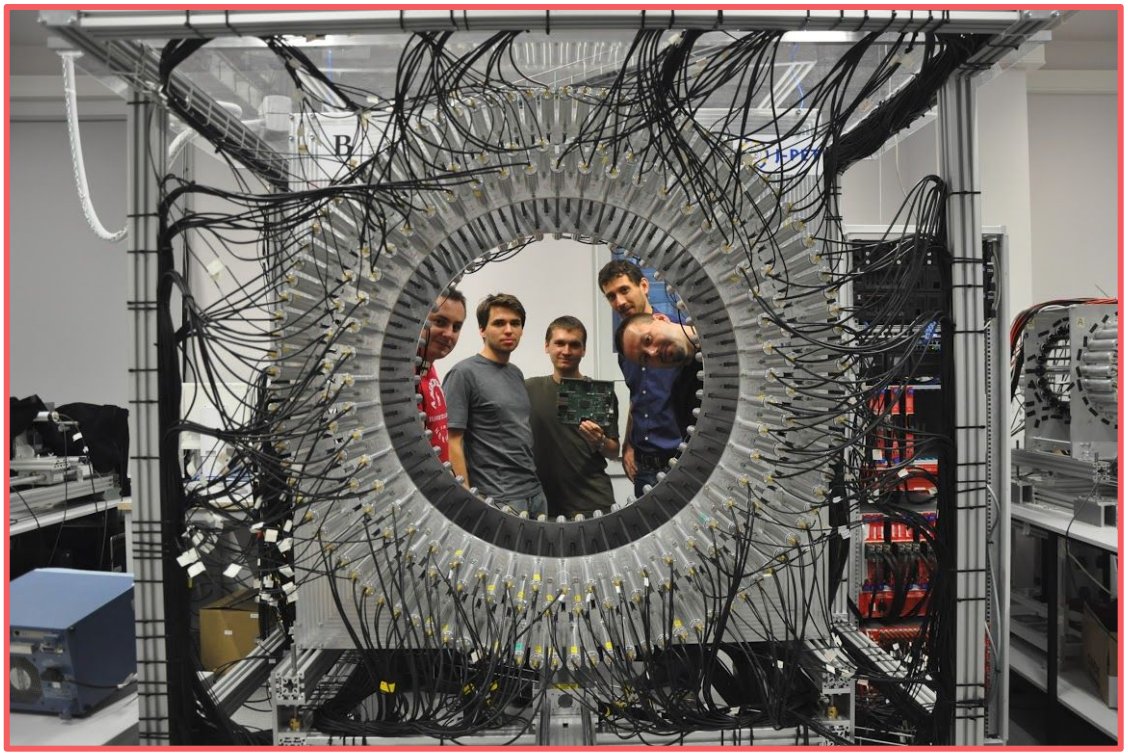
Precision test for T-symmetry violation in Positronium decay using the J-PET detector

Juhi Raj
On Behalf of the J-PET Collaboration
Jagiellonian University, Krakow, Poland



3rd Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, 23rd- 28th June, 2019

Overview:

1.) Motivation

- **Precision test in T-Symmetry Violation in the Leptonic Sector**

2.) Methodology

- **Experimental Method & Pre-selection of collected Data**

3.) Preliminary Results

- **Precision of T-Symmetry Violation**

Precision tests in T-Symmetry Violation in the Leptonic Sector:

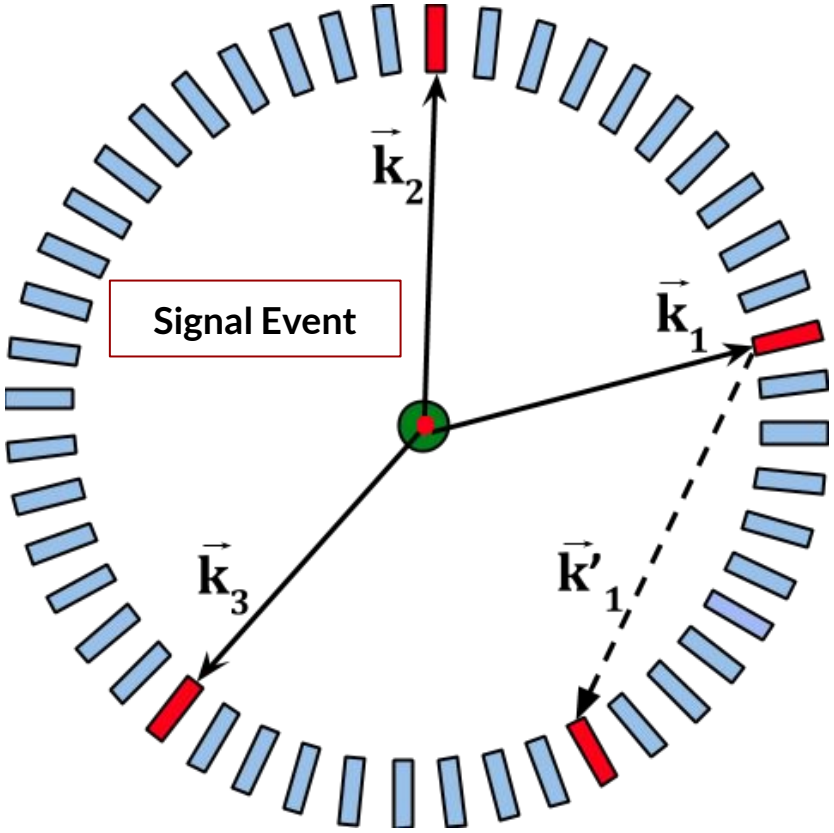


Figure 1: Schematic of the single layer of plastic scintillators in the J-PET detector as the blue ring. Measurement methods to study the operators in Table 1.

So far, No CP- violation was observed with a sensitivity of 2.2×10^{-3}.

T. Yamazaki et al., Phys. Rev. Lett. 104, 083401 (2010)

Operator	C	P	T	CP	CPT
$\vec{S} \cdot \vec{k_1}$	+	−	+	−	−
$\vec{S} \cdot (\vec{k_1} \times \vec{k_2})$	+	+	−	+	−
$(\vec{S} \cdot \vec{k_1}) \cdot (\vec{S} \cdot (\vec{k_1} \times \vec{k_2}))$	+	−	−	−	+
$\vec{\epsilon_1} \cdot \vec{k_2}$	+	−	−	−	+
$\vec{S} \cdot \vec{\epsilon_1}$	+	+	−	+	−
$\vec{S} \cdot (\vec{k_2} \times \vec{\epsilon_2})$	+	−	+	−	−

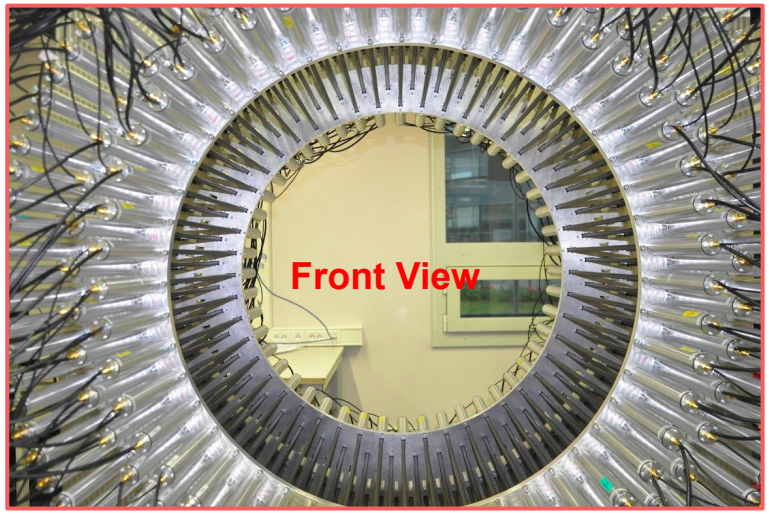
Operator	C	P	T	CP	CPT
$\vec{\epsilon_1} \cdot \vec{k_2}$	+	−	−	−	+

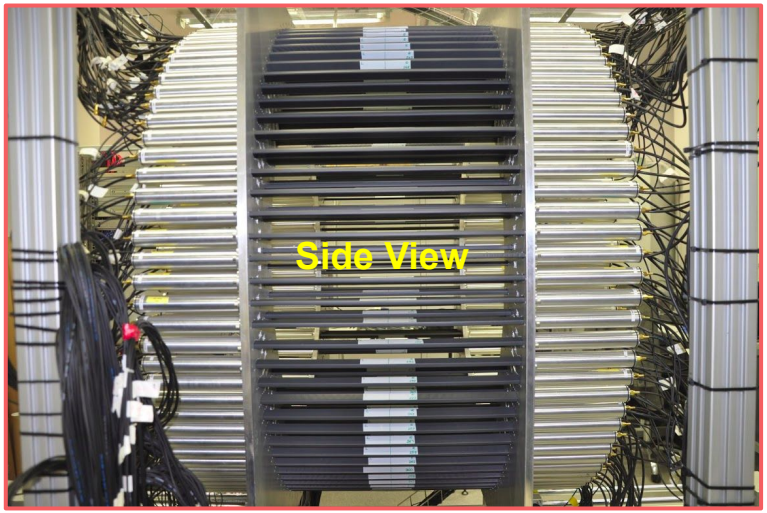
Table 1. Discrete symmetry odd-operators using spin orientation of the o-Ps as well as polarization and momentum directions of the annihilation photons

Talk by **Aleksander Gajos,** Wednesday (10:20 to 10:40)

P. Moskal et al., Acta Phys. Polon. B 47, 537 (2016)

Jagiellonian - Positron Emission Tomograph





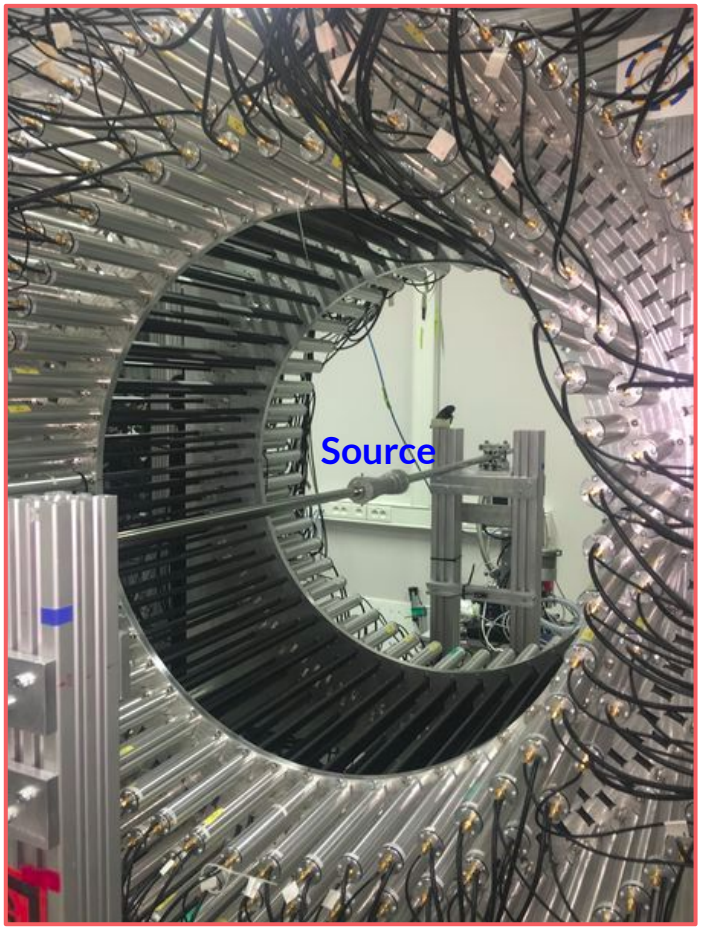


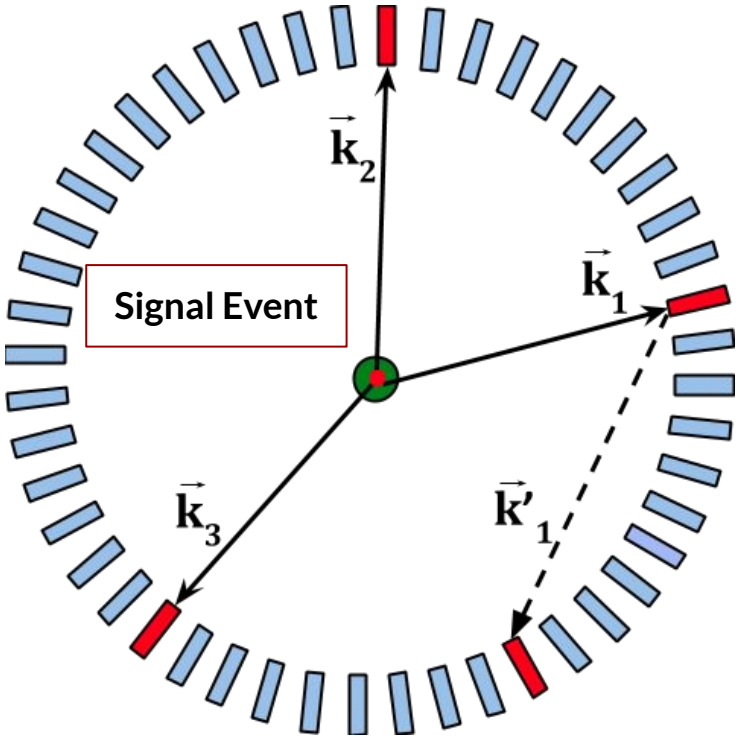
Figure 2: A point like positron source is placed in the center of the detector geometry, covered in XAD-4 porous polymer within the small metallic chamber.

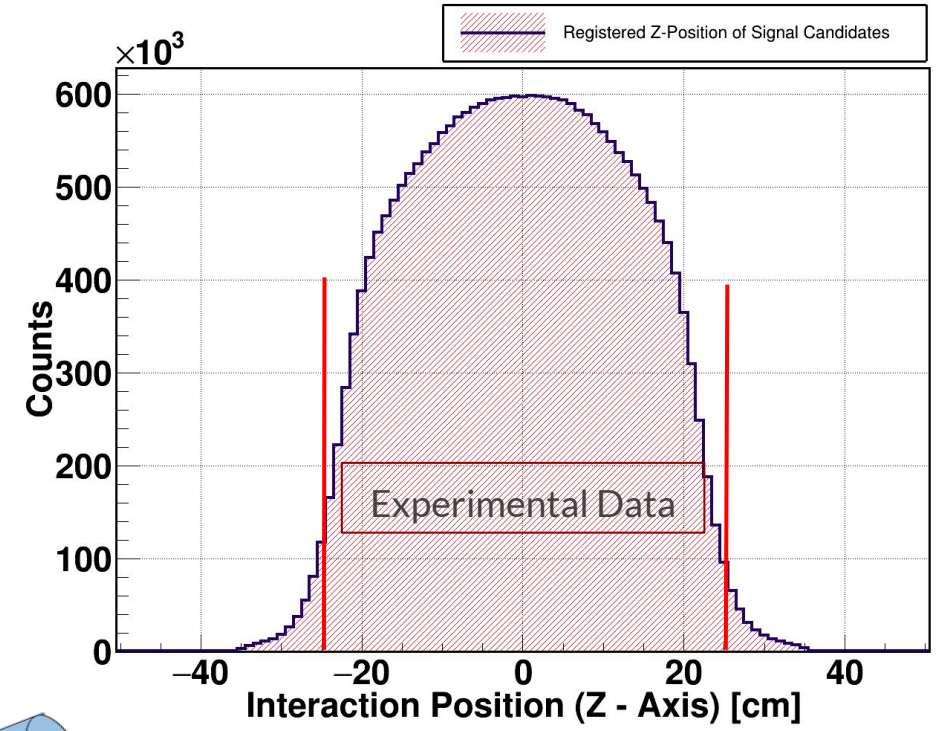
Talks by

Szymon Niedźwiecki (Thursday 10:05 to 10:25)

Grzegorz Korcyl (Thursday 10:45 to 11:00)

Pre-selection of the signal: o-Ps $\longrightarrow 3\gamma + \gamma'$





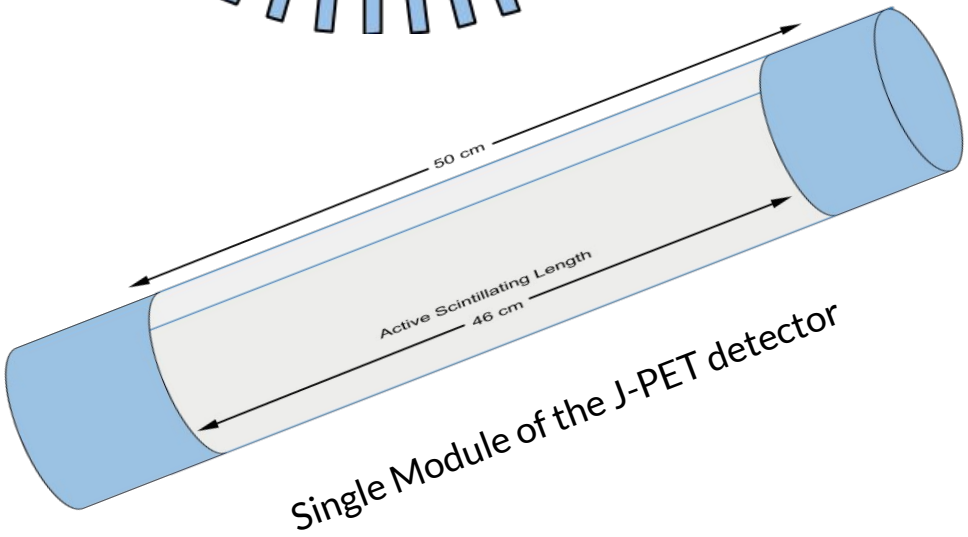


Figure 3: Presents the distribution of the interaction positions on the Z-axis of the photon interaction in the detector geometry.
The active scintillating region lies between -23.0 cm & +23.0 cm (Z-axis).

Energy Deposition as a function of Time Over Threshold (TOT):

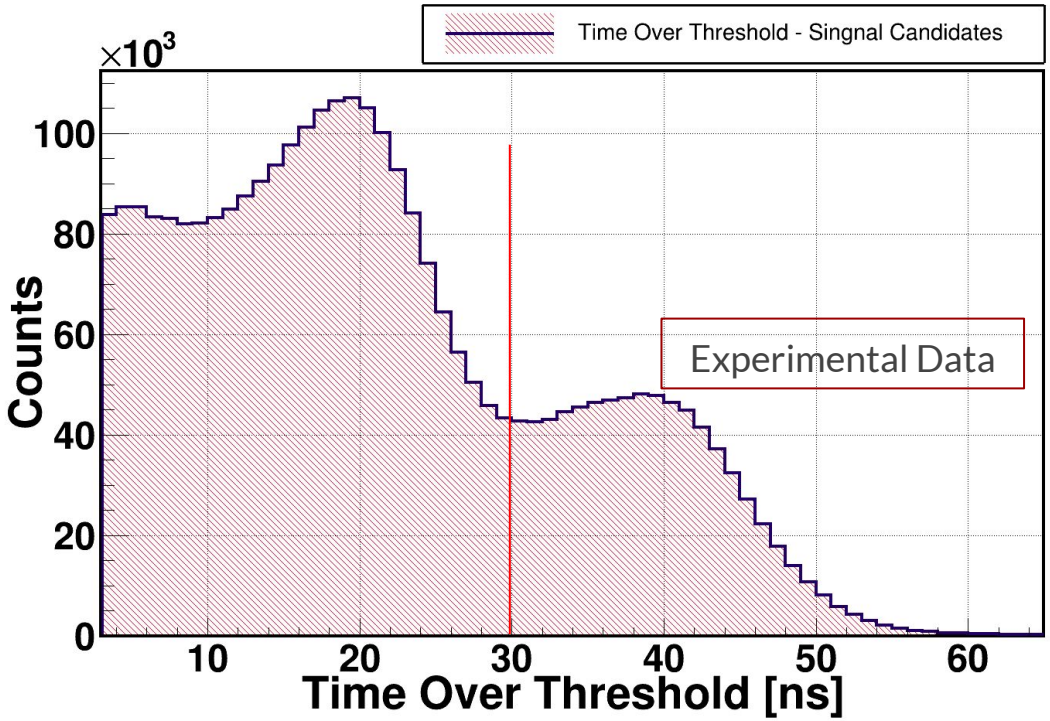
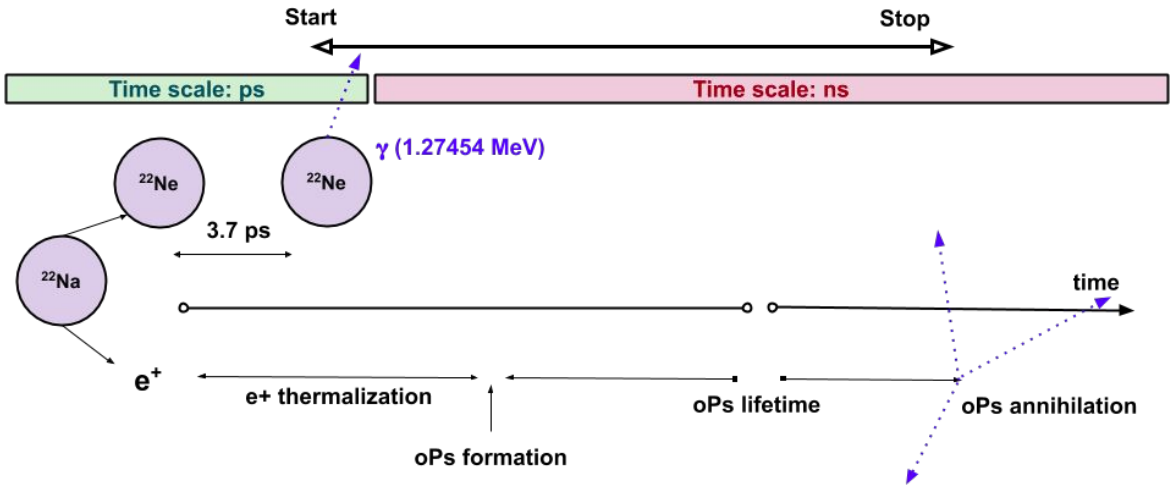


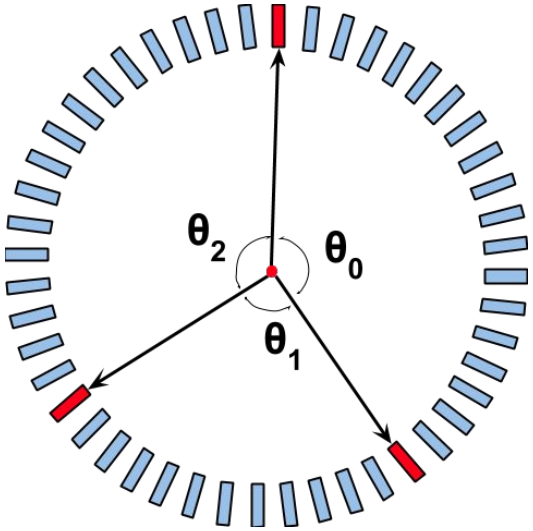
Figure 5: The de-excitation photon is identified using the time-over-threshold (TOT) measurement which is related to the energy deposited in the scintillator.

The figure shows the TOT distribution where one can clearly recognize Compton spectra from 511 keV and 1274 keV gamma photons. The de-excitation photon (1274 keV) may be rejected with the efficiency of about 66% when requiring TOT smaller than 30ns.

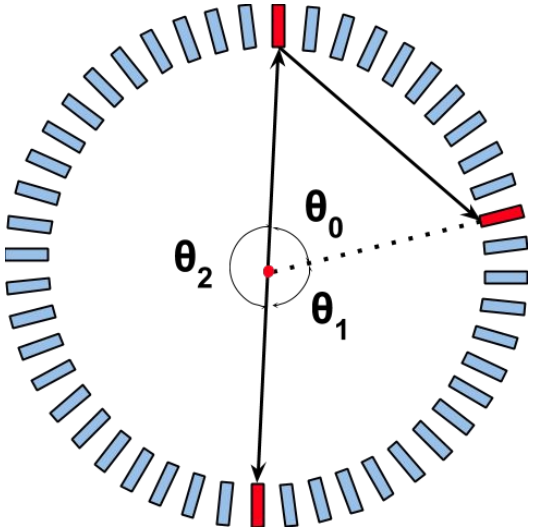


M. Palka et al., JINST 12 P08001, (2017)

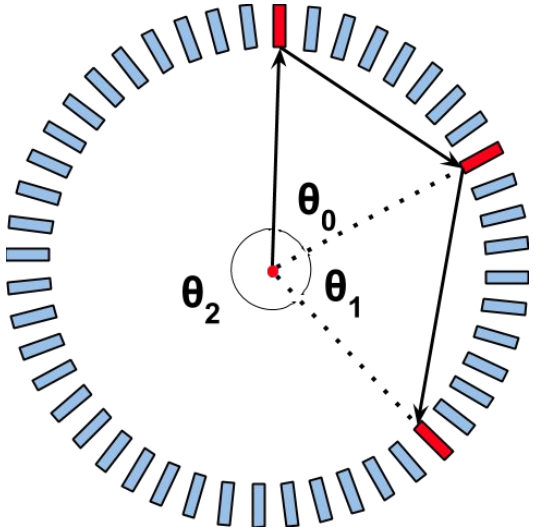
Relative azimuthal angles of the interacting photons in an event:



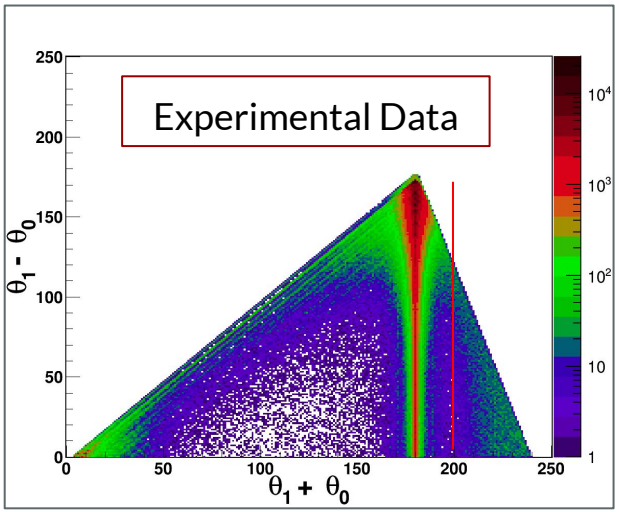
o-Ps -> 3g

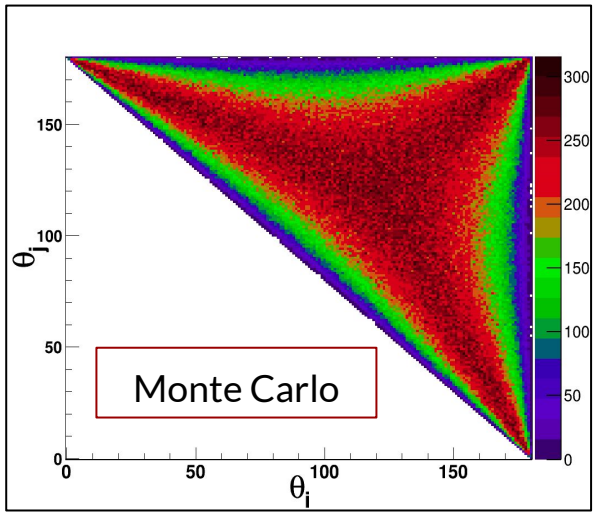


p-Ps -> 2g + g'



1 g + 2g'





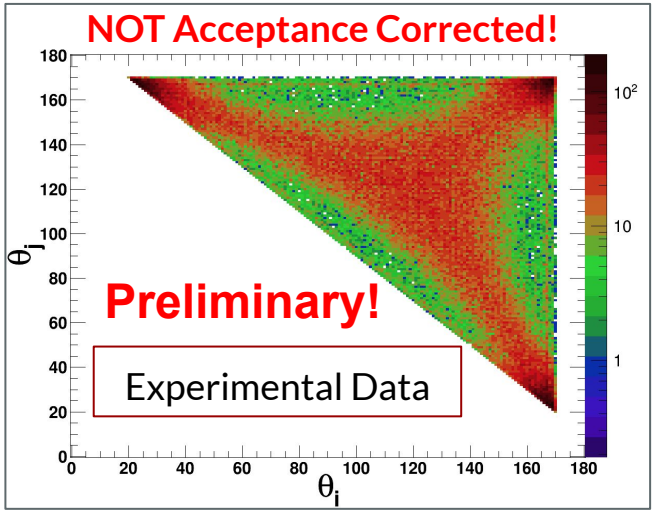


Figure 6 a: Represents the distribution of the sum ($\theta_1 + \theta_0$) and difference ($\theta_1 - \theta_0$) of the two smallest azimuthal angles between the 3γ of o-Ps decay.

Figure 6 b: Represents the distribution of the relative azimuthal angles between the decay of o-Ps into 3γ. (Left) Generated Monte Carlo and (Right) Measured Experimental Data.

ortho-Positronium Lifetime :

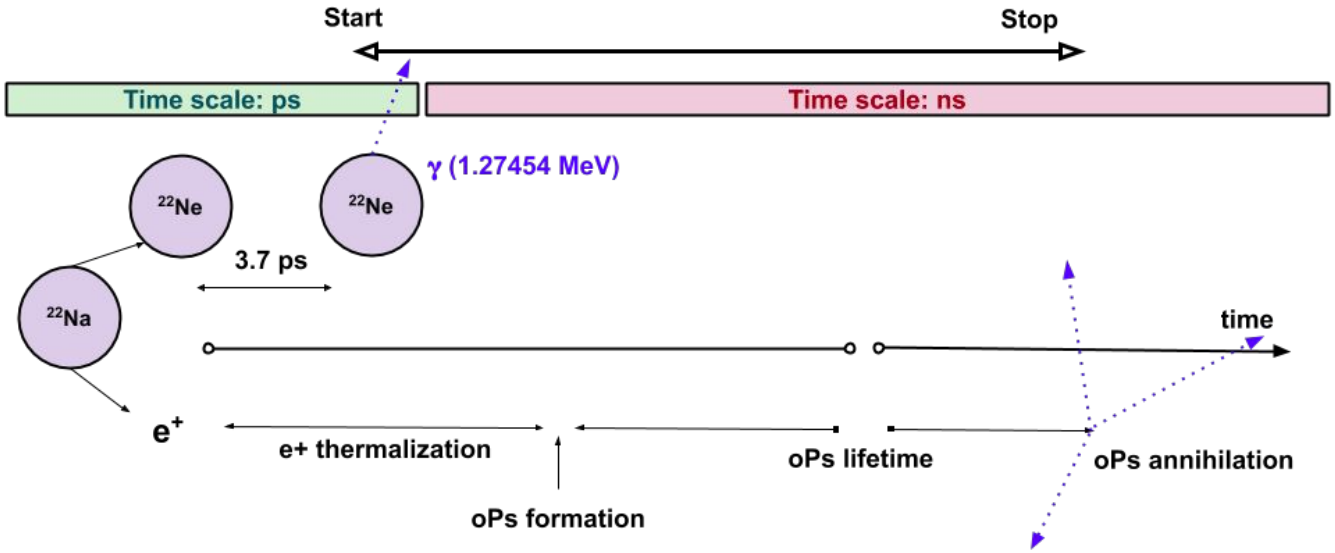


Figure 7a. Decay scheme of Sodium and formation of ortho-Positronium.

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

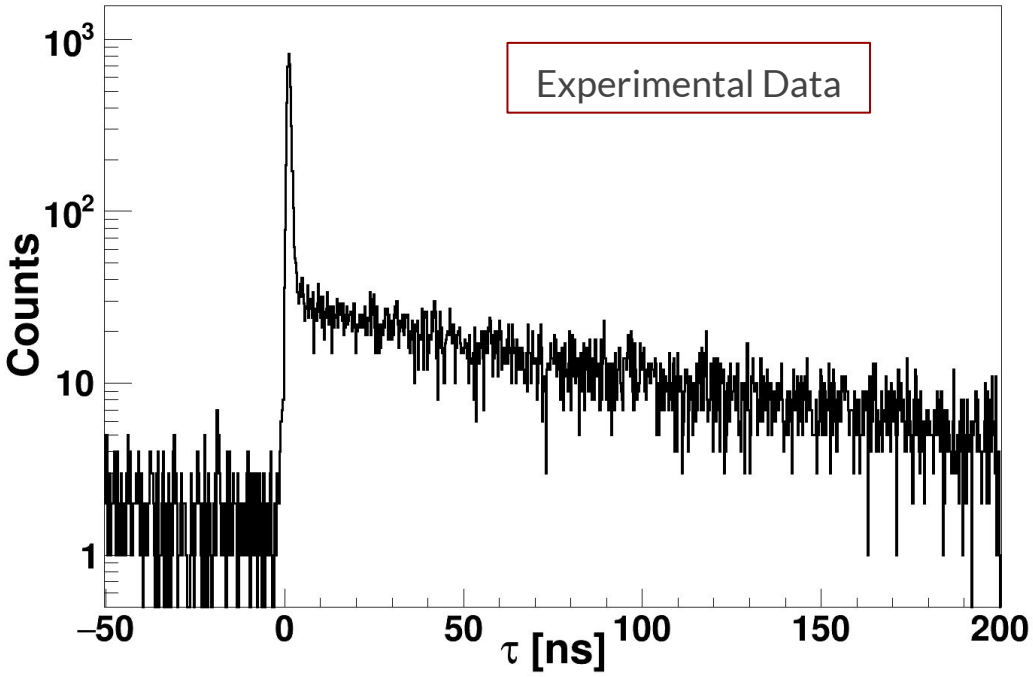


Figure 7b. Positron lifetime distribution in the XAD4, obtained from measurement with the J-PET detector.

Measurement was conducted by placing a ^{22}Na source covered in XAD4 polymer in the center of the geometry.

The lifetime spectra was obtained by identifying the prompt photon and the three annihilated photons from the decay of o-Ps

Identification of the Scattered Photon:

Where, $\Delta_{MC} = t_M - t_C$

t_C = Calculated Time of Flight
$t_M = t_{1'} - t_1$ = Measured Time of Flight

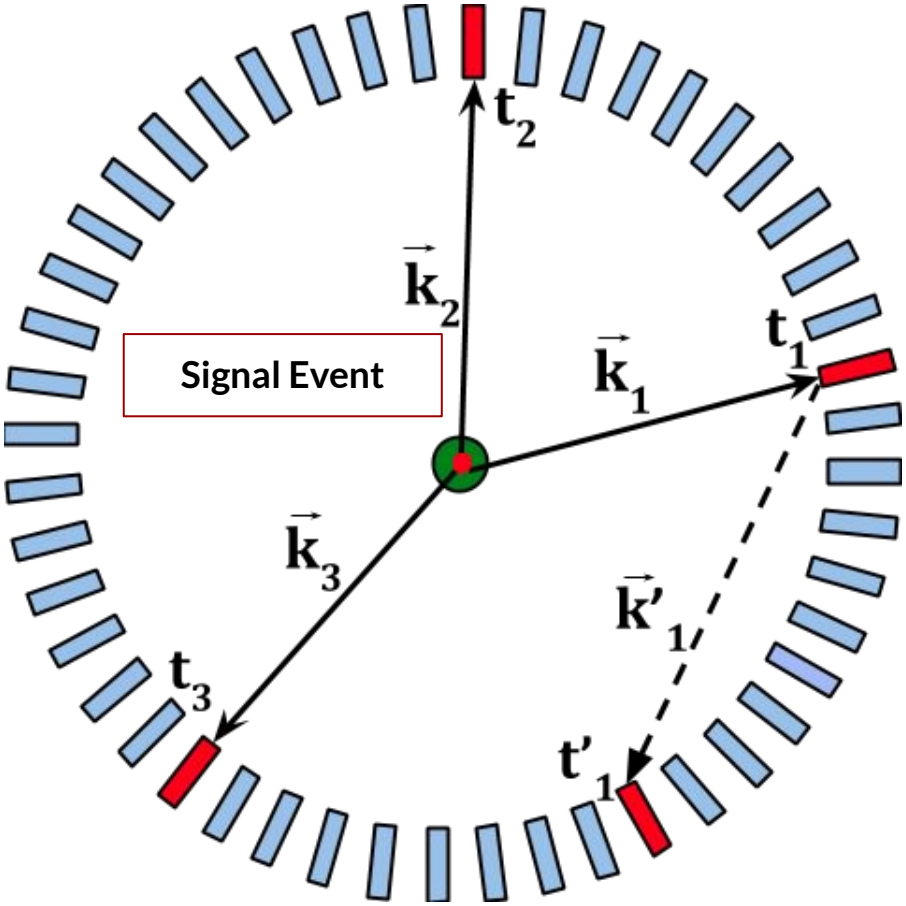


Figure 8a: Schematic of the single layer of plastic scintillators in the J-PET detector as the blue ring.
A point like positron source (red) is placed in the center, covered in XAD-4 porous polymer (green).
The superimposed arrows indicate the three gamma photons originating from the annihilation of ortho-positronium decay (k_1, k_2 and k_3), and scattered photon (k_1)

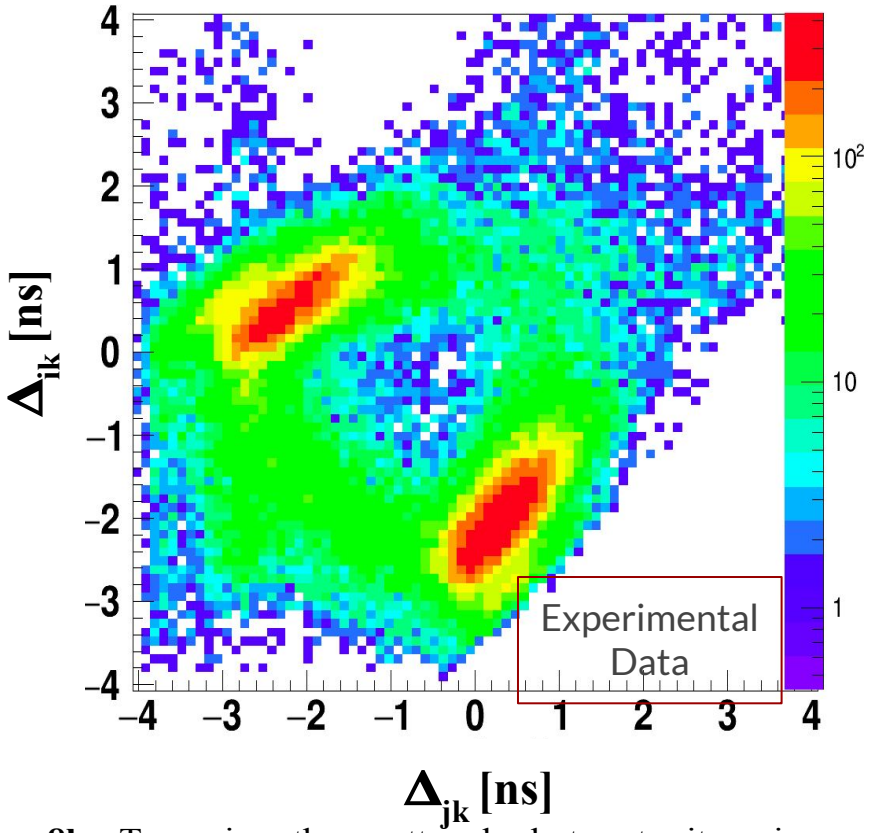
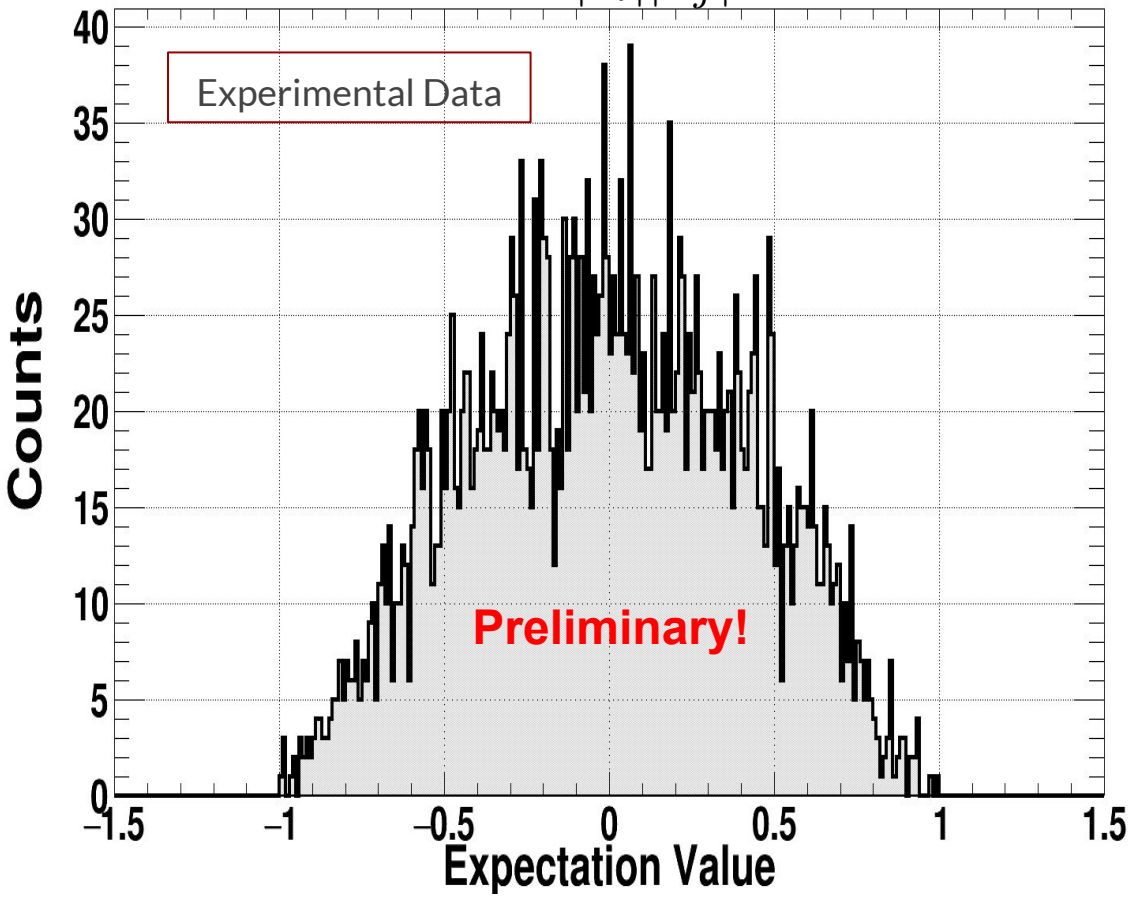


Figure 8b: To assign the scattered photon to its primary photon we introduce a parameter $\Delta_{ik} = (t_M - t_C)$, where, t_M and t_C are the measured and calculated time of flight between the i^{th} and k^{th} interaction, respectively. Therefore, Δ_{ik} should be equal to zero in case if the k^{th} signal is due to the i^{th} scattered photon

J. Raj, et al., Hyperfine Interact, 239:56 (2018)

Expectation value of the symmetry-odd-operator:

$$ExpectationValue = \frac{\vec{\epsilon_i} \cdot \vec{k_j}}{|\vec{\epsilon_i}||\vec{k_j}|}$$



So far, No CP- violation was observed with a sensitivity of 2.2×10^{-3}.

T. Yamazaki et al., Phys. Rev. Lett. 104, 083401 (2010)

- The presented result represents only **~1%** of the data collected so far.
- The detector is going to be upgraded with an added on layer to improve the acceptance.
- Improve the precision test of T-symmetry in the decay of o-Ps by one order of magnitude to the currently published value.

Expectation Value = $3.2 \times 10^{-4} +/- 2.2 \times 10^{-3}$

Note: No T-Symmetry Violation is observed with a precision of ~10^{-3}

Thank you!