Towards Charge conjugation symmetry test in EM Interaction using J-PET

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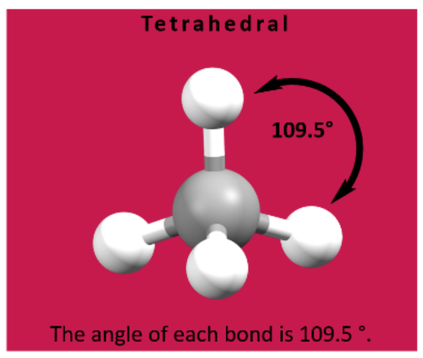
Abstract

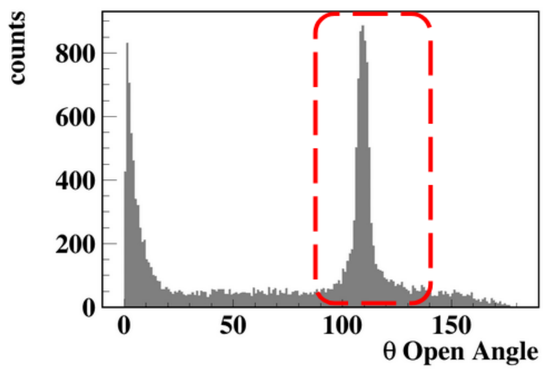
Charge conjugation symmetry (C symmetry) still remains a fundamental symmetry in the realm of physics. It is well-known to be maximally violated in weak interactions. However, its validity is yet to be tested in Electromagnetic (EM) and Strong interactions. With the aim to test this symmetry in EM interactions, the forbidden decay channel of the triplet Positronium state - the ortho-Positronium (oPs) shall be explored. The C symmetry forbids this state from decay into anything other than an odd number of photons; henceforth a search for four-photon decay extends the feasibility of testing the C symmetry in EM interaction using a J-PET detector. Furthermore, the bosonic nature of photons hints at a distinct configuration in the event of a C-symmetry violation. Known for its outstanding timing ($\sim$ 250 ps) and angular ($\sim$1 °) resolutions, J-PET offers a viable and substantial platform to perform this symmetry test. J-PET series of detectors has previously established its credibility in the tests of discrete symmetries, further supporting the feasibility of the aforementioned test. In this poster, the motivation behind the study, the theoretical assumptions, and recent advancements in the test of C symmetry using J-PET shall be discussed.

Motivation

Charge conjugation (C) symmetry constrains the decay of ortho-Positronium (oPs) such that only an **odd number of photons** can appear in the final state [3].

- Previous experimental bound on the four-photon decay: $BR < 3.7 \times 10^{-6}$ (90 $\%C.L.$) [4].
- **Hypothesis:** If C-symmetry is violated, Bose–Einstein statistics would allow oPs to decay into a regular tetrahedral photon configuration [5].
- Background from allowed four-photon decays of para-Positronium (pPs) is eliminated.





Characteristic 109.5° opening angle in a tetrahedral configuration (top). Distribution of opening angles between photons in the simulated sample (bottom).

References

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[3] S. Bass. *Acta Phys.Polon. B* **50**, (2019).
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Acknowledgements

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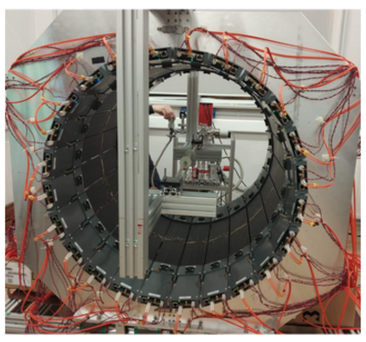
Detection System and Methodology

1. Compton-based photon Detector – J-PET

(a)



(b)

- Second-generation modular J-PET detector: 24 modules × 13 plastic scintillator units.
- SiPM-based electronic readouts for precise signal detection.
- High timing and angular resolution, enabling interdisciplinary studies with triggerless DAQ [1].

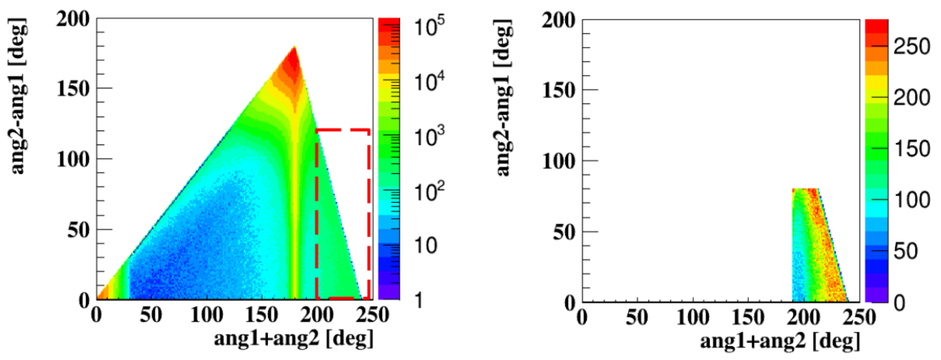
2. Branching ratio for 4 photon decay of oPs

$$\mathrm{Br}(\mathrm{oPs} \to 4\gamma) = \frac{\Gamma_{4\gamma}}{\Gamma_{3\gamma}} = \frac{N_{4\gamma} \times \epsilon_{3\gamma}}{\epsilon_{4\gamma} \times N_{3\gamma}}$$

where N: number of reconstructed events (signal and control), ϵ: detection efficiencies.

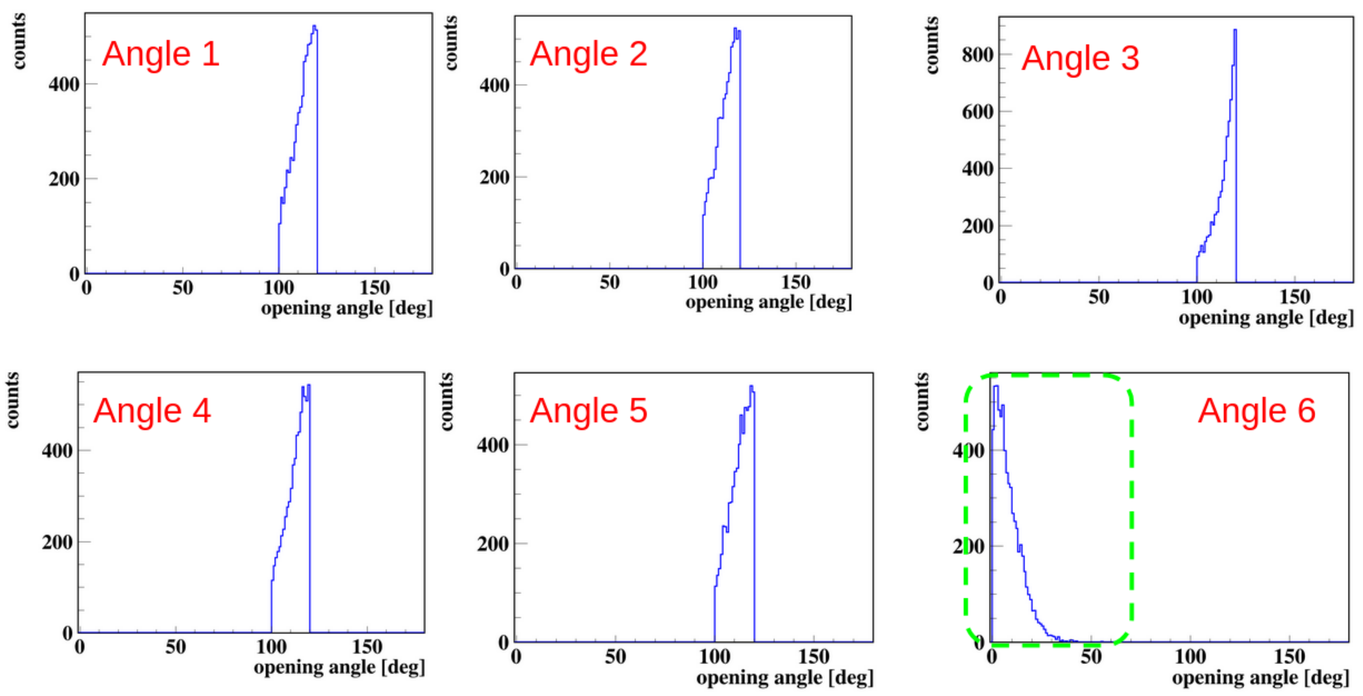
3. Control decay channel study: oPs $\to$ 3 γ

- Positron source: 1.209 MBq Sodium-22
- Kinematics-based event selection
- Estimated oPs: 6×10^8
- Cosmic background negligible ($\sim$ 0.01%)



Signal search for Tetrahedral configuration

Signal search in ∼8 hours of data from a 1.209 MBq sodium-22 source



Among the six photon–photon angles, five fall within 100°–120°, while the sixth deviates from this range, excluding the tetrahedral photon configuration in the analyzed data.

Conclusions and Future Work

The measured BR will serve as a key parameter for evaluating the following hypotheses:

- **C-symmetry violation** in EM interactions & **Bose–Einstein statistics** in multiphoton photon systems.
- **Distinguishability** of pPs and oPs beyond lifetimes.