Study the linear polarization of the positron and positronium by using the J-PET detector

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Abstract

A method for measuring the linear (vector) polarization of positron and positronium (Ps) atom is proposed which is based on the determination of the angular distribution of the normal to the decay plane with respect to the o-Ps spin orientation. The unique geometry and properties of the J-PET enables to design the positron source such that the polarization of produced o-Ps can be determined. Due to the parity violation in the beta decay the emitted positrons are longitudinally polarized with the average polarization equal to P=v/c where v denotes the positron velocity and c is the speed of light.

1. Introduction

The J-PET is a novel tomography device using plastic Scintillator instead of conventional crystal. It can be used to study the Ps polarization, where the linear polarization depends on the positron source's absorber and the initial polarization of the produced positrons [1 , 2]. Also we can study the degree of the o-Ps polarization which may be monitored based on the measurement of the angular distribution between the normal to the 3ɣ decay plane and the o-Ps spin direction, where a decay plane is defined as a plane containing momenta of photons from the o-Ps to 3ɣ decay. The distribution of the angle θ between the spin direction of o-Ps and a normal to the decay plane is proportional to the term $(1+\cos^2\theta)$ for m = 0, and proportional to the term $\frac{1}{2}(3-\cos^2\theta)$ for m = ±1 [3 , 4]. Therefore, JPET can be used to determine the degree of the linear polarization by the comparison of the angular distribution of the normal to the decay plane with respect to the direction of the Ps spin.

2.The Large annihilation chamber

In the Run-3 measurements the large annihilation chamber and a sodium source with activity 9.14 MBq closed in the kapton foil inside cylindrical aluminum chamber was used (see Fig. 1).

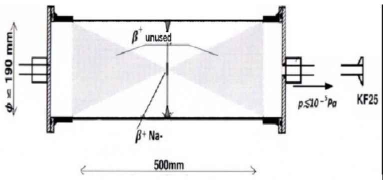

Fig.1: Scheme of large annihilation chamber.

3.The Jagiellonian-PET scanner

The J-PET is the first positron emission tomography scanner based on organic scintillators (see Fig.2), which can describe as an axially symmetric and high acceptance scanner with unique properties and very high angular resolution, where Sr=0.03 of 4π for the 1st layer's strips of J-PET, which can be used for tests of discrete symmetries in decays of o-Ps in addition to the medical imaging.

4.Determining the normal to the o-Ps decay plane and the spin direction

We can determine the orientation of the normal (n) of the o-Ps decay plane from the 3 hit points, 2 vectors will lie completely in the same plane, and the vector product of any two non-parallel vectors on the plane will give the normal (n) (See Fig.3).

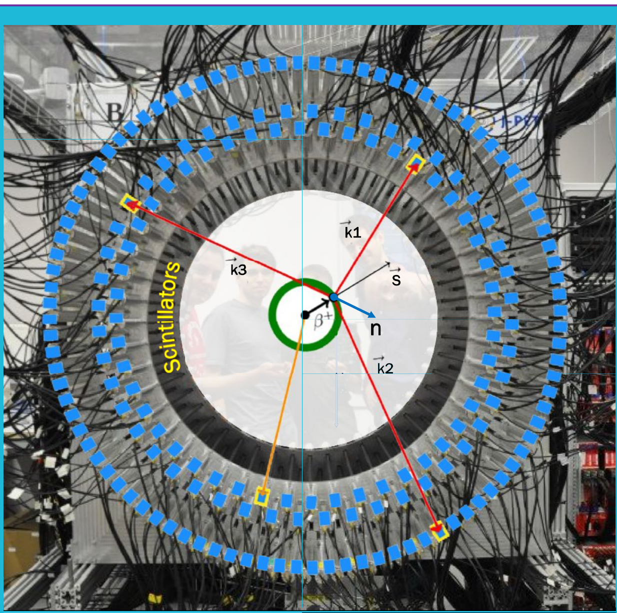

Fig.2: Photo of the Jagiellonian positron emission tomograph (J-PET). Where J-PET is made of 3 cylindrical layers of EJ-230 plastic scintillator strips (black) with dimension of 7 × 19 × 500 mm³ and Hamamatsu R9800 photomultipliers (blue- grey)[5].

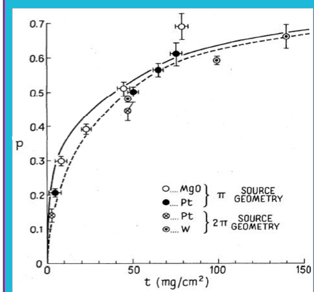

Fig.4: Slow positron (e+) polarization measured for different thicknesses t of beryllium (Z=4) or plastic (Z=6) absorbers placed between the source and moderator. The solid curve is for the π-sr Na source and the dashed curve is for the 2π-sr Na source. [6]

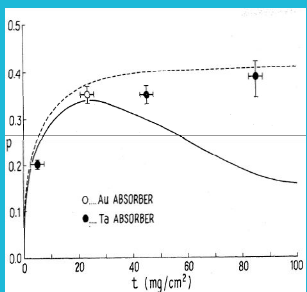

Fig.5: Polarization of the slow e+ emitted from Pt moderator after transmission through gold (Z=79) or tantalum (Z=73) absorbers of different thickness. Comparison with Fig.4 shows the substantial depolarization which occurs in high-Z absorbers. [6]

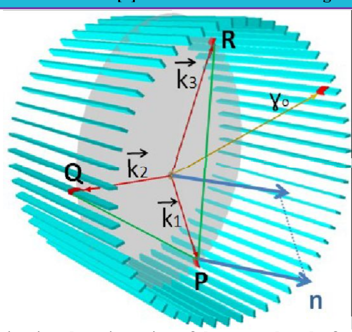

Fig.3: Determination the orientation of the normal to the 3ɣ decay plane.

Fig.6 shows a reconstruction method based on trilateration, intended for reconstructing the decay vertex which, in turn, allows us to estimate the positron momentum direction and spin direction of the o-Ps for the needs of discrete symmetry tests in o-Ps decays [2].

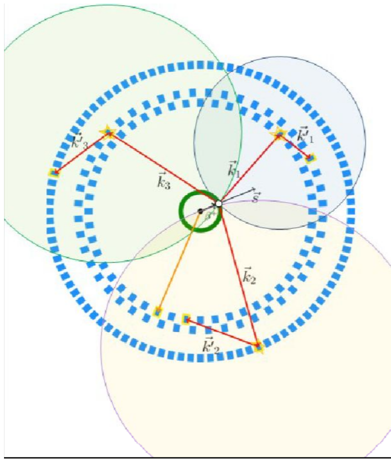

Fig.6: Scheme of the ortho-positronium decay trilateration- based reconstruction method.

5.Producing a highly polarized positrons

The previous studies [6] show that it is possible to achieve positrons polarization as high as P=0.69 with reduced intensity by selectively absorbing source positrons which are emitted at low energies and large angles relative to the normal to the source. The beam polarization is independent of moderator atomic number (Z), but does depend on the Z-number of the absorber. (see Fig.4 and Fig.5) [6].

Summary

The presented reconstruction methods can be used with J-PET detector to determine the o-Ps linear polarization with high precision, it can be used also in the tests of the CP and CPT symmetries.

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