New results of positronium 1S-2S transition and Muonium Fine structure

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Positronium and muonium, as purely leptonic atoms without internal structure, provide ideal systems for high-precision tests of quantum electrodynamics (QED) [1] and measurements of fundamental constants. Here, we present our recent results of the $1^3S_1 \rightarrow 2^3S_1$ transition in positronium, measured via two-photon optical spectroscopy with a continuous-wave laser. The preliminary analysis estimates that the total uncertainty of this measurement at 5 ppb, comparable to the most precise measurement to date (2.6 ppb) [2]. We also present a semi-analytical model for the lineshape of 1S-2S transitions in positronium. This expands on previous work with stable atoms [3, 4], and demonstrates remarkable agreement with lineshapes generated via Monte-Carlo simulations and validated by experimental data. This model provides a tool for optimising experimental parameters and for gaining deeper insights without the need for computationally intensive simulations. The future prospects of positronium and muonium 1S-2S spectroscopy employing a novel Ramsey-Doppler scheme [5] will also be presented.

In addition, we present a recent measurement of the fine structure of muonium, which follows from the experiment that determined the muonium Lamb shift [6, 7]. A preliminary analysis of the experimental data indicates that the observed transition frequency is consistent with theoretical predictions, with a total uncertainty of around about 7 parts in 10,000, making it the most precise determination to date. The upcoming High-Intensity Muon Beam (HiMB) at the Paul Scherrer Institute (PSI) in Switzerland will allow to increase the statistics on such a measurement to enable precise tests of bound state QED, while also providing tests of new physics [8].

References

[1] G. S. Adkins et al., *Phys. Rep.* **975,** 1 (2022).
[2] M. S. Fee et al., *Phys. Rev. Lett.* **70** (1993).
[3] R. A. Gustafson and F. Robicheaux *J. Phys. B: At. Mol. Opt. Phys.* **54** (2021)
[4] L. Azevedo and C. Cesar *Phys. Rev. A* **111**(2025)
[5] Javary, E., Thorpe-Woods, E., Cortinovis, I. et al. *Eur. Phys. J. D* **79,** 15 (2025).
[6] B. Ohayon, et al., *Phys. Rev. Lett*, **128**, (2022).
[7] G. Janka, et al. *Nat Commun* **13**, 7273 (2022)
[8] P. Blumer, et al. *arXiv:2412.19580*. (2025)