Feasibility study of a Positronium decays in view of Charge Symmetry violation using J-PET detector

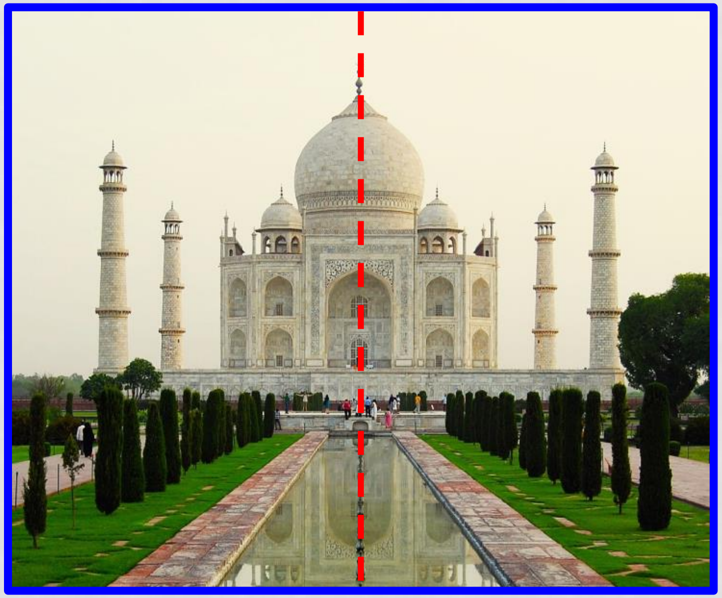
Jyoti Chhokar
On Behalf of the J-PET Collaboration

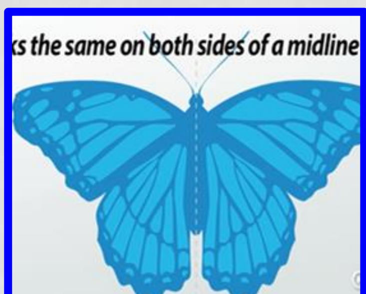
Date: 26-09-2019 Is Quantum theory is exact?

Overview

- Discrete Symmetries in physics
- Motivation
  - Precision test in C-symmetry and their experimental method
- Approach towards C- symmetry using J-PET detector and pre-selection of data
- Simulation and Experimental results of o-Ps
- Simulation of p-Ps->3γ

Symmetries





Noether's theorem: For every symmetry in Physics there is a corresponding conservation law.

Discrete symmetries:

1) Parity transformation:

$$P(\, x \,) = -x$$

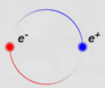
2) Charge conjugation :

$$\boxed{\text{particle} \leftrightarrow \text{antiparticle}}$$

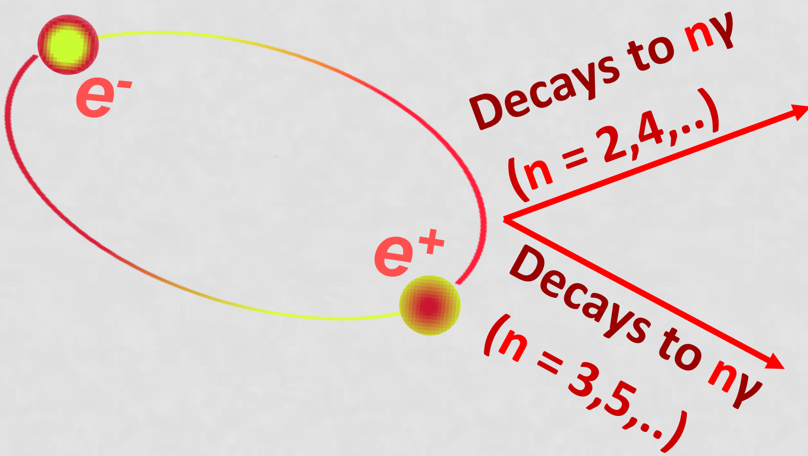
3) Time reversal:

$$t \rightarrow -t$$

Positronium (Ps)-- lightest Leptonic system



Due to Charge Conjugation



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

-Singlet state

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

--Triplet state

- With the **C-violating weak interaction**:

<u>Positronium gain access to new photonic decay modes</u>, the simplest one **$^1S_0$-> 3γ**

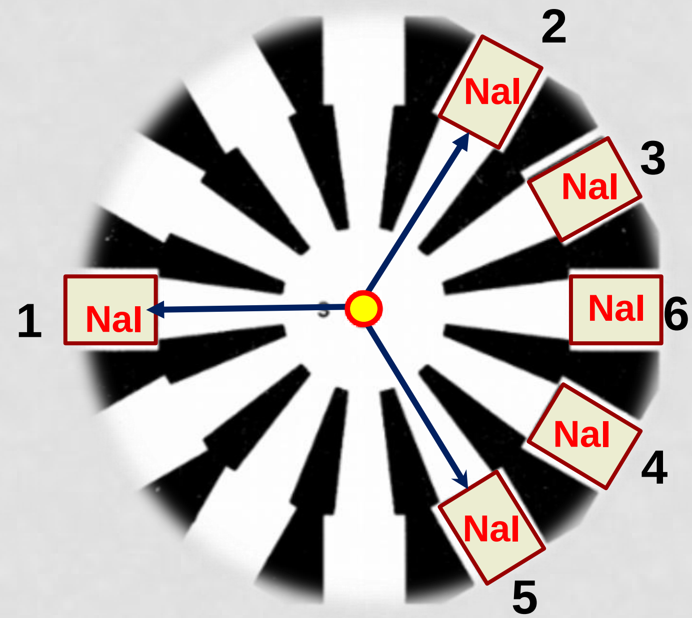
S. Berko and H. N. Pendleton, Ann. Rev. Nucl. Part. Sci. 30, (543-81) (1980)

Precision test in C - forbidden decay

Millls and Berko -- **1967** -- First experiment to test C-symmetry

Using Bose Statistics assumption:
Seperated the C-forbidden 3 **γ** decay of p-Ps from the allowed 3 **γ** decay of o-Ps state by studying angular distribution of 3 photons.

Branching Ratio (R=3γ/2γ) ~ 2.8 * 10^{-6} (68% C.L)



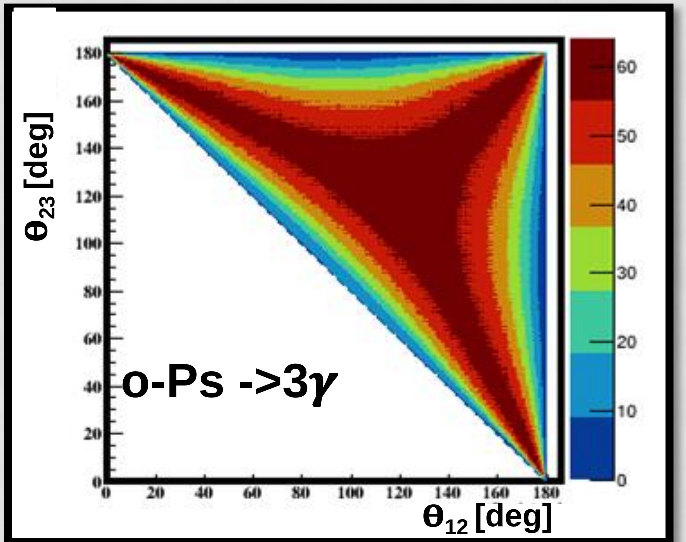
For calculation of R used only three combination of angles:

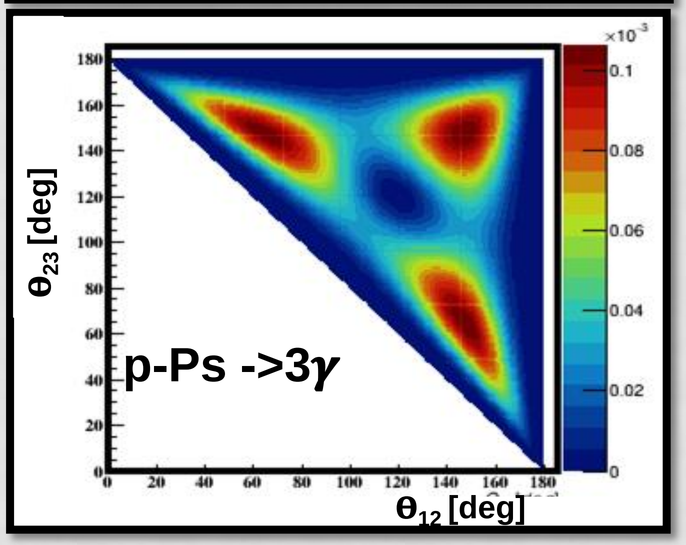
1. Symmetric configuration **(120°,120°,120°)**
2. Other set of angle **(60°,150°,150°)**
3. **(90°,120°,150°)**

- ➔ **Six NaI - scintillators**
- ➔ **Suppressed allowed 3 γ using NO as quenching**

A. P. Mills and S. Berko, Phys. Rev. Lett. 18, 420 (1967)

Angular distribution of 3 photons for o-Ps and p-Ps





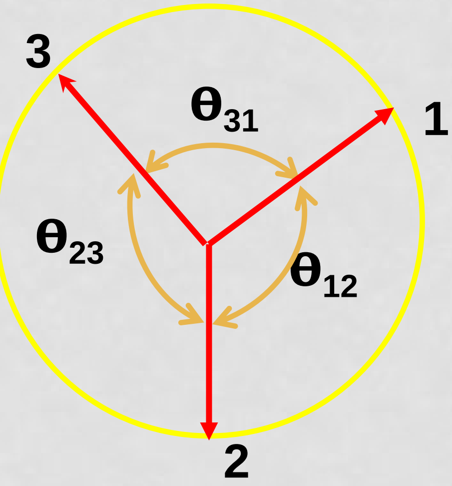
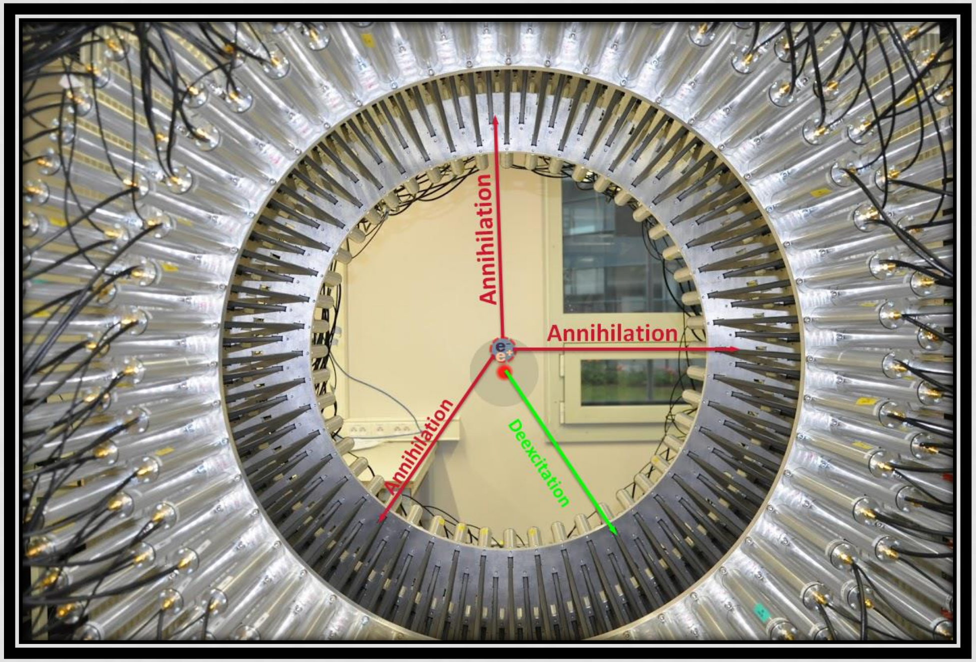


Fig. represents the angle between the 3 annihilation photons. Left side shows the angular distribution of these 3 photons (top) as decaying from o-Ps and (bottom) decaying from p-Ps, And <u>the calculations were based on the decay rate</u>

A. P. Mills and S. Berko, Phys. Rev. Lett. 18, 420 (1967)

J-PET Detector



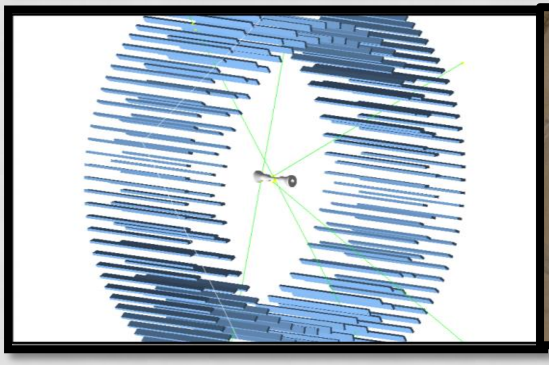
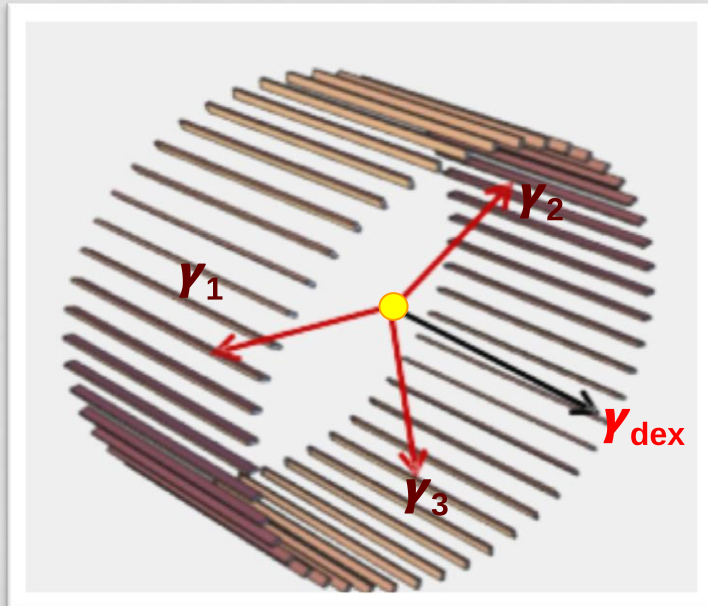
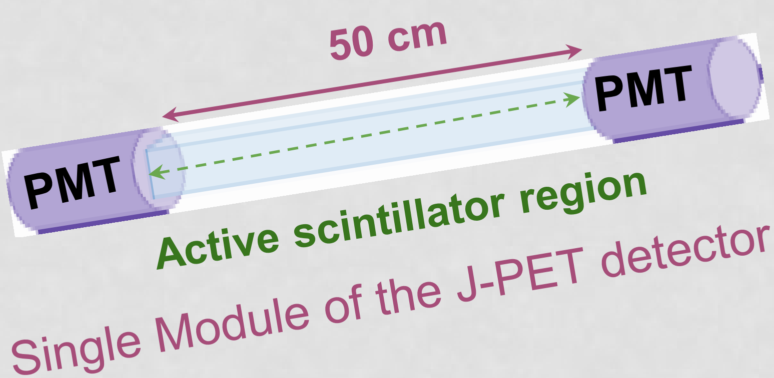


Fig. represents the front view of J-PET detector which is build out of 192 plastic scintillators. Also represents the angles between three photon which are annihilating from the ^{22}Na source placed in center of detector.

Preselection of the Signal: o-Ps-> 3γ



Signal Event --- $\gamma_1 + \gamma_2 + \gamma_3 + \gamma_{dex}$



Active scintillating region =|23.0|cm

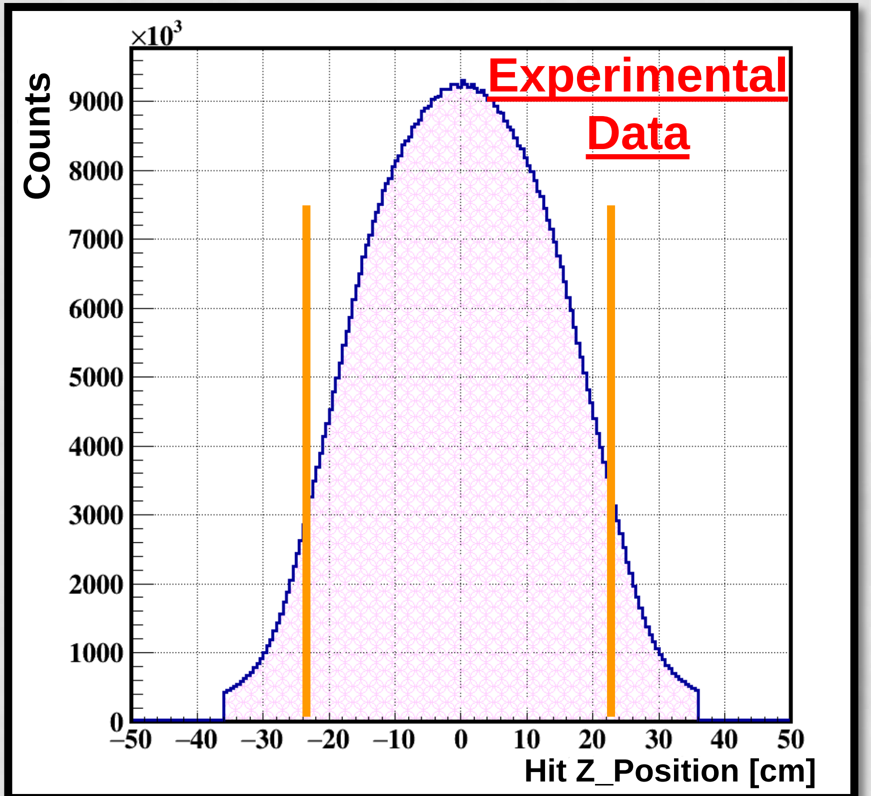
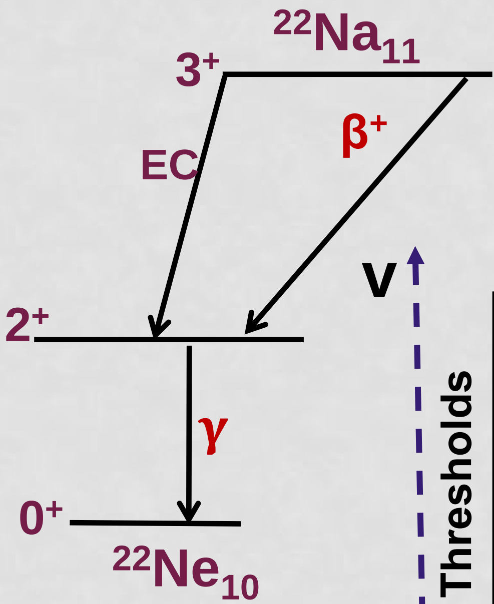
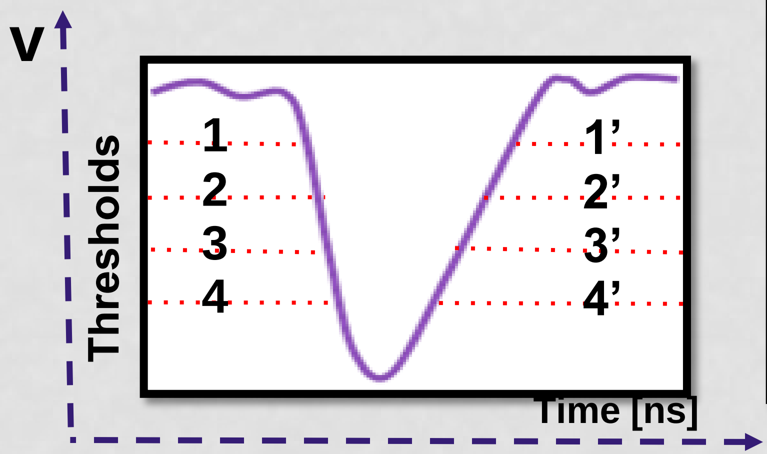
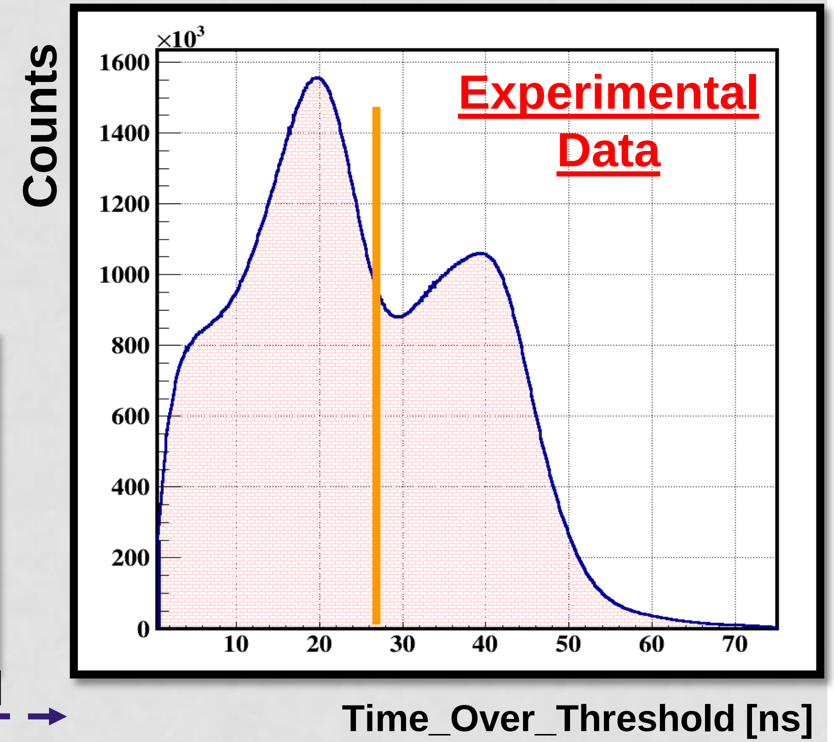


Fig. representation of the interaction positions on the Z-axis of the photon interacting in the detector geometry.

Time Over Threshold as a measure of Energy Deposition





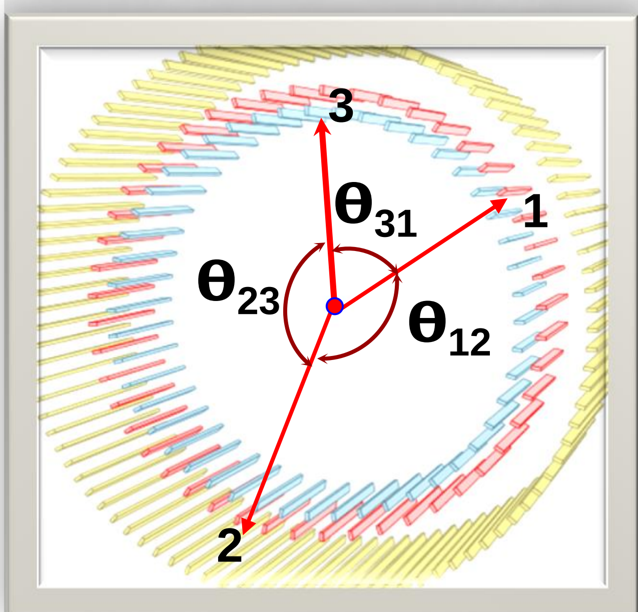


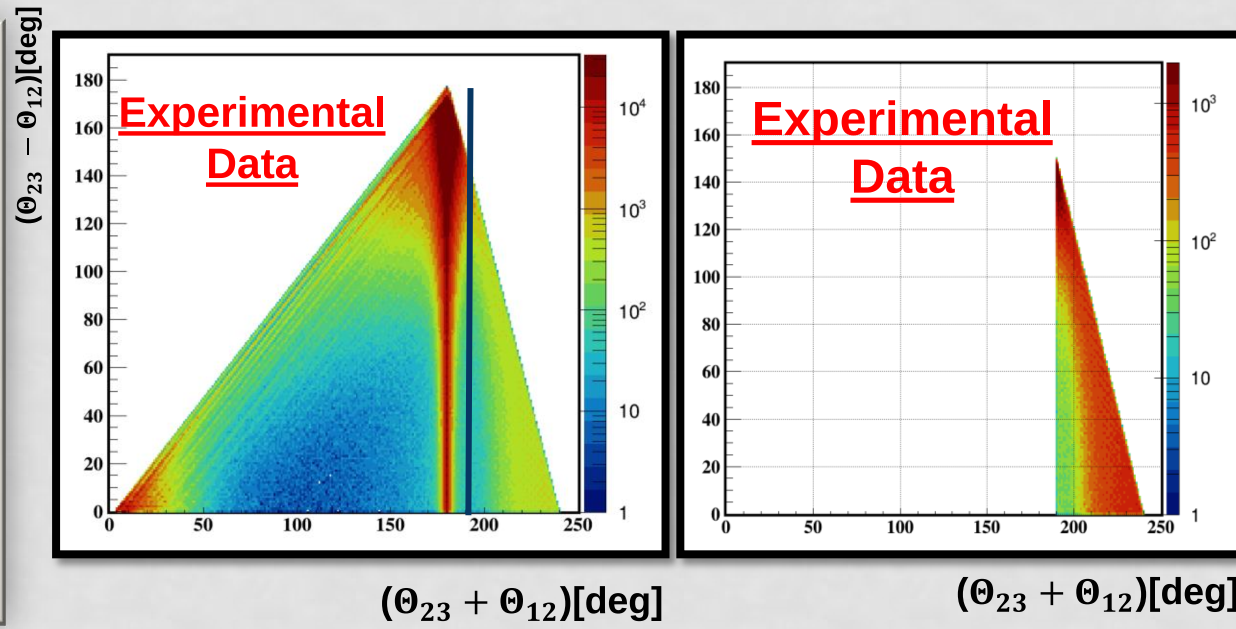
Sum of the TOT from four thresholds from both side of the scintillator

Fig. represents the signal (purple) from the two PMT fixed each side of scintillator, and signal from both of the PMT probed at four threshold. Right spectra shows the TOT distribution in which there is 2 Compton edges one for 511 kev and another for 1274 keV photons.

Selection of o-Ps using three angle of interacting Photons

o-Ps -> 3g

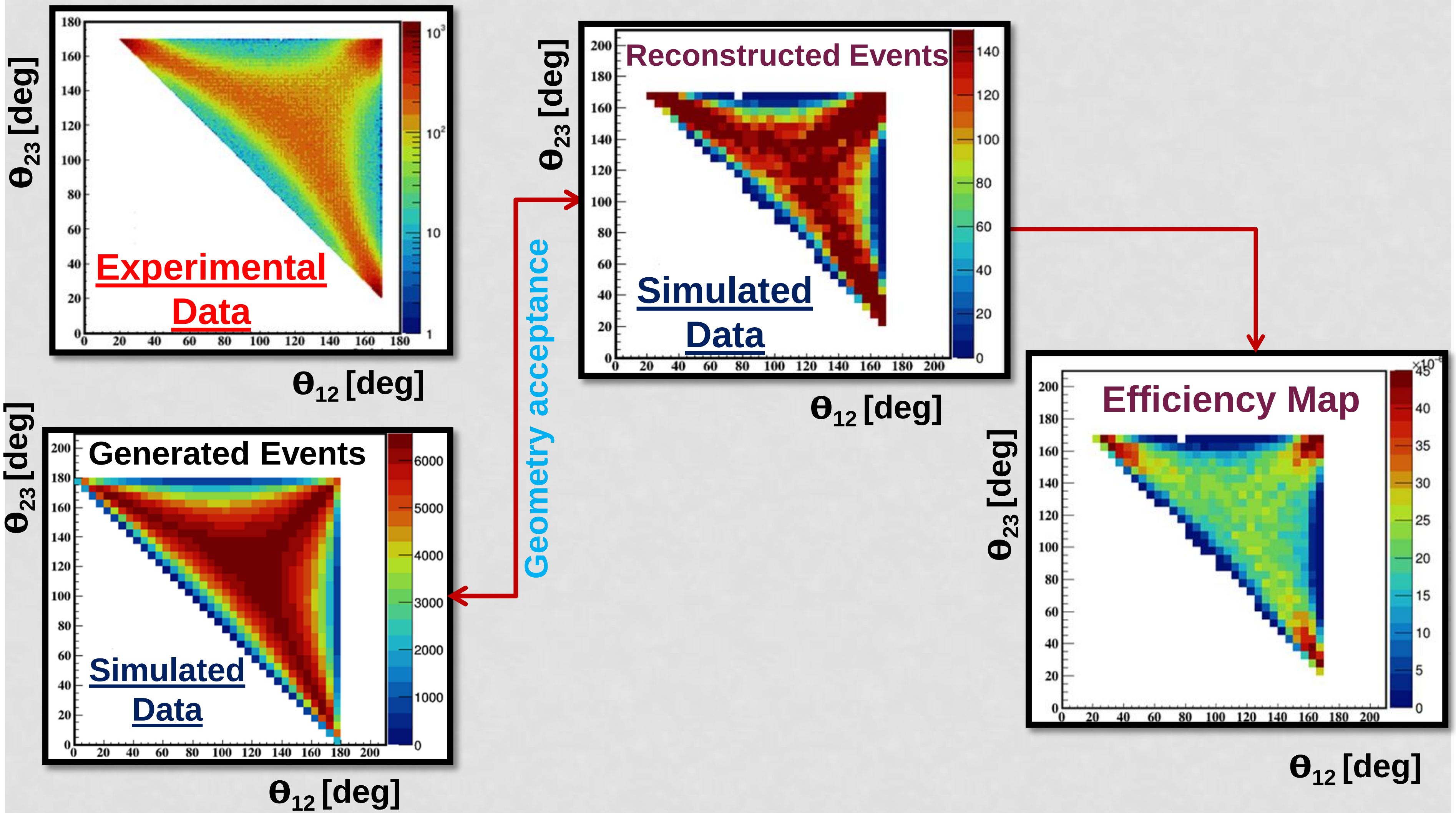




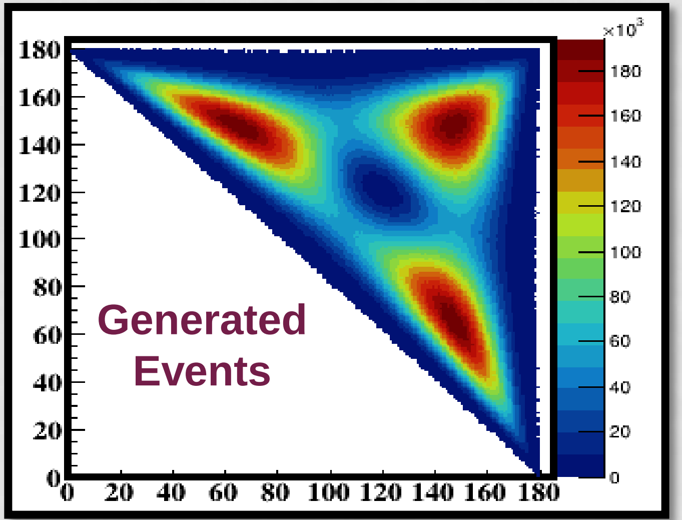
$\theta_{12}+\theta_{23} > 180°$

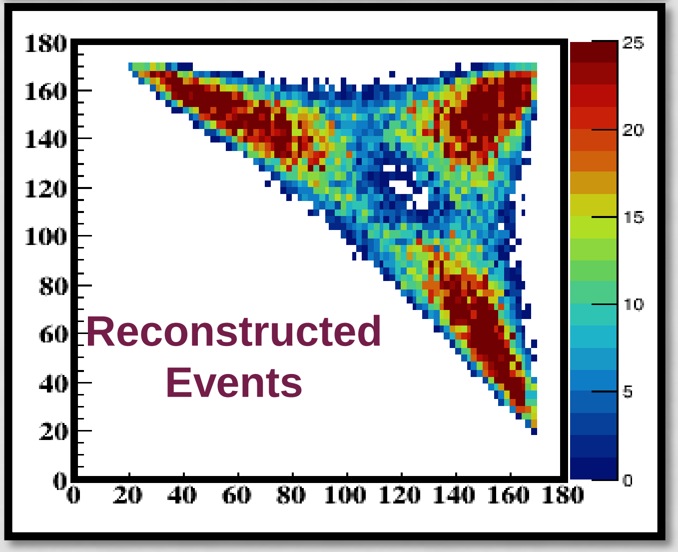
Fig. represents the distribution of the sum ($\theta_{12}+\theta_{23}$) and difference ($\theta_{12}-\theta_{23}$) of the two smallest angles between the 3γ of o-Ps decay (left) before cut (right) after cut

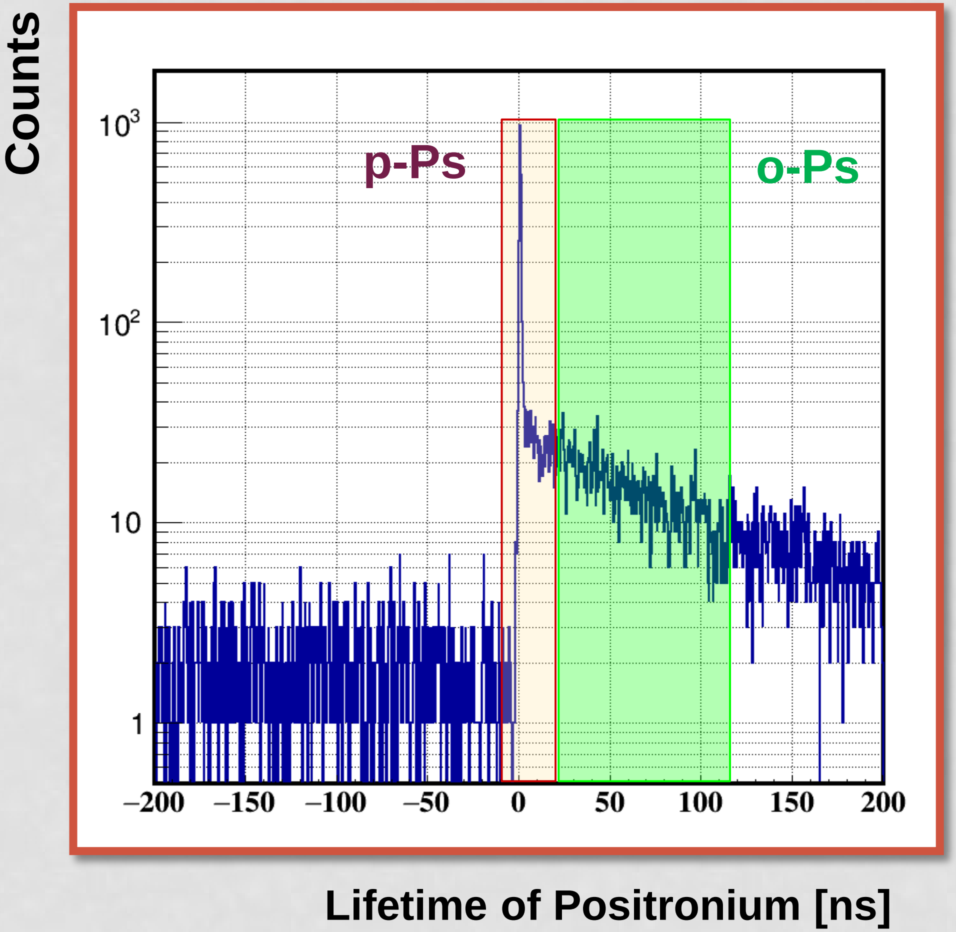
Angular Spectra for o-Ps -> 3g



3D Dalitz's Angular Plot for p-Ps -> 3g -- Simulated Data







K. Dulski, et al., Hyperfine Interact, 239:40 (2018)

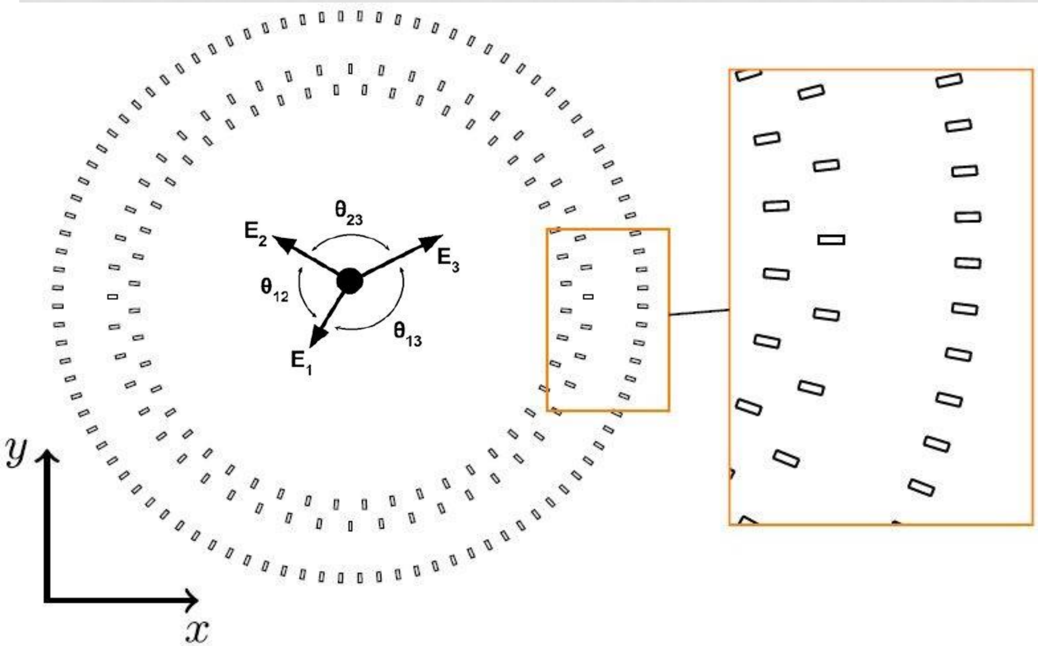
Conclusions

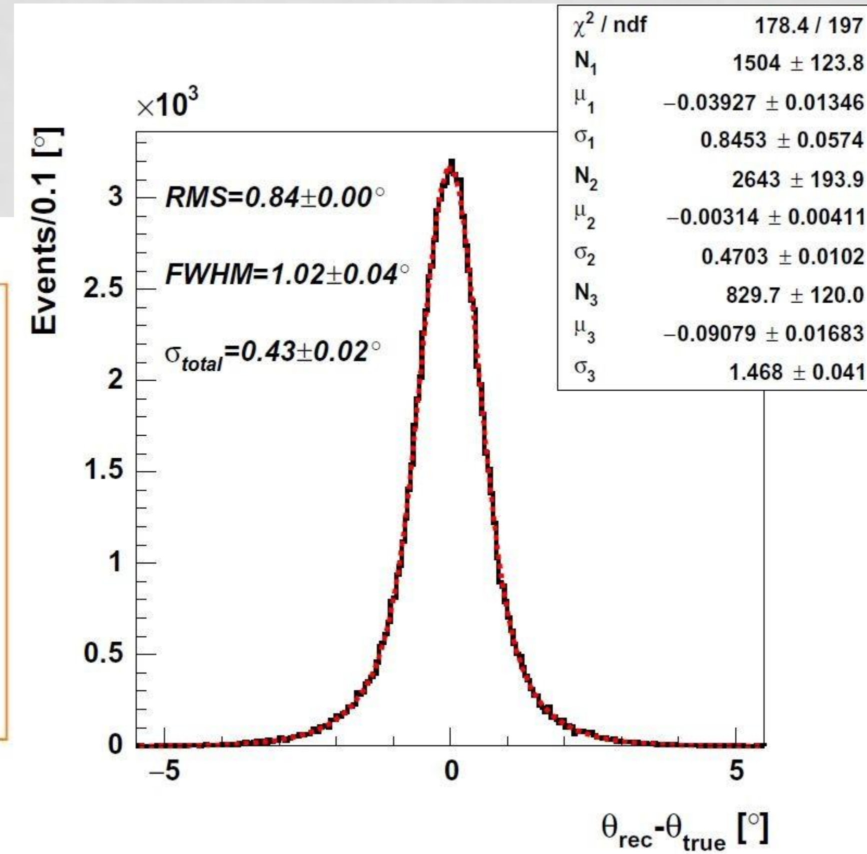
- ✓ **First Experimental Angular Distribution spectra** for the **o-Ps-> 3γ** using J-PET detector.
- ✓ Angular Distribution spectra for the **p-Ps->3 γ** obtained using Monte Carlo Simulation.
- ✓ And p-Ps and o-Ps will be separated using lifetime spectra.


Thank You
Grazie

Backup Slides!

DETECTOR PERFORMANCE: ANGULAR RESOLUTION (O-PS)



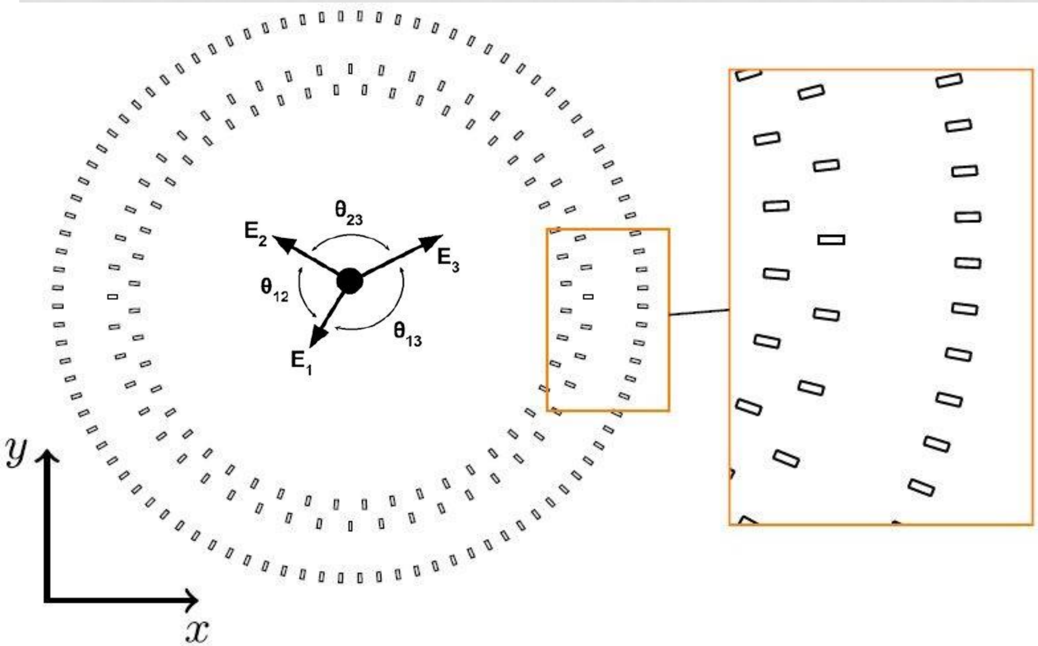


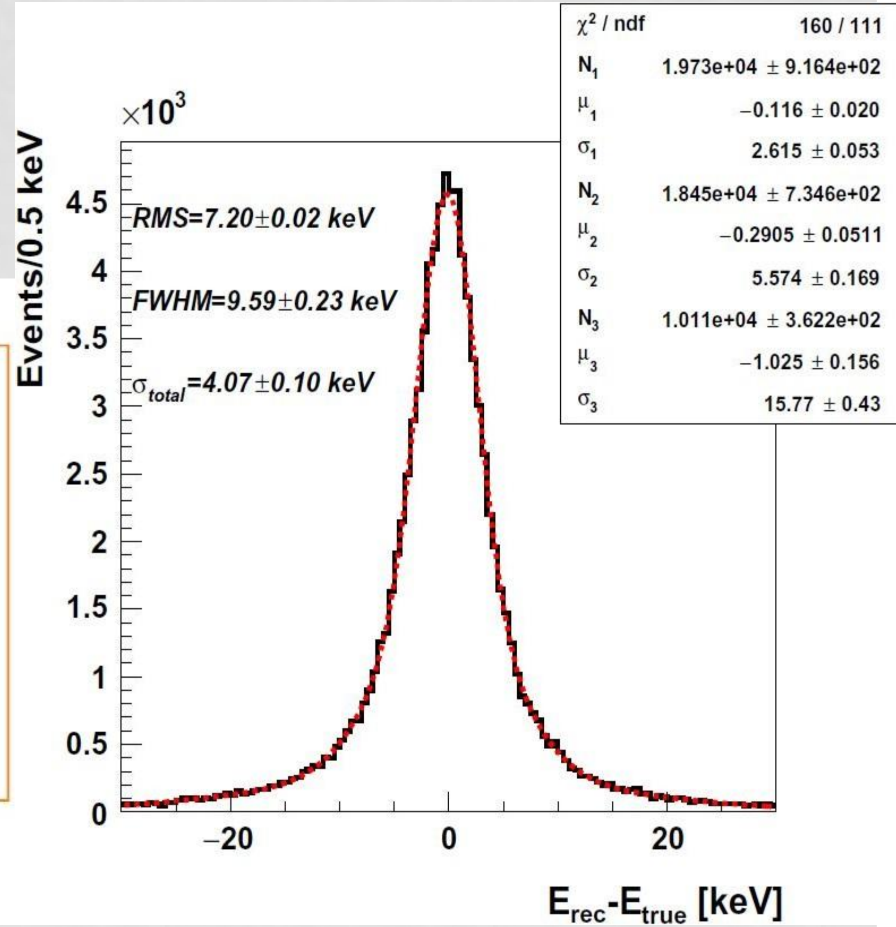
A feasibility study of ortho-positronium decays measurement with the J-PET scanner based on plastic scintillators

Eur. Phys. J. C (2016) 76:445

DOI 10.1140/epjc/s10052-016-429

DETECTOR PERFORMANCE: ENERGY RESOLUTION (O-PS)

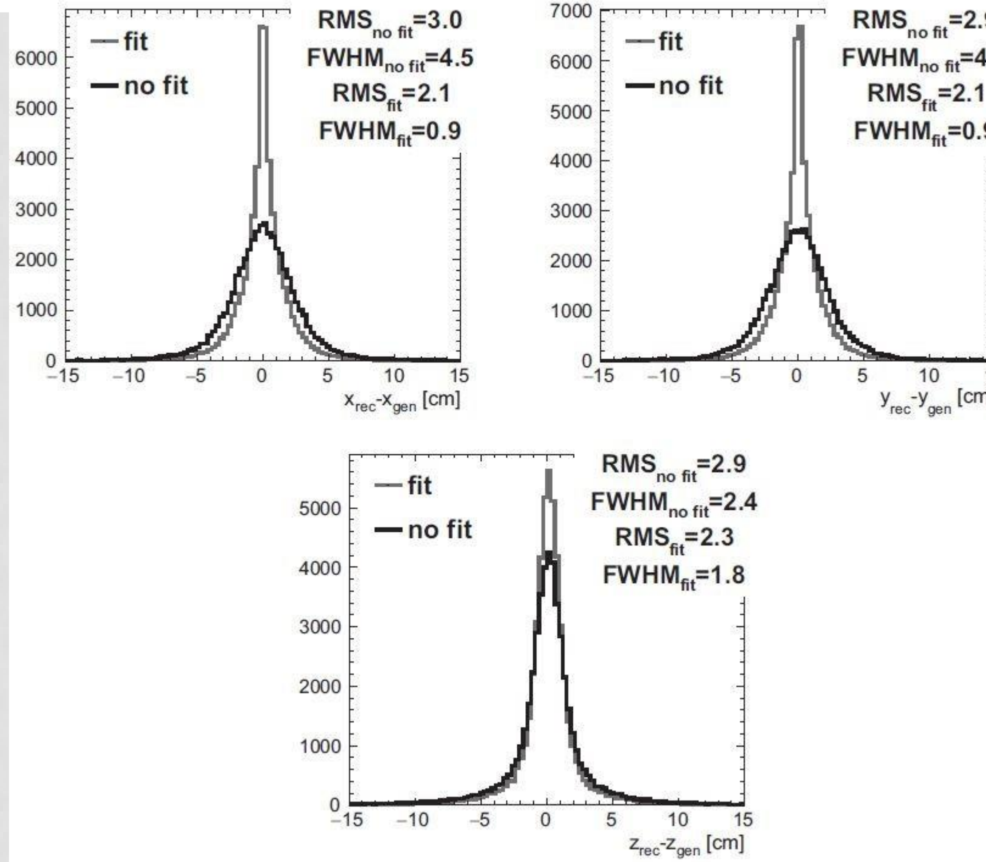


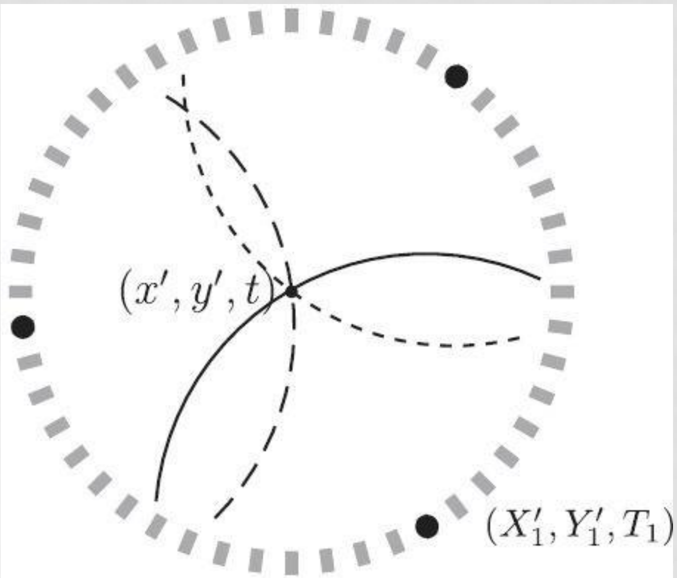


A feasibility study of ortho-positronium decays measurement with the J-PET scanner based on plastic scintillators

Eur. Phys. J. C (2016) 76:445
DOI 10.1140/epjc/s10052-016-429

DETECTOR PERFORMANCE: SPATIAL RESOLUTION (O-PS)





Trilateration-based reconstruction of ortho-positronium decays into three photons with the J-PET detector
Nuclear Inst. and Methods in Physics Research A 819 (2016) 54-59