Measuring the Orthopositronium Annihilation Decay Rate

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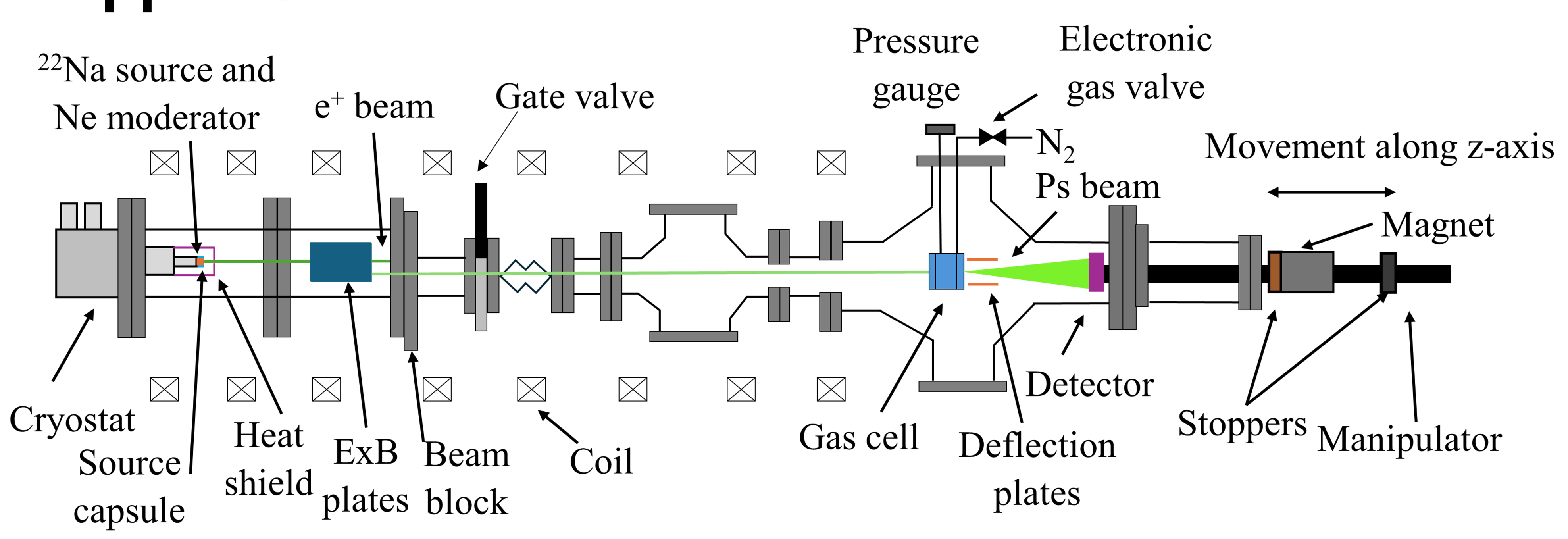
Introduction

- Precision measurements of Positronium (Ps), being a purely leptonic system with an absence of hadrons, may be used to test bound-state QED theory and create a more complete picture within the standard model.
- Current triplet ground state decay rate (o-Ps) measurements [1] exhibit uncertainties of 100 parts per million (100 ppm), two orders of magnitudes larger than theory (2.7 ppm [2]).
- The precision of previous measurements, utilising positronium annihilation lifetime spectroscopy (PALS) techniques [1,3,4], were limited by the need to consider interactions between Ps atoms and material in the formation target during decays, as well as external fields.
- We present a technique wherein interactions of Ps with the environment are not considered, by allowing an energetic Ps beam to decay in free space and assessing the surviving fraction of a beam as a function of flight time.

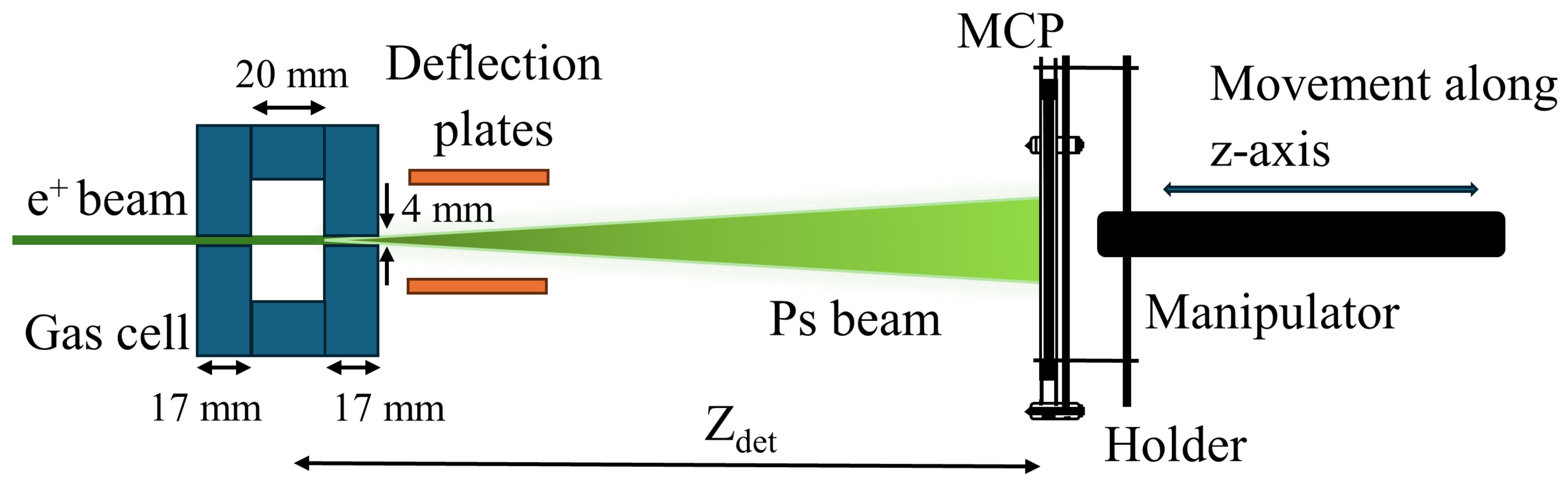
Apparatus



Positrons from a ^{22}Na source were thermalised by a solid neon moderator and emitted into a vacuum as a monoenergetic beam.

A Ps beam, primarily ground state, formed through positron-N_2 gas collisions in a gas cell [5, 6]. The beam was accelerated to the required energy by an electric field.

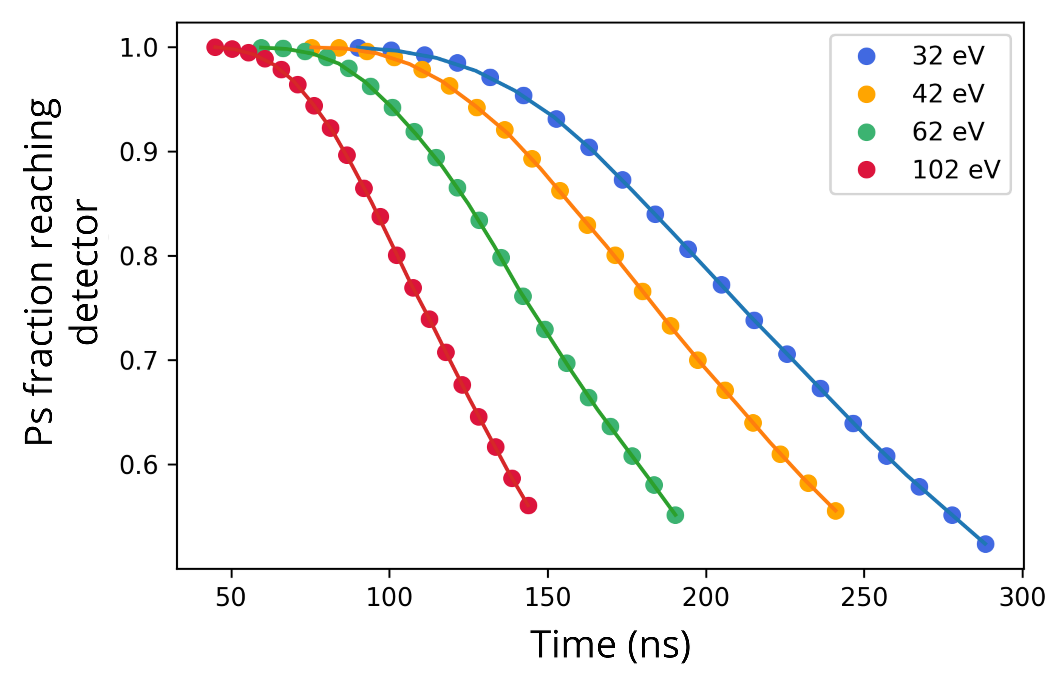
The energy distribution of the Ps beam, determined by the incident positron beam, follows a Gaussian distribution, with a full width at half maximum ≈ 1.3 eV [6].

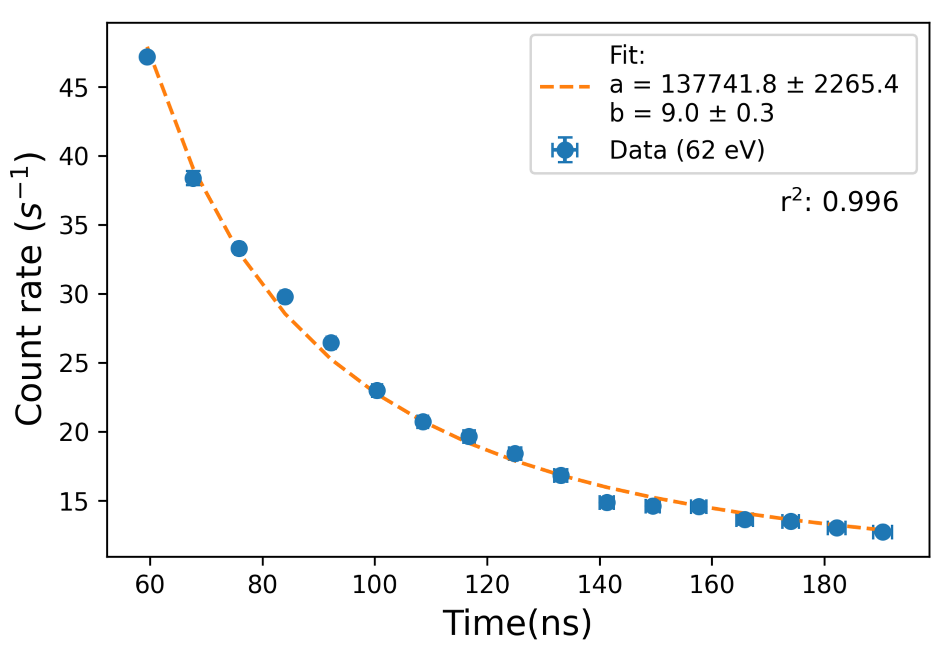


The counts at various distances from the gas cell were measured using an adjustable micro-channel plate (MCP) detector, mounted onto a linear magnetic manipulator.

Ps lifetime

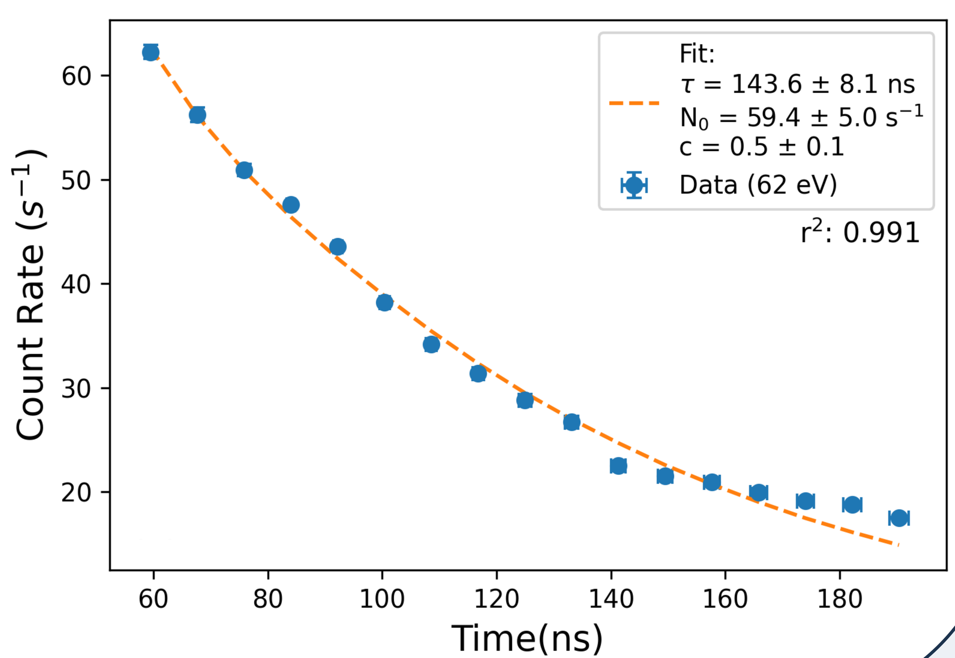
Monte Carlo simulations used measured velocity distributions to identify the Ps fraction missing the (37.5 mm radius) detector due to **beam divergence**, generating a function f(t) using linear interpolation.



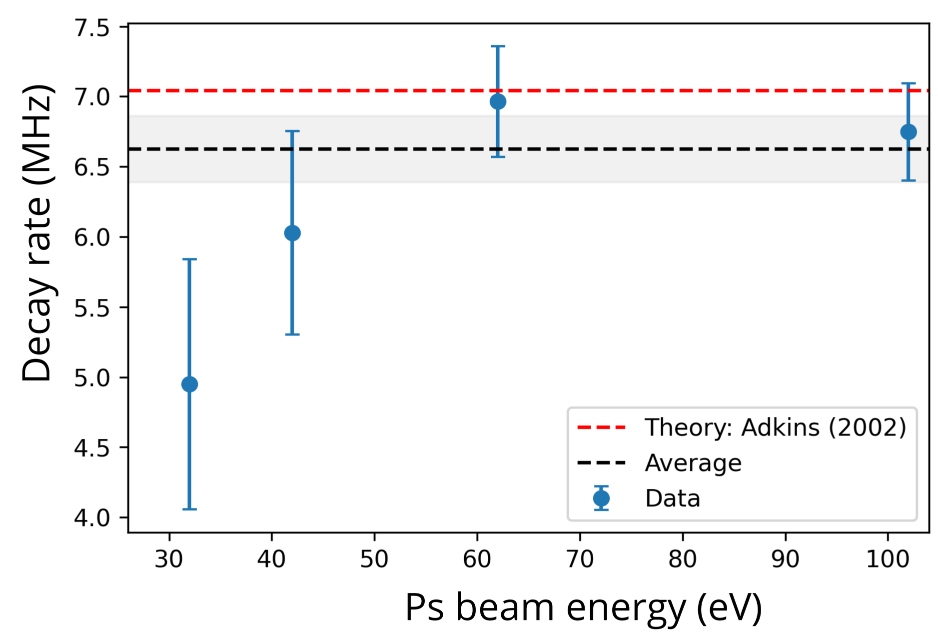


A function $g(t) \propto 1/t^2$, was fitted to the **background count rate** (2-photon background, electronic noise, dark counts) over flight time (obtained by dividing distances by Ps beam velocity.)

The o-Ps lifetime (τ), along with initial counts (N_0) and constant (c), were obtained as fit parameters from an exponential fit of $\mathbf{N_0 e^{-t/\tau} f(t) + c g(t)}$, on the total measured count rate as a function of flight time.



Decay rate



A weighted average over values for various Ps beam energies yielded a final decay rate: **6.62 ± 0.24 MHz**.

This is within **1.8σ** of the theoretical value (7.039979 MHz [2].)

The precision was limited by a high gamma background and low Ps formation rate, large measurement range and creation of some long-lived 2S state atoms (≈ 4%.)

Potential improvements:

- Shielding detector from radiation using a beam deflector and high-Z shield around gas cell.
- Decreasing range of Ps beam loss through collimation, a larger movable detector area or an imaging detector to identify point of loss.
- Eliminating 2S fraction with a high-power microwave radiation source to drive transitions to shorter lived states.

References

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