Characterization of a waveguide with Rydberg helium field sensing

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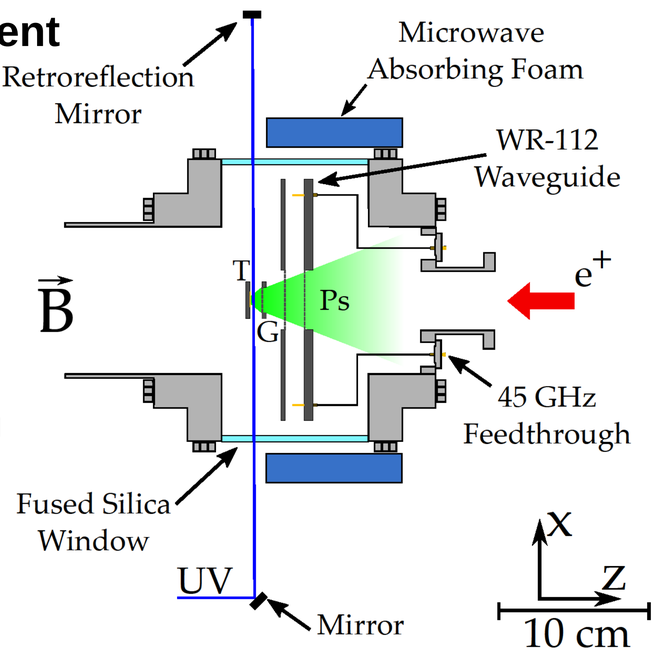
Introduction

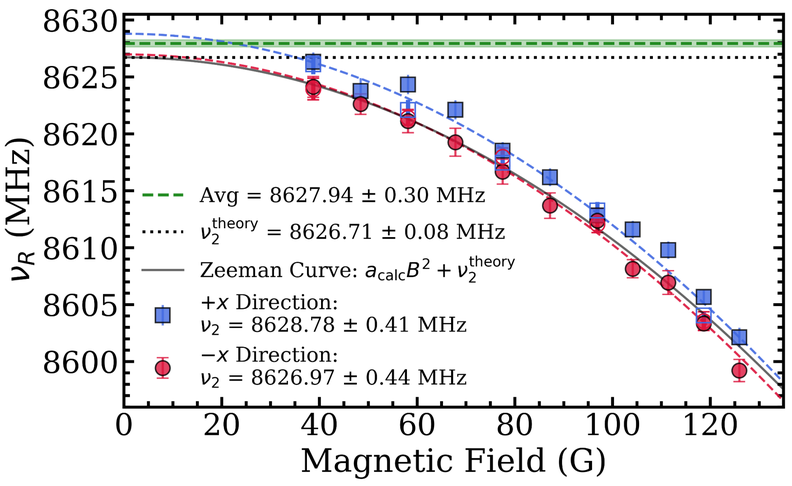
Precision measurements of positronium (Ps) can be considered to be direct tests of QED theory, and potential harbingers of physics beyond the standard model [1]. Measurements of the Ps $n = 2$ fine structure at UCL have in the past exhibited asymmetric line shapes, shifts from and uncertainties orders of magnitude larger than theory [2]. Here I present a summary of the most recent precision measurement of Ps [3] designed to mitigate these issues and discuss a new measurement using Rydberg helium performed to characterize systematics in the Ps apparatus.

Ps Waveguide Experiment

- New setup designed to limit reflections in the chamber.
- No more asymmetry.
- Two antennae: results differ for different microwave propagation direction.
- New systematic: likely structural irregularities.

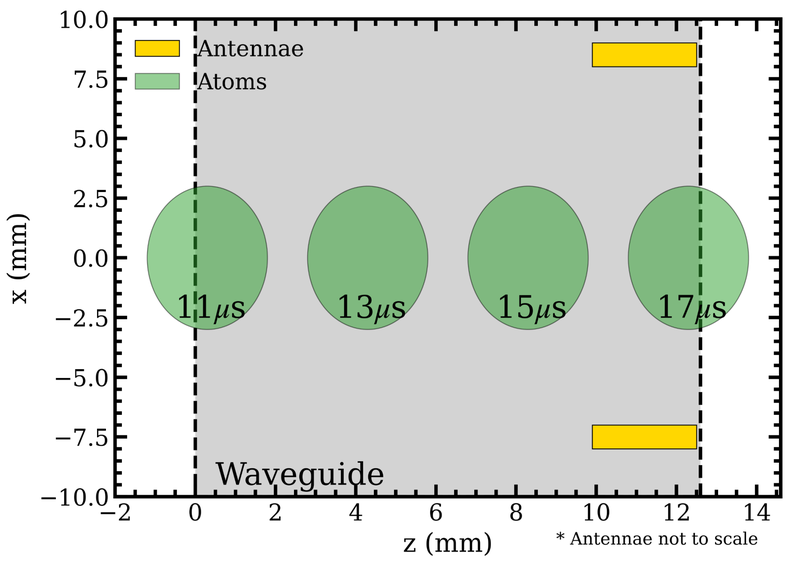


- Final result: $\upsilon_2 = 8627.94 \pm 0.30_{stat} \pm 0.91_{sys}$ MHz
- Shifted from theory by 1.3σ



- Zeeman curves for different propagation directions extrapolate back to different zero field centroid values: 1.8 MHz discrepancy.

Atom distribution in the waveguide



- Atoms outside the waveguide still exhibit line shapes.
- Lines on antenna side broader.
- No resolvable difference between propagation directions.

References

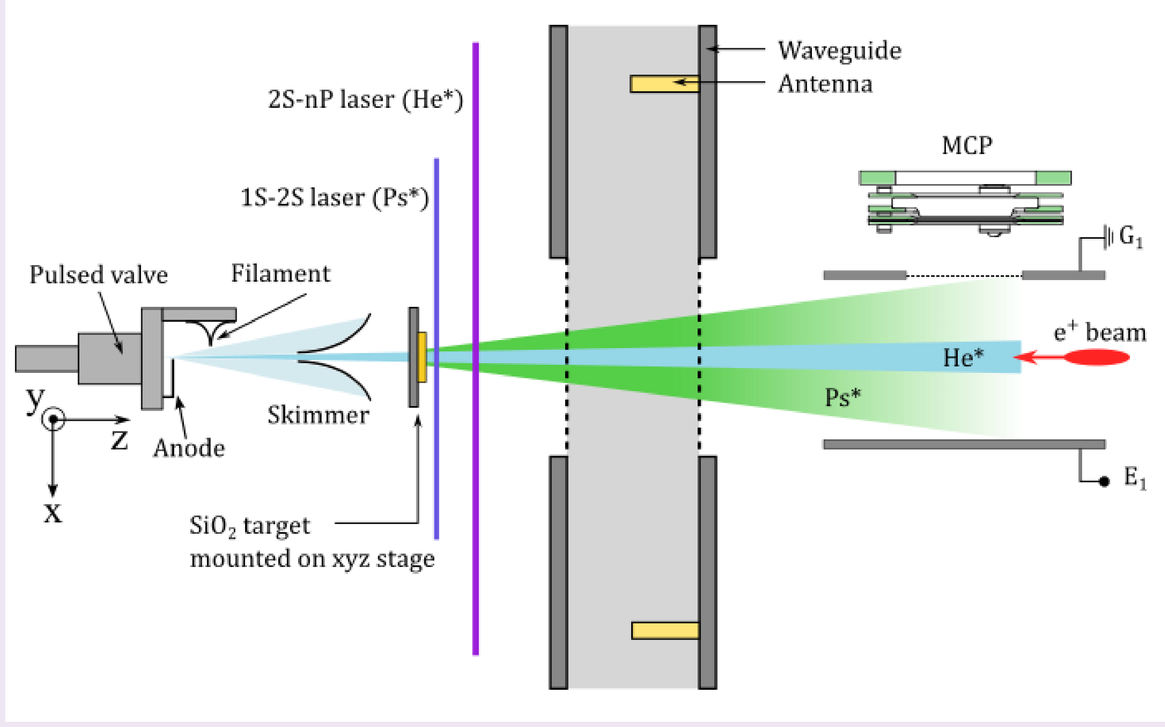
[1] S. G. Karshenboim, Physics Reports, vol. 422, no. 1-2, pp. 1–63, 2005.

[2] R. E. Sheldon, T. J. Babij, S. H. Reeder, S. D. Hogan, and D. B. Cassidy, Phys. Rev. A **107**, 042810 April 2023

[3] R. E. Sheldon, T. J. Babij, S. H. Reeder, S. D. Hogan, and D. B. Cassidy, Phys. Rev. Lett (Accepted for publication)

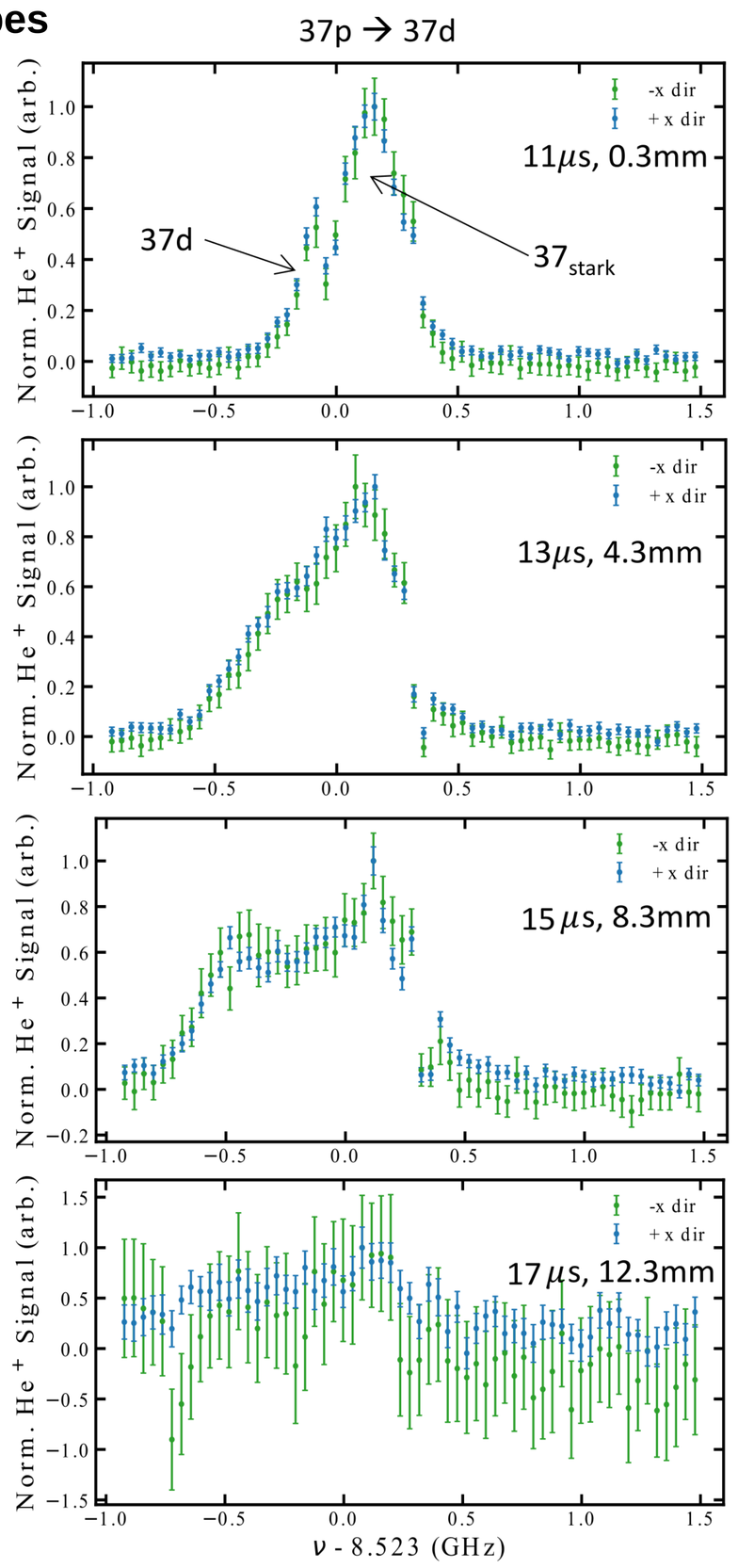
Helium Apparatus

- Same vacuum chamber and waveguide setup as Ps experiment.
- Metastable helium $2^3S_1 \rightarrow n^3P_J$ Rydberg states prepared with 260 nm.
- Rydberg atoms selectively field ionized.
- Plan to test further Ps experiments in-situ.



Helium Line shapes

- Line shapes measured by varying microwave frequency.
- Measurements performed at series of pulse times corresponding to different positions in the wave guide.
- Atom cloud approximately 3mm wide set by laser spot size, giving ~ 4 distinct points in the waveguide to measure field.
- Clear broadening of line shapes at one end of the guide implies inhomogeneous field distribution in z direction.



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