## A 37: Poster – Highly Charged Ions and their Applications

Time: Thursday 17:00–19:00 Location: Tent

A 37.1 Thu 17:00 Tent

**Towards quantum gate with highly charged ion** — •Shuying Chen[1], Lukas J. Spiess[1], Alexander Wilzewski[1], Malte Wehrheim[1], José R. Crespo Urrutia-López[2], and Piet O. Schmidt[1,3] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

Highly charged ions (HCI) are good candidates for constructing of high-precision optical clocks, due to low sensitivity to from external field perturbations. Long-lived clock states in HCI also offer promising prospects for highly-stable qubits for high-fidelity quantum gates. Furthermore, the engineering of entangled states in HCI enables the utilization of a decoherence-free subspace for magnetic field shift insensitivity or quadrupole moment measurements in HCI clocks. We present progress made in the construction of an entangled gate utilizing $Ni^{12+}$. Thus far, a three-ion crystal consisting of 2 $Ni^{12+}$ and one $Be^{+}$ have been prepared for sympathetic cooling and quantum logic readout by splitting the initial larger crystal and removing the excess $Be^{+}$ ions.The three axial motional modes were successfully identified and ground state cooled. Read out of the states of the two HCI are performed using quantum logic on the logic transition. The two $Ni^{12+}$ ions will be entangled through Mølmer-Sørensen gate.

A 37.2 Thu 17:00 Tent

**Breit interaction in dielectronic recombination of hydrogenlike xenon ions** — •Shu-Xing Wang[1,2], Carsten Brandau[1,3], Stephan Fritzsche[3,4,5], Sebastian Fuchs[1,2], Zoltán Harman[6,7], Christophor Kozhuharov[3], Alfred Müller[1], Markus Steck[3], and Stefan Schippers[1,2] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany — [2]Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung, Campus Gießen, 35392 Giessen, Germany. — [3]GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany. — [4]Helmholtz-Institut Jena, 07743 Jena, Germany. — [5]Institut für Theoretische Physik, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany. — [6]Institut für theoretische Physik, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany — [7]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Electron-ion collision spectroscopy of the KLL dielectronic recombination (DR) resonances of hydrogenlike xenon ions was performed at a heavy-ion storage ring with a competitive resolving power with x-ray spectroscopy of inner-shell transitions in highly charged ions. The resonance strengths were measured on an absolute scale and compared with results from Multi-Configuration Dirac-Fock (MCDF) calculations. These are in excellent agreement with the experimental findings when considering QED effects on the resonance energies and the Breit interaction. A significant 25% increase was found for the strength of the first resonance group.

A 37.3 Thu 17:00 Tent

**An ultra-stable optical reference cavity for spectroscopy of highly charged ions** — •Ruben B. Henninger, Elwin A. Dijck, Vera M. Schäfer, Christian Warnecke, Stepan Kokh, Andrea Graf, José R. Crespo López-Urrutia, and Thomas Pfeifer — Max Planck Institut für Kernphysik, Saupfercheckweg 1, Heidelberg, Germany

To investigate the potential existence of a fifth force influencing interactions between electrons and neutrons, our research aims to employ highly charged ions (HCIs). In particular xenon, with its numerous spin-zero isotopes, represents a promising candidate for this investigation. The use of narrow linewidth lasers in the sub-Hertz regime is essential for achieving the required precision for the identification of new physics. This poster introduces an optical reference cavity with a 10 cm ULE spacer intended to stabilize spectroscopy lasers for different ions. We theoretically investigate the influence of crystalline mirror substrates on the thermal noise floor of the cavity and build a system with a projected noise floor of 3.6e-16 relative frequency uncertainty at one second. We present the design of the cavity housing and characterization measurements.

A 37.4 Thu 17:00 Tent

**Laser spectroscopy of highly-charged ions in SpecTrap** — •Rima Schüssler[1], Manuel Vogel[1], Volker Hannen[2], Andreas Solders[3], and Thomas Stöhlker[1,4,5] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [2]Univeristät Münster — [3]Uppsala Universitet — [4]Helmholtz Institute Jena — [5]Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena

Heavy highly charged ions (HCI) provide a unique possibility to test fundamental physics in the presence of extreme electromagnetic fields. To this end, the SpecTrap experiment, located at the HITRAP facility at GSI, plans to perform laser spectroscopy of (hyper-)fine structure transitions in HCIs in a Penning trap. Measurements will include the test of bound-state QED as well as the nuclear transition in $^{229}$Th.

The HCIs are produced in the experimental storage ring at GSI and decelerated in the HITRAP facility, before being guided to the Penning trap. Within the trap they are cooled down by sympathetic cooling with laser cooled $Mg^{+}$ ions. The trap has optical access for lasers as well as to collect fluorescence of the HCIs

The whole experiment is currently being redesigned and the poster will show the current status as well as future plans.

A 37.5 Thu 17:00 Tent

**The Positron Source at the Lsym Experiment** — •Maria Pasinetti, Fabian Raab, Paul Holzenkamp, Andreas Thoma, Luca Falzoni, Bjoern-Benny Bauer, Sangeetha Sasidharan, and Sven Sturm — Max-Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

The Lsym experiment is a new cryogenic Penning trap experiment currently being designed at the Max-Planck-Institut fur Kernphysik of Heidelberg. The goal of Lsym is to conduct a stringent CPT test by comparing the properties of matter and antimatter with unprecedented precision by trapping simultaneously one electron and one positron in a Penning trap, thus performing a decoherence-free measurement. This project will present a few challenges, for instance the optimisation of positron production and accumulation, given a rather weak radioactive 22Na source (about 15 MBq). A positron trapping technique involving production of positronium atoms in a high Rydberg state is being tested; furthermore, an efficient detection method is being set up. As positrons follow a $\beta+$ decay energy spectrum, they must undergo a moderation stage before entering the trap: the positron is then cooled to the ground-state of motion in the center of the trap. This poster illustrates the principles and techniques that will be used for the positron source at Lsym.

A 37.6 Thu 17:00 Tent

**Generation of Highly Charged Ions with a miniEBIT** — •Finja Mayer, Stepan Kokh, Melina Gizewski, Yang Yang, Nadir Khan, Moto Togawa, Thomas Pfeifer, José R. Crespo López-Urrutia, and Vera M. Schäfer — Max-Planck-Institut für Kernphysik, Heidelberg

Is the fine structure constant really constant? The answer to this question calls for physical systems that are highly sensitive to potential variations of $\alpha$ over time. Particularly interesting are highly charged ions, since their energy levels and thus measurable atomic transition frequencies are subject to enhanced relativistic shifts, making them more sensitive to variations of $\alpha$. However, the generation of HCIs is difficult, because the removal of electrons necessitates increasingly greater amounts of energy with increasing charge number of the ion. As a solution, the Electron Beam Ion Trap (EBIT) ionises injected atoms with accelerated electrons that are collimated by a strong magnetic field. The electromagnetic potential of the electron beam and several electrodes then confine these ions within the trap, thus allowing for higher charge states to be reached. This poster focusses on the precise structure of the EBIT, the design considerations involved, and the techniques used for construction.

A 37.7 Thu 17:00 Tent

**Towards ground state cooling of mixed ion crystals in the intermediate Lamb-Dicke regime.** — •Devanarayanan Rajeeb Kumar, Elwin A. Dijck, Stepan Kokh, Vera M. Schäfer, Christian Warnecke, José R. Crespo López-Urrutia, and Thomas Pfeifer — Max-Planck-Institut für Kernphysik, Heidelberg

Precision measurements are one of the approaches in the search for new physics. Using highly charged ions (HCIs) offers reduced systematic effects and an increased number of available transitions for generalized King plot analyses [1]. Implementing quantum logic spectroscopy [2] of an HCI co-trapped with a $Be^{+}$ ion for cooling and state readout requires ground-state cooling of the axial motional modes. Building upon our ground-state cooling of a single beryllium ion by pulsed sideband cooling including excitation of higher order sidebands, we report on our progress in achieving ground-state cooling of axial modes of mixed-species crystals, although our current trap operates only in an intermediate Lamb-Dicke regime with $\eta$ as large as 0.8 for certain modes.

[1] Rehbehn et al., Phys. Rev. Lett. **131**, 161803 (2023)
[2] Schmidt et al., Science **309**, 749 (2005)

A 37.8 Thu 17:00 Tent

**High-precision synchrotron laser spectroscopy of highly charged O, N and C in an EBIT** — •Jonas Danisch[1], Marc Botz[1], Moto Togawa[1], Joschka Goes[1], Chintan Shah[1,3], Filipe Grilo[1,4], Awad Mohamed[2], Monica de Simone[2], Marcello Coreno[2], Thomas Pfeifer[1], and José Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]IOM-CNR, Trieste, Italy — [3]NASA/Goddard Space Flight Center, Greenbelt, USA — [4]LIBPhys, Lisbon, Portugal

Analysing X-ray observations from hot astrophysical plasmas depends on understanding the transitions of highly charged ions (HCI). In the absence of high-precision theoretical data for some HCIs, experimental studies on the ground are needed to obtain accurate data in order to benchmark and improve astrophysical models. To overcome this challenge in a laboratory environment, highly charged ions are generated and trapped with an electron beam ion trap (EBIT), while the ions are simultaneously excited with synchrotron radiation from a high-resolution beamline. The occurrence of photoexcitation can be observed using a silicon drift detector, while the process of photoionisation can be monitored using a time-of-flight measurement.

In this work we present the result at the Elettra synchrotron facility in Trieste, Italy for the investigation of line positions of $N^{2+} - N^{4+}$ as well of $O^{1+}, O^{2+}$. Moreover we search for the small isotopic shift $^{16}$O - $^{18}$O present in the resonant photoionization of Be-like oxygen $O^{4+}$ driven by the $K_\alpha$ transition $1s^2 2s^2 \rightarrow 1s2s^2 2p_{3/2}$ and determined an experimental value of $2.56 \pm 1.27$ meV.

A 37.9 Thu 17:00 Tent

**Optimising the efficiency of a beamline for highly charged ions** — •Melina Gizewski, Stepan Kokh, Finja Mayer, Ruben Henninger, Elwin Dijck, José R. Crespo López-Urrutia, Thomas Pfeifer, and Vera M. Schäfer — Max Planck Institut für Kernphysik Heidelberg

Highly charged ions (HCIs) are one of the most suitable systems to measure variations in the fine structure constant $\alpha$, due to increased relativistic shift of energy levels at high charge states.

Our planned experimental setup includes generating HCIs in an electron beam ion trap (EBIT) and then retrapping them in two Paul traps to perform spectroscopy and measure the relevant atomic transition frequencies. Especially when using rare elements such as $Cf^{17+}$, it is necessary to transport the HCIs from the EBIT to the Paul traps with the highest possible efficiency. Here the electrostatic bending in the beamline is of particular importance, since it severely limits the HCI transmission rates.

This poster will showcase simulations of different electrostatic bender designs and their corresponding beamlines.

A 37.10 Thu 17:00 Tent

**A high NA imaging lens for imaging Coulomb crystals in a cryogenic Paul trap experiment** — •Christian Warnecke[1,2], Elwin A. Dijck[1], Bettina Mörk[1], and José R. Crespo-López Urrutia[1] — [1]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [2]Heidelberg Graduate School for Physics, Heidelberg, Germany

Highly charged ions are promising candidates for studying beyond Standard Model phenomena and advancing frequency standards in the XUV regime. At the Max-Planck Institute for Nuclear Physics in Heidelberg, a novel quasi-monolithic superconducting quadrupole resonator is used as a Paul trap to provide a noise-free environment for quantum logic spectroscopy of highly charged ions. Due to the relatively large trap dimensions of approximately $220 \times 120 \times 120\,\mathrm{mm}^3$, a minimum working distance of 60 mm is required to collect photons for state readout. Additionally, measures were taken to minimize thermal blackbody radiation input to the 4K cooling stage. The imaging system, comprising six lenses thermally stabilized at 4K and 40K, achieves a numerical aperture of 0.4 and covers a $500\,\mu$m field of view at a design wavelength of 313 nm. We will discuss our approach and provide insights from current measurements.

A 37.11 Thu 17:00 Tent

**Atomic computations for plasma and astro physics** — •Stephan Fritzsche — Helmholtz-Institut Jena, Germany — Friedrich-Schiller University Jena

JAC [1], the Jena Atomic Calculator, has been developed for performing (relativistic) atomic structure calculations of different kind and complexity. In particular, this code has been designed and worked out to compute atomic processes and (plasma) rate coefficients, including photo ionization and recombination, electron-impact processes and several others. JAC automatically generates self-consistent fields and, hence, is suitable also for mass production of atomic data as they are frequently needed in plasma and astro physics. Moreover, we currently implement Saha-Boltzmann schemes to model equation-of-states under different plasma conditions.

[1] S. Fritzsche, Comp. Phys. Commun. 240 (2019) 1. [2] S. Fritzsche, P. Palmeri and S. Schippers, Atomic cascade computations. Symmetry (Basel) 13, 520 (2021).