# A 39: Highly Charged Ions and their Applications

Time: Friday 11:00–13:00 Location: KlHS Mathe

A 39.1 Fri 11:00 KlHS Mathe

**Laser cooling simulations for the FAIR SIS100** — •Aleksandar Dimitrov[1], Thomas Walther[1,2], Peter Spiller[3], and Danyal Winters[3] — [1]Technische Universität Darmstadt — [2]HFHF Campus Darmstadt — [3]GSI Helmholtzzentrum für Schwerionenforschnug GmbH Darmstadt

At the FAIR heavy-ion synchrotron SIS100, it is planned to reduce the longitudinal momentum spread and the emittance of stored heavy-ion beams using laser cooling. For the understanding and optimization of bunched beam laser cooling (of relativistic highly charged ions) simulations play a critical role. In this work, laser cooling of bunched ion beams using both continuous and pulsed laser light, and their combination, is being investigated. The relevant parameters and their effects on the final beam properties are being studied. Insights from these simulations aim to enhance the efficiency of laser cooling for future SIS100 experiments.

A 39.2 Fri 11:15 KlHS Mathe

**High-precision laboratory astrophysics with TES-microcalorimeter and EBIT** — •Marc Botz[1], Luciano Gottardi[2], Martin de Wit[2], Liyi Gu[2], Jonas Danisch[1], Chintan Shah[1], Alexeï Molin[3], Francois Pajot[3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]SRON, Leiden, Netherlands — [3]IRAP, Toulouse, France

We have combined a state-of-the-art array of transition edge sensor (TES) x-ray microcalorimeters with an electron beam ion trap (EBIT) for providing laboratory spectroscopy benchmarks needed to analyze observational data from the recently launched X-ray satellite XRISM. In the EBIT we produce, trap and excite by electron impact the same highly charged ions that mission observes, and collect high dynamic range spectra with the TES-array having a resolution between 1.5eV and 4eV over a wide spectral bandwidth from 300eV to 13keV.

We present measurements on highly charged iron and sulfur ions, demonstrating the systems exceptional performance. Our data on the dielectronic recombination of different charge states of iron allow for the determination of K-alpha emission energies with outstanding precision. Measurements of the radiative recombination and Rydberg transitions of helium- and hydrogen-like sulfur up to the series limit allow us to infer their transition rates.

The research leading to these results has received funding from the European Union's Horizon 2020 Programme under the AHEAD2020 project (grant agreement n. 871158)

A 39.3 Fri 11:30 KlHS Mathe

**Towards trapping positrons in the Lsym experiment** — •Fabian Raab, Maria Pasinetti, Paul Holzenkamp, Andreas Thoma, Luca Falzoni, Björn-Benny Bauer, Sangeetha Sasidharan, and Sven Sturm — Max-Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

Lsym is a new cryogenic Penning trap experiment that intends to test the symmetry of matter and antimatter in the lepton sector. In particular, the experiment will test for differences in mass, charge and g-factor of the positron and electron to achieve the most precise test for a hypothetical CPT violation for leptons so far. In the experiment the trapped positron has to be cooled to its ground state of motion. Therefore, the trap assembly is cooled to about 300 mK, where the trap cavity is largely depleted from black-body photons around the cyclotron frequency of 140 GHz. In this presentation our recent steps towards trapping positrons as well as an update on the microwave filter, that will be used to counteract heating above the groundstate, will be illustrated.

A 39.4 Fri 11:45 KlHS Mathe

**The microwave cavity Penning trap for the LSym projet** — •Paul Holzenkamp, Björn-Benny Bauer, Luca Falzoni, Maria Pasinetti, Fabian Raab, Andreas Thoma, Sangeetha Sasidharan, and Sven Sturm — 69117 Heidelberg, Saupfercheckweg 1

LSym is a cryogenic Penning trap experiment, aiming to significantly improve the precision of CPT tests for the electron and positron. Specifically, we will look for an asymmetry in their charge-to-mass ratio as well as their g-factors or determine stringent limits.

The trap will be cooled to about 300mK to minimize transition rates out of the ground states of the cyclotron and axial motion, respectively. While the cyclotron motion cools via synchrotron radiation, for the axial motion, cavity assisted side-band cooling will be employed. Furthermore, the main Penning trap ("CavityTrap") not only should provide a highly harmonic trapping potential, but also needs to support efficient millimeter wave spin control drives at the Larmor frequency and axial sideband, while efficiently rejecting photons at the cyclotron frequency. Additionally, the CavityTrap should allow for the separation of the singly charged helium ion and the positron that are trapped together.

Numerical simulations are used to design the CavityTrap geometry in order to simultaneously fulfill the requirements for the microwave cavity structure and also optimize the electrostatic potential of the Penning trap.

I will show the current status of the LSym CavityTrap design.

A 39.5 Fri 12:00 KlHS Mathe

**Broadband laser cooling of stored bunched relativistic carbon ions using a high repitition rate pulsed laser system** — •Sebastian Klammes[1], Lars Bozyk[1], Michael Bussmann[2,3], Noah Eizenhöfer[4], Volker Hannen[5], Max Horst[4], Daniel Kiefer[4], Thomas Kühl[1,6], Benedikt Langfeld[4,7], Xinwen Ma[8], Wilfried Nörtershäuser[4,7], Rodolfo Sánchez[1], Ulrich Schramm[3,9], Mathias Siebold[2], Peter Spiller[1], Markus Steck[1], Thomas Stöhlker[1,6,10], Ken Ueberholz[5], Thomas Walther[4,7], Hanbing Wang[8], Weiqiang Wen[8], and Danyal Winters[1] — [1]GSI Darmstadt — [2]HZDR Dresden — [3]Casus Görlitz — [4]TU Darmstadt — [5]Uni Münster — [6]HI Jena — [7]HFHF Darmstadt — [8]IMP Lanzhou — [9]TU Dresden — [10]Uni-Jena

Laser cooling of relativistic bunched ion beams at storage rings has proven to be a powerful technique to obtain very small relative longitudinal momentum spreads ($\Delta p/p \sim$1E-6 range). This contribution will give an overview of the principle, which is based on resonant absorption (photon momentum & energy) in the longitudinal direction and subsequent spontaneous random emission (fluorescence & ion recoil) by the ions, combined with a moderate bunching of the ion beam. We will report on the curent status and results from the latest laser cooling beamtime at the ESR, where broadband laser cooling of bunched relativistic $C^{3+}$ ion beams was successfully demonstrated for the first time using a sophisticated pulsed UV laser system with a very high repetition rate ($\sim$9 MHz), variable pulse durations (166-734 ps), and high UV power (>250 mW).

A 39.6 Fri 12:15 KlHS Mathe

**Cooling of heavy highly charged ions: The HITRAP-Penning Trap** — •Dimitrios Zisis[1], Wilfried Nörtershäuser[1], Zoran Andelkovic[2], Frank Herfurth[2], Nils Stallkamp[2,3], Simon Rausch[1], Jonas Ködel[1], Gleb Vorobjev[2], Svetlana Fedotova[2], Sergiy Trotsenko[2], Dennis Neidherr[2], and Wolfgang Geithner[2] — [1]Institut für Kernphysik, TU Darmstadt, Schloßgartenstr. 9, Darmstadt, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, Darmstadt, Germany — [3]Institut für Kernphysik, Goethe University Frankfurt, Germany

The Highly charged Ions TRAP (HITRAP) located at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, is a facility for deceleration and cooling of ions that are produced at the accelerator complex thereby providing heavy, highly charged ions at low velocities and small energy distributions. Ion bunches consisting up to $10^8$ ions are injected into HITRAP at energies of 4 Mev/u from the Experimental Storage Ring (ESR), which are then slowed down to 6 kev/u in the two-stages linear decelerator.

We present the current status of the cooling trap and the ongoing progress to demonstrate electron cooling of extended amounts of heavy HCI for the first time. During the last year, HCI coming from the accelerator complex were successfully trapped for the first time. Additional optimization is still required in order for cooling of online produced HCI to be cooled down to low temperatures.

A 39.7 Fri 12:30 KlHS Mathe

**FOSS Precision Timing Control for Heavy Ion Cooling at HITRAP** — •Jonas Ködel[1], Zoran Andelkovic[2], Svetlana Fedotova[2], Wolfgang Geithner[2], Henning Hegen[2], Frank Herfurth[2], Nikolaus Kurz[2], Dennis Neidherr[2], Wilfried

Nörtershäuser[1], Simon Rausch[1], Nils Stallkamp[2,3], Sergiy Trotsenko[2], Gleb Vorobjev[2], Michael Wiebusch[2], and Dimitrios Zisis[1] — [1]Institut f. Kernphysik, TU Darmstadt, Schloßgartenstr. 9, Darmstadt, Germany — [2]GSI Helmholtzzentrum f. Schwerionenforschung, Planckstr. 1, Darmstadt, Germany — [3]Institut f. Kernphysik, Goethe University Frankfurt, Germany

Operating modern scientific apparatus requires smooth interaction of hard- and software. Industry standard software solutions offered by for-profit companies create unfavourable dependencies, locking experimenters into a walled garden that is hard to leave, and costly to stay in. We present the deployment of a **f**ree, **o**pen-**s**ource **s**oftware (FOSS) solution for control of the Penning trap of the **hi**ghly charged ion **trap** (HITRAP) during the most recent beamtime. HITRAP is located at GSI Darmstadt and allows deceleration and cooling of heavy, **h**ighly **c**harged **i**ons (HCI) down to 6 kev/u. Sympathetic cooling of HCI by concurrently stored electrons in a Penning trap is used as the final deceleration and cooling stage. The electrodes of the trap are switched in user-programmed patterns with nanosecond accuracy. Hard- and software of the trap control system are developed in-house. Their capabilities and the feasibility of a FOSS solution to experiment control are proven by their successful deployment during the recent beamtime.

A 39.8 Fri 12:45 KlHS Mathe

**Experiments on Highly Charged Ions from S-EBIT II** — •Rex Simon[1,2,3], Tino Morgenroth[1,2,3], Sonja Bernitt[1,2], Sergiy Trotsenko[2], Reinhold Schuch[2,4], and Thomas Stöhlker[1,2,3] — [1]Helmholtz Institute Jena, 07743 Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [3]IOQ, Friedrich-Schiller-University Jena, 07743 Jena, Germany — [4]Department of Physics, Stockholm University, 10691 Stockholm, Sweden

Electron Beam Ion Traps (EBITs) are versatile tools for investigating electron-ion interactions. Dielectronic recombination (DR) is a critical process that governs the ion charge-state equilibria in hot plasmas, with implications for theoretical models and plasma diagnostics [1]. Facilities such as CRYRING, ESR, and HITRAP [2] at GSI rely heavily on a steady supply of ions for experimental research. However, the dependence on the GSI accelerator limits operational flexibility, S-EBIT II emerged as a promising candidate to address this challenge, offering to be a local ion source for HITRAP and a standalone functionality for diverse experimental setups. By enabling local experiments such as ARTEMIS, and supporting advanced research into highly charged ion interactions, DR processes, and X-ray spectroscopy. Recent commissioning efforts include DR measurements with argon, alongside ongoing improvements to the electron gun and preparing to attach S-EBIT II to HITRAP. References [1] Beilmann, C. et al., 2013, Phys. Rev. A, 88(6), 062706. [2] H.-J. Kluge et al., 2008, Progress in Particle and Nuclear Physics, 59, 100-115.