Tests of discrete symmetries using polarization of the annihilation photons

Sushil K. Sharma on behalf of the
Jagiellonian PET

Motivation

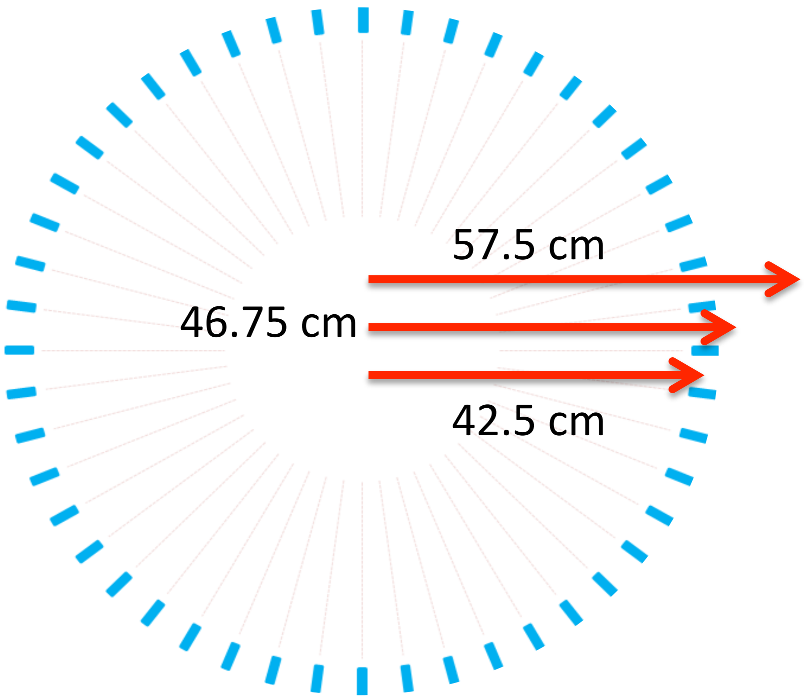
Presented by Eryk Czerwincski and Michal Silarski on Tuesday

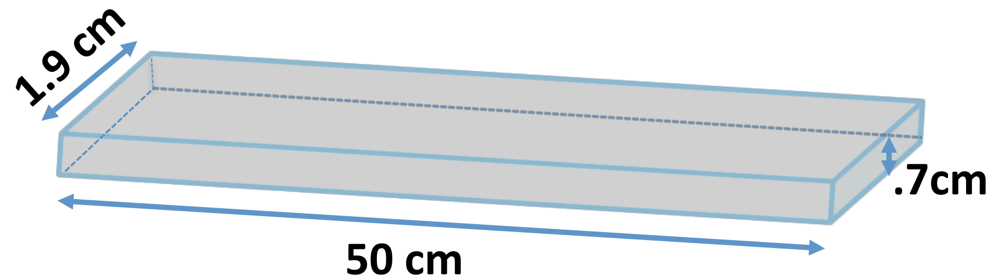
Operators	C	P	T	CP	CPT
$\vec{S} \cdot \vec{k}_1$	+	−	+	−	−
$\vec{S} \cdot (\vec{k}_1 \times \vec{k}_2)$	+	+	−	+	−
$(\vec{S} \cdot \vec{k}_1)(\vec{S} \cdot (\vec{k}_1 \times \vec{k}_2))$	+	−	−	−	+

Studies of discrete symmetries using the photon's polarization

Unique feature of the J-PET

2-D front view J-PET





192 plastic Scintillators

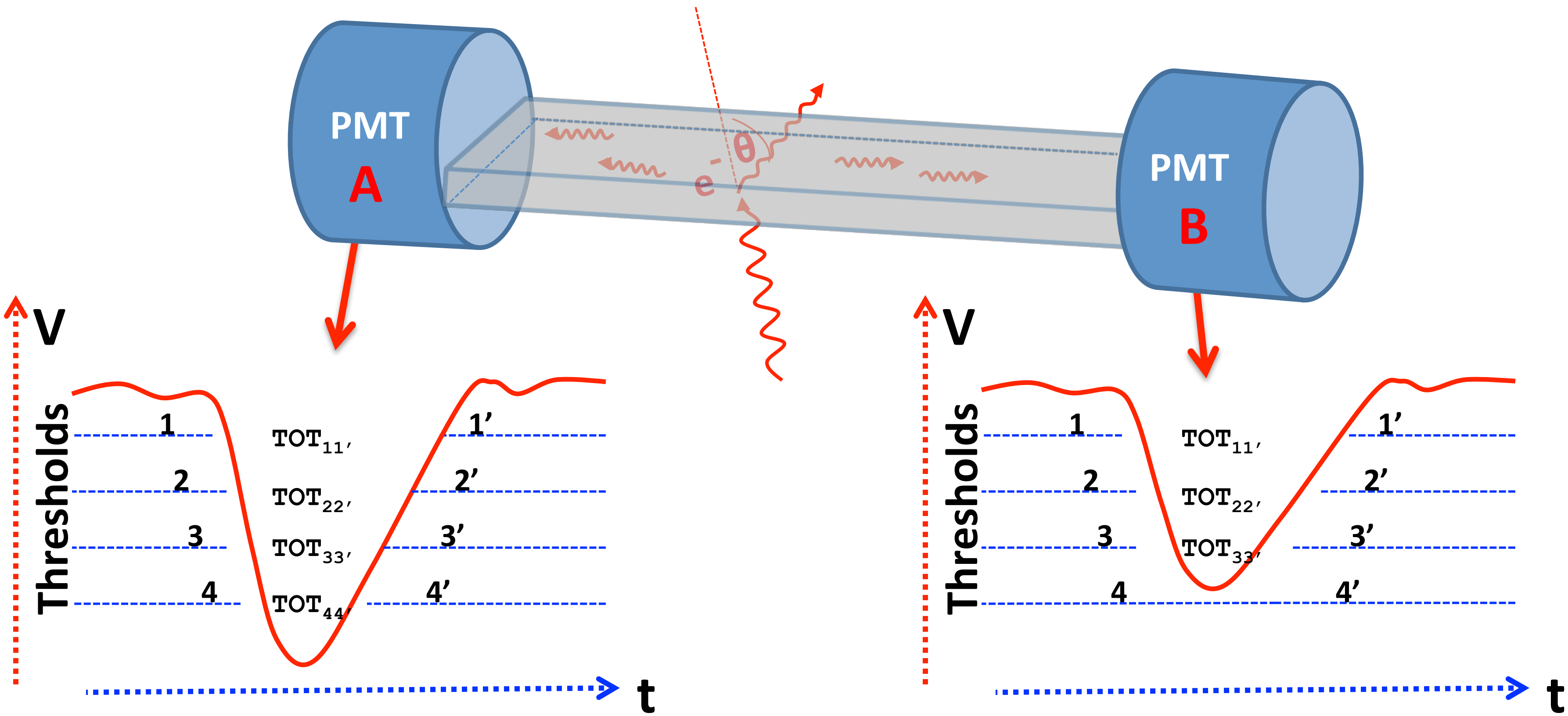
Arranged axially in 3 layers

Key features :

- ☑ **Trigger less and reconfigurable DAQ**
- ☑ **TOT as measure of energy deposition**

- ✓ *Good angular resolution and small light attenuation*
- ✓ *Superior time properties and lower pile-ups*

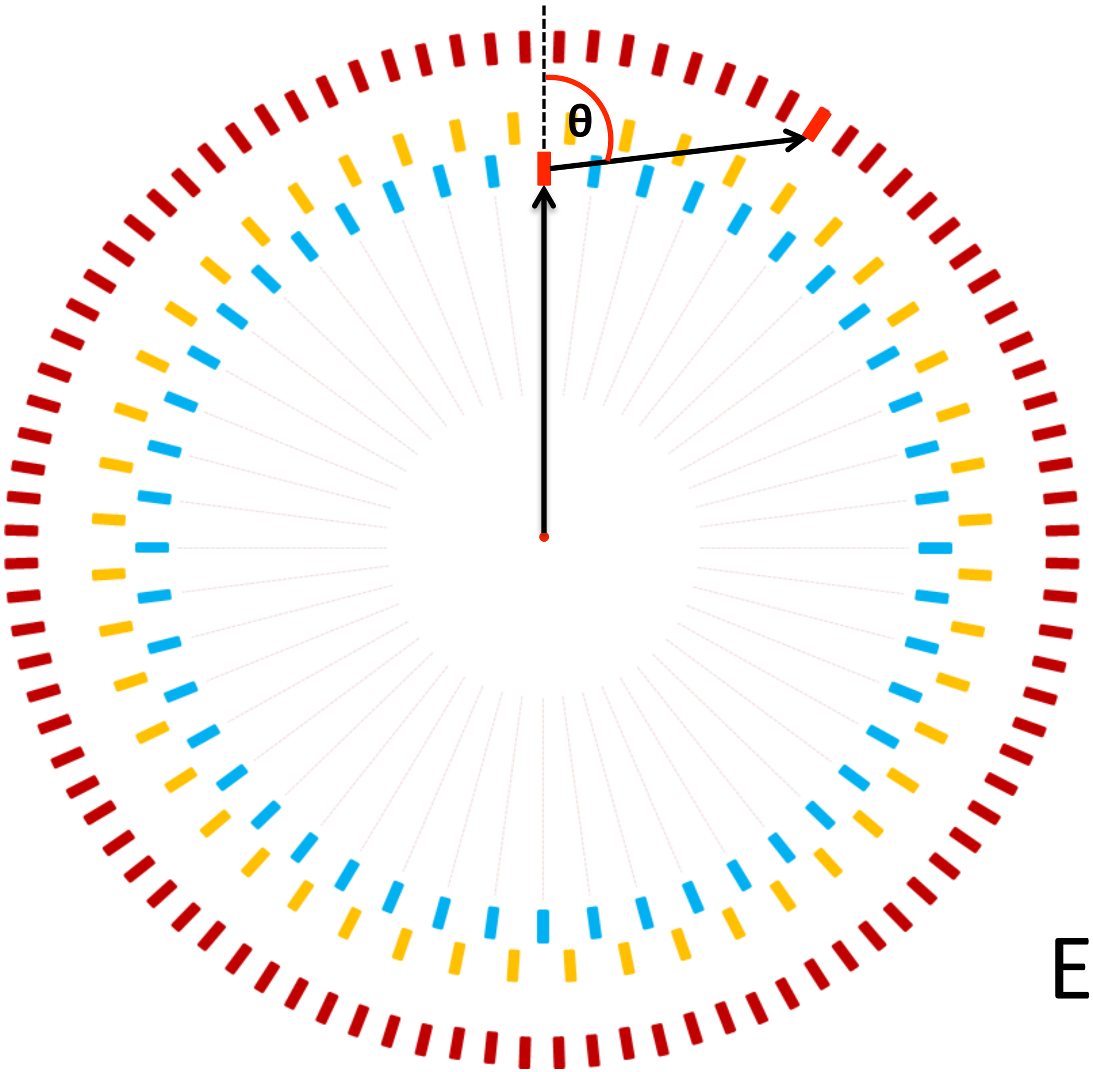
Time-Over-Threshold



Signals from each photomultiplier are ***probed at four thresholds***.

$$TOT = TOT_{sum}A + TOT_{sum}B$$

Time-Over-Threshold



What we have :

- ✓ Measured **TOT** values
- ✓ Hit positions and time of primary and scattered photon gives **access to the θ** values

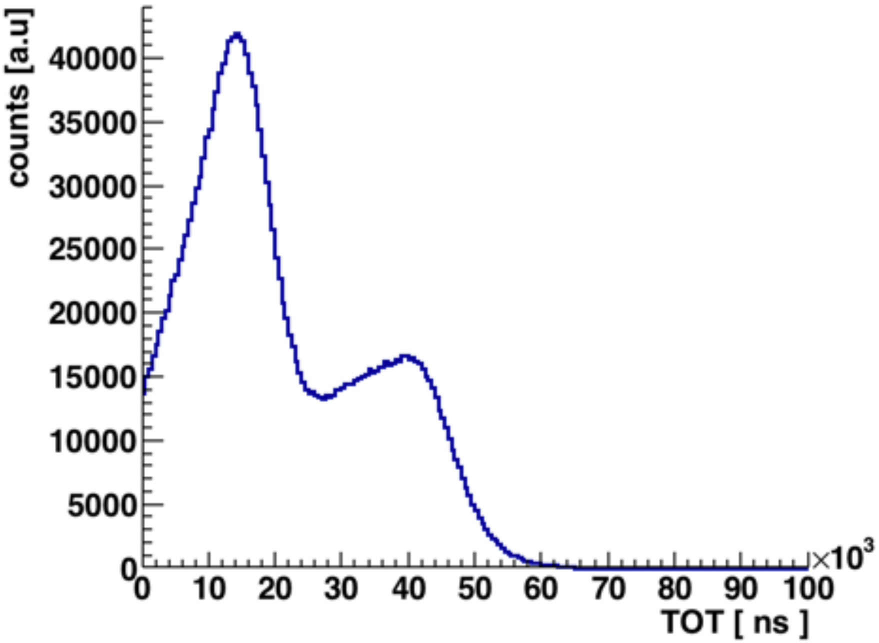
What is required :

✧ **Energy** of the **incident photon**

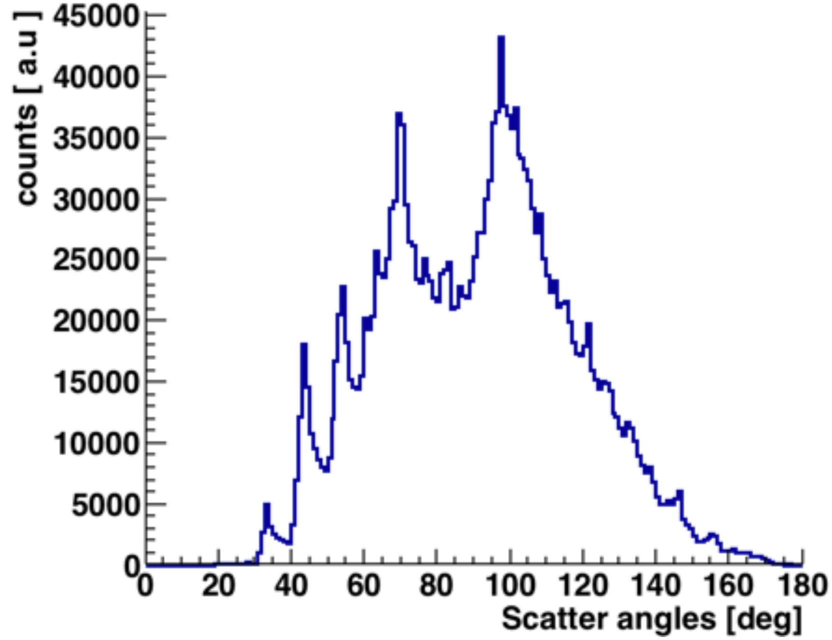
$$E_{dep} = f(E_{inc}, \theta)$$

TOT vs Energy deposition

TOT spectra

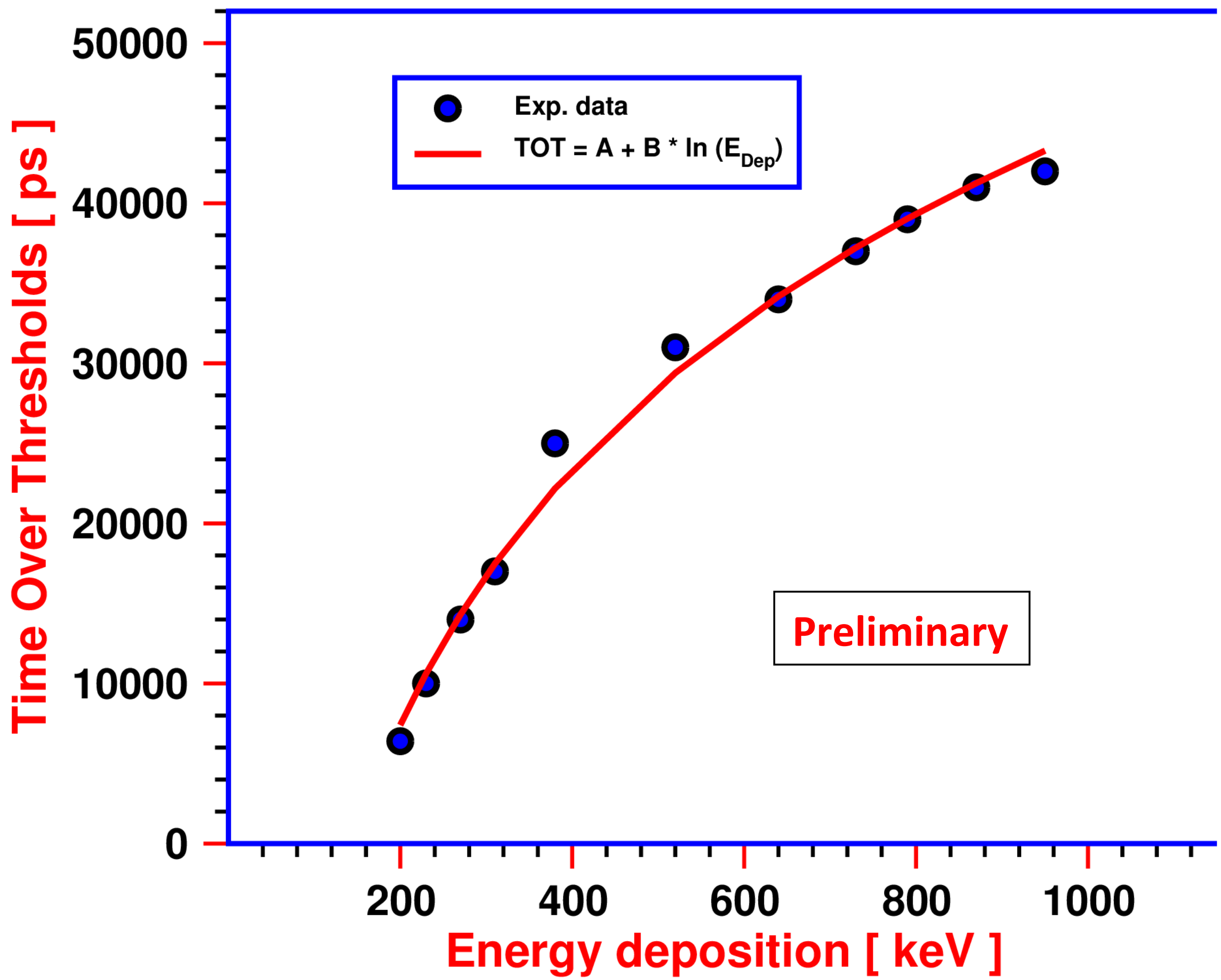


Scattered angles (θ)



- From the ^{22}Na source, one can get 511 keV from the e^+ e^- annihilation and 1274.6 from prompt.
- TOT spectra resemble the Compton like structure, where *TOT is the measure of energy deposition*.

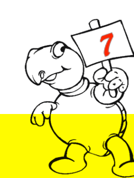
Results : TOT vs Edep



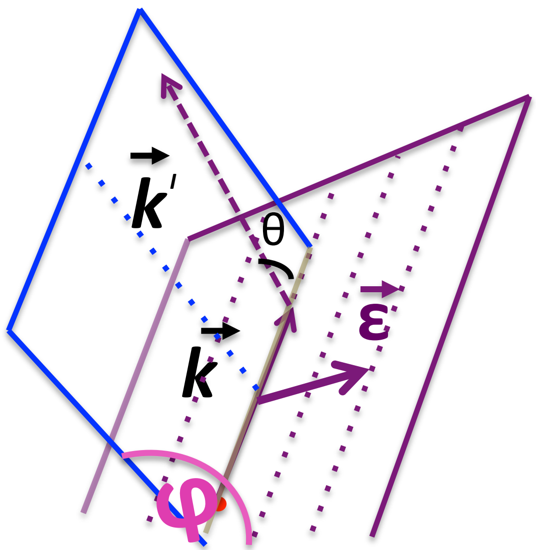
Discrete symmetry operators based on Photon's polarization

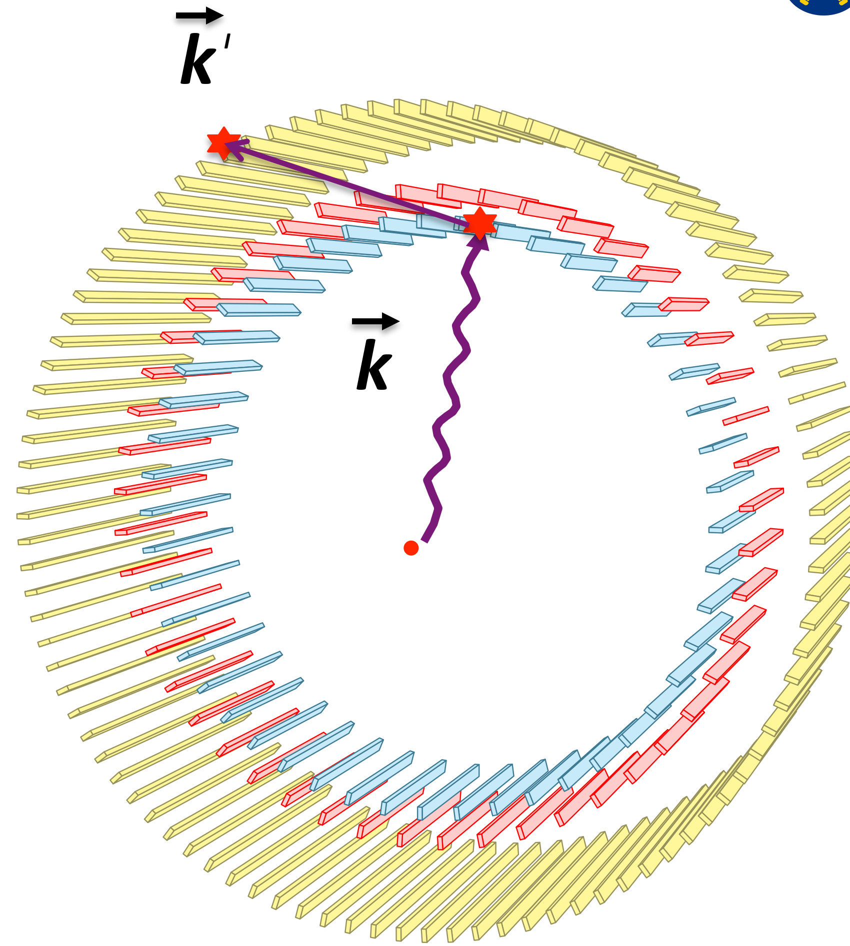
Operators	C	P	T	CP	CPT
$\vec{S}\cdot\vec{k}_1$	+	−	+	−	−
$\vec{S}\cdot(\vec{k}_1 \times \vec{k}_2)$	+	+	−	+	−
$(\vec{S}\cdot\vec{k}_1)(\vec{S}\cdot(\vec{k}_1 \times \vec{k}_2))$	+	−	−	−	+
New operators available with J-PET				With	$\boxed{\vec{\varepsilon}_i = \vec{k}_i \times \vec{k'}_i}$
$\vec{k}_2\cdot\vec{\varepsilon}_1$	+	−	−	−	+
$\vec{S}\cdot\vec{\varepsilon}_1$	+	+	−	+	−
$\vec{S}\cdot(\vec{k}_2 \times \vec{\varepsilon}_1)$	+	−	+	−	−

P. Moskal et al., Acta Phys. Polon. B 47 (2016) 509



Photon’s polarization





Photon’s Polarization

$$\vec{\varepsilon} = \vec{k} \times \vec{k}'$$

P. Moskal et al., **Acta. Phys. Polon. B 47** (2016) 509, P. Moskal et al., arXiv : 1809.10397v1

Limitation in determining the Single photon's polarization

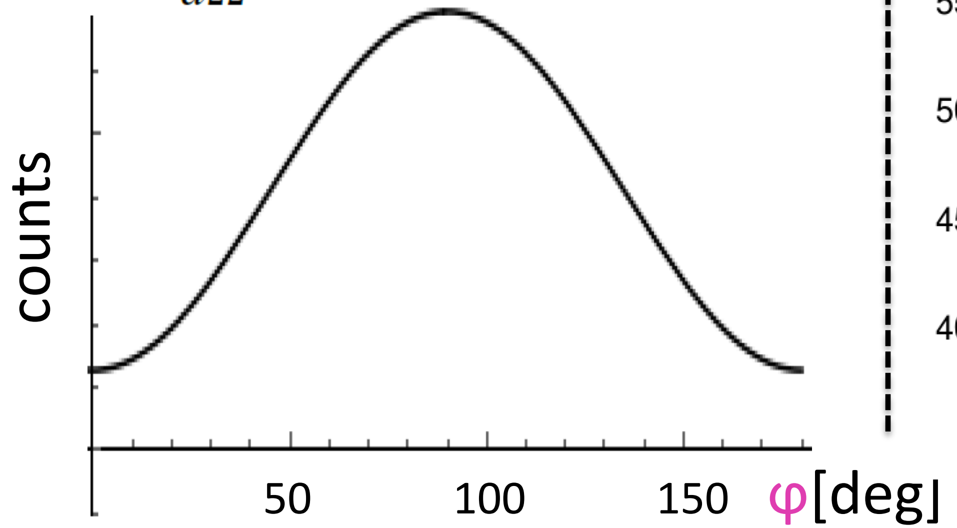
(Based on only the Compton scattering)

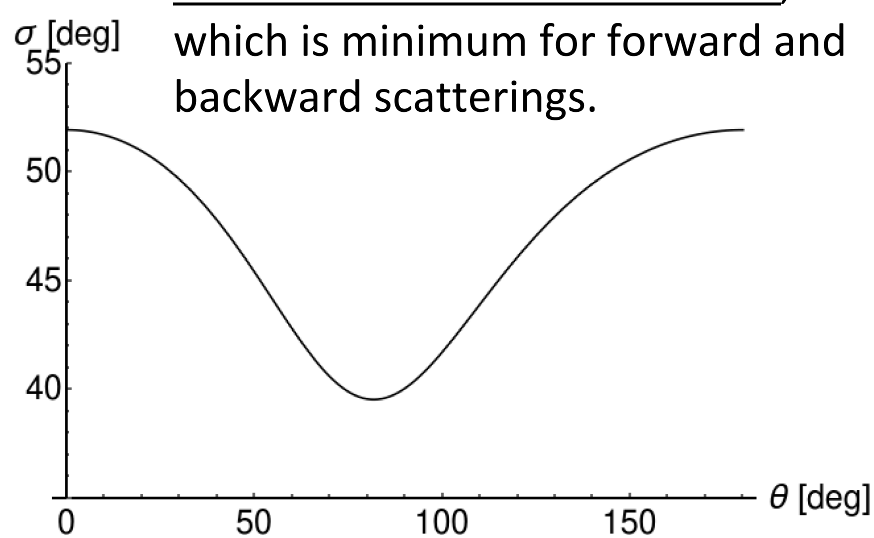
☑ The scattering distribution of photons in the interactions with electron can be described by Klein-Nishina diff. cross section.

☑ The visibility to observe the angular correlation between scattering and polarization plane(φ) is a function of **Photon's energy** and its **scattering angle** **(θ)**.

☑ For **511 keV** **photon** and scattering **θ = 81.66⁰** , the Klein-Nishina differential xn for φ:

$$\frac{d\sigma(E,\theta,\varphi)}{d\Omega}$$

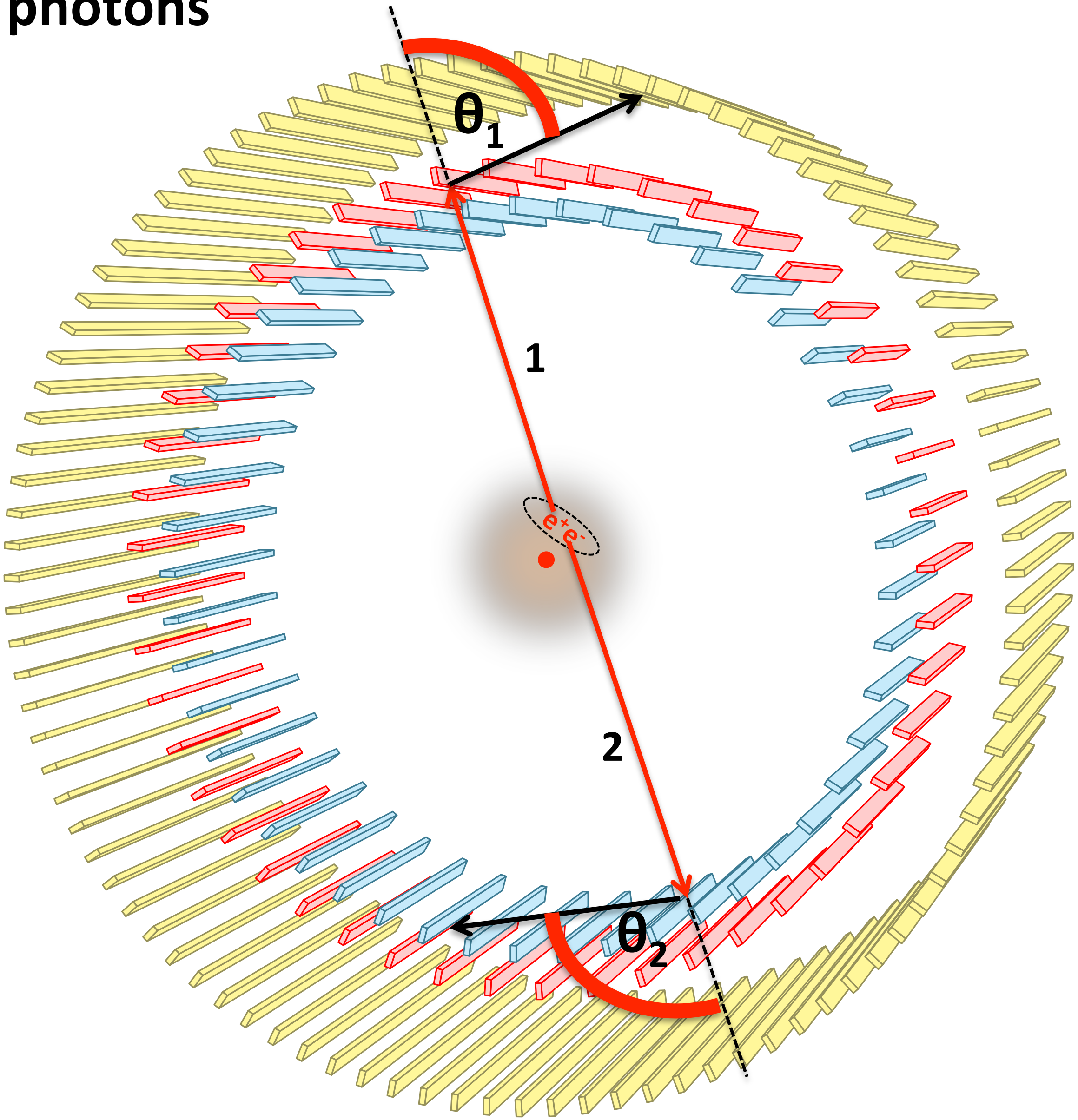




standard deviation around 40^0, which is minimum for forward and backward scatterings.

P. Moskal et al., **Acta. Phys. Polon. B 47** (2016) 509, P. Moskal et al., arXiv : 1809.10397v1

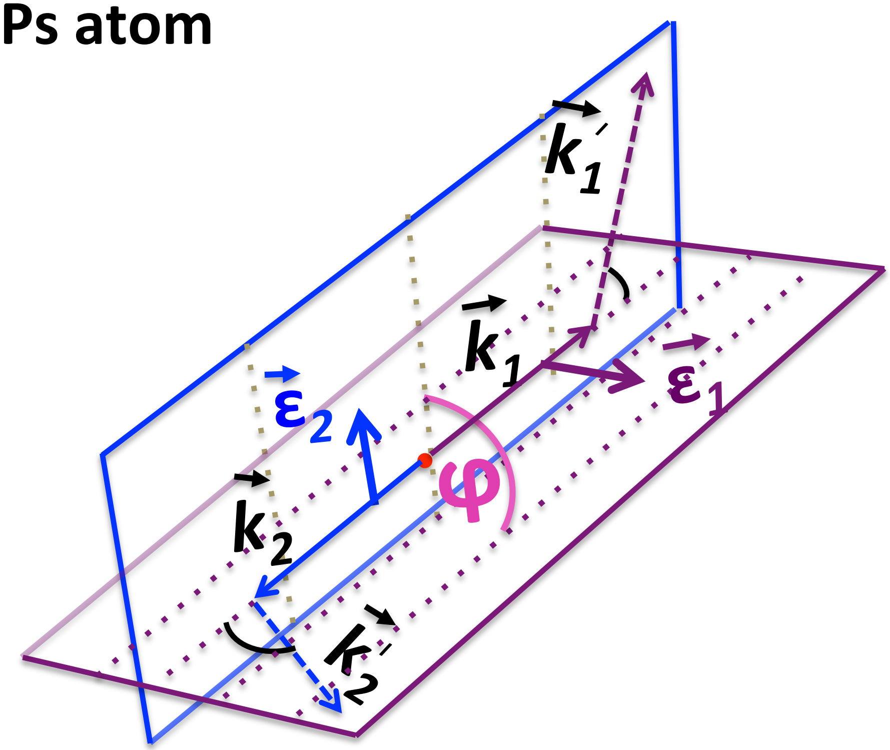
Eventwise observation of scattering angles of back -to- back photons

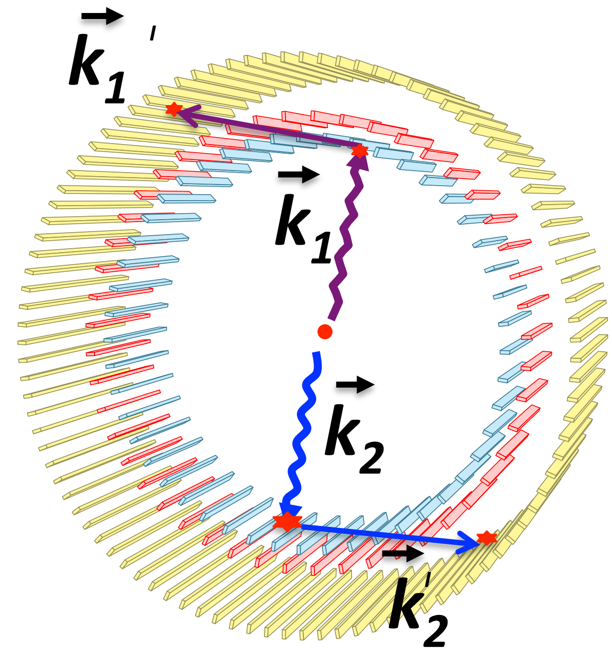


The positron emitting from the ^{22}Na source can annihilate into two photons, directly or through the formation of positronium atoms.

The interactions of the anni-hilated photons with electrons can be measured event-wise and allow to study the ***correlation between the scattering angles***.

Relative polarization of entangled annihilated photons in decay of p-Ps atom





- Polarization vectors of annihilation photons are mutually orthogonal states.
- Photons mostly scatter at right angles to their electric field vector and this impose an **Expected angular correlation** between the scattering angles.
- With the J-PET detector we can measure scatterings of back-to-back photons and thus can study the angular correlation(φ) between the scattering angles.
- Thus the **angle between two scattering planes(φ)** can be an estimator of relative polarization of two photons.

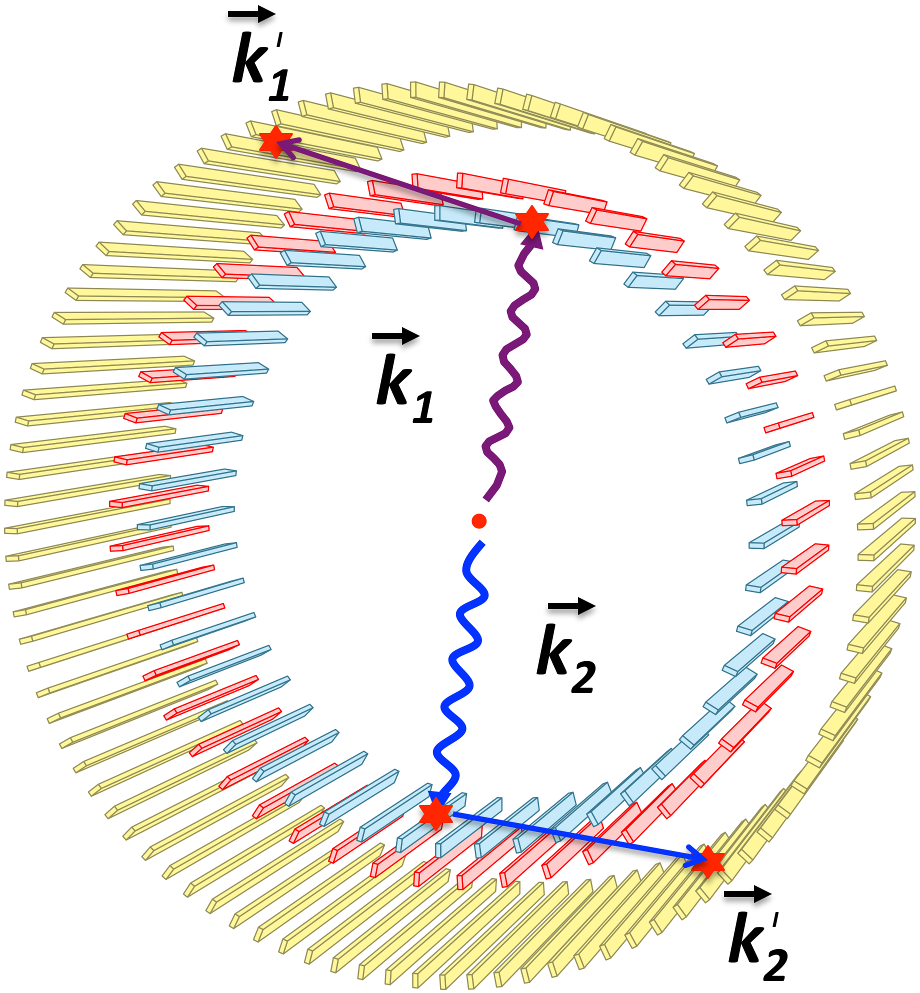
P. Moskal et al., **Acta. Phys. Polon. B 47** (2016) 509, P. *Moskal et al., arXiv : 1809.10397v1

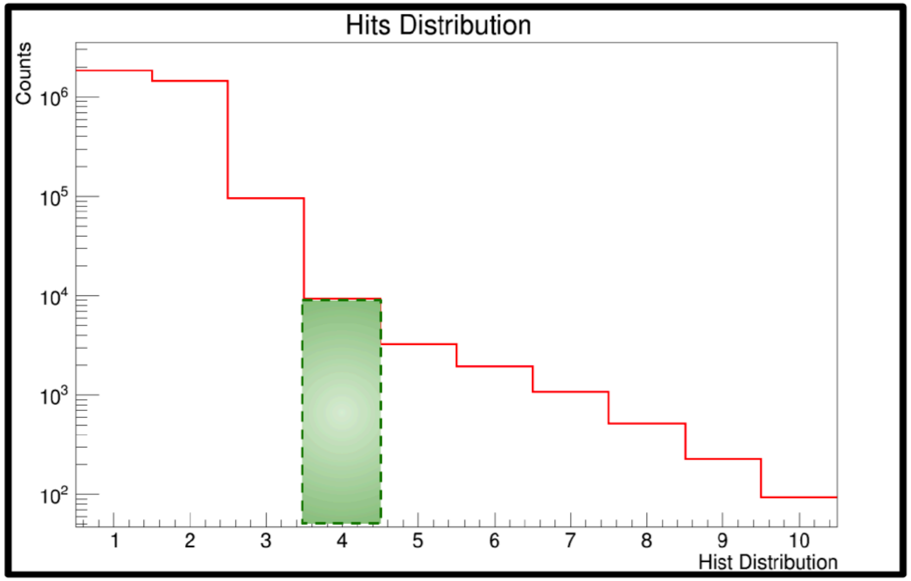
Experimental evidence for the measurement of photon’s polarization with the J-PET detector

(based on N. Krawczyk and J. Raj studies)

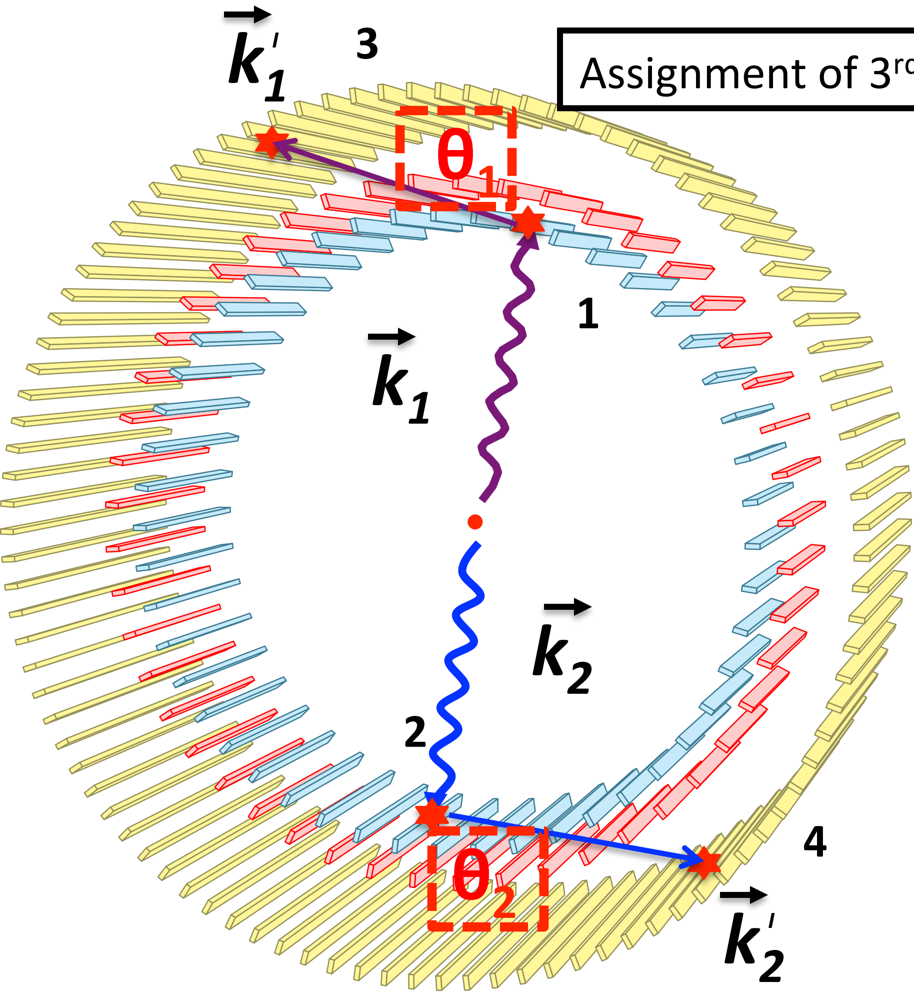
For the test – small annihilation chamber was used

4 – hit events were studied

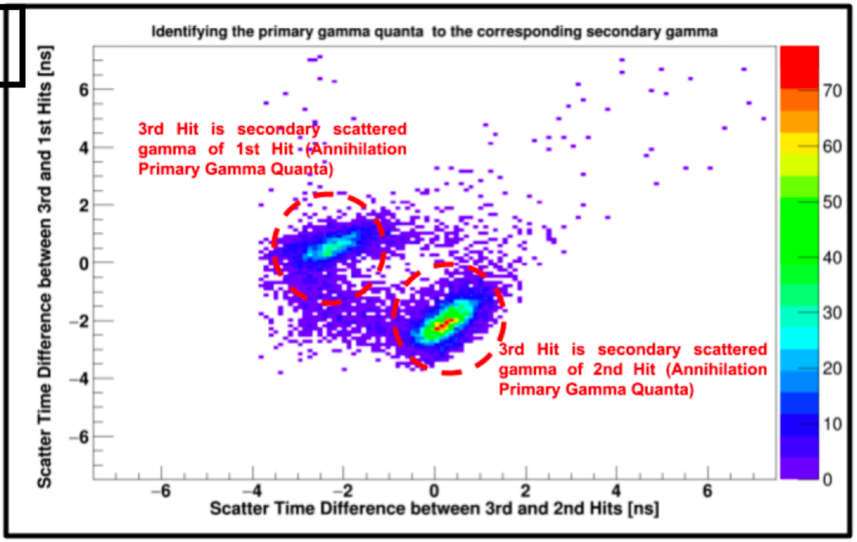


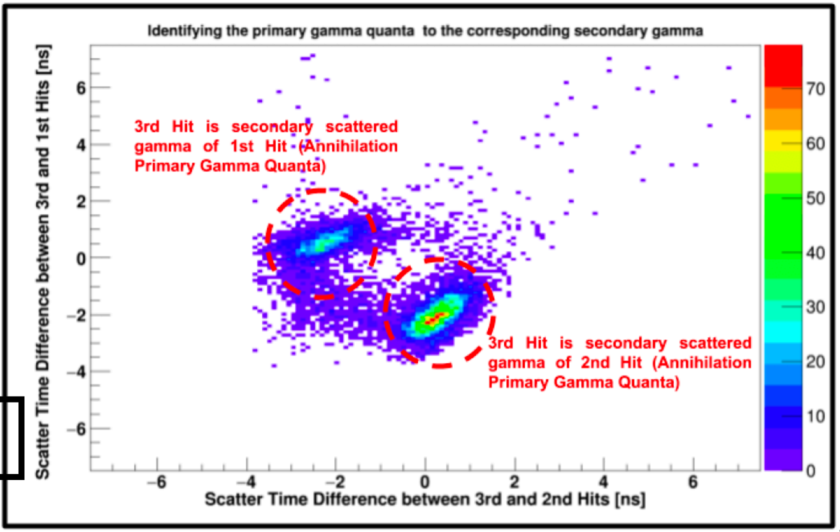


Scatter test = $\text{time}_{\text{measured}} - \text{time}_{\text{calculated}}$



Assignment of 3rd HIT

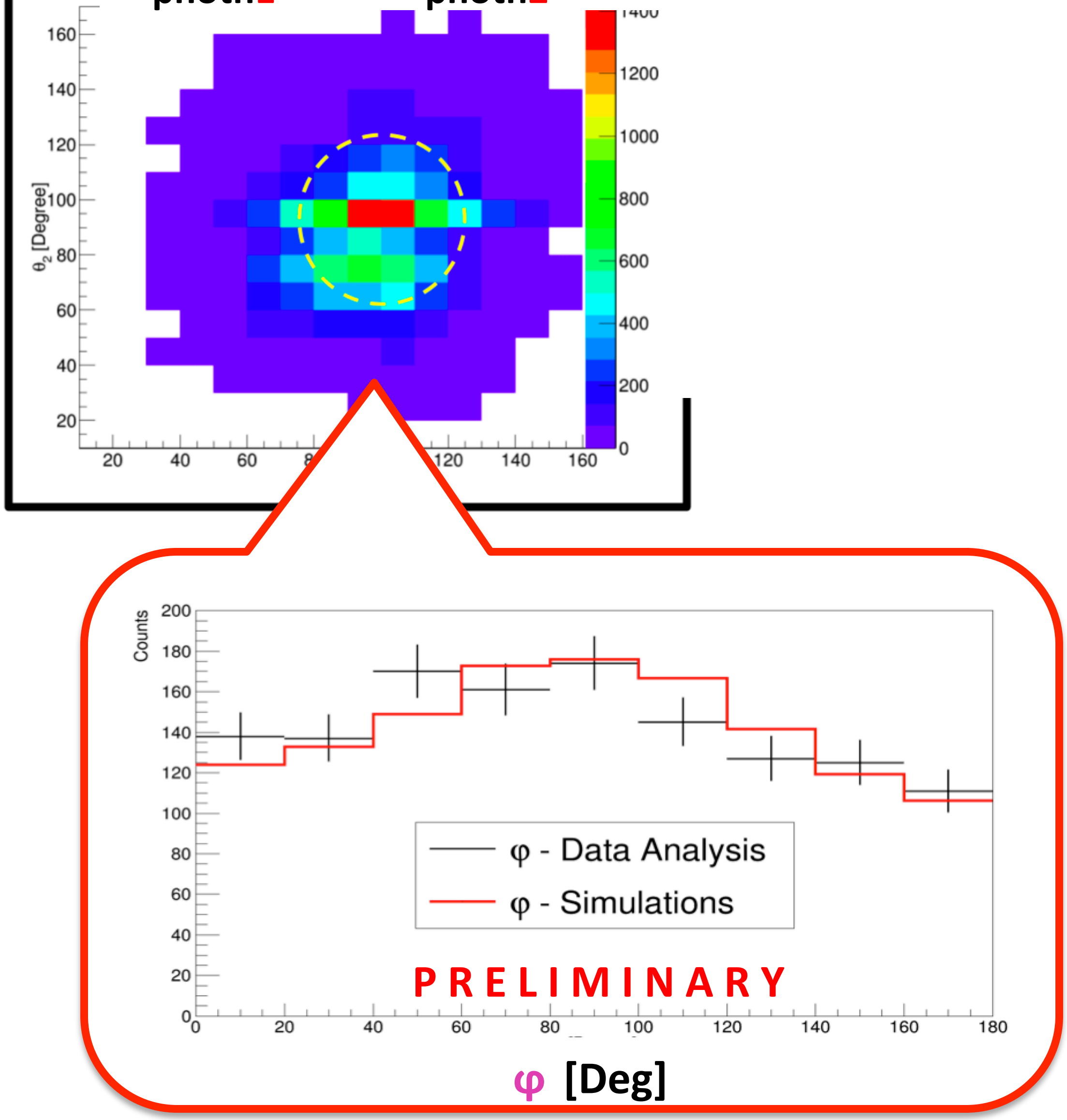


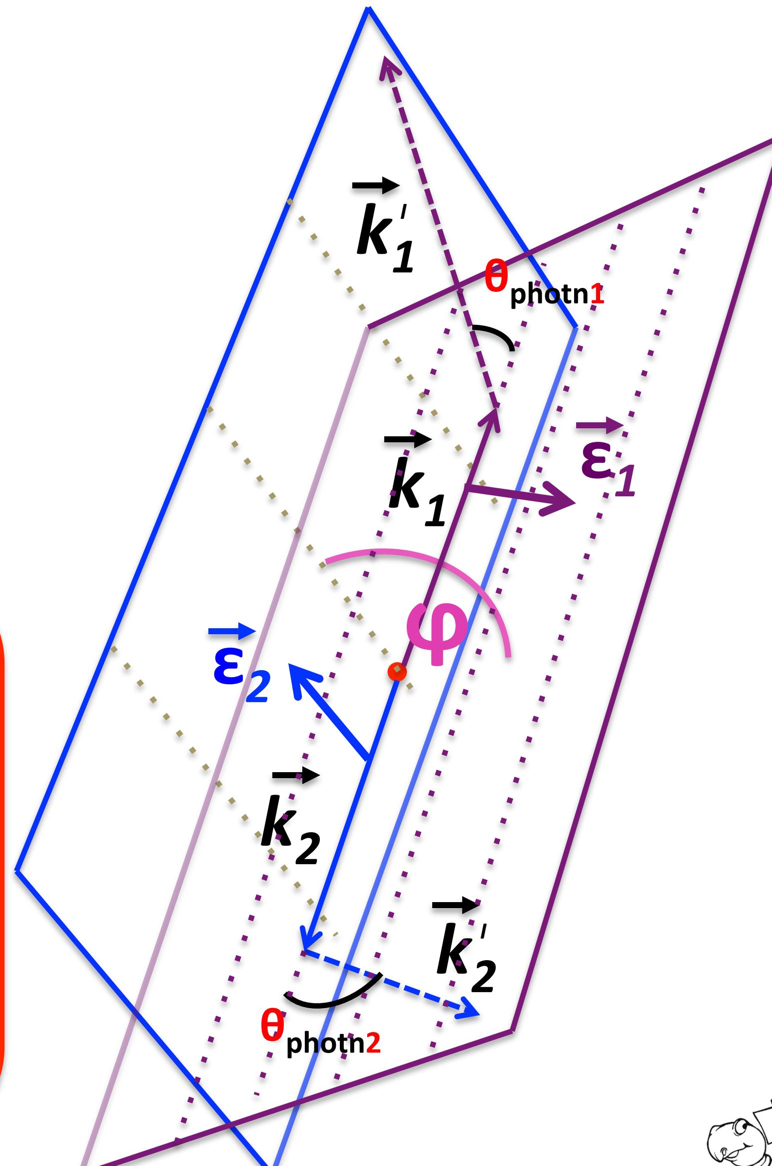


Assignment of 4th HIT

Relative angles between scattered planes *as a measure of* Relative polarization of annihillation photons

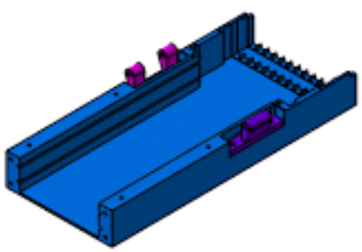
θ$_{photn1}$ Vs θ$_{photn2}$



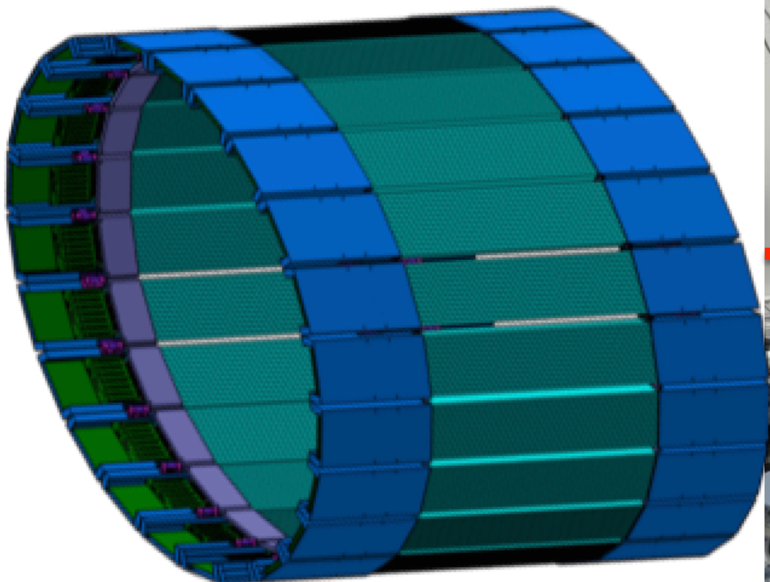


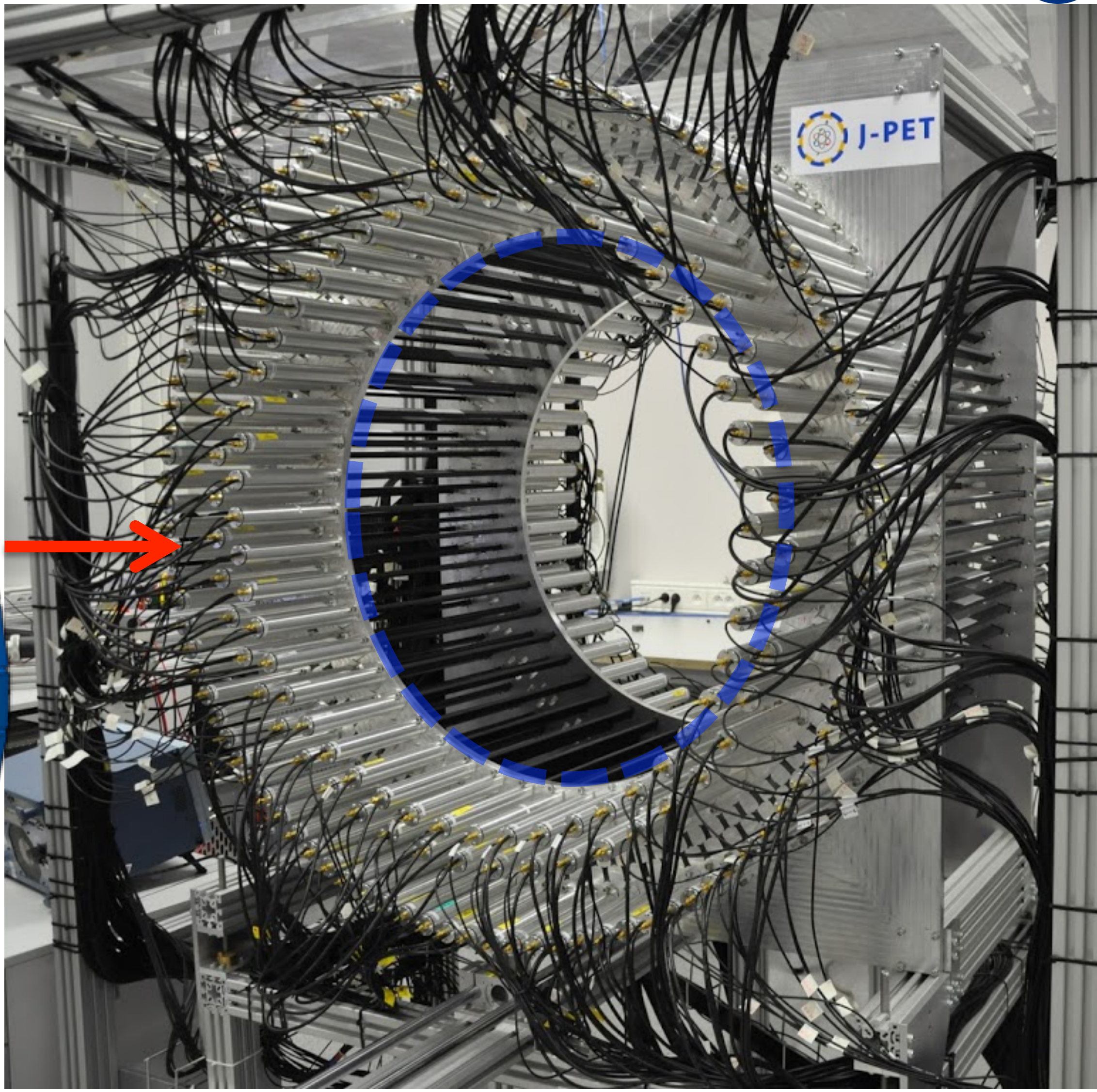
What's next

Modular J-PET



Fourth Layer along with current prototype

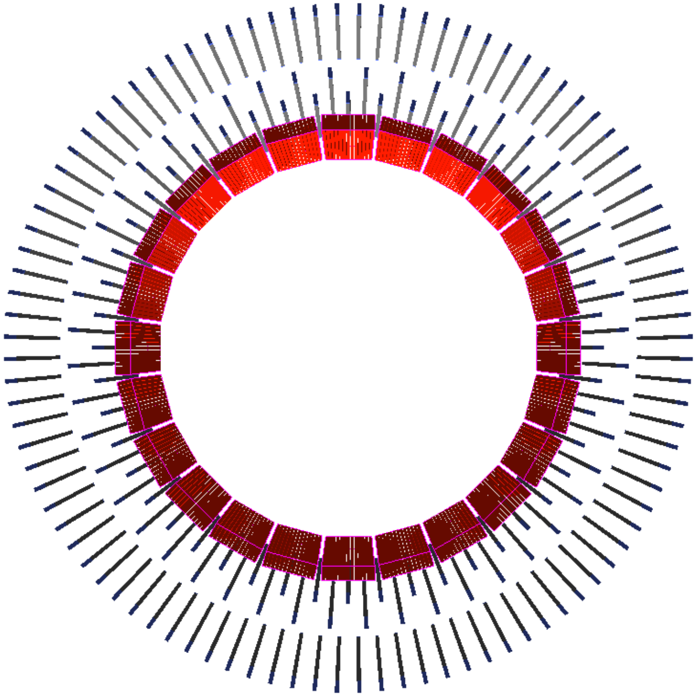




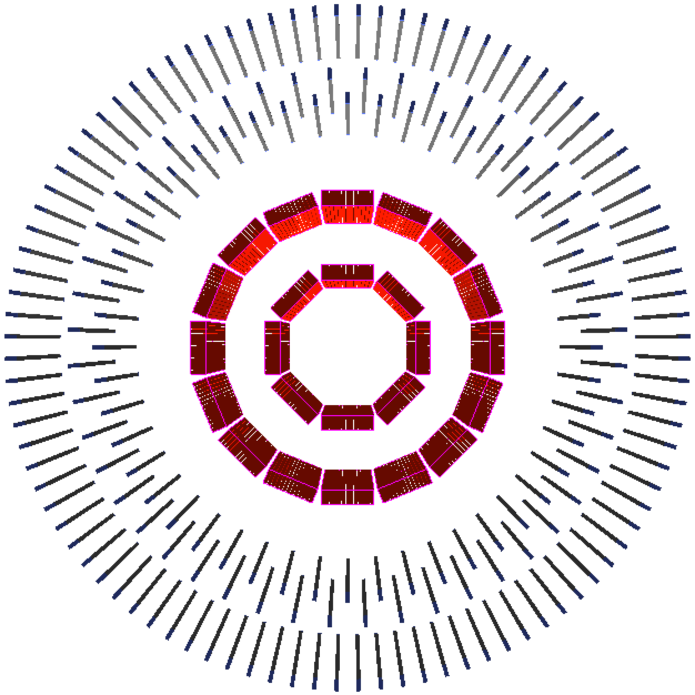
24 PORTABLE modules

Advantages with Modular J-PET

24 Modules placed as
the innermost layer



24 Modules rearranged
and add 2 layers



- ✓ **Several times better efficiency** **[Advantage]**
- ✓ **Standalone PET/detector** **[Advantage]**

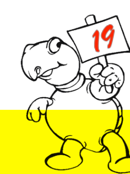
Summary and Outlook

- ☑ A Positron Emission Tomograph based on _plastic scintillators_ **constructed and commissioned**.

- ☑ J-PET has capabilities **to study the scatterings of photons** with large geometrical acceptance
  Polarization of annihilation photons can be estimated.

- ☑ By studying the relative scattering/angular distributions of photons originating from the decay of Positronium atom
  Allow to study the entangled states of photons.

- ☑ Knowing the polarization of photons
  Allow to study the new symmetry operators



J–PET collaboration

P. Moskal[1], M. Bala[1] C. Curceanu[2], E. Czerwiński[1], K. Dulski[1], A. Gajos[1], M. Gorgol[3], B. Hiesmayr[4], D. Kamińska[1], G. Korcyl[1], P. Kowalski[5], T. Kozik[1], W. Krzemień[5], E. Kubicz[1], M. Mohammed[1], N. Krawczyk[1] , M. Pawlik-Niedźwiecka[1], Sz. Niedźwiecki[1], M. Pałka[1], L. Raczyński[5], Z. Rudy[1], J. Raj[1], O. Rundel[1], N. Sharma[1], S. Sharma[1], Shivani[1], M. Silarski[1], J. Smyrski[1], A. Strzelecki[1], W. Wiślicki[5], B. Zgardzińska[3]

[1]Jagiellonian University, Poland; [2]LNF INFN, Italy; [3]Maria Curie-Skłodowska University, Poland; [4]University of Vienna, Austria; [5]National Centre for Nuclear Research, Poland;