MS 1: Precision Mass Spectrometry I

Time: Monday 11:00–13:00 Location: f128

Invited Talk MS 1.1 Mon 11:00 f128

Precision Mass Measurements on light Nuclei: The Deuteron's Atomic Mass — •Sascha Rau — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

The rest masses of many light nuclei, e.g. the proton, deuteron, triton and helion are of great importance for testing our current understanding of physics as well as in metrology. One example is the mass difference of triton and helion [1], which is used for systematic studies in the determination of $m(\bar{\nu}_e)$ in the KATRIN experiment. However, the relatively large ratio of kinetic energies compared to the low rest masses makes measuring light ions especially challenging. Recently discussed discrepancies in light ion mass measurements, carried out at different mass spectrometers and sometimes termed "light ion mass puzzle", give further motivation for independent measurements.

In the contribution the present progress and results of LIONTRAP (Light ION TRAP) [2] will be presented, an ion trap setup dedicated to high-precision mass measurements of light ions. We recently measured the proton's atomic mass by comparing the cyclotron frequencies of a single proton and a bare carbon nucleus, achieving a relative mass uncertainty of 3.2×10^{-11}. Compared to the CODATA-2014 value our result is a factor of three more precise and reveals a 3σ deviation.

After upgrading the experiment we are currently measuring the deuteron's atomic mass. These upgrades and the current status of the deuteron measurement campaign will be presented.

[1] E.G. Myers *et al.* Phys. Rev. Lett. **114**, 013003 (2015)
[2] F. Heiße *et al.* Phys. Rev. A **100**, 022518 (2019)

MS 1.2 Mon 11:30 f128

Systematic effects of high-precision mass measurements at Pentatrap — •Kathrin Kromer, Menno Door, Sergey Eliseev, Pavel Filianin, Wenjia Huang, Charlotte M. König, Alexander Rischka, Rima X. Schüssler, Christoph Schweiger, and Klaus Blaum — Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Pentatrap [1] is a high-precision Penning-trap mass spectrometer featuring a stack of five Penning traps and determining mass-ratios with a relative uncertainty of below 10^{-11}. Mass-ratio determinations of stable and long-lived highly charged ions at this level have numerous applications, among others, in neutrino physics [2] and tests of special relativity [3]. Systematic uncertainties include electric and magnetic field anharmonicities and missalignments as well as fluctuating environmental parameters like external magnetic fields, pressure, and temperature. The systematic uncertainties stemming from environmental influences are measured in order to find possible correlations to fluctuations in the cyclotron frequency of the trapped highly charged ions. Stabilization systems have been tested and have shown improvements, e.g. the active stabilization of the liquid-helium level and the pressure in the magnet's cold bore, resulting in Pentatrap's first mass-ratio measurement with a relative uncertainty of $1 \cdot 10^{-11}$.

[1] Repp, J. et al., Appl. Phys. B 107, 983 (2012)
[2] Gastaldo, L. et al., Eur. Phys. J. ST 226, 1623 (2017)
[3] Rainville, S. et al., Nature 438, 1096 (2005)

MS 1.3 Mon 11:45 f128

Towards an improved measurement of the antiproton *g*-factor — •Stefan Erlewein[1,2,3], Matthias Borchert[1,4], Jack Devlin[1,3], Markus Fleck[1,3], James Harrington[1,2], Motoki Sato[1,5], Jan Warncke[1,4], Elise Wursten[1,3], Matthew Bohman[1,2], Christian Smorra[1], Markus Wiesinger[1,2], Christian Will[1,2], Klaus Blaum[2], Yasuyuki Matsuda[5], Christian Ospelkaus[4,7], Wolfgang Quint[6], Jochen Walz[8,9], Yasunori Yamazaki[1], and Stefan Ulmer[1] — [1]RIKEN, Ulmer Fundamental Symmetries Laboratory, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117, Heidelberg, Germany — [3]CERN, Esplanade des Particules 1, 1217 Meyrin, Switzerland — [4]Institut für Quantenoptik, Leibniz Universität, Welfengarten 1, D-30167 Hannover, Germany — [5]Graduate School of Arts and Sciences, University of Tokyo, 3-8-1 Komaba, Meguro, Tokyo 153-0041, Japan — [6]GSI-Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, D-64291 Darmstadt, Germany — [7]Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany — [8]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität, Staudingerweg 18, D-55128 Mainz, Germany — [9]Institut für Physik, Johannes Gutenberg-Universität, Staudinger Weg 7, D-55128 Mainz, Germany

The BASE experiment, located at CERN's Antiproton Decelerator (AD) facility, measures the fundamental properties of protons and antiprotons in order to test CPT symmetry with high precision. In 2015, the first ever non-destructive observation of spin flips with a single trapped antiproton was demonstrated, allowing the measurement of the antiproton's magnetic moment to a fractional precision of 1.5 parts-per-billion (p.p.b.), which improved previous results by about a factor of 3000.

In my talk, I will give an overview of the BASE experiment and discuss limitations of the 1.5 p.p.b. measurement of the antiproton's magnetic moment. I will present a new technique for the detection of a single trapped antiproton's spinstate, which will allow for measurements at increased sampling rate. The application of this scheme and the introduction of additional experiment upgrades will enable an antiproton *g*-factor measurement with a fractional uncertainty of 100 p.p.t. on the short term.

MS 1.4 Mon 12:00 f128

Reduction of Measurement Uncertainty in MC-ICP-MS: A Precondition for the Dissemination of the SI Units Kilogram and Mole — •Axel Pramann and Olaf Rienitz — Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

After the revision of the SI units in 2019, one of the two main methods to realize and disseminate the kilogram and mole is the the X-ray-crystal-density (XRCD) method [1-3]. Here, silicon atoms in a silicon sphere are counted combining the measurements of the volume, the lattice parameter, the surface condition, and the isotopic composition using the fixed Avogadro constant. A key experiment uses high resolution multicollector inductively coupled plasma mass spectrometry (HR-MC-ICP-MS) to measure isotope ratios in natural and in 28Si enriched silicon to determine the respective molar mass (M) [4]. It is shown how the measurement uncertainty of the isotope ratios according to the *Guide to the Expression of Uncertainty in Measurement* influences the results and how this has been, is, and will be treated in the near future combining established and new experimental techniques with special emphasis on the mass resolution of the mass spectrometer. The target uncertainty is u(M) < 5 x 10-9 in case of enriched silicon and u(M) < 5 x 10-6 for natural silicon.

[1] K. Fujii et al., Metrologia, 53, A19 (2016). [2] D. Knopf et al., Metrologia, 56, 024003 (2019). [3] B. Güttler, O. Rienitz, A. Pramann, Annalen der Physik, 1800292 (2018). [4] A. Pramann, T. Narukawa, O. Rienitz, Metrologia, 54, 738 (2017).

MS 1.5 Mon 12:15 f128

Development of an electronic detectionmethod for FT-ICR-MS — •Sven Böhland[1], Steffen Lohse[1,2], Michael Block[1,2,3], Joaquín Berrocal[4], Gabriel Ramirez[5], and Daniel Rodríguez[4] — [1]JGU, Mainz — [2]HI Mainz — [3]GSI, Darmstadt — [4]Universidad de Granada — [5]Seven Solutions S.L., Granada

The existance of superheavy elements ($Z \geq 104$) stems from an enhanced stability as a result of nuclear shell effects. High-precision Penning trap mass spectrometry provides the nuclear binding energies of these elements. This will help constraining theoretical predictions of nuclear models, and in particular for the so-called Island of Stability, a region of relatively long-lived nuclides expected around $Z = 114 - 126$ and $N = 184$. Production rates for superheavy elements are exceptionally low, which requires the highest level of efficency and sensitivity. In recent years the cutting edge technique for mass spectrometry on single ions is the Fourier-Transform Ion-Cyclotron-Resonance method (FT-ICR). The outstanding performance has been shown in several experiments, pushing the border of precision beyond 10^{-10} for single ions of select stable nuclides. All these experiments have relied on a LC tank circuit formed by the capacity of the Penning trap electrode connected to a superconducting coil and only very recently, a novel quartz amplifier has been built and used for the first time with stored $^{40}Ca^{+}$-ions. Following the first tests, the amplifier has been characterized using the heavier $^{207}Pb^{+}$-ions. The results pave the way to measurements on super heavy elements.

MS 1.6 Mon 12:30 f128

Development of a Helium-3 source for the LIONTRAP experiment — •Sangeetha Sasidharan[1], Sascha Rau[1], Fabian Heisse[1], Florian Köhler-Langes[1], Wolfgang Quint[2], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

High-precision mass measurements of light atomic nuclei enable sensitive tests of fundamental physics. An ultra-precise measurement of the mass difference of ^{3}He and ^{3}T [1] will provide an important input parameter for the determination of the electron anti-neutrino mass with the KATRIN experiment [2]. At the LIONTRAP Penning-trap experiment we have measured the atomic mass of the proton with a relative uncertainty of 3×10^{-11} [3]. With the deuteron mass being measured at present to even higher precision, the next step will be a measurement of the ^{3}He mass. The LIONTRAP has a hermetically sealed trap chamber, which together with cryopumping results in a vacuum better than 10^{-16} mbar. However, this creates the necessity of an in-situ ion production method. Creating an in-situ ^{3}He source is a challenge due to the weak bonding capability of helium. The method being investigated for this is the use of activated charcoal as an adsorption agent. In this talk the current status will be discussed.

[1] E.G. Myers *et al.* Phys. Rev. Lett. **114**, 013003 (2015)
[2] M. Aker *et al.* Phys. Rev. Lett. **123**, 221802 (2019)
[3] F. Heiße *et al.* Phys. Rev. A **100**, 022518 (2019)

MS 1.7 Mon 12:45 f128

Optimizations of the laser ablation ion source at the SHIPTRAP setup — •Brankica Andelić[1,2], Michael Block[2,3,4], Pierre Chauveau[2,3], Premaditya Chhetri[2,3], Julia Even[1], Francesca Giacoppo[2,3], Nasser Kalantar-Nayestanaki[1], Oliver Kaleja[2,3,5], Sebastian Raeder[2,3], and Fabian Schneider[2,3] — [1]University of Groningen — [2]HI Mainz — [3]GSI Darmstadt — [4]JG University Mainz — [5]MPIK Heidelberg

The SHIPTRAP mass spectrometer allows direct high-precision ion-mass measurements that reveal detailed information on the evolution of the nuclear shell structure of heavy exotic nuclei as well as the decay probability of nuclides relevant in stellar nucleosynthesis and neutrino physics. In addition to online experiments, mass measurements that involve the offline production of ions using a laser ablation ion source are being performed.

To study long-lived rare and radioactive isotopes we have to cope with small sample sizes. Therefore, an efficient ion production and injection into the double Penning-trap system as narrow bunches of few ions are crucial. A gas-filled miniature Radio-Frequency Quadrupole (mini-RFQ) was recently implemented into the SHIPTRAP ion source to thermalize the laser-ablated ions and thus improve the production efficiency as well as the sample preparation. In addition, the laser ablation ion source is important also for the online measurements since it provides reference ions of suitable mass-over-charge ratio for magnetic field calibration. In this contribution, the performance of the recently improved laser ablation ion source will be presented.