State selective field ionization of Rydberg positronium

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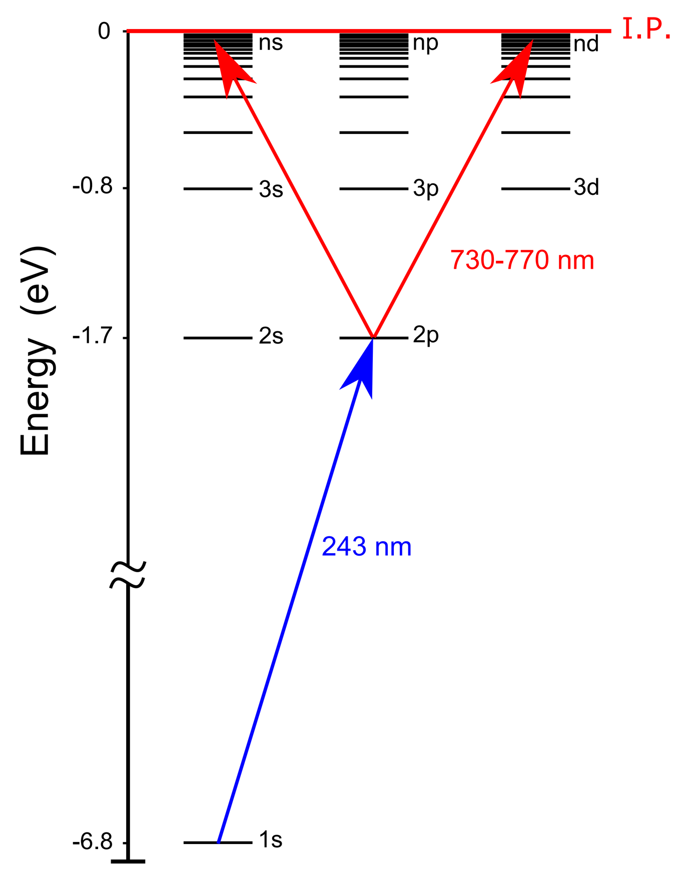
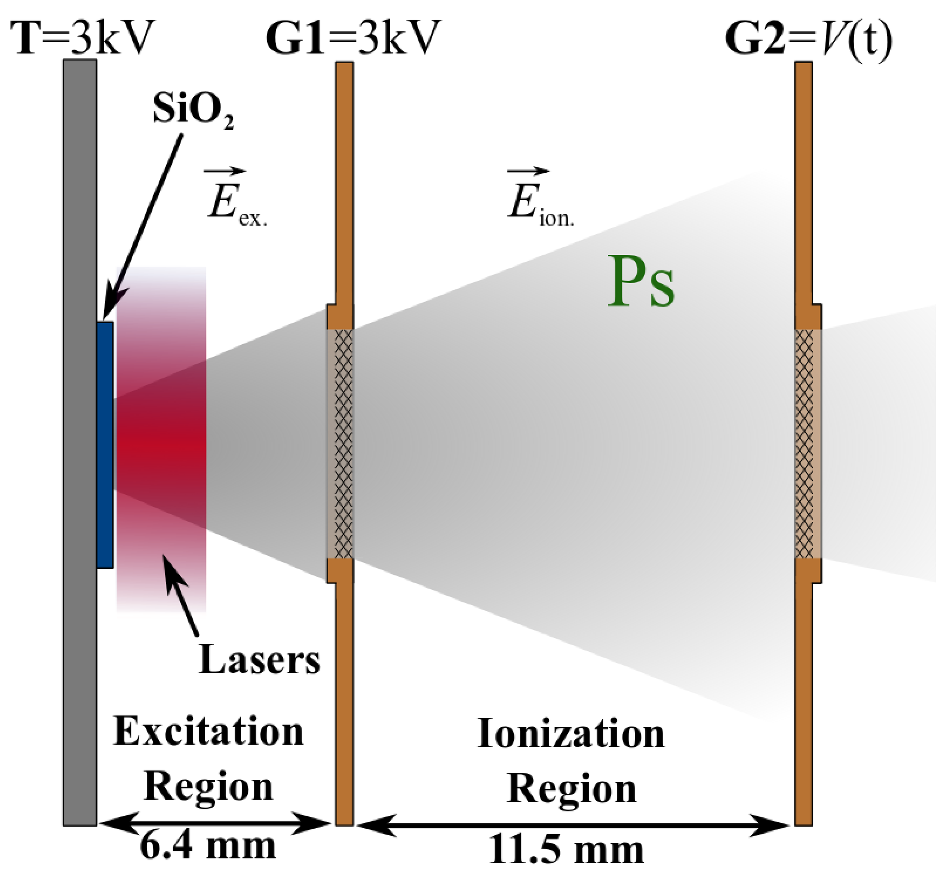
Introduction

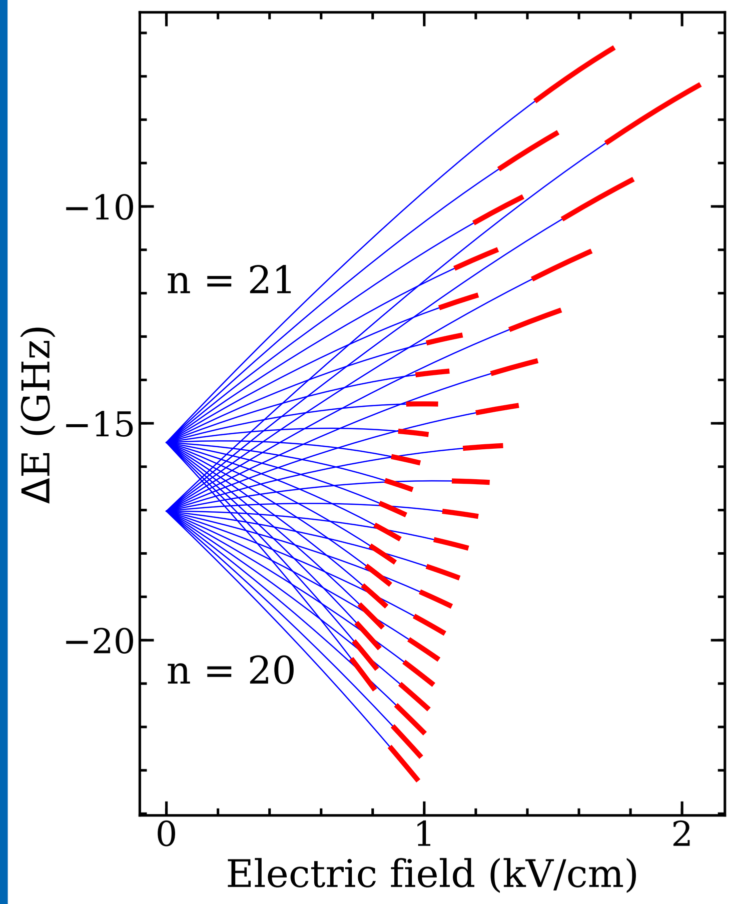
- Positronium (Ps) is the bound state of the electron and the positron
- Ps has a short annihilation lifetime in the ground state: 125 ps (singlet) and 142 ns (triplet)
- When excited to Rydberg states, self-annihilation of Ps is effectively switched off
- Additionally, Rydberg atoms have large tunnel ionization rates in relatively small electric fields [1]
- This property can be exploited for state selective detection of Rydberg atoms [2]
- This state selective detection method can be used for Rydberg Ps spectroscopy





Production, Excitation and Detection

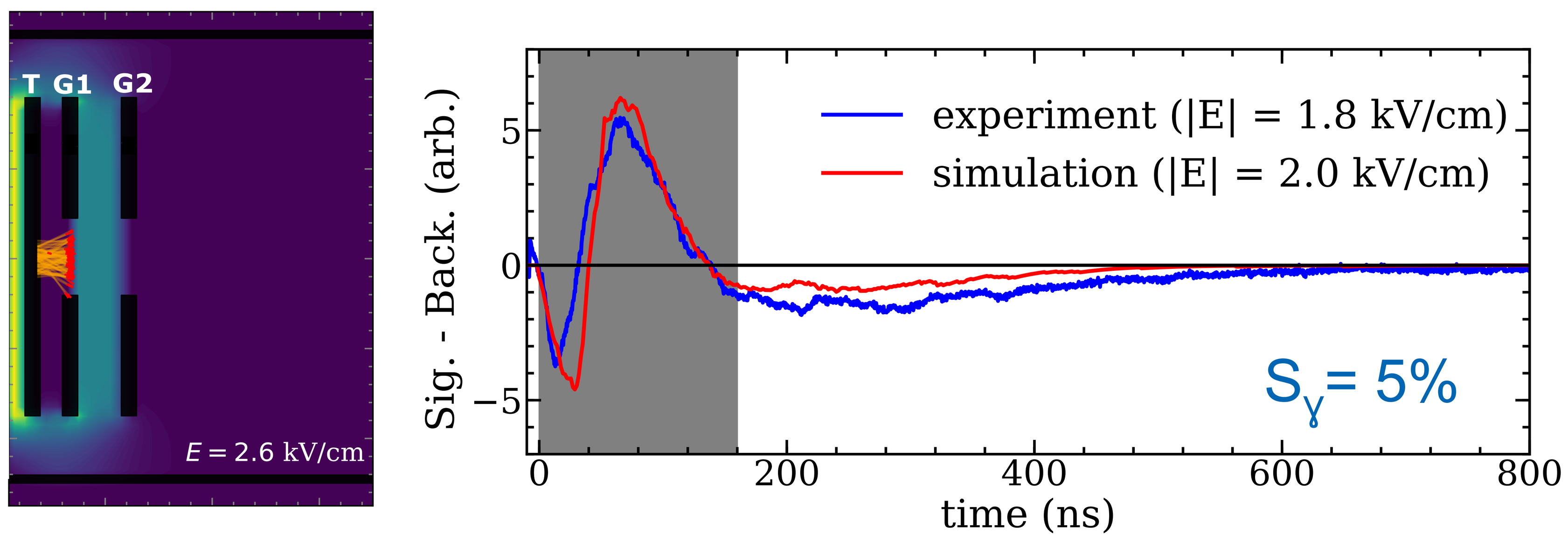
- Positrons from a Surko-type buffer gas trap are implanted into a mesoporous silica target to form ground state Ps
- Ps atoms are excited to Rydberg states via a two-photon, two-color excitation scheme: $1\,^3S_1 \rightarrow 2\,^3P_J \rightarrow n\,^3D_J\,/\,n\,^3S_J$
- Rydberg Ps atoms are allowed to enter the region between Grid 1 (**G1**) and Grid 2 (**G2**) where an ionising electric field is applied
- Ionisation was detected by measuring γ-ray lifetime spectra using single-shot lifetime spectroscopy (SSPALS) [3]



Static Field Configuration- Simulations

- The strength of the ionising field determines whether none, some or all Rydberg-Stark states in the *n* manifold are ionised
- Background subtracted signals (below) show explicitly where there is an excess or lack of annihilations with respect to ground state Ps
- In the high ionising field case (a) we observe a peak in the ionisation region (shaded) and in the low ionising field case (b) there is a dip in the ionising region
- Experimental data is in broad agreement Monte-Carlo simulations that include (scaled) tunnel ionization calculated for Hydrogen (H) [4]

a.



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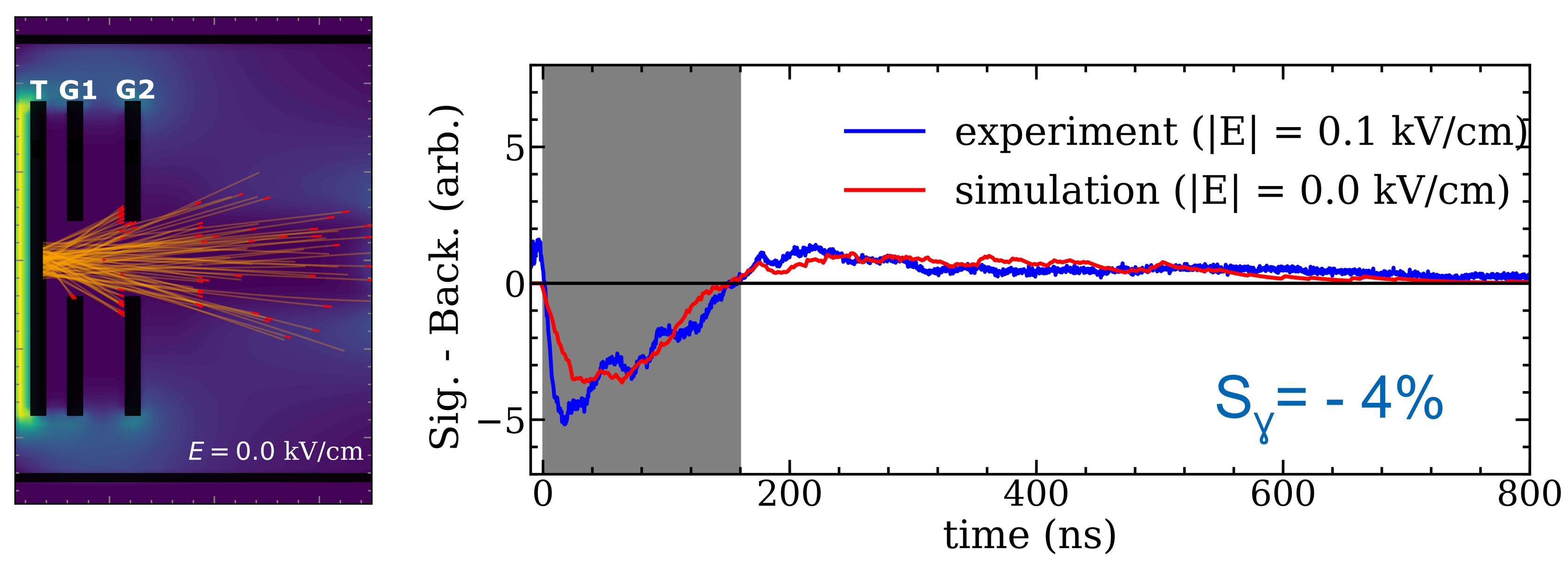
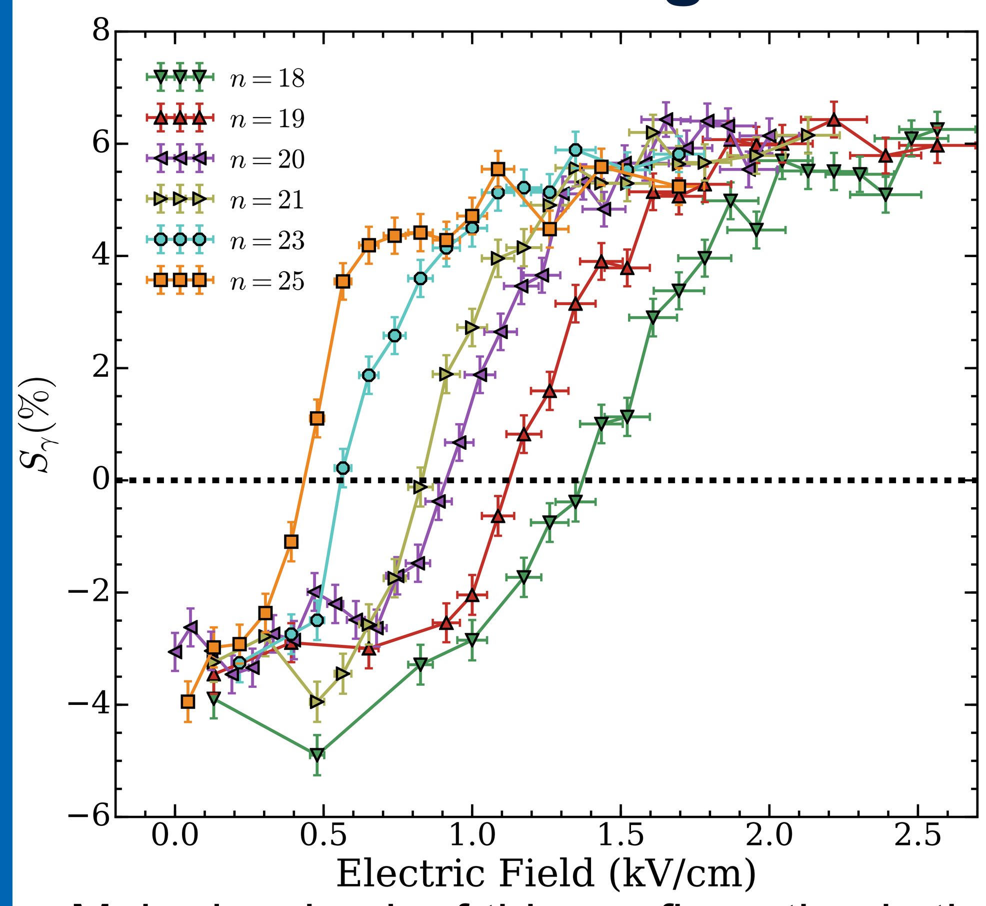


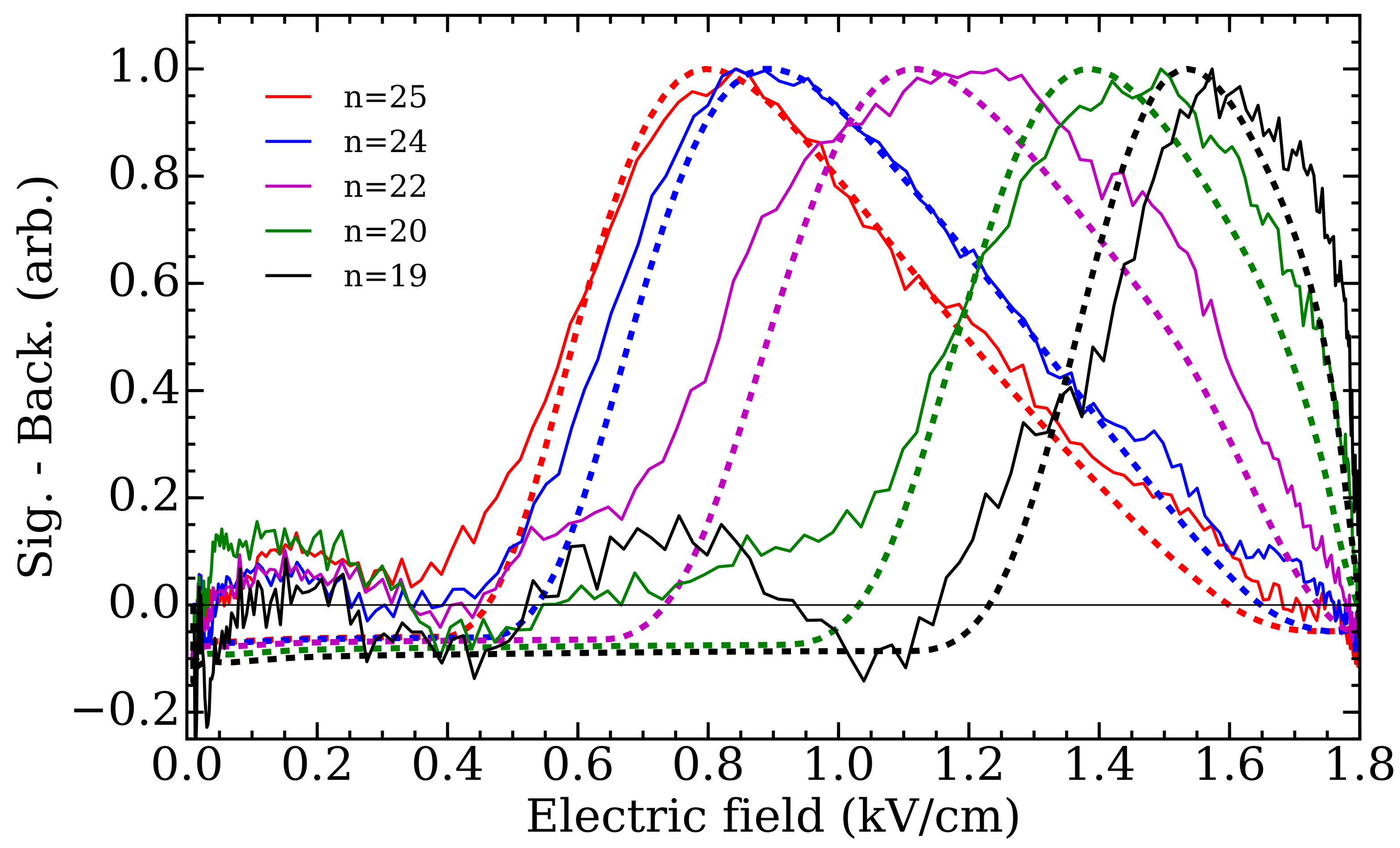
Static Field Configuration- Results



- S_γ parameter indicates where annihilations occur:
- Large positive S_γ: → excess early annihilations
- Large negative S_γ: → late annihilations
- S_γ = 0 indicates where half of the atoms annihilate in the ionization region while the other half travels through

- Main drawback of this configuration is that signal is convoluted with the velocity distribution of the atoms
- It would be difficult to measure a Rydberg-Rydberg transition in this configuration

Pulsed Field Configuration



- Ps atoms are allowed to enter ionization region before the ionising field is ramped with time. This eliminates the dependence of the signal on the velocity distribution of the atoms
- Different Rydberg states are distinguished by the time/field at which their ionization peak appears
- There is again broad agreement between measurement (**solid lines**) and simulations which include the scaled H ionisation rates [4] (**dashed lines**)
- This method can be used to measure a possible Rydberg-Rydberg transition

Summary

- The broad agreement between simulation and experiment indicating that the underlying tunnel ionisation process is not significantly affected by any processes that may occur in Ps by not H
- We have demonstrated state selective detection for Rydberg Ps in both a static and pulsed electric field configuration
- This detection technique opens the door to new spectroscopic investigations of Rydberg Ps and may be used for:

i) accounting for Rydberg-Rydberg transitions due to black-body radiation
ii) electric field cancellation methods to generate circular Rydberg states of Ps

References

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[3] *Single shot positron annihilation spectroscopy*. D. B. Cassidy, S. H.M. Deng, H. K. M. Tanaka, and A. P. Mills, Jr., Appl. Phys. Lett. **88**, 194105 (2006)
[4] *A hydrogen atom in a uniform electric field*. III. R. J. Damburg and V. V. Kolosov. J. Phy. B. 12, 2637 (1979).

Positronium Spectroscopy

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