STORI ´14

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September 28th – October 3rd, 2014

Sankt Goar, Germany

Book of Abstracts

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Programme

(All presentations will take place at Villa Rheinfels, room Dix/Beckmann)

Sunday, Sept. 28th

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Monday, Sept. 29th

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11:50	30'	The EXL project, recent results and the future perspectives	Kiselev, Oleg
12:20	20'	Reaction studies using stored ions	Reifarth, Rene
12:40	1h30'	Lunch	
14:10	40'	Recent results from ANKE, WASA, and PAX	Khoukaz, Alfons
14:50	40'	DAFNE and KLOE	De Santis, Antonio
15:30	20'	From CELSIUS to COSY: On the Observation of a Dibaryon Resonance	Clement, Heinz
15:50	20'	BES III	Wolke, Magnus
16:10	30'	Coffee	
16:40	30'	Precision mass measurements of short-lived nuclides at storage ring in Lanzhou	Zhang, Yuhu
17:10	30'	Results and perspectives of direct mass measurements with stored relativistic exotic nuclei	Knöbel, Ronja
17:40	20'	The isochronous mass spectrometry with two Time-of-Flight detectors at the CSRe	Wang, Meng
18:00	20'	Probing isospin-symmetry breaking with storage rings	Sun, Yang

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09:00	30'	The NuSTAR Project at FAIR	Nilsson, Thomas
09:30	30'	Physics prospects with PANDA at FAIR	Brinkmann, Kai-Thomas
10:00	30'	Coffee	
10:30	40'	Electron dynamics in strong electromagnetic fields: Atomic physics with highly-charged heavy ions	Surzhykov, Andrey
11:10	30'	QED at storage rings: theory and experiments	Indelicato, Paul
11:40	20'	Dielectronic recombination experiments of oxygen-like 78Kr28+ at the HIRFL-CSRm	Ma, Xinwen / Wen, Weiqiang
12:00	20'	Observation and manipulation of coherence in the time-reversed relativistic photoelectric effect	Tashenov, Stanislav
12:20	20'	Electron spectroscopy at the high-energy endpoint of electron-nucleus bremsstrahlung studies at the ESR	Hillenbrand, Pierre-Michel
12:40	1h30'	Lunch	
14:10	40'	Penning traps for fundamental tests of nature	Blaum, Klaus
14:50	20'	The HITRAP facility for slow highly charged ions	Herfurth, Frank
15:10	20'	Precision mass measurements of exotic ions with a MR-ToF system	Wienholtz, Frank
15:30	20'	High-Performance Multiple-Reflection Time-of-Flight Mass Spectrometers for the Research With Exotic Nuclei and for Analytical Mass Spectrometry	Plaß, Wolfgang
15:50	30'	Coffee	
16:20	30'	Storage ring experiments of resonant electron-ion collisions at the interface of atomic and nuclear physics	Brandau, Carsten
16:50	30'	Lifetime Measurements of Nuclei in Few-Electron Ions	Faestermann, Thomas
17:20	20'	Study projectile fragmentation reaction with Isochronous Mass Spectrometry	Tu, Xiaolin
17:40	20'	First Nuclear Transfer Reaction Measurement at the ESR, For the Investigation of the 15O(α,γ)19Ne reaction	Doherty, Dan
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08:40	30'	The CSR Project at MPIK	Von Hahn, Robert
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09:30	30'	Coffee	
10:00	30'	Antiproton Chain of FAIR Storage Rings	Katayama, Takeshi
10:30	30'	Physics with low energy antiprotons	Widmann, Eberhard
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09:20	30'	Internal targets at storage rings	Grigoryev, Kirill
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11:30	20'	Laser spectroscopic determination of the hyperfine splitting in Li-like bismuth – one step forward	Sanchez Alarcon, Rodolfo Marcelo
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12:10	20'	Precise determination of the 1s Lamb shift in hydrogen-like heavy ions at the ESR storage ring using microcalorimeters	Kraft-Bermuth, Saskia
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15:10	20'	Non-Achromatic vs. Achromatic Isochronous Mode of the Collector Ring at FAIR	Litvinov, Sergey
15:30	30'	Present status of the Rare-RI Ring facility at RIBF	Yamaguchi, Takayuki
16:00	20'	Isochronous field study of the Rare-RI Ring	Abe, Yasushi
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16:50	30'	The SCRIT electron scattering project at RIKEN RI Beam Factory	Ohnishi, Tetsuya
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09:00	20'	CRYRING@ESR: Present Status and Future Research	Lestinsky, Michael
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09:50	20'	The MOTReMi: A versatile tool to study ion-atom collisions	Schuricke, Michael
10:10	20'	A SQUID-based Beam Current Monitor for FAIR/CRYRING	Geithner, René
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11:40	30'	Electric Dipole Moment Measurements at Storage Rings	Pretz, Joerg
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12:40	1h30'	Lunch	
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14:40	30'	The Nuclotron/NICA Project at JINR	Shurkhno, Nikolay
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Poster session – Tuesday, Sept. 30th, 20:00

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A particle detector for bound-state beta-decay experiments (and more) at the ESR and CR	Najafi, Mohammad Ali	23
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Talks

Storage and Cooling of Ion Beams

Igor Meshkov

JINR, Dubna

A review of injection schemes used at different ion storage rings is presented. Special attention is focused on application of both electron cooling and stochastic one that increases significantly ion storage efficiency. Certain limitations that appear at radioactive ion storage are considered and measures to avoid or reduce their influence are discussed.

Modern Quests in Nuclear Astrophysics

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Exotic nuclei and their properties play an important role in many astrophysical scenarios. During the supernova collapse electron captures on protons in neutron-rich nuclei is the dominating weak-interaction process. Here decisive progress has been achieved due to large-scale shell model calculations, constrained by data obtainded from charge-exchange measurements on nuclei. Recently nuclear deexcitation by neutrino pair emission has been explored for the first time in supernova simulations. It has little effect on the dynamics, but is the major source of muon and tau neutrinos during the collapse phase. Important progress has also been achieved to describe inelastic neutrino-nucleus scattering on nuclei at the finite temperature of the collapse. Finally supernovae are also the site of explosive nucleosynthesis. This site as well as the mergers of two neutron stars are explored as the potential sites of the astrophysical *r*-process.

In-ring experiments for nuclear astrophysics

Philip J. Woods[1]

[1] University of Edinburgh (UE-SP)

The talk will initially review the first generation of nuclear reaction experiments with heavy ions on the ESR storage ring at GSI which have aimed at addressing key issues in nuclear astrophysics including the astrophysical p-process and the triggering of X-ray bursts. The talk will then go on to explore exciting new initiatives with an emphasis on the use of radioactive beams for such measurements.

The EXL project, recent results and the future perspectives

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EXL (**EX**otic nuclei studied in **L**ight-ion induced reactions at the NESR storage ring) is an integral part of NUSTAR [1] at FAIR [2]. The main idea of EXL is the investigation of light-ion induced direct reactions in inverse kinematics with radioactive ions stored in the storage ring. This enables one, due to the thin windowless targets and the beam cooling, performing high-resolution measurements, even for very slow target-like recoil particles originating from reactions at low momentum transfer, with reasonable luminosity by profiting from the accumulation and recirculation of the radioactive beams. A multipurpose detector system is planned around an internal target of the storage ring for the detection of the target-like recoils. One of the key interests and advantages of EXL with respect to external-target experiments is the possibility to study reactions at very low momentum transfers. Examples are the investigation of nuclear matter distributions, of giant monopole resonances (GMR) or Gamow-Teller transitions [3].

In the last few years, the EXL collaboration has performed several feasibility studies concerning, among others, the UHV compatibility of Si detectors with the ultra-high vacuum conditions of storage rings. Recently, proton and helium scattering on cooled and stored ^{56,58}Ni beams has been studied at the present ESR storage ring at GSI. Preliminary results of this experiment will be presented.

At present, the EXL collaboration investigates, together with other FAIR collaborations, the possibility of building an additional beam line connecting the new fragment separator SuperFRS and the storage ring ESR for first experiments at FAIR instead of using the new storage ring NESR, the construction of which will be delayed. Future experiments at other storage ring facilities, like TSR at ISOLDE and HIRFL-CSR at Lanzhou, will be also discussed.

References

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[2] http://www.fair-center.eu
[3] H.H. Gutbrod et al. (Eds.), FAIR Baseline Technical Report, ISBN-3-9811298-0-6, Nov. 2006

Reaction studies using stored ions

Jan Glorius[1,2], Carsten Brandau[2], Michael Heil[2], Bo Mei[1,2], Ralf Plag[2], René Reifarth[1], Kerstin Sonnabend[1], and the E062 collaboration

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Reactions of astrophysical interest in explosive scenarios, *e.g.*, with relevance for the γ- or rp-processes, often involve unstable isotopes that cannot be studied using traditional methods. In inverse kinematics, such isotopes are available making use of the Fragment Seperator (FRS) at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany. By using the ESR storage ring in combination with the gas jet target (p, γ) and (α,γ) reactions can be studied. The detection of the reacted beam can be achieved by using DSSSD which measure the spatial separation after the first dipol magnet.
At energies between 9 MeV/u and 11 MeV/u, a proof-of-principle experiment was carried out investigating the reaction $_{96}$Ru(p, γ). Details about the setup and the ongoing analysis will be presented.
In order to access lower energies, a new setup has been developed and installed at GSI. This new setup involves UHV compatible silicon detectors as well as mechanical manipulators for precise positioning. The current status of the setup, its design values, and the future plans will be presented.

This work is supported by DFG (SO907/2-1), HIC for FAIR, and HGS-HIRe.

Recent results from ANKE, WASA, and PAX

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The three complementary internal beam experiments ANKE, WASA, and PAX at the COoler-SYnchrotron COSY-Jülich offer unique and exciting opportunities for hadron physics with polarized and unpolarized hadronic probes. Due to the excellent properties of the COSY accelerator, which offers electron and stochastically cooled proton and deuteron beams with momenta up to 3.7 GeV/c, in combination with the high performance detection systems, a broad experimental program can be covered. One main emphasis of the studies at these facilities are measurements on symmetries in reactions and particle decays as well as high precision studies on particles and their properties. Furthermore, the availability of polarized beams and/or targets allows for investigations on hadronic reactions using the spin degree of freedom or studies towards polarized antiprotons.

The experimental facilities will be presented and recent results will be discussed.

DAΦNE and KLOE-2 physics run

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The DAΦNE collider, located in the Frascati National Laboratories of INFN, has two main rings, where electrons and positrons are stored to collide at a center of mass energy of 1.02 GeV, the Φ resonance mass. KLOE-2 experiment is located at the collider interaction region. The detector is capable to observe and collect data coming from Φ decay: charged and neutral kaon pairs, lighter unflavoured mesons (η, η' f_0, a_0, ω/ρ).
In the first half of 2013 the KLOE detector has been upgraded inserting new detector layers in the inner part of the apparatus, around the interaction region: a new tracking system, Inner tracker, to improve tracking eficiency and vertex resolution and two new calorimenters, QCAL and CCAL-T in order to improve detector hermeticity and acceptance. The long shutdown has been used to undertake a general consolidation program aimed at improving the Φ-Factory operation stability and reliability and, in turn, the collider uptime.
The DAΦNE collider has been successfully commissioned after the experimental detector modification and a major upgrade and consolidation program involving a large part of the accelerator complex.
This contribution presents the Φ-Factory setup and the achieved performances in terms of beam currents, luminosity, detector background and related aspects together with the KLOE-2 physics program, upgrade status report and recent physics results.

From CELSIUS to COSY: On the Observation of a Dibaryon Resonance

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Within the program to systematically study the two-pion production in nucleon-nucleon collisions by CELSIUS/WASA also the ominous ABC effect was investigated, which denotes an unusual huge low-mass enhancement in the invariant mass spectrum of an isoscalar pion pair produced in double-pionic fusion process. Due to the lack of convincing explanations the effect got named after Abashian, Booth and Crowe, who were the first to observe this phenomenon in inclusive measurements back in 1960.

After having confirmed the ABC effect by exclusive and kinematically complete experiments at CELSIUS/WASA first indications of a correlation of this effect with a resonance-like structure in the total cross section could be observed in the basic double-pionic fusion reaction $np \rightarrow d\pi^0\pi^0$ [1].

After the move of the WASA detector to COSY the two-pion production program could be continued with WASA-at-COSY with much superior intensity and precision. As a result the resonance effect could be established in all relevant two-pion channels and its quantum numbers determined to be $I(J^P) = 0(3^+)$ [2-4].

If the hypothesis of a genuine dibaryon resonance is true, then it has to be observable also in neutron-proton scattering directly – though its effect is expected to be tiny. Since the analyzing power is the best observable to sense even tiny contributions to the scattering amplitude, high-statistics measurements of polarized neutron-proton scattering have been performed over the region of the anticipated resonance with WASA-at-COSY. Incorporation of these new data into the SAID partial-wave analysis produces, indeed, a resonance pole in the $^3D_3$-$^3G_3$ coupled partial waves at $(2380\pm10 - i\ 40\pm5)$ MeV – in full agreement with the findings in the two-pion production channels and establishing thus the first observation of a dibaryon resonance[5].

References

[1] M. Bashkanov et al., Phys. Rev. Lett. 102, 052301 (2009).
[2] P. Adlarson et al., Phys. Rev. Lett. 106, 242302 (2011).
[3] P. Adlarson et al., Phys. Lett. B 721, 229 (2013)
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[3] P. Adlarson et al., Phys. Rev. Lett. 112, 202301 (2014).

Overview on BESIII results

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At present, the charmonium spectrum above the open charm threshold is far from being understood. While only few predicted states have been found, the properties of many of the observed states do not match the expectations. The BESIII experiment has accumulated large data samples in electron--positron annihilations in the charm energy region. Recent results from these data will be presented with a special focus on the charmonium--like Z states.

Precision mass measurements of short-lived nuclides at storage ring in Lanzhou

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Nuclear mass is the fundamental property of a nucleus. The complex interplay of strong, weak and electromagnetic interactions in the nucleus contributes to the difference between its mass and the sum of the masses of its constituent nucleons. Precise and systematic measurements of nuclear masses not only provide information on nuclear structure, but also find their important applications in nuclear astrophysics. Recent commissioning of the Cooler Storage Ring at the Heavy Ion Research Facility in Lanzhou (HIRFL-CSR) has allowed us for direct mass measurements at the Institute of Modern Physics in Lanzhou (IMP), Chinese Academy of Sciences (CAS). In the past few years, a series of mass measurement experiments have been carried out using the CSRe-based isochronous mass spectrometry (IMS). Masses of short-lived nuclides of both neutron-rich and neutron-deficient have been measured up to a relative precision of 10^{-6}-10^{-7} via fragmentation of the energetic beams of ^{58}Ni, ^{78}Kr, ^{86}Kr, and ^{112}Sn [1, 2, 3, 4, 5]. In this talk, the experiments and the results will be presented. The implications of our experimental results with respect to nuclear structures and stellar nucleosynthesis in the rp-process of x-ray bursts are discussed. Some disadvantages in the IMS method itself are pointed out and simulated, and further improvement using double ToF detectors are proposed.

References

[1] X. L. Tu et al, Phys. Rev. Lett. 106, 112501 (2011)
[2] X. L. Tu et al., Nucl. Instrum. Meth. A 654 ,213 (2011)
[3] Y. H. Zhang et al, Phys. Rev. Lett. 109, 102501 (2012)
[4] X. L. Yan et al., AstroPhys. Jour. Lett. 766, L8 (2013)
[5] P. Shuai et al., Phys. Lett. B 735, 327 (2014)

Results and perspectives of direct mass measurements with stored relativistic exotic nuclei

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The combination of the FRagment Separator (FRS) [1] and the Experimental Storage Ring (ESR) [2] at GSI [3] gives the possibility of performing high accuracy and high precision mass measurements on relativistic short-lived ions created in projectile fragmentation and fission reactions. The method of Schottky Mass Spectrometry (SMS) [4,5,6] gives access to nuclides with half-lives longer than several seconds, where Isochronous Mass Spectrometry (IMS) [7,8] opens the regions of nuclides with half-lives down to the sub-millisecond range. With these methods important isotopes are in reach which are necessary for a better understanding of nuclear structure and the pathways of nucleosynthesis. Recent results of experiments applying either SMS or IMS will be shown. New detector developments and improvements in data analysis will be presented and perspectives for future measurements at GSI and at the FAIR facility [9] will be given.

References

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The isochronous mass spectrometry with two Time-of-Flight detectors at the CSRe

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When an ion circulates in a storage ring, its revolution time depends on the mass-to-charge ratio as well as on the velocity. For one certain ion type, the faster ones always circulate in the longer orbits while the slower ones in the correspondingly shorter orbits. If the ring is set in the so-called isochronous mode for this ion species, the difference of the orbit lengths shall compensate exactly the difference of velocities leading to the mean revolution time, which depends only on the mass-to-charge ratio. In routine isochronous mass spectrometry (IMS) experiments, a time-of flight (TOF) detector is used for an accurate measurement of the revolution times. Using this technique, the nuclear masses can be deduced from the revolution times. Precision mass measurements have been successfully performed at the ESR-GSI in Darmstadt and at the CSRe-IMP in Lanzhou.

Inthe IMS the revolution times of the storedions should be independent of their velocity spread. However, this isochronous condition is fulfilled only in first order and in a small range of revolution times. Since a storage ring is a large-acceptance machine, it allows for storing ions in a broad range ofm/q values. This feature is essential for storage ring mass spectrometry, as it allows for very efficient mass measurements of many nuclides in a single experiment. It was suggested that the non-isochronicity effect can be corrected for if the velocity or the magnetic rigidity of each ion can be determined in addition to its revolution time.
To achieve the in-ring velocity measurement of each stored ion, two TOF detectors were developed and installed in the CSRe. The time resolution of the new detectors in offline tests was σ=19±2 ps, significantly improved compared to the TOF detector used up to now at CSRe. The new detectors were installed in the straight section,where also the internal target was placed in December, 2013.It is expected that the resolving power of the IMS could be significantly improved with double-TOF. However, in the present IMS setting the beam dispersion in this section is huge and the transmission efficiency of the exotic nuclides wasdramatically reduced, limiting its practical applicability for nuclides far from the valley of stability. It is planned that another IMS settings, that favour the beam transmission at this section, will be tested. The double-TOF system was tested in a recent experiment with the ^{78}Kr fragments. The data analysis is still in process and the preliminary results will be presented at the conference.

Probing isospin-symmetry breaking with storage rings

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Isospin is a fundamental concept in particle and nuclear physics. Study of the isospin-symmetry breaking is currently an active research subject with storage rings [1]. It is well known that in nuclei, the Coulomb force between protons breaks both charge symmetry and charge independence. The Coulomb displacement energy (CDE), i.e. the binding-energy difference between mirror nuclei, is a signature of charge-symmetry breaking while the triplet displacement energy (TDE) is regarded as a measure of breaking in charge independence. We show that the characteristic behavior of CDE and TDE can be reproduced if the isospin nonconserving (INC) nuclear force with $J = 0$ and $T = 1$ are introduced into large-scale shell model calculations [2]. Theoretical one- and two-proton separation energies are predicted for mirror nuclei with masses $A = 42$-95, and locations of the proton drip-line can thereby be suggested.

Experimental data for excited states in mirror nuclei of the upper fp-shell have recently become available [3,4]. Mirror energy differences (MED) and triplet energy differences (TED) in the $T = 1$ analogue states are other important probes of isospin-symmetry breaking. With shell model calculations, we find that the INC nuclear force has significant effect also on MED and TED in the upper fp-shell [5]. Thus, there are some indications that CDE and TDE for masses and MED and TED for excited states may have the same origin in this region. The present status of the field will be presented as well as the goals for future storage-ring-based mass measurements will be outlined.

This work is collaborated with K. Kaneko, T. Mizusaki, and S. Tazaki. Research at SJTU is supported by the National Natural Science Foundation of China (No. 11135005) and by the 973 Program of China (No. 2013CB834401).

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Storage rings at FAIR

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The NUSTAR Project at FAIR

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The FAIR (Facility for Antiproton and Ion Beams) installations, under construction at the GSI site in Darmstadt, will be addressing a wealth of outstanding questions within the realm of subatomic, atomic and plasma physics through a combination of novel accelerators, storage rings and innovative experimental set-ups[1]. One of the key installations is the fragment separator Super-FRS[2] that will be able to deliver an unprecedented range of radioactive ion beams (RIBs) in the energy range of 0-1.5 GeV/u. These beams will be distributed to three branches, each with its unique domain with respect to beam energies and properties. The high-energy branch will permit reactions with radioactive beams at relativistic energies, whereas the low-energy branch will supply decelerated beams for high-resolution spectroscopy, traps and laser spectroscopy. Finally, the ring branch will uniquely permit stored and cooled exotic beams for a range of methods only possible in a storage ring[3]. This ambitious programme is to be exploited within the NUSTAR (Nuclear Structure, Astrophysics and Reactions) programme[4]. Consequently, a broad experimental programme utilising these beams are envisaged, under the umbrella of the NUSTAR collaboration. Within the landscape of RIB facilities [5], FAIR-NUSTAR will be the premiere European in-ight facility [6], having the world-wide most energetic secondary beams.
The NUSTAR programme will be presented with emphasis on the _rst part to be realised, the modularized start version (MSV) [7] but with an outlook towards intermediate opportunities and short- and long-term extensions, in particular with respect to the projects using storage rings. The experimental methods and the associated instrumentation are currently being constructed and/or developed, partially through combining prototype tests and pilot experiments with the existing GSI installations.

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Physics prospects with PANDA at FAIR

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Physics with antiprotons in the charmonium mass region will play a major role at the future PANDA experiment at the FAIR research facility in Darmstadt. At PANDA, an antiproton beam with momenta of up to 15 GeV/c circulating in the high-energy storage ring HESR will interact with a stationary target (e.g. a pure hydrogen cluster jet). High interaction rates and unprecedented momentum precision will allow experiments addressing, among a variety of other physics goals, hidden and open charm spectroscopy. The detector system of PANDA is optimized to meet the challenges of high-resolution spectroscopy of charmonium states of any quantum number in formation and production with very good background suppression. At the same time, emphasis is placed on meeting the requirements of other parts of the physics program as, e.g. spectroscopy of hypernuclei, with a flexible setup of detector components. The design of the subsystems of the PANDA spectrometers, a target solenoid and forward dipole, is well advanced. Prototypes have been subjected to beam tests and the mechanical setup comprising all components is under study.
A status report on the aspects of the physics program with emphasis on charm production and spectroscopy in baryons and mesons will be given. The recent discovery of charged charmonia and states that do not fit the conventional level scheme of charmonium offers exciting perspectives for the PANDA experiment, which will have a strong focus on the properties of these objects as well as the unambiguous identification of exotic QCD states, which have been predicted in the mass range best accessible at PANDA. In addition, baryon and meson spectroscopy will be performed with very high statistics samples. The structure of the nucleon can be studied at PANDA through measurements of the time-like form factors of the proton. Hadrons in matter and hypernuclear physics can be studied using heavier targets and secondary reactions of hyperons in a specialized setup.
The talk will focus on selected topics from the wide physics program of the PANDA experiment and discuss these using simulations and estimates from ongoing feasibility studies.

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Electron dynamics in strong electromagnetic fields: Atomic physics with highly-charged heavy ions

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Owing to the recent advances in heavy-ion accelerators and storage rings, more possibilities arise to study ion-electron and ion-atom collisions. The fundamental atomic processes, that take place in these collisions, attract much current interest both in theory and experiment. At the GSI storage ring in Darmstadt, for example, a number of case studies on the charge transfer, atomic bremsstrahlung as well as Coulomb excitation and ionization have been performed during the last decade. The results of these experiments have revealed valuable information about electron-electron and electron-photon interactions in the presence of strong electromagnetic fields. In this contribution, we summarize the recent advances in the *theoretical* description of the basic collision processes with highly-charged heavy ions. Special attention will be paid to the radiative electron capture and bremsstrahlung as well as to the polarization properties of light emitted in these processes [1,2]. Moreover, we shall discuss how the analysis of the characteristic radiation following Coulomb excitation and dieletronic recombination of highly-charged ions may help us to gain more insight into the many-electron, quantum electrodynamic (QED) and even parity-violation phenomena in heavy atomic systems.

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QED at storage rings: theory and experiments

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Bound state quantum electrodynamics (BSQED) is the part of the standard model that describes properties of atoms and ions. Tests of BSQED can reveal new effects and processes, which could be manifestation of fundamental effects in the realm of even high-energy physics. A recent example is the case of muonic hydrogen and the proton size puzzle, where measurements in normal and muonic hydrogen lead to different proton charge radii [1]. Indirect tests of BSQED can also be performed at storage rings, by testing special relativity (time dilation), on which is based QED [2]. The most advanced theoretical calculations in BSQED concerns in 1- to 3-electron ions (see for example [3]), in particular transition energies and ground state hyperfine structure (see, e.g [4]-. There is a general agreement between results obtained at low and medium Z with BSQED calculations. I will describe the present status of theory and discuss recent results obtained for few-electron ions, using a variety of methods (EBIT [5], ECRIS [6], ESR for example [7,8]). I will also discuss the possible discrepancy in n=2 to n=1 transitions in heliumlike ions that has been claimed recently [9].
Another important test of QED in ions is the study of supercritical field, corresponding to Z>173, which can be obtained in heavy ion collisions. I will describe a new kind of experiment using heavy-ion storage rings.

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Dielectronic recombination experiments of oxygen-like $^{78}Kr^{28+}$ at the HIRFL-CSRm[a]

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Total recombination rate coefficients of $^{78}Kr^{28+}$ ions have been measured by employing the electron-ion merged-beams technique [1] at the main cooler storage ring (CSRm) at the Institute of Modern Physics, Lanzhou. The relative energies from 0 to 13.5 eV between the electron beam and the ion beam at center-of-mass frame is precisely tuned by a fast electron beam energy detuning system. The recombined ions are separated by a dipole magnet and detected by a scintillation detector [2]. The experimental results are shown in Fig. 1, the RR contribution has been removed from the spectrum by subtracting an empirical function from the experimental rate coefficients. A theoretical calculation using the flexible atomic code (FAC) has been carried out to calculate the recombination rate coefficients. The further data analysis is in progress.

In order to calibrate the detuning system at the CSRm, a DR experiment with Lithium-like Ar^{15+} ion beam is in preparation. We will also extend the DR experiments with highly charged ions (He-like and Li-like) into the experimental cooler storage ring (CSRe). The details of DR experiments at the CSRm and CSRe including experimental results and preparation works will be presented on the conference.

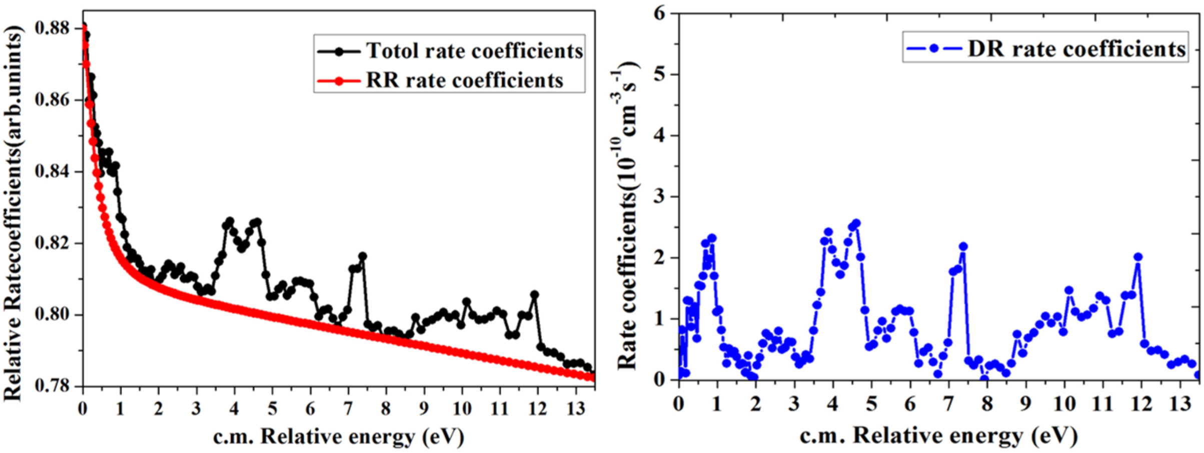

Fig. 1. The rate coefficients of total (Left) and subtracted RR contribution (Right) as a function of c.m. relative energy of Kr28+.

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[a] Further experiment will be performed within the DR-collaboration. The project is supported by NSFC91336102 and GJHZ1305.

Observation and manipulation of coherence in the time-reversed relativistic photoelectric effect

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The photoelectric effect was studied in the regime of hard x-rays via its time-reversed process of radiative recombination (RR). In the experiment the relativistic electrons recombined into the $2p_{3/2}$ excited state of hydrogenlike uranium ions and the RR x-rays and the subsequently emitted characteristic x-rays were detected in coincidence. In this new type of experiment the reaction plane is defined by the incoming (unpolarized) electron and the emitted RR x-ray propagation directions, and, most importantly, the formed excited state becomes a *coherent* superposition of the magnetic substates. Here the electron propagation direction in the ion rest-frame is taken as the quantisation axis. As the result of the coherence the state attains a new alignment axis, which is confined to the reaction plane and forms a finite angle γ with respect to the collision axis. The alignment angle γ can be measured via the angular distribution of the characteristic Lyα1 x-rays.

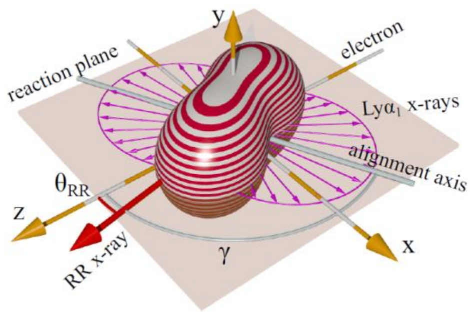

Figure 1: The angular density distribution of the charge cloud of the RR-populated 2p3=2 state when the RR x-ray is observed.

The results show the dominance of the relativistic effects and indicate the generation of the strong magnetic fields during the recombination process. The technique of the photon-photon coincidences was extended, for the first time, to the domain of hard x-rays and heavy ions. This is a qualitative improvement from the previous experiments, and it has a high potential for studies of alignment and polarization phenomena in atomic collisions. Moreover, by this technique we are able to manipulate and monitor the alignment and coherence of the excited states in heavy highly charged ions.

Electron spectroscopy at the high-energy endpoint of electron-nucleus bremsstrahlung studies at the ESR

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The high-energy endpoint of electron-nucleus bremsstrahlung is of fundamental interest due to its close relation to photoionization (PI) and radiative electron capture (REC). It provides most stringent tests for understanding the coupling between a matter field and an electromagnetic field. In this process, the incoming electron scatters inelastically off an atomic nucleus and transfers almost all of its kinetic energy onto the emitted bremsstrahlung photon. Alternatively the electron can be understood as being radiatively captured into the continuum of the projectile (RECC). Experimentally this process is only accessible using inverse kinematics, where quasi-free target electrons scatter off fast highly charged heavy projectiles. For collisions U^{88+} + N_2 @ 90 MeV/u new measurements of the electron energy distribution in coincidence with the emitted photon have been conducted at the Experimental Storage Ring ESR at GSI, using the upgraded magnetic electron spectrometer [1,2]. Furthermore electron energy distributions for non-radiative electron capture to continuum (ECC) and the electron loss to continuum (ELC) could be determined. Comparison with various theoretical calculations will be presented.

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Penning traps for fundamental tests of nature

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The presentation will provide an overview on recent fundamental applications of precision measurements with cooled and stored exotic ions in Penning traps going on at many places in the world. There is a rich variety of research areas and fundamental applications with these storage devices, which are much smaller than storage rings and the species of interest are stored at almost rest in space:

- Precision Penning-trap mass measurements on short-lived nuclides provide indispensable information for neutrino physics, nuclear physics and astrophysics, and for testing fundamental symmetries.
- In-trap experiments with-highly-charged one or few-electron ions allow for better determination of fundamental constants and for constraining quantum electrodynamics in extreme electromagnetic fields.
- Penning traps play a crucial role in experiments testing the Charge-Parity-Time reversal symmetry with protons and antiprotons.

The HITRAP facility for slow highly charged ions

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At the GSI accelerator complex, behind the universal linear accelerator UNILAC and the synchrotron SIS, highly-charged ions up to U72+ are produced at 400 MeV/nucleon. When this beam is sent through a gold foil all or nearly all remaining electrons will be stripped. The HITRAP facility is built to decelerate those ions to almost rest and to provide them to the experiments.

The decelerated ions will be used for precision experiments for atomic and nuclear physics purpose. They range from laser spectroscopy on stored ions, collision experiments with complete kinematic analysis to high precision mass measurements on single highly charged ions.

The deceleration starts in the ESR accompanied by stochastic and electron cooling. The beam is stored at 400 MeV/nucleon, cooled stochastically, decelerated to 30 MeV/nucleon, cooled by electrons, decelerated to 4 MeV/nucleon, again electron cooled, and ejected after rebunching. Then the ions are injected into a linear decelerator to be bunched and decelerated first to 500 keV/nucleon and finally to 6 keV/nucleon. For final cooling to an energy equivalent of 4 K the ions are caught in flight in a Penning trap. There the highly charged ions are cooled with electrons and resistively before ejection to the experiments.

In a number of commissioning beam times, the deceleration in the ESR, the extraction, bunching and deceleration to 0.5 MeV/u has been shown. The remaining steps, deceleration to 6 keV/u and cooling in a cryogenic Penning trap are ongoing and will be discussed.

Precision mass measurements of exotic ions with a MR-ToF system

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The masses of exotic nuclides are among the most important input parameters for modern nuclear theory and astrophysical models. At the high-precision Penning-trap mass spectrometer ISOLTRAP at ISOLDE/CERN, an electrostatic ion-storage device has been operated in combination with a Bradbury-Nielsen gate (BNG) as multi-reflection time-of-flight (MR-ToF) mass separator to achieve isobar purification with mass-resolving powers of 10^5 in a few tens of milliseconds [1]. The purified beam was forwarded to the Penning-trap for subsequent experiments [2].

Furthermore, the MR-ToF device itself can be used as a mass spectrometer (MS) to determine the masses of nuclides with short half-lives and produced with very low yields, where Penning-trap measurements become impractical due to the lower transport efficiency and decay losses during the purification and measurement cycles [3]. Recent cross-check experiments show that ISOLTRAP's MR-ToF MS allows mass measurements with uncertainties in the sub-ppm range. In a first application, mass measurements of the nuclides ^{53,54}Ca were performed [4], delivered with production rates as low as 10/s and half-lives of only 90(6) ms [5]. The nuclides serve as important benchmarks for testing modern chiral effective theory with realistic 3-body forces.

The contribution will present the new applications of the on-line mass spectrometer ISOLTRAP now possible due to the implementation of the MR-ToF MS. In particular, the mass measurements of the neutron-rich calcium isotopes up to A=54 will be discussed. In addition, preliminary results of the first results from the isotonic potassium isotopes will be reported.

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High-Performance Multiple-Reflection Time-of-Flight Mass Spectrometers for the Research With Exotic Nuclei and for Analytical Mass Spectrometry

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A class of multiple-reflection time-of-flight mass spectrometers [1] (MR-TOF-MS, also referred to as isochronous electrostatic ion beam traps) has been developed for the research with exotic nuclei at present and future accelerator facilities such as GSI Darmstadt, TRIUMF (Vancouver), and FAIR (Darmstadt). They can perform highly accurate mass measurements of exotic nuclei, serve as high-resolution, high-capacity mass separators and be employed as diagnostics devices to monitor the production, separation and manipulation of beams of exotic nuclei. Thus they help to overcome present limitations of rare isotope beam facilities, set by strong contamination from isobaric reaction products and the short lifetime of the nuclei to be studied. In addition, a mobile high-resolution MR-TOF-MS has been developed for in-situ applications in analytical mass spectrometry ranging from environmental research to medicine.

The MR-TOF-MS comprise an entrance RFQ for ion cooling and transmission, an injection RF trap for ion bunching, and a coaxial TOF analyzer, in which the ions are trapped by electrostatic fields. Several novel methods have been developed to further enhance the performance and versatility of MR-TOF-MS. Temporal focusing of the ions onto the detector plane regardless of the tuning of the analyzer is performed using either a post-analyzer reflector or a dynamic time-focus shift technique. Thus extremely high resolution can be achieved as well as very short flight times. Mass separation is performed using either a Bradbury-Nielsen-Gate or a novel mass-selective re-trapping technique. Mass resolving powers up to 600,000 (FWHM) at 50% transmission efficiency have been achieved. A mass resolving power of 130,000 at mass 133 has been reached after only 2.9 ms. Mass measurement accuracies on the level of 0.1 ppm, ion capacities of more than a million ions per second, and cycle frequencies has high as 1 kHz have been achieved. Operation as high-resolution mass separator has been demonstrated using various isobars. For the first time, direct mass measurements of heavy projectile fragments were performed with an MR-TOF-MS, among them the nuclide ^{213}Rn with a half-life of just 19.5 ms; mass determination with only 25 detected ions and at ion rates of four ions per hour has been demonstrated.

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Storage ring experiments of resonant electron-ion collisions at the interface of atomic and nuclear physics

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Resonant atomic electron-ion collisions, in particular the exploitation of the resonant channel of photorecombination, the dielectronic recombination (DR), have become a versatile alternative to the long-established conventional approaches in precision spectroscopy of highly charged ions [1]. DR collision spectroscopy can be regarded as "inverse" Auger spectroscopy since the initial step of DR, the so-called dielectronic capture is time-inverse to autoionization. The list of applications of this electron-ion collisions spectroscopy approach comprises topics in astrophysics, plasma physics, fundamental interactions, in atomic as well as in nuclear physics [1, 2].

In this presentation, I will discuss recent developments in the exploitation of DR as a sensitive spectroscopic tool at the interface of atomic and nuclear physics such as for QED studies or for the investigation of nuclear properties, i.e., charge radii, magnetic moments and nuclear spins [1,3,4]. The sensitivity of few-electron heavy ions to nuclear parameters,--nuclear size effects scale with Z^5 to Z^6, hyperfine splitting with Z^3, and hyperfine lifetimes with Z^9--, is both blessing and curse: The interpretation of spectroscopic data in terms of strong-field QED requires a profound knowledge about the impact of the nucleus on transition energies or matrix elements. On the other hand, isotope shift, hyperfine or lifetime data few-electron ions under examination can be evaluated with respect to nuclear parameters on a full QED level [3-5].

Recent advances in the field are exemplified by a series of experimental studies conducted at the electron cooler/electron target of the storage rings ESR in Darmstadt and TSR in Heidelberg. The experiments were carried out with stable ions, but also with in-flight produced radioisotopes or even on long-lived nuclear excited states (isomers) [6]. A primary asset of the technique is the combination of large atomic cross sections, of the repeated interaction (1-2 MHz) of the circulating ions with the target electrons and a ~100% collection efficiency of the recombined-ion reaction products. These features render DR collision spectroscopy ideally placed for experiments with dilute primary beam intensities such as artificially synthesized radioisotopes [6].

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Lifetime Measurements of Nuclei in Few-Electron Ions

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The experimental storage ring ESR at GSI has been used since its start to store highly charged ions and to study nuclear decays in these bare or few-electron ions. The modifications of the decay constant can play a drastic role in hot astrophysical environments where ions are also stripped to high charge states. To cool the ions we use both stochastic and electron cooling. Various detection methods will be described, like the periodic modulation of the Schottky noise reflecting the mass-to-charge ratio of the ions or the (destructive) use of particle detectors. The first observations of beta-decay into bound states of the electron will be explained as well as the influence of this decay mode on the cosmic clock ^{187}Re. The influence of the number of electrons on the electron capture (EC) decay probability will also be discussed. And finally I will present the observation of modulations in the two-body EC decay probability, which we have observed in different systems.

Study of projectile fragmentation reaction with Isochronous Mass Spectrometry

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Schottky (SMS) and Isochronous (IMS) Mass Spectrometry[1] are two complementary experimental techniques in storage rings which have been developed to resolve and determine mass to charge ratios by measuring the revolution frequencies of stored ions. Recently, with IMS, CSRe at IMP and ESR at GSI have successfully measured masses of very exotic nuclides with $T_z = 1/2$, 1 and 3/2. The IMS can be employed to identify fragments by combining the corresponding revolution frequencies and the average signal amplitudes. It is sensitive to single stored ions, which can be very short-lived, and thus, can be applied to study the projectile fragmentation reaction by measuring the yields of produced fragments. Nuclear reaction yields can provide unique information on the nuclear structure and the nuclear reaction properties. The isomeric yield ratios from projectile fragments have been measured at CSRe with the IMS, which can be seen as a complement to γ-ray spectroscopy for measuring the isomeric ratios in particular for high atomic charge states and long lifetimes. With the isomeric yield ratios of high-spin 19/2 state in ^{53}Fe, the angular momentum populations following the different projectile (^{58}Ni, ^{78}Kr, ^{112}Sn) fragmentation are studied. Compared with the predictions of sharp cutoff formula, that is based on the statistical abrasion-ablation description of relativistic fragmentation, the isomeric ratios of ^{53}Fe deduced from different projectiles suggest that the over- or underproduction in theoretical calculations depends not only on spin, as presented in literature[2], but also depends on the removed number of nucleons. Otherwise, the odd-even staggering of the relative fragments yields depends on both the pairing and shell structure. This was observed in the ^{78}Kr projectile fragmentation and can be explained by the odd-even staggering of the particle-emission threshold energies[3].

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First Nuclear Transfer Reaction Measurement at the ESR, For the Investigation of the $^{15}O(\alpha,\gamma)^{19}Ne$ reaction.

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The branching ratio, $\Gamma_\alpha / \Gamma_\gamma$, of the 4.033 MeV 3/2+ state in ^{19}Ne plays a critical role in the breakout from the hot CNO cylces to the rapid proton capture process in x-ray burst scenarios [1]. Here, the 4.033 MeV state was populated using the $^{1}H(^{20}Ne,^{2}H)^{19}Ne^{*}$ reaction at the Heavy Ion Storage Ring ESR, at GSI. The $^{19}Ne^{*}$ decay, via γ or α emission, was then measured by detecting the heavy reaction product (^{19}Ne or ^{15}O) in coincidence with the deuterons.

In this talk an update on the ongoing analysis of the data obtained in this pioneering study will be given.

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Isoscalar giant resonance studies in a stored-beam experiment for the EXL project

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In the first campaign of the EXL project, at the existing ESR storage ring in GSI, the collaboration has performed feasibility studies and first experiments by using ^{58}Ni beam with internal helium gas-jet target in order to investigate giant resonances with a stored-beam [1]. In this experiment, the inelastic scattered recoil particles (in forward angles in c.m., $\theta \leq 1$ deg.) were detected with a dedicated setup including UHV compatible DSSDs [2]. Preliminary results show evidence of Isoscalar Giant Monopole Resonance (ISGMR) and Isoscalar Giant Dipole Resonance (ISGDR) excitations of the ^{58}Ni nucleus. This also reveals the feasibility for studying, in the near future, giant resonances with radioactive stored-beams, like ^{56}Ni, and extracting important information about the nuclear matter incompressibility [3]. In the present work the current status of the data analysis and simulation results will be discussed. This work is supported by BMBF (06DA9040I and 05P12RDFN8), HIC for FAIR and TU Darmstadt-GSI cooperation contract.

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Electrostatic Storage Rings

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Since 1990, magnetic-confinement heavy-ion storage rings have been very useful tools in atomic and molecular physics. In these devices, ions are stored with kinetic energies most commonly in the range of MeV and for a multitude of experiments use is made of the, relatively speaking, high velocity of the ions. Either directly in collisions with stationary targets or by allowing for very low centre-of-mass energy collisions with velocity matched merged eV or keV electron beams. There are, however, many other cases where the storage energy is of no real concern for the experiment. For example one may want to monitor the decay of a stored beam of metastable ions to determine their intrinsic lifetimes or in case of laser interaction with the stored particles. For such cases storage at keV energies is sufficient and this was – beside the principle massindependence of electrostatic storage – a main motivation behind the first electrostatic ion-storage ring, the 7.6 m circumference racetrack shaped ELISA, in Århus[1].

Since then, several rings have been constructed; introducing new features such as an electron target[2], possibility of liquid-nitrogen temperature operation[3], somewhat increased size and energy range[4], somewhat smaller size and improved laser access[5] or cryogenic operation[6]. In Heidelberg, the very ambitious Cryogenic Storage Ring project will combine a size close to that of the smaller magnetic-confinement rings with cryogenic operation, an electron-cooling device and possibility to overlap beams of laser light and of neutral particles[7].

The DESIREE[8] (Double ElectroStatic Ion-Ring ExpEriment) in Stockholm introduces two rings in a common cryogenically cooled vacuum vessel. Beams of opposite charge polarity are stored in the two rings and overlap over a straight section. DESIREE is now fully operational as a one-ring machine, while optimization of beam overlap and product detection is in progress for the positive/negative ion reaction experiments. In this review, I will give examples of highlights of the science output from these machines and from the yet smaller electrostatic ion-beam traps. I will go into some detail when it comes to the description of the DESIREE facility.

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The CSR Project at MPIK

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In the last decade the demand of low-energy studies on atomic, photonic or electronic collisions as well as large ion mass ranges promoted the development of low energy electrostatic ion storage rings not requiring large accelerators, but offering all advantages of fast ion beams for efficient studies of atomic and molecular interactions.

In this line the electrostatic cryogenic storage ring CSR at MPIK is nearing completion. With 35 m circumference and beam energies of 20 keV to 300 keV per charge unit the CSR will allow experiments in a cryogenic environment with extremely good vacuum and a 10 K ambient temperature. This beam energy and the long field-free straight sections will make it possible to apply merged electron and atomic beams. In a copper-cladded stainless steel vacuum chamber kept at 10 K, the CSR uses a large number of cryopumping units connected to 2 K superfluid helium to reach a low residual gas density. This density will correspond to a room-temperature vacuum of $<10^{-13}$ mbar and was demonstrated within the CSR project in a prototype linear ion beam trap [1], whose ~3 m long cryogenic vacuum system was connected to a room-temperature ion injector system. In the CSR environment long storage times will be ensured for slow highly charged and singly charged atomic ions, as well as molecular and cluster ions. Moreover, the 10 K temperature keeps the internal excitations of molecular and cluster ions at a minimal level, populating well defined vibrational and, for smaller systems, also rotational levels for spectroscopy and collision experiments.

The cryogenic ion beam vacuum system of the CSR together with all ion optical elements is entirely housed in a cryostat [2]. Extensive tests investigating the required thermal, vacuum and high-voltage parameters were successfully completed on one quadrant. With the expertise gained from this quadrant assembly of the CSR was completed up to a point allowing a first room temperature operation for beam storage test purposes.

In spring 2014 a 50 keV Ar^+-beam, delivered from a new electrostatic (300 kV) ion accelerator platform could be successfully stored in the CSR operating at room temperature. Aside beam diagnostics such as position, current and Schottky pickups, particle detectors for neutral and charged fragments have been successfully tested. Presently the CSR is in preparation for a cryogenic test beam time featuring first proof-of-principle experiments.

Recent results will be presented, discussing the present project status as well as future plans.

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First Experiments at the Frankfurt Low Energy Electrostatic Storage Ring (FLSR)

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FLSR is an electrostatic storage ring for low-energy ions (up to 50-80 keV) at the Institut für Kernphysik der Goethe-Universität, Frankfurt am Main, Germany (IKF). It has especially been designed to provide a basis for experiments on the dynamics of ionic and molecular collisions in complete kinematics, as well as for high precision and time resolved laser spectroscopy [1]. The ring has “racetrack” geometry with a circumference of 14,23 m. It comprises four experimental/diagnostic sections with regions of enhanced ion density (interaction regions). First beam has successfully been stored in FLSR in summer 2013 (see Fig.1).

An experiment on dissociative recombination of vibrational cool $^{4}HeH^{+}$ -molecules is presently being installed in one of the experimental sections. First results from these measurements will be reported, which, to the best of our knowledge, will be the first time that kinematic energy release and the orientation of the dissociating molecule will be measured at a vibrational cooled beam.

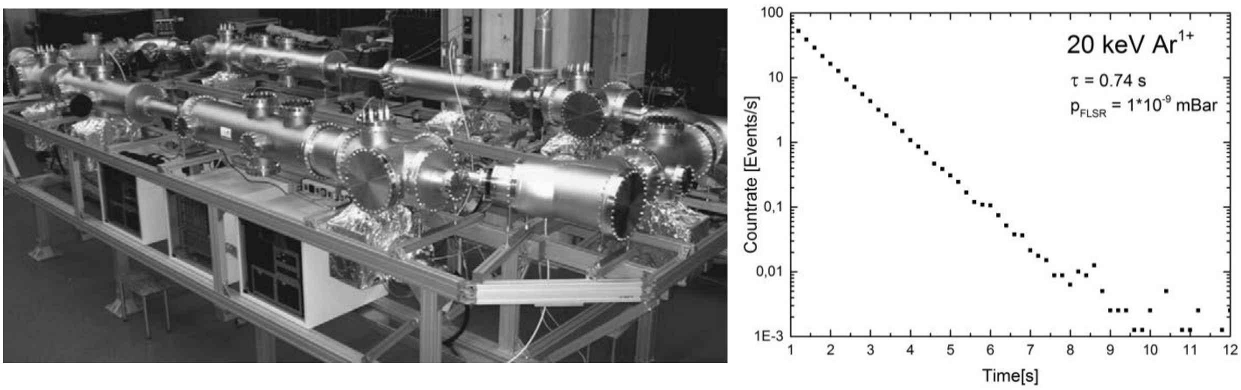

Figure 1: FLSR, the **F**rankfurt **L**ow Energy **S**torage **R**ing at IKF, right: first stored beam at a vacuum of $1*10^{-9}$ mbar.

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Antiproton Chain of FAIR Storage Rings

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In the Modularized Start Version (MSV) of FAIR project, the antiproton accumulation ring (RESR) and the New Experimental Storage Ring (NESR) are not included. Resultantly the exploitation of antiproton beam utility is severely limited. To attain the high resolution experiment in the High Energy Storage Ring (HESR) with thick (4e15 atoms/cm2) internal target, the full use of stochastic cooling is planned from the lowest energy 1 GeV to the max. energy 14 GeV. In addition the beam accumulation up to 1e10 (100 times injection from the pre-cooler ring, Collector Ring, CR) will be performed with the use of barrier bucket and the stochastic cooling system. This accumulation concept was experimentally confirmed at the GSI ESR with 400 MeV/u Ar beam.

Concerning the realization of low energy antiproton beam in the MSV, one of the possible scenarios is to use the HESR as the accumulation ring of 3 GeV antiprotons from the CR up to the intensity 1e9/100 sec (10 cycles) and to decelerate them from 3 GeV to 1 GeV in the HESR. After the shaping of the bunch length, the 1 GeV beam is fast extracted and transferred to the ESR. In this scenario the injected beam energy is well below the transition energy 1.25 GeV of ESR and there is no necessity of crossing the transition energy in ESR. The beam is further decelerated in the ESR down to 30 MeV using the electron cooling at 100 MeV for 6 sec to overcome the anti-damping of emittances, and then fast extracted to the CRYRING. In the CRYRING the beam is further decelerated to 0.3 MeV during 5 sec. In the middle flat, at 5 MeV, the electron cooling will be applied for 2 sec and finally the antiprotons will be fast or slow extracted from the CRYRING. The intensity of antiprotons in this scenario is estimated at 8e8 and then the space charge tune shift at the lowest energy 0.3 MeV could be the most stringent limitation. The overall accumulation and deceleration time from 3 GeV in HESR to 0.3 MeV in CRYRING is designed at 200 sec.

In the present paper the detailed simulation results of above described all process including the results of related experiments will be presented.

Physics with low energy antiprotons

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Low energy antiprotons are currently only available at the Antiproton Decelerator (AD) of CERN, where an additional deceleration ring called ELENA is currently under construction to lower the energy from 5 MeV to 100 keV. Due to the availability of only pulsed extraction, the physics program is centered around the study of antihydrogen formed from its ingredients using charged particle traps or spectroscopy of antiprotonic atoms created by stopping antiprotons in low-density gases. Antihydrogen atoms are regularly created and investigations focus on precision laser and microwave spectroscopy for tests of CPT symmetry, and a first ever measurement of the gravitational interaction of antimatter. Examples for both types of experiments from the ASACUSA and AEgIS collaborations will be presented.

The proposed Facility for Low-energy Antiproton and Ion Research (FLAIR) at FAIR aims at additionally providing slow extracted beams of antiprotons for nuclear and particle physics type experiments. Making use of the CRYRING storage ring currently being installed at the ESR of GSI, such experiments could become feasible if a beam line becomes available to transfer antiprotons from the production target at FAIR to the ESR. The physics potential of such an installation will be reviewed.

Toward polarized antiprotons: Machine development for Spin-filtering Experiments at COSY

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Renewed interest in experiments with polarized antiprotons aims at the production of a polarized antiproton beam at the HESR of FAIR at Darmstadt, Germany. In 2003, a Letter of Intent for a variety of spin-physics experiments with polarized antiprotons has been proposed by the PAX collaboration [1].

Although a number of methods to provide polarized antiproton beams have been proposed more than 20 years ago [2] and recently reviewed [3], no intense polarized antiproton beams have been produced so far. Therefore the PAX collaboration is developing a dedicated program to achieve this milestone.

Via spin filtering an originally unpolarized beam can be polarized by repeated interaction with a polarized gas target due to spin-selective attenuation. In order to complement the Heidelberg TSR spin-filtering experiment with protons [4] by a second measurement, and to commission the experimental setup for the proposed pbar p experiment at the AD of CERN, a spin-filtering experiment was performed in 2011 at COSY/Jülich. The measurement allowed the determination of the spin-dependent polarizing cross section, that compares well with the theoretical prediction from the nucleon–nucleon potential and it confirms that spin-filtering can be adopted as a method to polarize a stored beam.

The talk concentrates on the commissioning of the experimental equipment and the machine studies required for the first spin-filtering experiment with protons at COSY at a beam kinetic energy of 49.3 MeV. The implementation of a low-β insertion made it possible to achieve beam lifetimes of $\tau = 8000$s in the presence of a dense polarized hydrogen storage cell target of areal density $d_t = (5.5 \pm 0.2) \cdot 10^{13}$ atoms/cm². The developed techniques can be directly applied to antiproton machines and allow for the determination of the spin-dependent pbar p cross sections via spin filtering.

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Electron cooling at COSY and perspectives for the HESR

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The 2 MeV electron cooler was installed in the COSY ring in 2013. The new system enables electron cooling in the whole energy range of COSY. The electron beam is guided by a longitudinal magnetic field all the way from the electron gun to the collector. The electrical power to each section is provided by a cascade transformer. Electron beam commissioning and first studies using proton and deuteron beams were carried out. Electron cooling of proton beam up to 1670 MeV kinetic energy was demonstrated. The maximum electron beam energy achieved so far amounted to 1.25 MeV. A voltage up to 1.6 MV was demonstrated. The cooler was operated with an electron current up to 0.5 A. The paper provides insights into the recent progress in high energy electron cooling at COSY.

Laser cooling of hot, relativistic ion beams at FAIR

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At future high-energy facilities, such as FAIR[a] and HIAF[b], atomic and nuclear physics experiments can greatly benefit from ultra-cold ion beams. Such beams have a sharply defined velocity (distribution), which strongly improves the final precision of the results. Unfortunately, at such high energies, well-established cooling methods become either increasingly difficult to implement (electron cooling), or work best for low ion beam intensities (stochastic cooling). By means of laser cooling, ion beams can also be cooled down to very low temperatures and, therefore, obtain small momentum spreads. The infrastructure required for laser cooling can fairly easily be implemented and be adapted to the requirements (ion species, beam energies, lasers, diagnostics) [1].

Here, we present recent results from laser cooling experiments performed at the Experimental Storage Ring (ESR) at GSI in Darmstadt. Laser cooling was achieved by means of a novel continuous-wave laser system (table top), which could scan over a broad frequency range (without mode-hops) in order to cool the bunched ion beam (C^{3+}, 122 MeV/u) inside the "bucket". We also present results from several new diagnostic tools (Schottky resonator, fluorescence detection) at the ESR [2]. Finally, we will discuss how these techniques can be implemented and adapted to the High-Energy Storage Ring (HESR) and the heavy-ion synchrotron (SIS100) at FAIR, and what they could offer for experiments.

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Internal targets at storage rings

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Internal targets play a very important role in nuclear and high energy physics research. Nowdays, after many decades of development, these targets become very common and highly complex devices. Different types of polarized and unpolarized targets like atomic beam, gaseous, liquid, and solid state targets are used in a various experiments at storage rings all over the world. The choice and the usage of existing and development of new devices for internal experiments are strongly depend on many parameters of stored beams (dimentions, life time, cooling availability, polarization) and design parameters of the target (areal density, dimentions at the interaction point, target cooling, gas load to the target chamber and time structure of the target). All these parameters are tightly coupled and must be considered together. Application of different internal targets will be presented.

Prototype internal target design for storage ring experiments

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The introduction of cryogenically cooled, few micrometer-sized nozzle geometries and an essential modification of the experimental storage ring (ESR) target station for the first time allowed for a reliable operation using light target gases at area densities in the range of 10^{13} - 10^{14} cm^{-2}. This represents an improvement of one and three orders of magnitude for hydrogen and helium, respectively [1]. In the course of these optimization efforts, a remarkably versatile target source was established, enabling operation over the whole range of desired target gases (from H_2 to Xe) and area densities ($\sim 10^{10}$ to $\sim 10^{14}$ cm^{-2}).

Owing to certain geometrical restrictions arising from the present ESR inlet chamber setup, the potential offered by the novel target source could not be fully exploited. Hence, a completely new inlet chamber was proposed, based on the experience gained during previous modification processes [2]. The considerably smaller orifice diameter of the new target source enables a much more compact chamber design while, at the same time, maintaining the demanding vacuum requirements of a storage ring. Besides the improvements regarding the achievable area densities, the new target will feature a variable beam width down to 1 mm at the ion beam interaction region. This is of paramount importance with respect to the realization of high precision experiments, e.g. by reducing the inaccuracy of the observation angle causing the relativistic Doppler broadening [3]. While being intended for the deployment at the future high energy storage ring (HESR) within the FAIR project, the new inlet chamber can also replace the current one at the ESR or serve as an internal target for CRYRING.

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Experimental techniques for in-ring reaction experiments

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In recent years, nuclear reactions studies with storage rings have attracted much interest since they give access to scattering processes at very low momentum transfer. The spherical Silicon Particle Array (SPA) for the EXL project [1], designed for this purpose, comprises a large number of telescope-like detector systems of DSSDs and Si(Li)s, setting demands on the vacuum issue connected with the Ultra-High Vacuum (UHV) environment of a storage ring. In order to achieve UHV conditions all the components inside the storage ring have to be baked up to 200 °C for a couple of days which puts serious constraints on the choice of materials for the SPA detector components and structural material.

To fulfill these requirements a differential pumping concept was developed, where the UHV in the ring is separated from an Auxiliary Vacuum (AV) using the innermost DSSD sphere as a vacuum barrier. In such a design, the subsequent layers of DSSDs and/or Si(Li) detectors, together with all unbakeable and thus outgassing components are placed in the AV where at least three orders of magnitude worse vacuum conditions can be tolerated. Since the vacuum barrier DSSDs serve at the same time as fully operating thin-window silicon detectors, low-energy recoil particles, down to about 100 keV in energy, are accessible for registration.

A specially designed detection system, based on the differential pumping concept, was applied successfully in an experiment on elastic scattering of ^{56,58}Ni on p at the ESR storage ring at GSI. In the present contribution, the implementation and essential features of this novel technical concept will be discussed, as well as some adjacent UHV compatible equipment used, such as a silicon PIN diode array positioned at forward angles, and a remote-controlled slit aperture, based on a Piezo positioner. After cooling the beam, the aperture can accurately be positioned close to the target for assessment of a well-defined target-detector geometry and improvement of scattering angular resolution. Finally, perspectives of a next-generation EXL-type setup will briefly be discussed.

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Laser spectroscopy at storage rings

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The combination of storage rings and laser spectroscopy has proven to be an excellent pair being fruitful in both directions: Storage rings can provide ion species for laser spectroscopy that are otherwise not accessible, while lasers offer the opportunity to manipulate the degrees of freedom of an ion ensemble stored in the ring for other experiments. Proposals on laser cooling, laser-induced recombination, tests of Special Relativity with relativistic ion beams and spectroscopy of M1 transitions in highly charged ions have been discussed since the early days of storage rings. During the last couple of years, laser spectroscopy at the experimental storage ring ESR has been revived and new results were obtained. This included an improved test of time dilation in an Ives-Stilwell experiment, the first observation of the long sought-for transition in Li-like bismuth ions and the realization of laser cooling at relativistic speed with broadband lasers. Other proposals have been so demanding that they could be not realized so far.

In my talk I will present some examples on recent laser spectroscopic work at storage rings - with an focus on the recent work at GSI - and an outlook for possible future directions. New opportunities at the "next-generation" storage rings will also be highlighted.

Laser spectroscopic determination of the hyperfine splitting in Li-like bismuth – one step forward

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In summer 2011 we observed for the first time the hyperfine transition in the ground state of lithium-like Bi^{80+} by performing laser spectroscopy at the ESR (Experimental Storage Ring) located at the Helmholtz-Center for heavy ion research (GSI). The previous failing attempts to observe this transition had puzzled both, theory and experiment, for about fifteen years. Even though our result had a large systematic uncertainty dominated by uncertainties in the electron cooler voltage that is required to correct for the large Doppler shifts, it opened the perspective for testing QED in one of the strongest magnetic fields available in the laboratory.

To improve the accuracy of the measured hyperfine splitting, we have repeated this challenging experiment in March 2014 and remeasured this transition together with the hyperfine transition in hydrogen-like Bi^{82+}. This time, a high-precision high-voltage divider built at PTB (Physikalisch-Technische Bundesanstalt) Braunschweig was used, which allowed to monitor the electron-cooler voltage in situ during the measurement. Hence, we have a much better knowledge about the ion velocity and will therefore be able to extract both transition frequencies with higher accuracy.

The status of the ongoing data analysis and preliminary results will be presented and corresponding conclusions will be discussed.

FOCAL - Precision X-Ray Spectroscopy for the 1s Lamb-Shift in H-Like Gold

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High precision x-ray spectroscopy of heavy highly charged ions provides an excellent tool for a test of the most advanced theories describing the atomic structure in the regime of extreme field strengths. These theories take into account quantum electrodynamic (QED) corrections of higher orders and the structure of the atomic nucleus. In the present experiment the Lyman-α and -β transitions in hydrogen-like gold (Au^{78+}) were measured for the first time with the high-accuracy twin crystal spectrometer FOCAL [1] at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany. The spectra were produced at the experimental storage ring (ESR) by colliding initially bare Au ions with an argon gas target at a velocity of 0.47 c, where c denotes the velocity of light. After single-electron capture into an exited state of the projectile ion radiation is emitted by a decay cascade into the ground state part of which is Bragg-reflected at a curved Si crystal in Laue configuration and finally detected by a 2D position sensitive germanium detector. At the conference the status of the investigation along with experimental details will be reported.

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Precise determination of the 1s Lamb shift in hydrogen-like heavy ions at the ESR storage ring using microcalorimeters

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The precise determination of the energy of Lyman α1 and α2 lines in hydrogen-like heavy ions provides a sensitive test of quantum electrodynamics in very strong Coulomb fields [1]. To improve the precision of such experiments, the new detector concept of microcalorimeters is now exploited.

Microcalorimeters detect the temperature change of an absorber after an incoming particle or photon has deposited its energy as heat. This operation principle provides considerable advantage over conventional detectors with respect to energy resolution, detection efficiency, energy threshold and radiation hardness. For the detection of X-rays, a large dynamic range and a high absorption efficiency as well as sufficient detector solid angle are mandatory. Therefore, microcalorimeters for X-rays consist of arrays of silicon thermometers and X-ray absorbers made of high-Z material. With such detectors, a relative energy resolution of about 1 per mille is obtained in the energy regime of 1–100 keV.

The application of microcalorimeters for hard X-rays for the determination of the 1s Lamb Shift in hydrogen-like heavy ions has been pursued by GSI and the collaborating groups for more than two decades. Two successful measurement campaigns to determine the 1s Lamb Shift in Pb^{81+} and Au^{78+} have been completed: A prototype array has been applied successfully for the determination of the 1s Lamb shift of Pb^{81+} at the ESR storage ring at GSI in a first test experiment [2]. Based on the results of this test, a full array with 32 pixels has been equipped and has recently been applied to determine the 1s Lamb shift in Au^{78+} ions [3]. In this contribution, we will briefly introduce the detection principle, then we will present the experiments and the results. In addition, perspectives for other high-precision experiments, i.e. spectroscopy of inner-shell transitions or the determination of nuclear charge radii, will be discussed.

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Metallic Magnetic Calorimeters for High-Resolution X-ray Spectroscopy

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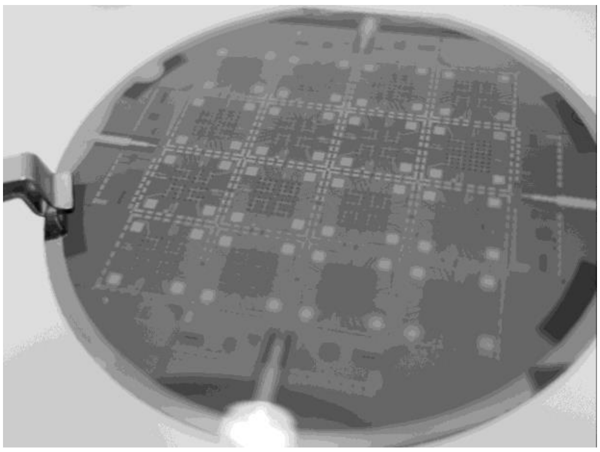
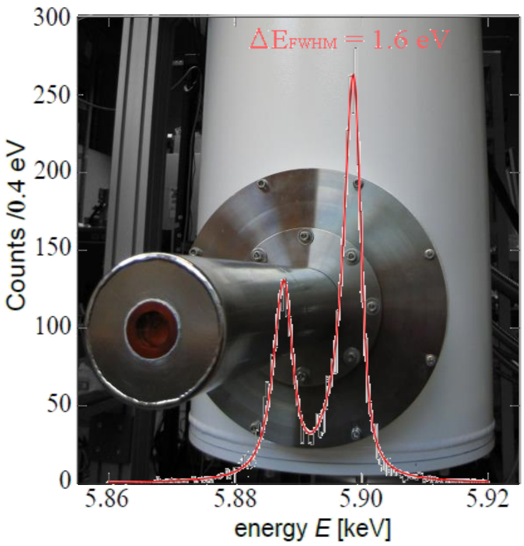
We are presently commissioning maXs, an 8x8 detector array of metallic magnetic calorimeters for high resolution X-ray spectroscopy. The detector is operated at T = 20 mK and is attached to the tip of a 400 mm long and 80 mm wide cold finger of a cryogen-free $^{3}He/^{4}He$-dilution refrigerator. Metallic magnetic calorimeters are particle detectors that convert the energy of a single incoming photon into a temperature rise, leading to a change of magnetization in an attached paramagnetic temperature sensor that is inductively read out by a SQUID magnetometer. Three different arrays, maXs-20, maXs-30 and maXs-200, optimized for X-rays with energies up to 20, 30 and 200 keV respectively, will be available. The cryogenic platform will also allow to operate polar-maXs, a novel high resolution Compton polarimeter which comprises active low-Z Compton scatterer surrounded by a belt of about 60 maXs-type detector pixels with high stopping power. In the ongoing commissioning phase single channel maXs-20 detectors achieved an energy resolution of 1.6 eV (FWHM) for 6 keV photons, which is unsurpassed by any other micro-calorimeter. maXs-20 and maXs-200 have been successfully operated at the MPI-K Heidelberg and the ESR at GSI (were a Au^{76+} ion beam was stored and targeted at a nitrogen gas target) respectively and have shown that the combination of high energy resolution, the fast signal rise-time, the large dynamic range and the excellent linearity up to tens of keV of photon energy, make metallic magnetic calorimeters to a powerful spectrometer for a number of challenging experiments.





Atomic physics at the future Facility for Antiproton and Ion Research

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The new international accelerator Facility for Antiproton and Ion Research (FAIR) which is currently under construction in Darmstadt, Germany has several key features that offer a wide range of exciting new opportunities in the field of atomic physics and related fields [1]. The proposed facility will provide highest intensities of relativistic ion beams (of virtually any element in any desired charge state), in combination with the strongest electromagnetic fields generated by high power lasers, thus allowing for extension of the atomic physics research into completely new domains. Moreover, heaviest highly-charged ions produced at relativistic velocities can be decelerated (down to rest) at dedicated facilities (HITRAP/FLAIR) and become available for high precision experiments in low-energy storage rings and traps [2, 3]. The world-wide unique experimental conditions and opportunities offered by the future FAIR facility will be combined with state-of-the-art as well as novel detection techniques for x-rays, electrons, ions, etc.

In the current contribution, an overview of the scientific program of the SPARC (Stored Particle Atomic Research Collaboration) will be given. These activities comprise, among others; the investigation of relativistic atomic collision dynamics, electron correlation in the presence of strong fields, physics phenomena at the borderline between atomic and nuclear physics, high precision tests of Quantum Electrodynamics (QED) in extreme electromagnetic fields, the use of atomic physics techniques for the accurate determination of various properties of stable and unstable nuclei, as well as proposals for accurate testing of the predictions of the standard model in the low-energy domain [4].

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The ILIMA project at FAIR

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The Isomeric beams, LIfetimes and MAsses (ILIMA) collaboration will exploit heavy-ion storage rings at the Facility for Antiproton and Ion Research (FAIR) for the study of exotic nuclei [1]. Single-ion sensitivity and exceptional production rates of bare or few-electron radioactive ions, with atomic numbers up to Z = 92, promise access to a wide range of short-lived nuclides for the first time. Measuring the masses, lifetimes and decay modes of ground and isomeric states with half-lives greater than ten microseconds will reveal key features of nuclear structure and nuclear astrophysics, extending, for example, to *r*-process waiting-point nuclides in the ^{208}Pb region.

In this contribution the status of the ILIMA project will be presented, focusing on some of the newest developments, such as the installation of the CRYRING at the present Experimental Storage Ring (ESR) and the heavy-ion operation of the High Energy Storage Ring (HESR).

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Non-Achromatic vs. Achromatic Isochronous Mode of the Collector Ring at FAIR

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In order to understand how the heavy elements from iron to uranium were produced in nature, masses and lifetimes of extremely exotic nuclei up to the limits of nuclear existence have to be measured. In particular, for modeling the r-process nucleosynthesis the nuclei close to the neutron drip line are relevant. However, such nuclei typically have very short half-lives and furthermore have tiny production cross-sections. The large acceptance Collector Ring (CR) [1] at FAIR [2] tuned into the isochronous ion-optical mode and operated as a Time-Of-Flight (TOF) spectrometer offers unique possibilities for such measurements.

Recently developed isochronous optics of the CR is achromatic and can be characterized by low transition energy (γ_t) and, correspondingly, by the high dispersion function in the arcs, which directly restricts the transverse and momentum acceptance of the CR. In order to increase the ring's acceptance an achromaticity breaking optics was suggested.

In this contribution, a comparison between the achromatic and non-achromatic isochronous optics will be presented in terms of the achievable mass resolving power. An importance of the TOF detector(s) installation in the dispersive free region will be shown. A possibility of the the 2nd-order dispersion correction with a sextupole magnet in addition to the isochronicity and chromaticity corrections will be discussed.

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Present status of the Rare-RI Ring facility at RIBF

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Nuclear masses are one of the fundamental properties of nuclides, reflecting a variety of shell structures and interactions among constituent nucleons. High-precision mass values of neutron-rich nuclei are also essential to elucidate the pathway for r-process nucleosynthesis. Currently, the challenge is to carry out high-accuracy measurements of the masses of extremely unstable, short-lived nuclei far from stability, the so-called rare isotopes. In conjunction with the highest-intensity radioactive nuclear beams available at the RI Beam Factory (RIBF) in RIKEN, a new storage-ring mass spectrometer, the Rare-RI Ring facility, is now being developed [1]. Radioactive secondary beams produced at the BigRIPS fragment separator are separated in-flight at 200 MeV/nucleon and are delivered to the storage ring. Rare isotopes are then sequentially injected into the storage ring with the fast kicker system. The ion optical condition for the storage ring is precisely tuned to be isochronous. Isochronous mass spectrometry (IMS) [2], originally developed at the ESR storage ring at GSI, is performed in this ring. Thus, precisely measured revolution times of the rare isotopes determine the mass-to-charge ratios with a precision of the order of 10^{-6}. The present contribution reviews the status of the Rare-RI Ring facility.

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Isochronous field study of the Rare-RI Ring

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Construction of the Rare-RI Ring to measure masses of short-lived rare-RI with a relative precision of 10^{-6} is in progress at RIKEN [1-3]. Creating isochronous magnetic field is one of the important issues in mass measurements with the Rare-RI Ring. In order to make an isochronous field, we installed 10 trim coils in the two outer dipoles among the four dipoles in each magnetic sector.

The isochronicity of the magnetic field have been confirmed by measuring time-of-flight (TOF) of alpha particles from an alpha-source (^{241}Am). The alpha-source was placed on a closed orbit. The TOF was measured using a thin foil type detector and a plastic scintillator. The foil detector was placed in front of the alpha-source, while the plastic scintillator was placed behind the alpha-source to detect alpha-particle after 1 turn. We measured TOF of alpha particles while changing the slope of the magnetic field by trim coils and evaluated the isochronicity from the width of TOF spectrum. The TOF width which is minimum value when a radial gradient of magnetic field $(\partial B\mathrm{y}/\partial x)/B_0 = 0.205$, which is in good agreement with COSY simulation. The offline test with alpha-source shows that the trim coils can be adjusted to achieve optimum isochronous field.

In this contribution, we will present the confirmation method of isochronous field of the Rare-RI Ring as well as the result of the achieved isochronicity in the offline test.

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The SCRIT electron scattering facility project at RIKEN RI Beam Factory

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Electron scattering experiment with short-lived unstable nuclei plays an important role in the study of unstable nuclei, because electron scattering can directly probe the internal structure of nuclei without any ambiguity of interaction. Though the electron scattering with unstable nuclei has been desired for long years, it has never been applied because of the difficulty of making radioactive isotope (RI) target.

The SCRIT electron scattering facility [1] has been constructed at RIKEN RI Beam Factory in order to realize electron scattering for RI using the SCRIT (Self-Confining Radioactive isotope Ion Target) technique [2, 3]. This facility consists of a racetrack microtron (RTM), an electron storage ring (SR2) equipped with the SCRIT system, an electron-beam driven RI separator for SCRIT (ERIS), and a cooler buncher system based on a linear radiofrequency quadrupole trap. Scattered electrons are analyzed by a newly constructed spectrometer named as Window-frame Spectrometer for Electron Scattering (WiSES).

The commissioning experiment was performed using $^{133}CS^{1+}$ and $^{132}Xe^{1+}$ ions supplied from ERIS [1]. The trapping efficiency of the SCRIT system was almost 90% at a 250 mA electron beam current, and the luminosity was achieved to more than $10^{26}/cm^2/sec$. In addition, the RI production at ERIS has been also started, and ^{132}Sn was successfully separated in the first attempt [4].

In this contribution, we would like to report the current status of the SCRIT electron scattering facility, and show the prospects for the electron scattering experiment with short-lived unstable nuclei.

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The ELISe experiment, potential paths towards ist realisation

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The ELISe experiment [1] represents a challenging attempt to realize an electron ion scattering facility using two intersecting storage rings. This experiment makes a pure leptonic probe available for the study of exotic nuclei. The main advantage, compared to the worldwide only other experiment [2] using the so-called self-confined RI target (SCRIT) technique, that has been already realized at the RIBF facility in Japan, is the possibility to take advantage of the colliding beam kinematics, which increases the achievable luminosity and detection efficiencies. The experiment has been designed [3,4] for an operation at the NESR at the FAIR facility. Due to its delayed realization we are currently studying alternative ways of realizing this challenging experiment within the modularized start version of the FAIR facility. The overall program of the experiment will be out-lined and possible integration scenarios, using the existing ESR, will be presented.

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The PANDA Central Straw Tracker

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The PANDA experiment is one of the main projects at the future Facility for Antiproton and Ion Research FAIR which is under construction at Darmstadt, Germany.
The Straw Tube Tracker (STT) together with the Micro Vertex Detector Inner Tracker present the central part of the PANDA Target spectrometer.
The main function of the STT is to measure the particle's momentum after track reconstruction as well as particle identification based on specific energy loss measurements in low momentum region. The design and characteristics of STT are described.
The basic features of STT design – self supporting structure and low material budget – were derived from the preparation and running of the TOF experiment at COSY. Mass production is in progress. Two different readout of analog and digital electronics are under development. Upcoming beam times at COSY with proton and deuteron beams with momenta from 3 GeV/c down to 600 MeV/c will provide data for the final choice of the electronics version and confirm the project parameters of the energy and space resolution. The preassembly of the STT detector together with other PANDA components and additional beam tests at COSY are planned before the final transportation to FAIR.

Spin coherence time studies of a polarized deuteron beam at COSY

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The measurement of a non-zero electric dipole moment (EDM) of a fundamental particle would probe new physics beyond the standard model. It has been proposed to search for the EDM of charged particles using a storage ring. The polarization of the charged particle beam is initially aligned along the velocity and the EDM signal would be a rotation of this polarization into the vertical direction as a consequence of the radial electric field always present in the particle frame.

This experiment requires ring conditions that can ensure a life time of the in-plane polarization (spin coherence time, SCT) up to 1000 s. A study has begun at the COoler SYnchrotron (COSY) located at the Forschungszentrum-Juelich to examine the effects of emittance and momentum spread on the SCT of a polarized deuteron beam at 0.97 GeV/c. A special DAQ [1] has been developed in order to provide a direct measurement of a rapidly rotating horizontal polarization as a function of time. The set of data presented here will show how second-order effects from emittance and momentum spread of the beam affect the life time of the horizontal polarization of a bunched beam. It will also be demonstrated that sextupole fields can be used to correct for these depolarizing sources and increase the spin coherence time up to hundreds of seconds.

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Two-photon exchange contribution in elastic electron-proton scattering: measurements at VEPP-3 storage ring

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In the last decade a series of measurements of the proton electromagnetic form factors at Jefferson Lab revealed a striking discrepancy between the results for the ratio of electric and magnetic form factors of the proton obtained by two approaches: the Rosenbluth extraction from the unpolarized cross section and the double-polarization measurements. This lead to a serious reexamination of the accuracy of the procedure used to account for the radiation corrections and especially of the role played by two-photon exchange diagrams. The evaluation of such diagrams is difficult, because an integral over all off-shell proton intermediate state contributions must be made and it is not known how to perform this calculation in model independent way. Various approximations are used, that means an experimental verification is mandatory.

One of the direct way to do this is to measure the ratio of electron-proton and positron-proton elastic scattering cross-section for identical kinematics. An experimental approach using an internal target in an electron/positron storage ring is uniquely suitable for such a measurement.

We report here on the measurement of the e+p/e-p elastic scattering cross-section ratio, which has been performed at the VEPP-3 storage ring at Novosibirsk. There were two runs at beams energy of 1.6 GeV and 1.0 GeV at several ranges of scattering angle. The measurements covered the transferred momentum $\boldsymbol{Q}^2$ up to 1.5 GeV^2 and the virtual photon polarization parameter $\boldsymbol{\varepsilon}$ down to 0.2 .

The VEPP-3 experimental approach will be described. The results of the measurements will be presented.

The TSR@ISOLDE Project at CERN

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The HIE-ISOLDE facility at CERN [1] will post-accelerate the wide range of exotic beams produced at ISOLDE, including isomeric pure beams, up to an energy of 10 MeV/nucleon. We have proposed to install a low-energy storage ring at HIE-ISOLDE using the existing ring TSR at the Max-Planck Institute for Nuclear Physics in Heidelberg [2]. The proposal, detailed in a Technical Design Report published in April 2012 [3], has been approved by the CERN Research Board.

The coupling of a storage ring to an ISOL facility opens up an extremely rich scientific programme in nuclear physics, nuclear astrophysics and atomic physics. Reaction and decay studies can benefit from the "recycling" of the rare exotic nuclei stored in the ring and from low background conditions. Studies of the evolution of atomic structure can be extended to isotopes outside the valley of stability. The TSR can also be used to remove isobaric contaminants from stored ion beams and for systematic studies within the neutrino beam programme. In addition to experiments performed using beams recirculating within the ring, cooled beams can be extracted and exploited by external spectrometers for high-precision measurements.

In this contribution we will present the proposal and its physics cases, including a number of flagship experiments that will be possible with this unique instrument.

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CRYRING@ESR: Present Status and Future Research

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The former storage ring CRYRING has been shipped from the Manne Siegbahn Laboratory in Stockholm to Darmstadt as a Swedish in-kind contribution to FAIR. At its new location downstream of ESR [1] all ion species presently accessible in ESR can be transferred to CRYRING in which ions with rigidities between 1.44 Tm and 0.054 Tm can be stored. The original Swedish layout has been modified by reconfiguring the sequence of straight sections and by slightly increasing the circumference to ESR/2. Ions can be injected from ESR or from an independent 300 keV/u RFQ test injector. The instrumentation of the ring includes an RF drift tube system for acceleration and deceleration (1 T/s, with a possibility for an upgrade to 7 T/s), electron cooling, a “free” experimental section, and both fast and slow extraction of ions.

The new ring gives a welcome opportunity to test many key technologies developed for FAIR in a compact and independently working environment with access to ion beams from the RFQ linac.

To the scientific communities, CRYRING@ESR is a major enrichment of the FAIR Start Version as it will provide access to a new class of slow stored highly charged ion beams. These enable a large set of the experiments proposed by the SPARC collaboration, as well as by FLAIR and NuSTAR. Such are, e.g., experiments on slow atomic collisions, for precision spectroscopy, for nuclear research at the Coulomb barrier and for intersections between atomic and nuclear physics. Also, research on material science and on biophysics can be envisaged.

We report on the present progress of this project, give a prospective timeline, and summarize the new research which will be enabled by this project.

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Reaction Microscopes in Storage Rings

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Our understanding of the dynamics in few-particle quantum systems is based on the systematic observation of scattering processes. The studies of such processes in collisions between ions and atomic or molecular systems experienced a substantial boost with the development of reaction microscopes, also referred to as COLTRIMS (cold target recoil ion momentum spectroscopy). With this technique fully-differential data became accessible for the first time about 10 years ago. The operation of reaction microscopes is ion storage rings is an ideal method to obtain detailed information on the collision dynamics, because storage rings provide excellent experimental conditions with respect to ion beam intensities and emittances. In this presentation some examples of earlier and recent and in-ring experiments with reaction microscopes are given. The perspectives of COLTRIMS experiments at future storage ring facilities will be discussed.

The MOTReMi: A versatile tool to study ion-atom collisions

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Studying the dynamics of atomic collisions enhances our understanding of the fundamental few-body problem in quantum dynamics. In this respect, fully-differential experimental data of ionizing collisions represent the most sensitive tests of theoretical models and calculations. For ion-impact ionization, such experimental data only became accessible about ten years ago using Reaction Microscopes, often referred to as Cold Target Recoil Ion Momentum Spectrometers (COLTRIMS). In these experiments, the momentum resolution is inherently limited by the initial temperature of the target atoms, which are usually prepared by supersonic expansion in a gas jet. Therefore, all fully-differential cross sections reported in literature thus far have been obtained for helium targets, since this element is the only one that can be cooled to temperatures of 1K with sufficient target density.

We present a recent experimental development, the so-called MOTReMi, a magneto-optically trapped (MOT) target of lithium atoms in a ReMi [1]. Integrating this apparatus in the ion storage ring TSR in Heidelberg, the first fully-differential data on ion-impact ionization of a target other than helium have been obtained [1-3]. In the MOT, lithium is cooled down to temperatures well below 1 mK resulting in a substantially improved resolution compared to conventional COLTRIMS experiments. Due to electronic transitions addressable by visible lasers, initial-state selective cross sections [2, 3] and polarized targets have become available in ion-atom collisions for the first time. In this contribution we will give a detailed overview on the experimental technique and recent improvements of the setup.

In future experiments the MOTReMi will be implemented in the upcoming ion storage rings at FAIR permitting detailed insights in the dynamics of collisions between highly charged ions and neutral atoms. These studies will not be limited to the lithium atom, as there are over 20 atomic species currently trapped in MOTs, i.e. all the alkalis and earth-alkalis, which are mostly not accessible with gas jets.

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A SQUID-based Beam Current Monitor for FAIR/CRYRING

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A SQUID-based beam current monitor was developed for the upcoming FAIR project, providing a non-destructive online monitoring of the beam current in the nA-range. The sensor part of the Cryogenic Current Comparator (CCC) was optimized for lowest possible noise-limited current resolution together with a high system bandwidth. It is foreseen to install the CCC prototype inside CRYRING, a low energy storage ring presently under (re-) construction at GSI. CRYRING will act as a well-suited test bench for beam tests to further optimize the CCC current resolution. In this contribution we present results of the completed CCC sensor for CRYRING and FAIR. Preparatory studies regarding the cryostat design or the installation of the CCC at CRYRING are presented.

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Fundamental Symmetries and Interactions

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In the field of Fundamental Interactions and Symmetries numerous experiments are underway or planned in order to verify the Standard Model in physics, to search for possible extensions to it and to exploit the Standard Model for extracting most precise values for fundamental constants. This review will cover recent developments. The plurality of ongoing activities demands a selection and restriction to covering a few topics only. Emphasis will be put on experiments that have a potential transformative character in the foreseeable future, i.e. such which may be able to guide and steer theoretical model building into new but defined directions. Among those are projects with antiprotons, muons and certain atomic nuclei.

Electric Dipole Moment Measurements at Storage Rings

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Electric Dipole Moments (EDM) of elementary particles are considered as one of the most powerful tools to discover CP violation beyond the Standard Model and to find an explanation for the dominance of matter over anti-matter in our universe.

Up to now experiments mainly concentrated on neutral systems (neutron, atoms, molecules). Storage rings offer the possibility to measure EDMs of charged particles by observing the influence of the EDM on the spin motion.
The Cooler Synchrotron COSY at the Forschungszentrum Jülich provides polarized protons and deuterons up to a momentum of 3.7 GeV/c and is thus an ideal starting point for such an experimental programme. Plans for measurements of charged hadron EDMs and results of first test measurements will be presented.

Colliding or Counter-rotating Ion Beams in Storage Ring for EDM Search

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A new approach to search for and measure the Electric Dipole Moment (EDM) of the proton, deuteron and some other light nuclei is presented. Idea of a method is to store in a ring with crossed electric and magnetic guiding field two ion beams circulating there with different velocities [1]. One beam is polarized and its EDM is aimed to be measured using the frozen spin method [2, 3]. The second beam, which has different from the first one velocity and charge to mass ratio Z/A, is used as co-magnetometer sensitive to the radial component of the magnetic field. Measuring by SQUID-pickups [4, 5] the relative vertical orbit shift of two beams, caused by the presence of radial magnetic field, one could control the unwanted MDM spin precession, which mimics the EDM signal. By proper choice of the bending electric and magnetic field values one could make rational the ratio of the revolution frequencies of two beams. Examples of parameters for proton-, deuteron-, hellion- and some other ion species EDM storage rings are presented. The use of crossed electric and magnetic fields helps to reduce the size of a ring by factor 10 to 20. We show that bending radius of such, all in one EDM storage ring, could be made of about 2-3 meters. Finally, a new method of increasing of the spin coherence time (SCT), the so called "Spin Wheel", is proposed and its applicability to the EDM search is discussed.

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The FAIR Project

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The Facility for Antiproton and Ion Research in Europe, FAIR, will provide worldwide unique accelerator and experimental detectors allowing for a large variety of unprecedented fore-front research in extreme state of matter physics and applied science. This presentation outlines the results of ongoing experimental activities on heavy ion accelerator facilities, providing intense beams capable of generating extreme state of matter by isochoric energy deposition regime. Considerations are focused on new experiments by using large synchrotron rings which appear to be efficient tools for investigations into the physics of high-brightness beams generation and high energy density research.
Development of new plasma diagnostic methods for high resolution measurements of dense, non-ideal plasmas parameters is discussed.

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http://www.fair-center.eu

The Nuclotron/NICA Project at JINR

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The NICA (Nuclotron-based Ion Collider fAcility) complex is presently under realization phase at JINR [1]. The main goal of the NICA scientific program is an experimental study of hot and dense strongly interacting matter in heavy ion collisions at nucleon-nucleon centre-of-mass energies of 4-11 GeV and at average luminosity of 10^{27} $cm^{-2}s^{-1}$ for Au (79+) in the collider mode. In parallel, fixed target experiments at the upgraded JINR superconducting synchrotron Nuclotron are carried out with the extracted beams of various nuclei species up to gold with the momenta up to 13 GeV/c for protons. The program also foresees a study of spin physics with extracted and colliding beams of polarized deuterons and protons at the centre-of-mass energies up to 26 GeV for proton collisions. The proposed program allows to search for possible signs of the mixed phase and critical endpoint, and to shed more light on the problem of nucleon spin structure.

An overview of the NICA project as well as the present project status will be presented.

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Introduction of HIAF project

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HIAF (High Intensity heavy ion Accelerator Facility) is a new accelerator facility to be built in the next ten years in China. The HIAF project aims to expand nuclear and related researches into presently unreachable region and give scientists possibilities to conduct cutting-edge researches. According to the present plan, there will be two construction phases. The main scientific motivation for the first phase includes the researches such as high energy density (HED) matter physics, the effective strong interaction binding atomic nuclide and the creation of the trans-iron elements in universe. The second phase of the HIAF project will focus on research of intrinsic structure of nucleon by electron-ion collision (EIC). The accelerator complex of the HIAF first phase consists of a 25MeV/u high current superconducting ion linac (iLinac) as an injector, a 34 Tm booster ring (BRing) for phase painting beam accumulation supported by electron cooling and beam acceleration, a 43 Tm high energy storage ring for beam stacking and beam compression (CRing), and a high precision spectrometer ring (SRing) both for internal target experiments and beam quality improvement through stochastic precooling and electron cooling. The unique features of the first phase of HIAF are high current pulsed injection beams from the iLinac and high intensity heavy ion beams with ultra-short bunch from the CRing. The cooled rare isotope beams also will be prepared through projectile-fragmentation (PF) method. A electron accelerator complex will be developed for researches based on the electron-ion collision (EIC) in the second phase. This talk will present an overview of the HIAF project with main focus on conceptual design of the HIAF accelerator, key technology challenge and related R&D.

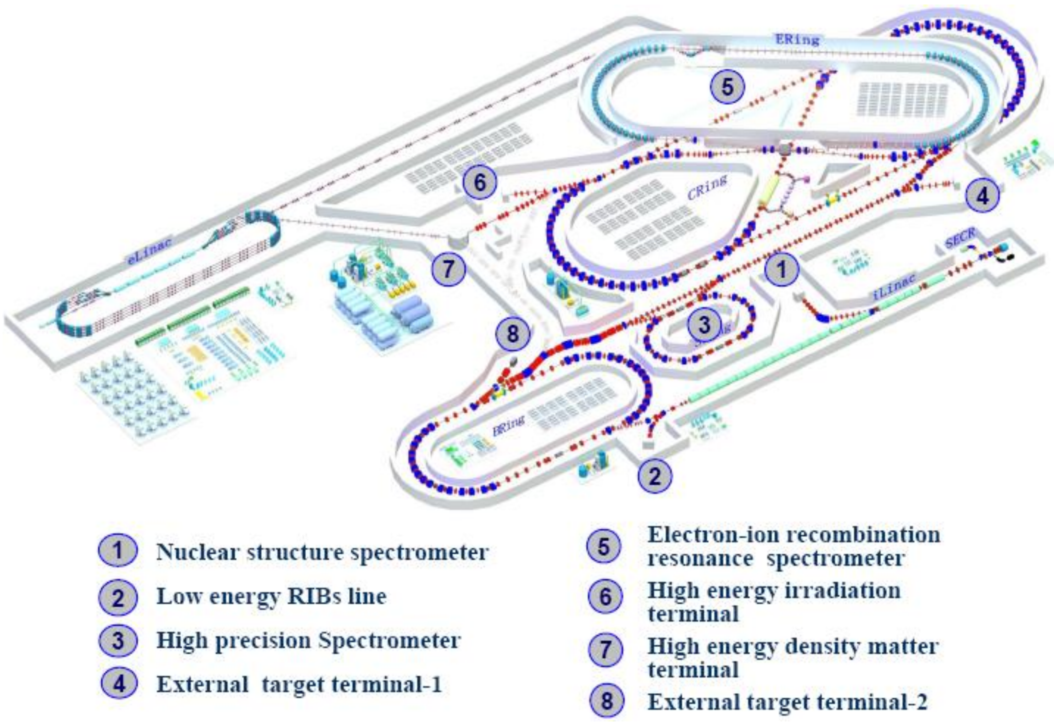

Fig. 1 The proposed experiment terminals of HIAF project

Next generation of secondary radioactive ion beam facilities

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The advent of high power accelerators producing intense stable and secondary radioactive ion beams (RIB) made possible the exploration of a new territory of nuclei with extreme in Mass and/or N/Z ratios. To pursue the investigation of this terra incognita several projects, a new generation of RIB facilities, all aiming at the increase by several orders of magnitude of the RIB intensities is now under construction and/or planned for the end of this decade worldwide. RIB production at SPES@Legnaro, SPIRAL2@GANIL, HIE-ISOLDE@CERN, ALTO@Orsay, TRIUMF (Canada), CARIF @Beijing, MYRRHA@Mol (Belgium) and EURISOL (EU) are based on the ISOL method. Projects of high intensity, heavy ions, low energy drivers (< 10 MeV/n) are also foreseen at Flerov Laboratory@DUBNA, SPIRAL2@GANIL, HIM@GSI and RILAC-GARIS@RIKEN. RIBF@RIKEN, FAIR@GSI with the new Super-FRS fragment –separator and the NUSTAR collaboration, FRIB@NSCL (USA), HIAF@Lanzhou and RAON-Korea takes advantage of the “In Flight” technique. Novel approach using high power laser and gamma beams are in development at the new ELI-NP project in Romania. Technical performances, innovative new instrumentation and methods, and keys experiments in connection with these second generation high intensity RIB facilities will be discussed.

Posters

Nuclear structure studies in the Rb and Cs region using high-precision Penning-trap mass data

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Many of the measured nuclei are not spherical symmetric but rather they show strong intrinsic deformations. These nuclei can be described in lowest order approximation as quadrupole deformed prolate or oblate ellipsoids. Corrections of higher order such as octopole or hexadecapole are also possible to contribute to the description of the nucleus.
We have performed high-precision mass measurements in the Rb and Cs region, especially mentioning the first time study of the neutron-rich ^{148}Cs and ^{99,100}Rb isotopes using the Penning-trap mass spectrometer ISOLTRAP [1]. The isotope ^{148}Cs is located in a region where the emergence of complex intrinsic shapes is expected. In the case of the Rb isotopes, experimental observables suggest a sudden onset of deformation in this region of the nuclear chart. We have carried out theoretical studies of nuclear deformation by employing the newly measured masses. The ^{99,100}Rb nuclei in our investigations exhibit a variety of intrinsic shapes, with stable prolate and oblate configurations lying close in energy [2].
In this contribution we will present the experimental technique, systematics of ground state properties such as two-neutron separation energy and charge radii as well as comparisons to theoretical calculations.

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Proton-proton elastic scattering studies using the internal target at COSY

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The analyzing power in pp elastic scattering has been measured at small angles using COSY-ANKE for six beam energies between 0.8 and 2.4 GeV using a polarized proton beam and unpolarized proton internal target. The analyzing power results agree well with the many published data at 796 MeV [1-4], and the ANKE data at the higher energies lie well above the predictions of the most recent published SAID solution (SP07) [5].

The new experimental ANKE results close an important gap in the database of polarized proton-proton elastic scattering. The small-angle range, accessible to ANKE and complementary to the EDDA angular range [6,7], has significantly influenced some of the phases and inelasticities in the low partial waves. It should be noted, that the asymmetries obtained independently by detecting the fast proton in the ANKE forward detector or the slow recoil proton in a silicon tracking telescope are strikingly consistent.

An updated phase-shift analysis that uses the ANKE results together with the World data leads to a new solution (also shown in the poster) that describes the measurements much better. This represents a major step forward towards a better phenomenological understanding of the nucleon-nucleon interaction, which is important in its own but also will have an impact on many other NN reactions.

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Search for heavy exotics with hidden charm in antiproton-proton annihilation

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The study of strong interactions and hadron matter in the process of antiproton-proton annihilation seems to be a challenge nowadays. One of the main goals of contemporary physics is to search for new exotic forms of matter, which must manifest in the existence of charmed hybrids $c\bar{c}g$ and multiquark states such as meson molecules and tetraquarks [1, 2]. The researches of spectrum of charmed hybrids and tetraquarks with hidden charm and strangeness ($cq\bar{c}\bar{q}'$, q and q' = u, d, s) together with the charmonioum spectrum are promising to understand the dynamics of quark interactions at small distances. It is a good testing tool for the theories of strong interactions: QCD in both perturbative and non-perturbative regimes, QCD inspired potential models, phenomenological models, non-relativistic QCD and LQCD. Two generic types of multiquark states have been described in the literature [2, 3]. The first, a molecular state, is comprised of two charmed mesons bound together to form a molecule. Since the mesons inside the molecule are weakly bound, they tend to decay as if they are free. The second type is a tightly bound four-quark state, so called tetraquark that is predicted to have properties that are distinct from those of a molecular state. A prediction that distinguishes tetraquark states containing a $c\bar{c}$ pair from conventional charmonia is possible existence of multiplets which include members with non-zero charge $cu\bar{c}\bar{d}$, strangeness $cd\bar{c}\bar{s}$, or both $cu\bar{c}\bar{s}$.
The detailed analysis of the spectrum of charmed hybrids with exotic ($J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}$) and non-exotic ($J^{PC}=0^{-+}, 1^{+-}, 2^{-+}, 1^{++}, 1^{--}, 2^{--}, 2^{++}, 3^{+-}$) quantum numbers and tetraquarks with hidden charm and strangeness was carried out, and attempts to interpret a great quantity of experimental data above the $D\bar{D}$ threshold were considered. The analysis of charmonium spectrum was carried out earlier. New higher lying states of charmonium, charmed hybrids and tetraquarks are expected to exist in the mass region above the $D\bar{D}$ threshold. But much more data on different decay modes are needed for deeper analysis. These data can be derived directly from the experiments with high quality antiproton beam. A special attention is given to the new *XYZ* states with hidden charm discovered recently. Their interpretation is far from being obvious nowadays. The experimental data from different collaborations like BES, Belle, BaBar, LHCb were carefully studied. Some of these states can be interpreted as charmonium and tetraquarks in the framework of the combined approach proposed earlier. It has been shown that charge/neutral tetraquarks must have neutral/charge partners with mass values which differ by few tens of MeV. This treatment coincides with hypothesis proposed by Maiani and Polosa. It seems to be a promising approach and needs to be carefully verified in experiments using high quality antiproton beam with momentum ranging up to 15 GeV/c.

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A 3D Molecular Fragmentation Imaging detector for the Cryogenic Storage Ring

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Molecular ions play an important role in the gas phase chemistry of the interstellar medium. Reactions of molecular ions with photons or electrons have been extensively studied for relatively light molecular ions in storage ring experiments using, e.g., the Test Storage Ring (TSR) in Heidelberg. However, these experiments hit limitations, especially for heavy species. On the one hand the thermal radiation in the room-temperature devices used so far excites rotational modes of many molecules. On the other hand the beam storage lifetimes of very slow ions are often too short to allow preparation of beams suitable for precision experiments.

The Cryogenic Storage Ring (CSR) [1], in commissioning at the Max Planck Institute for Nuclear Physics (MPIK) will overcome these limitations by using an all-cryogenic electrostatic beam line in combination with electron cooling of the stored ions. Photon or electron impact induced fragmentation of the molecular ions will be studied by fast-beam coincidence fragmentation imaging. The nearly coincident neutral fragments from single dissociation events will be detected by a 3D imaging system developed in the reported work. The detector consists of two MCPs in Chevron configuration with an active diameter of 120 mm and a phosphor screen operated inside the CSR cryostat. The phosphor screen will be observed from outside the CSR cryostat by a fast camera system developed at Université catholique de Louvain, Louvain-la-Neuve, Belgium. The requirements of the CSR regarding the huge temperature range from operation at 10 K to bake-out at 520 K as well as an extremely high vacuum of better than 1e-13 mbar placed strong demands on the design.

The detector system has been successfully tested in the first commissioning phase of CSR in room temperature operation. Currently the detector is in preparation for the first cryogenic operation of CSR with laser interaction experiments in autumn this year. The design and the first results of this cryogenic detection system will be presented.

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Study of nuclear level density in the case of the hot Sn neutron-rich isotopes.

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Properties of the nuclei at extreme conditions are important in various astrophysical scenarios such as in late stage of a supernova collapse and explosion. During this phenomenon, neutron-rich hot heavy nuclei can be produced. So, the study of properties of these exotic nuclei is essential for understanding processes in nuclear astrophysics. At finite temperature, very limited information exists on nuclear level density and thermodynamic properties particularly for such nuclei.

So, the purpose of the present paper is to perform the calculation of the nuclear level density of the Sn neutron-rich isotopes. It is well known that the Sn isotopes are of particular importance. Lifetimes of these nuclei are very small and production rates are also very low, presenting challenges to spectroscopic studies. So, as a first step, our study will include the ordinary Sn isotopes, it will then be extended to the neutron-rich nuclei. This will be done in the framework of a microscopic model including both fluctuations: quantal and statistical ones. In this aim, we use the modified Lipkin-Nogami method (MLN)[1].

The obtained results are compared to the conventional FT-BCS results [2] and to the MBCS [3] predictions as well as to the experimental data when available [4]. The present study illustrates that the inclusion of statistical fluctuations affect the phenomenon of pairing phase transition. Moreover, the experimental data of this physical quantity are better reproduced when the MLN method is used.

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Compton polarimetry with hard X-rays using segmented solid state detectors

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An important aspect of the study of heavy highly charged ions at storage rings is the measurement of the photons emitted by such systems. In addition to their energy and angular distribution, also their polarization should be determined in order to obtain more complete information on fundamental processes such as radiative electron capture, bremsstrahlung and characteristic transitions. Since these photons typically have energies in the hard X-ray regime, a suitable polarization measurement technique is required. A well-known method is the so-called Compton polarimetry. In this contribution we describe how this technique is applied for atomic physics experiments at storage rings using double-sided strip detectors (DSSDs) [1] as polarimeters. A general introduction is given as well as two examples of experiments, namely the measurement of the linear polarization of a characteristic transition [2] and bremsstrahlung [3], respectively.
A general performance improvement of the DSSDs can be achieved by replacing the NIM/VME-based analog readout electronics with a digital system. The GSI electronics department developed the FEBEX3 digitizer [4], which samples the output of the detector's preamplifier at a constant rate of several 10 Msamples/s. This allows the recording and storing of entire pulses, which provides the maximum information of the signals. An onboard FPGA can be used to digitally analyze the pulses online which removes the need for large storage capacities. First tests with a DSSD and digital readout electronics have been carried out using the previous model of the digitizer FEBEX2 [5].

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A new approach to the particle position detection in a storage ring

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For the beam position monitoring in a storage ring, physicists sometimes use cavity-based resonators to enhance sensitivity. However such a design is most suitable for machines with smaller apertures [1]. In order to achieve high sensitivity to low current beams in large aperture storage rings such as the CR at FAIR, we propose a novel design utilizing the monopole mode. It is a resonant cavity with the beam pipe placed off-centered, where the field distribution of the monopole mode starts to diminish gradually. Through the RF simulation with CST software, we could confirm the detection potential of such a configuration [2]. In this work, we present bench-top measurements of a model cavity based on this design. The result has in general proven the feasibility of the design, but also shown some limitations.

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Magnetic field distribution inside the aperture of a Steerer magnet prototype

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The HESR (High Energy Storage Ring), important part of the FAIR (Facility for Antiproton and Ion Research), contains, among other magnets, several corrector magnets used for vertical and horizontal beam deviation. A prototype of vertical Steerer magnet was designed (Fig. 1.a)) by ICPE-CA Romania in close cooperation with Forschungszentrum Jülich Germany and then manufactured and tested by ICPE-CA [1]. This magnet it's a normal conducting DC magnet (Fig. 1.b)), designed to adjust the trajectory of the particles beam in vertical direction with a maximum angle of $\varphi = 2\text{mrad}$ at $p_{\max} = 15\text{GeV/c}$ [2].

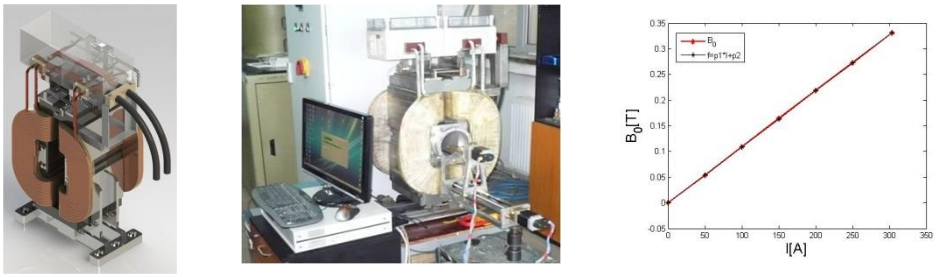

Fig. 1. a) Steerer SolidWorks 3D model *b)* The prototype of the Steerer c) Norm of magnetic flux density in the center of the magnet vs. current

Magnetic field measurements using a 3D Hall probe were performed. In order to check the spatial distribution of the magnetic field created inside the aperture of the Steerer magnet prototype, it was design and built a specialized measurement system (Fig. 1.b)) which consists of: the prototype of the Steerer magnet; a magnet power supply; a gaussmeter with a 3D Hall probe; a special device for positioning the Hall probe inside the aperture; a digital multimeter to measure the current through the magnet coils; an interface between the gaussmeter and the positioning device control system; a PC for controls input, data acquisition and data processing; a digital multimeter with a thermocouple probe, to monitor the temperature of the coils. System used for positioning of the Hall probe and data acquisition is also described.
Measured data and their analysis are presented. In the paper are presented the values of magnetic flux density measured in the center of the magnet, along horizontal and vertical axes for different excitation currents. Also was made a polynomial approximation of experimental data (Fig. 1. c)).

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Design of a New Time-Of-Flight Detector for Isochronous Mass Spectrometry in the Collector Ring at FAIR

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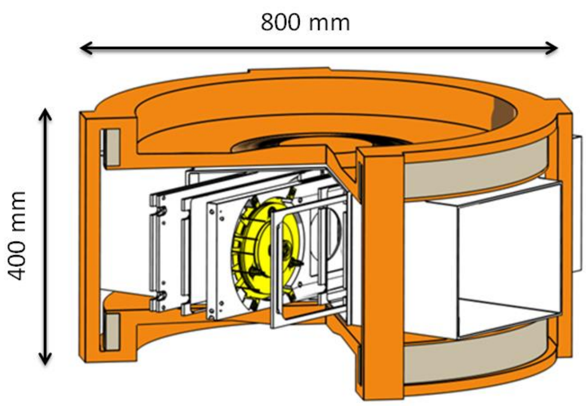
The masses of exotic nuclei can be measured directly in ion storage rings by determination of their revolution time in the ring. At the current FRS-ESR facility one method to perform such measurements is the Isochronous Mass Spectrometry (IMS). With the IMS method masses of exotic nuclei with lifetimes as short as a few tens of μs can be measured directly [1]. To determine these masses the revolution time of the ions in the isochronous ring is measured by a Time-Of-Flight (TOF) detector. To achieve a high mass resolution the performance of the detector is crucial and has been improved significantly [2].

The future Collector Ring (CR) at FAIR will be different compared to the current ESR not only in circumference but also in terms of beam dimensions and intensities. Based on extensive simulations, a new double detector system has been designed for improved IMS at the CR. It is adapted to the beam emittance of the ions in the CR and builds on two TOF detectors so that the velocity can be measured for every individual ion. This allows one to obtain correct mass values even for ions which are not perfectly isochronous. Improvements of almost a factor 2 for the timing accuracy with at least 95% detection efficiency will be achieved, even though the active area of the detector had to be increased by a factor of four to adapt to the larger emittance in the CR [3,4].



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Time-Domain Approach for Stochastic Cooling Study

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The beam dynamic under influence of the stochastic cooling forces can be studied by a particle by particle and turn by turn in the time-domain treatment. This treatment escapes the involvement of complicated, uncertain and changing frequency spectra, which anyhow are likely to be incomplete by considering Fokker-Planck Equation and its solution. To keep the computation times within reasonable limits, the scaling law that cooling times are proportional to the number of particles (for zero preamplifier noise and all other parameters remaining unchanged, except the gain) has been applied throughout. A typical simulation super-particle number is about (1-10) x 10^4.

In this paper the time domain algorithm is described and applied for the Palmer Cooling method. The possibility of using the Palmer system in such case for simultaneous longitudinal and transverse cooling by a suitable choice of the pickup to kicker distance is described. Using proposed method the special computer code has been developed to calculate beam cooling in time domain approach.

Status of the Collector Ring project at FAIR

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The Collector Ring is a dedicated ring for fast cooling of ions coming from separators at FAIR project. To accommodate optimal technical solutions, the structure of the magnet lattices were recently reviewed and modified. Consequently, more appropriate technical solutions for the main magnets could be adapted. The present general machine layout and design, e.g. of the demanding extraction schemes, have been detailed and open design issues were completed. The development and design of all major technical systems is in progress and prototyping has started or is in preparation. The final phase of collision checks and approval of the building planning is presently carried out and the tendering of the execution of the main construction work is under preparation.

Bound-state β^--decay of bare $^{205}Tl^{81+}$

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Beta decay into bound electron states of the daughter atom (β_b^-), accompanied by the emission of a monochromatic antineutrino, has been predicted by Daudel et al.[1]. However, a noteworthy probability of β_b^--decay exists only for highly-charged ions, which makes its observation rather difficult. The experimental storage ring ESR [2] at GSI, Darmstadt, was a unique tool for discovering β_b^--decay in 1992 [3], owing to its capability of storing and cooling stable as well as unstable ions for extended periods of time. A forthcoming experiment is the determination of the half-life of β_b^--decay of bare $^{205}Tl^{81+}$, which is related to both the solar pp-neutrino flux and the s-process nucleosynthesis. On the one hand, the LOREX [4] project addresses the relative amount of ^{205}Tl and ^{205}Pb atoms in deep-lying thallium-rich minerals (lorandite). There ^{205}Pb atoms are generated by the capture of solar pp-neutrinos, with an unprecedented small threshold of only 52 keV. The ratio of $^{205}Pb/^{205}Tl$ renders the product $<\Phi\nu_e> \cdot \sigma_{\nu e}$ of the mean pp-solar neutrino flux $<\Phi\nu_e>$ within 4.3 million years (age of the mineral), and the neutrino capture cross section $\sigma_{\nu e}$. The latter can only be obtained by measuring the half-life of β_b^--decay of bare $^{205}Tl^{81+}$ because ν_e-capture and β_b^--decay share the same nuclear matrix element. On the other hand, ^{205}Pb is the only purely s-process short-lived radioactivity which gives insight in nucleosynthesis just prior to Sun's birth. It has been demonstrated [5, 6] that in the stellar environment the production rate of ^{205}Pb in the s-process sensitively depends on both free electron capture of ^{205}Pb and β_b^--decay of bare and H-like ^{205}Tl. It is thus desirable to measure the half-life of the β_b^--decay of $^{205}Tl^{81+}$ which exploits a similar technique as applied in the case of bare $^{163}Dy^{66+}$ nuclei [3].

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Experimental Program at the Heidelberger Cryogenic Storage Ring CSR

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The application of storage rings in nuclear and atomic physics has been a success story in the past decades. Nevertheless, large magnetic storage rings, typically connected to high-energy accelerators to allow for the study of atomic and nuclear reactions, have shown limitations. The maximum mass of particles that can be stored is severely limited by the achievable magnetic field strength. Vacuum conditions in a room temperature environment limit the storage and experimental time due to residual gas collisions. Furthermore, the investigation of molecules in their vibrational and rotational ground states is hampered by blackbody radiation of the ambient temperature.

The Cryogenic Storage Ring (CSR) at the Max-Planck-Institut für Kernphysik in Heidelberg is designed to overcome these limitations [1,2,3]. The experimental vacuum chamber of the electrostatic ring is kept at temperatures below 10 K, such that stored particles are exposed to vacuum and temperature conditions similar to the cold interstellar medium. The purely electrostatic confinement allows the storage of ions in any mass range at energies of 20 keV to 300 keV per charge state. After successful room-temperature commissioning in the first quarter of 2014, where a 50-keV Ar^+-beam was stored for a couple of milliseconds, limited by restgas collisions, the CSR is currently prepared for first cryogenic operation.

In order to fully exploit its advantages and capabilities various ion sources, detection systems, and further experimental equipment will be added consecutively to the CSR. A merged laser-beam setup in combination with two particle detectors, one for position- and time-resolved analysis of neutral fragments and another one for charged, reaction products, will be available for first experiments at the beginning of 2015. In a second phase an electron cooler [3] and a merged ion-neutral beamline will be added. Furthermore the installation of a reaction microscope is foreseen.

A large variety of fundamental questions will be addressed within the experimental program of the CSR ranging from the dynamics of molecular reactions to the basic properties of large cluster and organic molecules. The perspectives will be presented and discussed.

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Ion-optical design of the CRYRING@ESR

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In 2012 the CRYRING storage ring [1] has been delivered from Stockholm to Darmstadt as a part of the Swedish in-kind contribution to the FAIR project. In combination with the Experimental Storage Ring (ESR) [2] it will serve as a new facility that provides exotic ions and antiprotons for atomic and nuclear physics research. CRYRING has also its own local injector giving a possibility to use it as a stand-alone facility for testing novel technical developments for FAIR under operation conditions [3].
The ring lattice has been slightly changed to meet optimal requirements to the injection conditions while keeping the main parameters as described in the Technical Design Report [4]. For the injection from ESR, a new transfer line has been designed. The local injector transfer line has been significantly modified [5] compared to the previous one in Stockholm taking into account the requirements imposed by the geometry of the existing GSI building in which the ring will be installed.
In this paper we present ion-optical properties of CRYRING@ESR including the ring and transfer lines. Single-turn injection from ESR and multi-turn injection from the local injector are discussed. Ion-optical calculations of fast and slow extraction from CRYRING will also be presented. Closed orbit correction scheme is considered taking into account the existing arrangement of the Beam Profile Monitors (BPM) and correction magnets. Based on the results of the calculations the requirements to the magnet alignment are finally discussed.

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Beyond First Order Electron Loss to Continuum ELC Cusp: $d\sigma/dE_E$ for 50 AMeV U^{28+} in the ESR Storage Ring

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The very high intensity beams of relativistic high Z ions with incident collision energies up to 2.7AGeV requested for experiments using the SIS100 synchrotron of FAIR requires that 1.3 10^{11} ions at 2.6Hz be injected from SIS12/18 into SIS100. The needed luminosity of the beam can only be achieved for such high Z ions when a low charge state q of the ion to be accelerated keeps the particle density via the space charge limit ($\sim A/q^2$) at the highest feasible level. For a thorough understanding of beam loss it is imperative that the mechanisms active in projectile ionization be understood quantitatively to provide benchmarks for advanced *ab initio* theories beyond first order. We have embarked on an experimental investigation of single differential projectile ionization cross sections ds/dE_e (SDCS) for single and multiple ionization of U^{28+} in the ESR storage ring by measuring the electron loss to continuum (ELC) cusp at 0^0 with respect to the beam axis employing our imaging forward electron spectrometer. This was motivated by the high relative fraction of multiple ionization estimated to exceed 40%. We report first results for absolute projectile ionization SDCS for U^{28+}. We find a remarkably high asymmetry for the ELC cusp. This is at strong variance with the line shape expected for validity of first order theories.

Metallic Magnetic Calorimeters for High-Resolution X-ray Spectroscopy

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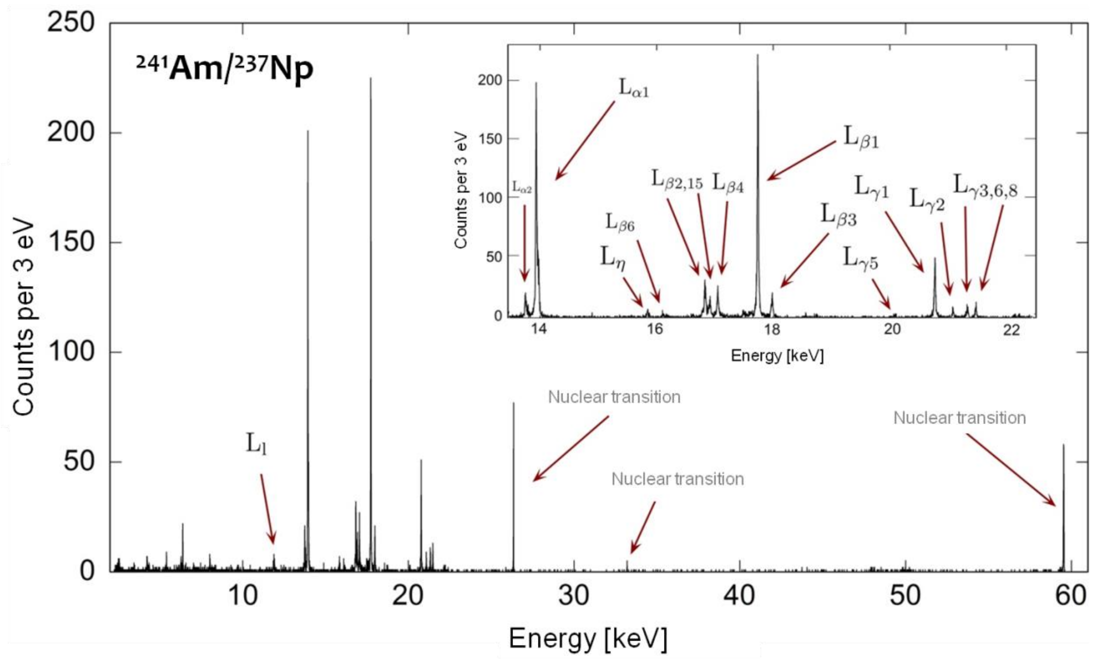
We are developing metallic magnetic calorimeters (MMC) for X-ray spectroscopy on highly charged ions in the energy range up to 200 keV. MMCs use a paramagnetic temperature sensor, read-out by a SQUID, to measure the energy deposited by single X-ray photons. Recent prototypes include two linear 8-pixel detector arrays, maXs-20 and maXs-200, as well as a first 2-dimensional 8x8 array, maXs-30, optimized for energies up to 20, 200, and 30 keV, respectively. We discuss the physics of MMCs, design considerations concerning cross talk, the micro-fabrication and the performances of the three prototypes. maXs-200 with its 200 µm thick absorbers made of electro-deposited gold has high stopping power for hard X-rays and achieves an energy resolution of 40 eV (FWHM). maXs-20 with its 5 µm thick absorbers has excellent linearity and a stopping power of 98% for 6 keV photons and presently achieves an instrumental line width of 1.6 eV (FWHM), unsurpassed by any other micro-calorimeter. We have been operating maXs-20 at an EBIT at the MPI-K Heidelberg and maXs-200 at the ESR (GSI). We will report on first atomic physics measurements as well as the particular challenges to detector operation in both experimental settings, including design considerations for the cryogenic setup that is necessary for the detector operation.



Isobar Analogue States (IAS), Double Isobar Analog States (DIAS), and Configuration States (CS) in Halo Nuclei. Halo Isomers.

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The IAS of the halo nuclei may also have a halolike structure [1]. In [2] it is shown that the IAS of the ^{6}He ground state (neutron halo nucleus), i.e., the 3.56 MeV 0^+ state of ^{6}Li, has a neutron-proton halo structure. In the general case [3] the IAS is the coherent superposition of the excitations like neutron hole–proton particle coupled to form the momentum $J = 0^+$. The IAS has the isospin $T=T_z+1=(N-Z)/2+1$, where $T_z = (N - Z)/2$ is the isospin projection. The isospin of the ground state is $T = T_z = (N - Z)/2$. When the IAS energy corresponds to the continuum, the IAS can be observed as a resonance. CS are not the coherent superposition of such excitations and have $T = T_z = (N - Z)/2$. One of the best studied configuration states is the antianalog state (AIAS) [4]. The CS formation is restricted by the Pauli principle. The DIAS has the isospin $T = T_z + 2$ and is formed as the coherent superposition of the excitations like two neutron holes–two proton particles coupled to form the momentum $J = 0^+$. For the IAS, CS, and DIAS the proton particles have the same spin and spatial characteristics as the corresponding neutron holes. When the parent state is a two-neutron halo nucleus, IASs and CSs will have the proton-neutron halo structure, DIASs and the double configuration states (DCSs) will have the proton-proton halo structure. For nuclei with enough neutrons excess IASs and CSs can have not only the pn halo component but also the nn halo component, DIASs and DCSs can have both pp, nn, and pn components [4]. IASs, CSs, and DIASs can be observed as resonances in nuclear reactions.

Such excited states and resonances as IAS, DIAS, and CS in halo nuclei can also have a halolike structure of different types (nn, pp, pn). IAS, DIAS, and CS can simultaneously have nn, np, and pp halo components in their wave functions [4]. When the halo structure of the excited and ground states are different than the isomers are able to be formed. From this point of view some CS, depending on CS halo structure, may be observed as isomers (halo isomers).

Structure of the excited states with different isospin quantum numbers in halolike nuclei and possible experiments are discussed.

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Decay of Zr isotopes and related nuclear structure effects

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The decay pattern of compound nucleus proves to be an effective tool to understand the nuclear reaction dynamics and associated properties such as nuclear structure, nuclear deformations and orientations, shell closure effects, isotopic effects etc. In view of this, we have calculated the decay cross-sections for Zr isotopes formed in ^{16}O + $^{70,72,74,76}Ge$ reactions at energies lying across the Coulomb barrier using dynamical cluster-decay model (DCM) [1]. The calculations are done in reference to the measured fusion excitation functions for $^{86,88,90,92}Zr^*$ isotopes [2,3] and the cross-sections have been estimated for evaporation residues [ER; ($A_2 \leq 4$)], intermediate mass fragments [IMFs; ($5 \leq A_2 \leq 20$)], and fission fragments with the inclusion of quadrupole (β_2) deformations having optimum orientations (θ_i^{opt}). Interestingly, DCM adequately differentiates between these decay processes and suggests ERs to be the dominant decay mode whereas, the IMFs and fission fragments contribute negligibly. Also, the mass distribution is observed to be symmetric for all isotopes. Within one parameter fitting of neck-length ΔR, the calculated ER cross-sections find nice agreement with the results of [2,3]. The comparative analysis of the fragmentation potential of Zr isotopes shows that at $\ell=0\hbar$ the potential energy surfaces behave almost similarly. However, at ℓ_{max} the decay pattern in fission region, shows systematic increase in the profile of fragmentation potential being least for $^{86}Zr^*$ and increasing with addition of neutrons. Almost similar trend is observed in the ER region whereas no systematic isotopic dependence is observed for IMFs. Although the α -nucleus structure persists for all the nuclei, its emergence is more prominent in case of lighter isotope $^{86}Zr^*$. Further investigation regarding isotopic analysis and related nuclear effects are in progress.

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Hadronic cross sections measurement with the SND detector at VEPP-2000 e^+e^- collider

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The SND [1] detector was taking data during 2010-2013 runs at VEPP-2000 collider, located at Novosibirsk. Here we want to present new high accuracy measurement of the $e^+e^-\to\pi^+\pi^-$ cross section, based on data collected at 2013 year. Systematic uncertainty of this measurement preliminary estimated to be 0.6%. Contribution to the muon anomalous magnetic moment calculated using this measurement agrees with calculation based on SND data inside 1σ, but have better accuracy.
We also observe the results base on data collected in 2010-2012 years at energy range 1-2 GeV. The cross section of the process $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$ was measured with accuracy ~1%. The intermediate state $\omega\pi^0$ was separated from other stats and $\gamma^*\omega\pi^0$ transition form-factor was obtained. The cross sections of the processes $e^+e^-\to\pi^+\pi^-\pi^0$, $e^+e^-\to\pi^+\pi^-\eta$ were measured with systematic accuracy about 5% and agrees with previous measurements. Also we present cross section measurements of the processes $e^+e^-\to\eta\gamma$, $e^+e^-\to\pi^0\pi^0\gamma$, $e^+e^-\to\pi^0\eta\gamma$, $e^+e^-\to\eta\eta\gamma$, some of them are measured for the first time.
Nucleons production cross sections were measured with SND data collected at 2011-2012 above the Nucleons threshold. The fraction G_E/G_M was determined using angular distribution. For the neutron-antineutron G_E/G_M was extracted for the first time.

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Investigation of the Heavy-Ion Mode in the FAIR High Energy Storage Ring

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High Energy Storage Ring (HESR) as a part of the future accelerator Facility for Antiproton and Ion Research (FAIR) will serve for a variety of internal target experiments with high-energy stored heavy-ion beams. Ion species such as, e.g. $^{238}U^{92+}$ are planned to be used as a primary beam. Since the storage time in some cases may reach tens of minutes it is important to focus on high-order effects which can potentially lead to beam losses. Therefore not only linear motion of the particles is examined here but also the non-linear beam dynamics in HESR in the heavy-ion mode is investigated.

In this study several ion optical designs are under discussion. Flexibility of the HESR magnet lattice with regard to various experimental setups is verified. The subjects of closed orbit correction, chromaticity correction as well as dynamic aperture in the HESR are addressed. Nonlinear beam dynamics simulations are carried out and proper solutions for beam lifetime enhancement are developed.

Laser spectroscopy of lithium-like ions at the HESR

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The physics of extreme atomic systems can uniquely be studied be means of heavy highly charged ions. These are true `few-electron systems´ (1-4 electrons), strongly bound to a heavy nucleus, and thus ideal candidates for a direct comparison between state-of-the-art atomic structure calculations and high-precision measurements. As a novel and unique possibility for research in ultra-high field science, the HESR [1] will provide brilliant intense stored ion pulses at relativistic velocities up to $\gamma = 6$. When such ion beams interact with counter-propagating laser pulses, exciting physics experiments can be performed. The ions namely `see´ the laser frequency to be Doppler shifted by more than one order of magnitude. In addition, the relativistic Doppler-effect will also shorten the counter-propagating laser pulse, in total boosting the power density by more than 2 orders of magnitude. (X)UV- lasers can then open up a new field to study ground-state electronic transitions in few-electron systems. A starting point, viable for FAIR "Day-One" experiments, can be the excitation by lasers where wavelengths down to 200 nm can be reached. Due to the large Doppler boost ($\sim 2\gamma$), these lasers will already reach ground-state transitions in lithium-like ions up to calcium (Z=20). The large Doppler boost also causes the fluorescence photons to be predominantly emitted in a forward cone (searchlight). In the example of a transition at 20 nm, excited by a 200 nm laser (at $\gamma=5$), the emitted photons will have a wavelength of about 2 nm. These XUV-photons can, exploiting the photoelectric effect, be detected using a metal target and an MCP detector. A detector of this kind has already been built, and is awaiting its first test run at the ESR. The next generations of experiments at HESR can also utilize XUV-radiation from soft x-ray lasers [2] or high-harmonics systems [3], reaching an even larger number of ion species and transitions.

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Precision determination of 7.8 eV isomeric states in ^{229}Th at heavy ion storage ring

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Precision determination of the predicted lowest isomeric state of ^{229m}Th is very attractive for nuclear physics and also for atomic physics. This topic has been becoming a hot topic especially after E. Peik et al [1] suggested that the isomeric state of the ^{229}Th can be used to construct a nuclear clock. C. J. Campbell et al [2] estimated that this nuclear clock will have an accuracy of 19th decimal, which has at least one to two orders higher precision than the best optical clock. Unfortunately, there is no direct measurement of the energy splitting of the isomeric state of ^{229}Th until now. Recently, indirectly measurement gives the value of 7.8 ± 0.5 eV by advanced x-ray microcalorimeter [3]. Therefore, precise determination of the transition is an important step towards its application for nuclear clock and also other fundamental physics.

In order to determine the energy splitting of ^{229}Th ground state doublet directly, various methods have been investigated by many groups around the world. The first international workshop of the "Nuclear Isomer Clock" about ^{229}Th was held at GSI, Darmstadt in Sep. 2012 [4]. The dielectronic recombination (DR) spectroscopy has been proposed to determine the nuclear isomeric states at CSRe of IMP and at the ESR of GSI, respectively. DR has been successfully used to study the atomic (hype)-fine structures at storage rings [5]. The coupling between electronic transition and nuclear transition is possible, and it has been proposed by using DR technique to investigate the process of the nuclear excitation by electron capture [6]. DR experiment was performed successfully with a multi-electrons heavy ion $^{112}Sn^{35+}$ at storage ring CSRm [7].

The experiment is designed as that ^{229}Th produced by ^{232}Th PF reaction on HIRFL_CSR standard configuration. Calculations show that the production of ^{229}Th is reasonable for injection into CSRe. When the ^{229}Th ions are stacked and electron cooled in CSRe, DR measurement can be exploited by detuning the electron beam energy from the cooling point, and hopefully the resonant transition can be found and determined with a precision better than a few milli-eV. The investigation will be carried out in DR-collaboration.

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A particle detector for bound-state beta-decay experiments (and more) at the ESR and CR

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The beta-decay into electronic bound states was already predicted in 1947, but it could not be observed until 1992 in pioneering experiments at ESR, GSI [1,2,3]. The measurement of the decay rate of $^{205}Tl^{81+}$ had to be postponed until now.

Bare $^{205}Tl^{81+}$ ions, produced from a primary ^{206}Pb beam, are stacked in the ESR using multiple injections to achieve the required intensity of 10^6 ions. During the storage time of one to a few hours, $^{205}Tl^{81+}$ decays via bound-state β-decay to $^{205}Pb^{81+}$. The decay rate is measured using two complementary methods: The Schottky noise detector and the in-pocket particle detector. Due to the small Q-value for the decay of only 31 keV the frequency traces of $^{205}Pb^{81+}$ cannot be resolved from $^{205}Tl^{81+}$. Therefore, the gas-jet target will be used to strip off the K-electron of the daughter ion and produce bare $^{205}Pb^{82+}$. This frequency change is sufficient to separate both species with the Schottky detector, or to count the $^{205}Pb^{82+}$ ions directly using the particle detector.

The particle detector is partially designed based on a previous detector used for the ^{207}Tl decay experiment [4], and it includes a stack of eight silicon PAD detectors and one DSSD for ΔE and position measurements, and a CsI(Tl) scintillator coupled to a silicon photo-diode that measures the residual energy of the beam ions.

In this presentation, we will report on the design, development, and primary tests of the in-pocket particle detector for the ESR experiment and will give an outlook for developments for the ILIMA project at the future Collector Ring (CR) at FAIR.

This work has been partially funded via the BMBF project 05P12RGFNJ (Multi-purpose pocket detector for in-ring decay spectroscopy), and the Helmholtz association via the Young Investigators Project "LISA - Lifetime Spectroscopy for Astrophysics" (VH NG 627), and the DFG cluster of excellence "Origin and structure of the universe" at the Maier-Leibnitz Laboratory in Munich.

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Applications of a Barrier Bucket Cavity for the Accumulation of Rare Isotope Beams in the ESR

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A Barrier Bucket Cavity will be installed into the existing ESR storage ring at GSI. The design of the cavity, the longitudinal beam dynamics with realistic barrier voltages, and its use for a novel accumulation scheme will be presented.

Measurements of neutron-induced reactions in inverse kinematics

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Neutron capture cross sections of unstable isotopes are important for neutron-induced nucleosynthesis [1] as well as for technological applications [2]. A combination of a radioactive beam facility, an ion storage ring and a high flux reactor would allow a direct measurement of neutron induced reactions over a wide energy range on isotopes with half lives down to minutes [3].
The idea is to measure neutron-induced reactions on radioactive ions in inverse kinematics. This means, the radioactive ions will pass through a neutron target. In order to efficiently use the rare nuclides as well as to enhance the luminosity, the exotic nuclides can be stored in an ion storage ring. The neutron target can be the core of a research reactor, where one of the central fuel elements is replaced by the evacuated beam pipe of the storage ring. Using particle detectors and Schottky spectroscopy, most of the important neutron-induced reactions, such as (n,γ), (n,p), (n,α), (n,2n), or (n,f), could be investigated.

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Development of a VUV-VIS-Spectrometer for Target Characterisation

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The collision of highly charged, heavy ions with atomic or molecular gas targets, free electrons or foils causes a variety of reactions such as electronic excitation, ionization, radiative electron capture and, in the case of molecules, dissociation [1,2]. These interactions have only been observed so far using X-ray spectroscopy.
After such a highly energetic reaction, these targets remain in superexcited electronic states which themselves may decay via fluorescence, autoionization into radiative states or dissociation into excited fragments. Typically, these processes are followed by the emission of one or more fluorescence photons in the spectral range from visible light (VIS) to vacuum-ultraviolet radiation (VUV).
To enhance the monitoring of the target after the interaction, a VUV-VIS-Spectropolarimeter for the use at heavy-ion storage rings that meets the required vacuum conditions is being developed.
The benefit of using a fluorescence spectrometer is the inherent sensitivity of this technique to the charge and electronic states of the target atoms and molecules [3]. Also, a diagnosis of the ion beam itself after an impact in gaseous targets and foils is an intended aim of the project. Processes to be investigated will be radiative electron capture and dielectronic recombination.
The setup consists of a Seya-Namioka type spectrometer that can be equipped with interchangeable diffraction gratings for the dispersion of the fluorescence radiation, each optimized for a different spectral range (VUV-VIS spectral range).
The detection of the photons is performed by 2-dimensional position- and time-resolving single-photon detectors that allow the simultaneous measurement of several fluorescence lines within a certain fluorescence wavelength range. Time resolution offers the option for lifetime or coincidence measurements.
Two detectors with wavelength ranges of 190nm to 700nm for the visible and 115nm to 300nm for the UV and VUV spectral range are available and will be tested in Kassel as soon as the mounting is constructed. A third detector for the EUV spectral range from 30nm to 150nm will be assembled at the University of Kassel and also tested after completion.
As a preliminary measurement, an already existing spectrometer can be used that does not meet the vacuum conditions and will be separated by a window. This restricts the detectable wavelengths to the visible and near-UV spectral range, however first experience can be gained with this test setup.

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HILITE – Ions in Intense Photon Fields

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We are currently devising an experimental setup with a cylindrical Penning trap for experiments concerning the interaction of highly charged ions with intense laser radiation [1]. We have established a superconducting magnet with a horizontal warm bore and a magnetic field strength of up to 6 T. The Penning trap is a mechanically compensated open-endcap trap consisting of three trap electrodes and two conical electrodes for dynamic capture of externally produced ions. The trap is optimized to allow the non-destructive detection also of small particle numbers over a large range of species. We will be able to select and confine one or more defined ion species of an arbitrary mass and charge state. By use of a rotating wall technique we will be able to define the ion number density up to values of about 10^9 cm^{-3}.
With this configuration we will investigate the ionization behaviour of ions under the influence of extreme laser fields up to an intensity of 10^{20} W/cm^2. We optimize the focusing parameters as well as our target ion cloud to maximize the number of particles which are exposed to an intensity above the ionization threshold. Since the whole setup is designed to be moved easily we are able to use a variety of high intensity lasers, e.g. PHELIX at GSI, JETI and POLARIS in Jena or FLASH at DESY. We plan to study the laser-ion interaction of several noble gases at intermediate charge states and will compare the measurement results with theoretical approaches of Keldysh [2] and Ammosov [3]. In following experiments we intend to conduct experiments with hydrogen-like ions up to neon.
We present the experimental outline, the devised setup with its current state and the intended experiments with their possible benefit.

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Prospects for laser spectroscopy of highly charged ions with high harmonic XUV and soft X-ray sources

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We present novel high photon flux XUV and soft X-ray sources based on high harmonic generation. The sources employ femtosecond fiber lasers, which can be operated at very high (MHz) repetition rate and average power (>100 W) [1]. High harmonic generation (HHG) with such lasers results in more than 10^{13} photons/s within a single harmonic line at ~40 nm (~30 eV) wavelength [2], a photon flux comparable to what is typically available at synchrotron beam lines. Furthermore photon energies of up to 300 eV have been generated recently. In addition, first results on resonant enhancement of high harmonic generation will be presented, which enables narrow-band harmonics with high spectral purity – well suited for precision spectroscopy [3].
These novel light sources will enable seminal studies on electronic transitions of highly-charged ions. For example the $2s_{1/2}$-$2p_{1/2}$ transition in li-like ions can be excited up to Z=92 (280 eV transition energy), which provides unique sensitivity to QED effects and nuclear corrections. We estimate fluorescence count rates of the order of tens per second, which would result in good statistics and enable studies on short-lived isotopes as well.
In combination with the Doppler up-shift available in head-on excitation at current (ESR) and future (HESR) heavy ion storage rings even multi-keV transitions can potentially be excited [4]. Since high order harmonics are phase-locked to the driving laser, pump-probe experiments with femtosecond resolution will be feasible as well, which allow accessing the lifetime of short-lived excited states and thus provide novel benchmarks for atomic structure theory.

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Conceptual design of elliptical cavities for intensity and position sensitive beam measurements in storage rings

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Position sensitive beam monitors 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 as well as enhancing precision in isochronous mass measurements.

Cavity based designs have always been favored when high sensitivity was desired, albeit at the cost of narrow-band operation. Historically, most successful designs were utilized in machines with small apertures [1]. Since the figures of merit degrade as a result of large beam pipe apertures and low intensities, a novel approach based on cavities with elliptical geometry was proposed to compensate for such limitations. In this work we discuss different design options using simulation results. An account of practical aspects and the measurement results will be given elsewhere [2].

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Heavy Ion Storage and Acceleration in the HESR with Stochastic Cooling and Internal Target

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In the modularized start version of FAIR the antiproton accumulator ring (RESR) and the New Experimental Storage Ring (NESR) are part of an upgrade program and only the collector ring CR is available from the beginning for antiproton and heavy ion beam cooling. To attain the high resolution antiproton mode in the High Energy Storage Ring (HESR) with a thick internal Pellet or gas-jet target for the PANDA experiment, antiproton accumulation will then be accomplished in the HESR by utilizing the already designed stochastic cooling system with moving barrier buckets[1]. In this contribution we investigate the recent proposal to utilize the HESR also for ion beam operation with an internal target. A bare uranium beam at 740 MeV/u is injected from the CR into the HESR. The beam preparation with a barrier bucket cavity and stochastic cooling for an internal target experiment at 740 MeV/u is outlined. The acceleration of the ion beam to 4.5 GeV/u is studied under the basic constraint of the available cavity voltages and the maximum magnetic field ramp rate in the HESR. Transition energy crossing is avoided by establishing an intermediate flat top at 3 GeV/u in the magnetic field ramp. After de-bunching the beam at 3 GeV/u the transition energy is changed. The beam is then adiabatically re-captured and accelerated to the final energy. The incoherent tune shift due to space charge forces is included in the simulations. Stochastic cooling of heavy ions is investigated under the constraint of the present hardware design of the cooling system and RF cavities foreseen for anti-proton cooling in the HESR. The cooling simulations include the beam-target interaction due to a Hydrogen target. A barrier bucket cavity is applied to compensate the strong mean energy loss of the beam due to the beam-target interaction. Diffusion caused by Schottky and thermal noise as well as intra beam scattering is accounted for. The higher charge states of the ions entail that Schottky particle noise power becomes an important issue. The analysis therefore considers the electronic power limitation to 500 W in case of momentum cooling. Fast Filter cooling is only available if the revolution harmonics do not overlap in the cooling bandwidth. Since overlap occurs for lower energies the application of the Time-Of-Flight (TOF) momentum cooling method with its larger momentum acceptance is envisaged at 740 MeV/u.

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SPARC experiments at the high-energy storage ring

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The physics program of the SPARC collaboration at the Facility for Antiproton and Ion Research (FAIR) focuses on the study of collision phenomena in strong and even extreme electromagnetic fields and on the fundamental interactions between electrons and heavy nuclei up to bare uranium. In this contribution we will give a short overview on the challenging physics opportunities of the high-energy storage ring at FAIR for future experiments with heavy-ion beams at relativistic energies with particular emphasis on the basic beam properties to be expected. Furthermore, since the low-energy storage ring CRYRING will be available already within the Modularized Start Version of FAIR, a outlook will be made on a possible early realization of the FLAIR physics.

Polarization phenomena in atomic bremsstrahlung

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The recent years have witnessed significant progress in the development of novel x-ray polarization detectors. When applied to the analysis of the photon emission in processes that involve highly-charged ions in storage rings, these detectors grant more insight into electron-electron and electron-photon interactions in the strong-field regime. Recently, a number of experiments have been initiated to analyze the angular and polarization properties of light emitted in the *atomic bremsstrahlung* [1,2]. This process attracts much attention since it plays an important role in the plasma diagnostics and provide, moreover, a unique tool for exploring the fundamental process of light-matter interaction in the realm of high energies and strong electromagnetic fields. Motivated by the new generation of experiments, a number of theoretical works were performed by us to explore the bremsstrahlung process [3,4,5]. In this contribution, we review these recent theoretical activities and make special emphasis on the investigation of how the photon polarization is affected when the incident electrons are themselves spin-polarized. To understand better such a ``polarization transfer'', we performed calculations for various target atoms and for incident electron energies in the range 50 keV < T_{kin} < 5 MeV. Results from the computations indicate that polarization of bremsstrahlung radiation might be very sensitive to the screening effects induced by the electrons of the target as well as to the energies of incoming and scattered electrons. The obtained results reveal important information about the electron–photon coupling at the still poorly studied high–relativistic region, which is of primary interest in future experiments at the GSI and future Facility for Antiproton an Ion Research (FAIR).

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A resonant Schottky pick-up for Rare-RI Ring at RIKEN

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The new heavy-ion storage ring project Rare-RI Ring at RIKEN RI Beam Factory launched in 2012 [1, 2]. The project aims at precision mass determination (δm/m~10^{-6}) of extremely neutron-rich nuclei to pin down the r-process path.

Rare-RI Ring is a storage ring based on isochronous mass spectrometry and single ion detection. To achieve the precise mass measurement, it is necessary to tune ion-optical condition to the isochronous condition of the order of 10^{-6}. To precisely tune the ion-optical condition to be isochronous, we will employ Resonant Schottky noise pick-up technique [3], which measures revolution frequencies of nuclei circulating in Rare-RI Ring. Resonant Schottky pick-up is installed at Rare-RI Ring and consists of a resonant cavity electrically isolated from the beam pipe. Resonant cavity itself, is air-filled, has the shape of a pillbox with an outer diameter of 750 mm and length of 200 mm. A revolution frequency spectrum of circulating ions is obtained with Fast Fourier Transform of the electromagnetic waves induced in the resonant cavity. Since the revolution frequency is proportional to momentum of the stored ion, frequency spread is a good measure to tune the isochronous field.

We have tested the resonant Schottky pick-up system and optimized it maximum output signal. The measured resonant cavity characteristics are in good agreement with simulation using Micro Wave Studio [4]. From the results of off-line test, a charge down to $q \simeq 10$ would be possible to detect. The resonant Schottky pick-up at Rare-RI Ring is adequate to tune precisely isochronous field.

In this contribution, we will present the off-line test as well as R&D status of the resonant Schottky pick-up at Rare-RI Ring.

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Search for T-odd P-even signal in the Proton - Deuteron Scattering

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Time-reversal invariance will be tested in proton-deuteron scattering in an internal target transmission experiment at COSY [1]. The total cross section $A_{y,xz}$ will be measured for transverse polarized proton beam (P_y) and tensor polarized deuterium target (P_{xz}). This observable provides a real null test of time invariance violating but P-parity conserving forces which do not arise in the standard model as a fundamental interaction, and this signal is not affected by the final state interaction [2]. To take under control background conditions of this experiment and estimate its accuracy one has to know magnitudes of several T-even, P-even spin-observables in pd scattering at energy of the planned experiment 100-200 MeV. In the present work the differential spin observables of the elastic pd scattering and total pd cross sections for polarized proton and deuteron are calculated within the Glauber theory. We use the formalism of Ref. [3] and develop it for inclusion of T-odd pN-scattering amplitudes. Furthermore, we properly modify the formalism of Ref. [3] to make a comparison with existing experimental data. The results of our calculations for unpolarized differential cross section, vector A_y and tensor A_{ij} analyzing powers, spin correlation parameters C_{ij}, $C_{ij,k}$ and spin-transfer coefficients $K_j^{i'}$ at 135 MeV and 250 MeV are in a reasonable agreement with the data [4,5] in forward hemisphere. The total hadronic polarized cross sections σ_1, σ_2, σ_3 are calculated using the generalized optical theorem as in Ref. [6]. In view of the planned accuracy of the $A_{y,xz}$ measurement of about 10^{-6} [1], the obtained numerical result for σ_1 put a strong restriction on the magnitude of the possible false vector polarization of the deuteron (P_y $<10^{-6}$). Analytical formulas are derived for the $A_{y,xz}$ observable and its energy dependence is calculated for several types of phenomenological T-odd P-even NN-interactions. This dependence differs from that found in Ref. [8] where only a breakup mechanism was taken into account. We found that the ρ-meson exchange contribution to $A_{y,xz}$ vanishes and the Coulomb interaction does not lead to divergences for the $A_{y,xz}$ observable.

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A new data acquisition system for Schottky signals in atomic physics experiments at GSI's and FAIR's storage rings

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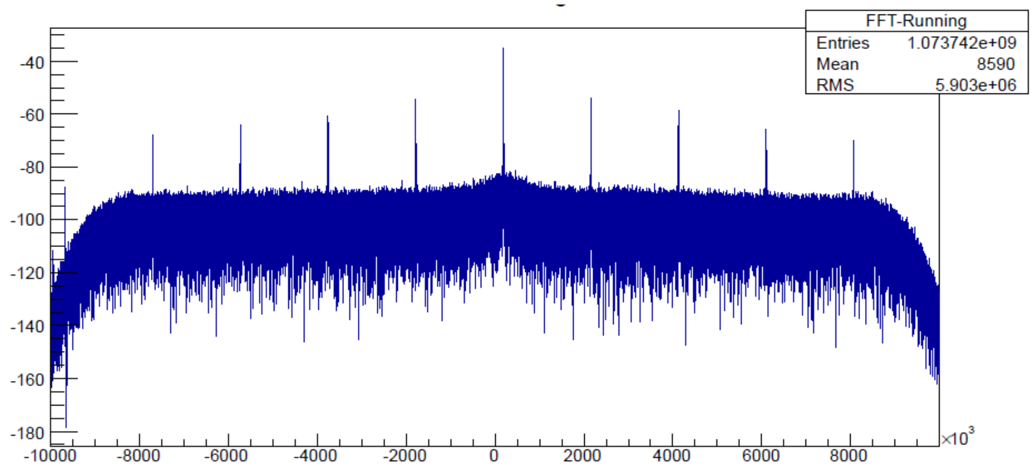

Fig.1. First Schottky spectrum ($^{12}C^{6+}$ at 400MeV/u) recorded with the new Schottky data acquisition system (DAQ). On the x-axis the offset to the carrier frequency of 244.5 MHz is displayed. The record consists of 65536 FFT points at an acquisition rate of $2 \cdot 10^7$ IQ-Samples per second. Nine harmonics of the circulating beam are visible.

Recently, a new resonant Schottky-detector with greatly improved sensitivity and time-resolution was implemented at the storage ring ESR [1]. For continuous recording of the Schottky RF signals with large bandwidth a new DAQ system is currently being installed and corresponding DAQ and analysis software developed. In this contribution we will discuss potential applications of these next-generation Schottky systems with emphasis on diagnostics and non-destructive particle detection for atomic physics experiments in storage rings.
We will present results obtained in first successful commissioning runs conducted early in 2014. These initial results exceeded our expectations. Not only were we able to record the ESR's full momentum acceptance with high resolution and low noise for days without problems, but also could high IQ acquisition rates of up to $3.5 \cdot 10^7$ S/s be achieved. With such a high bandwidth one can record more than ten harmonics of the beam at once (Fig. 1).

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Two-Photon Transitions in He-like Heavy Ions

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The study of two-photon transitions (2E1) in He-like heavy ions is of particular interest due to the sensitivity of its spectral shape to electron-electron correlation and relativistic effects. Therefore, a detailed study of the spectral shape of the two-photon distribution along the helium isoelectronic sequence (the simplest multi-electronic system) is of great importance for understanding the interplay between relativity and electron-electron correlations for medium to high-*Z* ions. Numerous experimental and theoretical studies have attempted to explore this process.

We will present the results of experimental investigations based on a novel approach for studying the exotic transition in few-electron high-*Z* ions. Here, relativistic collisions few-electron projectiles with low-density gaseous matter have been exploited to selectively populate the desired initial states, which allows us to measure the undistorted two-photon spectral shape. The 1s2s $^1S_0 \rightarrow 1s^2\ ^1S_0$ two-photon decay in He-like heavy ions was examined and the continuum shape of the two-photon energy distribution was compared with fully relativistic spectral distributions, which in turn are predicted to be *Z*-dependent. Compared to conventional techniques, the present approach improves statistical and systematic accuracy, which allowed us to achieve for the first time sensitivity to relativistic and electron correlation effects on the two-photon decay spectral shape as well as to discriminate the measured spectrum from theoretical shapes for different elements along the helium isoelectronic sequence.

Precision Spectroscopy of Highly Charged Ions Stored in Penning Traps

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Highly charged ions offer the possibility to explore electronic fine structures and hyperfine structures with precisions typical for optical lasers. In a Penning trap, the additional splittings of these structures in Zeeman sublevels (resulting from the magnetic fields used for confinement) are in the microwave domain and allow a determination of magnetic moments [1]. Combining optical and microwave spectroscopy, it is possible to obtain magnetic moments (g-factors) of bound electrons with precisions in the ppb regime and at the same time yields nuclear magnetic moments with precisions in the ppm regime [2]. For one-electron ions, diamagnetic shielding is completely absent, such that these measurements can be used to test corresponding shielding models. Both the optical and microwave spectroscopy can individually be used to measure effects of quantum electrodynamics in strong fields (bound-state QED) and hence allow to test corresponding calculations. This is true for the transition energies and lifetimes, as well as for the magnetic moments and higher-order contributions to the Zeeman effect. Here, we present the SPECTRAP [3] and ARTEMIS [4] experiments located at the HITRAP facility at GSI, Germany, which are currently being commissioned with test ions such as Ar^{13+}. We present the scientific outline, the experimental setups and first results with confined ions.

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Investigation of the Nuclear Natter Distribution of ^{56}Ni by Elastic Proton Scattering in Inverse Kinematics

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We have measured the nuclear matter distribution of the doubly-magic N=Z nucleus ^{56}Ni by investigating elastic proton scattering in inverse kinematics [1]. The radioactive beam of ^{56}Ni was injected and stored in the **ESR** (**E**xperimental **S**torage **R**ing, GSI) and interacted with an internal Hydrogen gas-jet target. The high revolution frequency of the ions in the ring allowed to achieve a high luminosity although very thin target was used. This allows measurements at low momentum transfer.
By measuring the recoiling protons, we were able to separate the elastic reaction channel from the inelastic scattering to the first excited 2^+state of ^{56}Ni and deduced the differential cross section of ^{56}Ni(p,p)^{56}Ni. The data were analyzed within the framework of the Glauber multiple-scattering theory in order to extract the nuclear matter radius and radial matter distribution of ^{56}Ni.
This experiment was part of the first **EXL** (**EX**otic nuclei studied in **L**ight-ion induced reactions at the NESR storage ring) [2] campaign at GSI and was the first successful investigation of nuclear reactions with a stored radioactive beam ever.
The details of the analysis will be presented and the results will be discussed.
This work was supported by BMBF (06DA9040I and 05P12RDFN8), the European Commission within the Seventh Framework Programme through IA-ENSAR (contract no. RII3-CT-2010-262010), HIC for FAIR and TU Darmstadt-GSI cooperation contract.

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Total projectile-ionization cross-sections of many-electron uranium ions in collisions with various gaseous targets

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Charge-changing processes, i. e. loss or capture of electrons, occurring in ion-atom and ion-ion collisions belong to the most basic interactions in all types of plasmas and also in accelerator facilities. Besides basic research, the investigation of these processes is also motivated by their importance for many applications, such as ion stripping and beam transport in accelerators and storage rings [1] as well as ion-driven fusion devices [2]. Essential here is that interactions between projectile ions and constituents of the residual gas can lead to a change of the projectile charge state. In the presence of dispersive ion optical elements the trajectories of these up- or down-charged ions are not matching the one of the reference charge state, resulting in a successive defocussing or even beam loss. Thus, exact knowledge of the charge-changing cross sections is of crucial importance for the planning of ion-beam experiments in existing accelerators and storage rings as well as for the design of new facilities or upgrade programs. This is of particular importance for the new FAIR facility, where future ion-beam experiments will require unprecedented luminosities. In order to reach the necessary beam intensities, while minimizing the limitations induced by space charge, and avoiding losses in stripper targets, the use of low to medium-charged, many-electron ions is planned [3].
As a continuation of our previous studies [4], beam lifetimes of stored U^{28+} and U^{73+} ions with energies between 30 and 150 MeV/u were measured in the experimental storage ring ESR of the GSI accelerator facility. By using the internal gas target station of the ESR, it was possible to obtain projectile ionization cross sections for collisions with several gaseous targets from the lifetime data. The resulting experimental cross sections are compared to predictions by various theoretical approaches and to a semiempirical scaling law.

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RF-bunching of the relativistic $^{12}C^{3+}$ ion beam for laser cooling experiments at the CSRe[a]

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In order to prepare the upcoming experiment of laser cooling of relativistic $^{12}C^{3+}$ ion beams at the experimental cooler storage ring (CSRe) [1] using cw and pulsed laser, a test experiment was performed with $^{12}C^{3+}$ ion beams at an energy of 122 MeV/u on the CSRe, at the Institute of Modern Physics, Lanzhou, China. In the experiment $^{12}C^{3+}$ ions were produced by an ECR ion source, after injection and acceleration in the main Cooler Storage Ring (CSRm), the ion beam was extracted and injected into the CSRe at the energy corresponding to an ion velocity of 47% of the speed of light. The number of $^{12}C^{3+}$ ion beam reached 5×10^8 ions, which satisfied the experimental requirement. A resonant Schottky pick-up was employed to record the Schottky spectra of the RF-bunched ion beams. The $^{12}C^{3+}$ ion beams were bunched by sinusoidal waveforms with fixed frequency and sweeping frequency and the Schottky spectra are shown in Fig. 1. The ultra-strong Schottky noise signals were observed from a square-waveform bunched ion beams. The experimental results demonstrated that the RF-buncher and diagnostic systems at the CSRe worked well during the $^{12}C^{3+}$ beam time, which indicated the CSRe is suitable for laser cooling experiment. We will present the experimental results including longitudinal dynamics of the electron cooled and bunched $^{12}C^{3+}$ ion beams and also the details of the upcoming laser cooling experiment at the CSRe on the STORI conference.

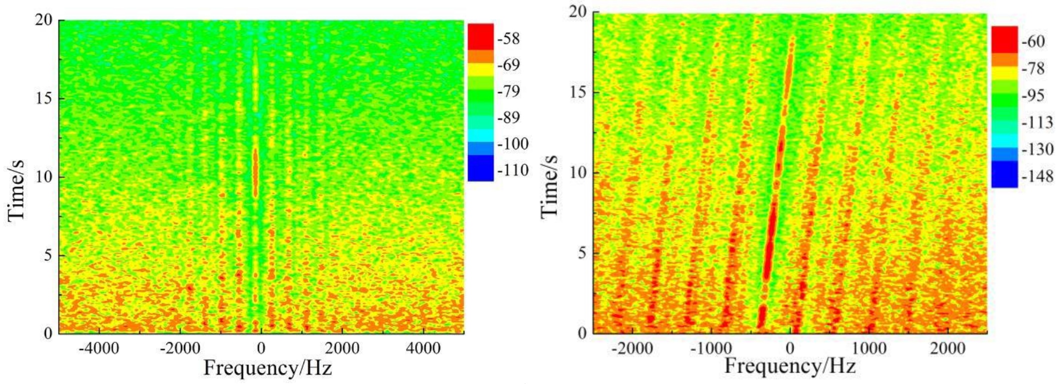

Fig. 1. The Schottky spectra of RF-bunched $^{12}C^{3+}$ ion beams using sinusoidal waveforms at the 50th harmonics. Left: single frequency; Right: sweeping frequency.

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[a] The experiment will be collaborated within the Laser Cooling Working Group. Supported by NSFC11221064 and GJHZ1305.

Orbital electron capture decay rates of highly charged heavy ions at the ESR

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The combination of the projectile fragment separator FRS and the cooler-storage ring ESR at the accelerator facility of GSI Darmstadt offers the opportunity to address nuclear beta decay under conditions prevailing in hot stellar plasmas, where - at "temperatures" of some 10 keV - the atoms are highly ionized.

In this contribution we discuss experiments on beta-decay, positron emission and the orbital electron capture (EC) of radioactive ions stored in the ESR. Fully-ionized, hydrogen- and helium-like ^{140}Pr, ^{142}Pm, ^{122}I ions have been investigated. These nuclei decay mainly by a single allowed Gamow-Teller (1^+—>0^+) transition.
It turned out that the measured EC-decay rates in H-like ^{140}Pr and ^{142}Pm ions are larger by a factor of 3/2 than those in He-like ions. Measurements of ^{122}I decays point to the effect that I —>I+1 transitions of the hyperfine ground state become forbidden.
This result can be explained by the conservation of the total angular momentum and its projection of the combined nucleus and lepton system. The observed effect can have several applications in nuclear structure and nuclear astrophysics. The present status and the ideas for future experiments will be discussed.

Fast-kicker system for Rare-RI Ring

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One of the main purpose of rare-RI ring is to measure the masses of extremely rare particles, which will be produced rarely even with BigRIPS [1]. To inject such rare particles into the rare-RI ring efficiently, we adopted a self-trigger individual injection method [2] with a fast-kicker system. Trigger signal for the kicker system will be generated by rare particle itself at the BigRIPS F3 focal plane, which locates in about 160 m upstream of the kicker magnets. To achieve the individual injection, it is necessary to excite the kicker magnets before the rare particle arrives at the kicker magnets. Then, the response time of the kicker power supply plays a key role in shortening the time taken for kicker excitation.

The kicker system is used not only for injecting a particle into the ring but also for extracting the particle from the ring within an interval of about 1ms. Therefore a new fast-recharging mechanism is indispensable in order to efficient extraction.

We carried out the feasibility studies about the fast-response and fast-recharging by using a prototype kicker system. As the results, the response time satisfied our requirement and we developed a new fast-recharging mechanism named the "hybrid charging system", which were able to realize the target recharge time accurately [3].

Recently, we started a performance test of an actual kicker system that reflected the results of the feasibility studies. The actual kicker system is constructed in a new power supply, which has a fast-response mechanism and the hybrid charging system, and a new large acceptance kicker magnet. The kicker magnetic field strength of about 870 gauss occurs by 67 kV charge, and the delay time between trigger input and flat-top center of kicker magnetic field is about 475 ns. In this contribution, we present the results of the performance test of the actual kicker system including the study of the injection/extraction scheme, and prospects.

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Direct mass measurements of neutron-deficient ^{152}Sm projectile fragments at the FRS-ESR facility

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Schottky mass spectrometry (SMS) is a storage-ring based technique for accurate mass measurements of short-lived nuclei. Masses of nuclides with half-lives as short as a few seconds and production rates as tiny as a few ions per day can be addressed. This technique provides a unique mass measurement method which allows for a large part of mass surface to be covered in a single experiment.

Direct mass measurement was performed on neutron-deficient ^{152}Sm projectile fragments at the FRS-ESR facility at GSI, employing the time-resolved Schottky Mass Spectrometry method [1]. Exotic nuclei were produced via fragmentation of relativistic ^{152}Sm projectiles in a thick beryllium target. The reaction products were separated in-flight with the fragment separator FRS, and injected into the storage-cooler ring ESR. 311 different nuclides were identified by means of their revolution frequency spectra. Masses for 10 nuclides (^{94n}Rh, ^{114}I, ^{122,123}La, ^{125}Ce, ^{127}Pr, ^{129}Nd, ^{132}Pm, ^{134}Sm, ^{137}Eu) have been determined for the first time. The new masses allow us to uncover a part of the previously unknown mass surface and will be used to constrain nuclear mass models.

A new mass evaluation method has been developed which reduces the systematic error by taking into account the charge-dependency of the difference between the fitted mass value and the literature mass value. The origin of this charge-dependency phenomenon is still under discussion [2]. A typical mass uncertainty of 20 keV could be reached finally. The data analysis progress as well as the preliminary result will be presented and the impact of new masses on nuclear structure will be discussed.

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Simulation of the isochronous mode at the HIRFL-CSRe

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When a storage ring is set to the isochronous mode, it is called Isochronous Mass Spectrometer (IMS). It is used to measure masses of stored short-lived nuclei. HIRFL-CSRe at the Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS) is one of the storage ring facilities capable of performing IMS measurements.

In order to invest and improve the performance of the IMS at the HIRFL-CSRe, a simulation code named SimCSR was developed. The code is based on a six-dimensional phase-space linear transport theory. A successful experiment with ^{58}Ni ions as the primary beam was simulated and the obtained spectrum of the revolution times of stored ions was compared with the experimental results. Some of the key parameters of the experimental set-up were revealed through the simulation. A very good agreement between the simulation and experimental results was reached, although only linear components were considered. Some of the parameters that significantly affect the resolution of the mass measurement experiments were investigated in detail.

The SimCSR code will be further developed to include nonlinear components, it will be used to improve the experiment resolution and explore new experiment set-ups.

In this contribution, the details of the isochronous mode of the CSRe in Lanzhou will be introduced. The simulations will be compared with the experimental results. Last but not least, the conclusions on how to improve the resolving power for future isochronous mass measurements independent of the particular storage ring facility will be outlined.

The CSR reaction microscope

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At the Max Planck Institute for Nuclear Physics in Heidelberg a cryogenic electrostatic storage ring (CSR) is currently under construction. With liquid helium cooling temperatures down to a few Kelvin as well as extreme vacuum conditions ($<10^{-13}$ mbar) can be reached. This allows to perform experiments with low-energy, highly charged ions, clusters or ultra-cold, well-groomed molecular ions (20-300 keV / charge state) with long storage times and low influence from the environment, *i.e.*, by residual gas or thermal radiation. We report the development of a cryogenic reaction microscope (REMI) with a gas-jet target and its implementation in the CSR

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