Studies on the charge conjugation symmetry in the decay of positronium atom using the J-PET detector

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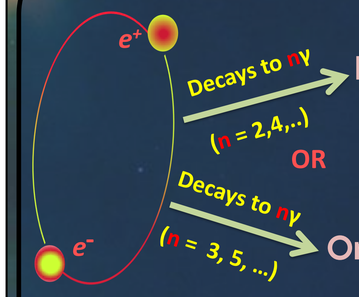
Introduction

Tests on discrete symmetries (reflection in space (P), reversal in time (T) and charge conjugation (C) retained the interest of scientific community in pursuing the reason of inequality between the matter and anti-matter in the universe. We owe our existence to this matter-antimatter asymmetry. The charge conjugation symmetry transforms particle into anti-particle and observed only to be violated in the weak interactions. So far, no C symmetry violation was observed in gravitational, strong and electromagnetic interactions. Positronium atom which is a bound state of electron and its anti-particle (positron) is proved an excellent tool for studying the various phenomena e.g., discrete symmetries [1-3] , entangled states of photons [4,5] etc. Mills and Berko performed the experiment to measure the C-forbidden decays of singlet state of positronium atoms $^1S_0$ by estimating the ratio of decay to 3γ to 2γ for various angular correlation between the photons [6]. The best limit they obtained was $R<<2.8x10^{-6}$ at 68% confidence level. With the better time and high angular resolution of the J-PET detector, We are aiming to perform the test to estimate the rate ratio (R) for three to two photon decay of positronium atom. One can expect better sensitivity in estimating the value of R approximately in the order of several times due to the large geometrical acceptance offer by the J-PET.

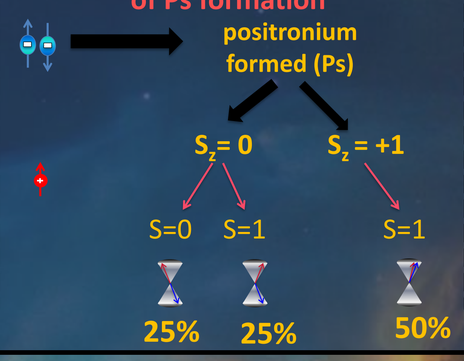
Positronium atom – a unique laboratory to perform tests on discrete symmetries



Para–positronium (p - Ps), τ = 125ps, $^1S_0$

Ortho – positronium (o - Ps), τ = 142ns, $^3S_1$

Schematic diagram of combined spin states probabilities of Ps formation



Charge Conjugation symmetry

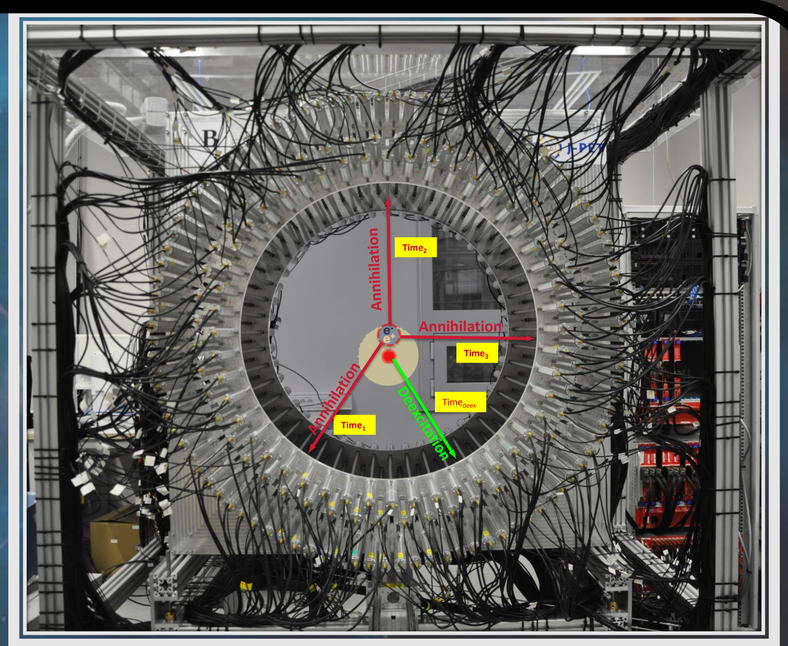
- With the C-violating weak interaction, Ps gains access to new photonic decay modes. The simplest one: p-Ps ->3γ.
- According to Bose Statistics, the rate of $^1S_0$ decaying into 3 Photons must vanish in the symmetric configuration.
- The limit for the branching ratio for the decay of p-Ps from 3 / 2 was measured ≈ 2.8 x 10-6 with the 68 % confidence level.

Motivation:

- Charge symmetry test
- Boss statistics test

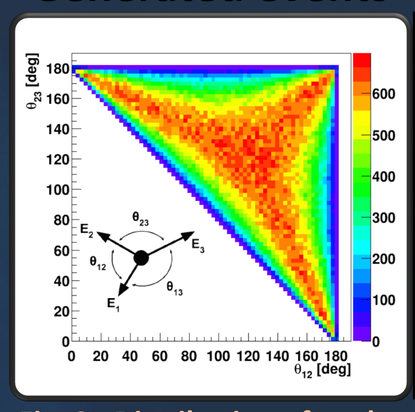
J-PET Detector to study the decay of positronium atom

- J-PET is constructed of 192 polymer scintillators, where each scintillator is attached with photomultiplier at each end.
- Positronium atom can be formed in the center of J-PET detector using the beta-emitter source placed inside a chamber and source is sandwiched between the aerogel material.
- Plastic scintillator offer high time and angular resolution.
- The signals are measured by using the trigger-less data acquisition.
- Time Over Threshold (TOT) is used as a measure of energy deposition.



Geant4 Simulations of J-PET detector for o-Ps decay

Generated events



Detected events

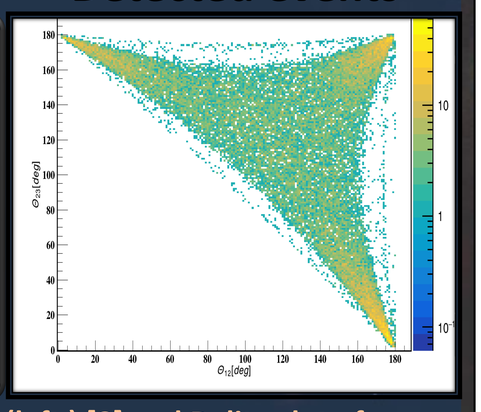


Fig. 3 : Distribution of angles (left) [8] and Dalitz plot of o-Ps → 3γ Monte Carlo based generation of o-Ps decays and angular correlations b/w the photons .

Lifetime Spectroscopy

Fig. 1 : Pictorial representation for the idea to measure the life time of Positronium atom.

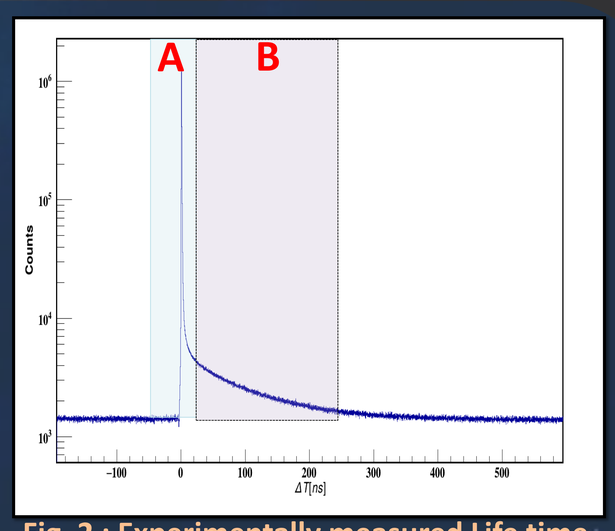


Fig. 2 : Experimentally measured Life time spectra of Positronium atom [7].

Experimental results

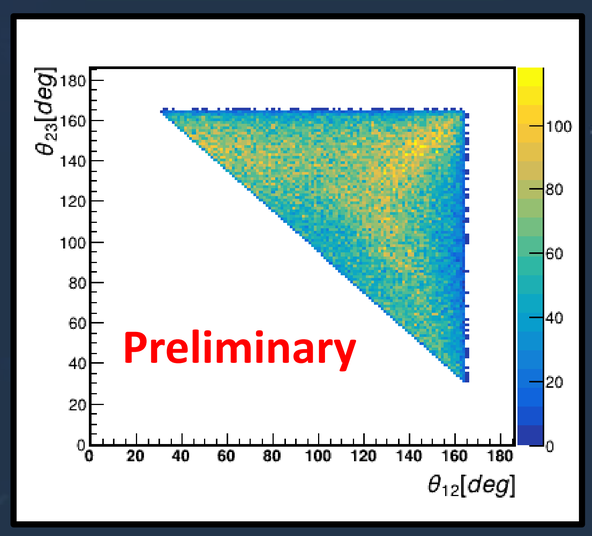


Fig. 4 : Angular correlation between annihilation photons.

Discussion and summary

① The life time of the positronium can be estimated based on the measured time difference (**Δt**) between detection of deexcitation gamma and the annihilation photons from the decay of Ps atom. Region **A** presents the time difference where one expect the photons from the decay of p-Ps decay, whereas **B** represents the expected decay from o-Ps with larger Δt values. Events with 4 interactions (three interactions of annihilation photons + one with prompt gamma) will be studied.

② Angular correlation between photons will be measured for both selected regions separately. Fig 3 (left) shows the angular correlation between the three photons originating from the o-Ps decay generated by Monte Carlo, whereas Fig 3 (right) are simulations using the Geant4 package by including the J-PET detector acceptance. First experimental angular correlation between the annihilation photons originating from the decay of o-Ps atom are presented in Fig. 4.

③ In case of 3γ from the decay of p-Ps, for the symmetrical configuration one should not expect any contribution from the p-Ps -> **3γ** [6]. The J-PET detector is unique for such studies due to the availability of many possible symmetrical configuration and investigate the influence on 3γ/2γ .

④ It is planned to compare the angular distributions for the two selected regions (A,B) divided based on the lifetime of positronium atom (Fig. 2). The voxelized based counts will be compared in order to quantify the difference between two measured distributions.

References

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Acknowledgement

The authors acknowledge the support by The Polish National Center for Research and Development through grant INNOTECHK1/IN1/64/159174/NCBR/12, the Foundation for Polish Science through the MPD and TEAM/2017-4/39 programmes, the National Science Centre of Poland through grants no. 2016/21/B/ST2/01222, 2017/25/N/NZ1/ 00861, the Ministry for Science and Higher Education through grants no. 6673/IA/SP/ 2016, 7150/E-338/SPUB/2017/1, 7150/E338/M/2017, 7150/E-338/M/2018 and the Austrian Science Fund FWF-P26783.