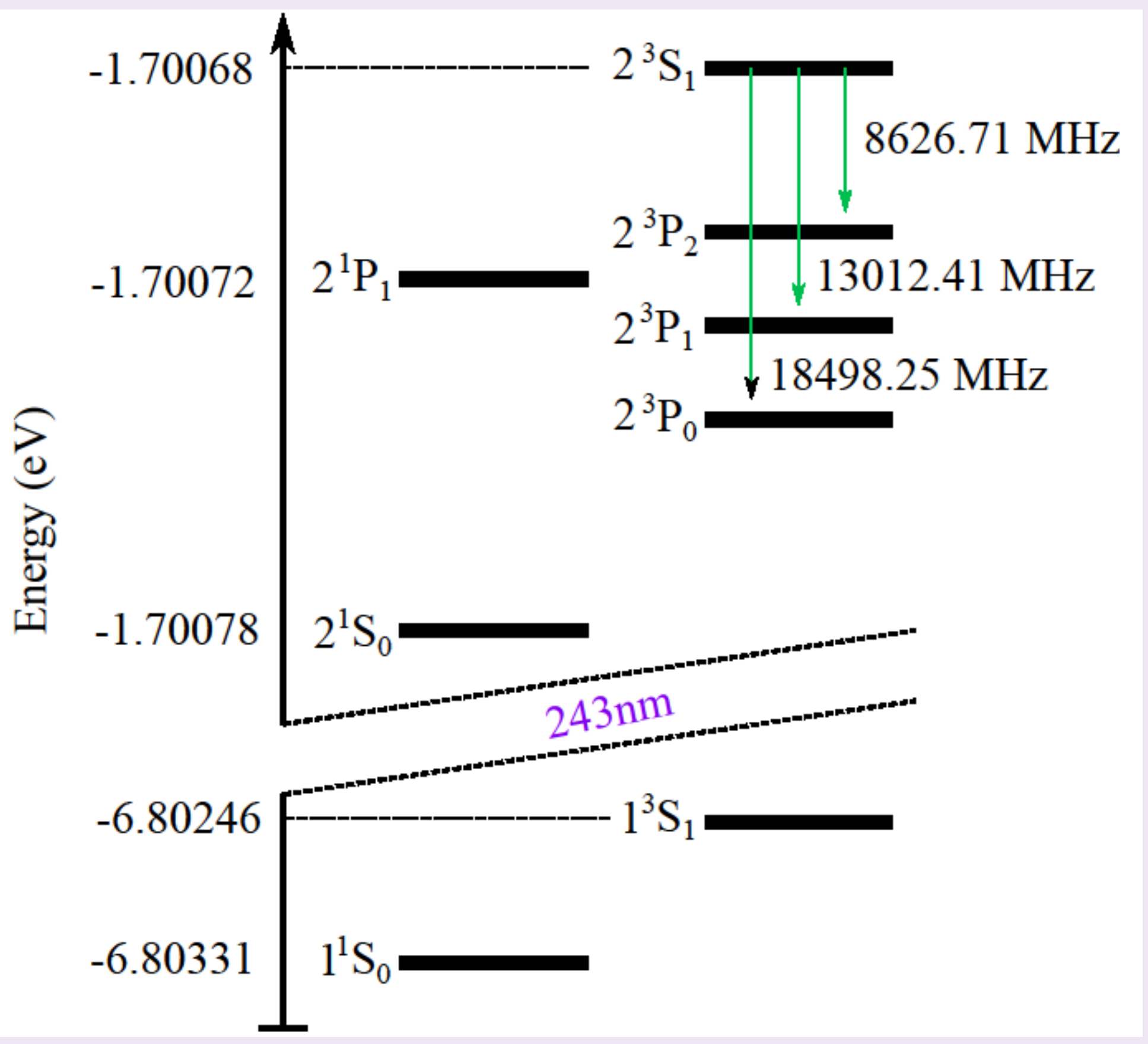
Microwave spectroscopy of the positronium fine structure

S. H. Reeder, R. E. Sheldon, T. J. Babij, S. D. Hogan, D. B. Cassidy

Department of Physics and Astronomy, University College London, UK

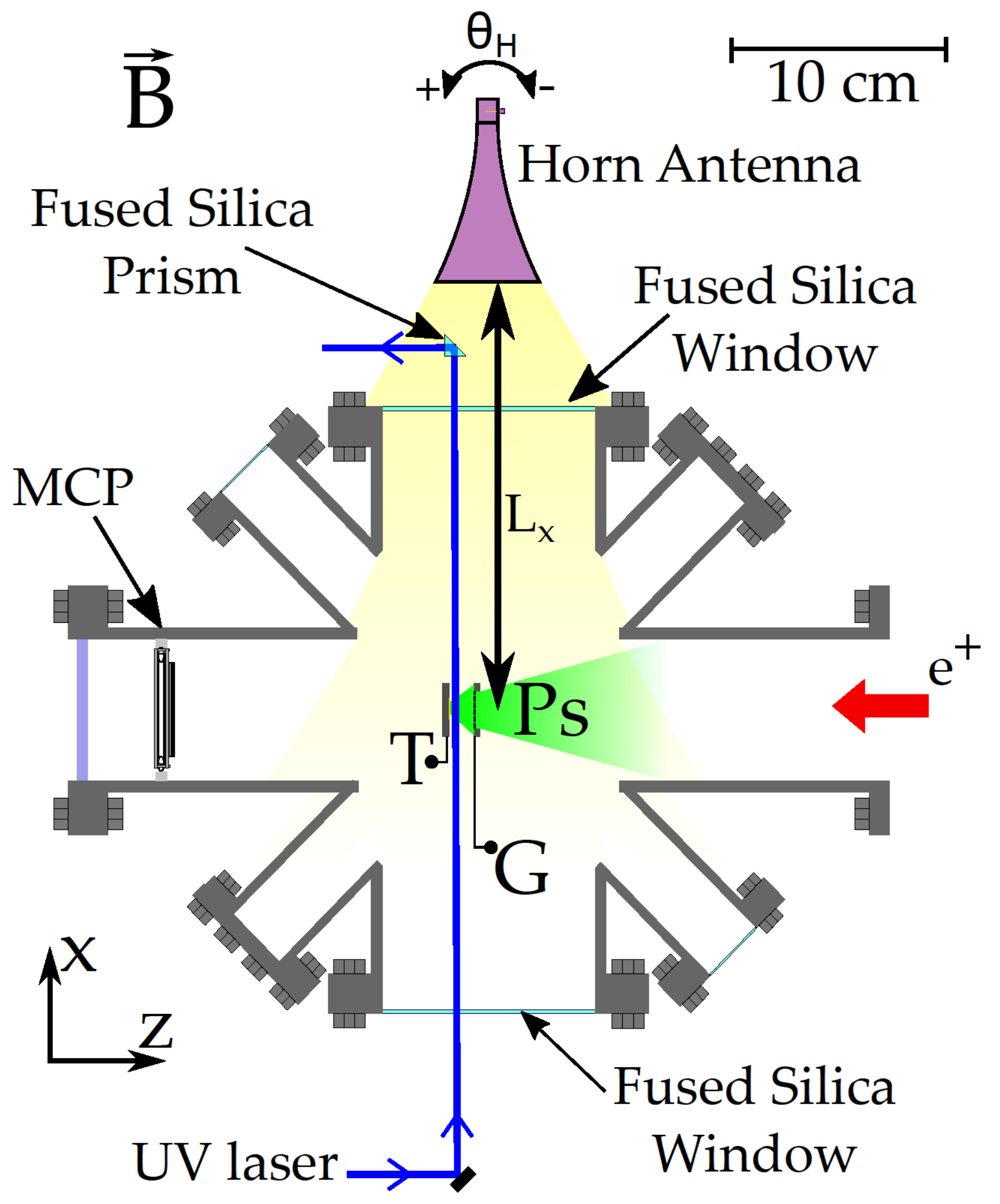
Introduction

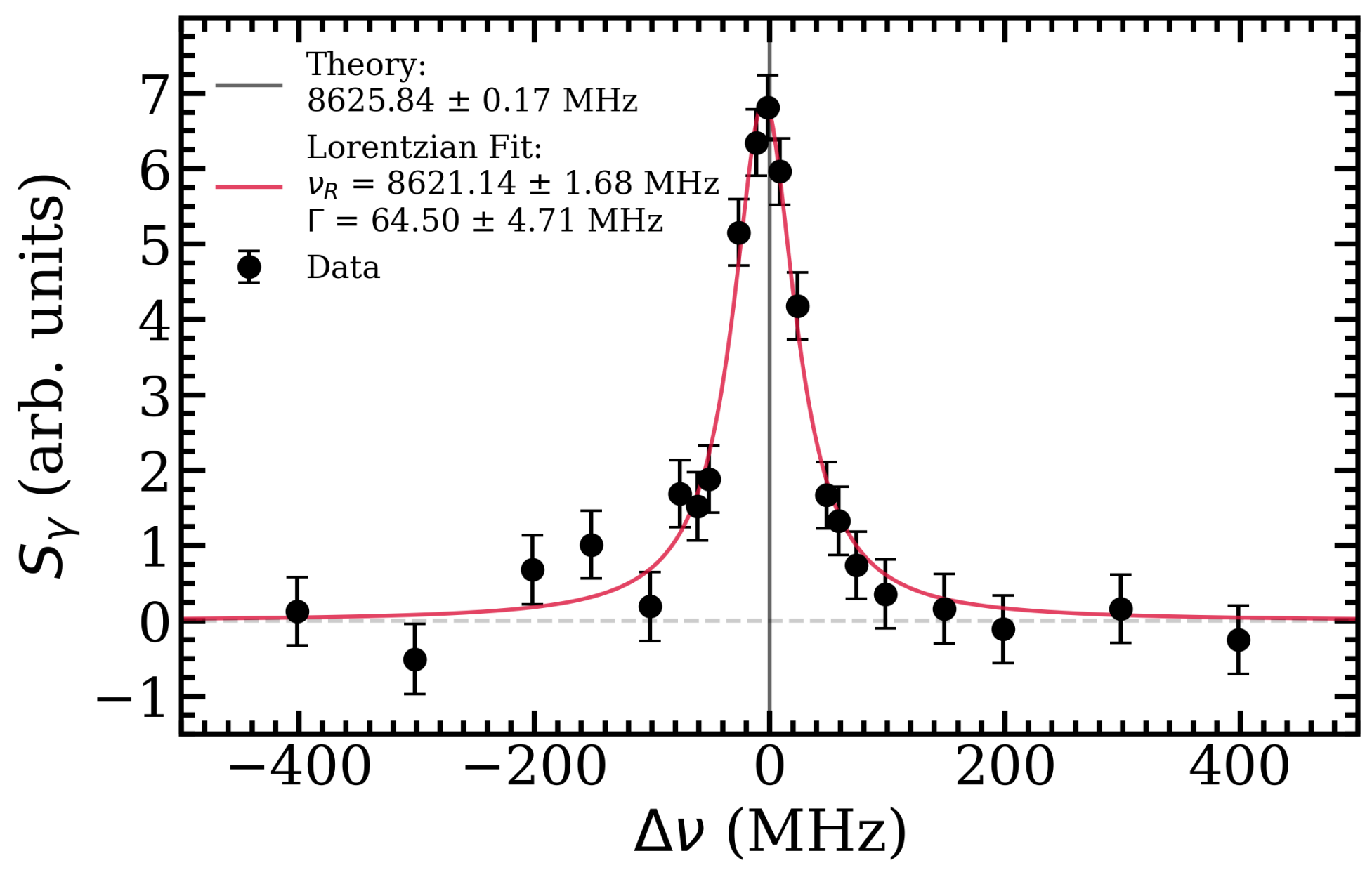
As positronium (Ps) is composed of only leptons and has no nuclear structure, it can be considered to be fully described by QED. Measurements of Ps fine structure are a direct test of bound state QED theory and a useful system to search for physics not included in the standard model [1]. The precision of QED calculations is presently much higher than experimental results. The υ_J intervals have all been calculated with an estimated uncertainty of 80 kHz [2] whereas corresponding experimental uncertainties are >1 MHz. The previous measurements at UCL achieved improved precision, but exhibited asymmetric line shapes and shifts from theory [3]. New microwave spectroscopy measurements have eliminated the asymmetry and further improved precision.



Horn Measurements

- SSPALS used to quantify 2 $^3S_1 \rightarrow 2\ ^3P_2$ transition.
- CST simulations and theoretical calculations [4] indicate reflections could cause shifts.
- Frequency dependent power fluctuations.
- Horn antenna employed to test this and mitigate transit time broadening [5].

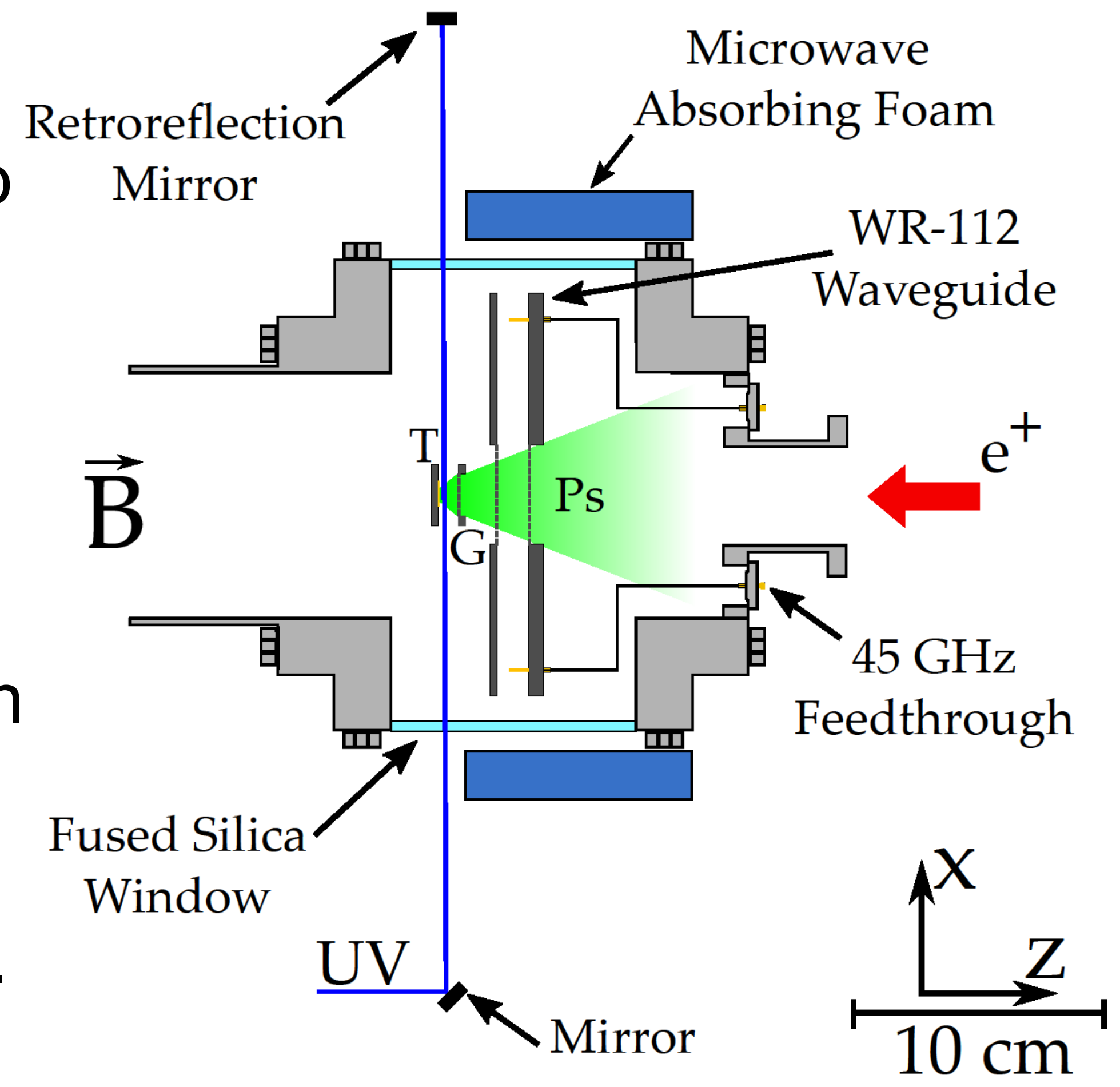




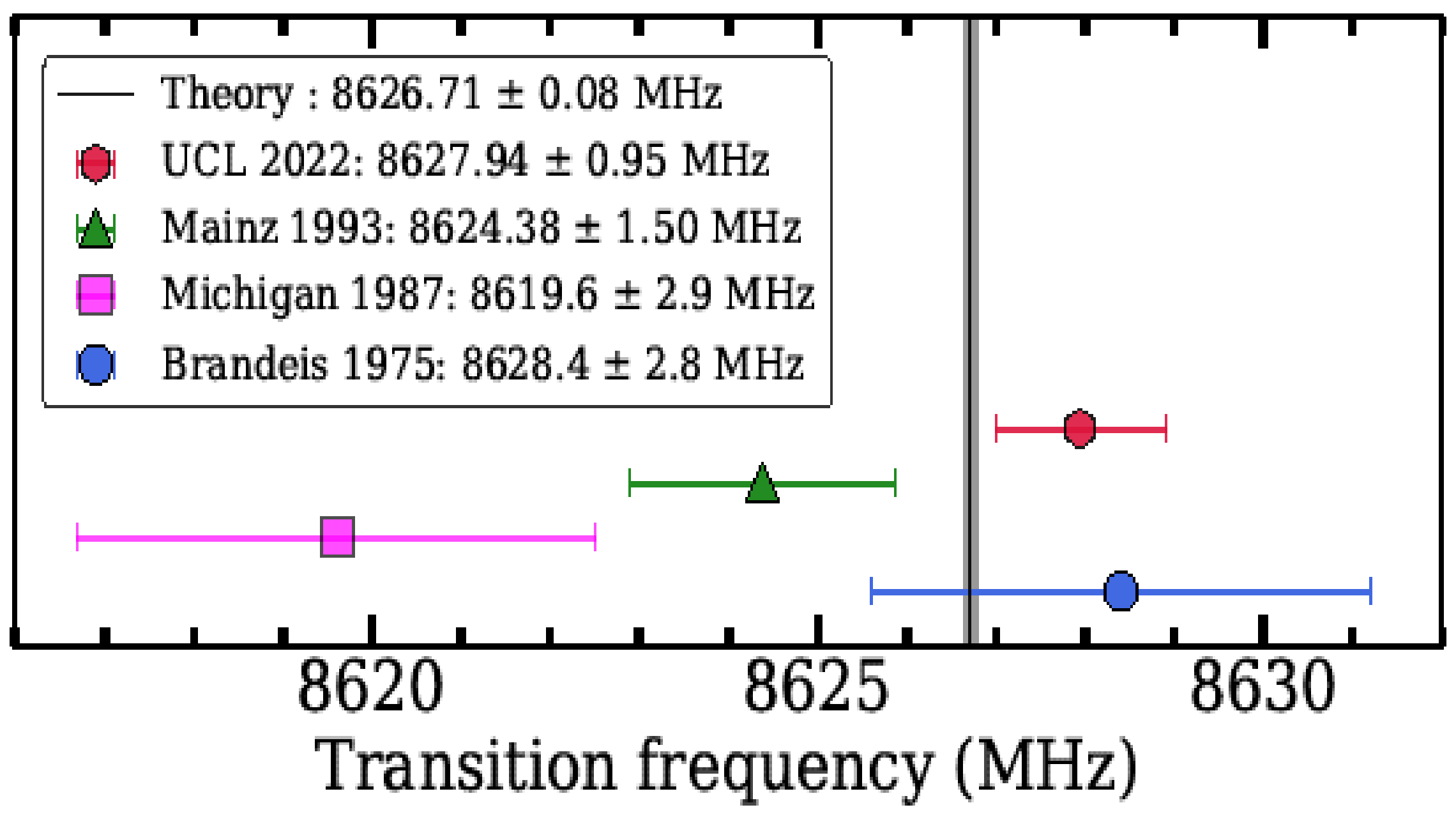
- Symmetric line shapes.
- Confirmed reflections large systematic in broad line shapes.
- Different horn angles lead to varying shifts in centroid value.

Modified Waveguide

- 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.

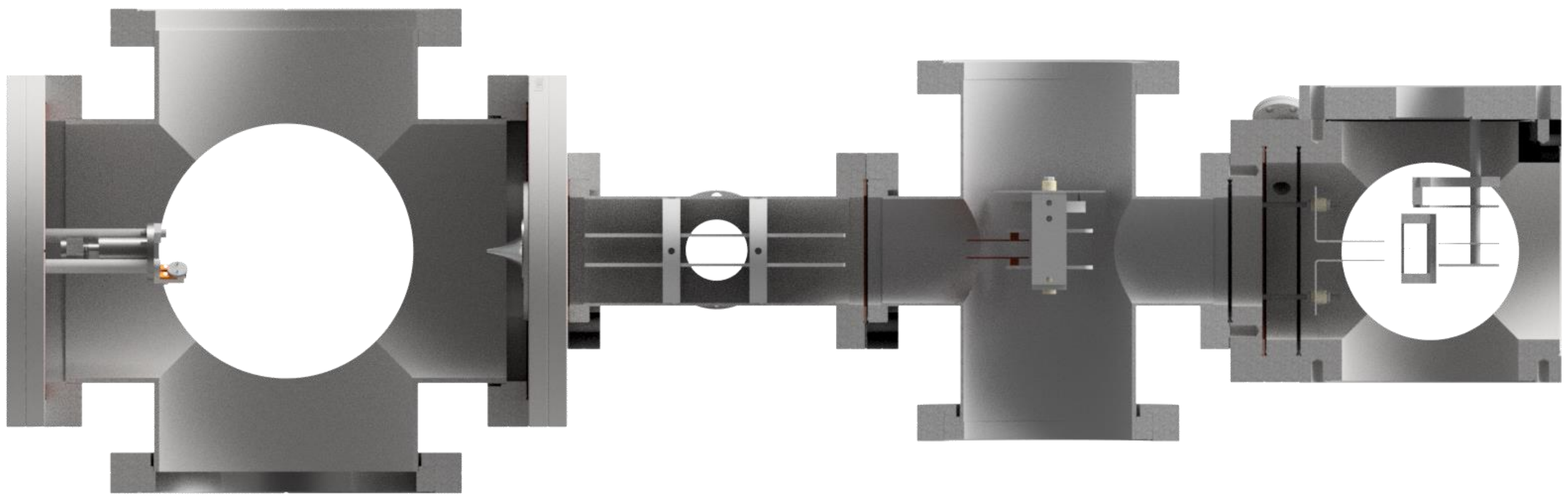


- Final result: $\upsilon_2 = 8627.94 \pm 0.30_{stat} \pm 0.91_{sys}$ MHz
- Shifted from theory by 1.3σ



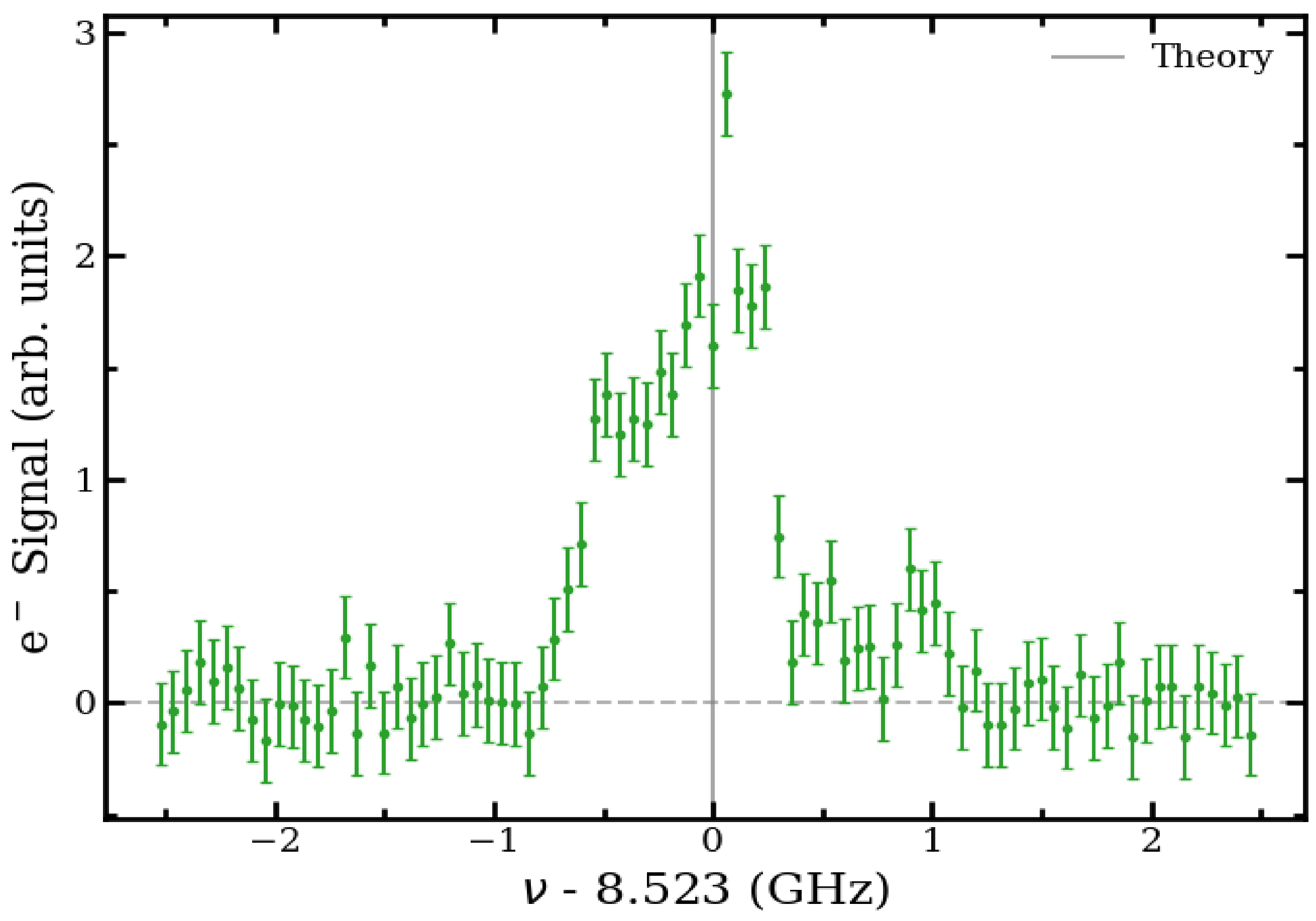
- Previous measurements of 2 $^3S_1 \rightarrow 2\ ^3P_2$ interval and the present work. The vertical line represents the theory value.

Helium Measurements



- Metastable helium $2^3S_1 \rightarrow n^3P_J$ Rydberg states prepared with 260 nm.

- New waveguide measurement uncertainty dominated by systematic caused by waveguide structure.
- Plan to characterise the fields in the waveguide using Rydberg helium microwave dressing method.
- Current estimate of stray electric fields ~0.4 V/cm.



References

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

[2] A. Czarnecki and S. G. Karshenboim, Proc. of the 14th International Workshop on High Energy Physics and Quantum Field Theory, pp. 538–544, 1999.

[3] L. Gurung, T. J. Babij, J. P´erez-R´ıos, S. D. Hogan, and D. B.Cassidy, Physical Review A, vol. 103, p. 042805, April 2021.

[4] L. A. Akopyan, T. J. Babij, K. Lakhmanskiy, D. B. Cassidy, and A. Matveev, Physical Review A, vol. 104, no. 6, pp. 1–14, 2021.

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

s.reeder@ucl.ac.uk