A 9: Precision Spectrosocopy II - trapped ions (joint session A/Q)

Time: Monday 14:00–15:45 Location: K 1.016

Invited Talk A 9.1 Mon 14:00 K 1.016

A ppb measurement of the antiproton magnetic moment — •C. Smorra[1], S. Sellner[1], M. Borchert[1,2], J. A. Harrington[3], T. Higuchi[1,4], H. Nagahama[1], A. Mooser[1], G. Schneider[1,5], M. Bohman[1,3], K. Blaum[3], Y. Matsuda[4], C. Ospelkaus[2,6], W. Quint[7], J. Walz[5,8], Y. Yamazaki[1], and S. Ulmer[1] — [1]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Saitama, Japan — [2]Leibniz Universität, Hannover, Germany — [3]Max-Planck Institute für Kernphysik, Heidelberg, Germany — [4]University of Tokyo, Tokyo, Japan — [5]Johannes Gutenberg-Universität, Mainz, Germany — [6]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [7]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [8]Helmholtz-Institut Mainz, Mainz, Germany

The BASE collaboration performs high-precision measurements of the fundamental properties of protons and antiprotons in a multi Penning-trap system. Such measurements challenge the Standard Model of particle physics, since any deviation in proton and antiproton properties would hint to yet unknown CPT-odd interactions that would act differently on matter and antimatter-conjugates.

We recently reported a measurement of the antiproton magnetic moment with 1.5 ppb uncertainty (68 % C.L.) based on the frequency ratio of the Larmor frequency to the cyclotron frequency measured with two single antiprotons. We apply a novel two-particle multi-trap scheme, which enhances the data accumulation rate compared to the double trap method. In this way, we improved limits on CPT-odd interactions on antiprotons by a factor 350.

Invited Talk A 9.2 Mon 14:30 K 1.016

Towards laser cooling of atomic anions — •Alban Kellerbauer — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

Currently available cooling techniques for negatively charged particles allow cooling only to the temperature of the surrounding environment, typically a few kelvin. Laser cooling of atomic anions could be used to produce an ensemble of negative particles at microkelvin temperatures. These could sympathetically cool any species of negatively charged particles – from antiprotons to molecular anions – to ultracold temperatures. For this indirect cooling technique [1], a fast electronic transition is required. Until now, there are only three known atomic anions with bound–bound electric-dipole transitions. We have investigated these transitions in Os^- [2] and La^- [3] by high-resolution laser spectroscopy to test their suitability for laser cooling. The principle of the method, its potential applications, as well as recent experimental results will be presented.

[1] A. Kellerbauer & J. Walz, "A novel cooling scheme for antiprotons". New J. Phys. **8** (2006) 45. doi:10.1088/1367-2630/8/3/045.

[2] U. Warring *et al.*, "High-resolution laser spectroscopy on the negative osmium ion". Phys. Rev. Lett. **102** (2009) 043001. doi:10.1103/PhysRevLett.102.043001.

[3] E. Jordan *et al.*, "High-resolution spectroscopy on the laser-cooling candidate La^-". Phys. Rev. Lett. **115** (2015) 113001. doi:10.1103/PhysRevLett.115.113001.

A 9.3 Mon 15:00 K 1.016

Towards Sympathetic Cooling of a Single Proton in a Penning Trap for a High-Precision Measurement of the Proton Magnetic Moment — •Markus Wiesinger[1,2], Matthew Bohman[1,2], Andreas Mooser[2], Georg Schneider[2,3], Natalie Schön[2,3,4], James Harrington[1], Takashi Higuchi[2,5], Stefan Sellner[2], Christian Smorra[2,7], Klaus Blaum[1], Yasuyuki Matsuda[5], Wolfgang Quint[6], Jochen Walz[3,4], and Stefan Ulmer[2] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Ulmer Fundamental Symmetries Laboratory, RIKEN, Wako, Japan — [3]Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany — [4]Helmholtz-Institut Mainz, Mainz, Germany — [5]Graduate School of Arts and Sciences, University of Tokyo, Tokyo, Japan — [6]GSI-Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [7]CERN, Geneva, Switzerland

Precise comparisons of the fundamental properties of protons and antiprotons, such as magnetic moments and charge-to-mass ratios, provide stringent tests of CPT invariance, and thus, matter-antimatter symmetry. Using advanced Penning-trap methods, we have recently determined the magnetic moments of the proton and the antiproton with fractional precisions on the p.p.b. level [1,2].

Both experiments rely on sub-thermal cooling of the particle's modified cyclotron mode using feedback-cooled tuned circuits. This time-consuming process is ultimately required to identify single spin quantum transitions with high detection fidelity, which is a major prerequisite to apply multi-trap methods.

In order to advance our techniques and to drastically reduce the measurement time, we are currently implementing methods to sympathetically cool protons and antiprotons by coupling them to laser-cooled beryllium ions, using a common endcap method [3]. In this talk we present the status of our ongoing efforts to deterministically prepare single protons and antiprotons at mK-temperatures.

[1] Schneider, G. *et al.* Science **358**, 1081 (2017)

[2] Smorra, C. *et al.* Nature **550**, 371 (2017)

[3] Heinzen, D. J. & Wineland, D. J. Phys. Rev. A, **42**, 2977 (1990)

A 9.4 Mon 15:15 K 1.016

Resonant coupling of single protons and laser cooled Be ions — •Natalie Schön[1,2,7], Matthew Bohman[2,3], Andreas Mooser[2], Georg Schneider[1,2], Markus Wiesinger[2,3], James Harrington[3], Takashi Higuchi[2,4], Stefan Sellner[2], Christian Smorra[2,5], Klaus Blaum[3], Yasuyuki Matsuda[4], Wolfgang Quint[6], Jochen Walz[1,7], and Stefan Ulmer[2] — [1]University of Mainz, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, Japan — [3]MPIK Heidelberg, Germany — [4]University of Tokyo, Japan — [5]CERN, Switzerland — [6]GSI Darmstadt, Germany — [7]Helmholtz Institut Mainz, Germany

The relativistic quantum field theories of the Standard Model are invariant under the combined charge (C), parity (P) and time (T) transformation. To test this fundamental symmetry the BASE collaboration compares the g-factor and charge to mass ratio of protons and antiprotons with highest precision. Using Penning traps, we have recently performed 0.3 ppb and 1.5 ppb measurements of the proton and the antiproton g-factors, respectively. The uncertainties in the g-factor values are dominated by effects due to the energy of the trapped particle at 4 K. To overcome this limitation, we plan to resonantly couple the axial modes of laser cooled beryllium ions and of single (anti)protons. To match the axial frequencies a resonant circuit is used, which however heats the particles. Thus, after frequency matching, the resonant circuit will be decoupled from the ions by switching its resonance frequency. To this end several switches, with high isolation resistance and low insertion loss, were tested at cryogenic temperatures.

A 9.5 Mon 15:30 K 1.016

Measurements with single antiprotons in an ultra-low noise Penning trap system — •Matthias Borchert[1,2], James Harrington[3], Takashi Higuchi[2,4], Jonathan Morgner[1,2], Hiroki Nagahama[2], Stefan Sellner[2], Christian Smorra[2], Matthew Bohman[2,3], Andreas Mooser[2], Georg Schneider[2,5], Natalie Schoen[5], Markus Wiesinger[2,3], Klaus Blaum[3], Yasuyuki Matsuda[4], Christian Ospelkaus[1,6], Wolfgang Quint[7], Jochen Walz[5,8], Yasunori Yamazaki[2], and Stefan Ulmer[2] — [1]Institut für Quantenoptik, Leibniz Univeristät Hannover, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Japan — [3]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [4]Graduate School of Arts and Sciences, University of Tokyo, Japan — [5]Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany — [6]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [7]GSI - Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [8]Helmholtz-Institut Mainz, Germany

The observed baryon asymmetry in our Universe challenges the Standard Model of particle physics and motivates sensitive tests of CPT invariance. Inspired by that, the BASE experiment at CERN compares the fundamental properties of antiprotons and protons with high precision.

In 2014 we performed the most precise measurement of the antiproton charge-to-mass-ratio $q_{\bar{p}}/m_{\bar{p}}$ [1], with a fractional precision of 69 ppt. Very recently we reported on a 350-fold improved measurement of the antiproton magnetic moment $\mu_{\bar{p}}$ [2] using a newly-invented multi-Penning trap method. The high-precision measurement of $\mu_{\bar{p}}$ was enabled by a highly-stabilised experimental apparatus including ultra-low electric field fluctuations.

In this talk I will focus on the characterisation and optimisation of electric field noise and the interpretation of heating rates at different radial amplitudes causing axial frequency fluctuations. The optimised Penning trap heating rates measured in BASE are well below the heating rates which are usually reported in Paul traps. Furthermore, I will summarize recent experimental developments and discuss future prospects of BASE.

[1] Ulmer et al., *Nature* **524**, 196-199 (2015)
[2] Smorra et al., *Nature* **550**, 371-374 (2017)