Q 51: Precision Measurements

Time: Thursday 14:30–16:30 Location: A320

Q 51.1 Thu 14:30 A320

Search of dark matter boson via isotope shift measurements in ytterbium ions — •Chih-Han Yeh[1], Laura S. Dreissen[1], Melina Filzinger[1], Nils Huntemann[1], Henning A. Fürst[1,2], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Astronomical observations support the existence of dark matter, but its origin and composition are unknown. A dark matter boson coupling neutrons and electrons in an atom could be observed with isotope shift measurements and a so-called King-plot analysis [1-3]. Here, known atomic and nuclear effects that dominate the isotope shift follow a linear scaling. We performed accurate isotope shift measurements in trapped ytterbium ions to search for these interactions via non-linearities in the King-plot. We determined the absolute frequencies of the $^2S_{1/2} \rightarrow {}^2D_{5/2}$ and $^2S_{1/2} \rightarrow {}^2F_{7/2}$ transitions in all 5 stable even isotopes of Yb^+ to the $\sim$10 Hz level. We reproduce the non-linearities observed in Ref. [4], but reach a 10 to 100 fold higher accuracy. With these results we hope to shed light onto the source of the observed non-linearity and investigate a possible coupling from a new boson beyond the previously explored parameter range.

[1] C. Delaunay, et al., *Phys. Rev. D* **96**, 093001 (2017). [2] J. C. Berengut, et al., *Phys. Rev. Lett.* **120**, 091801 (2018). [3] W. H. King, *Isotope Shifts in Atomic Spectra* (Plenum Press, New York, 1984). [4] J. Hur, et al., *Phys. Rev. Lett.* **128**, 163201 (2022.)

Q 51.2 Thu 14:45 A320

Measuring Beam Deflections via Weak Value Amplification — •Elina Köster[1,2], Carlotta Versmold[1,2], Jan Dziewior[1,2], Florian Huber[1,2], Jasmin DA Meinecke[1,2], Lev Vaidman[1,2,3], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel

The technique of weak value amplification was already used to precisely measure small deflections of light. Yet, so far the interaction region was included in the measurement device, when e.g. measuring a tiny deflection of a light beam [1]. Here we introduce an interferometric weak measurement setup able to measure displacements and deflections of a light beam that occur outside of the measuring device. This is achieved by spatially separating the arms of a Sagnac interferometer and inserting a Dove prism in one of them.

Due to the mirroring of one of the arms the center of mass of the resulting interference pattern depends on the initial deflection of the beam. Amplified by the weak value of the system this allows a highly sensitive determination of the deflection or displacement.

[1] Dixon et al, "Ultrasensitive beam deflection measurement via interferometric weak value amplification.", Physical review letters, 102.17 (2009): 173601

Q 51.3 Thu 15:00 A320

The Photon-Per-Day Detection System of the ALPS II Experiment — •Daniel Brotherton for the ALPS II-Collaboration — University of Florida, Gainesville FL, U.S.

Axions and axion-like particles are a class of particles extending the Standard Model. The Any Light Particle Search II (ALPS II) will soon begin its first science run to probe their miniscule interaction with light. ALPS II follows the “light shining through a wall” approach. Laser light directed through a magnetic field towards a wall may convert into axions and cross unimpeded. On the opposite side, the axions may reconvert to light amidst another magnetic field and be detected. With respect to ALPS II's design parameters and target sensitivity, a detector is required capable of resolving on the order of a photon per day over a 20-day measurement run. In this talk, I will introduce ALPS II's heterodyne interferometric detection scheme. I will discuss the characterization of the detector scheme's noise background and the amount of stray light leaked into the reconversion region.

This work is supported by NSF grant PHY-2110705 and Heising Simons foundation grant 2020-1841.

Q 51.4 Thu 15:15 A320

Characterization of the Optical Systems in the ALPS II Experiment — •Todd Kozlowski for the ALPS II-Collaboration — DESY, Hamburg, Germany

The Any Light Particle Search II (ALPS II) is a "light-shining-through-the-wall" particle search experiment at DESY, currently in its final preparations for a science run. ALPS II will probe for axions and axion-like particles, a family of hypothetical particles outside of the Standard Model, to a sensitivity unparalleled by other model-independent, laboratory-based experiments and most other broadband experiments. ALPS II aims to detect light which has undergone photon-axion and subsequent axion-photon conversion in the presence of a magnetic field. In the initial design, a 60 W laser provides a constant flux of photons for conversion. Opposite a light-blocking shutter, a 122 meter long, high finesse 'regeneration cavity' increases the reconverted signal rate. The resulting ultra-weak signal field can then be detected using optical heterodyne interferometry. In this presentation, I will characterize our optical and control systems in the context of the requirements for the first science measurement. These results will include the performance of the very long storage-time regeneration cavity and the position and phase stability of the fields on the experiment's central optical breadboard.

This work is supported by NSF grant PHY-2110705 and Heising Simons foundation grant 2020-1841.

Q 51.5 Thu 15:30 A320

Indirect excitation mechanisms for the ^{229}Th isomer — •Tobias Kirschbaum[1], Nikolay Minkov[2], and Adriana Pálffy[1] — [1]Julius-Maximilians-Universität Würzburg, Germany — [2]Institute for Nuclear Research and Nuclear Engineering, Sofia, Bulgaria

Amongst all nuclei, the ^{229}Th nucleus presents the lowest first excited state at around 8 eV with an expected radiative lifetime of a few hours. Hence, this transition should be accessible with VUV light. In combination with its narrow linewidth, this renders ^{229}Th an ideal candidate for a nuclear clock with excellent accuracy and stability [1]. However, a hindrance towards its experimental realization is the relatively large uncertainty on the transition energy which makes direct laser excitation cumbersome.

Here, we investigate theoretically two different approaches to indirectly populate ^{229}Th's isomeric state. The first approach deals with quantum optical transfer schemes involving STIRAP and π-pulses via the second excited state at 29.19 keV at the Gamma Factory [2]. The second approach considers Electronic Bridge (EB) schemes in a VUV-transparent crystal environment doped with ^{229}Th [3]. Here, EB involves electronic defect states which appear in the band gap due to ^{229}Th doping. We present different EB schemes and the corresponding excitation rates for ^{229}Th:LiCAF.

[1] E. Peik *et al.*, Quantum Sci. Technol. **6**, 034002 (2021).
[2] T. Kirschbaum, N. Minkov and A. Pálffy, Phys. Rev. C **105**, 064313 (2022).
[3] B. S. Nickerson *et al.*, Phys. Rev. A **103**, 053120 (2021).

Q 51.6 Thu 15:45 A320

Recent Developments towards the Lifetime Measurement of the ^{229m}Th Nuclear Clock Isomer — •Kevin Scharl[1], Daniel Moritz[1], Mahmood Hussain[1], Sandro Kraemer[1,2], Lilli Löbell[1], Florian Zacherl[1], Shiqian Ding[3], Benedict Seiferle[1], and Peter G. Thirolf[1] — [1]LMU Munich — [2]KU Leuven, Belgium — [3]Tsinghua University, Beijing, China

The elusive thorium-229 isomer (^{229m}Th) with its unusually low-lying first excited state (8.338±0.024 eV) represents the so far only candidate for the realization of an optical nuclear clock. Possible applications of a nuclear clock are not limited to highly precise time keeping, but reach into many other fields from geodesy to fundamental physics studies as dark matter research. Considerable progress was achieved in the past few years to characterize ^{229m}Th, from its first identification to recent observations of the long-searched radiative decay channel. While the determination of the nuclear resonance with laser-spectroscopic precision is still awaited, a measurement of the ionic lifetime of the isomer is being prepared by our group. There is experimental proof for the lifetime to last 10^3-10^4 s. To precisely target the quantity by hyperfine structure spectroscopy our experimental setup is based on a cryogenic Paul trap providing long enough storage of cooled ^{229m}Th. The talk will present the status of the experimental setup and first tests to characterize the cryogenic confinement of ^{229m}Th ions together with laser ablated $^{88}Sr^{+}$ ions, their sympathetic Doppler cooling and the spectroscopic readout of the trapped ion states. This work was supported by the European Research Council (ERC): Grant agreement No. 856415.

Q 51.7 Thu 16:00 A320

Towards VUV laser spectroscopy of the nuclear clock isomer 229mTh — •Mahmood Hussain[1], Johannes Weitenberg[2,3], Stephan H. Wissenberg[2], Tamila Rozibakieva[1], Hans-Dieter Hoffmann[2], Constantin L. Häfner[2,4], and Peter G. Thirolf[1] — [1]LMU Munich — [2]Fraunhofer ILT Aachen — [3]Max-Planck Institute of Quantum Optics, Garching — [4]RWTH Aachen University

The isotope 229-Thorium features a low-energy (approx. 8.3 eV) isomeric first nuclear excited state, the so-called thorium isomer. Its long coherence time and vacuum ultraviolet (VUV) transition energy make it the only nuclear transition that is accessible with current laser technology and therefore highly desirable for a clock operation. The small nuclear moments make the nuclear clock a unique quantum sensor to probe, e.g., dark matter or spatio-temporal fluctuations of fundamental constants. To drive the nuclear transition, we are developing a tabletop approx. 150 nm frequency comb that combines a high-power ultrastable frequency comb at 1050 nm, nonlinear pulse compression, and an enhancement resonator to produce VUV high power per comb mode (1 nW/mode) and a narrow comb linewidth (approx. 1 kHz) via high harmonic generation in Xe gas jet. Besides the VUV comb development, other challenges include, (i) coupling VUV pulses with trapped thorium ion(s) for coherent nuclear excitation and, (ii) orders of magnitude reduction in uncertainty of the transition frequency. The VUV comb's concept, the aforementioned challenges, and their prospective solutions will be discussed. Funding: European Research Council (ERC Synergy Grant, Agreement No. 856415).

Q 51.8 Thu 16:15 A320

Towards a Spaceborne Two-Photon Rubidium Frequency Reference — •Julien Kluge[1,2], Klaus Döringshoff[1,2], Daniel Emanuel Kohl[1,2], Moritz Eisebitt[2,3], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik, Humboldt-Universität zu Berlin — [3]II. Physikalisches Institut, RWTH Aachen University

Optical frequency standards based on two-photon spectroscopy using hot rubidium vapor are a promising candidate for realization of simple and compact optical clocks for application in next generation global navigation satellite systems.

In this presentation, we show the development of a two-photon frequency reference using FM spectroscopy at 778 nm for application in the CRONOS satellite mission. Recent results of our lab-based setups show a fractional instability below 3×10^{-13} per $\tau^{-1/2}$ for up to 1000 s. We present our design and first prototype of a spectroscopy module with a volume below 1/2 l, weight below one kilogramm and planned power budget of under 10 W for accommodation on a micro satellite. Additionally, reports on its performance and qualification for an in orbit verification mission are given. We further provide details on the architecture of the payload, the laser system for two-photon spectroscopy and the anticipated operation as part of an optical clock.

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