MS 1: Precision Mass Measurements I

Time: Monday 10:45–12:45 Location: H3

Invited Talk MS 1.1 Mon 10:45 H3
Precision Mass Measurements on Light Nuclei: The Deuteron's Atomic Mass — •Sascha Rau — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, Heidelberg

The rest masses of many light nuclei, e.g. the proton and the deuteron are of great importance for testing our current understanding of physics as well as in metrology. 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. Here I present progress and results of LIONTRAP (Light ION TRAP) [1], an ion trap setup dedicated to high-precision mass measurements of light ions, which has been constructed in an MPIK-GSI-University of Mainz collaboration. We recently measured the deuteron's atomic mass by comparing the cyclotron frequencies of a single deuteron and a bare carbon nucleus, achieving a relative mass uncertainty of 8.5×10^{-12}, a factor of 2.4 more precise than the CODATA-2014 value, and revealing a 4.8σ deviation with respect to this value [2]. Together with the LIONTRAP mass measurements of the proton [1] and the HD^+ molecular ion [2], as well as a measurement of the deuteron-to-proton mass ratio [3], this allows to determine the masses of the lightest nuclei with unprecedented precision. In this talk I will present these measurements and compare them with recent results from the spectroscopy of ro-vibrational states in HD^+.

[1] F. Heiße *et al.*, Phys. Rev. A **100**, 022518 (2019)
[2] S. Rau *et al.* Nature **585**, p. 43-47 (2020)
[3] D. J. Fink & E. G. Myers, Phys. Rev. Lett. **124**, 013001 (2020)

MS 1.2 Mon 11:15 H3
Latest results of high-precision mass measurements with Pentatrap — •Kathrin Kromer[1], José Ramon Crespo López-Urrutia[1], Menno Door[1], Sergey Eliseev[1], Pavel Filianin[1], Jost Herkenhoff[1,3], Wenjia Huang[4], Daniel Lange[1,3], Yuri Novikov[2], Alexander Rischka[1], Rima Xenia Schüssler[1], Christoph Schweiger[1], Sven Sturm[1], Stefan Ulmer[5], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Petersburg Nuclear Physics Institute, Gatchina, Russia — [3]Ruprecht-Karls-Universität Heidelberg, 69117 Heidelberg — [4]Advanced Energy Science and Technology Guangdong Laboratory, Huizhou 516003, China — [5]Ulmer Fundamental Symmetries Laboratory, RIKEN, Wako, Saitama 351-0198, Japan

The high-precision Penning-trap mass spectrometer Pentatrap[1] features a stack of five Penning traps and determines mass-ratios with a relative uncertainty below 10^{-11}. Mass-ratio determinations of stable and long-lived highly charged ions have numerous applications, among others, in neutrino physics [2] and the search of possible clock transitions in highly charged ions (HCI)[3]. The unique features of Pentatrap include access to HCI, a stablilized 7 T magnet, and a cryogenic detection system with single ion phase sensitivity. This is achieved by Fourier Transform Ion Cyclotron Resonance (FT-ICR) detection of the image-current induced in the trap electrodes. The latest measurements include the Q value of the β-decay of ^{163}Ho with a relative uncertainty of below $7 \cdot 10^{-12}$ and the mass of ^{208}Pb. In lead a long-lived metastable electronic state was discovered.

[1] J. Repp, *et al.*, Appl. Phys. B **107** (2012) 983
[2] J. Gastaldo, *et al.*, Appl. Phys. B **226** (2017) 1623
[3] M.G. Kozlov, *et al.*, Rev. Mod. Phys. **90** (2018)

MS 1.3 Mon 11:30 H3
The transportable antiproton trap BASE-STEP — •Christian Smorra[1], Fatma Abbass[1], Matthew Bohman[2,3], Daniel Popper[1], Ron Moller[1], Markus Wiesinger[2,3], Christian Will[2,3], Jack Devlin[2,4], Stefan Erlewein[2,4], Markus Fleck[2,5], Julia Jaeger[2,3], Barbara Latacz[2], Peter Micke[2,4], Elise Wursten[2,4], Klaus Blaum[3], Yasuyuki Matsuda[5], Christian Ospelkaus[6,7], Wolfgang Quint[8], Anna Soter[9], Jochen Walz[1,10], Yasunori Yamazaki[2], and Stefan Ulmer[2] — [1]Johannes Gutenberg-Universität, Mainz, Germany — [2]RIKEN, Wako-shi, Japan — [3]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [4]CERN, Geneva, Switzerland — [5]University of Tokyo, Japan — [6]Leibniz Universität Hannover, Germany — [7]PTB Braunschweig, Germany — [8]GSI, Darmstadt, Germany — [9]ETH Zürich, Switzerland — [10]Helmholtz Institute Mainz, Germany

High-precision comparisons of the proton's and antiproton's charge-to-mass ratios and magnetic moments constitute stringent tests of CPT invariance, one of the cornerstones in the Standard Model of particle physics. The BASE collaboration has advanced these tests by precision measurements on single trapped antiprotons in a multi-Penning trap system in the antiproton decelerator hall at CERN, where magnetic field noise from the facility operation have become a major concern. To further advance the precision, we have designed the transportable antiproton trap BASE-STEP to relocate antiproton precision measurements into other laboratories. I will present a design report and the status of the project.

MS 1.4 Mon 11:45 H3
Transportable Cryostat and Permanent Magnet Trap for STEP — •Daniel Popper[1], Fatma Abbas[1], Matthew Bohman[1,2], Steffen Gavranovic[1], Cristina Ibanez[1], Ron Moller[1], Samuel Ruhl[1], Markus Wiesinger[2,3], Christian Will[2], Jack Devlin[3,4], Stefan Erlewein[3,4], Markus Fleck[3,5], Julia Jaeger[2,3], Barbara Latacz[2], Peter Micke[3,4], Elise Wursten[3,4], Klaus Blaum[2], Yasuyuki Matsuda[5], Christian Ospelplaus[7,8], Wolfgang Quint[6], Jochen Walz[1,9], Stefan Ulmer[3], and Christian Smorra[1,3] — [1]Johannes Gutenberg University, Mainz, Germany — [2]Max-Plank-Institute for Nuclear Physics, Heidelberg, Germany — [3]RIKEN, Wako-shi, Japan — [4]CERN, 1211 Geneva, Switzerland — [5]University of Tokyo, Japan — [6]GSI, Darmstadt, Germany — [7]Leibniz Universität Hannover, Germany — [8]PTB, Braunschweig, Germany — [9]Helmholtz-Institut Mainz, Germany

STE$\bar{P}$, "Symmetry Tests in Experiments with Portable Antiprotons", is an addition to the BASE experiment. To enable antiproton measurements with improved precision, future measurements need to be conducted outside of the "Antiproton Decelerator" hall to circumvent limitations by magnetic field fluctuations. For this, we designed a transportable cryostat, a pulse-tube cooler and liquid helium tank to cool a Penning trap system down to 4K during transportation and periods were no power is available. Also a permanent magnet system will be used as an alternative approach to using a superconducting magnet to trap the particles. I will present and characterize the set-up of the transportable cryostat and the permanent magnet system.

MS 1.5 Mon 12:00 H3
An Accumulation Radio-Frequency Quadruple Cooler-Buncher for the PUMA Offline Ion Source — •Clara Klink[1], Frank Wienholtz[1], Carina Kanitz[2], Stephan Melbrunot[2], Markus Kristian Vilen[2], and Simon Lechner[2] — [1]TU Darmstadt, 64289 Darmstadt, Deutschland — [2]CERN, 1211 Meyrin, Schweiz

The antiProton Unstable Matter Annihilation (PUMA) experiment plans to utilise antiprotons to further characterise stable as well as radioactive nuclei. Antiprotons will be used to specify the isospin composition of the nuclei by analysing the reaction products of an antiproton-nucleon annihilation. Inter alia, PUMA plans on performing experiments with low-energy antiprotons from the ELENA facility of CERN with a broad range of stable isotopes from an offline ion source to observe their behaviour during antiprotonic annihilation. For a successful operation of PUMA a high event rate with a high-purity ion beam is crucial, to clearly differentiate from background annihilations, thus the offline ion source beamline must meet several requirements to transport and shape the ion beam. The purification of the ion beam is done with a multi-reflection time-of-flight mass spectrometer. For achieving a sufficiently high event rate and prevent the production of secondary particles in the experimental zone, the ion beam will be accumulated, bunched and buffer gas cooled in an RFQ. This talk will give an introduction on the principle of operation for the PUMA RFQ. The requirements for the RFQ will be defined and an overview of the PUMA offline ion source beamline is given.

MS 1.6 Mon 12:15 H3
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, Bundesallee 100, 38116 Braunschweig, Germany

After the revision of the SI units in May 2019, one of the two methods to realize and disseminate the kilogram and mole is the the X-ray-crystal-density (XRCD) method (1-2). Here, silicon atoms in a silicon sphere are *counted* combining the measurements of the volume, the lattice parameter, the surface properties, 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) (3). 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 when using natural or enriched silicon and how this has been, is, and will be treated in the near future combining established and new experimental techniques (4).

(1) K. Fujii et al., Metrologia, 53, A19 (2016). (2) B. Guettler, O. Rienitz, A. Pramann, Annalen der Physik, 1800292 (2018). (3) A. Pramann, T. Narukawa, O. Rienitz, Metrologia, 54, 738 (2017). (4) A. Pramann, J. Vogl, O. Rienitz, MAPAN J. Metrol. Soc. I, 35, 499 (2020).

MS 1.7 Mon 12:30 H3

Development and Characterization of a Multi-Reflection Time-of-Flight Mass Separator (MR-ToF MS) for the Offline Ion Source of PUMA — •Moritz Schlaich and Frank Wienholtz — TU Darmstadt, Darmstadt, Deutschland

The antiProton Unstable Matter Annihilation (PUMA) project aims at investigating the nucleon composition in the matter density tail of short-lived as well as stable isotopes by studying antiproton-nucleon annihilation processes. For this purpose, low-energy antiprotons provided by the Extra Low Energy Antiproton (ELENA) facility at CERN will be trapped together with the ions under investigation. While the unstable ions will be supplied by the Isotope mass Separator On-Line DEvice (ISOLDE) at CERN, the stable ions are taken from an offline ion source that should be able to provide a cooled and bunched as well as isotopically pure ion beam. It is used by means of comparison with known isotopes to benchmark the antiproton nuclear annihilation process as well as for development and reference measurements at ELENA. The ion source contains a radio-frequency quadrupole cooler-buncher for ion accumulation and bunching. To purify the beam, an MR-ToF MS will be used. The talk will give an overview of the working principle and the design of the MR-ToF MS for the PUMA offline ion source.