Exploring New Solutions to the Fine-Structure Anomaly in Heavy Muonic Atoms

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Spectroscopy of muonic atoms is of wide-ranging interest due to the low-lying muonic orbitals, which allow for the inference of nuclear structure from the spectrum. For lighter atoms, this is the standard technique used to extract the root-mean-square (rms) charge radius. However, in heavy muonic atoms such as $\mu-^{90}$Zr [1], $\mu-^{120}$Sn [2], and $\mu-^{208}$Pb [3,4], a significant discrepancy between the measured and theoretically predicted spectra complicates the extraction of the rms charge radius. This discrepancy, known as the fine-structure anomaly in heavy muonic atoms, has remained unresolved since the original measurements in the 1980s. Nuclear polarisation (NP), initially believed to be the solution to the puzzle, has recently been accurately determined and found to be insufficient in resolving the discrepancy [5].

We investigated the leading-order contribution of a new boson added to the Standard Model and come to the conclusion that a Beyond the Standard Model (BSM) explanation is unlikely [6]. Interactions mediated by a single new scalar, vector, pseudoscalar and pseudovector are considered. Spin-dependent couplings sourced by pseudoscalars or pseudovectors are disfavoured as solutions to the anomaly because of the vanishing angular momentum of the nuclei in question. Spin-independent interactions as a result of scalar or vector exchange are shown to be equally disfavoured because of non-overlapping parameter spaces required to fit different atomic states of the same nucleus.

With a BSM explanation being very unlikely, we comment on possible alternatives. This observation motivates a thorough re-investigation of the various effects involved in binding energy calculations and emphasizes the need for new experimental measurements to expand the available data pool.

[1] T. Q. Phan *et al.*, Phys. Rev. C **32** (1985) 609.
[2] C. Piller *et al.*, Phys. Rev. C **42** (1990) 182.
[3] Y. Yamazaki *et al.*, Phys. Rev. Lett. **42** (1979) 1470.
[4] P. Bergem *et al.*, Phys. Rev. C **37** (1988) 2821.
[5] I. A. Valuev *et al.*, Phys. Rev. Lett. **128** (2022) 203001.
[6] K. A. Beyer *et al.*, To be submitted.

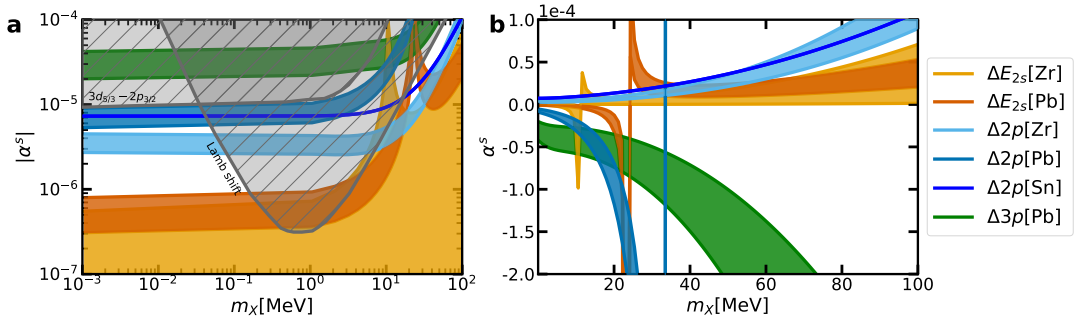

FIG. 1: The plot shows the parameter space for a new scalar/vector particle in logarithmic (a) or absolute (b) scales. The gray regions show previous exclusions coming from Lamb shift measurements of light muonic atoms and the transition $3d_{5/2} - 2p_{3/2}$ in $\mu-^{24}$Mg and $\mu-^{28}$Si. The coloured regions depict the parameter space for each transition and element for which the fine-structure anomaly in heavy muonic atoms would be explained by a new scalar or vector addition to the SM.