HK 25: Focus Session II: Accurate Nuclear Charge Radii of Light Elements

Time: Wednesday 14:00–15:30 Location: HS 1 Physik

Invited Talk HK 25.1 Wed 14:00 HS 1 Physik

First laser spectroscopic measurements of charge radii along the carbon isotope chain — •Kristian König, Emily Burbach, Phillip Imgram, Bernhard Maass, Patrick Müller, Wilfried Nörtershäuser, and Julien Spahn — TU Darmstadt, Germany

Light nuclei are ideal test cases for nuclear structure calculations as they exhibit many facets of nuclear structure like halos and clustering and are accessible for high-precision ab-initio calculations. The nuclear charge radius is a key observable and in an ongoing effort it is planned to determine absolute and differential charge radii, R_C and $\delta\langle r^2\rangle$, of the light elements Be to N by purely using collinear laser spectroscopy and non-relativistic quantum electrodynamics calculations (NR-QED). Helium-like ions of these species provide laser-accessible atomic transitions that can be calculated with high accuracy in the NR-QED approach. As a first step, the $1s2s\,^3\mathrm{S}_1 \rightarrow 1s2p\,^3\mathrm{P}_J$ transitions in $^{12-14}\mathrm{C}^{4+}$ were determined using the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. These represent the first optical charge radius measurements in the carbon isotopic chain and will be the starting point for the necessary improvement of the charge radii of the light-mass nuclei. This contribution will give an overview of the project and present the measured transition frequencies along with the extracted nuclear charge radii of $^{12-14}\mathrm{C}$, which are compared to results from electron scattering and muonic atom spectroscopy experiments as well as to state-of-the-art theory. This project was supported by DFG (Project-ID 279384907 - SFB 1245) and by BMBF (05P21RDFN1).

Invited Talk HK 25.2 Wed 14:25 HS 1 Physik

Precision radii of light elements using Metallic Magnetic Calorimeters — •Frederik Wauters — Institute for Nuclear Physics, Johannes Gutenberg University Mainz, Mainz, Germany

Nuclear charge radii are crucial for testing nuclear models and serve as key inputs for precision experiments. While optical isotope shift data provide charge radius differences, absolute radii are typically determined through muonic atom spectroscopy, a method particularly sensitive to nuclear finite size effects. Muonic hydrogen and helium have been measured using laser spectroscopy, achieving unprecedented accuracy. However, other light elements remain beyond reach.

At the Paul Scherrer Institute, a new high-precision X-ray spectroscopy initiative called QUARTET has been initiated, utilizing novel Metallic Magnetic Calorimeters. The goal is to improve the accuracy of charge radii measurements for light nuclei by an order of magnitude. Following a successful proof-of-principle measurement in 2023, a first physics run was completed in the 2024 campaign. I will present the current status and outlook of this project.

Invited Talk HK 25.3 Wed 14:50 HS 1 Physik

Precision Radii from the No-Core Shell Model via Neural Networks — •Robert Roth — Institut für Kernphysik, TU Darmstadt, Germany

The no-core shell model (NCSM) is one of the most rigorous and universal ab initio methods for light nuclei. It is based on the solution of the many-body problem in a finite model space, characterized by a single truncation parameter. For sufficiently large truncation parameters, observables are guaranteed to converge to the exact solution. The convergence pattern varies for different observables, and radii are particularly challenging due to their sensitivity to the long-range behavior of the wave functions. Therefore, fully converged calculations are only possible for few-nucleon systems. For p-shell nuclei, we obtain NCSM sequences that reveal a convergence pattern, but not a fully converged observable. To overcome this limitation, we have developed artificial neural networks (ANNs) that predict converged energies and radii based on NCSM convergence patterns using large sets of NCSM calculations for few-nucleon systems as training data. We demonstrate the application of the ANN-enhanced NCSM for radii of boron and carbon isotopes with different families of chiral two- plus three-nucleon interactions. In addition to the model-space uncertainties that are extracted from the ANNs in a statistical manner, we use Bayesian methods to asses chiral truncation uncertainties. This approach delivers precise NCSM predictions for radii with fully quantified theory uncertainties. Finally, we explore the generalization of ANN-enhanced NCSM calculations to other electromagnetic observables.

Common discussion: 15'