A 35: Poster VIII

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

A 35.1 Thu 17:00 Tent C

Narrow and Ultranarrow transitions of highly charged Xe as probes for fifth forces — •Nils-Holger Rehbehn[1], Michael Karl Rosner[1], Julian C. Berengut[2,1], Piet O. Schmidt[3,4], Thomas Pfeifer[1], Ming Feng Gu[5], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut for Nuclear Physics, 69117 Heidelberg, Germany — [2]School of Physics, University of New South Wales, Sydney, New South Wales 2052, Australia — [3]Physicalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [4]Leibniz-Universität Hannover, 30167 Hannover, Germany — [5]Space Science Laboratory University of California, 94720 Berkeley, California, USA

A hypothetical fifth force acting between constituents of an atom could lead to a New Physics Model beyond the Standard Model. Such a model could potentially explain several phenomenon categorized under Dark Matter. To this end, we measured thirteen optical transitions in highly charged xenon which can be used in future quantum logic spectroscopy method measurements. Its anticipated precision is used to evaluate theoretical King-plots to reveal the most sensitive pairs. The sensitivity to a fifth force will be improved by four orders of magnitude compared the the most recent King-plot analyses, while overcoming higher orders of the Standard Model and isotope mass uncertainties via the generalized King-plot.

A 35.2 Thu 17:00 Tent C

Characterization of a radiofrequency trap for electrons — •Vladimir Mikhailovskii[1], Natalija Sheth[1], Hendrik Bekker[1], Guofeng Qu[2], Yuzhe Zhang[1], Ferdinand Schmidt-Kaler[3], Christian Smorra[3], Hartmut Häffner[4], and Dmitry Budker[1,3,4] — [1]Helmholtz-Institut Mainz, GSI Helmholtzzentrum für Schwerionenforschung, Mainz, Germany — [2]Institute of Nuclear Science and Technology, Sichuan University, Chengdu, China — [3]Johannes Gutenberg-Universität, Mainz, Germany — [4]Department of Physics, University of California, Berkeley, USA

We demonstrate trapping of electrons in a radiofrequency trap. The low charge-to-mass ratio of electrons puts special requirements on the experiment. First, we need electrons at low energies. Since electrons lack internal structure, which is commonly used to laser cool ions, it is necessary to produce them at low energies at the trap center. This is achieved by two-step photoionization of a Ca beam [1], where the atoms are ionized only slightly above the ionization threshold. Second, the trap must be operated at high frequencies. We have realized such a trap, consisting of three PCBs described in [2], and are currently characterizing its performance at 1.6 GHz in a UHV system. After loading the trap, the electrons are detected after a variable waiting time by extraction and subsequent detection with an electron multiplier tube. The results on the trap depth and the lifetime of the trapped electrons are presented.

[1] S. Gulde et al, Appl. Phys. B; 73, 861(2001)
[2] C. Matthiesen et al, Phys. Rev. X; 11, 011019 (2021)

A 35.3 Thu 17:00 Tent C

Characterization of electron-production efficiency in ^{40}Ca two-step photoionization for loading electrons into a radiofrequency trap — •Natalija Sheth[1], Vladimir Mikhailovskii[1], Hendrik Bekker[1], Guofeng Qu[2], Yuzhe Zhang[1], Ferdinand Schmidt-Kaler[3], Christian Smorra[3], and Dmitry Budker[1,3,4] — [1]Helmholtz-Institut Mainz, GSI Helmholtzzentrum für Schwerionenforschung, Mainz, Germany — [2]Institute of Nuclear Science and Technology, Sichuan University, Chengdu, China — [3]Johannes Gutenberg-Universität, Mainz, Germany — [4]Department of Physics, University of California, Berkeley, USA

Radiofrequency (RF) traps are widely used for trapping ions, molecules, and even nanoparticles [1], while confining of electrons remains a challenging task. Within the AntiMatter On a Chip project we are characterizing an RF trap for electrons keeping in mind future possibility of trapping positrons. Loading electrons into the RF trap is realized by two-step photoionization (PI) of neutral Ca atoms [2]: excitation 4^1S_0 - 4^1P_1 with a 423 nm laser, and ionization from 4^1P_1 to continuum with a 393 nm laser. This approach allows production of cold electrons within the effective volume of the trap. A Ca atomic beam is produced by thermal evaporation of Ca. PI signal detection is realized by an electron-multiplier tube. Dependence of the PI signal on the lasers power and the detection efficiency are discussed.

[1].D. Bykov, et al. Rev. Sci. Inst; 93 (7), 073201 (2022)
[2].S. Gulde, et al. Appl Phys B; 73, 861 (2001).

A 35.4 Thu 17:00 Tent C

Theory of Bloch-oscillation-enhanced atom interferometry — •Ashkan Alibabaei[1,2], Florian Fitzek[1,2], Jan-Niclas Kirsten-Siemss[1,2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany

We investigate the fundamental limits of Large Momentum Transfer (LMT) Atom Interferometry by using the Bloch oscillations of atoms in optical lattices. A thorough theoretical framework for Bloch-oscillation-enhanced atom interferometry is presented and validated through a comparison with numerical solutions of the Schrödinger equation. This establishes design criteria to reach the fundamental efficiency and accuracy limits of large momentum transfer using Bloch oscillations. We apply our findings to current state-of-the-art experiments and make projections for the next generation of quantum sensors. Finally, we outline future steps to include the effects of the lattice potential in transverse direction towards a more realistic description. This will facilitate our ability to perform comprehensive analyses of the statistical and systematic errors for future Bloch-enhanced LMT atom interferometers.

A 35.5 Thu 17:00 Tent C

Proposal for a series of experiments on autonomous running and starting of an ion trap micro engine — •Diego Fieguth[1,2], Peter Stabel[1,2], and James Anglin[1,2] — [1]RPTU Kaiserslautern — [2]Landesforschungszentrum OPTIMAS

A minimal realization of a combustion engine, in the sense of a system that enables secular energy transfer across a large difference in dynamical time scales, can be achieved with only two or three degrees of freedom evolving as a closed dynamical system. We propose implementing a minimal engine model using only the three-dimensional motion of a single trapped ion. The transverse vibrational modes of the ion in the trap will be analogous to fuel or heat baths, to power work in the form of axial motion against an opposing force. We propose a step-by-step sequence of trapped ion experiments that involve launching the ion with some initial velocity in the axial direction. In all cases, the microscopic engine runs autonomously, in the sense that it evolves under a time-independent Hamiltonian with no external power and no external control. In addition, the proposed experiments demonstrate the non-trivial constraints which must be obeyed if the microscopic engine is to be able not only to run autonomously, but also to start autonomously. We explain how these constraints arise from unitarity, through the Kruskal-Neishtadt-Henrard (KNH) theorem of classical adiabatic theory and its recently proven quantum analog.

A 35.6 Thu 17:00 Tent C

Formation and Decay of Charged Rydberg Dimers and Trimers — •Neethu Abraham and Matthew Travis Eiles — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The preparation and detection of various types of Rydberg molecules, ranging from Rydberg macrodimers to Rydberg atom-ion molecules is a major advancement in the field of ultracold atomic physics. The lifetimes of these molecules are typically shorter than those of bare Rydberg atoms, indicating the involvement of non-radiative decay processes in their dynamics. Specifically, the presence of non-adiabatic coupling between electronic potential energy curves could be a significant factor in their decay. We explore this mechanism here in the Rydberg atom-ion molecule system, where a vibrational bound state can hop onto a repulsive potential curve and decay. We employ the streamlined version of the multichannel R-matrix method to compute the positions and widths of the resonance states, revealing notable alterations arising from the influence of this coupling. An extended version of the Rydberg atom-ion dimer is a Rydberg atom-atom-ion trimer system, and we investigate the prospect of its formation. The interaction between the two Rydberg atoms leads to interesting phenomena influencing the overall molecular configuration. Our primary objective is to provide a detailed exploration of the electronic and vibrational structure of this tri-atomic molecule.

A 35.7 Thu 17:00 Tent C

cryogenic strontium quantum processor — •Valerio Amico, Jackson Angonga, Roberto Franco, Xintong Su, and Christian Gross — University of Tuebingen

Optical tweezers lattices hosting neutral Rydberg atoms are a promising platform for quantum computing and simulation. However, the most demanding challenge consists in mitigating noise due to environmental coupling. In our ongoing project, we propose a pioneering approach that involves creating optical tweezer lattices, based in fermionic strontium 87, in a cryogenic environment at 4K. The use of a closed-cycle cryostat will provide an extremely high vacuum (XHV) environment of 1e-12 mbar which will reduce atom loss due to background gas and increase the atom lifetime in trap beyond 10 min thus enabling the assembly of larger arrays. Furthermore, operating at cryogenic temperatures will markedly reduce black-body radiation (BBR) and consequently reduce BBR-induced transitions between Rydberg levels. This will increase Rydberg lifetime and improve the fidelity of entangling gates and qubit coherence. In addition to shielding provided by the 4K copper case, the cryogenic environment enables the usage of superconducting coils, which offer outstanding passive stability of the magnetic field and thereby increases the qubit coherence. In this presentation we will showcase initial trapping and cooling of Sr-87 in our vacuum chamber, the design and construction of our cryogenic chamber and our current efforts towards cooling and transport of atoms into the cryostat.

A 35.8 Thu 17:00 Tent C

Realisation of a two-particle Laughlin state with rapidly rotating fermions — •Philipp Lunt, Paul Hill, Johannes Reiter, Maciej Galka, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

The fractional quantum Hall (FQH) effect features remarkable states that due to their strongly correlated nature and exotic topological properties have stimulated a rich body of research going far beyond the condensed matter community, where the effect was originally discovered. One fundamental class of FQH states is described by the celebrated Laughlin wavefunction, which accounts for a large number of plateaus in the Hall resistivity and already exhibits interesting anionic, fractionally charged quasi-particle excitations.

Here we present the direct realisation of the two-particle Laughlin wavefunction by rapid rotation of two interacting spinful fermions in a tight optical tweezer. We owe this result to our newly established experimental tools allowing us to precisely shape and modulate our optical potentials using coherently interfering laser fields.

Our observations reveal distinctive features of the Laughlin wavefunction, including a ground state distribution in the center-of-mass motion, a vortex distribution in the relative motion, correlations in the relative angle of the two particles, and the suppression of interparticle interactions. This achievement represents a significant step towards scalable experiments, enabling the atom-by-atom assembly of fermionic fractional quantum Hall states in quantum simulators.

A 35.9 Thu 17:00 Tent C

High fidelity quantum gates between electronic and nuclear spins in diamond — •Simon Gregor Walliser, Philipp Vetter, and Fedor Jelezko — Institut für Quantenoptik, Universität Ulm, Deutschland

Quantum computing is a rapid developing field which takes advantage of quantum mechanical phenomena to efficiently solve complex problems.

A potential candidate, for a small-scale proof-of-principle quantum computer, is the nitrogen vacancy (NV) center in diamond, a point defect in the diamond lattice. It allows manipulation and optical readout of its electron spin state at room-temperature and can control surrounding nuclear spins.

We implement several two-qubit gates between the electron spin of the NV center and surrounding, weakly coupled carbon spins, based on dynamical decoupling sequences. The performance of the gates is planned to be evaluated through several protocols, which take state and measurement errors into account, to ensure a fair comparison with other systems.

A 35.10 Thu 17:00 Tent C

Applying machine learning optimization to a transfer beamline for highly charged ions — •Elwin A. Dijck, Vera M. Schäfer, Stepan Kokh, Lukas F. Storz, Christian Warnecke, Thomas Pfeifer, and José R. Crespo López-Urrutia — Max Planck Institute for Nuclear Physics, Heidelberg

We optimize the production and transport of highly charged ions (HCIs) through a low-energy beamline that serves to decelerate and inject HCIs produced by an electron beam ion trap (EBIT) into a cryogenic radiofrequency trap for precision spectroscopy experiments [1]. The parameters to be optimized include EBIT settings, several dozen electrode voltages of electrostatic ion optics, as well as the timing of voltage pulses for deceleration, charge state selection and re-capture of HCI bunches. The online optimization is implemented using the open-source software package M-LOOP, which includes the machine learning methods of Gaussian process regression and a gradient-based approximator using an artificial neural network. The automated procedure allows faster optimization, as well as the investigation of apparatus stability over time. We discuss defining appropriate cost functions and the results obtained.

[1] Dijck et al., Rev. Sci. Instrum. **94**, 083203 (2023)

A 35.11 Thu 17:00 Tent C

Dynamics of melting linear mixed-species Coulomb crystals — •Elwin A. Dijck[1], Luca A. Rüffert[2], Lars Timm[3], José R. Crespo López-Urrutia[1], and Tanja E. Mehlstäubler[2,3] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]Leibniz University, Hannover

We investigate the disappearance of ordered structure with increasing system temperature of linear ion Coulomb crystals trapped in a linear radiofrequency trap using molecular dynamics simulations. Understanding these dynamics is valuable for optimizing the operation of multi-ion optical clocks and experiments using highly charged ions for tests of fundamental physics. The thermal motion at higher temperature causes ions to swap places at increasing rates, depending on ion properties and trapping parameters. In particular, we study how the melting dynamics are affected by the presence of ion species with differing charge and/or mass. We support the simulation results with experimental data of small Be^+ ion crystals with and without a highly charged ion, controlling the ion temperature using Doppler cooling/heating. We discuss different criteria for defining the melting point and how the increased Coulomb repulsion by a highly charged ion alters the crystal structure such that these mixed-species ion crystals exhibit localized melting.

A 35.12 Thu 17:00 Tent C

Compact high precision electronics in space applications — •Alexandros Papakonstantinou, Thijs Wendrich, Christian Reichelt, Matthias Koch, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

Atom interferometers with two species of cold degenerate quantum gases have been used to measure the Eötvös ratio. Ground-based experiments face limitations due to the trajectory of atoms within the confined space of the science chamber, which impacts the improvement of the Eötvös ratio in the interferometer due to the limitation of the free-fall time. However, employing a microgravity environment, provided for example by a sounding rocket or the ISS, presents advantages as it bypasses the constraints imposed by the apparatus size. In order to achieve interferometers for such conditions, the development of high-precision, compact electronics that meet the required standards and safety regulations for both the ISS and unmanned sounding rockets is essential. The electronics presented in this poster were developed with our experience in the QUANTUS family projects and proved their qualification by driving the lasers and magnetic fields to create degenerate quantum gases of two species during the MAIUS-2 sounding rocket mission.

A 35.13 Thu 17:00 Tent C

Synthetic dimension-induced pseudo Jahn-Teller effect in one-dimensional confined fermions — •André Becker[1,2], Georgios M. Koutentakis[3], and Peter Schmelcher[1,2] — [1]Center for Optical Quantum Technologies, Department of Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Institute of Science and Technology Austria (ISTA), am Campus 1, 3400 Klosterneuburg, Austria

We demonstrate the failure of the adiabatic Born-Oppenheimer approximation to describe the ground state of a quantum impurity within an ultracold Fermi gas despite substantial mass differences between the bath and impurity species. Increasing repulsion leads to the appearance of non-adiabatic couplings between the fast bath and slow impurity degrees of freedom which reduce the parity symmetry of the latter according to the pseudo Jahn-Teller effect. The presence of this mechanism is associated to a conical intersection involving the impurity position and the inverse of the interaction strength which acts as a synthetic dimension. We elucidate the presence of these effects via a detailed ground state analysis involving the comparison of ab initio fully-correlated simulations with effective models. Our study suggests ultracold atomic ensembles as potent emulators of complex molecular phenomena.