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Measurement of nuclear charge radius difference in metastable helium isotopes

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One long-standing puzzle in modern physics is the discrepancy between the most accurate proton charge radius measurements from muonic hydrogen spectroscopy and electronic hydrogen spectroscopy [1]. Despite theoretical improvements over the last decade, the mismatch remains [2], potentially hinting at physics beyond the Standard Model [3].

Helium, the next simplest atom after hydrogen, provides another testbed. Muonic helium spectroscopy was performed by the CREMA collaboration [4, 5], while more work has been done in normal helium spectroscopy [6–11]. The nuclear charge radius can be extracted with greater precision from high-accuracy spectroscopic measurements. The 2^3S_1–2^3P transition in helium is theoretically calculated to 2 MHz accuracy, with predictions of reaching 10 kHz [12]. We can also determine the charge radius difference using difference measurement, enabling direct theory comparison. We aim to measure the 2^3S_1–2^3P transition frequencies in ^{4}He and ^{3}He using ultracold metastable atoms. Ultracold clouds minimize the first-order Doppler shift, a dominant error in previous isotope-shift determinations. We present the design of a sub-kHz-resolution precision absolute laser facility and methods to suppress systematic errors, paving the way for the most precise nuclear charge radius measurement in helium to date.

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Author: SURESH KUMAR, Kannan (Australian National University)

Co-authors: Mr PADMANABAN, Srihari (Australian National University); Mr YAN, Xintong (Australian National University); Mr ATHREYA, Yogesh (Australian National University); Prof. BALDWIN, Kenneth (Australian National University); Dr HODGMAN, Sean (Australian National University); Prof. TRUSCOTT, Andrew (Australian National University)

Presenter: SURESH KUMAR, Kannan (Australian National University)

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