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Testing quantum electrodynamics in extreme fields using helium-like uranium

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Transition energy measurements in heavy, few-electron atoms are a unique tool to test bound-state QED in extremely high Coulomb fields, where perturbative methods cannot be implemented. In such fields, the effects of the quantum vacuum fluctuations on the atomic energies are enhanced by several orders of magnitude with respect to light atoms. However, up to now, experiments have been unable to achieve sensitivity to higher-order (two-loop) QED effects in this strong regime. Here we present a novel multi-reference method based on Doppler-tuned x-ray emission from fast uranium ions stored in the ESR ring of the GSI/FAIR facility. By accurately measuring the relative energies between $2p_{3/2} \rightarrow 2s_{1/2}$ transitions in two-, three-, and four-electron uranium ions, we were able, for the first time in this regime, to disentangle and test separately high-order (two-loop) one-electron and two-electron quantum electrodynamics (QED) effects, and set a new important benchmark for QED in the strong field domain [1]. Moreover, the achieved accuracy of 37 parts per million allows us to discriminate between different theoretical approaches developed throughout the last decades for describing He-like systems.

[1] R. Loetzsch et al., *Nature* **625**, 673-678 (2024).

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