Probing Mirror Matter via Ortho-Positronium Decays with J-PET detector

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on behalf of the J-PET Collaboration

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Objectives

Positronium (Ps), an atom made of an electron and a positron, is a sensitive system for testing Quantum Electrodynamics (QED) and searching for physics beyond the Standard Model, including dark matter candidates like mirror matter. Some theories predict that ortho-positronium (o-Ps) can oscillate into invisible mirror states, altering its lifetime. We investigate this with the Jagiellonian Positron Emission Tomograph (J-PET) [1], a high-resolution detector based on plastic scintillators and SiPM readout [2, 3, 4].
Experiments are performed in vacuum with XAD4 porous polymer [5] to boost positronium formation. Using Monte Carlo simulations, advanced event reconstruction, and background suppression, we isolate three-photon o-Ps decays and measure lifetimes with high precision. Our aim is to reach 10^{-6} sensitivity, enabling stringent QED tests and indirect searches for mirror matter, thereby constraining hidden-sector models and informing dark matter research.

Mirror matter

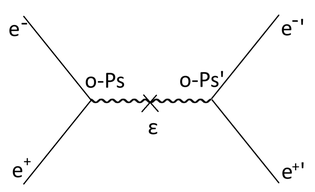
- predicted to exist parallel to the familiar matter we observe,
- interacts very weakly with ordinary matter,
- consists of particles, which are reflections of the observed particles,
- **an excellent candidate for Dark matter**

Mirror matter in o-Ps

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

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

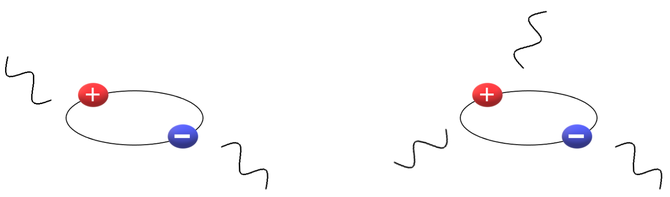
γ' escapes detection $\rightarrow$ observed o-Ps lifetime deviates from prediction [6]



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

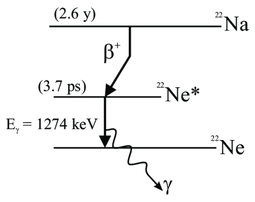
Positronium

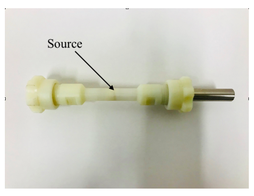
State bound through electromagnetic interactions that consists of an electron and a positron.

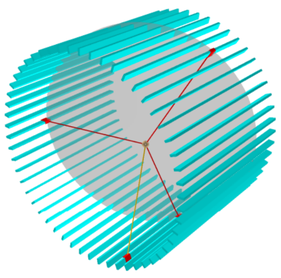


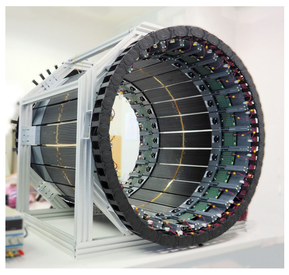
It exists in two forms: a triplet state (o-Ps) and a singlet state (p-Ps). The triplet state (o-Ps) primarily decays into three photons.

o-Ps in J-PET







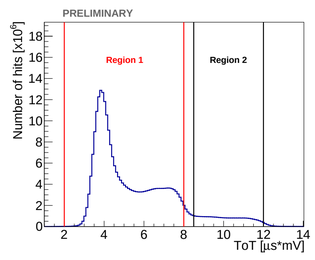


Main background sources

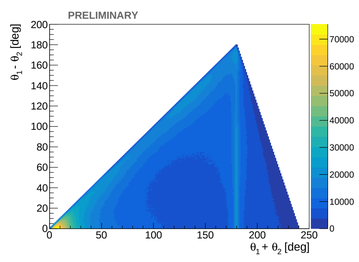
- random coincident events,
- cosmic rays and particles (less than 1%[10]),
- scattered photons,
- pick-off- events where positron from a positronium annihilate with different electron from detector volume.

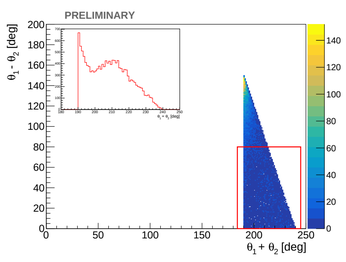
Data selection

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

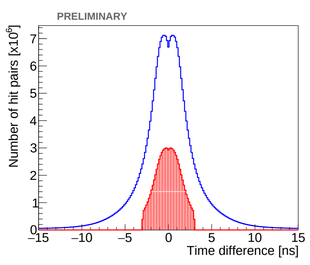


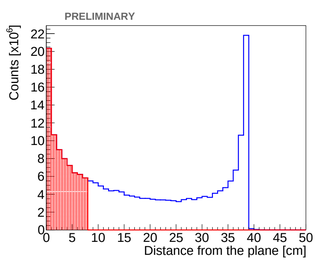
3. sum of two smallest angles $\geq 190^o$



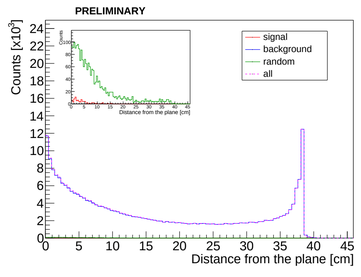


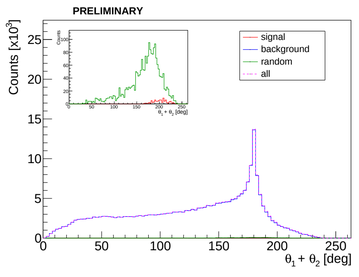
4. time difference between annihilation hits < 3 ns
5. Source distance from 3-hit plane < 8 cm





Event categories in MC





Summary

- The research aims to explore **mirror matter**, a potential dark matter candidate.
- **Positronium**, due to its unique properties, provides a sensitive probe for testing physics beyond the Standard Model.
- The overarching goal is to precisely determine the **positronium lifetime** using the **J-PET detector**, optimized 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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