# A 34: Precision spectroscopy of atoms and ions II (with Q)

Time: Thursday 11:00–13:00 Location: f428

**Invited Talk** A 34.1 Thu 11:00 f428

**The magnetic moment of the antiproton** — •Stefan Sellner[1], Klaus Blaum[2], Matthias Borchert[3], Takashi Higuchi[1,4], Nathan Leefer[5], Yasuyuki Matsuda[4], Andreas Mooser[1], Hiroki Nagahama[1,4], Christian Ospelkaus[3], Wolfgang Quint[6], Georg Schneider[7], Christian Smorra[1,8], Toya Tanaka[4], Jochen Walz[5,7], Yasunori Yamazaki[9], and Stefan Ulmer[1] — [1]Ulmer Initiative Research Unit, RIKEN, Wako, Japan — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [4]Graduate School of Arts and Sciences, University of Tokyo, Tokyo, Japan — [5]Helmholtz-Institut Mainz, Mainz, Germany — [6]GSI-Helmholzzentrum für Schwerionenforschung, Darmstadt, Germany — [7]Institut für Physik, Johannes Gutenberg-Universität Mainz, Mainz, Germany — [8]CERN, Geneva, Switzerland — [9]Atomic Physics Laboratory, RIKEN, Wako, Japan

The Standard Model describes the fundamental interactions and properties of elementary particles. Being a Lorentz-invariant theory, the absolute values of the properties like charge, mass, and magnetic moment, of matter and antimatter-conjugates, are invariant under the combined charge, parity, and time transformation. Any violation of this CPT symmetry would indicate new physics. The BASE experiment tests this symmetry at lowest energy and with highest precision. We use an advanced multi-Penning trap system to compare charge-to-mass ratios and magnetic moments of single protons and antiprotons, respectively.

Our aimed relative precision is 1 ppb ($10^{-9}$) for the magnetic moment measurement. Last year, we succeeded in measuring the charge-to-mass ratio of the antiproton and the proton [1], confirming CPT invariance down to the atto-electron volt scale with a measurement precision of 69 parts per trillion. Next, we will focus on magnetic moment measurements.

In my talk, I will present the techniques and recent results of our measurements at BASE and give an outlook on future improvements.

[1] S. Ulmer et al, Nature 524, p. 196-199 (2015)

A 34.2 Thu 11:30 f428

**RIS studies of high-lying energy levels in erbium for the determination of the first ionization potential** — •Dominik Studer[1], Patrick Dyrauf[1], Pascal Naubereit[1], Matsui Daiki[2], and Klaus Wendt[1] — [1]Institute of Physics, Johannes Gutenberg-University Mainz — [2]Department of Physics, Nagoya University

For most lanthanides, the extremely rich atomic spectrum is not completely known and proper level identification is still a challenge. Theoretical approaches are often incapable to deconvolute the stuffed structures, as obtained from atomic spectroscopy in particular for higher excitation energies, due to missing level assignments. In addition, precise and meaningful experimental data is still lacking in that range. Correspondingly, the ionization potentials of a number of lanthanide elements were determined with an insufficient precision of a few cm$^{-1}$. Here, we report on two-step resonance ionization spectroscopy in the spectrum of erbium. The accurate measurement of energy positions of a multitude of high-lying Rydberg-states in the range of principal quantum number $15 < n < 60$ was performed. To account for perturbations of the observed Rydberg-series from interloper states, an extension of the conventional Rydberg-Ritz formalism is required for a correct description of the observed s, d and g series. It allows for a determination of the ionization potential with a precision of better than 0,1 cm$^{-1}$. This talk presents the spectroscopic data and discusses the analysis of the Rydberg-series comparing two different approaches for the evaluation of perturbed Rydberg-series.

A 34.3 Thu 11:45 f428

**Laser spectroscopy of the element Nobelium** — •Felix Lautenschläger for the RADRIS Collaboration — Technische Universität Darmstadt

Laser spectroscopy is one of the most powerful tools to investigate the atomic properties of transfermium elements (Z≥100). In particular, finding atomic levels in such elements allows to benchmark theoretical predictions and to understand the influence of relativistic- and QED-effects on their shell structure. To this end, we employ the Radiation Detected Resonance Ionisation Spectroscopy (RADRIS) [1]. The latter method is well suited to reveal the atomic properties of such elements, which can be only artificially produced in a complete fusion reaction at on-line facilities such as GSI in Darmstadt.

In my talk I will introduce this technique and report on laser spectroscopy of the element nobelium (Z=102).

[1]: H.Backe et al., Eur. Phys. J. D 45, 99-106 (2007).

A 34.4 Thu 12:00 f428

**Mass measurements of neutron-rich copper isotopes and technical developments at ISOLTRAP** — •Andree Welker[1] and ISOLTRAP Collaboration[2] — [1]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, 01069 Dresden, Germany — [2]CERN

We present very recent results from ISOLTRAP [1] measurements of neutron rich copper isotopes, where - with the help of the multi-reflection time-of-flight mass spectrometer (MR-ToF) [2] - $^{79}$Cu was reached for the first time. With the gained knowledge of the copper binding energies, which are a really sensitive probe for the evolution of shell structure, we are only one proton above the $Z = 28$ core, close to the doubly-magic $^{78}$Ni isotope. These measurements belong to an extended ISOLTRAP campaign on very neutron-rich nuclides for nuclear-structure and astrophysical cases. To be able to reach out even further exotic nuclides at very high precision, a position-sensitive ion detector was installed behind the precision Penning trap. This major step will allow the application of the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) [3] method, which was developed at SHIPTRAP/GSI. The new technique offers higher precision in less measurement time as well as a much higher resolving power, and thus the ability to resolve low-lying isomers, compared to the present Time-of-Flight Ion-Cyclotron-Resonance (ToF-ICR) technique [4]. The current status and an outlook on the implementation of the PI-ICR technique at ISOLTRAP will be presented.

A 34.5 Thu 12:15 f428

**The high-precision Penning-trap mass spectrometer PENTATRAP** — •Alexander Rischka[1], Hendrik Bekker[1], Christine Böhm[1], José Ramón Crespo López-Urrutia[1], Andreas Dörr[1], Sergey Eliseev[1], Mikhail Goncharov[1], Pavel Filianin[1], Yuri Novikov[2], Rima Schüssler[1,3], Sven Sturm[1], Stefan Ulmer[4], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Petersburg Nuclear Physics Institute, 188300 Gatchina, Russia — [3]Universität Heidelberg, Fakultät für Physik und Astronomie, 69120 Heidelberg, Germany — [4]RIKEN, Ulmer Initiative Research Unit, Japan

The Penning-trap mass spectrometer PENTATRAP is currently in the commissioning phase at the Max-Planck-Institute for Nuclear Physics in Heidelberg. We are aiming at measurements of mass ratios using highly charged ions with a relative uncertainty of better than $10^{-11}$. This allows, among others, contributions to neutrino physics research by a sub-eV measurement of the $Q$-value of $^{163}$Ho/$^{163}$Dy. Furthermore, for a precision test of the energy-mass equivalence $E = mc^2$ and thus of special relativity, the $Q$-value of $^{35}$Cl/$^{36}$Cl and the sum of energies of the gamma-rays emitted after the neutron capture in $^{35}$Cl are needed. Former one will be measured at PENTATRAP and the latter one at ILL Grenoble. To reach trapping times of weeks for the highly charged ions and to perform a full characterization of the Penning-trap system in order to start first precision measurements, a major revision of the cryogenic setup and the ion transfer beamline is presently prepared and will be commissioned soon.

A 34.6 Thu 12:30 f428

**A large array of microcalorimeters for high-precision X-ray spectroscopy** — •Pascal Scholz[1], Victor Andrianov[2], and Saskia Kraft-Bermuth[1] — [1]Justus-Liebig-Universität, Gießen, Germany — [2]Lomonosov Moscow State University, Moscow, Russia

High-precision X-ray spectroscopy of highly-charged heavy ions, commonly performed at storage rings, provides a sensitive test of quantum electrodynamics. Silicon microcalorimeters, which detect the X-ray energy as heat rather than by charge production, have already demonstrated their potential to improve the precision of such experiments due to their excellent energy resolution for X-ray energies around 100 keV.

To improve their performance with respect to statistical as well as systematic uncertainties, a large array of silicon microcalorimeters for high-precision X-ray spectroscopy, especially optimized for experiments at storage rings, has now been designed. With an active area of about 100 mm$^2$, it will be the largest microcalorimeter array currently available for storage ring experiments. In addition, the large dynamic range will allow the intrinsic determination of the Doppler correction, which is a prominent source of systematic uncertainty in such experiments. The presentation will introduce the detection principle, present the new detector design as well as first tests of performance, and discuss potential applications.

A 34.7 Thu 12:45 f428

**Precise high voltage measurements based on laser spectroscopy** — •Kristian König, Phillip Imgram, Jörg Krämer, Bernhard Maass, Tim Ratajczyk, 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.

The setup consists of an ion source that provides $^{40}\mathrm{Ca}^+$ ions and an acceleration region between two chambers of which one is equipped with a fluorescence detection. The well-known $4s_{1/2} \rightarrow 4p_{3/2}$ and the $3d_{3/2} \rightarrow 4p_{3/2}$ transitions are used to identify the ion velocities before and after acceleration based on the Doppler shift as proposed in [2]. In order to obtain the targeted accuracy, precise control and knowledge of the ion beam properties is required. We present the current status of the experiment.

[1] O. Poulsen, Nucl. Instr. Meth. Phys. Res. 202 (1982) 503.

[2] S. Götte, et al., Rev. Sci. Instrum. 75 (2004) 1039.