A 15: Poster – Highly Charged Ions and their Applications

Time: Tuesday 17:00–19:00 Location: Philo 1. OG

A 15.1 Tue 17:00 Philo 1. OG

Efficient production of ^{229m}Th via Cascade Decay — •Yumiao Wang[1,2] and Changbo Fu[1] — [1]Fudan University, Shanghai, China — [2]Johannes Gutenberg Universität Mainz, Germany

The low-energy nuclear isomeric state of ^{229m}Th (8.36 eV) provides a unique bridge between nuclear and atomic physics, with promising applications in nuclear clocks and precision metrology. However, its efficient and controllable population remains a long-standing experimental challenge.

An indirect excitation scheme based on nuclear cascade decay in an electron beam ion trap (EBIT) and a storage ring (SR) is formulated for highly charged ^{229}Th ions, for which the strengthened electron–nucleus interaction leads to enhanced excitation cross sections. In this scheme, ^{229}Th nuclei are first excited to higher-lying nuclear states via electron-induced processes, namely nuclear excitation by inelastic electron scattering (NEIES) and nuclear excitation by electron capture (NEEC). The corresponding excitation cross sections are calculated within the Dirac-Hartree-Fock-Slater framework.

This study establishes a unified theoretical scheme linking electron-induced nuclear excitation and cascade nuclear relaxation in EBIT and SR environments, providing a realistic pathway toward the efficient and controllable production of ^{229m}Th.

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A 15.2 Tue 17:00 Philo 1. OG

Optimised Y-bender design for efficient ion transport — •Sophia Dorra, Stepan Kokh, Magdalena Winkelvoss, Anton Sterr, Melina Gizewski, Finja Mayer, Maili Schube, José Ramon Crespo López-Urrutia, Thomas Pfeifer, and Vera Schäfer — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Precision spectroscopy to search for possible variations of the fine-structure constant α require atomic systems with strong relativistic level shifts. Highly charged ions (HCIs) are ideal candidates, but experiments involving rare isotopes such as californium demand efficient production, transport, and retrapping of HCIs. In our setup, HCIs are generated in an electron beam ion trap (EBIT) and subsequently transferred to one of two Paul traps for high-precision spectroscopy of selected transition frequencies.

To maximize the overall transmission efficiency from the EBIT to the trapping region, we are developing a new Y-bender beamline element composed of two symmetric 45° electrostatic benders. This design enables deflection of the HCI beam to either side while preserving beam quality and improving transport efficiency compared to a single 90° deflection. As a preparatory step toward constructing the Y-bender, we investigate the geometric and electrostatic properties of a previously used 90° bender. The goal of these measurements and simulations is to understand how electrode geometry influences beam focusing and transmission in order to optimize the design of our 45° bender modules.

A 15.3 Tue 17:00 Philo 1. OG

Hyperfine-induced transitions of nuclei and atoms — •Stephan Fritzsche[1,2], Houke Huang[1], Wu Wang[3], and Yong Li[3] — [1]Helmholtz-Institut Jena, Germany — [2]Friedrich-Schiller University Jena, Germany — [3]Hainan University, Haikou 570228, China

The hyperfine interaction between nuclear moments and the electronic charge and current distributions is present in all atoms and ions with non-zero nuclear spin I. However, this interaction becomes visible only in transition probabilities, lifetimes and angular distribution of emitted photons, if the combined system "nucleus + electrons" supports additional multipole transitions, which are not accessible alone for the individual subsystems. Different communities have studied such "hyperfine phenomena" with varying notations and physical pictures in mind, including hyperfine transitions, the nuclear hyperfine effect or various kinds of (so-called) electron-bridge processes [1,2]. We here show how all these phenomena can readily be interpreted as special cases of hyperfine-induced nuclear and/or electronic multipole transitions.

[1] W. Wang, F. Zou, S. Fritzsche and Y. Li; Isomeric population transfer of the 229 Th nucleus via hyperfine electronic bridge; Phys. Rev. Lett. 133, 223001 (2024). [2] W. Wang, S. Fritzsche and Y. Li; Search for variations of the fine-structure constant via the hyperfine electronic bridge in highly charged 229Th ions; Phys. Rev. A112, 022811 (2025).

A 15.4 Tue 17:00 Philo 1. OG

Interplay of Hyperfine Mixing and Nuclear-Atomic Interactions in Highly Charged Ions — •Kaiqiang Shi[1,2,3], Xinwen Ma[1,2], and Adriana Pálffy[3] — [1]Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China — [2]School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing, China — [3]Institute of Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany

As nuclear-scale effects become increasingly relevant in atomic physics, it is crucial to understand how atomic and nuclear degrees of freedom couple in ions. Nuclear hyperfine mixing (NHM) [1] is central to this problem. Beyond its role in ^{229}Th, recent theory [2] suggests that boronlike ^{205}Pb ions, with a 2.329 keV nuclear transition, may show strongly enhanced NHM-driven decay, greatly shortening the isomer's radiative lifetime. This indicates that systems other than ^{229}Th could also serve as platforms for studying nuclear-atomic coupling.

Bound internal conversion (BIC), the inverse of NEET [3], offers another channel linking nuclear excitation to the electronic shell. Although NHM and BIC are subject to different requirements—magnetic coupling versus energy matching—some heavy nuclei with low-lying transitions may naturally meet both. We investigate such cases, in which the interplay between NHM and BIC becomes significant and must be considered when analyzing nuclear decay in complex ionic environments.

[1] V. M. Shabaev et al., Phys. Rev. Lett. 128, 043001 (2022).
[2] W. Wang and X. Wang, Phys. Rev. Lett. 133, 032501 (2024).
[3] S. K. Arigapudi and A. Pálffy, Phys. Rev. A 85, 012710 (2012).

A 15.5 Tue 17:00 Philo 1. OG

Convolutional Neural Network for fast and accurate ion-number counting with Micro-Channel Plate detector — •Jun Huang[1], Stefan Ringleb[1], Manuel Vogel[2], and Thomas Stöhlker[1,2,3] — [1]Friedrich-Schiller-Universität Jena — [2]GSI Helmholtzzentrum für Schwerionenforschung Darmstadt — [3]Helmholtz-Institut Jena

Micro-channel plates (MCP) are ideal detectors for detecting and counting ions extracted from ion traps as long as the ion rate is low enough to detect single ion hits. During our laser experiment with the HILITE Penning trap, a huge amount of ions are expected to arrive at the MCP within microseconds, hence overlapping of multiple ions is very probable. The manual data evaluation is time consuming, as a large amount of datasets is expected. A Convolutional Neural Network (CNN) is extremely helpful in handling two-ion signals overlapping in order to recognise and count them rapidly in large datasets. In our evaluation method, single-ion signals are first hand selected and trained into a CNN of Single Ion Model (SIM) for detection with high accuracy. Due to the low number of existing double-ion data for model training, the single-ion data is used to create artificial double-ion signal, which enrich the training data for CNN of Double Ion Model (DIM). In our created CNN models, single-ion signals and double-ion signals are rapidly recognised by SIM and DIM, and the detection is then used to obtain the total ion number. We will present the model and its ion counting capabilities with a special focus on detection accuracy.

A 15.6 Tue 17:00 Philo 1. OG

Laser spectroscopy of highly charged ions in SpecTrap — •Rima X. Schüssler[1,2,3], Manuel Vogel[1], Volker Hannen[4], Wilfried Nörtershäuser[5], Gerhard Birkl[5], Andreas Solders[6], and Thomas Stöhlker[1,2,3] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [2]Helmholtz Institute Jena — [3]Friedrich Schiller Universität Jena — [4]Universität Münster — [5]Universität Darmstadt — [6]Uppsala Universitet

Heavy, highly charged ions (HCI) provide a unique possibility to test fundamental physics in the presence of extreme electromagnetic fields. To this end, the SpecTrap experiment, located at the HITRAP facility of the GSI Helmholtz Centre for Heavy Ion Research, plans to perform laser spectroscopy of (hyper-)fine structure transitions in HCIs in a Penning trap. Measurements will include the test of bound-state quantum electrodynamics as well as the nuclear clock transition in $^{229}Th^{89+}$ in the framework of the HiThor project.

The HCIs are produced in the accelerators of GSI and then decelerated by the HITRAP facility, before being guided to the cryogenic Penning trap. Within the trap, they are sympathetically cooled down with Mg^{+} ions. The trap has optical access for lasers as well as to collect fluorescence of the HCIs.

A 15.7 Tue 17:00 Philo 1. OG

Lamb shift and g-factor shift calculations due to vacuum polarization in s states — •Jay Dipakbhai Solanki, Zoltán Harman, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Two-loop vacuum polarization contributions to the Lamb shift and the bound-electron g factor are calculated with perturbative quantum electrodynamics (QED) and some concepts from relativistic quantum mechanics. The g factor – or magnetic moment – of an electron bound in the strong Coulomb potential of a nucleus can nowadays be measured to an astonishing accuracy [1], enabling QED tests at the two-loop level. The Källén-Sabry potential describing certain diagrams is rederived using the optical theorem. The corresponding g factor shifts are calculated analytically from the expectation value of the potential using some simple properties of the Dirac equation. The results reproduce and extend corrections derived in the framework of nonrelativistic QED. — [1] J. Morgner, B. Tu, C. M. König, *et al.,* Nature **622**, 53 (2023).

A 15.8 Tue 17:00 Philo 1. OG

Highly charged ion beamline for efficient ion transmission with charge state selection — •Shreya Rao Kodancha, Sebastian Davidson, Elwin A. Dijck, Ruben B. Henninger, Devanarayanan Rajeeb Kumar, Vera M. Schäfer, Thomas Pfeifer, and José R. Crespo López-Urrutia — Max Planck Institute for Nuclear Physics

Highly charged ions (HCIs) are promising candidates for searches for physics beyond the Standard Model, such as King plot isotope shift studies. In the VAUQSI apparatus under development, HCIs will be interrogated in a cryogenic superconducting RF Paul trap, where the anticipated low Lamb*Dicke factor should enable efficient ground-state cooling. HCIs produced in the electron beam ion trap (EBIT) must be transported to the trap through a low-energy beamline consisting of multiple electrostatic lenses for focusing, a 90° bender for steering, and a pulsed drift tube for deceleration and bunching. Charge-state and isotope selection along the beam path will also be explored. Optimizing ion transmission involves a large parameter space, including electrode voltages, EBIT extraction rate and switching times for charge-selection electrodes. Building on our experience with the CryPTEx-SC beamline, automated optimization tools will be employed. We report on the beamline design, accompanying simulations, current progress and the planned optimization for VAUQSI.

A 15.9 Tue 17:00 Philo 1. OG

Development of a rare-isotope injector for optical spectroscopy of highly charged ions at HD-EBIT — •Nutan Kumari Sah[2], Lakshmi Priya Kozhiparambil Sajith[2], Filipe Grillo[2], Joschka Goes[1], Thomas Pfeifer[1], Steven Worm[2], Hendrik Bekker[3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, D-69117 Heidelberg, Germany — [2]DESY, D-15738 Zeuthen, Germany — [3]Helmholtz Institute Mainz, 55099 Mainz, Germany

Highly charged ions (HCI) are promising candidates for advanced frequency metrology and precision tests of fundamental physics. Transitions between their strongly bound electronic states are insensitive to external perturbations. Interestingly, the presence of a $5f-6p$ orbital crossing in several charge states of californium enables strongly forbidden optical transitions with exceptionally high sensitivity to a hypothetical variation of the fine-structure constant. However, due to theoretical uncertainties emission spectroscopy is needed to accurately determine their wavelengths for future frequency metrology. We are implementing at the superconducting Heidelberg electron beam ion trap a laser-ablation-based injection system requiring only nanogram amounts of californium and other rare elements. We will present an update and outline the next steps towards spectroscopy of californium HCI.