A 35: Poster – Precision Spectroscopy of Atoms and Ions (joint session A/Q)

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

A 35.1 Thu 17:00 Tent

Highly Charged Heavy Ions for Quantum Logic Spectroscopy and Novel Optical Clocks — •Lukas Kau[1,2,3], Nadine Homburg[1,2,3], Zoran Andelkovic[1], Thomas Stöhlker[1,2,3], and Peter Micke[1,2,3] — [1]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt — [2]Helmholtz Institute Jena — [3]Friedrich Schiller University Jena

Heavy, highly charged ions (HCI), such as hydrogen- or lithium-like ions, possess unique properties that make them ideal for probing the fundamental laws of physics. These simple atomic systems offer forbidden optical transitions in their hyperfine structure and extreme electromagnetic fields to which their bound electrons are exposed.

We are developing a versatile platform for quantum logic spectroscopy of heavy HCI (e.g. $^{207}Pb^{81+}$ with a clock transition at 1020 nm). To achieve this, we are leveraging on recent advancements in precision spectroscopy [1] and clock operation [2] with medium-light HCI of intermediate charge state ($^{40}Ar^{13+}$) and the heavy-ion accelerator chain of GSI for ion production and deceleration. Quantum logic spectroscopy, carried out in a cryogenic Paul trap, has the potential to improve the accuracy of optical hyperfine-structure transitions by many orders of magnitude to enable unprecedented tests of fundamental physics.

[1] P. Micke et al., *Nature* **578**, 60–65 (2020), [2] S. A. King et at. *Nature* **611**, 43–47 (2022).

A 35.2 Thu 17:00 Tent

Development of a CW Laser System at 185 nm — •Felix Waldherr[1], Jonas Gottschalk[2], and Simon Stellmer[2] — [1]Universität Heidelberg, Germany — [2]Rheinische Friedrich-Wilhelms-Universität Bonn, Germany

Generating stable and high-power deep ultraviolet (DUV) light is a formidable challenge, where recent advancements in laser technology motivate new attempts to reach wavelengths below 200 nm. We develop a DUV laser system based on two VECSEL lasers, which are frequency converted via multiple stages of sum-frequency generation, to produce light at 185 nm. Once operational, the system will be used for spectroscopy of mercury transitions and to explore molecular oxygen transitions in the Schumann-Runge bands, with implications for fundamental physics and astrochemistry.

A 35.3 Thu 17:00 Tent

Precise solution of Dirac equation and the calculation of the electron bound-g-factor for H_2^+ molecular ion — •Ossama Kullie[1], Hougo D. Nogueira[2], and Jean-Philippe Karr[2,3] — [1]Mathematics and Natural Sciences. University of Kassel, 34132 Kassel, Germany — [2]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, Paris, France. — [3]Université d'Évry-Val d'Essonne, Evry, France

A new generation of experiments is aiming at performing high-resolution spectroscopy of molecular hydrogen ions H_2^+ in Penning traps [2]. In these experiments the internal state of the molecule is detected via the dependence of spin-flip transition frequencies on vibrational and rotational degrees of freedom. This requires precise knowledge of these transition frequencies, which depend on the g-factor of the bound electron in the molecule. In the present work we calculate the relativistic g-factor using relativistic wave functions obtained by solving the Dirac equation for H_2^+ with high precision in the Born-Oppenheimer approximation [3,4]. Together with nonadiabatic and recoil corrections at the leading order [5] evaluated by solving the three-body Schrödinger equation [6] as well as leading radiative corrections, these results allow for very accurate predictions of the bound-electron g-factor. [1] M. R. Schenkel et. al. Nat. Phys. 20, 383 (2024). [2] E. G. Myers, PRA 98, 010101(R) (2018). [3] O. Kullie et. al. PRA 105, 052801 (2022). [4] H. D. Nogueira et. al. PRA 105, L060801 (2022). [5] J.-Ph. Karr, PRA 104, 032822 (2021). [6] V. I. Korobov, Mol. Phys. 116, 93 (2018).

A 35.4 Thu 17:00 Tent

Towards a Monolithic Linear Paul Trap for Cryogenic Quantum Logic Clocks — •Nadine Homburg[1,2,6], Lukas Kau[1,2,6], Stepan Kokh[3], Jacob Stupp[4], Malte Werheim[5], Vera Schäfer[3], Fabian Wolf[5], Piet O. Schmidt[4,5], and Peter Micke[1,2,6] — [1]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt — [2]Helmholtz Institute Jena — [3]Max Planck Institute for Nuclear Physics, Heidelberg — [4]Leibniz University Hannover (LUH) — [5]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig — [6]Friedrich Schiller University Jena

Quantum logic spectroscopy (QLS) enables optical frequency metrology with atomic and molecular ions that are promising for novel optical clocks and tests of fundamental physics but lack optical E1 transitions for laser cooling and state detection. QLS is based on two-ion crystals, which necessitate the use of linear Paul traps. Imperfections in trap geometry due to manufacturing, assembly, or cryogenic cool-down can cause axial micromotion, which cannot be compensated for and has been identified as a leading systematic effect in a previous trap design. Addressing this limitation, we report on simulation-based studies of a new linear Paul trap, based on a monolithic design by PTB and LUH. We explore an asymmetric and symmetric drive that can be provided by a superconducting YBCO step-up resonator. Additional features of the novel design include independent DC electrodes to allow mode coupling via parametric modulation of the trapping field. These design enhancements offer significant potential for improving the accuracy of future quantum logic clocks.

A 35.5 Thu 17:00 Tent

Towards X-ray Spectroscopy with sub-eV Absolute Energy Calibration up to 100 keV — •A. Striebel, A. Abeln, A. Brunold, D. Kreuzberger, D. Unger, D. Hengstler, A. Reifenberger, A. Fleischmann, L. Gastaldo, and C. Enss — Kirchhoff Institute for Physics, Heidelberg University

Metallic magnetic calorimeters (MMCs) are energy-dispersive X-ray detectors which provide an excellent energy resolution over a large dynamic range combined with a very good linearity. MMCs convert the energy of each incident photon into a temperature pulse which is measured by a paramagnetic temperature sensor. The resulting change of magnetisation is read out by a SQUID magnetometer.

To investigate electron transitions in U^{90+} within the framework of the SPARC collaboration, we developed the 2-dimensional maXs-100 detector array. It features 8x8 pixels with a detection area of 1 cm^2, an absorber thickness of 50 μm, a photo efficiency of 18 % at 100 keV, an energy resolution of 40 eV at 60 keV and was successfully operated in a recent beamtime at CRYRING@FAIR. To increase the photo efficiency to above 35 % at 100 keV we develop a new maXs-100 detector with 100 μm thick absorbers.

Currently, the absolute energy calibration is limited not by the detector itself, but by the Struck SIS3316 analog-to-digital converter. We present a technique to precisely determine the ADCs' non-linearity using an Analog Devices EVAL-ADMX1002B ultra low-distortion sine wave generator. This allows to correct for the non-linearity. We discuss the effect of this correction on actual MMC spectra.

A 35.6 Thu 17:00 Tent

Towards large-area 256-pixel MMC arrays for high resolution X-ray spectroscopy — •Andreas Abeln, Daniel Hengstler, Daniel Kreuzberger, Andreas Reifenberger, Andreas Fleischmann, Loredana Gastaldo, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

Metallic Magnetic Calorimeters (MMCs) are energy-dispersive cryogenic particle detectors. Operated at temperatures below 50 mK, they provide very good energy resolution, high quantum efficiency as well as high linearity over a large energy range. In many precision experiments in X-ray spectroscopy the photon flux is small, thus a large active detection area is desirable. Therefore, we develop arrays with increasing number of pixels.

In this contribution we present a detector setup featuring a novel dense-packed 16×16 pixel MMC array. The pixels provide a total active area of 4 mm $\times$ 4 mm and are equipped with 5 μm thick absorbers made of gold. This ensures a stopping power of at least 50 % for photon energies up to 20 keV. The expected energy resolution is 1.4 eV (FWHM) at an operating temperature of 20 mK. For the cost-effective read-out of the 128 detector channels we envisage the flux-ramp multiplexing technique. We present first results of the detector characterization obtained utilizing parallel 2-stage dc-SQUID read-out chains. We discuss the detector performance, focusing on the thermal behavior within the detector as well as to the thermal bath.

A 35.7 Thu 17:00 Tent

Spectroscopy on the 657nm and 456nm calcium clock transitions in a heat pipe — •Andreas Reuss, David Röser, Frederick Wenger, Hans Kessler, and Simon Stellmer — Physikalisches Institut, Universität Bonn

Alkaline-earth metals have become the system of choice in atomic clocks and quantum computing devices. Among these elements, calcium appeals to both the atomic physics community, owing to the availability of suitable clock transitions, as well as to the nuclear physics community, as the calcium nucleus is particularly *hard* and isotopes disperse around two nuclear shell closures.

Two clock transitions, very different in character, are available: the spin-forbidden 657-nm intercombination line and the 458-nm quadrupole transition.

We are preparing for co-located, simultaneous spectroscopy of these two transitions using a Ramsey-Bordé scheme on a beam of atoms. For preparation, we have performed spectroscopy of these transition in a heat pipe and will report on these studies.

A 35.8 Thu 17:00 Tent

Excited-state magnetic properties of carbon-like calcium — •Shuying Chen[1], Lukas J. Spiess[1], Alexander Wilzewski[1], Malte Wehrheim[1], Jan Gilles[1,2], Andrey Surzhykov[1,2], Erik Benkler[1], Melina Filzinger[1], Martin Steinel[1], Nils Huntemann[1], Charles Cheung[3], Sergey G. Porsev[3], Andrey I. Bondarev[4,5], Marianna S. Safronova[3], José R. Crespo López-Urrutia[6], and Piet O. Schmidt[1,7] — [1]Physikalisch-Technische Bundesanstalt, Germany — [2]Technische Universität Braunschweig, Germany — [3]University of Delaware, USA — [4]Helmholtz-Institut Jena, Germany — [5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany — [6]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [7]Leibniz Universität Hannover, Germany

Highly charged ions (HCI) are good probes for fundamental physics and the construction of high-precision optical clocks. The low number of electrons allows for possible precise theoretical calculations, which can be compared to accurate measurements. Magnetic properties, including the linear Zeeman shift, characterized by the g-factor, and the second order Zeeman shift, characterized by the C2 coefficient, are such feature. In this contribution, we demonstrate an excited-state g-factor measurement of Ca^{14+} via the estimation of the magnetic field using a co-trapped Be^+ ion and compare the result to theoretical calculations, finding excellent agreement. Furthermore, we measured the C2 coefficient and verified the predicted small second-order Zeeman shift in HCI. The technique presented here can be extended to other HCIs.

A 35.9 Thu 17:00 Tent

Addressed excitation and coherent manipulation of Rydberg states in a linear ion string — •Robin Thomm, Harry Parke, Natalia Kuk, Marion Mallweger, Vinay Shankar, Ivo Straka, and Markus Hennrich — Department of Physics, Stockholm University, Sweden

Rydberg excitation of trapped ions is a novel and promising approach for quantum sensing, simulation, and computation. Building on our previous demonstrations of coherent single-ion Rydberg excitation (Higgins *et al.* PRL 119, 220501 (2017)), zero-polarizability states (Pokorny *et al.* arXiv:2005.12422 (2020)) and a two-qubit gate (Zhang *et al.* Nature 580, 345-349 (2020)), we report recent progress toward integrating these achievements for addressed Rydberg excitation in linear ion strings. Key advancements include electromagnetically induced transparency (EIT) cooling of $^{88}Sr^+$ ions, the implementation and characterization of single-ion addressing for the two-photon Rydberg excitation lasers, and the dressing of different Rydberg states via microwave radiation. Additionally, I will present first experimental results on coherent manipulation of Rydberg states with microwaves and the realization of a two-qubit gate in a linear ion string.

A 35.10 Thu 17:00 Tent

A cyclotron detector for (anti-)protons in a cryogenic Penning trap — •Yannick Priewich[1], Jan Schaper[1], Nikita Poljakov[1], Julia Coenders[1], Juan Manuel Cornejo[1], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN, Japan — [4]Heinrich-Heine-Universität, Düsseldorf, Germany

As part of the BASE collaboration, the BASE Hannover experiment aims to contribute to CPT symmetry tests [1-3] by using quantum logic techniques for g-factor measurements of (anti-)protons with $^9Be^+$ as cooling and logic ion [4]. Towards this, temperature control and transport of $^9Be^+$ ions have been extensively studied in a cryogenic Penning trap [5,6]. In our next measurement run, we aim to study the coupling of a single proton and a single $^9Be^+$ ion in a double-well potential in a designated so-called "micro-coupling trap" [4].

In this contribution, we will show the design and development of a cryogenic resonator and low-noise amplifier circuit for detection and cooling of the cyclotron motion of (anti-)protons in a Penning trap as well as upgrades to our Penning trap stack.

[1] G. Schneider et al., Science 358, 1081 (2017) [2] C. Smorra et al., Nature 550, 371 (2017) [3] M.J. Borchert et al., Nature 601, 53 (2022) [4] J. M. Cornejo et al., New J. Phys. 23, 073045 (2023) [5] J. M. Cornejo et al., Phys. Rev. Research 6, 033233 (2024) [6] T. Meiners et al., Eur. Phys. J. Plus 139, 262 (2024)

A 35.11 Thu 17:00 Tent

Spectroscopy of Titanium and Molecular Ions — •Maximilian J. Zawierucha[1,2], Till Rehmert[1,2], Piet O. Schmidt[1,2], and Fabian Wolf[1] — [1]Physikalisch-Technische Bundesanstalt — [2]Leibniz Universität Hannover

Extending quantum control to increasingly complex systems is crucial for advancing quantum technologies and fundamental physics. Molecules for example offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well suited for the study of fundamental physics. However, the additional degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, state preparation and detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy. In addition to the single molecular ion, one well-controllable atomic ion is co-trapped, coupling strongly to the molecule via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection. Using a far detuned Raman laser and Ca^+ as a logic ion, we have implemented a quantum logic scheme for coherent manipulation of Zeeman states in the a^4F ground state of titanium ions. With this we are able to determine the ion's finestructure state, prepare a Zeeman edge-state and precisely measure the g-factors of titanium. The developed techniques are applicable to a wide range of complex ionic systems and are currently being transferred to enable control over MgH^+ molecular ions.

A 35.12 Thu 17:00 Tent

Precision X-Ray Spectroscopy of Kα transitions in He-like Uranium using Metallic Magnetic Calorimeter Detectors — •Daniel A. Müller[1,3], Philip Pfäfflein[1,2,3], Marc O. Herdrich[1,3], Felix M. Kröger[1,2,3], Michael Lestinsky[2], Daniel Hengstler[4], Andreas Fleischmann[4], Christian Enss[4], Günter Weber[2,3], and Thomas Stöhlker[1,2,3] — [1]HI-Jena, Jena — [2]GSI, Darmstadt — [3]FSU, Jena — [4]KIP, Heidelberg

He-like ions, as the simplest atomic multibody system, provide a unique testing ground for the interplay of the effects of electron-electron correlations and quantum electrodynamics (QED) in various field strengths. Especially heavy highly charged ions are ideal for probing higher order QED terms, where experiments with ions at nuclear charge states $Z > 54$ currently are not available. An X-ray spectroscopy study of He-like uranium ions has been performed at the electron cooler of the storage ring CRYRING@ESR at GSI Darmstadt, using detectors of the maXs series, developed within the SPARC collaboration. Those detectors are a powerful tool for spectroscopy, measuring photons of a few keV to over 100 keV allowing the simultaneous investigation of Balmer-like and Kα transitions. The application of detectors in forward and backward direction furthermore enabled the determination of the Doppler shift. The achieved spectral resolution of better than 90 eV at X-ray energies close to 100 keV reveals the substructure of the Kα1 and Kα2 lines for the first time. This breakthrough paving the way for future tests of bound-state QED and many-body effects in extreme field strengths is presented in the poster.

A 35.13 Thu 17:00 Tent

Construction and characterization of an atomic gas jet — •anant agarwal, lennart guth, jan-hendrik oelmann, tobias heldt, lukas matt, josé r. crespo lópez-urrutia, and thomas pfeifer — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Spectroscopy of the narrow band transitions of highly charged ions (HCI) which lie in the extreme-ultraviolet (XUV) regime offers opportunities for next generation atomic clocks and precision studies of fundamental constants. To enable these studies, we developed an XUV frequency comb using cavity-enhanced high-harmonic generation, driven by a 100 MHz near-infrared frequency comb [1]. We plan to perform two-photon spectroscopy of neutral argon atoms prior to probing the HCI transitions with our XUV frequency comb in order to characterize the properties of the comb. Our two-photon spectroscopy scheme uses one comb tooth of the 13th harmonic to excite a Rydberg state and a CW NIR laser to further ionize the argon. The freed electrons are subsequently measured using a velocity-map imaging setup. We will discuss the construction and characterization of an atomic gas jet, which plays a crucial role in the setup by enabling Doppler-free delivery of argon atoms, and present first results towards the argon excitation.

[1] Opt. Express 29, 2624-2636 (2021)

A 35.14 Thu 17:00 Tent

MMC-based X-ray Detector for Transitions in light Muonic Atoms — •Peter Wiedemann, Andreas Abeln, Christian Enss, Andreas Fleischmann, Loredana Gastaldo, Daniel Hengstler, Daniel Kreuzberger, Andreas Reifenberger, Adrian Striebel, Daniel Unger, and Julian Wendel for the QUARTET-Collaboration — Kirchhoff Institute for Physics, Heidelberg University

High energy resolution X-ray spectroscopy of muonic atoms is used for the determination of charge nuclear radii. The QUARTET collaboration aims to improve the accuracy of nuclear charge radii of light elements from Li to Ne up to one order of magnitude by using Metallic Magnetic Calorimeter (MMC) arrays. These Detectors have already demonstrated excellent energy resolution and energy calibration with sub-ev prevision. We present the result obtained with the newly developed MMC array optimized to reach a quantum efficiency of 98% at 19 keV with 4 eV ΔE_{FWHM} We Discuss the performance achieved with this new MMC array at the light of precision X-ray spectroscopy of muonic lithium, beryllium and boron.

A 35.15 Thu 17:00 Tent

Detection of Ultra-light Dark Matter with a Network of Cavities — •Luis Hellmich[1,2], Cigdem Issever[1,2], Ullrich Schwanke[2], and Steven Worm[1,2] — [1]DESY Zeuthen, Zeuthen, Deutschland — [2]Humboldt-Universität zu Berlin, Berlin, Deutschland

The measurement of the temporal variation of fundamental constants would be strong evidence for new physics. In particular, many different theories predict the variation of the fine-structure constant α and proton-to-electron mass ratio μ. Optical atomic clocks and cavities are high precision measurement devices, which are sensitive to variations of the fundamental constants. In this work, we are investigating the sensitivity of a network of cavities to variations of fundamental constants induced by ultra-light dark matter (ULDM). ULDM is expected to oscillate coherently on macroscopic length scales. We are exploring the possibility to detect such oscillations with a network of spatially separated cavities. The proposed setup could detect frequencies in the sub-Hz regime, making it possible to constrain dark matter masses m $> 10^{-14}$ eV. We present projected limits on the scalar coupling to Standard Model particles for a few benchmark scenarios and compare them to existing constraints from equivalence principle tests.

A 35.16 Thu 17:00 Tent

Digital Pulse Shape Analysis for Metallic-Magnetic Calorimeters (MMC) — •Johanna H. Walch[1,2], Marc O. Herdrich[1,2,3], Philip Pfäfflein[1,3], Günter Weber[1,3], Daniel A. Müller[1,2], Daniel Hengstler[4], Andreas Fleischmann[4], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI-Jena, Jena — [2]FSU, Jena — [3]GSI, Darmstadt — [4]KIP, Heidelberg

In the recent years, cryogenic MMCs have emerged as excellent single photon detectors, exhibiting a broad spectral acceptance range and a high energy resolution of $E/\Delta E_{FWHM} \approx 6000$ [1]. Together with an adequate rise time, they represent a superb opportunity for fundamental research in atomic physics. However, the MMC absorbs a photon, generating a signal depending on its energy. The shape depends on the intrinsic detector response, noise and artefacts. To optimise performance, relevant pulse features must be extracted while suppressing noise. Several techniques involving finite impulse response (FIR) filters have been explored. Additional correction techniques are needed to mitigate the effects of integrated non-linearity and temperature drift of analog-to-digital converters gain. Finally, the drift in sensor sensitivity due to temperature fluctuations of the substrate must be considered. This work presents an overview of the involved steps and compares several FIR filter-based techniques. Two filters of particular interest for MMCs are the moving window deconvolution algorithm (Herdrich [2]) and the optimal filter (Fleischmann [3]). [1] J. Geist. PhD thesis, 2020; [2] M. O. Herdrich. PhD thesis, 2023; [3] A. Fleischmann. PhD thesis, 2003

A 35.17 Thu 17:00 Tent

Recent advances at the AntiMatter-On-a-Chip (AMOC) project — •Vladimir Mikhailovskii[1], Natalija Sheth[1], Yuzhe Zhang[1], Hendrik Bekker[1], Günther Werth[2], Guofeng Qu[3], Zhiheng Xue[4], K. T Satyajith[5], Qian Yu[6], Neha Yadav[6], Hartmut Häffner[6], Ferdinand Schmidt-Kaler[7], and Dmitry Budker[1,2,6] — [1]Helmholtz-Institut Mainz, GSI Helmholtzzentrum fur Schwerionenforschung, Mainz, Germany — [2]Johannes Gutenberg-Universitat, Mainz, Germany — [3]Institute of Nuclear Science and Technology, Sichuan University, Chengdu, China — [4]University of Science and Technology of China, Hefei, China — [5]Nitte, Mangalore, India — [6]Department of Physics, University of California, Berkeley, USA — [7]QUANTUM, Institute für Physik, Johannes Gutenberg-Universitat, Mainz, Germany

AMOC aims at production of antihydrogen by confining positrons and antiprotons in the same radiofrequency (RF) trap [1]. The general project workflow includes development of a RF trap for cotrapping e^+ and p^-, and their sources. The current stage is focused on testing the dual-frequency RF trap with e^- and Ca^+ ions, and development of low energy e^+ source. The RF trap used is a linear one made of 3 printed boards [2] and is capable of trapping e^- and Ca^+. For low energy e^+ production, we plan to use a Na-22 source with moderator and a buffer gas trap. In this report, we give an overview of the project, main experimental and simulation results, and discuss future steps.

1. N. Leefer, et al. Hyperfine Interact 238, 12 (2017)
2. C. Matthiesen et al, Phys. Rev. X; 11, 011019 (2021)

A 35.18 Thu 17:00 Tent

Artificial clock transitions with trapped $^{40}Ca^+$ ions. — •Kai Dietze[1,2], Lennart Pelzer[1,2], Ludwig Krinner[1,2], Fabian Dawel[1,2], Johannes Kramer[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30157 Hannover, Germany

State-of-the-art optical atomic clocks based on trapped ions achieve unprecedented precision but often require long averaging times to reduce the statistical uncertainty, compared to neutral atom clocks. The measurement uncertainty is usually limited by the quantum projection noise. It can be reduced by either extended probe times with the clock laser and/or simultaneous probing of multiple ions. By employing interrogation schemes that create a decoherence free subspace (DFS) against frequency shifts on the clock transitions, the effects of external noise and transition broadening, common in multi-ion systems, can be mitigated. We demonstrate a continuous dynamical decoupling sequence engineering a the clock transition in $^{40}Ca^+$ to be insensitive against magnetic field noise and the quadrupole shift, making the simultaneous probing of multiple ions feasible [1]. Additionally, we present our experimental results of a frequency reference based on two entangled ions within a DFS, achieving near-lifetime-limited interrogation times and surpassing the sensitivity limits of uncorrelated measurement protocols.

[1] L. Pelzer *et al.*, PRL 133, 033203 (2024)

A 35.19 Thu 17:00 Tent

Probing physics beyond the standard model using ultracold mercury — •Thorsten Groh, Sascha Heider, and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn

Mercury, being one of the heaviest laser-coolable elements, is an ideal platform for beyond standard model physics like baryon asymmetry searches [1]. Additionally excellent for isotope shift spectroscopy [2, 3] it possesses five naturally occuring bosonic isotopes, all of which we laser cool in our lab.

We report on deep-UV isotope shift spectroscopy of all stable bosonic mercury isotopes on multiple transitions, where we observe strong deviations from linearity. Furthermore, we report on recent improvements and upgrades to the machine for transferring magneto-optically trapped mercury atoms to a high power optical dipole trap giving an outlook to beyond state-of-the-art measurements of the atomic electric dipole moment of mercury.

[1] Graner PRL 116,161601 (2016)
[2] Delaunay, PRD 96, 093001 (2017)
[3] Berengut, PRL 120, 091801 (2018)

A 35.20 Thu 17:00 Tent

Trapping and sympathetic cooling of Thorium ions with Calcium — •Valerii Andriushkov[1,2], Yumiao Wang[3,4], Nutan Kumari Sah[3], Florian Zacherl[3], Ke Zhang[3], Keerthan Subramanian[3], Srinivasa Pradeep Arasada[3], Jonas Stricker[1,2,3], Dennis Renisch[1,2,3], Lars von der Wense[3], Christoph E. Düllmann[1,2,3], Ferdinand Schmidt-Kaler[3], and Dmitry Budker[1,2,3,5] — [1]Helmholtz Institute Mainz, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [3]Johannes Gutenberg Universität Mainz — [4]Fudan University, Shanghai, China — [5]Department of Physics, University of California, Berkeley, USA

The TACTICa [1] (Trapping and Cooling of Thorium Ions via Calcium) experiment aims to use ion trapping techniques for precision isotope shift measurements and to explore the nuclear structure of Th. In addition, ^{229}Th ions can also be used as a platform for direct laser spectroscopy of its first nuclear excited state and the development of a nuclear optical clock. This work is conducted in collaboration with the NuQuant project, which recently partnered with TACTICa. Since direct laser cooling of Th ions in a Paul trap is inefficient, sympathetic cooling using calcium ions is employed. Our goal is to implement quantum logic spectroscopy on the Th^{+}-Ca^{+}, enabling high-precision spectroscopy of Th transition. This work is supported by the DFG Project 'TACTICa' (grant agreement no. 495729045) and the BMBF Quantum Futur II Grant Project 'NuQuant' (FKZ 13N16295A).

[1] K. Groot-Berning et al., Phys. Rev. A 99, 023420 (2019)

A 35.21 Thu 17:00 Tent

JAC – A toolbox for (just) atomic computations — •Stephan Fritzsche — Helmholtz-Institut Jena, Germany — Friedrich-Schiller University Jena

Electronic structure calculations of atoms and ions have a long tradition in physics with applications from basic research to precision spectroscopy, and up to the realm of astrophysics. With the Jena Atomic Calculator (JAC), I here present a modern (relativistic) atomic structure code for the computation of atomic amplitudes, properties as well as a large number of excitation and decay processes. JAC [1,2] is based on Julia and provides an easy-to-use but powerful platform to extent atomic theory towards new applications. The toolbox is suitable for (most) open-shell atoms and ions across the periodic table of elements.

[1] S. Fritzsche. A fresh computational approach to atomic structures, processes and cascades. Comp. Phys. Commun., 240, 1 (2019), DOI:10.1016/j.cpc.2019.01.012. [2] S. Fritzsche. JAC: User Guide, Compendium & Theoretical Background. https://github.com/OpenJAC/JAC.jl, unpublished (02.11.2024).