Q 44: Precision spectroscopy of atoms and ions (with A)

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

Q 44.1 Wed 16:30 Empore Lichthof

Quantum Algorithmic Readout in Multi-Ion Clocks — •Marius Schulte[1], Niels Lörch[1], Ian D. Leroux[2], Piet O. Schmidt[2,3], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Callinstrasse 38, 30167 Hannover, Germany — [2]QUEST Institut, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [3]Institute for Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany

The methods of quantum information theory have already found many applications in trapped ion technologies. Even today, new generations of ion clocks often rely on quantum logic readouts in order to reference to a specific optical transition. Thereby they use two ion species in the same trap to exploit their different properties. Guided by a quantum algorithm, we present a non-demolition measurement strategy to transfer excitation probabilities among the two species. This method can be used for clocks with larger ion crystals in order to improve their short term stability. Our approach scales favorable in the number of logic ions and entangling-gates needed for the information transfer. We also discuss a possible realization based on a five ion crystal with Al and Ca ions, taking the full normal mode spectrum into account.

Q 44.2 Wed 16:30 Empore Lichthof

The ALPHATRAP g-Factor Experiment — •Andreas Weigel[1,2], Ioanna Arapoglou[1,2], Alexander Egl[1,2], Henrik Hirzler[1,2], Sandro Kraemer[1,2], Tim Sailer[1,2], Robert Wolf[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Fakultät für Physik und Astronomie, Universität Heidelberg

The Penning-trap based experiment ALPHATRAP is currently being set up at the Max-Planck-Institut für Kernphysik in Heidelberg. It is the follow-up to the Mainz g-factor experiment, which has performed the most sensitive test of bound-state quantum electrodynamics (BS-QED) by measuring the g-factor of the remaining electron bound in hydrogen-like $^{28}Si^{13+}$ at an uncertainty level of 10^{-11} [1] in a cryogenic double Penning-trap system. ALPHATRAP aims for g-factor measurements on even heavier highly charged ions up to hydrogen-, lithium- and boron- like lead, with simultaneously improved accuracy. To achieve this, the ALPHATRAP experiment, consisting of an improved cryogenic double Penning-trap setup, will be coupled via an ultra-high vacuum beamline to the Heidelberg Electron-Beam Ion Trap, which provides the highly charged ions. In combination with currently conducted BS-QED calculations, the measurements are expected to further contribute to the exploration of the limits of BS-QED and also aim for an independent determination of the fine-structure constant α with high precision. An overview and the current status of the project will be presented.

Q 44.3 Wed 16:30 Empore Lichthof

Metallic Magnetic Calorimeters for high resolution X-ray spectroscopy — •M. Krantz, D. Hengstler, C. Schötz, M. Keller, J. Geist, P. Schneider, S. Kempf, L. Gastaldo, A. Fleischmann, and C. Enss — KIP Heidelberg University.

We develop microfabricated, energy dispersive particle detector arrays based on metallic magnetic calorimeters (MMCs) for high resolution x-ray spectroscopy to challenge bound-state QED predictions. Our MMCs are usually operated below 30 mK and use a paramagnetic temperature sensor placed in a weak magnetic field, read-out by a SQUID, to measure the energy deposited by single X-ray photons. MMCs combine the properties of high energy resolution, high energy bandwidth and near perfect linearity in one detector. We discuss the microfabricated devices and performances of three different detector arrays. The maXs-20 is a 1x8 pixel linear array optimized for x-rays up 20 keV with an achieved energy resolution of 1.6 eV for 6 keV x-rays and experiments with maXs-20 at the MPI-K yielded new reference measurements of V-like and Ti-like tungsten. The maXs-200 is a 1x8 pixel linear array optimized for x-rays up 200 keV with an achieved energy resolution of 45 eV for 60 keV x-rays. We discuss sucessfully performed measurements at the Experimental Storage Ring (ESR) at GSI with the maXs-200. Our first 2d prototype with 8x8 pixels, maXs-30, is optimized for x-rays up to 30 keV with an estimated energy resolution below 6 eV.

Q 44.4 Wed 16:30 Empore Lichthof

The new CRYRING facility at GSI / FAIR and experiments with optical ion polarization — •Zoran Andelkovic[1], Wolfgang Geithner[1], Frank Herfurth[1], Michael Lestinsky[1], Wilfried Nörtershäuser[2], and Gleb Vorobyev[1] — [1]GSI Darmstadt — [2]TU Darmstadt

The CRYRING storage ring, the Swedish in-kind contribution to FAIR, is in the final installation phase. Tests of ion injection from the ESR are foreseen for the upcoming GSI beamtime period, followed by the commissioning of the ring within the following year.

A new transfer line has been designed for the injection from the Experimental Storage Ring (ESR). Thus all ion species presently accessible in ESR can be transferred to CRYRING. In addition, a local injector is available for ring commissioning and first operation. This local injector transfer line has been significantly modified compared to the former Stockholm configuration to meet the requirements at GSI. It provides stand-alone operation from a 40 kV platform where different ion species can be produced, transported to the RFQ and accelerated to the necessary 300 keV/u for injection into the ring.

One of the first experiments which can be performed with the offline source and the local injection is the investigation of polarized ion beams inside a storage ring. Recently, in an experiment at the ESR, an indication for optical polarization of an ion beam has been observed. Further systematic tests of optical pumping and polarization conservation of singly charged Mg or Be ions are foreseen at CRYRING.

Q 44.5 Wed 16:30 Empore Lichthof

Laser system for Precise High Voltage measurements — •Tim Ratajczyk, Phillip Imgram, Kristian König, Jörg Krämer, Bernhard Maass, Johannes Ullmann, and Wilfried Nörtershäuser — Institut für Kernphysik, TU Darmstadt

The ALIVE experiment at the TU Darmstadt is a new collinear laser spectroscopy setup. The goal of the experiment is the measurement of high voltages in the range of 10 to 100 kV using precise laser spectroscopy of ions with a well-known transition frequency [1]. The aim is to achieve a precision of at least 1 ppm, which is of interest for many applications.

For first experiments using a $^{40}Ca^{+}$ beam, a diode laser based system has been established. The well-known $4s_{1/2} \rightarrow 4p_{3/2}$ transition is used to identify the ion velocity by the Doppler shift. The laser system consists of an external cavity diode laser at 786 nm in combination with a tapered amplifier to provide a narrow bandwidth beam with sufficient power for frequency doubling in an LBO crystal. We present the current status of the experiment and an outlook for the laser system that will be used for spectroscopy on indium.

[1] O. Poulsen, Nuclear Instruments & Methods in Physics Research 202 (1982) 503.

Q 44.6 Wed 16:30 Empore Lichthof

Simulation and characterization of a multiwire backgammon gaseous detector for soft X-ray detection — •Mykhailo Dumchev, Jens Oberrath, and Anthimos Georgiadis — Institut für Produkt- und Processinnovation, Leuphana Universität Lüneburg, Deutschland

To proof the QED corrections of the $1s$ Lamb shift, high precision X-ray spectroscopy of low energetic transitions in high Z-ions is necessary. Since photons will be detected in coincidence with down-charged ions, a time resolution less than 50 ns and spatial resolution less than 100 μm is required.

A promising candidate to meet these requirements is a multiwire backgammon gaseous detector (MWB). It consists of a spacer, an inlet gas plate, an array of seven wires as anode plane, and a cathode plane shaped like a backgammon surface. This anode-cathode arrangement allows for the required spatial resolution in two dimensions as shown by Beyer and Deslattes [1]. To proof that such a detector is able to fulfill the required time resolution, simulations with the software tool Garfield were performed. It turned out that a time resolution of about 26 ns can be reached. Based on these results a MWB is constructed and tested. Within this contribution measurements with this detector will be presented and compared to simulation results.

[1] H. F. Beyer and R. D. Deslattes, GSI Scientific Report 1983, p. 350

Q 44.7 Wed 16:30 Empore Lichthof

Integrated electronic and photonic structures in vapor cells for quantum optics and sensing — •Johannes Schmidt[1,2], Ralf Ritter[1], Nico Gruhler[3], Patrick Schalberger[2], Holger Baur[2], Harald Kübler[1], Robert Löw[1], Wolfram Pernice[3], Norbert Frühauf[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Germany — [3]Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany

Rydberg atoms in thermal vapor are discussed as promising candidates for the realization of quantum devices such as single photon sources and sensors [1]. We present a sealing method based on anodic bonding, which is compatible with state of the art thin film technology offering both scalability and miniaturization [2]. We show that we are able to integrate electronic devices ranging from simple electrode structures to complex circuits like operational amplifiers into the vapor cell. Properties of different electrode materials and encapsulation methods are discussed as well.

Furthermore, we can implement integrated optics such as waveguide structures, which offer dozens of applications, like miniaturized atomic vapor spectroscopy, signal processing and sensing [3].

[1] J. A. Sedlacek, et al., Phys. Rev. Lett. 111, 063001 (2013)
[2] R. Daschner, et al., Appl. Phys. Lett. 105, 041107 (2014)
[3] R. Ritter, et al., Appl. Phys. Lett. 107, 041101 (2015)

Q 44.8 Wed 16:30 Empore Lichthof

High precision measurement of the Ho-163 electron capture spectrum — •Gastaldo Loredana for the ECHo Collaboration — Kirchhoff-Institut für Physik, Universität Heidelberg, INF 227, 69120 Heidelberg, Germany

The sensitivity to the neutrino mass achievable with the analysis of the calorimetrically measured electron capture spectrum of Ho-163 is strongly dependent on the precise understanding of the expected spectral shape. Already at the level of energy resolution that is presently achieved in the ECHo experiment for the Ho-163 spectrum it is obvious that several parameters for the theoretical description of the spectral shape need to be defined with higher accuracy. The determination of higher order processes to the atomic de-excitation within the daughter atom dysprosium might play an important role for achieving sub-eV sensitivity on the electron neutrino mass. We compare the parameters obtained by the analysis of the calorimetrically measured Ho-163 spectrum with the ones available in literature and discuss the discrepancies with present models and available data. We present new experimental methods and discuss recently theoretical models to achieve a better accuracy in the determination of the parameters describing the Ho-163 spectrum.

Q 44.9 Wed 16:30 Empore Lichthof

Towards a quantum logic based CPT test using single trapped (anti-)protons — •Teresa Meiners[1], Malte Niemann[1], Anna-Greta Paschke[1], Matthias Borchert[1], Alexander Idel[1], Johannes Mielke[1], Amado Bautista-Salvador[1,2], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Universität Hannover — [2]Physikalisch Technische Bundesanstalt, Braunschweig — [3]Ulmer Initiative Research Unit, RIKEN

We present sympathetic laser cooling and detection concepts for a CPT test based on a g-factor comparison between single protons and antiprotons in a Penning trap. Following the proposal by Heinzen and Wineland [1] the (anti-)proton can be coupled to a laser-cooled (beryllium) ion to achieve reliable preparation near the motional ground state, reducing systematic uncertainties and difficulties in state detection using the continuous Stern-Gerlach effect. Using sideband cooling techniques to the motional ground state, quantum logic spectroscopy can provide an alternative readout scheme.

We discuss ion trap geometries and state transfer schemes as well as laser systems and optical systems for loading, manipulating and detecting the atomic ion. We acknowledge funding by the ERC (ERC StG QLEDS). This project is supported by the BASE collaboration.

[1] Heinzen and Wineland, PRA 42, 2977 (1990)

Q 44.10 Wed 16:30 Empore Lichthof

Towards a nuclear clock based on ^{229}Th: Internal conversion rates for Th ions — •Pavlo Bilous and Adriana Pálffy — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg, Germany

The thorium isotope ^{229}Th bridges atomic and nuclear physics with its unique long-lived nuclear excited state with the energy of 7.8 eV [1]. The advantages of this nuclear transition are its very narrow width, the stability with respect to external perturbations and an accessible frequency within the VUV region, rendering it a candidate for a nuclear clock system. Due to the small excitation energy, typical for outer shell electron transitions, the strongest decay channel of the 7.8 eV nuclear state in a Th atom is internal conversion.

Here we carry out *ab initio* calculations of internal conversion rates for Th using multi-configurational Dirac-Fock wave functions [2] for the bound atomic electron. We consider internal conversion in atoms and ions with charge states Th^{+} and Th^{2+} and several ground and excited state configurations. These results are required for a better understanding of the decay properties of the ^{229}Th clock transition in different materials and experimental setups.

[1] B. R. Beck *et al.*, Phys. Rev. Lett. **98**, 142501 (2007).
[2] P. Jönsson *et al.*, Comput. Phys. Commun. **184**, 2197 (2013).

Q 44.11 Wed 16:30 Empore Lichthof

Search for optical excitation of the low-energy nuclear isomer of ^{229}Th — •Johannes Thielking, David-Marcel Meier, Maxim V. Okhapkin, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

Direct optical excitation of the nuclear transition between ground state and the 7.8 eV isomer in ^{229}Th is the missing link towards a study of this system as a precise nuclear clock. To excite the nuclear isomer via electronic bridge [1]/NEET processes, we use two-photon laser excitation of high-lying electronic levels in Th^{+} within the energy range from 7.3 to 8.3 eV [2,3]. We investigate the hyperfine structure of electronic levels of Th^{+} as means for detection of the isomeric state and to examine its nuclear structure. We also study a possible two-photon excitation scheme in Th^{2+} for energies higher than 8.3 eV, since this range is hardly accessible in Th^{+} because of resonantly enhanced three-photon ionisation in our experiment.

[1] S. G. Porsev et al., Phys. Rev. Lett. 105, 182501 (2010)
[2] O. A. Herrera-Sancho et al., Phys. Rev. A 85, 033402 (2012)
[3] O. A. Herrera-Sancho et al., Phys. Rev. A 88, 012512 (2013)

Q 44.12 Wed 16:30 Empore Lichthof

The g-factor of the muon bound in a nuclear potential — •Bastian Sikora, Nikolay Belov, Zoltán Harman, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

We present the theory of the g-factor of the muon bound in a nuclear potential. One-loop self-energy and vacuum polarization corrections are included, taking into account the interaction with the nuclear potential exactly. Moreover, we incorporate finite nuclear size and finite nuclear mass corrections.

The theory of the bound-muon g-factor, combined with possible future experiments involving bound muons can be used in principle to test quantum electrodynamics in stronger electric fields than possible with bound electrons. Furthermore, since contributions due to nuclear effects are large for bound muons, nuclear parameters can be determined by comparing the theoretical and experimental bound-muon g-factor.

Q 44.13 Wed 16:30 Empore Lichthof

Investigations of nuclear effects in highly charged ions — •Hendrik Bekker[1], Sebastian Kebrich[1], Kathrin Kromer[1], Andrey V. Volotka[2], Zoltán Harman[1], Christoph H. Keitel[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Helmholtz-Institut Jena

Treatment of the interaction between electrons and nucleus beyond the point-like Coulomb potential approximation leads to modification of the energy level structure of bound electrons. Nuclear properties such as its spin, magnetic moment, charge and magnetization distributions can be investigated by measuring how they affect the electronic structure of atoms and ions. Highly charged ions (HCI) belonging to the H-like isoelectronic sequence are specially suitable for this. We aim to measure the hyperfine splitting of the $^2S_{1/2}$, $F = 3-2$ ground state in H-like Pr^{58+}, which is predicted to be at approximately 847 nm.

We use the Heidelberg electron beam ion trap to produce, trap, and collisionally excite HCI. Fluorescence light in the optical domain is measured using a grating spectrometer with which a precision of 1 ppm can be reached. Using this setup we have also measured the $J = 2-3$ transition in the $3d^4$ ground term of Ti-like Pr^{37+} and Re^{53+}. The many hyperfine levels and the strong magnetic field at the trap center give rise to a complex line shape, which is accurately reproduced by theory. Additionally, we have investigated the *KLL* dielectronic recombination in He- to O-like Pr, which is an important tool for trap optimization. Current efforts are towards the efficient production and trapping of H-like Pr^{58+}.

Q 44.14 Wed 16:30 Empore Lichthof

Spectroscopy of trapped $^{138}Ba^{+}$ ions for atomic parity violation and optical clocks — •Elwin A. Dijck, Amita Mohanty, Nivedya Valappol, J. Olivier Grasdijk, Oliver Böll, Andrew T. Grier, Klaus Jungmann, Mayerlin Nuñez Portela, and Lorenz Willmann — Van Swinderen Institute, University of Groningen, The Netherlands

The heavy alkaline earth ions Ba^{+} and Ra^{+} are good candidates for a precision measurement of the weak mixing angle at low energy as well as for building an optical atomic clock. One requirement for these applications is to determine the atomic structure to percent level. We have studied the lifetime of the metastable 5d $^2D_{5/2}$ level in $^{138}Ba^{+}$ as a benchmark for theory calculations. Systematic effects are investigated by comparing multiple measurement schemes on a single and multiple trapped ions. In addition, we have measured the transition frequencies between the 6s $^2S_{1/2}$, 6d $^2P_{1/2}$ and 5d $^2D_{3/2}$ levels in $^{138}Ba^{+}$ to 100 kHz accuracy [1], improving the knowledge of these frequencies by more than two orders of magnitude.

[1] E. A. Dijck et al., Phys. Rev. A **91**, 060501(R) (2015)

Q 44.15 Wed 16:30 Empore Lichthof

Atomic Parity Violation in Ytterbium — •Anne Fabricant[1], Dionysios Antypas[2], Lykourgos Bougas[2], Nathan Leefer[2], Konstantin Tsigutkin[3], and Dmitry Budker[1,2] — [1]Johannes Gutenberg Universität-Mainz, Mainz, Germany — [2]Helmholtz Institut-Mainz, Mainz, Germany — [3]ASML, Veldhoven, The Netherlands

Atomic-parity-violation (APV) experiments enable us to probe fundamental electroweak physics at low energies on a tabletop. Ytterbium (Yb) is a good candidate for APV measurements because of its particularly strong parity-violating effects and the availability of seven stable isotopes. The previous incarnation of the experiment, at UC Berkeley, succeeded in measuring the largest APV effect ever observed. Currently we are developing a new experimental apparatus in Mainz, in order to improve the accuracy of the measurements. This will enable us to investigate neutron distributions in the nucleus (the neutron skin), as well as the anapole moment arising from the weak interaction between nucleons.

Q 44.16 Wed 16:30 Empore Lichthof

Development of a high resolution VUV grating spectrometer — •Stepan Dobrodey[1], Michael A. Blessenohl[1], Sven Bernitt[1,2], Laurent Mercadier[3], Clemens Weninger[4], Nina Rohringer[4], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]IOQ, Friedrich-Schiller-Universität, Jena, Germany — [3]Centre for Free-Electron Laser Science, Hamburg, Germany — [4]Max-Planck-Institut für Struktur und Dynamik der Materie, Hamburg, Germany

We present the design and development of a high resolution normal incidence grating spectrometer for the VUV range. First successful measurements have been carried out at the free-electron laser (FEL) FLASH in Hamburg to study the lasing activity of atomic transitions in xenon and krypton after inner-shell excitation with FEL pulses. With an achieved resolving power of 50000 this instrument will be utilized in the near future for observations of transitions in the VUV range in highly charged ions produced in an electron beam ion trap. This will allow for better understanding of astrophysical processes and tests of fundamental theories.

Q 44.17 Wed 16:30 Empore Lichthof

A superconducting resonator-driven linear radio-frequency trap for long-time storage of highly charged ions — •Julian Stark[1], Lisa Schmöger[1,2], Andrii Borodin[1], Janko Nauta[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Cold, strongly localized highly charged ions (HCIs) are particularly interesting candidates for novel frequency standards at a potential 10^{-19} level relative accuracy and searches for physics beyond the Standard Model, such as possible drifts in the value of the fine structure constant α. For sympathetic cooling of HCIs, these are simultaneously trapped with laser-cooled Be^{+} ions in a cryogenic linear radio-frequency (RF) Paul trap [1,2]. Stable localization requires a high voltage RF drive with low noise. Currently, a new RF resonator is commissioned which includes the quadrupole trapping electrodes in the cavity. The high quality factor Q of the resonator will drastically reduce Paul trap heating rates as well as improve the overall stability of the trapping conditions. This will render electrodynamical losses of trapped ions negligible and enables precise localization of HCIs which is needed for high precision laser spectroscopy.

[1] M. Schwarz et al., Rev. Sci. Instrum. 83, 083115 (2012)
[2] L. Schmöger et al., Science 347, 6227 (2015)

Q 44.18 Wed 16:30 Empore Lichthof

Line shape of frequency modulation spectroscopy of molecular iodine — •Nivedya Valappol, Amita Mohanty, Elwin A. Dijck, Oliver Böll, Klaus Jungmann, and Lorenz Willmann — Van Swinderen Institute, FMNS, University of Groningen, The Netherlands

High resolution saturated absorption spectroscopy of $^{127}I_2$ hyperfine transitions deliver a natural frequency grid in the 500 nm-900 nm range. An external-cavity diode laser system at 650 nm is stabilized to the frequency modulated absorption signal of the R(25)(6-5) transition in molecular I_2 which is 412 MHz above the $6p^2P_{1/2}$ - $5d^2D_{3/2}$ transition in Ba^{+} ions. The diode laser can be phase locked to a frequency comb which transfers the stability of the GPS disciplined Rb clock of 10^{-12} optical range. We present a well-defined line shape which permits an accurate description of the observed signals. The stability of the frequency modulated saturated spectroscopy of I_2 lines reaches a precision of kHz level. We find that the residual amplitude modulation, which is inherent in modulation spectroscopy, shifts the zero crossing of the line. The line shape model provides for accurate extraction of density shift, broadening and hyperfine splitting.

Q 44.19 Wed 16:30 Empore Lichthof

Resonant excitation of the 136 eV $2s$-$2p$ transition in Li-like Kr^{33+} at FLASH — •Sven Bernitt[1,2], Günter Brenner[3], René Steinbrügge[1], Stepan Dobrodey[1], Michael A. Blessenohl[1], André Cieluch[1], Zachary Hockenbery[1], Steffen Kühn[1], Janko Nauta[1], Miguel-Angel Sanchez[1], Sascha W. Epp[4], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]IOQ, Friedrich-Schiller-Universität, Jena, Germany — [3]DESY, Hamburg, Germany — [4]Max-Planck-Institut für Struktur und Dynamik der Materie, Hamburg, Germany

We use the transportable electron beam ion trap FLASH-EBIT to provide a target of Li-like Kr^{33+} for monochromatized VUV light from the the free-electron laser FLASH. By detecting resonantly excited fluorescence as a function of the photon energy, we were able to perform high precision spectroscopic studies of the $1s^22s$-$1s^22p$ transition at 136 eV. We reached an accuracy of 6 meV, providing an improvement by a factor of 7 over previous measurements. These results serve as a benchmark for atomic theory and help with the interpretation of VUV spectra from astrophysical and laboratory plasmas. Future work aims at investigations of nuclear size effects which currently impede the full analysis of QED experimental data of H-like systems.

Q 44.20 Wed 16:30 Empore Lichthof

Stopping of highly charged ions in laser-cooled Be^{+} Coulomb crystals — •Lisa Schmöger[1,2], Maria Schwarz[1,2], Thomas M. Baumann[1], Oscar O. Versolato[1,2], Baptist Piest[1], Thomas Pfeifer[1], Joachim Ullrich[2], Piet O. Schmidt[2,3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, QUEST, Braunschweig, Germany — [3]Leibniz Universität Hannover, Germany

Cold highly charged ions (HCIs) are promising candidates for the development of novel ultra-precise clocks and the search for possible variations of fundamental constants. However, in the laboratory HCIs are produced by energetic processes, such as electron impact ionization, leaving the trapped ensemble at translational temperatures on the order of MK. We demonstrate a versatile preparation technique for cold HCIs which are nearly at rest in space. It is based on the generic modular combination of a pulsed HCI source with a cryogenic linear Paul trap [1]. A beamline for deceleration and precooling connects both instruments. Slow HCIs, specifically Ar^{13+} ions, are injected into the linear Paul trap where they are forced to perform an oscillatory motion along the trap axis. Finally, the HCIs are stopped by damping

this motion through multiple interactions with a prestored and continuously laser-cooled Be^+ Coulomb crystal.

[1] L. Schmöger, *et al., Rev. Sci. Instrum.* **86**, 103111 (2015)

Q 44.21 Wed 16:30 Empore Lichthof

Coulomb crystallized highly charged ions for fundamental physics research — •Lisa Schmöger[1,2], Oscar O. Versolato[1,2], Maria Schwarz[1,2], Matthias Kohnen[2], Alexander Windberger[1], Baptist Piest[1], Stefanie Feuchtenbeiner[1], Jofre Pedregosa-Gutierrez[4], Tobias Leopold[2], Thomas M. Baumann[1], Michael Drewsen[5], Joachim Ullrich[1,3], Piet O. Schmidt[2,3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, QUEST, Braunschweig, Germany — [3]Leibniz Universität Hannover, Germany — [4]Aix-Marseille Université, France — [5]Aarhus University, Denmark

Production of cold, strongly localized highly charged ions (HCIs) has been an experimental challenge for two decades. We succeeded in re-trapping and sympathetically cooling HCIs [1] - produced with an electron beam ion trap - in our cryogenic radiofrequency linear Paul trap. The strongly suppressed thermal motion (mK scale) of the co-crystallized HCIs will be a great advantage for high precision laser spectroscopy of forbidden transitions in HCI. Those are particularly interesting both for fundamental research, such as searching for physics beyond the Standard Model, and for technological applications such as high accuracy atomic optical clocks. Our first test experiment will be the study of the $^2P_{3/2}$-$^2P_{1/2}$ M1 transition in Ar^{13+} at 441nm.

[1] L. Schmöger, *et al., Science* **347**, 6227 (2015)

Q 44.22 Wed 16:30 Empore Lichthof

High resolution spectroscopy in HCI using High-order Harmonic Generation — •Janko Nauta[1], Andrii Borodin[1], Peter Micke[1,2], Lisa Schmöger[1,2], Maria Schwarz[1,2], Julian Stark[1], José R. Crespo López-Urrutia[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

Highly charged ions (HCI) are atomic systems with a few tightly bound electrons. HCI exhibit much more pronounced quantum-electrodynamics effects than neutrals and singly charged particles, thus allowing accurate tests of fundamental theory to be performed, and high precision determination of values of fundamental constants. Most observations in HCI are made with ions at temperatures of more than 10^2 eV using electron-beam ion traps. Recent progress in trapping HCI in a cryogenic linear quadrupole trap, and sympathetic cooling with Be^+ ions [M. Schwarz *et al*, Rev. Sci. Inst. **83**, pp. 1-10 (2012), L. Schmöger *et al*, Science **347**, pp. 1233-1236 (2015)], opens up the possibility for high-precision laser spectroscopy. Many transitions in HCI have energies of few ten eV. So far, excitation of these transitions required the use of free-electron lasers. The aim of this project is to perform high-resolution spectroscopy of extreme ultraviolet transitions by high-order harmonics generated by femtosecond laser pulses, which are amplified by an enhancement cavity. An experimental scheme for realizing this approach will be presented.

Q 44.23 Wed 16:30 Empore Lichthof

A vibration-free cryogenic system for ion traps — Maria Schwarz[1,2], •Peter Micke[1,2], Lisa Schmöger[1,2], Tobias Leopold[2], Thomas Pfeifer[1], José R. Crespo López-Urrutia[1], and Piet O. Schmidt[2,3] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, QUEST, Braunschweig, Germany — [3]Leibniz Universität Hannover, Germany

Cold highly charged ions (HCI) can be sensitive detectors for possible small variations of fundamental constants, e.g. of the fine-structure constant on a level of 10^{-19} per year. High precision spectroscopy, such as quantum logic spectroscopy, is needed to probe the highly forbidden optical transitions in HCIs. A cryogenic environment is essential to suppress charge exchange with residual gas in order to achieve long HCI storage times. We have set up a cryogenic system based on the one of CryPTEx [1], using a pulse-tube cryocooler and nested temperature stages. In the upgraded CryPTEx-II, the cryocooler and the trap are 2 m apart, located in separate rooms for acoustic decoupling, and thermally linked by a vibration-suppression system. Mechanical vibrations due to pumps and the cryocooler are decoupled by means of edge-welded bellows, flexible ultra-pure copper links and a massive inertial pendulum.

[1] M. Schwarz *et al., Rev. Sci. Instrum.* **83**, 083115 (2012)

Q 44.24 Wed 16:30 Empore Lichthof

Polar-maXs: Micro-calorimeter based X-ray polarimeters — •Christian Schötz[1], Daniel Hengstler[1], Loredana Gastaldo[1], Sebastian Kempf[1], Andreas Fleischmann[1], Christian Enss[1], Günter Weber[2,3], and Thomas Stöhlker[2,3,4] — [1]Kirchhoff Institute for Physics, Heidelberg University — [2]Helmholtz-Institute Jena — [3]GSI Darmstadt — [4]IOQ, Jena University

We are presently developing the x-ray detector system Polar-maXs, which will combine for the first time the high energy resolution, large dynamic range and excellent linearity of magnetic micro-calorimeters with the sensitivity to polarization caused by polarization-dependent Compton or Rayleigh scattering in an array of scatterers.

Polar-maXs consists of two layers. The first layer comprises a 4 x 4 array of x-ray scatterers behind a corresponding array of collimator holes. Depending on the energy range of interest and whether Compton or Rayleigh scattering is to be used, these scatterers are fabricated from low-Z or high-Z material. The scattered x-rays are detected by an array of 576 x-ray absorbers read-out by paramagnetic temperature sensors as metallic magnetic micro-calorimeters (MMC). Each absorber covers an area of 0.5mm x 0.5mm and is made of 15 micrometer thick gold, to guarantee high stopping power for x-ray with energies up to 20 keV and an energy resolution of better than 20eV (FWHM) in the complete energy range. We discuss general design considerations as well as the results of Monte-Carlo simulations for a variety of detector designs. We present micro-fabricated devices and discuss the results of first experimental tests.