MS 1: Penning-Trap Mass Spectrometry

Time: Monday 14:00–16:00 Location: MS-H9

Invited Talk MS 1.1 Mon 14:00 MS-H9

Direct high-precision measurement of the electron capture Q-value in ^{163}Ho for the determination of the effective electron neutrino mass — •Christoph Schweiger[1], Martin Brass[2], Vincent Debierre[1], Menno Door[1], Holger Dorrer[3], Christoph E. Düllmann[3,4,5], Sergey Eliseev[1], Christian Enss[6], Pavel Filianin[1], Loredana Gastaldo[6], Zoltan Harman[1], Maurits W. Haverkort[2], Jost Herkenhoff[1], Paul Indelicato[7], Christoph H. Keitel[1], Kathrin Kromer[1], Daniel Lange[1], Yuri N. Novikov[8,9], Dennis Renisch[3,4], Alexander Rischka[1], Rima X. Schüssler[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Institute for Theoretical Physics, Heidelberg University, Germany — [3]Department Chemie - Standort TRIGA, Mainz University, Germany — [4]Helmholtz-Institut Mainz, Germany — [5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [6]Kirchhoff-Institute for Physics, Heidelberg University, Germany — [7]Laboratoire Kastler Brossel, Sorbonne Université, Paris, France — [8]NRC "Kurchatov Institute"-Petersburg Nuclear Physics Institute, Gatchina, Russia — [9]St. Petersburg State University, Petersburg, Russia

Among the most important quantities for fundamental physics is the effective mass of the electron neutrino m_ν, which has far-ranging consequences for cosmology and theories beyond the Standard Model. At present, the most precise indirect upper limit on m_ν is $<$120 meV/c^2 resulting from astrophysical observations while the most precise direct limit is set by the KATRIN collaboration with $<$0.8 meV/c^2, based on the kinematic study of the tritium β-decay. Complementary, the ECHo and HOLMES collaborations investigate the electron capture decay in ^{163}Ho using microcalorimeters. In order to reach the anticipated sub-eV limits on m_ν with calorimetric measurements, the exclusion of possible systematic uncertainties is crucial and is achieved by a comparison of the calorimetrically determined Q-value of the decay to an independently measured one with the same uncertainty level. Within this talk, an independent, direct, ultra-precise measurement of this Q-value using the Penning-trap mass spectrometer Pentatrap is presented with a sub-eV uncertainty. Using this technique, the Q-value is determined by measuring the ratio of the free cyclotron frequencies of highly charged ions of the mother and daughter nuclides, the synthetic radioisotope ^{163}Ho and ^{163}Dy, respectively. The Q-value is finally determined from the measured ratio of cyclotron frequencies by including precise atomic physics calculations of the electronic binding energies of the missing electrons in the measured highly charged ions. This more than 40-fold improved Q-value compared to the previous best direct measurement paves the way for a sub-eV upper limit on m_ν within the ECHo and HOLMES collaborations.

MS 1.2 Mon 14:30 MS-H9

Plans and development of the gas-jet apparatus for laser spectroscopy of the heavy actinides at GSI/HIM — •Danny Münzberg[1,2,3], Michael Block[1,2,3], Premaditya Chhetri[4], Arno Claessens[4], Piet Van Duppen[4], Rafael Ferrer[4], Jekabs Romans[4], Sandro Kraemer[4], Jeremy Lantis[3], Mustapha Laatiaoui[3], Steven Nothhelfer[1,2,3], Sebastian Raeder[1,2], Moritz Schlaich[5], Lutz Schweikhard[6], Simon Sels[4], Thomas Walther[5], and Frank Wienholtz[5] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, DE — [2]Helmholtz-Institut, Mainz, DE — [3]Department Chemie, Johannes Gutenberg-Universität, Mainz, DE — [4]Institut voo Kern- en Stralingsfysica, KU Leuven, Leuven, Belgium — [5]Technische Universität Darmstadt, DE — [6]Universität Greifswald, DE

At GSI-Darmstadt we use the Radiation-Detected Resonance-Ionization Spectroscopy (RADRIS) technique, to study elements in the heavy actinide region to determine their basic nuclear and atomic properties. A setup combining the features of RADRIS with laser spectroscopy in a gas-jet is currently under development to minimize broadening mechanisms occuring in the gas environment of RADRIS, improving the spectral resolution by about an order of magnitude. Due to low production rates in these experiments it is important to minimize the background from other reaction or decay products. In addition, for long-lived nuclides a decay-based detection will not be feasible. With a multi-reflection time-of-flight mass seperator (MR-ToF MS) a separation of ions with different mass to charge ratio can be achieved with a high mass resolving power, suppressing background from unwanted species. For this reason an MR-ToF MS will be added to the gas-jet apparatus. A technical overview oft the MR-ToF MS will be given and its integration into the system will be discussed.

MS 1.3 Mon 14:45 MS-H9

Precision mass measurements of actinides at SHIPTRAP — •Manuel J. Gutiérrez[1,2], Michael Block[1,2,3], Christoph E. Düllmann[1,2,3], Francesca Giacoppo[1,2], Oliver Kaleja[1,4], Kanika Kanika[1,5], Jacques J. W. van de Laar[2,3], Yury Nechiporenko[6,7], Yuri Novikov[6,7], Wolfgang Quint[1,5], and Dennis Renisch[2,3] — [1]GSI Darmstadt, Germany — [2]HIM Mainz, Germany — [3]JGU Mainz, Germany — [4]University of Greifswald, Germany — [5]University of Heidelberg, Germany — [6]PNPI Gatchina, Russia — [7]Saint Petersburg State University, Russia

The existence of superheavy nuclides is possible due to quantum-mechanical shell effects. A region of enhanced stability, dubbed *island of stability*, was long ago predicted at the next spherical shell closure above the doubly magic ^{208}Pb. Although not yet experimentally found, its location has been pinned down to around Z=114–126 and N=184. More information can be retrieved from the study of the actinides, linked to heavier nuclides by decay chains.

Penning-trap mass spectrometry provides precise measurements of atomic masses, which directly translate into binding energies. Their high-resolution measurement provides a powerful indicator of nuclear structure effects. An offline campaign for direct mass measurements of selected U and Pu isotopes was recently carried out at the SHIPTRAP mass spectrometer at GSI, usually devoted to the investigation of superheavy elements. The campaign complements the more extensive program carried out at the TRIGA-TRAP setup in Mainz. This contribution presents the first results of the SHIPTRAP campaign.

MS 1.4 Mon 15:00 MS-H9

Status report on the TRIGA-Trap experiment — •Stanislav Chenmarev[1,2], Klaus Blaum[1], Michael Block[3,4,5], Christoph E. Düllmann[3,4,5], Steffen Lohse[3,4], Szilard Nagy[1], and Jacques J. W. van de Laar[3,4] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, DE — [2]Petersburg Nuclear Physics Insitute, Gatchina, RU — [3]Department Chemie - Standort TRIGA, Johannes Gutenberg-Universität Mainz, DE — [4]Helmholtz-Institut Mainz, DE — [5]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, DE

The TRIGA-Trap setup [1] is a double Penning-trap mass spectrometer at the research reactor TRIGA Mainz. Currently we are performing high-precision mass measurements of long-lived transuranium isotopes. A new cylindrical measurement trap made possible the implementation of the phase-imaging ion cyclotron resonance (PI-ICR) technique [2], originally developed at SHIPTRAP. The current status including results for several long-lived actinide isotopes will be presented. Our results find application in nuclear structure studies and provide reliable atomic mass anchor points in the transuranium region.

1. J. Ketelaer *et al.*, Nucl. Instrum. Meth. A **594**, 162-177 (2008).
2. S. Eliseev *et al.*, Phys. Rev. Lett. **110**, 082501, (2013).

MS 1.5 Mon 15:15 MS-H9

Status of precision mass measurements at the LIONTRAP experiment — •Sangeetha Sasidharan[1,2], Olesia Bezrodnova[1], Sascha Rau[1], Wolfgang Quint[2], Sven Sturm[1], and Klaus Blaum[1] — [1]MPIK, Heidelberg, Germany — [2]GSI Helmholtzzentrum, Darmstadt, Germany

The LIONTRAP experiment is a high-precision mass spectrometer dedicated to light ions. The results at LIONTRAP include the atomic mass measurements of the proton [1], the deuteron and the HD$^+$ molecular ion [2]. The deuteron mass was measured to a relative precision of 8.5 ppt [2]. Our results show an excellent agreement with values extracted from laser spectroscopy of HD$^+$ [3] and the comparison is limited by the precision of the electron's atomic mass. The electron mass in atomic mass units (amu) is currently extracted from the bound electron g-factor measurement of $^{12}C^{5+}$ [4]. This could be improved in the future via a better measurement of the magnetic moment of the bound electron. ^{4}He ion is a prime candidate for the same as it has smaller theoretical uncertainties for the g-factor due to its lower

Z than $^{12}C^{5+}$ and also has a simpler nuclear structure. Currently, we are measuring the atomic mass of ^{4}He to support such a determination of the electron mass in amu. In this contribution, the present status of the experiment will be discussed.

[1] F. Heiße *et al.*, Phys. Rev. A **100**, 022518 (2019).
[2] S. Rau *et al.*, Nature **585**, (2020) pp. 43-47.
[3] I. V. Kortunov *et al.*, Nature Physics, **17**, (2021) pp. 569-573.
[4] S. Sturm *et al.*, Nature **506**, (2014) pp. 467-470.

MS 1.6 Mon 15:30 MS-H9

Latest results of the high-precision Penning-trap mass spectrometer Pentatrap — •M. Door[1], J. R. Crespo López-Urrutia[1], P. Filianin[1], J. Herkenhoff[1], K. Kromer[1], D. Lange[1], Y. Novikov[2], A. Rischka[1], F. Herzog[1], Ch. Schweiger[1], S. Sturm[1], S. Ulmer[3], S. Eliseev[1], and K. Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Peterburg Nuclear Physics Institute, Gatchina, Russia — [3]RIKEN, Fundamental Symmetries Laboratory, Saitama, Japan

Measurements with the Penning-trap mass spectrometer Pentatrap [1], located at the Max-Planck-Institut für Kernphysik in Heidelberg, allow to determine mass ratios with a relative uncertainty in the few parts per trillion regime using highly charged ions [2]. Pentatrap's mass measurements of selected nuclides allow, among others, to contribute to tests of special relativity, bound-state quantum electrodynamics and neutrino-physics research. Achieving this level of precision requires using a cryogenic image-current detection system with single-ion sensitivity and phase-sensitive detection methods in combination with highly charged ions provided by external ion sources. The talk will present recent measurement results on neon for tests of bound-state quantum electrodynamics as well as medium heavy isotopes of ytterbium for dark matter search [3].

[1] Repp, J. et al., Appl. Phys. B 107, 983 (2012).
[2] Filianin, P. et al. Phys. Rev. Lett. 127, 072502 (2021).
[3] Counts, I. et al. Phys. Rev. Lett. 125, 123002 (2020).

MS 1.7 Mon 15:45 MS-H9

Towards a High-Precision Atomic Mass Measurement of the ^{3}He and T Nuclei — •Olesia Bezrodnova[1], Sangeetha Sasidharan[1,2], Sascha Rau[1], Wolfgang Quint[2], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

The mass difference of T and ^{3}He nuclei, measured with the highest precision, will allow an important consistency check for the systematic uncertainty of an upper limit of the $m(\bar{\nu}_e)$ by the KATRIN project [1]. The most precise mass measurements of the lightest nuclei, including ^{3}He nucleus, revealed considerable inconsistencies between the values reported by different experiments [2]. In order to provide an independent cross-check, LIONTRAP, a multi-Penning trap mass spectrometer, has carried out mass measurements on the proton [3], the deuteron and the HD^{+} molecular ion [4].

The present activities of the LIONTRAP group aim at ultra-precise mass measurements of the ^{3}He and T nuclei with a relative uncertainty better than 5 ppt. In this contribution, I present the current status of the experiment, which includes the ^{3}He source preparation for the upcoming mass measurement campaign and modifications of the experimental setup for the radioactive T source placement.

[1] M. Aker *et al.* Phys. Rev. Lett. **123**, 221802 (2019)
[2] S. Hamzeloui *et al.* Phys. Rev. A **96**, 060501(R) (2017)
[3] F. Heiße *et al.* Phys. Rev. A **100**, 022518 (2019)
[4] S. Rau *et al.* Nature **585**, 43-47 (2020)