Studies of the decay of positronium atoms with the J-PET detector

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Introduction

Jagiellonian-Positron Emission Tomograph (J-PET) is first of its kind which is composed of long plastic scintillators (Fig. 1). It is developed as a cost-effective scanner for the simultaneous metabolic imaging of human body with large axial field of view. The detector geometry and properties of plastic scintillators in terms of high time and high angular resolution enables the J-PET to perform the studies in detecting the annihilation photons originating from the decays of positronium atoms (Ps). Positronium atom, a bound state constituted of electron and positron can be used as a unique laboratory with potential to test the various physical phenomena e.g., discrete symmetries (charge conjugation C, reversal in time T, reflection in space P) violation in scarce leptonic sectors [1–3], photons polarization [4], multi-particle entanglement [5, 6].

Detector descriptions

J-PET is constructed of 192 plastic scintillators arranged axially in 3 layers. First and second layers consist of 48 modules whereas the third layer is made of 96 modules. Each module comprises one plastic scintillator made of EJ-230 material of dimension 500 × 19 × 7 mm^3 coupled with R9800 Hamamatsu Photomultiplier at each end. The modules in different layers are placed at angular displacements calculated by 2π divide by the number of modules such that the layers are not overlaying each other. In order to utilize the fast timing and low pile-ups properties of the plastic scintillators, Time Over Thresholds approach is adopted as the measure of energy deposition.

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The data acquisition is operated in trigger-less mode [7, 9, 9] and for the offline data processing, a dedicated analysis framework is developed [10]. The detailed and technical information about the J-PET can be found in the published works [11–16].

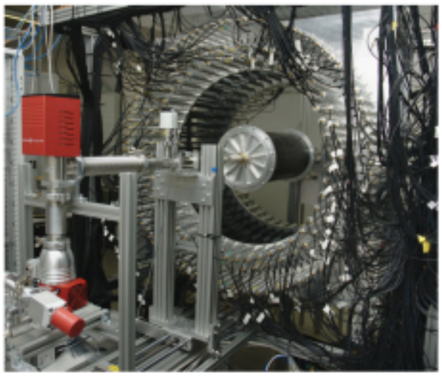

FIG. 1: Photo of the J-PET detector prototype of three layers with the cylindrical chamber at the center which is hollow from inside with the possibility to place the high activity source. The inner walls of the chamber are coated with the Porous R60 silica.

Positronium atom and the tests on discrete symmetries

Positronium atom is the lightest atom made of particle (e^-) and its anti-particle (e^+). Under the charge conjugation operator, the ground states of Ps atom, the triplet 1^3S_1 state (ortho-positronium, o-Ps) is an 'odd' C eigenstate: decays into odd number of gammas mainly into three whereas the singlet state 1^1S_0 (para-positronium, p-Ps) is an 'even' C eigenstate : decays into even number of gammas mostly into two. Furthermore, as an atom bound by central potential, it is also a parity eigenstate. Therefore, Ps atom

is a unique object to study the discrete symmetries. According to standard model predictions, the limit for the symmetry violation due to weak interactions are expected at level of 10^{-14} [17] and in photon-photon interactions at the level of 10^{-9} [18]. The experimental limits on CP and CPT symmetry violation in the decays of positronium atom are achieved so far at the level of 2.2×10^{-3} [19], six order of magnitude less than the predictions by standard model. Furthermore, the present experimental upper limit is observed at the level of 10^{-7} [20] for the charge conjugation violation, still two order of difference where the experimental precision can be improved. J-PET detector is optimized for the registration of photons emitted from the decay of positronium atom. The access to their momentum vector along with the spin orientation of the triplet state(o-Ps) of positronium atom allow to measure the expectation values of CP and CPT symmetry odd operators [2, 21, 22]. Feasibility to measure the photon polarization [4] based on their scattering angles enables to define the new odd symmetry operators to test [2].
In the talk, the status of research and the capabilities of the J-PET detector to perform the tests on the discrete symmetries in the decays of positronium atom will be presented.

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