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All-optical determination of the nuclear charge radii of ^{12,13}C^{4+}

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Laser spectroscopy has since long been used to determine differential nuclear charge radii $\delta\langle r^2\rangle$ for stable and short-lived isotopes. Only for hydrogen-like systems it has been possible to extract the nuclear mean-square charge radius $\langle r^2\rangle$ directly from optical spectra, which has been successfully used for hydrogen [1], muonic hydrogen [2], deuterium [3] and helium [4]. Recently, much effort was put in improved calculations of helium-like systems to be able to extract nuclear charge radii from $1s2s\,^3\mathrm{S}_1 \rightarrow 1s2s\,^3\mathrm{P}_J$ transition frequencies [5]. This can be used also in heavier He-like ions, i.e., Be to N, in which the metastable state has sufficient lifetime to perform collinear laser spectroscopy and the transition wavelengths are in the laser accessible region.

The isotope ^{12}C has one of the best-known nuclear charge radii from elastic electron scattering and muonic atom spectroscopy. It is therefore an ideal study case to test atomic theory. So far, high-precision laser spectroscopy data is absent for all carbon isotopes. We have now studied the $1s2s\,^3\mathrm{S}_1 \rightarrow 1s2s\,^3\mathrm{P}_{0,1,2}$ transitions in helium-like ^{12,13}C^{4+} using the **Co**llinear **A**pparatus for **L**aser Spectroscopy and **A**pplied Physics (COALA) at the Institute of Nuclear Physics, TU Darmstadt. By measuring the resonance frequencies in collinear and anti-collinear geometry simultaneously with lasers referenced to a frequency comb, we reach an accuracy of 2 MHz. As soon as theory reaches comparable accuracy, the uncertainty of the absolute mean square nuclear charge radii will be on par with the uncertainty in ^{12}C from muonic spectroscopy. Measurements performed on ^{13}C^{4+} to investigate the hyperfine structure splitting show significant hyperfine mixing which will serves as another benchmark for testing atomic-structure theory. Finally, mass-shift calculations between ^{12,13}C^{4+} will provide $\delta\langle r^2\rangle^{12,13}$ with very high precision in the conventional approach.

[1] Beyer *et al.*, Science **358**, 79-85 (2017)
[2] Pohl *et al.*, Nature **466**, 213-216 (2010); Antognini *et al.*, Science **339**, 417-420 (2013)
[3] Pohl *et al.*, Science **353**, 669-673 (2016)
[4] Krauth *et al.*, Nature **589**, 527-531 (2021)
[5] Yerokhin *et al.*, Phys. Rev. A **106**, 022815 (2022)

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