Probing a Fifth Force in Muonic Atoms through Lamb Shifts and Hyperfine Structure

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Abstract

Motivated by the ATOMKI anomalies observed in 8Be and 4He transitions, we present a system- atic survey of X17-induced Lamb shifts and hyperfine splittings in muonic atoms with stable nuclei up to Z $ $15. The muon–nucleus bound-state problem is solved within the Gaussian Expansion Method using a unified Hamiltonian that includes the standard electromagnetic baseline together with vector- and pseudoscalar-X17 exchange. A central feature of this work is that the Lamb-shift and hyperfine sectors are treated with different nuclear couplings: the spin-independent Lamb shift is described by a coherent vector muon–nucleus interaction, while the spin-dependent hyperfine sec- tor is constructed isotope by isotope from shell-model spin fractions. Benchmark muon couplings are chosen in accordance with the 2025 Muon g−2 result. We find a clear complementarity between mediator hypotheses. The vector Lamb-shift signal grows strongly toward heavier nuclei, while in the hyperfine sector the vector scenario preferentially enhances odd-N nuclei and the pseudoscalar scenario favors odd-Z systems. To compare different systems on a common experimental footing, we introduce the signal-to-precision ratio. Among systems with existing precision benchmarks, the most promising near-term probes of the vector Lamb-shift channel are µd, µ3He+, and µ4He+. For future spectroscopy, the largest absolute vector Lamb-shift signal is predicted in µ31P, while the leading 1S1/2 hyperfine targets are µ29Si for the vector scenario and µ31P for the pseudoscalar sce- nario. The dominant theoretical uncertainty arises from the Schmidt-model treatment of nuclear spin content, indicating that beyond-Schmidt nuclear-structure input will be the key ingredient for quantitative follow-up studies of the leading hyperfine targets.

Note: Figure translations are in progress. See original paper for figures.