A 21: Highly charged ions and their applications

Time: Wednesday 16:30–18:30 Location: P

A 21.1 Wed 16:30 P

Non-perturbative dynamics in heavy-ion-atom collisions — •Pierre-Michel Hillenbrand[1,2], Siegbert Hagmann[2], Alexandre Gumberidze[2], Yury Litvinov[2,3], and Thomas Stöhlker[2,4,5] — [1]Justus-Liebig-Univ., Giessen — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [3]Ruprecht-Karls-Univ., Heidelberg — [4]Helmholtzinstitut Jena — [5]Friedrich-Schiller-Univ., Jena

Experimental data for atomic collisions of highly-charged ions are essential for benchmarking the theoretical description of fundamental dynamical processes in atomic physics. Of particular challenge is the accurate description of those processes that exceed the applicability of relativistic first-order perturbation theories. Recently, we have investigated two characteristic cases of such collision systems at the GSI heavy-ion accelerator. For collisions of U^{89+} projectiles with N_2 and Xe targets at 76 MeV/u, we studied the electron-loss-to-continuum cusp both experimentally and theoretically. We compared the continuum electron spectra of the two collision systems, which originate from the ionization of the projectile, and were able to identify a clear signature for the non-perturbative character of the collision systems [1]. Furthermore, we performed an x-ray spectroscopy experiment for slow collisions of Xe^{54+} and Xe^{53+} with a Xe target at 30 and 15 MeV/u. We analyzed the target $K\alpha$ satellite and hypersatellite lines to derive cross section ratios for double-to-single target K-shell vacancy production and compared the results to relativistic two-center calculations [2].

[1] Phys. Rev. A **104**, 012809 (2021)
[2] Phys. Rev. A, submitted

A 21.2 Wed 16:30 P

Laser cooling of stored relativistic bunched ion beams at the ESR — •Sebastian Klammes[1,2], Lars Bozyk[1], Michael Bussmann[3], Noah Eizenhöfer[2], Volker Hannen[4], Max Horst[2], Daniel Kiefer[2], Nils Kiefer[5], Thomas Kühl[1,6], Benedikt Langfeld[2], Xinwen Ma[7], Wilfried Nörtershäuser[2], Rodolfo Sánchez[1], Ulrich Schramm[3,8], Mathias Siebold[3], Peter Spiller[1], Markus Steck[1], Thomas Stöhlker[1,6,9], Ken Ueberholz[4], Thomas Walther[2], Hanbing Wang[7], Weiqiang Wen[7], Daniel Winzen[4], and Danyal Winters[1] — [1]GSI Darmstadt — [2]TU Darmstadt — [3]HZDR Dresden — [4]Uni Münster — [5]Uni Kassel — [6]HI Jena — [7]IMP Lanzhou — [8]TU Dresden — [9]Uni-Jena

At heavy-ion storage rings, almost all experiments strongly benefit from cooled ion beams, i.e. beams which have a small longitudinal momentum spread and a small emittance. During the last two decades, laser cooling has proven to be a powerful tool for relativistic bunched ion beams, and its "effectiveness" is expected to increase further with the Lorentz factor (γ). The technique is based on resonant absorption (of photon momentum & energy) in the longitudinal direction and subsequent spontaneous random emission (fluorescence & ion recoil) by the ions, combined with moderate bunching of the ion beam. We will report on recent (May 2021) preliminarily results from a laser cooling beam experiment at the ESR at GSI in Darmstadt, Germany, where broadband laser cooling of a relativistic ion beam could be successfully demonstrated for the first time using a pulsed UV laser system with a high rep.-rate, variable pulse lengths and high UV power.

A 21.3 Wed 16:30 P

Redefined vacuum approach and gauge-invariant subsets in two-photon-exchange diagrams — •Romain Soguel[1], Andrey Volotka[2], Dmitry Glazov[3], and Stephan Fritzsche[1] — [1]Helmholtz-Institut Jena, Jena, 07743, Germany — [2]ITMO University, St. Petersburg, 197101, Russia — [3]St. Petersburg State University, St. Petersburg, 199034, Russia

Within bound-state QED, the interelectronic interaction is treated perturbatively as an expansion over the number of exchanged photons. So far, zeroth-order many-electron wave-function constructed as a Slater determinant (or sum of Slater determinants) with all electrons involved were used in the performed derivations. The vacuum redefinition in QED, which is extensively used in MBPT to describe the states with many electrons involved, is proposed as a path towards an extension of two-photon-exchange calculations to other ions and atoms.

The two-photon-exchange diagrams for atoms with single valence electron are investigated. Calculation formulas are derived for an arbitrary state within rigorous bound-state QED framework utilizing the redefined vacuum formalism. This approach enables the identification of gauge-invariant subsets at two- and three-electron diagrams and separate between the direct and exchange contributions at two-electron graphs. Thus, the consistency of the obtained results is verified by comparing the results for each identified subset in different gauges. The gauge invariance of found subsets is demonstrated both analytically (for an arbitrary state) as well as numerically for 2s, 2p1/2, and 2p3/2 valence electron in Li-like ions.

A 21.4 Wed 16:30 P

Laser Cooling of Relativistic Ion Beams Employing a Transportable Pulsed UV Laser System — •Benedikt Langfeld[1], Lars Bozyk[2], Michael Bussmann[3,4], Noah Eizenhöfer[1], Volker Hannen[5], Max Horst[1], Daniel Kiefer[1], Nils Kiefer[6], Sebastian Klammes[2], Thomas Kühl[2,7], Markus Löser[3], Xinwen Ma[8], Wilfried Nörtershäuser[1], Rodolfo Sanchez[2], Ulrich Schramm[3,9], Mathias Siebold[3], Peter Spiller[2], Markus Steck[2], Thomas Stöhlker[2,7,10], Ken Ueberholz[5], Thomas Walther[1,11], Hanbing Wang[7], Weiqiang Wen[7], and Danyal Winters[2] — [1]TU Darmstadt — [2]GSI Darmstadt — [3]HZDR Dresden — [4]CASUS Görlitz — [5]Uni Münster — [6]Uni Kassel — [7]HI Jena — [8]IMP Lanzhou — [9]TU Dresden — [10]Uni Jena — [11]HFHF Ffm

Laser cooling of relativistic ion beams has been shown to be a promising technology to generate bright ion beams. To strongly reduce intrabeam scattering, a well-known problematic effect for high-intensity ion beams, pulsed laser systems with broad bandwidths can be employed.

In this work, we present preliminary results from a recent (May 2021) laser cooling "beam experiment" at the ESR storage ring at GSI Helmholtzzentrum Darmstadt, employing relativistic C^{3+} ion beams and our tuneable high repetition rate UV laser system. We have developed a transportable master-oscillator-power-amplifier system, supplying Fourier transform limited pulses with a continuously adjustable pulse duration between 50 and 735 ps and repetition rate of 1 to 10 MHz. With two SHG stages, the desired wavelength of 257.25 nm can be achieved, yielding > 200 mW during the beam experiment.

A 21.5 Wed 16:30 P

Sensitivity to new physics of isotope-shift studies using forbidden optical transitions of highly charged Ca ions — •Nils-Holger Rehbehn[1], Michael Karl Rosner[1], Hendrik Bekker[1,3], Julian Berengut[1,7], Piet Schmidt[2,8], Steven King[2], Peter Micke[2,1], Ming Feng Gu[6], Robert Müller[2,4], Andrey Surzhykov[2,4,5], and José Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Helmholz Institut Mainz, Johannes Gutenberg University, Germany — [4]Technische Universität Braunschweig, Germany — [5]Laboratory for Emerging Nanometrology Braunschweig, Germany — [6]Space Science Laboratory, University of California, Berkeley, USA — [7]School of Physics, University of New South Wales, Sydney, Australia — [8]Leibniz Universität Hannover, Germany

A hypothetical fifth force between neutrons and electrons could be detected through so-called King plots, where the isotope shifts of two optical transitions are plotted against each other for a series of isotopes. Deviations from the expected linearity could reveal such fifth force. We explore six forbidden transitions in highly charged (HCI) calcium, where some are suited for upcoming high-precision coherent laser spectroscopy. With this number of transitions it is possible to utilize the generalized King plot method, which will remove higher-order SM nonlinearities and thus more sensitivity to unknown forces. Currently further research is conducted in HCI Xe, which has a greater number of isotopes for the King plot.

A 21.6 Wed 16:30 P

From the first production run with CRYRING@ESR to the future — •Michael Lestinsky[1], Esther Menz[1,2,3], Zoran Andelkovic[1], Angela Bräuning-Demian[1], Wolfgang Geithner[1], Frank Herfurth[1], Stefan Schippers[4,5], Reinhold Schuch[6], Gleb Vorobjev[1], and Thomas Stöhlker[1,2,3] — [1]GSI Darmstadt — [2]HI Jena — [3]FSU Jena — [4]JLU Gießen — [5]HFHF Campus Gießen — [6]Stockholm University

With the installation and commissioning of the CRYRING@ESR facility being largely complete, the first heavy ion storage ring of the FAIR facility in Darmstadt is now in service as a user facility. The ring is able to store all ion species the GSI accelerator complex can produce as beams – from the lightest protons to bare uranium – and operates at significantly lower beam energy range down to few 100~keV/u. This opens new experiment opportunities and the SPARC collaboration at FAIR has proposed a rich research program on precision spectroscopy, slow atomic collisions and astrophysically relevant processes. During the 2021 beamtime period, first experimental installations of SPARC were successfully taken into operation and several experiment proposals were taken to data production. Even though the data analysis is still largely ongoing, it has already become apparent that the performance of the facility is largely meeting the high expectations. In addition we have been able to identify realistic opportunities for further improvement. We will give an overview of the storage ring, its performance, available and planned experimental installations, and invite discussion on further opportunities of the facility.

A 21.7 Wed 16:30 P

Production of a mixed highly charged ion Coulomb crystal — •Malte Wehrheim[1], Elwin A. Dijck[1], Christian Warnecke[1,2], Ruben Henninger[1], Michael Karl Rosner[1,2], Alvaro Garmendia[1], Andrea Graf[1], Julia Eff[1], Claudia Volk[1], Kostas Georgiou[1,3], Christopher Mayo[1,3], Lakshmi P. Kozhiparambil Sajith[1,3,4], Morten Will[1], José Ramon Crespo López-Urrutia[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Heidelberg Graduate School for Physics — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen

Precise spectroscopy of highly charged ions (HCI) is a promising candidate for the search of physics beyond the standard model. As a precondition we demonstrate the co-trapping of Ar^{13+} in a precooled beryllium Coulomb crystal with the novel design of our cryogenic Paul trap. After the extraction of hot HCI (10^3K range) from our electron beam ion trap (EBIT) the desired charge state is selected and the HCI beam is brought into the Trap. The main chamber of our experiment CryPTEx-SC (Cryogenic Paul Trap Experiment - superconducting) combines the geometry of a linear Paul trap with a superconducting resonator for the most stable radiofrequency fields. There we achieve the preparation of mixed beryllium and HCI Coulomb crystals of variable size with mK temperatures. By characterizing our trap, we verify that the correct charge state was selected which will be used for a benchmark measurement of the $2p^2P_{1/2} \rightarrow {}^2P_{3/2}$ fine structure transition of Ar^{13+} using quantum logic spectroscopy.

A 21.8 Wed 16:30 P

DR experiment on Ne^{2+} at CRYRING@ESR — •Esther Babette Menz[1,2,3], Michael Lestinsky[1], Sebastian Fuchs[4,5], Weronika Biela-Nowaczyk[6], Alexander Borovik Jr.[4], Carsten Brandau[1,4], Claude Krantz[1], Gleb Vorobyev[1], Bela Arndt[1], Alexandre Gumberidze[1], Pierre-Michel Hillenbrand[1], Tino Morgenroth[1,2,3], Ragandeep Singh Sidhu[1], Stefan Schippers[4,5], and Thomas Stöhlker[1,2,3] — [1]GSI, Darmstadt — [2]Helmholtz-Institut Jena — [3]IOQ, Friedrich-Schiller-Universität Jena — [4]I. Phys. Institut, Justus-Liebig-Universität — [5]Helmholtz Forschungsakademie Hessen für FAIR, Campus Gießen — [6]Institute of Physics, Jagiellonian University Kraków

After its move from Stockholm to GSI, CRYRING@ESR is now back in operation with previously inaccessible ion species available from the accelerator complex as well as a smaller selection from a local injector. The first merged-beam measurements of dielectronic recombination (DR) were performed at the CRYRING@ESR electron cooler since its move from Stockholm using a newly established particle detection and data acquisition setup. We present results from a scheduled experiment on low-energy DR of Ne^{2+} in May 2021. Neon is an astrophysically abundant element and absolute DR rates for low charge states are important for the modelling of cold, photoionized plasmas such as planetary nebulas. We plan to continue our DR experiments with a series of other low charge state ions which are of key importance for the quantitative analysis of astrophysical data.

A 21.9 Wed 16:30 P

Cold highly charged ion dynamics in a superconducting Paul trap — •Elwin A. Dijck[1], Christian Warnecke[1,2], Malte Wehrheim[1], Julia Eff[1], Alvaro Garmendia[1], Andrea Graf[1], Ruben Henninger[1], Claudia Volk[1], Morten Will[1], Kostas Georgiou[1,3], Lakshmi P. Kozhiparambil Sajith[1,3,4], Christopher Mayo[1,3], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Heidelberg Graduate School for Physics — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen

By integrating a niobium superconducting radio-frequency resonator with a linear Paul trap, the CryPTEx-SC experiment demonstrates a new ion trap concept developed for achieving ultra-low noise conditions [1]. Filtering of the trap drive by the high quality factor of the resonator and suppression of magnetic field fluctuations by the Meissner–Ochsenfeld effect will be beneficial for precision spectroscopy of highly charged ions using quantum logic techniques. Highly charged ions are captured and sympathetically cooled by Be^+ ions in the superconducting ion trap. This enables the exploration of dynamics in mixed species Coulomb crystals consisting of ions with disparate charge-to-mass ratios.

[1] J. Stark et al., Rev. Sci. Instrum. **92**, 083203 (2021)