Mirror matter: towards a precise measurement of ortho-positronium lifetime

Justyna Mędrala-Sowa [1, 2], Elena Perez del Rio [1, 2], Paweł Moskal [1, 2]
on behalf of the J-PET Collaboration

[1]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Kraków, Poland,
[2]Centre for Theranostics, Jagiellonian University, 31-501 Kraków, Poland

Objectives

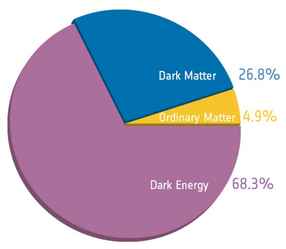
Positronium (Ps) is an exotic atom composed of an electron and its antiparticle, the positron, bound together in a short-lived quantum system. This bound state serves as a unique system for probing fundamental physics, as its properties are precisely predicted by Quantum Electrodynamics (QED) within the Standard Model (SM). Furthermore, its decay processes, which are effectively modeled using Monte Carlo simulations, provide valuable information on various domains of particle physics.

At the Jagiellonian University, the J-PET detector (Jagiellonian Positron Emission Tomograph), a novel tomography system based on plastic scintillator detectors, has been developed [1]. This setup offers high angular and timing resolutions [2, 3, 4], enabling multidisciplinary studies of positronium decays. Therefore, it is possible to measure the lifetime of positronium with high precision with J-PET.

In this work, we report on ongoing searches for Dark Matter signatures in ortho-positronium (o-Ps) decays using the J-PET detector. The primary objective is to explore the existence of Mirror Matter, a hypothetical form of matter proposed to restore parity symmetry and considered a plausible candidate for the Dark Matter component of the Universe. Our study aims to refine current experimental limits by achieving high-precision measurements of the o-Ps lifetime in its three-photon decay channel, comparing these results with QED predictions to search for potential deviations that could be interpreted as a signal of the presence of Dark Matter [5].

Dark matter

- Hypothesized as an elusive substance that constitutes a large part of the universe's total mass.



- Plays a crucial role in the formation and evolution of galaxies.
- Despite extensive searches, it has not been directly detected with current instruments.
- Does not emit, absorb, or reflect electromagnetic radiation.

Mirror matter

- predicted to exist parallel to the ordinary matter we observe,
- interacts very weakly with ordinary matter,
- consists of particles, which are reflections of the observed particles,
- **an excellent candidate for Dark Matter**

Mirror matter in o-Ps

$\varepsilon < 5 \cdot 10^{-8}$[7]

$$\mathcal{L} = \varepsilon F_{\mu\nu} F'^{\mu\nu}$$

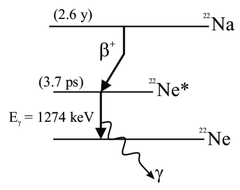
γ' escapes detection $\rightarrow$ observed o-Ps lifetime deviates from prediction [6]

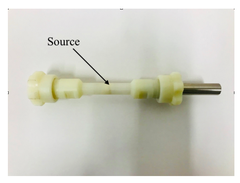
$\Gamma_{\text{theory}} = 7.039979(1) \times 10^6$ [8]
$\Gamma_{\text{experimental}} = 7.0401 \pm 0.0007 \times 10^6$ [9]

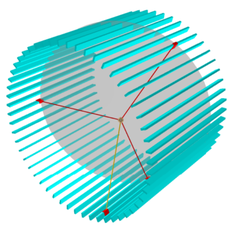
Positronium

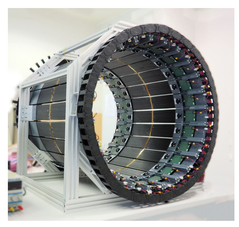
State bound through electromagnetic interactions that consists of an electron and a positron.

o-Ps in J-PET









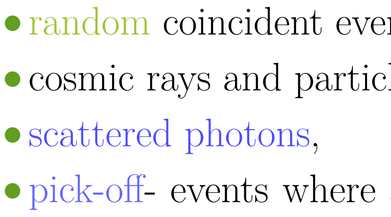
Main background sources

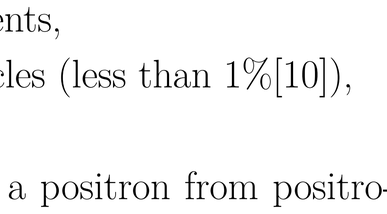
- random coincident events,
- cosmic rays and particles (less than 1%[10]),
- scattered photons,
- pick-off- events where a positron from positronium annihilates with an electron from the detector volume.

Data selection

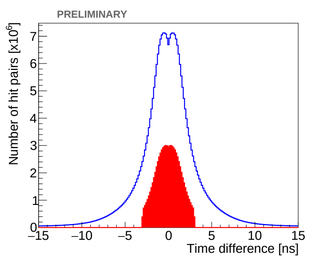
1. number of the hits ≥ 4: $o-Ps \rightarrow 3\gamma + \gamma_{prompt}$
2. Region 1:
   $\geq$3 annihilation hits
   Region 2:
   1 prompt hit

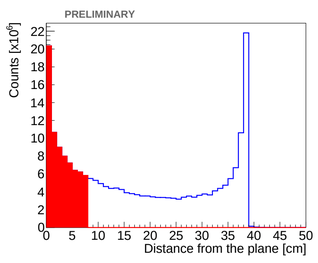
3. sum of two smallest angles $\geq 190^o$



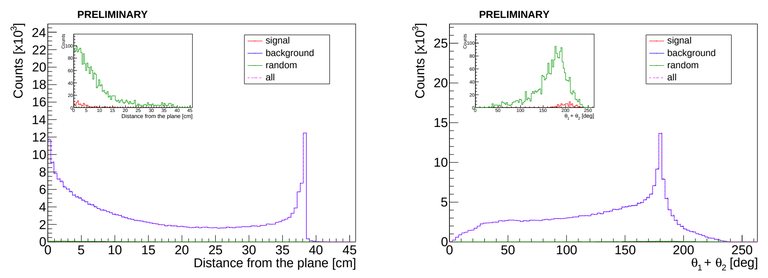


4. time difference between annihilation hits < 3 ns
5. Source distance from 3-hit plane < 8 cm





Event categories in MC



Summary

- The goal is to determine the positronium lifetime with high precision using the **J-PET detector**, optimised for studying annihilation processes.
- The studies focus on **careful data selection and detailed Monte Carlo (MC) simulations** within the **Modular prototype**, aiming to accurately model experimental conditions. These high-quality MC datasets are then prepared for **machine learning applications** [11], enabling advanced pattern recognition, background suppression, and improved event reconstruction.

References

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Acknowledgements

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