STORI'17

10th International Conference on Nuclear Physics at Storage Rings

Book of Abstracts

Contents

November 14th (Tue.)

Heavy Ion Storage Ring Technology and Operational Aspects

Nov. 14th
10:00-10:30

Presenter: Dr. STECK, Markus
GSI Darmstadt

Heavy ion storage rings are very valuable for nuclear and atomic physics research. For a large variety of physics experiments special methods to prepare and diagnose the stored beam were developed. The most important method of beam preparation is beam cooling. As a result beams with unprecedented energy definition and resolution and well defined spatial position can be provided. Beam cooling allows beam accumulation, e.g. for low intensity secondary beams, and efficient deceleration. Both techniques are well established at the ESR storage ring at GSI which is operated with highly charged ions and rare isotope beams. Beam diagnostics matched to the experimental requirements and to the properties of cooled beams are available. Experimental set-ups use internal targets which due to the availability of beam cooling can be operated without beam quality degradation. Ultrahigh vacuum is the basis for long storage time and the achievement of lowest energy of the stored beam.

Direct and indirect measurements of neutron-induced cross sections at storage rings*

Nov. 14th
10:30-11:00

Presenter: Dr. JURADO, Beatriz
CENBG, Bordeaux, France

Neutron-induced cross sections of short-lived nuclei are highly relevant in many domains such as fundamental nuclear physics, astrophysics and applications in nuclear technology. In particular, these cross sections are essential for understanding the synthesis of elements in stars and solving the mystery of the r-process site. However, the measurement of such cross sections with current techniques is very difficult or even impossible, because of the difficulties to produce and handle the necessary amounts of radioactive nuclei. Reaching the nuclei of interest is only possible by inverting the reaction kinematics with radioactive beams. The possibility to perform nuclear-reaction measurements at storage rings that was recently demonstrated at the ESR [1] opens up new, largely unexplored possibilities for the development of direct and indirect methods for the measurement of neutron cross sections in inverse kinematics. In this contribution we will present a project for indirectly determining neutron cross sections via the surrogate-reaction method. This project is based on the measurement of transfer-induced decay probabilities in inverse kinematics at storage rings. The measured probabilities are then used to tune nuclear-reaction models that will provide much more accurate predictions of the desired neutron cross sections. But our ultimate goal is to directly measure neutron cross sections in inverse kinematics. This is the aim of a very ambitious and long-term project consisting in the combination of a radioactive beam facility, an ion storage ring and a spallation neutron source [2, 3]. We will discuss this project and possible realizations at different experimental facilities.

* For the NucAR collaboration (http://exp-astro.physik.uni-frankfurt.de/nucar/)

[1] Bo Mei et al., Phys. Rev. C 92 (2015) 035803
[2] René Reifarth and Yuri Litvinov, Phys. Rev. ST Accel. Beams 17 (2014) 014701
[3] R. Reifarth, K. Göbel, M. Weigand, B. Jurado, F. Käppeler, Y. A. Litvinov, Phys. Rev. Accel. Beams 20 (2017) 044701

Nov. 14th
11:20-11:50

Status of ELENA, the CERN Extra Low ENergy Antiproton ring

Presenter: Mr. ERIKSSON, Tommy
CERN

ELENA (Extra Low ENergy Antiproton ring) is an upgrade project at the CERN AD (Antiproton Decelerator). The smaller ELENA ring will further decelerate 5.3 MeV antiprotons from the AD ring down to 100 keV using electron cooling to obtain good deceleration efficiency and dense beams. An increase of up to two orders of magnitude in antiproton trapping efficiency is expected at the AD experiments. This paper will report on the current status of ELENA where beam commissioning is now taking place. Phase one of the ELENA installation has been completed with ring and injection lines in place, while phase two will finalize the project with removal of the present 5.3 MeV transfer lines and installation/commissioning of the new 100 keV lines connecting the experiments to ELENA. This will take place during the long CERN shut-down in 2019/2020 after successful beam commissioning of the ring.

Challenging the Standard Model by Comparisons of the Fundamental Properties of Baryonic Matter and Antimatter

Nov. 14th
11:50-12:20

Presenter: Dr. ULMER, Stefan

RIKEN, Ulmer Fundamental Symmetries Laboratory

The Standard Model (SM) is the theory that describes Nature's particles and fundamental interactions, although without gravitation. However, this model is known to be incomplete which inspires various searches for physics beyond. Among them are tests of charge, parity, time (CPT) invariance that compare the fundamental properties of matter/antimatter conjugates at lowest energy and with great precision. The physics program at the antiproton decelerator (AD) of CERN targets high-precision comparisons of the fundamental properties of antiprotons and protons, as well as antihydrogen and hydrogen.?Recent dramatic progress towards sensitive CPT tests with antihydrogen has been achieved by the ALPHA collaboration, which reported on the first observation of optical transitions in antihydrogen [1] and a first measurement of the ground state hyperfine splitting of the anti-atom at the level of 350 p.p.m. [2]. From spectroscopy of buffer-gas cooled antiprotonic helium, the ASACUSA collaboration extracted the antiproton-to-electron mass ratio with a fractional resolution of 0.8 p.p.b [3]. The BASE collaboration reported on the most precise comparison of the antiproton-to-proton charge-to-mass ratio with a fractional precision of 69 parts in a trillion [4] and ATRAP performed a measurement of the magnetic moment of the antiproton with a fractional accuracy of about 5 p.p.m. [5] which was later improved by a factor of six my BASE [6]. Another branch of experiments is dealing with tests of the weak equivalence principle by investigating antihydrogen in the earths gravitational field. Data-taking of the related AEgIS, ALPHA-g and GBAR collaborations is planned after CERNs long shut down in 2020. The talk will summarize the rapid progress accomplished at CERNs antiproton decelerator community in recent years.

[1] Ahmadi, M. et al., Nature 541, 506510 (2017)
[2] Ahmadi, M. et al., Nature 548, 66 (2017)
[3] Hori, M. et al., Science 354, 610 (2016)
[4] Ulmer, S. et al., Nature 524, 196 (2015)
[5] DiSciacca, J. et al. Phys. Rev. Lett. 110, 130801 (2013)
[6] Nagahama, H. et al., Nat. Commun. 8, 14084 (2017)

Nov. 14th
12:20-12:50

PUMA: antiprotons and radioactive isotopes

Presenter: Dr. OBERTELLI, Alexandre
TU Darmstadt

Antiprotons as probe for nuclear studies with short-lived radioactive isotopes remain unexploited despite past pioneer works with stable nuclei at CERN/LEAR and Brookhaven. Antiprotons may provide a one-of-its-kind sensitivity to the ratio of neutron and proton densities at annihilation site, i.e. at the very surface of the nucleus.?A new project, PUMA, aims at storing antiprotons in a Penning trap at CERN/AD/ELENA and at transporting them to ISOLDE where annihilation on short-live nuclei after capture will be measured. In this talk, the project will be introduced.

Nov. 14th
14:30-15:00

Recent applications and results obtained with of ISOLTRAPs multi-reflection time-of-flight mass separator/spectrometer (MR-ToF MS) and the adjunct Penning traps

Presenter: WIENHOLTZ, Frank
For the ISOLTRAP Collaboration: https://isoltrap.web.cern.ch/isoltrap/
CERN

The multi-reflection time-of-flight mass separator/spectrometer (MR-ToF MS) [1, 2] installed at the ISOLTRAP setup [3] at ISOLDE at CERN has proven to be a valuable asset to the setup, 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 that is recorded for every species can also be used to determine the masses of the beam constituents with sufficient precision for many physics topics. The use of the MR-ToF MS goes, however, beyond purification for mass-spectrometry [5,7,8] or actual mass measurements by itself [8-10]. It can also be used for decay spectroscopy on clean samples [6] or, in combination with the Resonant Ionization Laser Ion Source (RILIS) of ISOLDE, for in-source laser-spectroscopy measurements with background suppression [11]. Its capabilities also make it a very attractive tool for target and ion source optimization and ion yield determination [12]. The contribution will present recent examples of the applications mentioned above. Furthermore, it will present recent results that were obtained with the Penning traps.

[1] R.N. Wolf et al., Int. J. Mass Spectrom. 349-350, 123 (2013)
[2] R.N. Wolf et al., Nucl. Instrum. Meth. A 686, 82 (2012)
[3] G. Mukherjee et al., Eur. Phys. J. A 35, 1 (2008)
[4] S. Kreim et al., Nucl. Instrum. Meth. B 317, 492 (2013)
[5] R.N. Wolf et al., Phys. Rev. Lett. 110, 041101 (2013)
[6] N.A. Althubiti et al., submitted to Phys. Rev. C (2017)
[7] V. Manea et al., Phys. Rev. C 8, 054322 (2013)
[8] D. Atanasov et al., Phys. Rev. Lett. 115, 232501 (2015)

[9] F. Wienholtz et al., Nature 498 346 (2013)
[10] M. Rosenbusch M et al., Phys. Rev. Lett. 114 202501 (2105)
[11] B.A. Marsh et al., Nucl. Instrum. Meth. B 317, 550-556 (2013)
[12] A. Gottberg et al., Nucl. Instrum. Meth. B 336, 143-148 (2014)

Recent achievements at TITAN

Nov. 14th
15:00-15:30

Presenter: Dr. REITER, Moritz Pascal
TRIUMF, JLU

TRIUMFs Ion Trap for Atomic and Nuclear science (TITAN) is located at the Isotope Separator and Accelerator (ISAC) facility, Vancouver. Titan 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 short-lived exotic nuclei using its Measurement Penning Trap (MPET). In order to reach the highest possible precision, ions can be charge bred into higher charge states by an Electron Beam Ion Trap (EBIT), reducing the required excitation time for a needed precision. Thus using highly charged ions, TITAN is capable of performing mass measurements of short lived heavy species with high precision. Although ISAC can deliver high yields for some of the most exotic species, many measurements suffer from a strong isobaric background. This background often prevents the high precision measurement of the exotic species of interest. To overcome this limitation an isobar separator based on the Multiple-Reflection Time-Of-Flight Mass Spectrometry (MR-TOF-MS) technique has been installed recently at TITAN, similar to other ion trap on-line facilities. At TITAN the mass selection is achieved using dynamic re-trapping of the species of interest after a time-of-flight analysis in an electrostatic isochronous reflector system. Additionally the MR-TOF-MS enables mass measurements of very short-lived nuclides that are weakly produced, complementing TITANs existing mass measurement program of short-lived exotic nuclei. In this way TITAN is able to expand its mass measurements towards even more exotic isotopes produced at very low production yields. Results from recent high-precision mass measurements of super-allowed beta decays emitters, as well as mass measurements for nuclear structure and nuclear astrophysics will be shown employing singly and highly charged ions with MPET and the new MR-TOF-MS.

Nov. 14th
15:50-16:20

Nuclear reactions in the storage ring ESR with EXL

Presenter: Prof. KROELL, Thorsten
TU Darmstadt

EXL (EXotic nuclei studied in Light-ion induced reactions) is a project within NUSTAR at FAIR that aims to investigate nuclear structure at storage rings with direct reactions in inverse kinematics. The programme is mainly focussed on reactions with very low momentum transfers. The existing storage ring ESR at GSI provides a unique opportunity to perform part of the programme already now. We successfully performed experiments with stable ^{58}Ni as well as radioactive ^{56}Ni beams. The beams hit the internal gas-jet target (H2 or ^{4}He) and the respective target recoils were measured by a newly developed UHV compatible Si detector setup [1]. The first physics goal was to deduce the nuclear matter radius of ^{56}Ni from elastic proton scattering at 390 MeV/u [2]. This experiment can be considered as the first successfully observed nuclear reaction with a stored radioactive beam ever. As a proof of principle experiment, a ^{58}Ni beam at 100 MeV/u was impinged on a ^{4}He target. Besides elastic scattering [3], in inelastic scattering the excitation of the isoscalar giant monopole resonance was observed [4]. This first experimental campaign has successfully demonstrated the feasibility of the EXL concept and first physics results have been obtained. The status of the project and the possibilities for an upgraded detector setup covering a larger solid angle and further reaction experiments in the storage rings - CRYRING, ESR and HESR - at FAIR are presented.

This work was supported by German BMBF (06DA9040I,05P15RDFN8 and 05P15RDFN1), the European Commission within the Seventh Framework Programme through IA-ENSAR (contract No. RII3-CT-2010-262010), the Hungarian NKFI Foundation No. K124810, the Sumitomo Foundation, the National Natural Science Foundation of China (contract No. 11575269), the HGF through the Helmholtz-CAS Joint Research Group HCJRG-108, HIC for FAIR, GSI-RUG/KVI collaboration agreement, TU Darmstadt-GSI cooperation contract and the STIBET Doctoral program of the DAAD. The contribution will be given on behalf of the EXL-E105 collaboration.

[1] B. Streicher et al., NIM A 654, 604 (2011); M. Mutterer et al., Phys. Scr. T166, 014053 (2015)
[2] M. von Schmid et al., submitted; M. von Schmid (doctoral thesis, TU Darmstadt, 2015)
[3] J.C. Zamora et al., Phys. Rev. C (in press)
[4] J.C. Zamora et al., Phys. Lett. B 763, 16 (2016); J.C. Zamora (doctoral thesis, TU Darmstadt, 2016)

The EXL* Project - Present Status and Future Perspectives at FAIR

Nov. 14th
16:20-16:50

Presenter: Prof. EGELHOF, Peter

GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

The investigation of direct reactions with radioactive beams in inverse kinematics has already been proven to be a valuable tool for providing important information on the structure of exotic nuclei. In particular, it turned out that in many cases essential nuclear structure information can be deduced from high-resolution measurements at low momentum transfer. Such experiments can favourably be performed with the new and innovative method of using stored and cooled radioactive beams interacting with thin internal targets at storage rings. This technique, due to the thin windowless targets and due to beam cooling, enables high resolution measurements down to the region of low momentum transfer with very low recoil energies, and provides a gain in luminosity from accumulation and recirculation of the radioactive beams. A brief overview on the EXL* project will be given, followed by a discussion of experimental techniques for reaction studies at internal targets of storage rings. Finally the plans for future EXL experiments at the international facility FAIR, presently under construction, will be presented.

* EXL: EXotic nuclei studied in Light-ion induced reactions at the NESR storage ring

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Selective separation of the reactions products in the ESR at GSI

Nov. 14th
16:50-17:10

Presenter: Dr. LITVINOV, Sergey

GSI Darmstadt

Proton capture reaction (p,gamma) is a key reaction for the p-process nucleosynthesis. Recently, this nuclear reaction has been experimentally investigated in the ESR storage ring at GSI [1].?A big issue for such experiments in magnetic storage rings is an impossibility to resolve desired (p,gamma)-daughters from other unwanted species which have almost the same mass-to-charge ration (m/q) and can be produced from the electron-capture or electron-loss of mother ions in the internal target or with a residual gas. However, applying a special ion-optical scheme we can extract all reaction products out of the ESR and put them into electrostatic field where (p,gamma)-daughters can easily be selected and detected. Here, the corresponding ion-optical simulations will be presented and a possibility of the usage similar scheme for the low-energy ring CRYRING [2] will be discussed. The ESR is a worldwide known powerful instrument for precise beta-decay experiments with stable and exotic highly-charged ions [3]. Beta-decay daughters can only be stored and detected if the decays occur in the two straight sections of the ESR. The daughters with same (m/q) appearing in different straight sections will have different trajectories in the ring and therefore, come on different positions in the detector [4]. Thus, we can select the nuclei of interest, scraping unwanted daughters and another same (m/q) species (electron capture by mother ion in the cooler section) in the other part of the ring. We present here experimental results from two ESR experiments and the corresponding ion-optical simulation.

November 15th (Wed.)

Status and challenges of high intensity heavy ion accelerator facility (HIAF) in China

Nov. 15th
9:30-10:00

Presenter: Prof. YANG, Jiancheng
Institute of Modern Physics, Chinese Academy of Sciences

HIAF (High Intensity heavy ion Accelerator Facility) is a proposed new accelerator facility in China. The facility is being designed to provide intense primary and radioactive beams for a wide range of research fields. The HIAF facility plan was approved by central government of China in December 2012. The final approval of central government was in December 2015. The machine studies are now mainly focused on design optimization and key technical R Projected funding for HIAF is estimated to be up to $500 million and the approximately 8-year period is expected to design and construct the facility. The unique features of the first phase of HIAF are high current pulsed beams from iLinac and high intensity heavy ion beams with ultra-short bunch length from BRing. The cooled rare isotope beams also will be prepared through projectile-fragmentation (PF) method and advanced beam cooling technology. To reach the main goals of the HIAF facility, there are still several technical challenges such as operation with high intensity beams, control of the dynamic vacuum pressure, beam compression for very short pulse beam and the design of Nuclotron-type superconducting magnets. For most of those challenges solutions have been found and prototypes are being built through close international collaborations. The general description, accelerator challenges and present status are given in the presentation.

Project of Ion Collider NICA at JINR

Nov. 15th
10:00-10:30

Presenter: Prof. SYRESIN, Evgeny
JINR

The Nuclotron-based Ion Collider fAcility (NICA) is under construction at JINR. The NICA goals are providing of colliding beams for studies of hot and dense strongly interacting baryonic matter and spin physics. The collider experiments will be realized with heavy ions Au^{79+} at the energy range of $\sqrt{s_{NN}}$ =4-11 GeV and average luminosity $10^{27}cm^{-2}s^{-1}$. Two modes of operation are foreseen, collider mode and extracted beams with two detectors: MultiPurpose Detector MPD and Baryonic Matter at Nuclotron BM@N. The polarized beams will be operated at the energy range of $\sqrt{s}$ =12-27 GeV for protons and $\sqrt{s_{NN}}$ =4-13.8 GeV for deuterons at average luminosity 10^{30}cm^{-2}s^{-1}. The accelerator facility of collider NICA consists of following elements: Alvarez-type linac LU-20 of light ions at energy 5 MeV/u, heavy ion linac HILAC with RFQ and IH DTL sections at energy 3.2 MeV/u, superconducting booster synchrotron at energy up 600 MeV/u, acting superconducting synchrotron Nuclotron at gold ion energy 4.5 GeV/n and two collider storage rings with two interaction points. The present status of NICA project is discussed in the talk.

Nov. 15th
10:30-11:00

ILIMA project: isomeric beams, lifetimes and masses at the FAIR storage rings

Presenter: Dr. YAMAGUCHI, Takayuki
Saitama University

Today challenge is to measure the masses and the lifetimes of exotic nuclei far from the stability line. They are the basic properties to figure out nuclear structure evolution over the chart of nuclides and to reveal the mysteries of astrophysical element syntheses. To extend the success at the existing FRS-ESR facility, the international collaboration ILIMA (Isomeric beams, lifetimes and masses) aims at precision experiments at the storage rings in FAIR (Facility for antiproton and ion research). The fragment separator Super-FRS provides exotic beam to be stored in the ring for a sufficient period of time. Two methods are employed for precision mass measurements: Schottky mass spectrometry for electron-cooled beam of long-lived nuclei, and isochronous mass spectrometry for short-lived nuclei. A great advantage of both methods is the single-ion sensitivity. An excellent mass resolving power of storage ring technique can also create pure isomeric beams. Highly charged radioactive ions show unique decay phenomena, such as bound-state beta decay. Along with the achievements in the ESR experiments, we will present the status and the future plan of ILIMA project.

Nov. 15th
11:20-11:50

Precision mass measurement of short-lived nuclides at CSRe

Presenter: Dr. WANG, Meng
Institute of Modern Physics, Chinese Academy of Sciences

Mass measurements of short-lived nuclei have been conducted using an isochronous mass spectrometry (IMS) technique at HIRFL-CSR (Cooler Storage Ring) in Lanzhou. The radioactive nuclei were produced by projectile fragmentation and injected into the experimental storage ring CSRe. Revolution times of the ions stored in the CSRe were measured, from which masses of short-lived nuclei have been determined with a relative uncertainty of about $10^{-6} \sim 10^{-7}$. Based on the precise results, some issues in nuclear structure and nuclear astrophysics have been addressed. In this talk, the technical improvements will be presented and some typical results will be introduced. We also outline the plans for future experiments.

The isochronous mass sepctrometry of ^{112}Sn fragments and the calculation of rp and vp process

Nov. 15th
11:50-12:10

Presenter: Mr. XING, Yuanming

Institute of Modern Physics, Chinese Academy of Sciences

The masses of neutron-deficient nuclides ^{79}Y,^{81,82}Zr,^{83,84}Nb have been precisely measured by the isochronous mass spectrometry of ^{112}Sn experimental storage-ring at Lanzhou, China. Besides the measurements, the masses of the neighboring N=Z nuclides are also extrapolated based on these new measured mass values. These nuclides are just located at the rp and vp process pathway and have an important impact on the related nucleosynthesis along the proton-drip line.

Lifetime of exponential decay determined via statistical approaches

Nov. 15th
12:10-12:30

Presenter: CHEN, Xiangcheng

Institute of Modern Physics, Chinese Academy of Sciences

Radioactive particles decay exponentially with a rate characterized by the lifetime. To evaluate this parameter from the experimental data, the least-squares fitting to an exponential function seems to be a standard method and widely adopted by nuclear spectroscopists. However, when the data size becomes scarce, the fitting may lead to an inaccurate result, or even fails due to the irregular histogram to be fitted with. We hence, from the statistical basis, tried to tackle this problem. In the development of our method, the finite observing time constraint for the decay process, which is encountered in almost every experiment, was also incorporated. Various experimental scenarios that can arise from the constraint were fully addressed, and the method was adapted accordingly. As an example, this method was applied in the data analysis for the isomeric transitions of bare ^{94m}Ru, which were measured by the isochronous mass spectrometry CSRe in Lanzhou. The validity of this method was supported by the nice agreement between the measured lifetime and the literature value. This work has recently been peer-reviewed and published in Phys. Rev. C (DOI: 10.1103/PhysRevC.96.034302).

Nov. 15th
14:30-15:00

RIBF - recent activities and highlights -

Presenter: Dr. SAKURAI, Hiroyoshi
RIKEN Nishina Center for Accelerator-Based Science

"Exotic nuclei" far from the stability line are unique objects of many-body quantum system, where ratios of neutron number to proton number are much larger or much smaller than those of nuclei found in nature.?Their exotic properties and phenomena emerge from their large isospin asymmetry, and even affect scenarios of nucleosynthesis in universe. To access nuclei far from the stability line, especially neutron-rich nuclei, the "Radioactive Isotope Beam Factory (RIBF)" facility at RIKEN, Japan was constructed to deliver intense radioactive isotope (RI) beams and the operation started in 2007. The RIBF facility is highly optimized for in-flight production of fission fragments via a U beam. Super-conducting Ring Cyclotron (SRC) in the accelerator complex delivers a 345 MeV/u U beam. The U nuclide is converted at a target to fission fragments. An in-flight separator BigRIPS was designed to collect about 50% of fission fragments produced at the target and separate nuclei of interest. The RI beams produced at BigRIPS are then delivered to several experimental devices. In this talk, research activities at RIBF would be introduced and special emphasis would be given to selected recent highlights obtained from RIBF.

Nov. 15th
15:00-15:30

Mass measurements of short-lived nuclei with a multi-reflection time-of-flight mass spectrograph - recent results and future plans -

Presenter: Prof. WADA, Michiharu
WNSC, IPNS, KEK, RIKEN Nishina Center

We developed a multi-reflection time-of-flight mass spectrograph (MRTOF-MS), which is an electrostatic ion storage device, for precise mass measurements of short-lived nuclei [1,2]. The masses of more than 80 nuclei, including mendelevium and einsteinium isotopes, were measured [3,4,5] at the gas-filled recoil ion separator (GARIS-II) of RIKEN RIBF. We achieved a relative precision of 3.5×10^{-8} (2.1 keV/c^2 in mass excess uncertainty) for ^{65}Ge isotope with a high statistics measurement [5] and 10^{-7} level precisions for very short-lived (T1/2 $\approx$ 10 ms) Ra isotopes. We have shown that the MRTOF-MS is the most promising mass spectrometer for those nuclei having lifetimes of 10-100 ms with precisions of 10^{-7} level and reasonably high efficiencies. We will place multiple MRTOF-MS setups at three different RI-beam facilities, the new GARIS-II, the KEK Isotope Separator System and the BigRIPS + SLOWRI to perform comprehensive mass measurements of short-lived nuclei including hot fusion super heavy elements such as nihonium and moscovium.

[1] P. Schury et al., NIM B 335 (2014) 39
[2] Y. Ito et al., Phys. Rev. C 86 (2013) 011306
[3] P. Schury et al., Phys. Rev. C 95 (2017) 011305(R)
[4] Y. Ito et al., submitted. (arXive: 1709.06468)
[5] S. Kimura et al., submitted. (arXive: 1709.00186)

Direct mass measurements of neutron-deficient Actinium and Radium isotopes; Probing indirect mass links in the region of heavy nuclei

Nov. 15th
15:30-15:50

Presenter: Dr. ROSENBUSCH, Marco

RIKEN Nishina Center of Accelerator-Based Science

The two-body nature of the alpha decay and the precision of energy measurements achieved by experimental devices made nuclear alpha-spectroscopy become one of the most relied upon techniques for accurate linking of nuclear masses. Based on a nucleus of well-known mass serving as anchor point, masses of all mother and daughter nuclei that possess an alpha-decay channel can be determined precisely by the energy of the emitted alpha particles. However, for indirectly-determined masses in general a confirmation by direct mass measurements is needed as the evaluation of masses from spectroscopic data can be influenced by presently unknown (especially low-lying) states in the daughters. Further, in some cases complicated spectra include a large number of isotopes at the same time where difficulties arise for interpretation. In such cases as, e.g., the beta-decaying ^{150}Ho (in the 1990s [1]), direct measurements with high precision can cause large corrections of the adopted mass value. At the in-flight facility GARIS behind RILAC at the RIKEN Nishina Center of Accelerator-based science, the nuclides $^{210-214}$Ac have been produced by ^{169}Tm(^{48}Ca,xn)$^{217-x}$Ac and $^{210-214}$Ra by ^{169}Tm(^{48}Ca,pxn)$^{216-x}$Ra reactions. Direct atomic-mass measurements of these isotopes have so far been carried out only for $^{211,213-214}$Ra [2-4] by Penning-trap mass spectrometry at ISOLDE/CERN and GSI/Darmstadt. The other isotopes have been investigated by alpha spectroscopy from the 1960s on (see e.g. [5]) and more recently by alpha-gamma coincidence measurements performed at GSI (see e.g. [6,7]). In this contribution, direct mass measurements of the complete isotope set from from multi-reflection time-of-flight mass spectrometry (MRTOF-MS), will be presented. The previously adopted mass values could be confirmed in favor of alpha-gamma coincident measurements. Among the results, an outline for desired future measurements will be given and the SHE-mass facility of RIKEN/KEK as well as the data-analysis procedure will be discussed.

[1] D. Beck et al., Eur. Phys. J. A 8, 307 (2000)
[2] C. Weber et al., Nucl. Phys. A 803, 1 (2008)
[3] M. Kowalska et al., Eur. Phys. J. A 42, 351 (2009)
[4] C. Droese et al., Eur. Phys. J. A 49, 13 (2013)
[5] K. Valli et al., Phys. Rev. 167-4, 1094 (1968)
[6] F.P. Heßberger et al., Eur. Phys. J. A 8, 521 (2000)
[7] F.P. Heßberger, S. Hofmann, D. Ackermann, Eur. Phys. J. A 16, 365 (2000)

Nov. 15th
15:50-16:10

High precision mass measurements of intermediate-mass neutron-deficient nuclei via MRTOF-MS

Presenter: KIMURA, Sota
University of Tsukuba

Nuclear masses along the $N = Z$ line up to the ^{100}Sn region are crucial in determining the *rp*-process pathway which drives explosive astronomical phenomenon called type I X-ray burst. The *rp*-process has several waiting-point nuclei such as ^{64}Ge, ^{68}Se, and ^{72}Kr, and its pathway strongly depends on their effective lifetimes. They depend exponentially on their Q-values of one- and two-proton capture reaction. Those Q-values are determined by their nuclear masses and the uncertainties of smaller than 10 keV are required to significantly improve the precision of *rp*-process calculations. Half lives of the key nuclei, which determine the effective lifetimes of waiting point nuclei, are of the order of several tens to several hundreds of milliseconds. The multireflection time-of-flight mass spectrograph (MRTOF-MS) has an advantage in achieving precision mass measurements for short-lived nuclei owing to its measurement time less than 10 ms. The SHE-mass facility combining the gas-filled recoil ion separator GARIS-II with MRTOF-MS has been developed to enable mass measurements of superheavy elements (SHE) produced at RIKEN, is also applicable to mass measurements of *rp*-process nuclei. Precision mass measurements of ^{63}Cu, $^{64-66}$Zn, $^{65-67}$Ga, $^{65-67}$Ge, ^{67}As, ^{78,81}Br, $^{79\mathrm{m}}$Kr, $^{80,81\mathrm{m}}$Rb, and ^{79,80}Sr were performed with the SHE-mass facility. In this experiment, for ^{65}Ga, a mass uncertainty of 2.1 keV, corresponding to a relative precision of $\delta m/m = 3.5 \times 10^{-8}$, was obtained and the mass value was in excellent agreement with the 2016 Atomic Mass Evaluation. We found discrepancies between our measured mass values and literature values for ^{67}Ge and ^{81}Br, whose masses were previously evaluated by indirect measurements. We will report initial efforts using the SHE-mass facility for masses of *rp*-process nuclei, and will discuss future plans based on the existing results.

Nov. 15th
16:30-17:00

Results from the Cryogenic Storage Ring CSR

Presenter: Dr. GEORGE, Sebastian
Max-Planck-Institut fr Kernphysik

The Cryogenic Storage Ring (CSR) [1] located at the Max-Planck-Institut fr Kernphysik in Heidelberg marks a new generation of purely electrostatic storage devices. With a circumference of 35m constructed in a fully cryogenic environment this large scale experimental setup guarantees storage of ion beams up to 300 keV ranging from small atoms and diatomic systems up to large biomolecules. By cooling the experimental chambers down to 6 K extreme vacuum conditions with a rest-gas density lower than 100 particles per cm^3 (corresponding to less than 10-14 mbar pressure at 300 K) can be reached, which ensures storage times of several hours for fast ion beams [1]. In addition, the low ambient temperatures of a few Kelvin offer ion beam storage under conditions where warming by blackbody radiation can be almost neglected in comparison to standard laboratory experiments. Under such extreme conditions infrared active molecules can cool down to the rovibrational ground state via radiation. A comprehensive experimental program aims at investigating ground-state properties and collisions of molecular and cluster ions with neutral particles or electrons in the gas phase. First experiments addressed the rotational cooling of stored diatomic ions in the ambient radiation field at cryogenic temperatures. The rotational relaxation of CH^+ cations stored in the CSR were reported [2]. Furthermore, the internal state population of OH^- were monitored up to 1200s by near-threshold photodetachment [3]. The state resolved relative photodetachment cross sections for the three lowest rotational states at employed photon energies were measured with a precision of about 10%. Hence the equilibrium population distribution of OH^- can be determined almost independently of theoretical cross-section calculations. As the data show a radiative temperature in the CSR of 15.3(3) K at equilibrium 90% of the population are in the rovibrational ground state. Thus, CSR demonstrated its capability for cluster and molecular studies in lowest quantum states. Very recently an electron cooler was brought into operation, being the first one in an electrostatic storage device. Results and future perspectives will be discussed.

[1] R. von Hahn et al., Rev. Sci. Instrum. 2016, 87, 063115
[2] A.P. O'Connor et al., Phys. Rev. Lett. 2016, 116, 113002
[3] C. Meyer et al., Phys. Rev. Lett. 2017, 119, 023202

Cryogenic ion storage ring RICE for atomic and molecular physics

Nov. 15th
17:00-17:30

Presenter: Dr. NAKANO, Yuji
Rikkyo University

The RIKEN Cryogenic Electrostatic ring (RICE) has been build and commissioned with simple atomic and molecular ions at ∼10 keV beam energies [1]. The entire vacuum chamber of the storage ring was cooled by GM cryocoolers down to 4.2 K. This brought the ring into an extremely low-pressure condition, which suppressed the unwanted collisions between stored ions and residual gases in the ring. The cryogenic condition is also crucial for molecular ion beams because their vibrational and rotational transitions lie below the energies of black-body radiation from the room-temperature surfaces. In the commissioning run, the storage lifetime of a 15-keV Ne^+ ion beam was measured to be 780 s. This estimated the residual gas density at a few 10^4 cm^{-3}, and thus, the room-temperature-equivalent pressure of the ring at around 1×10^{-10} Pa. Currently, RICE is working for precise molecular structure and reaction studies through a high-resolution laser spectroscopy. At the same time, beam injections from a cryogenic ion trap and a neutral beam source is ongoing for various collision experiments. The latest status will be reported.

[1] Y. Nakano et al., Rev. Sci. Instrum. 88, 33110 (2017)

November 16th (Thus.)

Application of a compact ion trap to fundamental beam-dynamics studies

Nov. 16th
9:30-10:00

Presenter: Prof. OKAMOTO, Hiromi
Hiroshima University

A novel experimental approach has been established at Hiroshima University to explore diverse fundamental issues in accelerator physics. The compact apparatus developed in Hiroshima is called "S-POD" (Simulator of Particle Orbit Dynamics) that enables us to reproduce the complex collective behavior of an intense hadron beam in a local tabletop environment. The idea is based on the fact that the collective beam motion in a modern alternating-gradient accelerator is approximately equivalent to the motion of a non-neutral plasma confined in a linear Paul trap. A brief summary is given of some recent experimental results obtained with S-POD. Particular attention is paid to the resonant beam instability originating from the periodic nature of the electromagnetic potential in a storage ring. Several common misconceptions about collective resonances are clarified through typical S-POD data and theoretical predictions.

First result from SCRIT electron scattering facility with ^{132}Xe target

Nov. 16th
10:00-10:30

Presenter: Dr. TSUKADA, Kyo
ELPH, Tohoku University

We have developed the SCRIT (Self-Confining RI Ion Target) electron scattering facility for realizing electron scattering off unstable nuclei at RIKEN in Japan. Electron scattering provides the most powerful and reliable information about the structure of atomic nuclei as demonstrated for stable nuclei in the latter half of the 20th century. It has, however, never been applied for short-lived unstable nuclei with few exceptions due to difficulties of preparing the target. The SCRIT is a novel technique to achieve the high luminosity of more than 10^{27} [$cm^{-2}s^{-1}$] with a small amount of target ions, typically 10^8, by trapping the target ions on the electron beam.

After the completion of the construction of the facility, the commissioning experiment with several stable nuclear targets have been performed to study performances of spectrometers and ion transportation systems. Recently, we carried out a series of elastic electron scattering for ^{132}Xe target with the electron beam energy of 151, 201, and 301 MeV, and verified that the nuclear shape could be extracted by the obtained spectra with only 10^8 target ions. In this talk, we will present the first result from SCRIT electron scattering facility, and future plans to realize experiments with unstable nuclear targets.

Nov. 16th
10:30-10:50

Properties of ion trapping inside the electron storage ring at the SCRIT experiment

Presenter: ENOKIZONO, Akitomo
RIKEN

SCRIT (Self-Confining RI Ion Target) is an unprecedented technique to three-dimensionally trap short-lived radioactive isotope (RI) ions inside the electron storage ring, and make it possible to achieve a high luminosity of the electron-RI scattering. The luminosity of electron-target ion scattering by the SCRIT technique, however, depends on various factors related to the ion trapping power e.g. the mass and charge state of target and residual gas ions, the electron beam energy, current and condition, etc. Hence, to understand the detailed properties of the ion trapping inside the electron storage ring, which have never been measured before, is crucial to achieve a higher luminosity and a better S/N condition. The luminosity monitor (LMon) was designed to measure the count rate of bremsstrahlung photons emitted from electron-RI scattering and estimate the absolute luminosity using the calculatable cross-section of the bremsstrahlung process. Measuring the absolute luminosity is needed to obtain the angular differential cross-section of the electron-RI scattering for a wide effective momentum transfer region, but we soon realized LMon is also a powerful device to get insights into the properties of ion trapping. In 2015-2016, commissioning experiments using ^{132}Xe target has been carried out at the electron beam energy of 151, 201 and 301 MeV. In this presentation, we will report the properties of ion trapping by the SCRIT technique revealed by the LMon in addition to the the performance and luminosities measured with the commissioning experiments.

IGISOL facility at ELI-NP

Nov. 16th
11:10-11:30

Presenter: Prof. BALABANSKI, Dimiter
ELI-NP, IFIN-HH

The advent of the ELI-NP research facility will provide a new set of research tools to the field of nuclear physics: high power laser systems and high brilliance gamma beams, used together or separately [1]. A diverse research program in the field of nuclear science and applications is under preparation at ELI-NP [2-5]. One of the experimental programs proposed at the facility are nuclear structure studies with radioactive isotope beams generated via photo-fission of actinide targets exposed to the high-intensity gamma beam [6]. Experimental studies of the structure of exotic neutron-rich nuclei produced by photo-fission, in particular isotopes of refractory elements, are of great interest and require the development of an IGISOL-type facility. The status of the project will be reported with an emphasis on the design of the cryogenic stopping cell, which will be used for the production and extraction of the beams of the isotopes of interest. The optimal design of the cell will be discussed. Benchmark calculations of the photo-fission rates and of the rates of related background processes will be presented [7]. Simulations of the plasma effects in the gas cell will be discussed [8] and estimates for the extraction time and extraction efficiency of the fission fragments will be provided. The considered rare-isotope beamlines will be discussed, too, as well as the experimental program which is under consideration at the facility.

[1] N. V. Zamfir, Nucl. Phys. News 25:3, 34 (2015)
[2] ELI-NP TDR teams, Rom. Rep. Phys. 68S (2018)
[3] D. Filipescu et al., Eur. Phys. J. A 51 (2015) 185
[4] S. Gales et al., Phys. Scr. 91 (2016) 093004
[5] D.L. Balabanski et al., Europhys. Lett. 117 (2017) 28001
[6] D.L. Balabanski et al., Rom. Rep. Phys. 68 (2016) S621
[7] P. Constantin, D.L. Balabanski, P.V. Cuong, Nucl. Inst. Meth. B 372 (2016) 78
[8] P. Constantin, D.L. Balabanski, L.T. Anh, P.V. Cuong and B. Mei, Nucl. Inst. Meth. B 397 (2017)

*Extreme Light Infrastructure Nuclear Physics (ELI-NP) Phase II is a project co-financed by the Romanian Government and the European Union through the European Regional Development Fund the Competitiveness Operational Programme (1/07.07.2016, COP, ID 1334).

Nov. 16th
11:30-11:50

Past and future of Rare-RI Ring

Presenter: Dr. OZAWA, Akira
Institute of Physics, University of Tsukuba

We will present past and future of Rare-RI Ring (R3). In R3, heavy ion storage ring, TARNII in INS, Univ. Tokyo, was reused. We will introduce brief history of R3 from TARNII in this talk. Main purpose of R3 is mass measurements for extremely neutron-rich nuclei. However, R3 has a big potential to extend its research subjects to other. In this talk, we will also discuss future of R3 including mass measurements.

November 17th (Fri.)

Experimental results of high energy electron cooling at COSY

Nov. 17th
9:30-10:00

Presenter: Dr. KAMERDZHIEV, Vsevolod

Forschungszentrum Jülich, IKP-4

COSY, a COoler SYnchrotron and storage ring has been initially equipped with a low energy electron cooler. It was mainly used to improve the quality of the beams extracted to fixed-target experiments, to enable transverse stacking of polarized beams to be used with targets in the ring, and to improve the beam lifetime for internal experiments. In 2013 a high-energy e cooler covering the entire energy range of COSY (up to 2,88 GeV for protons) was added. Since then high-energy e cooling has been demonstrated together with stochastic cooling and dedicated cooling beam studies with dc and bunched proton beam have been performed. Furthermore, we took a first look at the e cooling process in presence of an internal cluster jet target continuously affecting the beam circulating in the machine. We review the status of electron-cooling activities at COSY, present the latest experimental results, and discuss problems encountered and possible cures.

Search for Electric Dipole Moment in Storage Rings

Nov. 17th
10:00-10:30

Presenter: Prof. LENISA, Paolo

University of Ferrara and INFN

An electric dipole aligned along the spin axis of a fundamental particle, nucleus, or atomic system violates both parity conservation and time reversal invariance. The observation of such a phenomenon would, at present or proposed levels of experimental sensitivity, signal new physics beyond the Standard Model. The usual method for identifying an electric dipole moment (EDM) in such searches is to observe the rotation of the spin axis or polarization under the influence of a strong electric field. The use of a storage ring opens the search to charged, polarized particles such as the proton, deuteron, ^{3}He, etc. that would otherwise not be manageable in such a field. The best procedure begins with the alignment of the beam polarization along the velocity of the beam followed by the observation of any slow rotation of that polarization into the vertical direction perpendicular to the ring.
Electric ring fields of the right strength or the correct combination of electric and

magnetic ring fields are needed to ensure that the polarization does not rotate relative to the velocity ("froze" spin). This imposes several feasibility requirements. First, the ring must utilize a special combination of higher order fields to ensure that the usually unstable polarization along the direction of the velocity remains for times up to 1000 s to allow any EDM effect to accumulate to a measurable level. Second, the beam must be slowly sampled during the storage time by a polarimeter capable of detecting a change in the vertical polarization of several ?rad over the 1000 s storage time. The required large polarimeter efficiency and polarization sensitivity may be achieved by continuously extracting the beam onto a carbon target several cm thick. Dedicated studies are presently performed at the COSY Storage Ring at FZ-Juelich. Recently it was successfully demonstrated the use of higher-order (sextupole) fields in the storage ring to lengthen the coherence time of the stored, horizontal beam polarization. In addition, unprecedented precision in the measurement of spin-tune has been reached allowing the implementation of a control system for the phase of the spin-processing beam. This presentation is meant to provide a general introduction to the EDM search by means of polarized beams in storage rings and to highlight the developments at the COSY ring towards the first direct measurement of the deuteron EDM.

Nov. 17th
10:30-10:50

Time Reversal Invariance Test at the COSY ring

Presenter: Dr. CIULLO, Giuseppe
University of Ferrara and INFN

It is everybody's experience that, in the macroscopic world, movies running backwards do not reproduce the behavior of everyday reality; however, even if time reversal symmetry is neither necessary nor desirable for the description of Nature, it has been a property of the laws of physics throughout most of its historical evolution: Newtonian celestial mechanics, Maxwell's electrodynamics and Einstein's general relativity, all respect it. Nevertheless, it is now well understood that time reversal violation (T-V), like the equivalent violation of the combined symmetries of charge (C) and parity (P) (CP-V), is a necessary ingredient for modern theories to address the mystery of matter-antimatter asymmetry of our Universe. The unique experimental environment offered by the COSY storage ring at Forschungszentrum-Jlich (Germany) promises to improve the present limit on T-V by one to two orders of magnitude through a precise measurement of the double polarized proton-deuteron elastic scattering. The originality of the idea lies in the exploitation of the particle spin as a time reversal knob and of the accelerator itself as a zero degree spectrometer/detector. Given its Time Reversal Violating - Parity Conserving character, this investigation can be considered complementary to the searches for EDMs, originating by Time Reversal and Parity Violating interactions. After a general introduction, the presentation will give an overview about the status of the preparation of the experiment.

Review of the muon g-2 experiments at Fermilab and J-PARC and other applications

Nov. 17th
11:10-11:40

Presenter: Dr. PARK, Seongtae
IBS/CAPP

We, at the Center for Axion and Precision Physics Research (CAPP) of the Institute for Basic Science in Korea, are working on storage ring related precision physics research such as the muon g-2 experiments at Fermilab and J-PARK and the storage ring proton/deuteron EDM experiments. In this report, we give an overview of the muon g-2 experiments and discuss the recent research results on the CBO reduction with RF field at the Fermilab version of the experiment. An introduction to storage ring proton/deuteron EDM experiments is given and other CAPP activities related to the storage ring EDM experiment are also presented.

In-ring applications of UHV-compatible charged particle detectors

Nov. 17th
11:40-12:10

Presenter: Dr. DAVINSON, Thomas
University of Edinburgh

Storage rings offer a range of opportunities for nuclear physics research. High resolution studies of nuclear reactions producing low-energy charged particles require in-ring UHV-compatible detectors. The design, development and operation of such detectors is challenging. Examples of such detectors and experiments will be discussed and plans for an advanced, UHV-compatible silicon strip detector array for CRYRING will be presented.

Proton-capture studies on stored $^{124}Xe^{54+}$ for explosive nucleosynthesis

Nov. 17th
12:10-12:30

Presenter: Dr. GLORIUS, Jan
GSI Dramstadt

The nucleosynthesis of the so-called p nuclei is believed to occur in different stellar scenarios such as supernovae or x-ray bursts. In order to fully understand the nuclear reaction network evolving in such environments, it is crucial to diminish uncertainties in reaction rates and cross sections by measurement. The key reactions in the associated nucleosynthesis processes are often related to proton capture and it has been shown recently [1] that this type of reaction can be directly studied using decelerated beams at the ESR facility at GSI. In 2016 a successor experiment was carried out investigating the reaction ^{124}Xe(p,gamma) by storing $^{124}Xe^{54+}$ in the ESR and making use of the internal multi-phase hydrogen target [2]. For the first time in a nuclear reaction study at a storage ring the astrophysically relevant energy region below 6 MeV/u, the so-called Gamow Window, could be reached.?I will report about the experimental challenges, the current status of analysis and preliminary results. Additionally, an outlook to nuclear astrophysics experiments at the CRYRING@ESR facility will be given.

Nov. 17th
12:30-12:50

Laser spectroscopy at storage rings

Presenter: Dr. SANCHEZ ALARCON, Rodolfo Marcelo
GSI Dramstadt

I provide a brief overview on the laser spectroscopic experiments at the magnetic storage ring ESR at GSI and highlight the recent results obtained on the hyperfine measurements in bismuth. New opportunities at the high-energy storage ring at FAIR are also presented.

Nov. 17th
14:30-15:00

Mass measurement of exotic nuclei using Rare-RI Ring

Presenter: Dr. NAGAE, Daisuke
RIKEN

The Rare-RI Ring is an isochronous storage ring at RI Beam Factory of RIKEN. A mission of the ring is measuring masses of most neutron-rich nuclei related r-process nucleosynthesis. The Rare-RI Ring is based on the isochronous mass spectrometry technique to achieve a mass measurement with a precision of 10^{-6} in less than 1-ms measurement time. A demonstration of mass measurement for well-known nuclei ^{79}As, ^{77}Ga, ^{76}Zn, and ^{75}Cu have been performed. The isochronous magnetic field of the ring was adjusted for reference particle of ^{78}Ge. We confirmed the storage of particles by using an in-ring detector. We also successfully extracted these nuclei from the ring. The isochronous condition for the particles of interest is slightly different. To evaluate the masses of nuclei with non-isochronism, we correct the Time of Fright (TOF) in the ring by the velocity measured at upstream of the ring. Using their TOF in the ring and velocity, we deduced their masses. In this contribution, the result of the demonstration of mass measurement will be discussed.

Nov. 17th
15:00-15:20

Analysis of isochronism in Rare-RI Ring

Presenter: Dr. ABE, Yasushi
RIKEN

The Rare-RI Ring (R3) to measure masses of short-lived rare-RI with a relative precision of 10^{-6} was constructed at the RIKEN RI Beam Factory. A design concept of R3 is that one can determine mass with high precision independently of the RI beam quality such as momentum spread and emittance even a poor statistics. A large acceptance is necessarily required to accept hot RI beams. A precision of the isochronism is one of the key issues of R3, because it directly determines the precision in mass determination with a poor statistics expected for rarely produced exotic nuclei. In order to provide high-precision isochronism while having large acceptance, we designed the ring structure in analogy with that of a separate-sector ring cyclotron. Two outer magnets of each sector are additionally equipped by ten trim coils to form the isochronism. A commissioning experiment using ^{78}Ge

beam of 175 MeV/u as reference particle was performed last year. In the result, its revolution time was within 5.4×10^{-6} in standard deviation independent of the momentum. We simulated the revolution time for particles with finite emittance and momentum based on 4th-order Runge-Kutta calculation.
In this contribution, a comparison between the simulation and experimental results of isochronism will be presented. The isochronism that can be achieved by tuning of the trim coils will be also discussed.

A method to measure the transition energy of the isochronously tuned storage ring

Nov. 17th
15:20-15:40

Presenter: Dr. CHEN, Ruijiu
IMP

The Isochronous Mass Spectrometry (IMS) is a powerful technique developed in heavy-ion storage rings for measuring masses of very short-lived exotic nuclei. The IMS is based on the isochronous setting of the ring. One of the main parameters of this setting is the transition energy γ_t. It has been a challenge to determine the γ_t and especially to monitor the variation of γ_t during experiments. In this paper we introduce a method to measure the γ_t online during IMS experiments by using the acquired experimental data. Furthermore, since the storage ring has (in our context) a relatively large momentum acceptance, the variation of the γ_t across the ring acceptance is a source of systematic uncertainty of measured masses. With the installation of two time-of-flight (TOF) detectors, the velocity of each stored ion and its revolution time are simultaneously available for the analysis. These quantities enabled us to determine the γ_t as a function of orbital length in the ring. The presented method is especially important for future IMS experiments planned at the new-generation storage ring facilities FAIR in Germany and HIAF in China.

November 18th (Sat.)

Fundamental physics with cooled radioactive atoms

Nov. 18th
9:30-10:00

Presenter: Prof. SAKEMI, Yasuhiro
CNS, the university of Tokyo

An Electric Dipole Moment (EDM) of the elementary particle is a good prove to observe the phenomena beyond the Standard Model of particle physics. A non-zero EDM shows the CP violation, which is one of the important signals to understand the mechanism how the mater-antimatter asymmetry has been produces in our universe. In paramagnetic atoms, an electron EDM results in an atomic EDM enhanced by the factor of the 3rd power of the charge of the nucleus due the relativistic effect appeared in the heavy atoms. A heaviest alkali element francium (Fr), which is the radioactive atom, has the largest enhancement factor K $\sim$ 895. At present, we are developing a high intensity laser cooled Fr factory at Cyclotron and Radioisotope Center (CYRIC), Tohoku University to perform the search for the EDM of Fr with the accuracy of 10^{-29} e·cm. The laser cooling techniques are quite important to realize the high accuracy measurement of EDM, which can be achieved with the long interaction time using the optical lattice. In this talk, the present status and future plan of laser cooled RI EDM experiments will be discussed.

Performance of time-of-flight detector and demonstration of completely new position detector for mass measurements with the Rare-RI Ring

Nov. 18th
10:00-10:20

Presenter: Dr. SUZUKI, Shinji
University of Tsukuba

Development of the Rare-RI (Radioactive Isotope) Ring (R3) is in progress at the RI beam factory (RIBF) in RIKEN. The main purpose of the R3 is to measure the masses of the short-lived nuclei with the isochronous mass spectrometry. The mass-to-charge ratio of exotic nuclei is determined by the velocity of the nuclei and the revolution time of that in the R3. We are developing the time-of-flight detector which measures both the velocity of the ions, and the revolution time of that in the R3. For successful mass measurements, the detector must have the timing resolution of less than 100 ps, the detection efficiency of 100%, and be as thin as possible to minimize the change of velocity in the detector. In order to satisfy these requirements, the TOF detector utilizes secondary electrons emitted from a thin foil following the pioneer detectors used in the ESR at GSI and the CSRe at the IMP. For the small prototype detector, the satisfied timing resolution and the sufficient detection efficiency were obtained with the strong electromagnetic field except for an acceptance requirement. Keeping the strong electromagnetic field which improves performance of the detector, the present detector has the larger effective area (ϕ40 mm) than the previous prototype (ϕ15 mm) to accept the beam size of the RIBF. In addition to the TOF detector, a thin position detector to minimize the change of velocity of ions in the detector is needed for measuring the magnetic rigidity of ions at the momentum-dispersive focal plane. For this purpose, we present the completely new position detector which utilizes the principle of the TOF detector. To measure positions where ions pass through, the transport-time difference between forward electrons and backward electrons created at a thin foil is used. We made a prototype detector to demonstrate the principle of the position determination. The performance tests of the TOF detector and the position detector were carried out with the ^{84}Kr beams of 200 MeV/nucleons provided by HIMAC (Heavy Ion Accelerator in Chiba) in NIRS (National Institute of Radiological Sciences). For the TOF detector, the timing resolution achieved less than 100 ps, and the maximum detection efficiency recorded 99% in the preliminary results. For the position detector, we successfully observed a correlation between the transport time of secondary electrons and the horizontal positions at which ions pass through the foil. In the conference, we will show the design of these detectors and the results of the performance test of those.

Nov. 18th
10:20-10:40

Observation of ^{78}Kr stored in Rare-RI Ring with a resonant Schottky pick-up

Presenter: Dr. SUZAKI, Fumi
RIKEN Nishina Center

To measure the masses of unstable nuclei to a precision of 10^{-6}, Rare-RI Ring was constructed in RIKEN RI Beam Factory. The masses contribute to make clear the astrophysical r-process path. We employed the Isochronous mass spectroscopy method for the mass measurement. The achievement the level of 10^{-6} isochronous field is necessary for the goal precision. A resonant Schottky pick-up is developed as a monitor to tune the isochronous field setting. The resonant Schottky pick-up which has a pillbox-type resonant cavity can detect the induced signal by a circulating ion. The resonant Schottky pick-ups data contain the information about the revolution frequency of circulating ion. At the first commissioning of Rare-RI Ring, a ^{78}Kr^{36+} ion was detected by the resonant Schotkty pick-up. We confirmed that ^{78}Kr^{36+} was stored over 4 seconds in the ring with the data of Schottky pick-up. The detailed analysis is going on. In this contribution, we will present recent status of the resonant Schottky pick-up focusing on the commissioning.

QED tests with highly-charged ions: A theoretical perspective

Nov. 18th
11:00-11:30

Presenter: Prof. SURZHYKOV, Andrey
Physikalisch Technische Bundesanstalt

With the recent advances in ion storage rings and trap facilities, more possibilities arise to study collisions of highly-charged ions with atoms and electrons. Fundamental atomic processes, occurring during and following these collisions, may serve as valuable probes to explore many-body, nuclear and quantum electrodynamics (QED) effects in strong electromagnetic fields. In my talk, I will review recent theoretical investigations of the electronic structure and dynamics of highly-charged ions. Special emphasis will be placed to the question of how these studies help to develop our knowledge of nuclear properties. I will show how the atomic physics techniques provide access not only to the properties of the nuclear ground or isomeric states but also to the nuclear dynamics.

Tests of quantum electrodynamics and fundamental physics with stored highly charged ions

Nov. 18th
11:00-11:30

Presenter: Prof. INDELICATO, Paul
CNRS

I will give a review of current and proposed experiments designed to test fundamental physics and in particular bound state quantum electrodynamics (BSQED) with highly charged ions. I will focus on results obtained with storage rings and traps. I will show a detailed comparison between experiment and theory for transition energies in few electron ions and discuss on what is needed to improve tests of strong-field QED. I will also show how measurements of the ground state hyperfine splitting in few electron ions contributes to tests of BSQED in strong magnetic fields. Finally I will discuss of the expected impact of recent and future experiments measuring Landé g-factors and atomic masses of cold highly charged trapped ions. In particular I will discuss of new determinations of the fine structure constant in view of the probable adoption of a new, fundamental-constant based, international system of units in 2018.

Poster Session (November 17th (Fri))

Table of contents

P1: Status of the Spectrometer Ring design at the HIAF project

Presenter: Mr. WU, Bo (Institute of Modern Physics, Chinese Academy of Sciences)

The Spectrometer Ring (SRing) is an essential part of the High Intensity heavy-ion Accelerator Facility project (HIAF) in China. It is designed as a multi-functional experimental storage ring with three ion-optical operation modes. The SRing will be used as a time-of-flight mass spectrometer for short-lived, especially neutron-rich nuclei. It will also be used to collect and cool Rare Isotope Beams (RIBs) or highly-charged stable ion beams for nuclear physics and atomic physics experiments. The designed magnetic rigidity is in the range 1.5 to 15 Tm. The beam cooling system consists of stochastic cooling and electron cooling devices. With the help of electron cooling, the stored ions can be decelerated to a minimum energy of 30 MeV/u by the RF system. The extraction system of the SRing will allow the cooled ion beams to be extracted to the external target for further ion manipulation or reaction experiments.

P2: Ion-optical design and simulation of in-flight fragment separator HFRS at HIAF

Presenter: Dr. SHENG, Lina (Institute of Modern Physics, Chinese Academy of Sciences)

In order to study the properties of rare isotopes far away from the line of their beta stability and involved nuclear reactions of astrophysics interests, an in-flight superconducting FRagment Separator at HIAF (HFRS) with the maximum magnetic rigidity of 25 Tm is designed and will be constructed by the Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS). It will separate and purify the rare isotopes produced by the projectile fragmentation of all primary beams up to Uranium or by the fission of Uranium ions via a $B\rho$-ΔE-$B\rho$ method. The HFRS consists of two-stage magnetic system, Pre-Separator and Main-Separator. The Pre-Separator will produce and pre-separate the radioactive beams, and the Main-Separator will separate and identify the desired rare isotopes with two ion-optical modes for different experiment requirements. There are several important characteristics of HFRS, for example, a big magnetic rigidity, large beam acceptances and high momentum resolutions. In this report, the design and beam optics simulation of HFRS are presented, and the separation performance of 132Sn from the fission and of 100Sn from the fragmentation is discussed.

P3: Construction of a position sensitive resonant Schottky cavity

Presenter: Mr. DMYTRIIEV, Dmytro (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-upcavities 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.

Keywords: storage rings, Shottky detector, ion beam measurement

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P4: Performance and testing of ultra high vacuum compatible silicon strip detectors at GSI storage rings

Presenter: Mr. VARGA, Laszlo (GSI, Germany)

In the nucleosynthesis of the so-called p nuclei radiative capture reactions like (p,γ) or (α,γ) play an important role to model the reaction network and to explain the stellar production yields in different explosive scenarios [1]. The storage rings at GSI, the Experimental Storage Ring (ESR) and the CRYRING, provide unrivaled opportunity to allow the corresponding reaction studies. Both grant the storage of sufficient amount of ions in a nearly background-free environment for reaction studies in inverse kinematics. After the successful investigation of the cross section of 96Ru(p,γ) in 2009 [2] and the cross sections of 124Xe(p,γ) in 2016, the performance and commissioning of improved ESR and CRYRING detection system designs are carried out for the first experiments in 2018. The particle detection with a nearly 100% efficiency is realized by ultra high vacuum (UHV) compatible double-sided silicon strip detectors (DSSSD), which are excellent candidate to measure first time the proton-capture inside the Gamow-window using stored, radioactive ions.

References: [1] - M. Pignatari et al. 2016 Int. J. Mod. Phys. E 25 1630003 [2] - B. Mei et al., Phys. Rev. C92 (2015) 035803

P5: Preparation for the measurement of the bound-state beta-decay of bare 205 Tl ions at the ESR

Presenter: Mr. SIDHU, Ragandeep S. (GSI)

Bound-state beta-decay (β b) accompanied by the emission of a monochromatic antineutrino, was first predicted by Daudel et al [1] in 1947 and then discussed in detail by Bahcall [2]. The first direct observation of the bound-state beta decay (β b decay) was done in 1992 by Jung et al [3] with the use of bare 163 Dy 66+ ions stored in the heavy ion storage ring ESR at GSI. In the present study we aim to determine the bound-state beta-decay rate of fully-ionized 205 Tl, which is needed to determine the matrix element for the electron capture decay of the 2.3 keV excited state in 205 Pb to the ground state of 205 Tl. This matrix element is important for the determination of neutrino capture probability into the 2.3 keV state of 205 Pb [4] and for modelling the last stages of the s-process [5]. The experiment proposal has been already submitted and will be evaluated by the GSI program advisory panel. We aim to conduct the experiment in 2018, when the accelerator complex of GSI is going to restore its operation. In this presentation, the production of bare 205 Tl 81+ from 206 Pb beam, it's separation from contaminants, transmission, storage and beam preparation in the ESR, as well as detection of decay events and auxiliary calibration measurements will be discussed.

[1] R. Daudel, M. Jean and M. Lecoin, J. Phys. Radium 8, 238 (1947). [2] J. N. Bahcall, Phys. Rev. 124, 495 (1961). [3]M. Jung et al., Phys. Rev. Lett. 69, 15 (1992). [4]M.K. Pevicevic et al., Nucl. Instr. and Meth. A 621, 282 (2010). [5]J.B. Blake and D.N. Schramm, Astroph. J. 197, 615-629 (1975).

P6: Search for long-lived isomers in neutron-rich Hf isotopes in the Experimental Storage Ring

Presenter: Mr. KULIKOV, Ivan (GSI)

Isomers are long-lived nuclear states with nuclear properties different from the corresponding ground state formed by the same numbers of protons and neutrons. They can give a key information about nuclear structure, heavy-element nucleosynthesis and limits to particle stability. High-K isomers and their decays provide opportunity to study the high-spin structure especially in neutron-rich (A~190) region where protons and neutrons are in the upper regions of their respective shells (Z=50-82, N=82-126). These isomers are predicted to coexist with well-deformed collective oblate rotation [1]. Significant contributions to this research field have already been made by GSI with the successful identification of isomers in exotic nuclei, using projectile-fragmentation reaction, A/q and Z selection in the FRS and the final isomer identification in the storage ring ESR. For instance, 183mHf, 184m2Hf and 186mHf isomers were discovered along with their excitation energies and half-life measurement [2]. The observation of 188Hf and confirmation of previous isomers is one of goals of the new experiment at the Experimental Storage Ring at GSI. The details of the experiment and the present status of preparations will be presented.

References: [1]- G.D. Dracoulis et al., Rep. Prog. Phys. 79(2016) 076301. [2]- M.W. Reed et al., Phys. Rev. C 86 (2012) 054321.

P7: Multi-peak extraction from noisy Schottky spectra

Presenter: CHEN, Xiangcheng (IMP)

The idea of isochronous Schottky spectroscopy, which applies a Schottky resonator in the isochronous ion-optical mode of a storage ring, for the simultaneous measurements of masses and lifetimes has been proposed years ago. This novel technique saves the cooling time, which amounts to several seconds in the otherwise Schottky mass spectrometry, and hence pushes downwards the lower limit of the measurable lifetimes with a Schottky resonator. However, in the meantime, the large momentum dispersion of the fragmented beams as well as the imperfection of ion-optical settings will adversely affect the signal-to-noise ratios of the stored ions, thus hinder accurate detection for the mass measurements. Averaging over a number of consecutive Schottky spectra can, to some extent, mitigate this problem at the cost of degrading the time resolution for the lifetime measurements. Besides, the instability of the dipole magnets will also broaden the ion peaks after the averaging. We thus adapt the method of subspace-based system identification, which is commonly used in the field of control system, to the multi-peak extraction in Schottky data analysis. By simulations and tests on real-world data, this method allows for accurate frequency detection while retaining minimum time resolution. Potential applications of this method within the framework of Schottky data analysis are promising as it advances towards the realization of isochronous Schottky spectroscopy at CSRe in Lanzhou.

P8: The data acquisition system and preliminary data analysis program of Schottky detector at CSRe

Presenter: WANG, Qian (Institute of Modern Physics, Chinese Academy of Sciences)

To meet the requirement of the planned nuclear decay experiments at experimental cooler storage ring CSRe in Lanzhou, the new data acquisition system (DAQ system) and its corresponding preliminary data analysis program have been successfully established in 2016. The whole DAQ system is based on a spectrum analyzer (R FSVR), and an IQ recorder (R IQR 100) accompanied with an independent trigger (built on Arduino Yun). All the devices are connected to a server via Ethernet. To implement the data acquisition in an automatic way, its remote-control program, written in Python 3, has been developed. This program displays the real-time state of the processing devices and catches the keyboard to pause or terminate the process. The tests for this new system have been successfully completed in the mass measurement experiment in Dec. 2016. It satisfies the demands of successively collecting large amounts of measurement data. The preliminary data analysis program is based on nonparametric spectral estimation of power density spectrum for Schottky signal. Common window functions (Welch, Hamming, Hann and so on.) and multitaper method to reduce bias due to leakage are available in the program. The program displays both power spectrum at each sampling time and the waterfall plot of frequency versus time. By using this program, we could get a sharp time-frequency spectrogram of (_^40)Ar^(18+) (the particle of main beam) from one of the data files of Dec. 2016 mass measurement experiment.

P9: Basic study on delta-ray detection for in-ring revolution time determination

Presenter: Ms. INOMATA, Kumi (Saitama University)

The Rare-RI Ring facility [1] at the RI Beam Factory in RIKEN aims to measure the masses of exotic nuclei far from the stability line. The masses are derived from the revolution times of stored nuclei under the isochronous ion-optical condition. However, the Rare-RI Ring injects and stores only one particle in principle, conventional techniques of beam diagnostics in storage rings cannot be applied. A dedicated beam monitor is essential to adjust the injection scheme and to confirm ion storage in the ring. In this direction, we have already installed a thin timing detector which generates periodic pulses of a stored particle. Each time when a particle circulates, secondary electrons are emitted from a thin foil and are guided to a MCP (multi channel plate) by a static electric field. However, the efficiency varies depending on the charge of particle and the electronic noise condition. As an alternative of the present beam monitor, we are planning to use high-energy secondary electrons, delta-rays, directly emitted from a foil without any guiding electromagnetic field. The prototype successfully detected stored ions in a commissioning run. To improve the precision of revolution time determination, we systematically measured delta-ray angular distributions in the present study. From the result, we expect a timing resolution less than 100 ps for a practical detector. In this poster contribution, we will present the results of beam test at the HIMAC facility [2] and the future plan which will be implemented in near future.

References [1] A. Ozawa, T. Uesaka, M. Wakasugi, Prog. Theo. Exp. Phys. 2012 (2012) 03C009. [2] M. Kanazawa et al., Nucl. Phys. A746 (2004) 393c.

P10: Beam test of a long scintillating fiber as a position sensor for storage ring facility

Presenter: Ms. INOMATA, Kumi (Saitama University)

We report the result of beam test of a long scintillating fiber using a heavy ion beam 84Kr of 200 MeV/u. Recently scintillating fibers become popular in nuclear physics experiments. Fibers are low-cost and easy-handling so that they are employed to many applications. A conventional way of application is position sensitive detectors in nuclear and high-energy physics experiments. The working principle is straightforward; many thin fibers are arranged to be a flat plane, where a beam passing through generates the scintillating light pulses in each fiber that are read out by photo-sensors individually. The hit pattern of scintillating fibers is directly related to the beam position distribution. In the present study, we investigated a potential capability of a long scintillating fiber as a position sensor in a long beam line of accelerator facilities. As an example, in a storage ring facility, Rare-RI Ring [1], at the RI Beam Factory in RIKEN, long scintillating fibers could be a position sensor of beam diagnostics. Because the Rare-RI Ring injects and stores only one particle in principle, conventional devices are not employed. A long fiber along the storage ring circumference could be a useful tool of beam diagnostics, in particular during injection sequence. In a test experiment, a 200-MeV/u 84Kr beam was irradiated on several positions in a scintillating fiber of 18 m. The scintillating light is read out from both ends of the fiber through MPPCs (multi-pixel photon counter). A position resolution of a few centimeters was obtained. In this poster contribution, we will present the result of beam test detail and future perspectives.

References [1] A. Ozawa, T. Uesaka, M. Wakasugi, Prog. Theo. Exp. Phys. 2012 (2012) 03C009.

P11: Properties of a thin YAP(Ce) scintillation counter for heavy ions

Presenter: Mr. ARAKAWA, Hiroki (Saitama University)

The Rare-RI Ring facility [1] at the RI Beam Factory in RIKEN has launched to clarify the pathway of astrophysical r-process nucleosynthesis, where nuclear masses have a crucial role. The masses of such neutron-rich exotic nuclei are measured one by one in an isochronous storage ring with the individual injection scheme. The individual injection technique was realized recently. It makes feasible the storage of short-lived nuclei at the cyclotron facility. In this injection scheme, the Rare-RI Ring facility uses a long beam line of the fragment separator BigRIPS [2]. A particle of interest is identified upstream (F3 focal plane) of the timing counter which generates the kicker excitation timing signals. The particle identification is based on the $B\rho$-ΔE-TOF method. TOF is measured by the plastic scintillation counters between the second focal plane F2 and F3. Energy-loss ΔE is measured by an ionization chamber placed at F3. To reduce background particles produced by in-flight fission reaction, a new TOF gate system was included in the injection scheme. The TOF gate uses RF signals of the cyclotrons. Because any secondary beam is synchronized with a specific phase of RF, a proper timing of RF can select the time-of-flight of particle of interest to be injected in the ring. However, ΔE signals of ionization chamber are too slow to select the charges of incoming beams. So, we are developing a new fast ΔE counter using a thin inorganic scintillator YAP(Ce). In general, YAP(Ce) has large light output relative to NaI(Tl) and a fast decay constant of about 28 ns. These properties are suitable for the present purpose. In this poster contribution, we will report a preliminary result of timing and charge resolutions of YAP(Ce) scintillator using a heavy ion beam.

References [1] A. Ozawa, T. Uesaka, M. Wakasugi, Prog. Theo. Exp. Phys. 2012 (2012) 03C009. [2] T. Kubo, Nucl. Instrum. Methods Phys. Res. B 204 (2003) 97.

P12: Development of electrostatic mirror type MCP detector at Rare RI Ring

Presenter: Mr. GE, Zhuang (RIKEN/Saitama Uni.)

High precision atomic masses are important for both nuclear structure and astrophysics studies. The newly commissioned storage ring, Rare RI Ring(1) (R3) is designed for mass measurements of exotic nuclei performing as an isochronous mass spectrometry to achieve a precision of 10-6 at Radioactive Isotope Beam Factory (RIBF), RIKEN. For the purpose of high precision and accuracy mass measurements, beam monitoring and increasing injection efficiency of the heavy ions at R3, a series of MCP detectors are being developed. Among them an electrostatic mirror type detector(2), which consists of a conversion foil to induce secondary electrons (SEs), electrostatic plates (mainly accelerating plate for acceleration of SEs produced from conversion foil, equal potential plates for free drift of SEs and a mirror plate for bending the accelerated ions to MCP) and the well coupled Chevron MCPs with position sensitive delay-line anode, is being developed to measure the position and timing of heavy ions at the same time. The timing resolution of this type of detector has been tested at HIMAC (Heavy Ion Medical Accelerator in Chiba) in February of this year, and a timing resolution of ~40 ps was achieved. The position resolution has been tested offline with alpha source and the test by online heavy ion beam at HIMAC is in preparation. The best position resolution tested by alpha source is better than 1 mm in sigma. The online test for timing resolution and offline test with alpha for position resolution compared to the simulation results will be presented.

Referece: 1) A. Ozawa et al.: Prog. Theor. Exp. Phys. 03C009, 2012. 2) N. Nankov et al.: Wiss. Tech. Berichte FZR-423, 25 (2005) (Annual Report 2004).

Summary:

The timing and position detection performance of an electrostatic mirror type foil MCP detector has been tested and the simulation results compared to the experimental results will be presented.

P13: A simple readout method of a position-sensitive detector using plastic scintillation bars

Presenter: Mr. WAKAYAMA, Kiyoshi (Department of Physics, Saitama University)

We are developing a new simple readout method of position determination of a plastic scintillation counter. Position sensitive detectors are essential for beam diagnostics of heavy ion beams. Conventional and well-established detectors such as PPAC (parallel plate avalanche counter) and MWPC (multi wire proportional counter) are employed in the beam lines of accelerators. Such detectors provide an excellent position resolution, however, the gas handling and dedicated electronics with calibration procedure are often time-consuming and increase manpower and costs, in particular for a long beam line such as an injection beam line of the Rare-RI Ring facility [1]. The beam line detectors are used for relatively short periods of time only for beam diagnostics, and are not used in the production runs. So, a simple, easy-handling, position sensitive detector is helpful for a quick check of beam condition. The present prototype detector consists of 20 plastic scintillator bars (3x3x100 mm3) arranged like scintillating fibers. Each end of the scintillator bars is connected to a common light guide bar. Beam position is obtained from the time and charge differences of scintillation light pulses propagated from each end of the light guide bars. MPPCs (multi-pixel photon counter) are used as the photon sensors. In this poster contribution, we will report the detector design concept with the present readout method and a preliminary result of beam test at the HIMAC facility [2].

References [1] A. Ozawa, T. Uesaka, M. Wakasugi, Prog. Theo. Exp. Phys. 2012 (2012) 03C009. [2] M. Kanazawa et al., Nucl. Phys. A746 (2004) 393c.

P14: A large area position sensitive TOF MCP detector at the Rare RI Ring

Presenter: Mr. LI, Hongfu (RIKEN)

Mass is one of the fundamental properties of the atomic nuclei. It reflects all interactions, including strong, weak and electromagnetic interactions among nucleons in the nucleus.

Hence, nuclear mass plays an essential role in the understanding of nuclear structure and the origin of elements in the cosmos. Many of the exotic nuclei far from β-stability line has unknown masses. However, precision mass measurement of these exotic nuclei is limited by their low production rates and short half-lives. The Rare RI Ring (R3) is a newly developed cyclotron-like storage ring mass spectrometer for exotic nuclei far from stability at Radioactive Ion Beam Factory (RIBF) in RIKEN. In order to transport the nuclei of interest individually to the central orbit of the R3 with high efficiency and to improve the resolution of the mass measurements at the R3, a large area position sensitive TOF MCP detector for the R3 is designed. The detector consists of a thin foil for secondary electrons (SEs) production, acceleration and electrostatic mirror grids for accelerating and bending the SEs, a stack of multi-channel plates (MCPs) and a two-dimensional delay-line position-sensitive anode. In this contribution, preliminary offline test results with an alpha source will be presented.

P15: Development of experimental devices for precise mass measurements at the Rare-RI Ring facility

Presenter: Mr. OMIKA, Shunichiro (Saitama University)

The Rare-RI Ring [1] at the RI Beam Factory in RIKEN is the dedicated apparatus aiming at precise mass measurements of exotic nuclei. The revolution times of a particle of interest are measured with a dedicated detector setup in the time sequence of injection, storage and ejection. The mass is determined from the measured revolution times by comparing those of an isochronous reference particle. In this contribution, we will present dedicated devices and detectors developed for the mass measurements using the Rare-RI Ring. Firstly, we will present the injection scheme in detail. The Rare-RI Ring developed a new method called individual injection. In this method, the kicker magnet is excited by the signal from a fast-timing detector on the beam line. A new module called isotope selector based on the FPGA technology with a fast-transmitting air-core coaxial cable was introduced. We will present specifications and performance of these devices for the injection. We will also show a new technique that efficiently selects rare RIs from fission fragments using the RF driving signals of the cyclotrons. Secondly, we will present the detectors for monitoring particle storage after the injection to the Rare-RI ring. We have been developing two types of detectors to confirm the circulation of particles. The first one is a detector using a MCP (multi channel plate) with a carbon foil. This detector confirms circulation by detecting low-energy secondary electrons in a guiding electromagnetic field, which are generated by the stored particle passing through the foil. The second one is similar but directly detects high-energy electrons called delta-rays without any guiding field. This detector consists of a plastic scintillator and a photo detector MPPC (multi-pixel photon counter). Two detectors work in a complementary style. Finally, we will present the detector setup after extraction, which measures the stop timing of the revolution time and provides additional information of particle identification.

References [1] A. Ozawa, T. Uesaka, M. Wakasugi, Prog. Theo. Exp. Phys. 2012 (2012) 03C009.

P16: Mass Analyzer for Radioactive Molecular Ion Beam with a Double Focusing Magnet

Presenter: Dr. MIYAHARA, Nobuyuki (NIRS)

At NIRS, re-acceleration of unstable 11C ion beam with the medical synchrotron, HIMAC has been pursuit in order to enable the real time imaging of carbon ion irradiation in malignant tumor. Up to now 11C6+ ion beams have been tried with very limited intensities of ~105 per pulse by a projectile fragment scheme and it was not possible to obtain a diagnosable imaging. Recently the usage of a target fragment 11C ion beam, produced by the irradiation of a high intensity proton beam coming from the AVF cyclotron at NIRS has been investigated. For this purpose we are now studying the capability to separate with a double focusing magnet the molecular 11CO2+ ion beam from the overwhelming 12CO2+ ion beam. In the present paper the mass separation system is presented.

P17: The SCRIT electron scattering facility at RIKEN RI Beam factory

Presenter: Dr. OHNISHI, Tetsuya (RIKEN)

SCRIT (Self-Confining Radioactive Isotope Ion Target) is a novel technique to form internal targets inside an electron storage ring using the transverse potential produced by electron beam and the longitudinal barrier potential applied to electrodes. By using this technique, high luminosity for electron scattering can be achieved even with short-lived unstable nuclei. After the validity and performance of the SCRIT technique was demonstrated, the SCRIT electron scattering facility was constructed at RIKEN RI Beam Factory for electron-RI scattering. The SCRIT electron scattering facility consists of a compact racetrack microtron, an electron storage ring equipped with the SCRIT system, an online isotope separator, and a buffer-gas-free dc-to-pulse beam converter. For scattered electron, an electron spectrometer is installed besides the SCRIT system and a luminosity monitor is installed at the downstream exit of the straight section of the electron storage ring. In the commissioning, various property of the ion trapping were studied and maximum luminosity was achieved to about 1.8 $\times$10^{27}cm^{-2}s^{-1} with 250-mA electron beam and 10^8 injected ions. Consequently, the elastic electron scattering with ^{132}Xe was performed successfully and the charge density distribution of ^{132}Xe was deduced. The RI production using the photofission of uranium was also started since 2013 and the rate of ^{132}Sn was obtained as 2.6$\times$10^5 atoms/s with 15-g uranium and a 10-W electron beam. In this contribution, we will report the present status and discuss the technical performance of the SCRIT electron scattering facility.

P18: Fringing-RF-Field-Activated DC to Pulse Converter at the SCRIT electron scattering facility

Presenter: Dr. OHNISHI, Tetsuya (RIKEN)

A new-type beam converter, FRAC (Fringing-Rf-field-Activated dc to pulse Converter), was developed at the SCRIT electron scattering facility. FRAC was installed between the ISOL system and the SCRIT system in order to provide the high intensity pulsed beam using the continous RI beam from the ISOL system. FRAC is based on a liner RFQ ion trap and workable under the ultra-high vacuum condition without any buffer gas. Ion beams injected continuously are decelerated in the longitudinal direction by the RF fringing field between the edge of the RF rods and the entrance/exit electrode. This effect is depend on various parameters, the injection position, the injection timing, and the property of the injection beam energy. It is required that the injection ion energy is less than a few eV at the entrance and its energy spread is considerably small. Then, some part of continuously injected ions are stacked inside FRAC, and stacked ions are extracted as a pulse beam with short pulse width after the stacking time. In the case of a 1-s stacking time and a 500-μs extracted pulse width, the pulse height extracted using FRAC is about 40 times of that using continuous beam and the conversion efficiency was obtained as about 6.4%. In this contribution, we will present details of FRAC and report results in various operation modes.

P19: Development of a Bunch Length Monitor with Two-photon Correlation at SCRIT facility.

Presenter: HORI, Mitsuki (Rikkyo University)

Two photon correlation has been used to measure the length of incoherent light emitters. We attempt to measure the electron beam bunch length utilizing this principle at the electron scattering facility called "SCRIT" at RIKEN. Two photon correlation is a phenomenon peculiar to quantum theory. Indistinguishable two photons tend to occupy a same state. This is called photon bunching. When two bremsstrahlung photons are emitted by an electron beam bunch, which is circulating in a storage ring, they should have observable photon bunching. When the two photons enter a half-mirror followed by two PMT's, the photon bunching contribute to decrease in the coincidence counts. If a relative delay is introduced to one of the two PMT signals, the amount of coincidence suppression should depend on the delay timing. The bunching effect should be observed as a dip whose width corresponds to the bunch length. The simulation result gives the statistical error of the bunch length measurement is 9% in 35min measurement.