disposal. The system foresees the presence of an operator. Due to the residual activity of the irradiated target, shielding calculations have to be performed based on the frequency and on the duration of the planned operations.

The ambient dose equivalent rate has been calculated with Fluka Monte Carlo code, for the two different target compositions, SiC and UCx, during the TIS removal operations. Different shielding conditions have been analyzed. Shielding calculations performed for both the semi-automatic handling system and for the exhausted target unit temporary storage represent mandatory inputs for the design of the SPES project.

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Development of a new in-ring beam monitor in the Rare-RI Ring

Presenter: Shunichiro Omika (RIKEN, Saitama Univ.)

The precise masses of neutron-rich nuclei are important for the study of the r-process nucleosynthesis as well as nuclear structure far from stability. The newly constructed storage ring, Rare-RI Ring, is a device dedicated for the precise mass measurements for short-lived nuclei [1][2]. The masses are determined by comparing the revolution time of a reference particle with known mass and that of a particle of interest with unknown mass, based on the isochronous mass spectrometry.

To adjust several magnets in the injection orbit properly, we need a detector to confirm the circulation of the stored particle. The detector should be sensitive to a single ion because the Rare-RI Ring handles only one particle at each injection. In addition, it is necessary to measure the revolution time to adjust the isochronous magnetic field precisely using a narrow-band Schottky pick-up [3]. Therefore, we developed a new in-ring beam monitor which consists of a thin foil, a scintillator, and multi-pixel photon counters (MPPCs) [4].

The operation principle is based on the secondary electrons including delta-rays which are generated when the stored particle passes through the foil at each revolution. The secondary electrons are detected by a scintillator coupled with MPPCs without any guiding field. We carried out beam experiments to verify the principle for a prototype detector at the Heavy-Ion Medical Accelerator in Chiba (HIMAC) synchrotron facility.

After verification, we installed the detector in the ring. The detector consists of a 3-μm-thick aluminum foil, one large plastic scintillator (100 × 100 mm2 with 3-mm thickness) and two small ones (80 ×50 mm2 with 3-mm thickness), and 10 MPPCs (S12572-100C) for scintillation light readout. In November 2016, we conducted a machine study of the Rare-RI Ring and successfully measured revolution times using present detector. The result showed that the revolution time was determined in a precision of 8.0 × 10−4.
In this contribution, we will present the details of the experiments, analysis, and results.

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Infrastructure for the Production and Development of Targets at CERN-ISOLDE

Presenter: Sebastian Rothe (CERN)

ISOLDE is a radioactive ion beam facility within CERN's proton accelerator complex. Ion beams of more than 70 different elements can be produced using a selected combination of ion source types and target materials available. In 2017 a total of 36 target and ion source units (targets) were constructed, tested and irradiated at ISOLDE for scheduled physics experiments, used for the commissioning of the new MEDICIS facility or served for pure machine development.

Both development studies and routine production share the same infrastructure, including an off-line mass separator and a thermal calibration test stand. Since the target production schedule has to be prioritized this creates a bottleneck for development work that is required to meet the demand in new and more exotic beams by the ISOL community.

While this is addressed by ongoing projects envisaging the construction of additional facilities with off-line-2 currently in commissioning phase and a future off-line-3 planned for the Class A laboratory, the existing off-line-1 mass separator has undergone several upgrades and additions.

Here we will give an overview about the infrastructure and procedures involved for the ISOLDE target production and documentation. We will discuss the ongoing upgrade programme to improve and extend our capabilities such as upgrades of the control software, addition of residual gas analysers, automation and data logging. A second part will be focussed on the dedicated infrastructure towards the development and study of new ion sources and the formation of molecular beams. We will conclude with an overview over the development programme foreseen during the LHC Long Shutdown 2 period (LS2) where no protons will be delivered to ISOLDE.

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Status of MIRACLS' proof-of-principle experiment

Presenter: Varvara Lagaki (Ernst Moritz Arndt Universitaet (DE))

Collinear laser spectroscopy (CLS) is a very effective tool to measure nuclear spins, magnetic moments, quadrupole moments and mean-square charge radii of short-lived isotopes far from stability with high precision and accuracy [1]. Conventional CLS relies on the optical detection of fluorescence photons from laser-excited ions or atoms. Depending on the specific case and spectroscopic transition, it is limited to radioactive ion beams (RIB) with yields of more than 100 to 10,000 ions/s. As a consequence, it is essential to develop more sensitive experimental methods for the study of more exotic nuclei.

Complementary to Collinear Resonance Ionization Spectroscopy (CRIS) technique [2], the MIRACLS project at ISOLDE/CERN aims to preserve the high resolution of conventional CLS and at the same time to enhance its sensitivity by a factor of 20 to 600. This will be achieved by extending the effective observation time, depending on the specific nuclides' mass and lifetime. The novel MIRACLS concept is based on an Electrostatic Ion Beam Trap/Multi-Reflection Time-of-Flight (MR-ToF) device which confines a 30keV ion beam in between two electrostatics mirrors [3].

In order to demonstrate the potential of this novel approach, a proof-of-principle experiment for MIRACLS is being set up around an existing MR-ToF device [4] which is modified for the purpose of CLS. Mg ions are extracted from an offline electron-impact ionization source , are subsequently accelerated by a 250 V voltage gradient and injected into a linear Paul trap which allows for beam accumulation, bunching and cooling. After extraction from this buncher, the ions are accelerated at 2 keV and then they are trapped in the MR-ToF device which hosts an optical detection region to register fluorescence photons from laser excited Mg ions.
This poster contribution will introduce the MIRACLS proof-of-principle experiment and will present the first observation of photons in the MR-ToF device.

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The upgraded ISOLDE yield database: a new tool to predict beam intensities

Presenter: Jochen Ballof (Johannes Gutenberg Universitaet Mainz (DE))

Developed more than 10 years ago, the ISOLDE yield database [1] serves as a valuable source for experiment planning. At the moment, it contains in total 2445 yield entries for 1333 isotopes of 74 elements and 55 different target materials. In addition, information about the time structure of the release is available for 427 yields [2].

With the increasing demand for more and more exotic beams, needs arise to extend the functionality of the database and website not only to provide information about yields determined experimentally, but also to predict yields of isotopes, which can only be measured with sophisticated setups. The individual prediction of yields is a time-consuming process in which several parameters have to be considered. The rate of radionuclides generated inside the target by the driver beam (in-target production) is the first parameter that has to be addressed by means of costly simulations. This theoretical rate is obtained with two codes that are well-benchmarked at ISOLDE: ABRABLA [3] and FLUKA [4]. Due to the limited lifetime of the radioactive species, a certain fraction of isotopes will already have decayed before having reached the ion source. This partial yield can be obtained by mathematical operations from a release curve of a longer-lived isotope of the chemical element of interest [5].

Currently, release curves for 427 yield entries are available in the yield database. Comparing the in-target production multiplied by the release fraction with the measured yield of the same isotope, allows to extract a combined parameter that accounts for ionization efficiency, chemical efficiency and other losses. For cases, in which the release is well understood, the yield database has the capability to store all the necessary data to predict yields automatically.

The website of the ISOLDE yield database is now being further developed to present this additional data. A campaign of simulations has been launched, to obtain in-target production values for all the target materials in the database, including the different proton driver beam energies (0. 6, 1.0 and 1.4 GeV) and also a possible 2.0 GeV upgrade, increasing the prediction capabilities of the database. We also contribute to the CRIBE (Chart of Radioactive Beams in Europe) project [6] aiming to establish a common yield database for operational and planned European ISOL-facilities.

Within this contribution, we present the yield predicting algorithms, including the in-target production simulations, and the new version of the ISOLDE yield database website.

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High resolution isomer separation using collinear resonant laser ionization

Presenter: A. Teigelhöfer (TRIUMF)

A contamination free isotope beam is one of the key requirements for the success of many experiments located at radioactive ion beam facilities. Resonant ionization laser ion sources (RILIS), which rely on the unique optical spectrum for each element, are well known for their ability to provide radioactive ion beams with reduced isobaric background. However, even though the optical spectrum differs for atom with a nucleus in ground or isomeric state, the difference in the hyperfine structure spectrum is in most cases too small for being resolved with a RILIS.
Therefore, an ionization method based on a spectroscopy method with higher resolution is required, such as collinear fast beam laser spectroscopy. By overlapping the continuous wave (cw) light of a 1.5W blue diode laser with that of the resonant excitation transition along the polarizer beam line at TRIUMF, 85Rb was ionized with a laser induced ionization enhancement of 8.3(15)%. Especially for nuclear structure experiment this additional purification could be of interest.

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Highly Efficient Ion Source for Surface and Laser Ionization

Presenter: Maxim Seliverstov (NRC "Kurchatov Institute" PNPI)

The application of mass-separators for the production of high-purity radionuclides used for diagnostics and therapy is a promising and extensively developed method. Among the most widely used medical radionuclides are isotopes with relatively low ionization potential, for example, isotope-generator 82Sr which is utilized for PET diagnostics of heart and brain diseases, alpha-ecaying 223,224Ra used for the therapy of different malignant tumors at a very early stage of their formation and some Tl and In isotopes. The simplest way to ionize these isotopes for subsequent delivering by a mass-separator to its collector is the surface ionization technique. As a rule, the ionizer is made of a tungsten or tantalum tube at the temperature of about 2300 °C to produce the surface-ionized species. However, the ionization efficiency of such a type of ionizer for non-alkalis is low (for example, about 1% for Tl). On the other hand, surface ionization is the simplest and cheapest ionization method.

To increase the surface ionization efficiency, a new type of surface ion source has been proposed and put into operation at the mass-separator IRIS working on-line with the 1-GeV proton synchrocyclotron of Petersburg Nuclear Physics Institute. The main part of this ion source is the tube made from a mono crystal of tungsten with the orientation of the tube axis along the crystallographic [111] direction. The work function of the tube internal surface is about 5 eV.

The ionization efficiency is determined as the ratio of the yield of the chosen long-lived isotope at the exit of the mass-separator to its in-target production rate. The latter is readily calculated with the known target and proton beam parameters along with the cross-sections of the reaction (p 1GeV, 238U)A, where A is the isotope in question [1]. The yields have been deduced by the measurement of the characteristic gamma or alpha-line intensities. The life-lives of the chosen isotopes were sufficiently long (larger than several hours) to neglect the decay losses due to the release time. For elements with the moderate ionization potentials, IP,the ionization efficiencies prove to be sufficiently high to consider the new ion source as the part of the future installation for the medical isotope production. Values of the ionization efficiencies for Tl (IP = 6.1 eV), In (IP = 5.8 eV) and Ra (IP = 5.3 eV) are 21(8), 33(8) and 38(10)% correspondingly.

This ion source tube was also successfully used as a hot cavity of a laser ion source during the experiments on in-source laser spectroscopy of the short-lived Bi isotopes [2]. The increase of the laser ionization efficiency in comparison with the efficiency obtained with the conventional tungsten ion-source tube at the same temperature was observed.

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Phoswich scintillator assemblies: Application to the Simultaneous detection of Particle and Gamma radiation – PASPAG

Presenter: Olof Tengblad (IEM - CSIC)

PASPAG is a Joint Research Activity within ENSAR2 project. PASPAG aims to improve infrastructure for European Large Scale Facilities to make best use of the high investment in delivering radioactive ion beams. Efficient gamma-ray and charged-particle detection are key tools for experimental nuclear physics. Future nuclear physics facilities will make strong demands on the capability and performance of such detector systems.

PASPAG aims for Simultaneous detection of Gamma and Particle Radiation by the use of new scintillator materials combined with the phoswich technique.

In this presentation, we will discuss the achievements of the project so far and concentrate the discussion to the R&D leading to societal applications, especially in relation to detection systems for homeland security.

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