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Report of Contributions

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Contribution ID: **4** Type: **Invited talk**

Electron and stochastic beam cooling for intensive heavy ion beams at NICA complex: experiments and plans

The Nuclotron-based Ion Collider fAcility (NICA) is under mounting in JINR. The Collider first beam tests are planned for the second half of 2025. The goal of the NICA project is to provide colliding beams for studies of collisions of heavy fully stripped ions at energies up to 4.5 GeV/u. The NICA accelerator facility consists of following accelerators: the new acting heavy ion linac HILAC at energy 3.2 MeV/u, new acting superconducting Booster synchrotron at energy up 600 MeV/u, acting superconducting synchrotron Nuclotron at gold ion energy 3.9 GeV/u and mounted two Collider storage rings with two interaction points. There are two electron cooling systems –one in the Booster synchrotron having 60 keV maximum electron energy, another one in the Collider having two electron beams with maximum electron energy 2.5 MeV and two stochastic cooling systems. The status of acceleration complex NICA with its cooling systems is presented. The paper reports the results of experimental studies of electron cooling in Booster carried out during commissioning of the injection complex of NICA. Further plans of electron and stochastic cooling developments and usage are described as well.

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Contribution ID: **5** Type: **Invited talk**

Precision Tests of the Standard Model at low energies using stored exotic ions

The four fundamental interactions and their symmetries, the fundamental constants as well as the properties of elementary particles like masses and moments, determine the basic structure of the universe and are the basis for our so well tested Standard Model (SM) of physics. Performing stringent tests on these interactions and symmetries in extreme conditions at lowest energies and with highest precision by comparing, e.g., the properties of particles and their counterpart, the antiparticles, will allow us to search for physics beyond the SM. Any improvement of these tests beyond their present limits requires novel experimental techniques.
An overview is given on recent mass and g-factor measurements with extreme precision on single or few cooled exotic ions stored in Penning traps. Among others the most stringent test of bound-state quantum electrodynamics could be performed and the accuracy of the electron atomic mass could be improved by a factor of 13.

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Contribution ID: **6** Type: **Invited talk**

Münster Jet Targets for Hadron Physics Experiments

Jet beams are widely used as targets in many fields of physics. Prominent examples are scattering experiments at hadron and lepton accelerators or at terawatt laser facilities, where pure and windowless targets with adjustable thickness are required in vacuum. Depending on the specific experimental situation, different types of targets such as gas-jets, cluster-jets or pellet streams can be used to fulfil the required properties. However, in recent years new experimental challenges have emerged that require a significant improvement in the performance of existing target technologies and the development of new target beam generation and monitoring techniques. The PANDA experiment, which is to be set up at the future HESR storage ring at FAIR, and the MAGIX experiment at the new energy-recovering accelerator MESA can be mentioned here as examples. Inspired by this, new research projects have been initiated, focusing on the development of state-of-the-art jet targets. This talk gives an overview of the developments on cryogenic gas-jet, cluster-jet and droplet targets in Münster.

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Contribution ID: **7** Type: **Invited talk**

How to observe vacuum decay in low-energy heavy-ion collisions

It is known that in slow collisions of two bare nuclei with the total charge number exceeding the critical value, Z_1+Z_2 > Z_c =173, the initially neutral vacuum can spontaneously decay into a charged vacuum and two positrons. The detection of spontaneous emission of positrons would be a direct proof of this fundamental phenomenon. However, the spontaneous emission of positrons is usually masked by the dynamic (induced) emission of positrons, which is caused by a rapidly changing electric field created by colliding nuclei. For many years, it was believed that vacuum decay can only be observed in collisions with nuclear sticking, when the nuclei are bound for a period of time due to nuclear interactions. But to date, there is no evidence that nuclear sticking occurs in such collisions of heavy ions. In our recent papers [1-4] it has been shown that vacuum decay can be observed without any sticking of nuclei. This can be done by measuring the probabilities of the creation of positrons or positron spectra for a given set of nuclear trajectories. The results of this study will be presented in the talk.

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Contribution ID: **10** Type: **Invited talk**

From relativistic energies to zero: ion beam deceleration and experiments with slow HCI

HITRAP is a facility for deceleration of highly charged ions (HCI) produced by the GSI accelerator [1]. It consists of an IH-structure and an RFQ for deceleration down to several keV/q, as well as three beam bunchers and several beam transport sections. The linear deceleration stages reduce the ion energy from 4 MeV/u to 500 keV/u and to 6 keV/u respectively, resulting in a slow, but very hot ion bunch, following two non-decelerated bunches. Customized detectors are used to separate the energy components and optimize the deceleration process, while an electrostatic beamline guides the slow ions to a Penning-Malmberg trap. Finally, the ions are ejected towards various experiments.

The decelerator facility has made major progress recently. Last year, electron cooling was demonstrated with about 10^5 HCI produced by an EBIT, mixed with about 10^9 electrons. Depending on the energy, density and trap configuration, the ions transferred most of their energy to the electrons within a few seconds. Furthermore, during two commissioning campaigns, HCI produced by the GSI accelerator were decelerated from relativistic energies to essentially zero and captured in the ion trap –to our knowledge a unique procedure worldwide.

Based on this success, the first experiments with decelerated ions are planned. These include the irradiation of surfaces with slow HCI and the formation of nanometer-sized hillocks [2], scheduled for the beam time period of 2025. Properties of two-species ion Coulomb crystals have already been investigated in the SPECTRAP experiment [3]. In the future, this process will allow rapid cooling of highly charged ions. A new, similar approach involves mixing single HCIs with laser-cooled beryllium ions in a Paul trap [4]. The excitation is detected by quantum logic, which offers much higher sensitivity than classical fluorescence spectroscopy. The ultimate goal is to develop novel optical frequency standards based on HCIs. The goal and status of these and other experiments will also be presented.

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Contribution ID: **13** Type: **Invited talk**

Present and future of the Rare-RI Ring facility at RIBF

The Rare-RI Ring (R3) facility is a unique storage ring facility coupled with the cyclotron complex at the RIKEN RI beam factory [1]. Ions of interest are in-flight selected and are individually injected in the storage ring where the precision isochronous condition is realized. The event-by-event data processing is performed with information from auxiliary detectors installed at the fragment separator BigRIPS. Since the successful developments of related devices and construction in 2013, several experiments have been conducted; a highlight is the masses in the vicinity of the r-process nucleosynthesis [2]. In this talk, I will summarize the physics programs, completed and planned, at the BigRIPS-R3 facility, and will discuss possible extensions and collaborations in the future.

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Contribution ID: **14** Type: **Poster**

In-ring detector developments for the Rare-RI Ring facility

We present several particle detectors dedicated for the Rare-RI Ring (R3) storage ring. Since R3 in the cyclotron facility stores only a single ion at each injection, conventional beam diagnostics such as beam profile monitors and wire scanners are inapplicable. Thus, we have developed unique detectors as follows,

1. Revolution time monitor, "delta-ray"detector which directly measures high-energy secondary electrons emitted from a thin foil by means of plastic scintillation detectors without any guiding field. Multi-pixel photon counters (MPPC) are employed for readout.
2. Shaped plastic and fiber scintillation detectors for position detection. The number of readout channels is reduced for convenience and versatility for users but also for a general beamline monitor.
3. GAGG(Ce) in-ring total energy detector. A compact shape with the high density fits the ring aperture. Fast signal character is also suitable for timing measurements.

These detectors were tested with heavy ion beams at the Heavy-Ion Medical Accelerator in Chiba (HIMAC) synchrotron facility, and we achieved a reasonable performance; approximately 300 ps in time resolution, 1 mm position resolution, and 1% in energy resolution for a typical case. Some of them were installed and were successfully used at R3. The details of the detectors will be presented.

The present work is part of master theses by S. Omika, N. Tadano, K. Inomata, D. Kajiki, K. Okubo for the delta-ray detection technique, by K. Wakayama, D. Hamakawa, M. Kanda, K. Sasaki for several position monitors, and by K. Yokota, N. Shinozaki for the GAGG(Ce) crystal detectors.

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Contribution ID: **16** Type: **Poster**

Signature Splitting in Three Quasiparticle Rotational Bands of Odd-A Nuclei

In odd-A nuclei, for excitation energy greater than proton or neutron pairing gaps, either a proton-proton or a neutron-neutron pair can break to generate a three-quasiparticle (3qp) quadruplet, on each member of which one rotational band is formed. Rotational bands and associated high-spin phenomena are one of the important aspects of nuclear structure. The dynamics of these high-spin phenomena are influenced through the interplay between pairing interactions, moments of inertia, Coriolis interaction and particle-particle interactions. In present work, we explored one of the intriguing high-spin phenomena namely signature effects observed in 3qp rotational bands of odd-A nuclei. The signature effects refer to splitting of one rotational band (ΔI=1) into two rotational spin sequences with ΔI=2 and characterized as favored and unfavored branches. When the expected favored branch become unfavored at particular spin then the condition is knowing as signature inversion. To perform an extensive and systematic analysis of signature effects, we extracted the experimental data of 3qp rotational bands having strong signature effects (signature splitting and signature inversion) observed in rare-earth mass region. We found total 27 three quasiparticle rotational bands in ^{155}Dy, ^{157}Ho, ^{163}Er, $^{157,165}Tm$, $^{159,163,165,167}Lu$, $^{167,173}Ta$, $^{165,167,179}W$, ^{181}Re, $^{171,181,183,185}Os$ and ^{185}Pt isotopes which possess pronounced signature splitting and sometime signature inversion also. To identify the underlaying mechanism behind these phenomena, we employed the Three Quasiparticle Plus Rotor Model (3QPPRM) [1] approach which relies on the Coriolis and particle-particle band mixing among various rotational bands present in the basis space. The 3QPPRM is preferred because it is in terms of angular momentum which is a physical observable in the experiments and hence a direct comparison with the experimental data can be made. For the test case, we select the rotational band built over 3/2[521]x1/2[660]x1/2[660] 3qp configuration observed in ^{155}Dy [2]. This band arise due to the coupling of low-Ω and high-j orbitals and is good example to illustrate the transmission of energy staggering through Coriolis (ΔK=1) and particle-particle couplings (ΔK=1). For the above said 3qp configuration, there are four possible bandheads namely K=5/2$^-$, 3/2$^-$, 3/2$^-$ and 1/2$^-$. From the available experimental indicators, it was not possible to assign to which bandhead (out of above four) the experimentally observed band corresponds. In order to resolve this problem as well as to reproduce the experimentally observed signature effects, we have carried out the complete Coriolis mixing calculations in the framework of 3QPPRM. The basis space of present calculations consists of 48 rotational bands. The single particle wave functions by using the Nilsson model [3] with deformation parameters as ϵ_2 =0.210, ε_4 =-0.02 [4] and potential parameter κ =0.0636, μ =0.393 [5]. The optimized values of crucial variable parameters such as bandhead energies, inertia parameters and Newby Shifts are obtained using Minute minimization subroutine [6] by minimizing the deviation among experimental and theoretical energies. We successfully reproduced the observed signature splitting and assigned the band under investigation as K=5/2$^-$: 3/2[521]x1/2[660]x1/2[660]. The RMS deviation among calculated and experimental energies for spin range from I=25/2$^-$ (at 2012.3 keV) to 77/2$^-$ (at 11972 keV) is found to be 82.6 keV which indicate the reliability of present calculations. The calculations of signature effects in other odd-A isotopes are in progress.

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Contribution ID: **21** Type: **Invited talk**

Development of in-ring nuclear reaction at HIRFL-CSR

Reactions at low momentum transfer induced by intermediate-high energy protons are sensitive and pure probes for investigating, e.g. matter density distributions and isovector giant dipole Resonance, which provide important information on nuclear structure and astrophysics. Recently, a novel in-ring reaction experimental method based on stored beam and internal gas-jet target has attracted much interest. This method as one of important supplementary experiments of direct nuclear reactions are characterized by low-momentum sensitivity and low background. As one of the existing facilities, the Cooler Storage Ring at the Heavy Ion Research Facility in Lanzhou (HIRFL-CSR), which is equipped with the electron cooler and internal H2-gas-jet target, also provides an opportunity for performing such kinds of experiments based on inverse kinematics. In this talk, we will present the progress of in-ring reaction investigations at the HIRFL-CSR, including the detector, data analysis and physical experiment. Especially, the recent neutron distribution radius determination of 133Cs and its impact on the interpretation of the coherent elastic neutrino-nucleus scattering measurement (CEvNS-CsI) will also be introduced.

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Contribution ID: **22** Type: **Invited talk**

Laser cooling of relativistic ion beams

We present an overview of laser cooling as a new method to cool highly relativistic beams at future research facilities such as FAIR and HIAF. We first dive into understanding the mechanisms of laser cooling at relativistic energies, giving estimates for cooling times and their scaling with beam energy and ion charge state for a given accelerator. We further look into the specific beam dynamics of ultracold ion beams and the need for and prospects of using optical diagnostics to investigate the longitudinal dynamics of laser cooled beams as a complimentary technique to high resolution Schottky dynamics. We will present results from laser cooling of ion beams at various storage rings, including ESR and CSRe, that illustrate the technical requirements for succesful laser cooling with special emphasis on te development of suitable laser systems. We conclude by focsusing on the exciting physics that become accessible with ultracold, highly relativistic ion beams.

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Contribution ID: **24** Type: **Invited talk**

Static and Oscillating EDM Searches of Charged Particles in Storage Rings

The Electric Dipole Moment (EDM) of subatomic particles serves as a source of CP violation, which could explain the observed matter-antimatter imbalance. Detecting an EDM larger than the tiny theoretical predictions from the Standard Model would indicate additional CP violation and point to new physics beyond the Standard Model.

Axions, initially proposed to resolve the strong CP problem, are leading candidates for dark matter. For low-mass axions or axion-like particles (ALPs), they behave as a classical field, inducing an oscillating EDM when coupled with gluons and potentially generating observable signals when the ALPs field frequency resonates with the beam's spin precession frequency.

Both static and oscillating EDM effects can create a measurable vertical polarization component, which can be detected using a polarimeter. The JEDI collaboration conducted the first direct measurement of the deuteron EDM and the first proof-of-principle search for axions or ALPs particles in a storage ring using polarized deuteron beams at the Cooler Synchrotron (COSY). In this talk, I will discuss these measurements and results, as well as potential future experiments.

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Contribution ID: **26** Type: **Talk**

The use of storage rings in the study of reactions at low momentum transfers

Several nuclear reactions are best investigated when the momentum transfer to the nucleus is small. Among these are the IsoScalar Giant Monopole Resonance (ISGMR) which helps determine one of the parameters of the equation of state, namely the incompressibility of nuclear matter, and proton elastic scattering from nuclei which is sensitive to parameters of nuclear density such as the matter root-mean-square radius.
These have been extensively studied in the past using stable beams. However, with the advent of radioactive ion facilities around the world, it is desirable to study these reactions with unstable nuclei. The reactions, however, have to take place in inverse kinematics in which the radioactive ions impinge on a light target (hydrogen or helium).
Simple kinematics calculations show that the outgoing recoil particles possess extremely low energies (down to few hundred keVs). External targets are, therefore, not suitable for these reactions. There are two alternative methods to deal with this challenge: either do the experiments in storage rings with gas jet targets or any other
thin targets, or perform the measurements with an active target which also acts as a detector. In both cases, the energy threshold will be much lower than a fixed target of a reasonable thickness. We have performed measurements with the radioactive 56Ni using both methods. In the ring measurements, proton elastic scattering was the main goal for this nucleus while feasibility studies were done with 58Ni and a helium target to investigate ISGMR. In this presentation, the experimental method used in the storage ring will be discussed
along with some results to show the superiority of the rings for this type of measurements.

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Contribution ID: **28** Type: **Invited talk**

Dielectronic Recombination of Highly Charged Ions in the ESR and CRYRING@ESR Heavy-Ion Storage Rings

Dielectronic recombination is an important electron ion-collision process that governs the charge balance of plasmas. Moreover, the resonant nature of this process can be exploited for the spectroscopy of multiply excited levels in atomic ions. This electron-ion collision spectroscopy is particulary competitive for highly charged ions where lasers are not available for the large transition energies involved. Consequently, electron-ion collision spectroscopy via dielectronic recombination is a central part of the atomic physics program at GSI/FAIR. In my talk I will introduce the technique and discuss the latest results from the storage rings ESR and CRYRING. I will also briefly mention related work on electron-impact ionization of ions that is carried out at the Justus-Liebig-University Giessen.

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