Measurement of the fluorescence decay rate of 2^3P_J positronium

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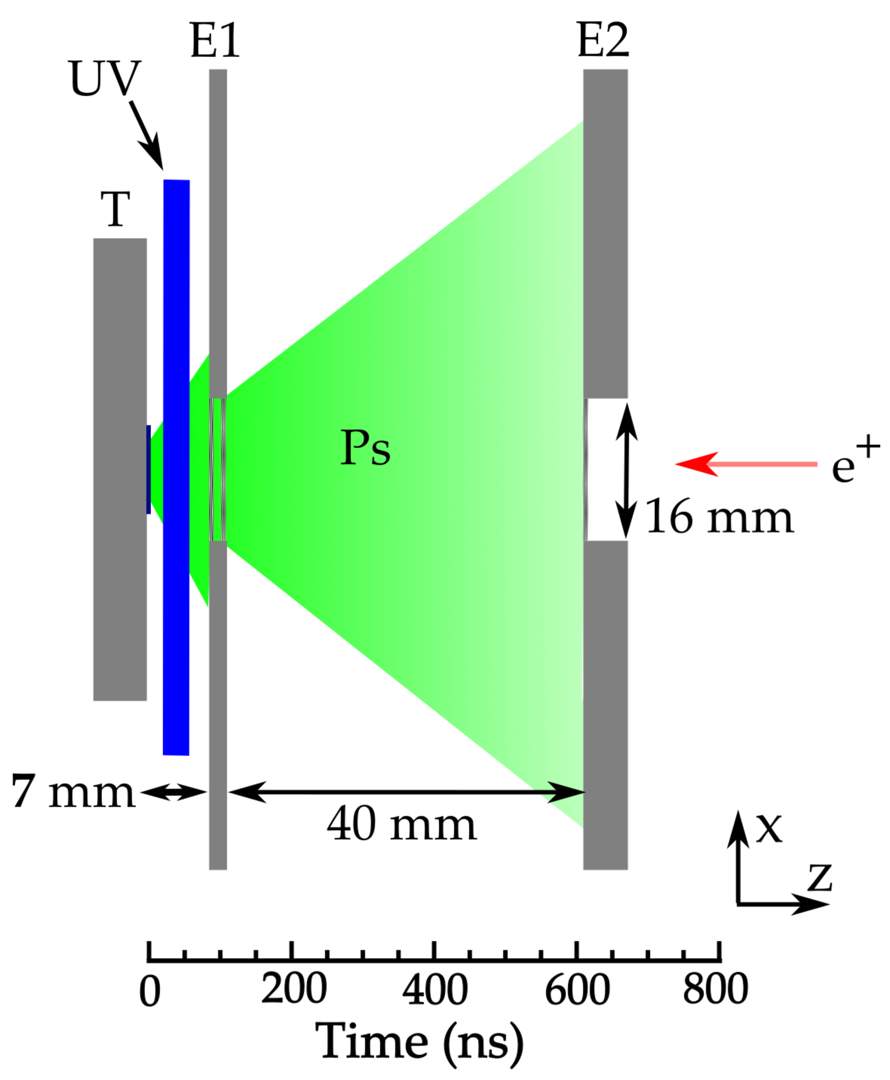
Introduction

- Measurements of positronium (Ps) decay rates can be used to test QED theory [1] and contribute to the search for new physics.
- Due to its composition as a particle-antiparticle system, Ps is metastable, and can decay by fluorescence and self-annihilation at rates that depend on the overlap of the electron-positron wavefunctions.
- The decay rates of the $1\,^1S_0$ and $1\,^3S_1$ Ps ground states have been measured [2,3], and in 2020 the $2\,^3S_1$ annihilation decay rate was measured as $\Gamma_{exp}(2\,^3S_1) = 843 \pm 72$ kHz [4], which is consistent with theory.
- Here we report a measurement of the fluorescence decay rate of the excited $2\,^3P_J$ state of Ps.

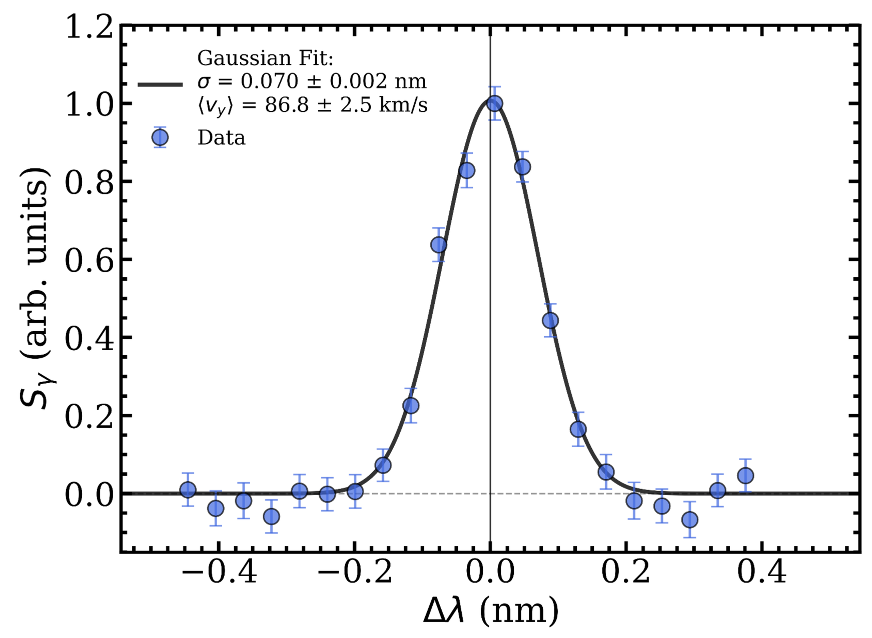
Ps production

- DC positrons emitted from an Na-22 source were pulsed in a Surko-type buffer gas trap to produce pulses of 3 ns, 3 mm (FWHM) consisting of ~10^5 positrons.
- The positron pulses were implanted into an SiO_2 target to produce Ps atoms.
- Ps atoms were emitted from the target, to be irradiated by ultra-violet (UV) (λ = 243 nm, Δt = 4 ns, $\Delta\nu \approx$ 100 GHz and infra-red (IR) (λ = 730 nm, Δt = 5 ns, $\Delta\nu \approx$ 5 GHz) dye lasers.



Ps excitation scheme

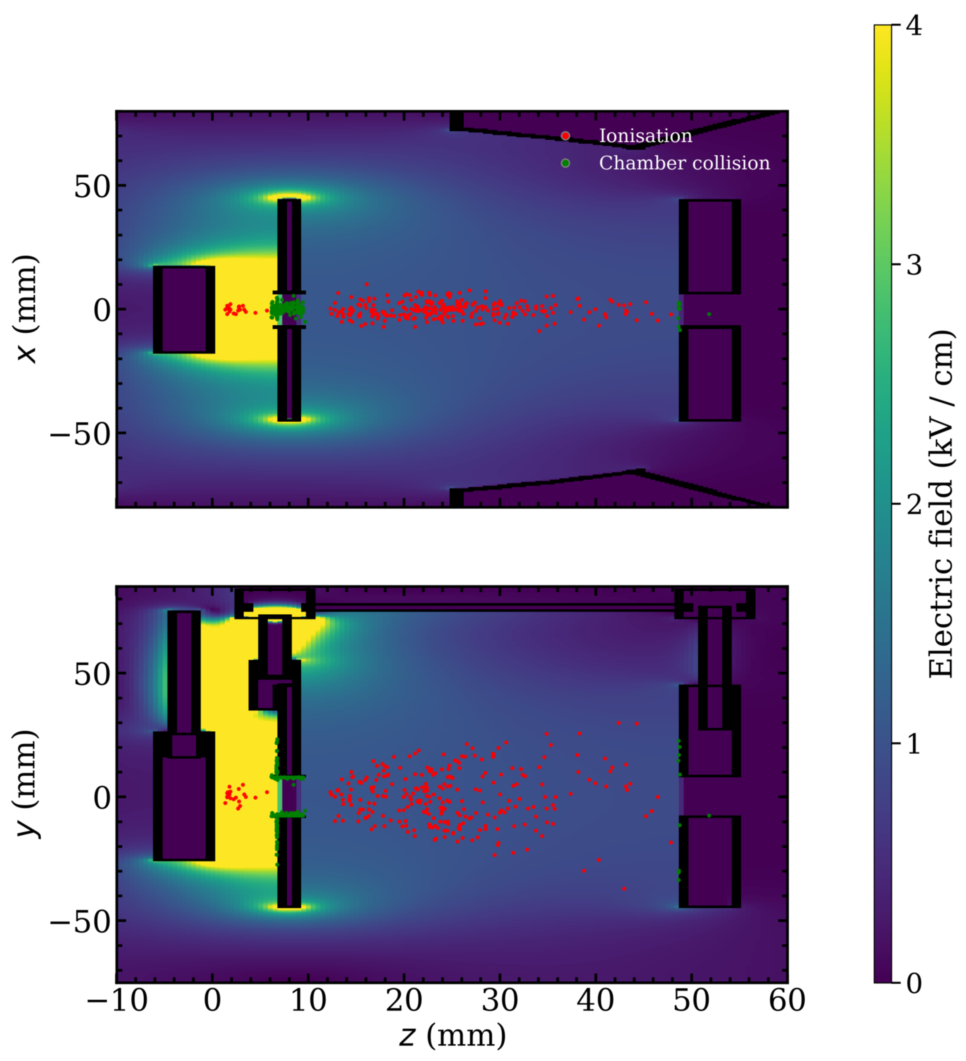
- Ground state Ps atoms were irradiated by the UV laser in a large electric field.
- This produced Stark-mixed $2\,^3S^m{}_1$ states: these are n = 2 excited states with both $2\,^3S_1$ and $2\,^3P_J$ character.
- States with more $2\,^3P_J$ character are more likely to decay quickly by fluorescence.



State	τ_{ann} (ns)	τ_{fl} (ns)
$2\,^3S_1$	1 136	243 100 000
$2\,^3P_0$	100 000	3.19
$2\,^3P_1$	$\simeq \infty$	3.19
$2\,^3P_2$	384 000	3.19

- The electric field is then quickly removed so that the $2\,^3S^m{}_1$ states adiabatically evolve into pure $2\,^3S_1$ states.

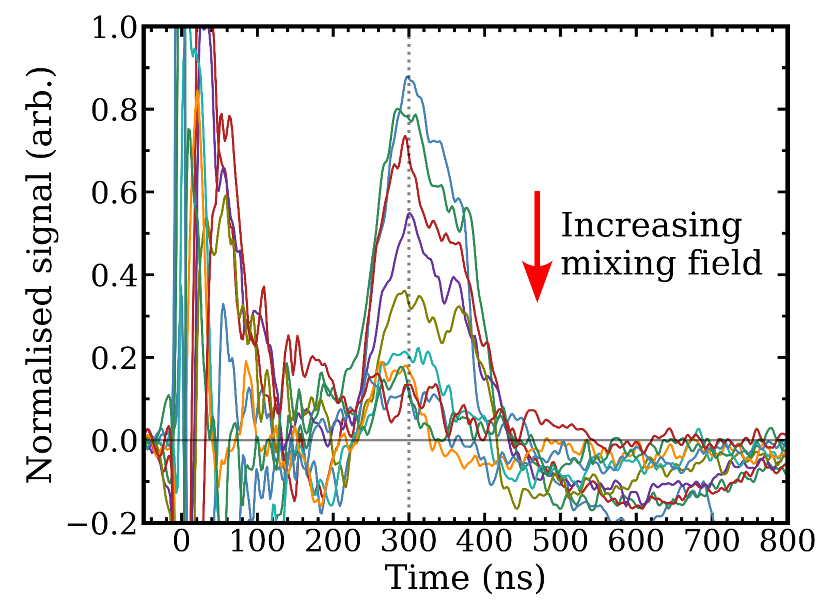
$2\,^3P_J$ lifetime measurement method

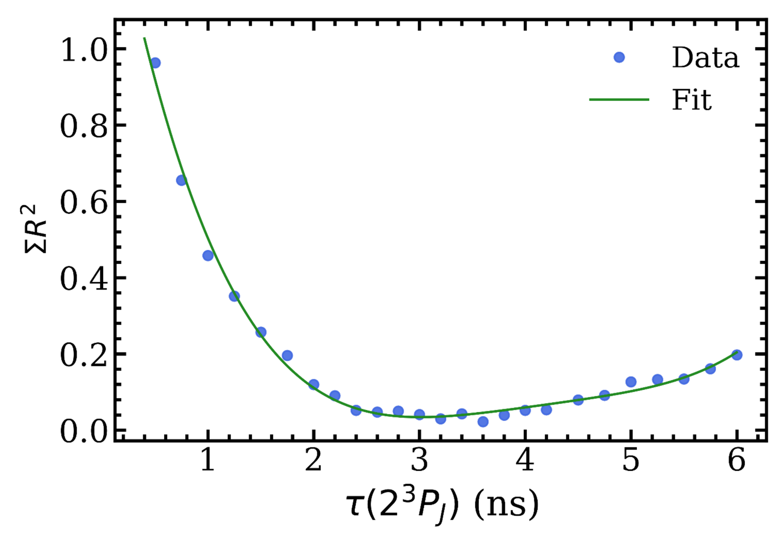


- The $2\,^3S_1$ atoms entered a DC 'mixing' field and gained $2\,^3P_J$ character by Stark mixing.
- The atoms were left to propagate for a time T, and some mixed states decayed via $2\,^3S^m{}_1 \rightarrow 1\,^3S_1 \rightarrow \gamma\gamma\gamma$
- A large field was then applied to quench the remaining mixed-state atoms via the same decay route, producing photons which were measured.
- This was repeated for a range of mixing field strengths, to introduce various levels of $2\,^3P_J$ character.

$2\,^3P_J$ lifetime result

- The quenching experiment was simulated, with the $2\,^3P_J$ decay rate as a variable parameter.
- The $2\,^3P_J$ decay rate corresponding to the best match between simulation and experiment is our result.
- We obtain $\Gamma_{exp}(2\,^3P_J)$ = 345 $\pm$ 59 MHz, in broad agreement with the theoretical value of 313 MHz.





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