SPARC-Call for Proposals for beamtime in 2023/2024

Wednesday 01 June 2022 - Wednesday 01 June 2022

Zoom

Book of Abstracts

Contents

Cryring@ESR / 1

Nuclear astrophysics with CARME@CRYRING

Author: Carlo Bruno[1]

[1] *The University of Edinburgh*

Corresponding Author: carlo.bruno@ed.ac.uk

CARME has been successfully commissioned with beam at CRYRING in February-March 2022, in spite of some issues with the newly mounted internal target. Its science programme will be supported by an ERC Starting Grant going forward.

I will discuss our plans for the future, in terms of re-submitting proposals that have already been accepted (e.g. 2H+1H), and the potential to submit new proposals with the local CRYRING injector.

I will also mention our plans for a FISIC+CARME experiment, and technical requirements.

Cryring@ESR / 2

Measurement of the astrophysically relevant alpha-capture reaction rate Ti-44(α,p)V-47

Author: Oliver Forstner[1]

[1] *Friedrich-Schiller-Universität Jena*

Corresponding Author: oliver.forstner@uni-jena.de

The proposal for measuring the reaction Ti-44(α,p)V-47 at CRYRING@ESR was granted beam time for the year 2022 in the last G-PAC (E151). However, due to various delays neither the internal gas target nor the CARME detector setup was ready and fully commissioned for successfully performing the proposed beam time. A first commissioning beam time could be performed in spring this year with one quarter of the CARME detector and only nitrogen gas at the internal target.

I will discuss our future plans of re-submitting the proposal with the updated timeline of the completion of CARME, the availability of helium in the internal target and the transport and installation of the EBIT at the CRYRING local injector.

Cryring@ESR / 3

Indirect measurements of neutron-induced reaction cross sections at storage rings

Authors: Beatriz Jurado[1]; Manfred Grieser[2]; Jerome Pibernat[None]; Michele Sguazzin[None]; Jacobus Swartz[None]; Camille Berthelot[None]; Jan Glorius[3]; Yury Litvinov[3]; Klaus Blaum[2]; Rene Reifarth[4]; Philippe Alfaurt[None]; Roche Mathieu[None]; Antonio Moro[5]; Perard Sean[None]; Bertrand Thomas[None]

[1] *CENBG*

[2] *Max-Planck-Institut für Kernphysik*

[3] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[4] *Goethe-Universität Frankfurt(UFfm)*

[5] *Universidad de Sevilla*

Corresponding Author: jurado@cenbg.in2p3.fr

Obtaining reliable cross sections for neutron-induced reactions on unstable nuclei is a highly important task and a major challenge. These data are essential for understanding the synthesis of heavy elements in stars and for applications in nuclear technology. However, their measurement is very complicated as both projectile and target are radioactive. The best alternative to infer these cross sections is to use the surrogate-reaction method in inverse kinematics, where the nucleus formed in the neutron-induced reaction of interest is produced by a reaction involving a radioactive heavy-ion beam and a stable, light target nucleus. The decay probabilities (for fission, neutron and gamma-ray emission) of the nucleus produced by the surrogate reaction provide precious information to constrain models and enable much more accurate predictions of the desired neutron-induced reaction cross sections.
Our aim is to investigate surrogate reactions in inverse kinematics at the CRYRING@ESR, which is the ideal instrument for this purpose as it will allow us to measure the decay probabilities of many short-lived nuclei with unrivaled accuracy.
Several steps are necessary before conducting the first surrogate-reaction experiment at CRYRING. In June 2022, we will perform a first proof-of-principle experiment at the ESR to demonstrate the validity of our new methodology for measuring gamma-ray- and neutron-emission probabilities. In the present proposal, we propose a second proof-of-principle experiment to measure, in addition, the fission probability. For this purpose, the set-up developed in the first proof-of-principle experiment will be complemented with several fission detectors made of solar cells. The full set-up and methodology will be validated by measuring for the first time simultaneously the fission, neutron and gamma-ray emission probabilities of several uranium isotopes formed in the interaction of a 238U92+ beam with a deuterium gas-jet target.
This proposal is part of the ERC-Advanced grant NECTAR (Nuclear rEaCTions At storage Rings), PI: B. Jurado.

ESR / **4**

Proton capture on 91Nb in ESR

Authors: Jan Glorius[1]; Yury Litvinov[1]; Rene Reifarth[2]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Goethe-Universität Frankfurt(UFfm)*

Corresponding Author: j.glorius@gsi.de

We intend to submit a proposal to measure the reaction 91Nb(p,g)92Mo in ESR as a continuation of the proton-capture campaign that has been very successful in the recent past. 91Nb is a radionuclide, which in a first step has to be produced in FRS using a primary beam of 94Mo or similar. Furthermore, accumulation, cooling and deceleration in the ESR down to energies of 5-10 MeV/u are needed, as it was already demonstrated for fragments of 118Te in E127.

The solar amounts of 92,94Mo and 96,98Ru are not reproduced by current models of explosive nucleosynthesis, which prone to the large nuclear physics uncertainties connected to unstable nuclei. The reaction 91Nb(p,g) is one of the key reactions of the nucleosynthesis around this long-standing Mo/Ru anomaly. It is the main source of uncertainty for the production of 92Mo in the gamma process and also a central part of the 92Nb/92Mo chronometer. By direct measurement of the reaction cross-section, the tremendous uncertainties in the gamma process yields can be diminished and a reliable application of the chronometer feature is in reach. Both of these targeted results represent a major step towards clarifying the mysterious origin of 92Mo and its nuclear neighborhood.

ESR / **5**

Rate Measurement of the Nuclear Excitation by Electron Capture process

Author: Alex Zylstra[1]

Co-authors: Yury Litvinov [2]; Dieter Schneider [1]; Jeff Burggraf [1]

[1] *LLNL*

[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: y.litvinov@gsi.de

In extremely hot and dense astrophysical plasmas, high-Z atomic nuclei become highly ionized and the nucleus can couple to the atomic system via processes like electron capture (NEEC) or electronic transition, resulting in the nucleus being in an excited state, which can affect nuclear properties in scenarios like the r process. The NEEC rate is presently controversial, with a claimed observation differing from theory by nine orders of magnitude. We will develop a storage ring measurement technique to determine the NEEC rate unambiguously by observing the nuclear excitation in coincidence with electron capture.

Cryring@ESR / 6

Search fo NEEC at CRYRIG

Authors: Yury Litvinov[1]; PHILIP WALKER[2]; Adriana Palffy[3]; Thomas Stöhlker[1]; Michael Lestinsky[1]; Jan Glorius[1]; Shahab Sanjari[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *UNIVERSITY OF SURREY*

[3] *Friedrich Alexander University Erlangen-Nürnberg*

Corresponding Author: y.litvinov@gsi.de

One of the physics cases motivating the construction of CRYRING at the ESR was the search for NEEC through neutralization of highly-charged ions in nuclear isomeric states. The isomer of interest is 129Sb or 93Mo.

ESR / 7

Laser spectroscopy of the (1s2 2s2p) 3P0 - 3P1 level splitting in Be-like krypton

Authors: Danyal Winters[1]; Volker Hannen[2]; Sebastian Klammes[1]; Thomas Kühl[3]; Paul Indelicato[4]; Eva Lindroth[5]; Dieter Schneider[6]; Reinhold Schuch[7]; Thomas Stöhlker[1]; Thomas Walther[8]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Institut für Kernphysik, Uni Münster*

[3] *GSI, Darmstadt*

[4] *Laboratoire Kastler Brossel(LKB)*

[5] *Stockholm University*

[6] *LLNL*

[7] *Stockholm university*

[8] *TU Darmstadt*

Corresponding Author: d.winters@gsi.de

[E135 -resubmission]
Our proposal was first presented to the G-PAC in 2010 (rank A, 21 shifts). It was resubmitted for re-evaluation in 2017 (rank A-, 21 shifts). We had a "test beamtime" (shared with S467) at the ESR from the 20th until the 25th February 2020. It was 13½ shifts long, but effectively we could use only 12 shifts. The ion beam was isotope 86Kr, not 84Kr.
We have made great progress in terms of laser and detector development, as has been demonstrated in May 2021 (12C3+ at ESR), and are therefore even better prepared for experiment E135. Now, we can tune the laser frequency over a broad range and have much more laser power in the UV. Also the much improved ion bunch - laser pulse timing and the data analysis will strongly contribute to measuring the (1s2 2s2p) 3P0 - 3P1 level splitting in Be-like krypton. For these reasons, we will resubmit proposal E135 to the G-PAC in 2022.

Cryring@ESR / 8

Commissioning and First Storage Ring Experiments of the Transverse Free-Electron Target

Author: Carsten Brandau[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: c.brandau@gsi.de

A BMBF-funded free-electron target for GSI's/FAIR's storage rings that operates in transverse collision geometry, i.e., with an interaction angle of 90◦ between electrons and stored ions, is presently being built up and tested at the University of Giessen. The target is intended as a user facility for electron-ion collision experiments and x-ray spectroscopy with free electrons. Originally, it was intended to install and commission the target in 2021 and 2022, respetectively. Due to a long list of unforeseeable events (Corona, quality problems with vacuum equipment, late or canceled delivery of components, manpower due late start of BMBF funding) the commissioning in 2022 had to be postponed.
In this proposal we ask for beamtime for commissioning of the electron target, of the experimental spectroscopy set-up at the CRYRING and for first x-ray experiments with highly charged ions. The commissioning is planned in 2 phases: In the initial general commissioning phase, ions from the local injector will be used (e.g. H-like/He-like oxygen; ECR source). In the second phase, a first x-ray experiment with highly charged ions (H-like, He-like; Z>54) from the ESR is envisaged.

Cryring@ESR / 9

High-resolution electron-ion collision spectroscopy of beryllium-like heavy ions in CRYRING@ESR

Author: Stefan Schippers[1]

[1] *JLU Giessen*

Corresponding Author: schippers@jlug.de

The feasibility of high-resolution electron-ion collision spectroscopy at CRYRING@ESR of few-electron highly-charged ions from the GSI chain of accelerators has been demonstrated in a previous beam time (E131) in March 2021. In particular, it was shown that the electron-energy spread at the CRYRING electron cooler is indeed as low as expected. Building on this success, our collaboration will propose new spectroscopic measurements with highly charged heavy ions that feature recombination resonances at energies below 10 eV. Examples for such ions are Be-like Sb47+, Xe50+, Sm58+, Ir73+, Au75+, and U88+. For kinematic reasons the experimental resolving power and, thus, the experimental accuracy are highest at such low electron-ion collision energies. The expected results will allow one to sensitively probe higher-order contributions to quantum-electrodynamical (QED) calculation of binding energies in strong fields.

Cryring@ESR / 10

Atomic processes in the wake of neutron-star mergers: Electron-ion recombination of low-charged heavy ions

Author: Stefan Schippers[1]

[1] *JLU Giessen*

Corresponding Author: schippers@jlug.de

In 2017, the LIGO/Virgo collaboration detected the first gravitational-wave signal from the merger of a neutron-star binary. Less than two seconds later, a network of telescopes detected a short gamma-ray burst, followed by a longer optical “afterglow” powered by the radioactive decay of the neutron-rich material ejected in the merger, i.e., a kilonova. The kilonova light-curves potentially reveal the abundances of the heavy chemical elements that are produced in the preceding violent neutron-star merger events. In order to be able to reliably infer elemental abundances from the astronomical observations, absolute cross sections are required for the basic atomic processes that occur in the afterglow. So far, local thermodynamic equilibrium (LTE) conditions have been assumed in the astrophysical modeling of kilonovae, which certainly is an oversimplification given the highly dynamic and transient nature of the phenomenon. Any future more accurate non-equilibrium modeling will have to rely on accurate atomic cross sections, which generally cannot be easily calculated (if at all) to a sufficient precision for the heavy many-electron ions of interest. In order to satisfy these data needs we will measure absolute rate coefficients for the electron-ion recombination of low-charged heavy ions as part of the scientific program of the Hessian cluster project ELEMENTS. In a first attempt, we will use moderately charged xenon ions from the CRYRING local injector, which can be rather easily produced with the existing ECR ion source.

ESR / 11

Nuclear Hyperfine Mixing and Laser Excitation of H-like 229Th89+

Author: Carsten Brandau[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: c.brandau@gsi.de

Continuation of E142.

The “nuclear clock” isomeric state 229-Thorium with its exceptional low excitation energy of around 8.3 eV is in the research focus of many laboratories worldwide.
At GSI, an alternative approach to the physics of 229-Th is under development: We propose to investigate and utilize a phenomenon that is unique to very highly charged 229Th such as one-electron 229Th89+. In high thorium charge states, in addition to the ordinary hyperfine structure, the very strong magnetic field mediates a mixing of the F = 2 levels of ground state (g.s.) and isomeric state (i.s.). The mixing results in a drastical change of the nuclear lifetime which decreases drastically by 5-6 orders of magnitude, from a few hours down to a few 10 ms. The vastly accelerated decay e.g. in 229Th89+ implies that the excitation probability with a laser and the detection of fluorescense light are each enhanced by these 5-6 orders of magnitude.
It is proposed to investigate nuclear hyperfine mixing using laser spectroscopy at the storage ring

ESR. In a first run (E142) and also in a further experiment that aimes at laser excitation of the HF-splitting in H-like 208-Bi (E128), substantial progress towards laser experiments with artificially synthesized radioisotopes was achieved and the general feasibility of of such low-intesity laser experiments was demonstrated. Furthermore, production, separaion and storage of a few times 10^4 229Th89+ was achieved,and an upgrade path for future experiments identified. Yet, the 20222 experiment suffered from the availabilty of stable, intense primary beam and a long list of technical issues from the accelarator side, such that only a small fraction (2 to 3 days) of the allotted beamtime (~2 weeks) could be used to search for the 229-Th resonance.
It is proposed to continue E142, and to search for the two laser excitation pathways in hyperfine mixed 229Th89+.

ESR / **12**

Exploring the limits of bunched beam laser cooling of relativistic stored ions

Authors: Danyal Winters[1]; Michael Bussmann[2]; Jens Gumm[3]; Volker Hannen[4]; Sebastian Klammes[1]; Mieczyslaw Witold Krasny[5]; Thomas Kühl[6]; Benedikt Langfeld[7]; Xinwen MA[8]; Mathias Siebold[9]; Peter Spiller[1]; Markus Steck[1]; Thomas Stöhlker[1]; Ken Ueberholz[10]; Thomas Walther[3]; Hanbing Wang[8]; Weiqiang Wen[8]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Helmholtz-Zentrum Dresden - Rossendorf*

[3] *TU Darmstadt*

[4] *Institut für Kernphysik, Uni Münster*

[5] *LPNHE sorbonne University Paris and CERN BE-ABP department*

[6] *GSI, Darmstadt*

[7] *Technische Universität(TUDA)*

[8] *Institute of Modern Physics, Chinese Academy of Sciences*

[9] *Helmholtz-Zentrum Dresden-Rossendorf*

[10] *Westfälische Wilhelms-Universität Münster(UMs-IKP)*

Corresponding Author: d.winters@gsi.de

Laser cooling has been successfully demonstrated at the ESR, using bunched beams of Li-like carbon ions at 47% of the speed of light. We now wish to explore the limits in terms of particle number (stored ions), temperature (relative momentum spread) and stability (over time) more carefully. We propose to study these using a "chain" of stored ions in the ESR. In addition, we wish to study a scheme for transverse cooling of the stored ion beams. Finally, we would like to study the fluorescence, emitted from the laser-excited ions, in more detail. Especially the distribution of fluorescence within a bunch of ions is of interest. Ultimately, one might find an answer to the question if the fluorescence emission from ion bunches is somehow coherent. We will request one week of beamtime (21 shifts) for these studies at the ESR.

ESR / **13**

3-beam (broadband) laser interaction with stored relativistic ions

Authors: Danyal Winters[1]; Michael Bussmann[2]; Jens Gumm[3]; Volker Hannen[4]; Sebastian Klammes[1]; Thomas Kühl[5]; Benedikt Langfeld[6]; Mathias Siebold[7]; Peter Spiller[1]; Markus Steck[1]; Thomas Stöhlker[1]; Ken Ueberholz[8]; Thomas Walther[3]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Helmholtz-Zentrum Dresden - Rossendorf*

[3] *TU Darmstadt*

[4] *Institut für Kernphysik, Uni Münster*

[5] *GSI, Darmstadt*

[6] *Technische Universität(TUDA)*

[7] *Helmholtz-Zentrum Dresden-Rossendorf*

[8] *Westfälische Wilhelms-Universität Münster(UMs-IKP)*

Corresponding Author: d.winters@gsi.de

The ultimate scheme for laser cooling of stored relativistic ions is to use a bunched ion beam and 3 independent laser beams. Here, the entire longitudinal momentum distribution of the ion beam should be addressed simultaneously using the unique combination of one cw and two pulsed laser beams*. Each beam will be produced by a separate laser system, but the 3 laser beams are all in the UV range (all at 257 nm). The pulsed laser beams are "short" in time and therefore "broad" in frequency and should cover the large width of the ion momentum distribution (after injection into the ring). The cw laser is "narrow" in frequency and therefore has a very high spectral power, which is perfect for final cooling and keeping the ion beam cold. This scheme is also planned for laser cooling at the SIS100 and is therefore highly relevant for FAIR. The main challenge is to spatially, timely and spectrally overlap the 3 laser beams. To demonstrate this scheme, we will request one week (21 shifts) of beamtime at the ESR, using 12C3+ at ~122 MeV/u. Alternatively, we could also use a 14N4+ at ~260 MeV/u. (Laser cooling of N4+ was never done before.)

*The cw laser system and one pulsed laser system (50 - 740 ps) will be provided by the TU Darmstadt. The other pulsed laser system (1 - 100 ps) will come from the HZDR / TU Dresden.

Cryring@ESR / 14

Absolute rate coefficients from dielectronic recombination for astrophysically important ion species

Authors: Esther Babette Menz[1]; Michael Lestinsky[1]; Michael Fogle[2]; Weronika Biela-Nowaczyk[3]; Carsten Brandau[1]; Sebastian Fuchs[4]; Stefan Schippers[5]; Gleb Vorobyev[1]; Andrzej Warczak[3]; Thomas Stöhlker[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Auburn University*

[3] *Jagellonian University Krakow(JUK)*

[4] *Justus-Liebig-Universität Gießen*

[5] *JLU Giessen*

Corresponding Author: m.lestinsky@gsi.de

Spectroscopic data from astronomical observations obtained at ground-based or satellite observatories are analyzed with the help of spectral synthesis codes. From complex rate equation networks, based largely on theoretical plasma rate coefficients of various up- and downcharging processes, a charge state distribution is modelled and emission and absorbtion features synthesized and matched to spectroscopic data. For a confident astrophysical analysis toolchain it is thus essential, that these calculated rate coefficents are verified with experimental evidence (Kallman and Palmeri, 2007).
Heavy ion storage rings are ideal environments to precisely determine such data, as ion beams can be prepared in purely one charge state, isotopic purity and free of metastable composition and with well-defined kinematics, reactions can be studied in isolated thin-target single-collision conditions. CRYRING in Stockholm and TSR in Heidelberg used to be reliable facilities to determine experimental data for astrophysical application with a long list of publications (Schippers, 2012, and papers cited therein). After its move from Stockholm to Darmstadt (Andelkovic et al., 2015; Danared et al., 2011; Lestinsky et al., 2012a, 2015, 2016), CRYRING is now capable of continuing its work and the measurement setup is ready to deliver scientific output.
On behalf of the SPARC collaboration, we propose a beamtime at CRYRING on merged-beams electronion collision spectroscopy on low-q Ne ion beams, which are of astrophysical importance. The

process to be studied in particular is dielectronic recombination which contributes significantly to the charge state distribution in astrophysical plasma. Thanks to its ultracold electron cooler (Danared et al., 2000), CRYRING is able to deliver precise, absolute high-resolution spectra, a(E), for center-of-mass collision energies E from 0 to several hundred eV. From the measured spectra, we determine plasma recombination rate coefficients (PRRC) a(T) for astrophysical modelling for relevant plasma temperatures in the ranges of 10^3 and 10^6 K.

ESR / 15

X-ray spectroscopy of slow Xe54+ + Xe collisions

Author: Pierre-Michel Hillenbrand[1]

[1] *Justus-Liebig-Universität Giessen*

Corresponding Author: p.m.hillenbrand@gsi.de

The experimental study of slow Xe54+ + Xe collisions has been defined in the "Physics book: CRYRING@ESR" as an intermediate milestone on the path towards heavy quasi-molecular collision in supercritical fields. In our recently published investigation of Xe54+ + Xe collisions at 30 and 15 MeV/u performed at the ESR, we learned valuable lessons for the experimental feasibility of such studies. As a next step, we propose to perform a high-resolution x-ray spectroscopy experiment at the CRYRING gas-jet target using bare Xe54+ injected from ESR at ~12 MeV/u.

ESR / 16

E137: Experimental investigation of the precision limit for spectroscopic measurements in relativistic, few-electron high-Z ions by the method of resonant coherent excitation (RCE) of ions in a crystal.

Author: Angela Bräuning-Demian[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: a.braeuning-demian@gsi.de

We propose a new measurement for the precise determination of the 2s1/2 →2p3/2 transition energy in Li-like uranium by means of resonant coherent excitation of ions in a thin Si-crystal. The goal of the proposed measurement is to determine the transition energy with an accuracy of the order ppm by a more precise determination of the ion beam energy. Also the RCE in non-channeling conditions (3D-RCE) will be tested for the same transition.
The present proposal was two times recommended by the G-PAC with A score and was scheduled for runs in 2020, 2021 and 2022. The first two schedules where canceled due to the covid19-pandemic. In 2022 the experiment was prepared for the beam time in cave a but unfortunately the accelerator could not deliver the needed beam in due time.
The GSI management proposed to consider the experiment for the beam time schedule 2023 without additional G-PAC evaluation.
Approved shifts: 18 shifts (main)

ESR / 17

Investigation of light phenomena observed during interaction of highly charged ions with a liquid droplet beam target

Author: Nikolaos Petridis[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: n.petridis@gsi.de

[Resubmission E133]
High density low-Z droplet target beams have been realized at the Experimental Storage Ring (ESR) since many years. In the course of the past beamtimes the droplet target source underwent a thorough characterization. However, a puzzling observation was made in the course of the optical imaging of the interaction region. Occasionally, bright light traces appeared on the pictures exhibiting a much higher photon intensity than the light emitted from the interaction region.
Unfortunately, no systematic measurements could be performed in order to further investigate in detail these unexpected observations. The main reason was the absence of fast detection techniques in order to correlate the emergence of the light traces with secondary detector devices, e.g. particle detectors.
Besides the very interesting question on the origin of these observations, their understanding is of upmost importance since the new droplet target source is foreseen to be applied at all FAIR storage rings. Furthermore, the interaction of stored highly charged ions with micrometer-sized droplets has never been investigated before and thus the proposed investigations could open up a new research field for storage rings.

The aim of the proposed experiment is the systematic investigation of the light traces in time correlation with charged particles emitted from the target interaction region.

Cryring@ESR / 18

Systematic measurement of electron capture cross sections in the low collision energy regime

Author: Nikolaos Petridis[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: n.petridis@gsi.de

We propose a systematic measurement of electron capture cross sections for heavy, bare ions at projectile energies below 5.5 MeV/u at different parameters, namely the projectile charge number, the collision energy and the target charge number. The measurement will be realized by introducing a novel internal target station setup to the CRYRING@ESR. The required diagnostic tools will be three semiconductor x-ray detectors, placed at the interaction chamber equipped with beryllium windows, and a channel electron multiplier for the detection of the down-charged projectile ions.

In order to reproduce previous results obtained at the ESR (as a reference measurement) we request a bare Xe54+ beam at an energy of 5.5 MeV/u and a hydrogen target. The number of stored ions should be in the order of 10E6 particles. After performing this initial measurement as a benchmark, we plan a systematic measurement of the electron capture cross sections at lower energies (down to 3 MeV/u), different projectile ions (U92+) and target species (nitrogen). According to our experience to date, NRC is expected to be the dominating process towards lower ion energies and higher target nuclear charges. Overall, the goal is to provide accurate experimental data in the up to now unexplored low-energy region of the CRYRING@ESR for the refinement of the theoretical electron capture models.

HITRAP / 19

Nanostructuring of monolayer graphene by highly charged ions

Author: Anna Niggas[1]

Co-author: Richard A Wilhelm [1]

[1] *TU Wien, Institute of Applied Physics*

Corresponding Author: niggas@iap.tuwien.ac.at

Upon impact on a surface, slow highly charged ions (HCIs) deposit large amounts of their potential energy within the first few monolayers of the material. Depending on material properties relaxation processes can lead to nanosized material modifications, e.g. hillocks and craters in bulk samples or pores in 2D materials - often in a similar manner as after swift heavy ion (SHI) impact. For atomically thin graphene, so far no pore formation could be observed after irradiation with HCIs (up to charge states of typically 40+), while the formation of cracks was reported after SHI irradiation. A possible explanation could be the existence of a potential energy threshold which needs to be exceeded in order to enter the nanostructuring regime. Such thresholds have previously been found for bulk samples, with CaF2 being a particularly well investigated case. Studies with slow ions in very high charge states (» 40+) so far are rather scarce — both for bulk samples and 2D materials — which makes HITRAP perfect for exploring this uncharted territory.

There are two scenarios where we could perform our measurements: Either we use the existing diagnostics chamber in-between RFQ decelerator and cooling Penning trap on the ground floor of the HITRAP facility or we install an ultra-high vacuum system consisting of an experimental chamber, a sample holder (for bulk and atomically thin materials) and a pumping stage at the HITRAP platform on the second floor. In the second scenario, an alignment of the new setup for perfect sample irradiation conditions will be achieved prior to the beam time with ions from the present EBIT ion source.

In the first scenario, we will irradiate a freestanding single-layer graphene sample with 6 keV/u U92+ from HITRAP and for comparison also one CaF2 single crystal of 1cm x 1cm size. Considering a 60s repetition rate and 105 ions per pulse, which is a conservative assumption, the samples will have to be irradiated for 3 days each to achieve a total fluence of 4x108 ions/cm2. For 6 keV/u U92+ the potential energy of ~1 MeV is in the same order of magnitude compared to the kinetic energy of 1.4 MeV ≙ 1.07x106 m/s ~ 0.5v0 with v0 being the Bohr velocity, which is considered a slow highly charged ion. Even regarding an energy width of ~ 2keV/u, the maximum velocity stays < 0.6v0. In the second scenario, the cooled HCI beam extracted from the cooling Penning trap is expected to have a transport energy of 5keV/q with narrow energy distribution and an intensity smaller compared to the first scenario due to the efficiency of the cooling Penning trap.

After the irradiation, the samples will be taken out of the vacuum, stored under protective atmosphere and shipped to TU Wien, where we will analyse ion-induced material modification via STEM and AFM.

We therefore want to apply for one week of HITRAP beam time, i.e., 21 shifts à 8 hours.

ESR / 20

High-resolution measurements of the 1s(2s)^2 state decay branches in Li-like uranium

Author: Sergiy Trotsenko[1]

Co-authors: Alexandre Gumberidze [1]; Andreas Fleischmann [2]; Daniel Hengstler [3]; Saskia Kraft-Bermuth [4]; Peter Egelhof [4]; Pascal Scholz [5]; Dariusz Banas [6]; Heinrich Beyer [4]; Siegbert Hagmann [7]; Pierre-Michel Hillenbrand [8]; Paul

Indelicato [9]; Christophor Kozhuharov [1]; Stephan Fritzsche ; Michael Lestinsky [1]; Renate Märtin [4]; Tino Morgenroth [1]; Uwe Spillmann [1]; Martino Trassinelli [10]; Günter Weber [1]; Thomas Stöhlker [11]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Uni Heidelberg*

[3] *Kirchhoff Institute for Physics*

[4] *GSI, Darmstadt*

[5] *Universitaet Giessen*

[6] *Jan Kochanowski University*

[7] *Goethe-Universität Frankfurt(UFfm-IKP)/GSI-Darmstadt*

[8] *Justus-Liebig-Universität Giessen*

[9] *Laboratoire Kastler Brossel, Université Pierre et Marie Curie, CNRS, ENS*

[10] *Insitut des NanoSciences de Paris*

[11] *Friedrich-Schiller Universität Jena*

Corresponding Author: s.trotsenko@gsi.de

The proposed experiment is aiming at the first high-resolution measurement of the exotic, dipole allowed, “two-electron one-photon” decay (TEOP) of the $1s(2s)^2$ state in the heaviest Li-like ion (U^{89+}). This transition is mediated by electron-electron correlation and in lithium-like uranium it is (surprisingly) expected to be the dominant decay mode. However, it is entwined with an M1 transition of very close transition energy. The use of high-resolution microcalorimeters will allow the separation of the two transitions and thus a clear identification of the TEOP decay. In addition, the relative decay rates can be measured for the first time, thus testing the corresponding theoretical predictions that differ considerably between different models. In addition to the radiative decay branches, the Auger decay channel will be measured as well, thus allowing for a complete measurement of all the decay channels of this particular quantum state.

ESR / 21

Multi-Electron Emission from Projectile Ionization of U28+Ions at Relativistic Velocities in Heavy-ion Storage Rings Letter of Intent (LOI) for Continuation Request for Proposal E117

Author: Siegbert Hagmann[1]

Co-authors: Pierre Michel Hillenbrand [2]; Jan Glorius [3]; Uwe Spillmann [3]; Yury Litvinov [3]; Beatriz Jurado [4]; Michele Sguazzin ; Jerome Pibernat ; Michael Lestinsky [3]; Alexandre Gumberidze [3]; Sergiy Trotsenko [3]; Markus Steck [3]; Robert Grisenti [3]; Nikolaos Petridis [3]; Shahab Sanjari [3]; Carsten Brandau [3]; Sergey Litvinov [3]; Hermann Rothard [5]; Dieter Schneider [6]; Regina Heß [7]; Emmanouil Benis [8]; Thomas Stöhlker [3]

[1] *Goethe-Universität Frankfurt(UFfm-IKP)/GSI-Darmstadt*

[2] *GSI*

[3] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[4] *CENBG*

[5] *CIMAP-Ganil CNRS*

[6] *LLNL*

[7] *GSI, Darmstadt*

[8] *University of Ioannina*

Corresponding Author: s.hagmann@gsi.de

We propose to follow up on our previous study E117 of the dynamics of the projectile ionization for multi-electron heavy ions with near relativistic velocities
U28+ + A ⟶ U(28+n)+ + {A+*} + n e-(≈00-cusp)

by developing instrumentation for coincident detection of upcharged Uq+(29<q<45) inside the dipole following the jet target. This module is based on successful position sensitive solar cell particle detectors developed currently by B Jurado and J Glorius. This new detector inside the dipole then allows measuring coincidences between forward cusp electrons in the 00-electron spectrometer and the charge exchanged Uq+ projectiles. We will compare single and multiple forward electron continua originating from projectiles of relevance for accelerator technology, e.g. low charged U28+(…4f145s25p2).
The very strong and target Z dependent asymmetry of the electron loss to continuum (ELC) cusp which we found in our first non-coincident experiment with U28+ in the ESR, E117, clearly indicates that for these collision systems first order Born theories are not applicable; this entails potentially significant uncertainties in current predictions of beam lifetimes in future FAIR facilities. Therefore, we propose to expand the study of ELC cusp asymmetries by focussing on their dependence on the electron emission multiplicity. The coincidence techniques needed here is only now possible in the ESR as newly developed 2D PSD solar cell detector arrays have been successfully developed by Jurado and Glorius; this will enable identifying the upcharged projectiles after the collision on the inside of the magnetic dipole chamber following the target.

The differential cross sections (DCS) for electron emission with well-defined multiplicity distinguish one-electron processes from theoretically not yet understood multi-electron processes, which, however, are strongly contributing in the projectile ionization of U28+ .These DCS will present necessary benchmarks in the decidedly non-Born regime for generating dependable cross sections beyond first Born approximation for calculating beam lifetimes required for accelerator design and FAIR facilities. They will in particular permit, to our knowledge, the first and stringent tests for ab initio higher order theories in the strong perturbation regime, beyond the estimation of total cross sections given by current first order theories, which are applied far outside their range of validity.

Cryring@ESR / 22

Fast Ion – Slow Ion Collisions for Atomic Physics (FISIC @ CRYRING)

Authors: Emily Lamour[1]; Christophe PRIGENT[2]; Martino Trassinelli[3]; Dominique VERNHET[4]; Sebastien STEYDLI[5]; Stéphane Macé[6]; Mariette JOLLY[6]; Daniel Schury[None]; Jimmy Rangama[7]; Alain Méry[7]; Hervé Savajols[8]; Christelle Stodel[8]; Alexandre Gumberidze[9]; Angela Bräuning-Demian[9]; Michael Lestinsky[9]; Thomas Stöhlker[9]; Uwe Spillmann[9]

[1] *Institut Des NanoSciences de Paris(INSP)*

[2] *INSP/UPMC*

[3] *Insitut des NanoSciences de Paris*

[4] *INSP- UMR CNRS 7588- UPMC- Sorbonne Universités*

[5] *UPMC / INSP*

[6] *INSP*

[7] *CIMAP*

[8] *GANIL*

[9] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: emily.lamour@sorbonne-universite.fr

Electronic processes in ion-ion collisions are of fundamental interest from atomic physics point of view and they play an important role in astrophysical and fusion plasmas as well as in ion-matter interaction. At the same time, the ion-ion collisions are mostly unexplored up to now. This is especially true for the so-called intermediate velocity regime where the ion stopping power is maximum, and where there is a lack of both experimental and theoretical data on the electronic cross sections. To precisely investigate this regime, the study of ion-ion collisions are necessary for a large variety of systems with the needed option to scan the charge state of each ion partner. Besides the possibility to reach the pure three-body problem (bare ion on hydrogenic target) as a benchmark for theories, the role of additional electrons bounded to the ions -one by one- should allow disentangling and

quantifying electron effects such as:
• electron-electron interactions: besides correlations, the presence of additional electrons can also directly increase (anti-screening) or decrease (screening) the mechanism probabilities ;
• closure and/or opening of different channels: such as capture channels, that are open for bare projectiles but may be closed (or less likely) for other charge states;
• multi-electron processes: often neglected, they can become as large as single processes in some cases.
The FISIC set-up is a complex experiment designed to perform collisions between fast (MeV/u) ion beams from CRYRING with slow (keV/u) ion beams provided by the FISIC platform, to measure absolute electronic cross sections using coincidence methods. The FISIC platform can deliver ions from carbon to argon ( ) with charge states from 1+ to fully stripped. The intermediate regime is reached when the relative target (slow ions)-projectile (fast ions) velocity is of the same order as the ones of the active electrons in their initial state. Below are a few examples with rather "light" ions:
Fast projectile ions from CRYRING Slow target ions @ a few keV/u from the FISIC platform
CQ+ at around 1 MeV/u Cq+
ArQ+ at around 4 MeV/u Neq+
ArQ+ at around 8 MeV/u Arq+

where for the fast ions (Q+), fully stripped and a few-electron ions are of interest. By scanning the target charge state (q+), already a significant amount of experimental data never investigated so far may be obtained. Beyond these symmetrical or moderately asymmetrical collision systems, the intermediate regime can be approached by choosing very asymmetrical systems, i.e. by choosing much heavier fast ions such as KrQ+ and XeQ+ (with energies up to 14 MeV/u).

HITRAP / **23**

Charge exchange at low collision energies

Author: Sonja Bernitt[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Author: s.bernitt@hi-jena.gsi.de

We propose to measure x-ray fluorescence following charge exchange between bare Xe^{54+} ions and different gas targets at ultra-low collision energies at HITRAP. By detecting fluorescence in coinicidence with projectile ions, and recording ion time-of-flight, reaction channels can be separated. This will provide charge-exchange data for an energy regime inaccesible in storage ring setups, and complementing previous as well as future measurements, e.g. at the CRYRING internal gas target. It will allow more in-depth benchmarks of charge-exchange models.

ESR / **24**

Probing ultra-short-lived excited states in Be-like Carbon at the ESR

Author: Jan Rothhardt[1]

Co-authors: Robert Klas [1]; Vinzenz Hilbert [2]; Philipp Gierschke [3]; Günter Weber [1]; Alexander Kirsche [3]; Jens Limpert [3]; Thomas Stöhlker [1]; Stephan Fritzsche ; Stefan Schippers [4]; Alexander Borovik [5]; Volker Hannen [6]; Christian Weinheimer [7]; Arno Ehresmann [8]; Danyal Winters [1]; Zoran Andelkovic [1]; Michael Lestinsky [1]; Angela Bräuning-Demian [1]; Frank Herfurth [1]; Rodolfo Marcelo Sánchez Alarcón [1]; Yury Litvinov [1]; Viorica Stancalie Stancalie [9]; Stancalie Andrei [10]; Mihalcea Razvan [11]; Mihai Laura [12]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *IOQ Friedrich Schiller Universität Jena*

[3] *Friedrich Schiller University Jena*

[4] *JLU Giessen*

[5] *Justus-Liebig Universität Gießen*

[6] *Institut für Kernphysik, Uni Münster*

[7] *Institut für Kernphysik, University of Münster*

[8] *Kassel University*

[9] *National Institute for Laser,Plasma and Radiation Physics, Department of Lasers*

[10] *Department of Lasers, Bucharest*

[11] *Department of Lasers, Bucharest*

[12] *National Institute for Laser, Plasma and Radiation Physics, Department of Lasers, Bucharest*

Corresponding Authors: r.klas@gsi.de, j.rothhardt@gsi.de

We propose to measure the lifetime of short-lived excited states in Be-like Carbon by a pump-probe experiment. Utilizing two synchronized and delayed Femtosecond XUV pulses allows accessing these lifetimes with Femtosecond precision for the first time. These measurements will provide sensitive tests of state-of-the art atomic structure calculations beyond the capabilities of established methods and challenge recent calculations. In future, X-ray transitions at sub-fs dynamics will be accessible by employing this approach at HESR.

ESR / **25**

Towards testing three-loop effects of bound-state QED in He-like uranium

Authors: Martino Trassinelli[1]; Robert Lötzsch[2]

[1] *Institut Des NanoSciences de Paris(INSP)*

[2] *Friedrich-Schiller-Universität Jena(FSU-IOQ)*

Corresponding Author: trassinelli@insp.jussieu.fr

We propose here an evolution of the past E125 proposal that uses H-like scandium as reference line and a smaller gas-jet target (from 5 to 1 mm) to measure the $1s_{1/2}2p_{3/2}$ J=2 $\rightarrow$ $1s_{1/2}2s_{1/2}$ J=1 intrashell transition in He-like uranium. This improvement will allow to reach the accuracy of 10~meV for the 4.5~keV line, sufficient to start to be sensitive to three-loop and more QED effects in such bound system, which are estimated to contribute with about 17~meV. The X-ray Bragg spectroscopy experiment E125 that took data in 2021 at ESR successfully measured $1s_{1/2}2p_{3/2}$ J=2 $\rightarrow$ $1s_{1/2}2s_{1/2}$ J=1 intrashell transition in He-like uranium with an accuracy of 0.17~eV, providing the most accurate test of QED in heavy He-like systems, enough to be sensitive to two-loop QED effects evaluated to 0.20~eV in such a transition. This result was however strongly limited by the accuracy of similar Li-like and Be-like uranium transition used as reference and measured in the past with an uncertainty of 0.21~eV. By using the Lyman-α line of H-like scandium ($Z = 21$) as a reference line from moving ions, an accuracy in the energy difference of 10~meV can be obtained. Differently from such heavy ions, Lyman-α H-like scandium H-like scandium could be precisely measured in lower energy facilities such EBIT or ECRIT ion plasma sources. As an alternative, theoretical predictions can be trustfully used for such a low-Z H-like ion. Two-loop QED contribution amount to only 1.7~meV in such low-Z ion and the largest uncertainty contribution comes from its hyperfine structure with only 5~meV.
Moreover, by reducing the target width from 5 to 1 mm, as planned at ESR, a gain a factor five on the statistical uncertainty is expected, with a reduction to about 7~meV only. Differently from E125 experiment, where a nitrogen gas-jet target with a relatively low-density was implemented to reduce possible double electron capture indistinguishable in by the CCDs spectrometer detectors, the reduction of the gas-jet target (and the possible use of heavier gas target to increase the induced photon flux) will requires the use time-coincidence position-sensitive detectors. The use of arrays of timepix3 detectors is planned for this purpose.
A total amount of 50 shift will be required (33 of high-intensity H-like uranium beam, 3 of bare scandium and 14 for beam preparation).

HITRAP / 26

HITRAP Experiments Proposal E130 with ranking A

Authors: Manuel Vogel[None]; Zoran Andelkovic[None]; Gerhard Birkl[None]; Volker Hannen[None]; Max Horst[None]; Kanika[None]; Jeffrey Klimes[None]; Wilfried Nörtershäuser[None]; Wolfgang Quint[None]; Simon Rausch[None]; Reinhold Schuch[None]; Andreas Solders[None]; Thomas Stöhlker[None]; Richard C. Thompson[None]; Christian Weinheimer[None]

Re: E130 'Cooling and precision spectroscopy of 209Bi82+ ion ensembles with the ARTEMIS and SPECTRAP experiments at the HITRAP facility'
The beamtime proposal E130 for HITRAP has been approved by the GPAC with ranking A a couple of years ago. In the years 2018 to 2021 it was not possible to take the approved beamtime of 30 shifts. Presently, from May 17th to 28th 2022, the HITRAP facility is being re-commissioned in a machine time with highly charged nickel ions. No beamtime with 209Bi82+ ions could be foreseen due to the priority of re-commissioning the HITRAP facility. In preparation for the beamtime, the ARTEMIS experiment is being commissioned with Ar13+ ions from an offline source. The connection of the ARTEMIS setup to the low-energy beamline of HITRAP has been successfully established recently. A new superconducting magnet, which is a Swedish inkind-contribution, for an upgrade of the SPECTRAP experiment has been installed at the HITRAP platform. The existing setup of SPECTRAP will be adapted to the new magnet and commissioned with offline ions.
The authors of the proposal E130 want to ask the GPAC to reschedule the approved beamtime for the years 2023 and 2024.

ESR / 27

Electron-impact excitation of the heaviest helium-like ion (U90+) in relativistic collisions

Authors: Alexandre Gumberidze[1]; Sergiy Trotsenko[1]; Pierre Michel Hillenbrand[2]; Christophor Kozhuharov[1]; Siegbert Hagmann[3]; Nikolaos Petridis[1]; Uwe Spillmann[1]; Günter Weber[1]; Yury Litvinov[1]; Shahab Sanjari[1]; Jan Glorius[1]; Robert Grisenti[1]; Thomas Stöhlker[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *GSI*

[3] *Goethe-Universität Frankfurt(UFfm-IKP)/GSI-Darmstadt*

Corresponding Author: a.gumberidze@gsi.de

Here we propose to measure the fundamental atomic process of electron-impact excitation (EIE) for the heaviest helium-like ion (U90+) at the gas-jet target of the ESR. Thereby we plan to extend the previous successful study where the EIE process has been identified for the first time for such a system, but only relative cross sections could be extracted and compared to theory. In the proposed study, we plan to obtain absolute EIE cross sections by using the process of Radiatve Electron Capture (REC) occurring in the same collisions for normalization. Relying on the accurate knowledge of the REC cross sections, we aim to obtain the absolute EIE cross sections with an accuracy of few percent. This will allow to distinguish between the EIE calculations using the Breit Interaction or the Generalized Breit interaction for the first time, and thereby provide a benchmark test for the electron-electron interaction in the regime of extreme fields. In addition, we plan to measure the linear polarization of the characteristic Lyman radiation by using a novel Compton polarimeter and thus provide a more stringent test of the state-of-the-art theory.

ESR / 28

Radiative Electron Capture Studies for Bare Uranium Ions in Collisions with Spin-Polarized Target Electrons

Authors: Joerg Pretz[1]; Thomas Stöhlker[2]

[1] *Forschungszentrum Jülich, Institut für Kernphysik*

[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Corresponding Authors: t.stoehlker@gsi.de, pretz@physik.rwth-aachen.de

Radiative electron capture (REC), the time reversed photon ionization process in ion–atom collisions, has been studied in great detail for projectile nuclear charges covering virtually the whole periodic table of elements up to fully stripped uranium ions [1]. With regard to the beam energies, the available data span from the low-collision energy regime up to high relativistic energies of almost $\gamma \approx 200$ where γ denotes the relativistic Lorentz factor. Beside total electron-capture cross-sections, photon angular distributions and recently even the associated photon polarization phenomena were subject of these studies with an in general excellent agreement with rigorous relativistic calculations. Here we propose to extend these studies at the internal target of the ESR to radiative capture of spin-polarized target electrons into a high-Z ion e.g. U92+. By means of Compton polarimetry [2,3], the high sensitivity of the photon polarization to the initial electron spin polarization will be exploited to control the polarization transfer to the ion. Subsequently performing total electron-capture cross-section studies of spin polarized electrons into ions having already captured a spin-polarized electron, we should be able to study the polarization build up for the stored ion beam.
This experiment is the beginning of a series of experiments whose ultimate goal is the generation of spin-polarized particle beams in flight. To this end, the teams at IKP in Jülich (with their detailed knowledge in preparation, control and experiments with stored polarized particle beams) and the AP/SPARC group at GSI (with their experience in REC studies for high-Z projectiles as well as in photon polarization studies for hard x- and γ-rays) team up. We note that polarized beams of heavy ions have never been realized before and represent a new degree of freedom for heavy ion storage-ring experiments. This is in particular relevant for future studies in the realm of fundamental symmetries.

[1] J. Eichler, and Th. Stöhlker, Radiative electron capture in relativistic ion–atom collisions and the photoelectric effect in hydrogen-like high-Z systems Physics Reports - 439, 1 (2007).
[2] R. Märtin et al., Polarization Transfer of Bremsstrahlung Arising from Spin-Polarized Electrons, Phys. Rev. Lett. 108, 264801 (2012).
[3] K. H. Blumenhagen et al., Polarization transfer in Rayleigh scattering of hard x-rays, New Journal of Physics 18, 9 (2016).
[4] W. Middents et al., Possible Polarization Measurements in Elastic Scattering at the Gamma Factory Utilizing a 2D Sensitive Strip Detector as Dedicated Compton Polarimeter, Annalen Der Physik, 2100285 (2021).

Cryring@ESR / 29

High-Resolution Spectroscopy of X-Ray Transitions in He-like Uranium at the CRYRING@ESR

Authors: Günter Weber[1]; Thomas Stöhlker[1]; Alexandre Gumberidze[1]; Uwe Spillmann[1]; Sergiy Trotsenko[1]; Sonja Bernitt[1]; Michael Lestinsky[1]; Daniel Hengstler[2]; Andreas Fleischmann[3]; Christian Enss[4]; Christoph Hahn[1]; Philip Pfäfflein[1]; Binghui Zhu[5]; Felix Kröger[6]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Kirchhoff Institute for Physics*

[3] *Uni Heidelberg*

[4] *Kirchhoff-Institut für Physik*

[5] *Helmholtz Institute Jena*

[6] *FSU Jena, IOQ Jena, HI Jena*

Corresponding Author: g.weber@gsi.de

Helium-like ions are the simplest atomic multibody systems and their study along the isoelectronic sequence provides a unique testing ground for the interplay of the effects of correlation, relativity and quantum electrodynamics. However, for high-Z ions with nuclear charge Z > 54, where inner-shell transition energies reach up to 100 keV, there are currently no data available to challenge state-of-the-art theory [1]. In this context the development of metallic magnetic calorimeter (MMC) detectors is of particular importance. Their high spectral resolution of a few tens of eV FWHM at 100 keV incident photon energy in combination with a broad spectral acceptance down to a few keV will enable new types of precision x-ray studies [2].

In a recent beam time at CRYRING@ESR we employed for the first time MMC-type detectors at the 0° and 180° view ports of the electron cooler to perform precision spectroscopy of hard x-rays from high-Z ions, namely U90+. By exploiting the time resolution of MMC detectors for the first time to set a coincidence condition on the detection of photons together with down-charged ions, we succeeded in obtaining high-resolution spectra from a few keV to above 100 keV [3]. A spectral resolution between 70 and 90 eV was achieved for the K_alpha lines, thus enabling for the first time to resolve the substructure of these transitions in a high-Z system. While the measurement was quite successful as a proof-of-principle, the obtained spectra suffer from low statistics as more than half of the allocated beam time was lost due to tuning and outages of the accelerator. Only in the last few days a stable operation with an acceptable beam intensity of 2 x 10^6 ions was achieved.

To fully exploit the physics potential of the demonstrated experimental scheme and also as a crucial stepping stone towards the long-standing goal of a new 1s Lamb shift measurement in hydrogen-like uranium, we want to apply for 10 days of beam time to run again with U91+ as the primary beam.

ESR / 30

Hyperfine Structure in ^{208,209}Bi$^{80+,82+}$ - a Test of QED in Strong Magnetic Fields

Authors: Wilfried Noertershaeuser[1]; Rodolfo Marcelo Sánchez Alarcón[2]; Zoran Andelkovic[2]; Carsten Brandau[2]; Volker Hannen[3]; Kristian König[1]; Yury Litvinov[2]; Konstantin Mohr[2]; Markus Steck[2]; Thomas Stöhlker[2]; Danyal Winters[2]

[1] *TU Darmstadt*

[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[3] *Institut für Kernphysik, Uni Münster*

Corresponding Author: wnoertershaeuser@ikp.tu-darmstadt.de

The measurement of the ground-state hyperfine structure in H-like and Li-like highly charged ions is supposed to provide the best test of QED in the strong magnetic field regime. The measurement of both charge states is required to remove nuclear structure uncertainties, originating in the magnetic dipole moment distribution inside the nucleus (Bohr Weisskopf effect). Such a test has been carried out for ^{209}Bi and – after correction of the nuclear magnetic moment from an NMR experiment – the agreement between experiment and theory was reasonable. There is, however, still an ongoing discussion about the appropriateness of the specific difference between the hyperfine structures of the two charge states to remove nuclear structure uncertainties. To resolve this issue, a measurement of the hyperfine structure in ^{208}Bi has been started but sensitivity has to be improved. This isotope has to be artificially produced in a thick stripper foil and to be isolated in the ESR. This procedure has been established in the beamtimes of E142 for the production of ^{229}Th and is now employed in the still ongoing beamtime of E128.
For hydrogen-like ^{209}Bi^{82+}, a laser resonance signal with a very good signal-to-background ratio was just detected with approximately 2×10^5 ions in the storage ring. A search for the resonance signal of ^{208}Bi^{82+} is currently ongoing. For ^{208}Bi^{80+} photon detection is not suitable anymore at such low ion numbers since the transition is in the red region (more background) and has about two orders of magnitude longer lifetime (less photons). Therefore it has been suggested to explore whether dielectronic recombination can be used as a tool for the detection of the laser resonance transition. This proposal was twice ranked with grade A in the G-PAC meeting 2017 and 2020 but so far this experiment was not possible due to the short-circuit in one of the drift tubes in the electron cooler. Instead, we had used the beamtime to search for the hyperfine structure in H-like ^{208}Bi.
We propose to carry out the experiment on the Li-like ion after the electron cooler has been repaired.

ESR / 31

Bound state beta decay of 205Tl (possible resubmission)

Authors: Yury Litvinov[1]; Iris Dillmann[2]; Guy Leckenby[3]; Ragandeep Singh Sidhu[1]; Rui Jiu Chen[1]; Thomas Stöhlker[1]; Shahab Sanjari[1]; Helmut Weick[1]; Takayuki Yamaguchi[4]; Jan Glorius[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Tri-University Meson Facility (TRIUMF)(TRIUMF)*

[3] *TRIUMF*

[4] *Saitama Univ.*

Corresponding Author: gleckenby@triumf.ca

On behalf of the entire 205Tl-Collaboration
The bound state beta decay of 205Tl has been determined. Multiple corrections had to be applied due to not properly functioning detectors during the Beamtime leading to quite large error bars of 20%. The sensitivity study is presently ongoing to evaluate the need for a more precise half-life determination. In a positive case a resubmission of the proposal is anticipated.

Cryring@ESR / 32

Ion beam and level population dynamics in Mg+ laser spectroscopy at CRYRING@ESR

Authors: Rodolfo Sánchez[1]; Konstantin Mohr[1]; Zoran Andelkovic[1]; Volker Hannen[2]; Kristian König[3]; Claude Krantz[1]; Michael Lestinsky[1]; Yury Litvinov[1]; Wilfried Noertershaeuser[3]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Institut für Kernphysik, Uni Münster*

[3] *TU Darmstadt*

Corresponding Author: r.sanchez@gsi.de

We want to continue laser spectroscopy experiments at CRYRING@ESR with Mg^+ ions in order to study population dynamics in the ions as well as electron-cooler ion beam dynamics.
Synchrotron oscillations in bunched beam operation lead to fast hyperfine level pumping of all velocity classes within a few revolutions. This surprising behaviour shall be further studied using laser intensity modulation to vary laser-ion beam interaction times. Moreover, optical pumping using Lambda-transitions in coasting beam operation will be investigated, to have similar conditions as in the lithium experiment at the ESR were optical pumping was supposedly observed.

In our first E148 beamtime with Mg^+ ions at CRYRING@ESR we found laser spectroscopy to be a sensitive monitor for the dynamics in electron cooling of low-energy ion beams, which requires very precise control of the cooler and ring parameters. A damping and subsequent re-excitation of synchrotron oscillations was observed utilizing the laser-excited fluorescence of the ion beam. This re-excitation was caused by a slight misalignment of the electron beam with respect to the ion beam. The position-dependent potential well of the electron beam and the dispersive coupling between the horizontal and longitudinal degrees of freedom lead to a positive feedback and enforced the oscillations. A closer inspection of these effects as well as of the electron beam space charge on the ion energy is planned.

ESR / 33

Influence of hyperfine interaction on the nuclear electron capture decay in ^{64}Cu

Authors: Ragandeep Singh Sidhu[1]; Rui Jiu Chen[1]; Jan Glorius[1]; Shahab Sanjari[1]; Helmut Weick[1]; Klaus Blaum[2]; Sergey Litvinov[1]; Yury Litvinov[1]; Markus Steck[1]; Thomas Stöhlker[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[2] *Max-Planck-Institut für Kernphysik*

Corresponding Author: r.s.sidhu@gsi.de

Beta-decay properties of highly-charged ions can differ significantly from the ones known in neutral atoms. Here, we propose to investigate the dependence of the nuclear electron capture rate in fully-ionized, hydrogen-like, and helium-like ^{64}Cu ions at the FRS-ESR facility by employing the time-resolved Schottky mass spectrometry.
The present proposal was evaluated with grade A by the G-PAC in the year 2007 but was never scheduled. We request the GSI management to consider the experiment for the beam time schedule in 2023 without any additional G-PAC evaluation.
Approved shifts: 17 shifts

34

Dielectronic and trielectronic recombination in sulfur ions

Authors: Weronika Biela-Nowaczyk[1]; Pedro Amaro[2]; Carsten Brandau[3]; Sebastian Fuchs[4]; Filipe Grilo[5]; Michael Lestinsky[3]; Esther Babette Menz[3]; Stefan Schippers[6]; Thomas Stöhlker[3]; Andrzej Warczak[1]

[1] *Jagellonian University Krakow(JUK)*

[2] *LIBPhys-UNL*

[3] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[4] *Justus-Liebig-Universität Gießen*

[5] *Laboratory of Instrumentation, Biomedical Engineering and Radiation Physics (LIBPhys-UNL)*

[6] *JLU Giessen*

Corresponding Author: weronika.biela@doctoral.uj.edu.pl

With use of collisional spectroscopy at the electron cooler and with a ions from
local ion source we would like to investigate DR and intrashell TR processes.
Mainly:
Be-like S^{12+} + e^- $\longrightarrow$ S^{11+}
Here, resonances:
DR $2s^2 \longrightarrow 2s^1 2p^2$ and TR $2s^2 \longrightarrow 2p^3$ (collisional energy <1.2eV)
DR $1s^2 2s^2 \longrightarrow 1s^1 2p^2$ and TR $1s^2 2s^2 \longrightarrow 1s^1 2p^3$ (collisional energy ~2000eV)