Rydberg Positronium manipulation for a new measurement of the Rydberg constant

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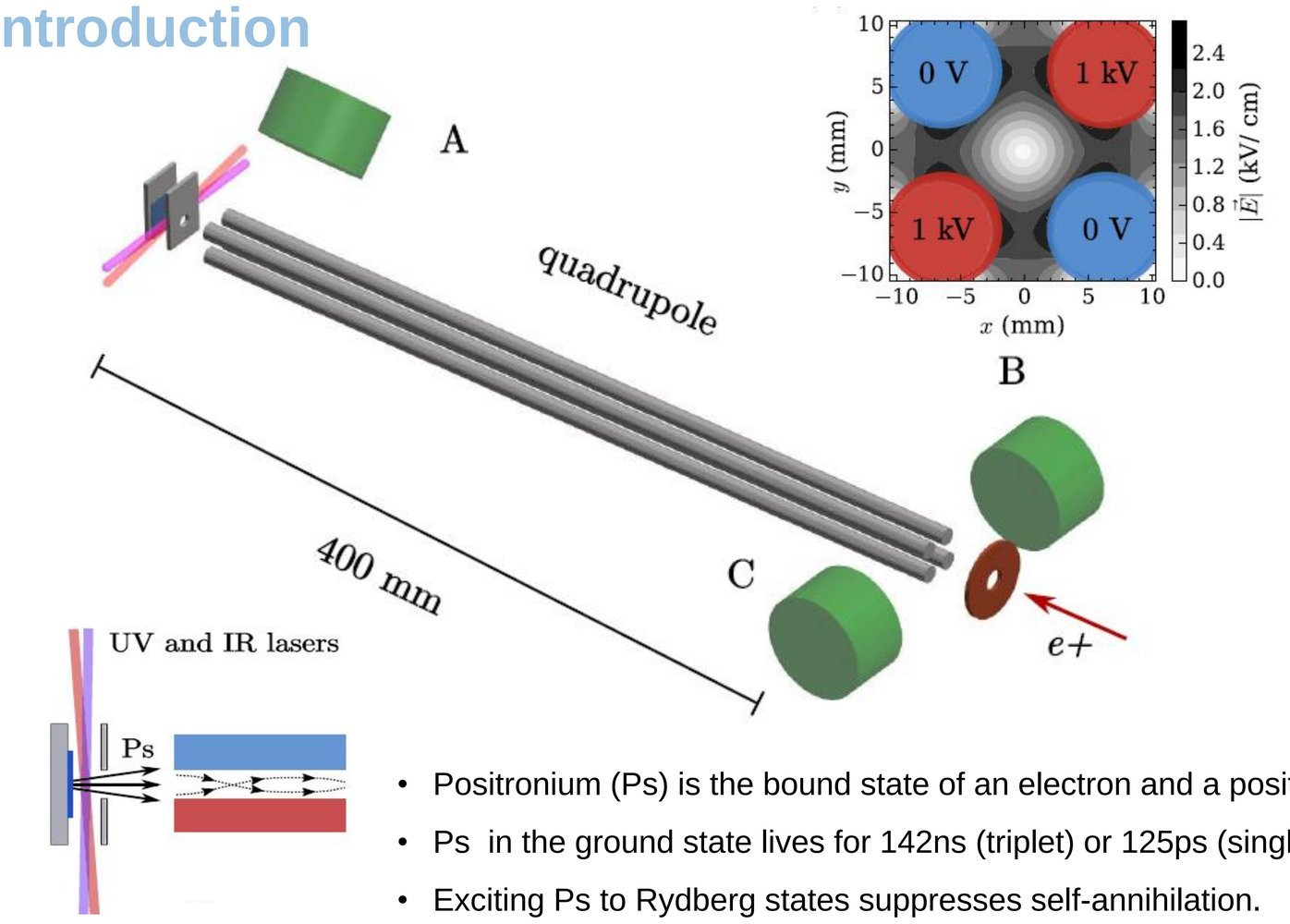
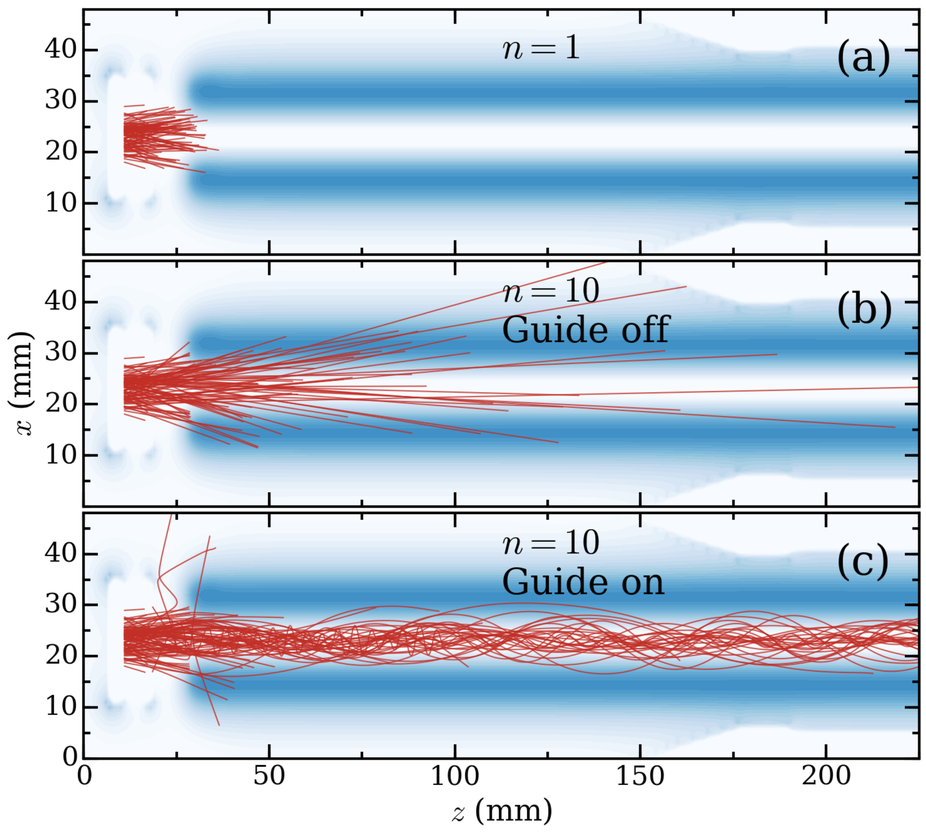
Introduction

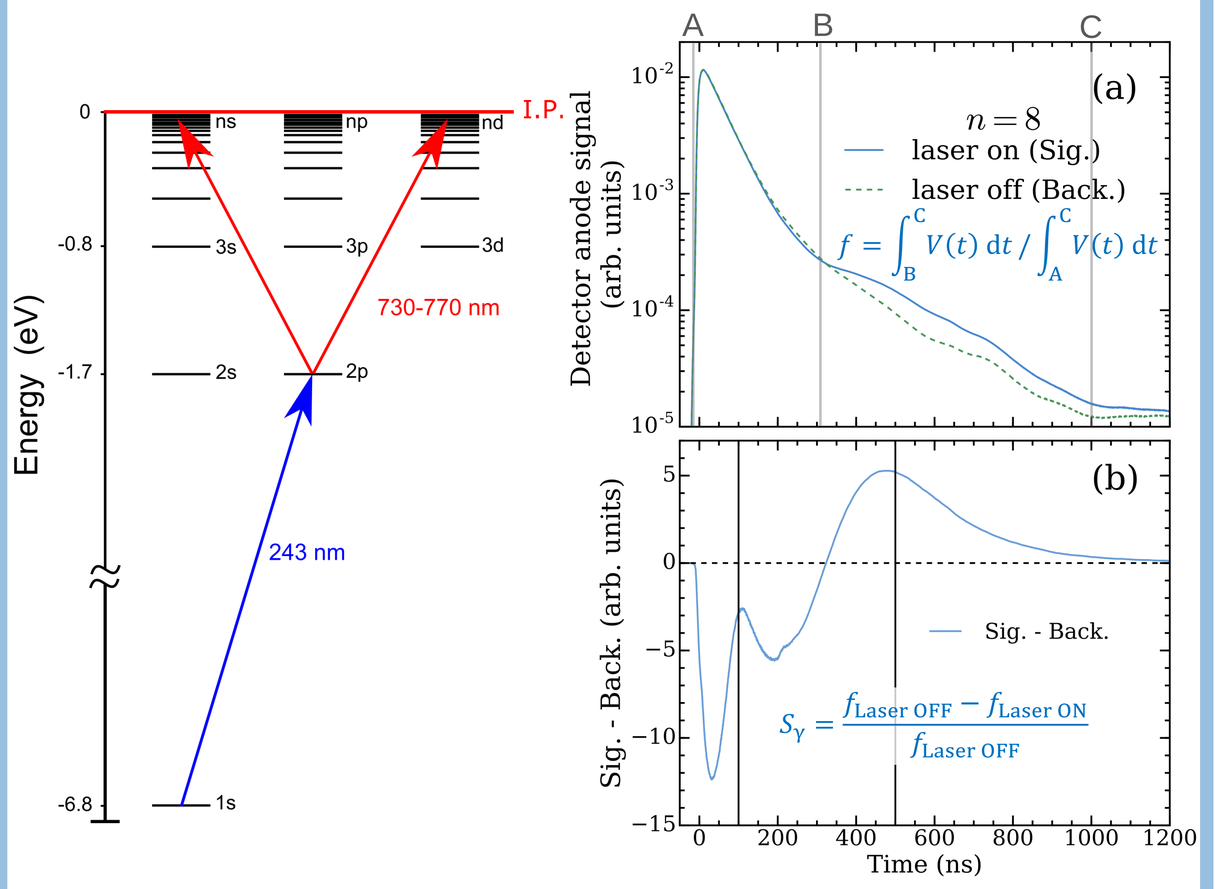


- Positronium (Ps) is the bound state of an electron and a positron.
- Ps in the ground state lives for 142ns (triplet) or 125ps (singlet).
- Exciting Ps to Rydberg states suppresses self-annihilation.



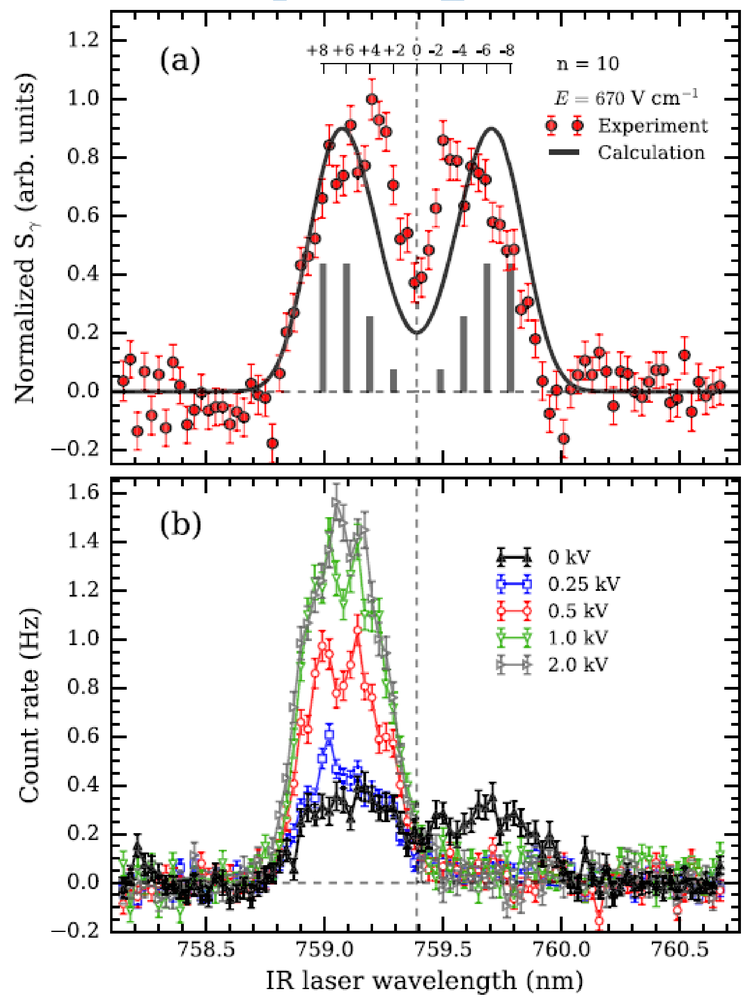
Ps may be guided in a quadrupole electric field if excited to low-field seeking states. See simulations showing increased lifetimes and radial confinement due to quadrupole.

Production, excitation and detection



- e^+ pulse produced with buffer gas trap [1] and implanted into porous SiO_2 target, forming a dilute Ps gas of density up to $\rho = 10^7 \mathrm{cm}.^{-3}$.
- Excitation performed via $1\,^3S_1 \rightarrow 2\,^3P_J \rightarrow n\,^3D_J/\,^3S_J$ two-photon scheme.
- **Detector A:** Ps atoms detected by measuring γ-ray lifetime spectra with a scintillator using single shot annihilation lifetime spectroscopy [2]. Region of interest, defined as f. Signal S_γ defined as fractional change in f.
- **Detectors B & C:** Guided Ps atoms (low field seeking states) were detected via single-event counting achieving combined detection rates of 1-2 Hz.

Guided Rydberg Ps



Measurement of $n = 10$ manifold at various guide voltages [3]:

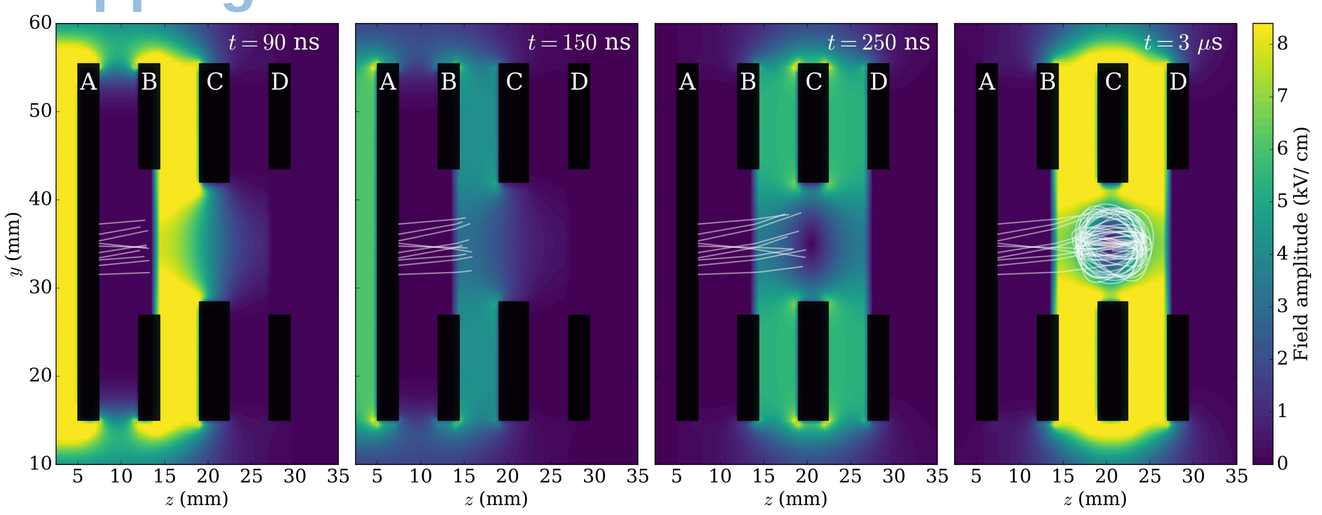
(a) S_γ as measured by detector A.

(b) count-rate for detectors B & C.

When no voltage is applied, a small amount of both low and high field seeking states are transmitted.

Low field seeking count-rates are enhanced with higher electric fields since the confinement potential is increased. Simulations suggest efficiencies of ~10%.

Trapping simulations



Simulations for deceleration and trapping Ps atoms. Velocity spreads are fitted to experimental data and suggest trapping efficiencies of >5% are possible.

Outlook

A slow Rydberg Ps beam will be key for making a new measurement of R_∞[4] since second-order Doppler effects are very large for Ps. Such a measurement would contribute towards the “proton radius puzzle” [5]: a measurement of the proton charge radius using muonic hydrogen which disagrees with atomic hydrogen. Measuring R_∞ with Ps will not include finite-size corrections (Lamb shift) since it is a purely leptonic system. If this measurement were used to calculate the proton radius, it could determine if the discrepancy is caused by previously unknown corrections to R_∞.

References

[1] J. R. Danielson, *et. al* Rev. Mod. Phys **87**, 247 (2015).

[2] D. B. Cassidy, *et. al* Jr., Appl. Phys. Lett. **88**, 194105 (2006).

[3] A. Deller, *et. al* Phys. Rev. Lett. **117**, 073202 (2016)

[4] J. C. De Vries PhD Thesis MIT (2001).

[5] R. Pohl *et al* Nature, **466**, 213 (2010). Phys. **13**, 18705 (2011).

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