# Q 49: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Thursday 14:30–16:15 Location: HS 1098

Q 49.1 Thu 14:30 HS 1098

**Laser-spectroscopic determination of the nuclear charge radius of $^{13}$C** — •Patrick Müller[1], Emily Burbach[1], Phillip Imgram[2], Kristian König[1], Wilfried Nörtershäuser[1], and Julien Spahn[1] — [1]Institut für Kernphysik, TU Darmstadt, 64289 Darmstadt, Germany — [2]Instituut voor Kern- en Stralingsfysica, KU Leuven, 3001 Leuven, Belgium

Collinear laser spectroscopy (CLS) has proven to be a powerful method to benchmark nuclear and atomic structure calculations. Light heliumlike systems are ideal test cases for both worlds as they exhibit a greatly varying nuclear structure and are accessible for high-precision ab-initio calculations. In an ongoing effort, it is planned to determine absolute and differential nuclear charge radii, $R_C$ and $\delta\langle r^2\rangle$, of the light elements Be to N by purely using CLS and ab-initio nonrelativistic quantum electrodynamics calculations in the helium-like ions. As a first step, the $1s2s\,^3S_1 \rightarrow 1s2p\,^3P_J$ transitions in $^{12,13}C^{4+}$ were determined using the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. We present results for $\delta\langle r^2\rangle^{12,13}$ and the hyperfine structure of $^{13}C^{4+}$, which is modulated by significant hyperfine-induced mixing, and compare them to ab-initio nuclear and atomic structure calculations. In both cases, our model independent results can be used to improve theory and help quantifying theoretical uncertainties. A comparison to the model-dependent results from elastic electron scattering and muonic atom spectroscopy will help to improve these experimental methods.
This project is supported by DFG (Project-ID 279384907 - SFB 1245).

Q 49.2 Thu 14:45 HS 1098

**Coherent excitation of a Sub-mHz optical magnetic quadrupole transition** — •Valentin Klüsener[1,2], Sebstian Pucher[1,2], Dimitry Yankelev[1,2], Felix Spriestersbach[1,2], Jan Trautmann[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Ultranarrow clock transitions to metastable states are fundamental for many applications in quantum metrology, simulation and information. We report on the first coherent excitation of the $^1S_0$-$^3P_2$ magnetic quadrupole (M2) transition in $^{88}$Sr. By confining atoms in a state insensitive three-dimensional optical lattice, we achieve excitation fractions of 97 % and observe Fourier limited linewidths as narrow as 55 Hz. We characterize the coherence of the prepared states by performing Ramsey spectroscopy and find coherence times of 10 ms, which can be extended to 250 ms with a spin-echo sequence. Finally, we use our spectroscopic results to determine the decay rate of the M2 transition to $154(32) \times 10^{-6}\,s^{-1}$ in agreement with longstanding theoretical predictions. These results establish an additional clock transition in neutral strontium and pave the way for applications of the metastable $^3P_2$ state in precision quantum metrology, simulation and information processing.

Q 49.3 Thu 15:00 HS 1098

**Multi-Cubic-Meter Atom Trapping for Project 8** — •Alec Lindman for the Project 8-Collaboration — Institute for Physics and Excellence Cluster PRISMA+, Johannes Gutenberg University Mainz

The Project 8 direct neutrino mass experiment will achieve its next-generation sensitivity of 40 meV by improving precision (with its Cyclotron Radiation Emission Spectroscopy method), statistics (which scale with active volume in Project 8 rather than area), and control of systematics (by replacing molecular tritium with atomic tritium).

Since atomic tritium recombines on contact with surfaces, a large, static magneto-gravitational trap will hold the tritium atoms in free space. To achieve its sensitivity, Project 8 requires a density of about $10^{17}$ atoms per m$^3$ at about 1 mK and a total volume of about 100 m$^3$, divided among ten identical 10 m$^3$ traps.

Keeping such a trap full over the multi-year runtime of the experiment requires producing a high flux of atoms ($10^{19}$ atoms/s) with a hot atom source, continuously cooling them (first on surfaces, and then using magnetic fields and gas-gas collisions), and finally injecting the cold beam into the trap. This talk will describe the intended trap design, the difficulties and advantages of a large trap, plans for the cooling system, and experimental progress on a high-flux tritium-compatible atom source.

Q 49.4 Thu 15:15 HS 1098

**Sensitivity of Project 8's wire detector for an atomic tritium beam** — •Darius Fenner and Martin Fertl — Institut für Physik, Johannes Gutenberg-Universität Mainz, Mainz, Deutschland

The Project 8 experiment aims to achieve a sensitivity of 40 meV on the neutrino mass through precise measurements of the tritium beta spectrum near its endpoint. To achieve the required energy resolution, the production of atomic tritium is imperative because it has no molecular final state distribution. Such a distribution, caused by vibrational and rotational modes of the molecules, smears the energy spectrum. At the setup in Mainz the thermal dissociation of hydrogen instead of tritium is studied. The efficiency of this process is quantified using a wire detector equipped with three 5$\mu$m tungsten wires. As atomic hydrogen recombines on the wire surface and releases the recombination energy, the temperature change of the wire is measured as a resistance change. However, the measured signal depends on the position along the wire, as heat can more readily dissipate near the mountings. In this work, the wire's sensitivity curve is determined as a function of wire position. The measurement process involves a 2D scan of the wire while performing pointwise heating with a laser. Moreover, the sensitivity is simulated in a COMSOL heat transfer simulation to complement the experimental findings.

Q 49.5 Thu 15:30 HS 1098

**Using Non-linear Dissociation Processes of BeH+ for the Alignment of the Laser Pulse Overlap in XUV Frequency Comb Spectroscopy of He+** — •Florian Egli, Jorge Moreno, Theodor Wolfgang Hänsch, Thomas Udem, and Akira Ozawa — Max-Planck-Institut für Quantenoptik, Garching, Deutschland

The energy levels of hydrogen-like atoms and ions are accurately described by bound-state quantum electrodynamics (QED). With spectroscopic measurements of hydrogen and hydrogen-like atoms, the Rydberg constant and the proton charge radius can be determined. The comparison of the physical constants obtained from different combinations of measurements serves as a consistency check for the theory. The hydrogen-like $He^+$ ion is an interesting spectroscopic target for QED tests. Due to their charge, $He^+$ ions can be held nearly motionless in the field-free environment of a Paul trap, providing ideal conditions for high-precision measurements. The 1S-2S two-photon transition in $He^+$ can be directly excited by an extreme-ultraviolet frequency comb at 60.8 nm generated by a high-power infrared frequency comb using high-order harmonic generation (HHG). In order to perform Doppler-free spectroscopy on the 1S-2S transition, the frequency comb is split into double pulses which are overlapped at the ions. As a signal for the pulse overlap alignment, we investigate non-linear dissociation processes of $BeH^+$. The processes discussed here are using 204 nm and 255 nm light, which can be generated from our infrared frequency comb.

Q 49.6 Thu 15:45 HS 1098

**An optical clock for robust operation and remote comparisons** — •Saaswath JK, Martin Steinel, Melina Filzinger, Jian Jiang, Ekkehard Peik, Nils Huntemann, and the Opticlock consortium — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

We report on a transportable and easy-to-operate optical clock that uses the $^2S_{1/2} - {}^2D_{3/2}$ transition of a single trapped $^{171}Yb^+$ ion at 436 nm as the reference. The system has been developed within a pilot project for quantum technology in Germany led by industry and is set up in two 19" racks [1]. In this way, transportation can easily be realized, and the large degree of automatization allows for robust operation. Comparisons to existing high-accuracy optical clock systems at PTB enabled verification of the clock's uncertainty budget at the low $10^{-17}$ level. During these tests, operation with 99.8% availability over more than 14 days has been achieved. Furthermore, the system has been operated for a significant fraction of the year 2023, enabling a very accurate determination of its frequency and contributions to timescales. We are currently improving the robustness of the setup and reducing uncertainties of shifts from thermal radiation and elec-

tric field gradients. This prepares Opticlock well for transportation to Finnland and Czechia, where it will be compared to other high-performance optical clocks. This will demonstrate a novel approach for key comparisons in time and frequency.

[1] J. Stuhler, et al. Measurement: Sensors 18, 100264 (2021)

Q 49.7 Thu 16:00 HS 1098

**Laser spectroscopy of Fermium-255 at the RISIKO mass separator facility** — •Matou Stemmler for the Fermium-Collaboration — Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany

Laser spectroscopy can provide information about fundamental properties of both atomic and nuclear structure. Such measurements are of particular importance for the heaviest actinides and superheavy elements, where data is sparse. During the last measurement campaign at the RISIKO mass separator facility in the Institute of Physics at Johannes Gutenberg University Mainz (JGU), nine successive samples of the artificially produced ultra-rare isotope $^{255}$Fm (Z=100) of $10^8$ to $10^9$ atoms each, were used to study the atomic and nuclear structure of fermium. The samples originate from an initial $^{254}$Es sample that was produced at the Oak Ridge National Laboratory high flux nuclear reactor (USA). The sample was subsequently re-irradiated at the Institut Laue-Langevin reactor in Grenoble (F) with thermal neutrons to produce $^{255}$Es (half-life: 39.8 d), which decays to $^{255}$Fm (20.07 h) via $\beta^-$ decay. This presentation will focus on the atomic structure studies of $^{255}$Fm, for which a new three-step laser ionization scheme was developed. Rydberg convergences were studied and the accuracy of the ionization potential was improved [1].

[1] J. Am. Chem. Soc. 44, 14609-14613 (2018)