Improved test of CPT invariance in ortho-positronium decays at J-PET

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On behalf of the J-PET collaboration
Jagiellonian University, Krakow, Poland

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NATIONAL SCIENCE CENTRE
POLAND

J-PET

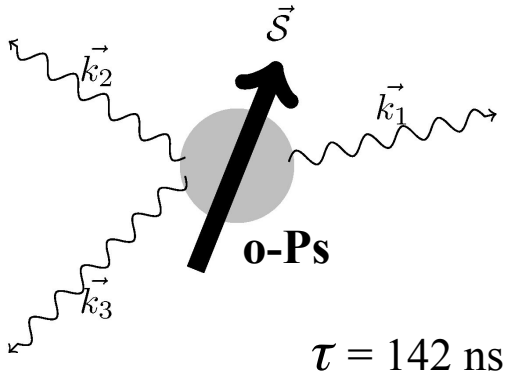
CPT symmetry test in o-Ps→3γ decay

$$e^+e^- \rightarrow o\text{-}Ps \rightarrow 3\gamma$$

Search for CPT Symmetry violation in ***ortho-positronium decays***

Testing CPT symmetry using the **angular correlations** between spin and decay plane of oPs → 3γ.

Searching for non-zero expectation value of **CPT odd** angular correlation operators.



τ = 142 ns

Operator	C	P	T	CP	CPT
$\vec{S} \cdot \overrightarrow{k_1}$	+	-	+	-	-
$\vec{S} \cdot (\overrightarrow{k_1} \times \overrightarrow{k_2})$	+	+	-	+	-
$(\vec{S} \cdot \overrightarrow{k_1})(\vec{S} \cdot (\overrightarrow{k_1} \times \overrightarrow{k_2}))$	+	-	-	-	+

$$< O^{(-)}_{CPT} > \stackrel{?}{=} 0$$

$$|\overrightarrow{k_1}| > |\overrightarrow{k_2}| > |\overrightarrow{k_3}|$$

W. Bernreuther, Z. Phy. C 41, 143 (1988)

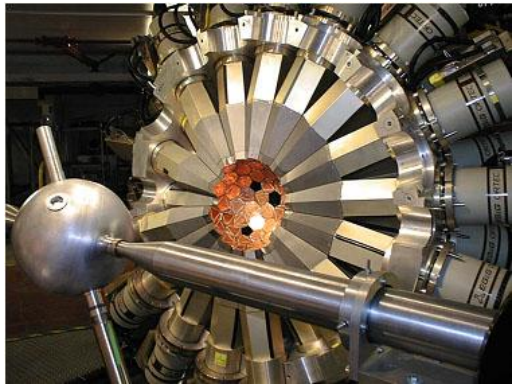
P. Moskal, Acta Phys. Pol. B 47, 509 (2016)

CPT symmetry test in o-Ps→3γ decay

Experimental search for CPT violating decay processes in positronium using $\vec{S} \cdot (\overrightarrow{k_1} \times \overrightarrow{k_2})$

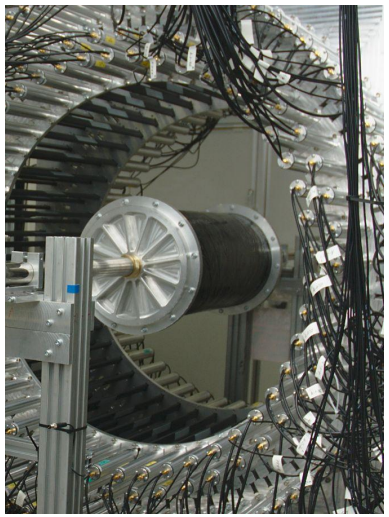
Gammasphere detector
Search for CPT violation
$C_{CPT} \sim 10^{-3}$
(PRL 91, 263401)

2003



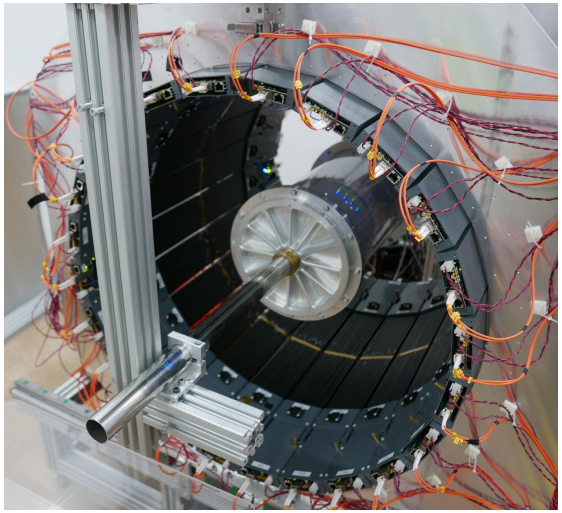
J-PET
Search for CPT violation
$C_{CPT} \sim 10^{-4}$
Nat. Commun 12, 5658

2021

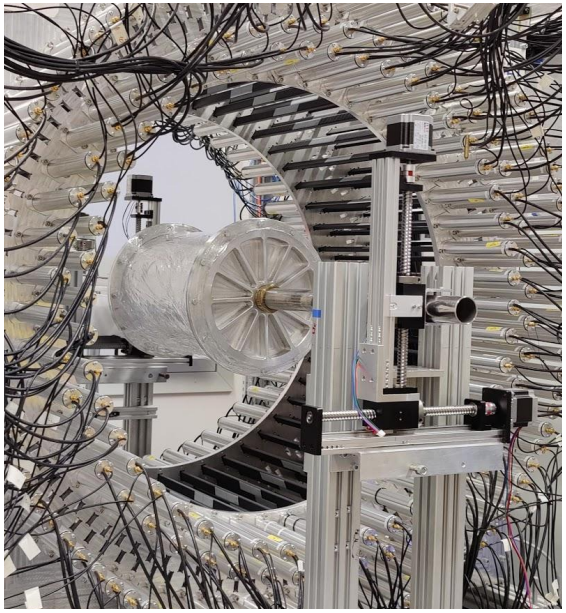


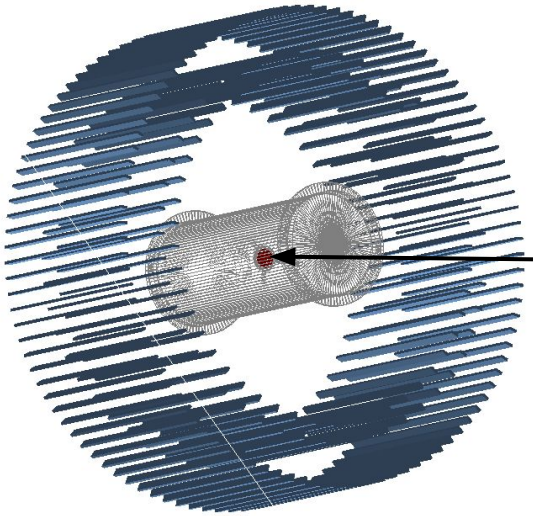
J-PET
To extend the sensitivity to 10^{-5}

In future



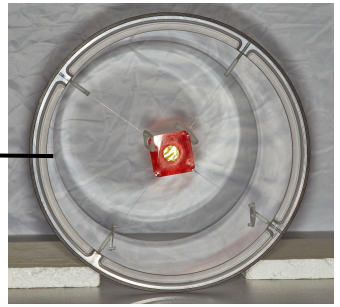
CPT odd operator study with J-PET





Geometrical representation of annihilation chamber inside the J-PET detector

^{22}Na source



$$^{22}Na \rightarrow {}^{22}Ne^{*} + e^{+} + \nu$$

Jagiellonian Positron Emission Tomograph

- A cost-effective PET scanner built from **192 plastic scintillators.**
- Time resolution ~ 250 ps &
  Angular resolution ~ 1°

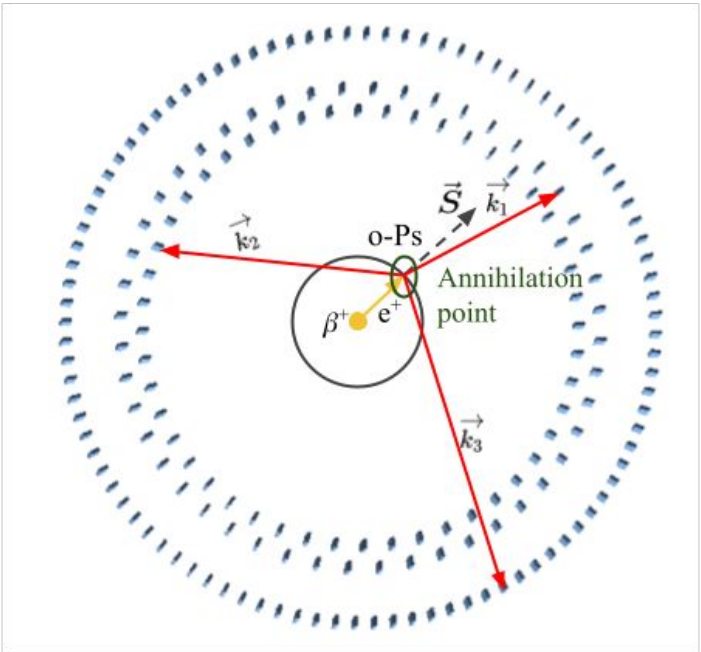
Talk by Eryk Czerwiński

Annihilation chamber

- **β^{+} emitter** source placed at the center of chamber.
- Coating of porous silica on the inner walls of chamber to **enhance positronium (Ps)** formation.
- Annihilation chamber is **vacuumized**

S. Niedźwiecki, Acta Phys. Pol. B 48, 1567 (2017)

CPT odd operator study with J-PET

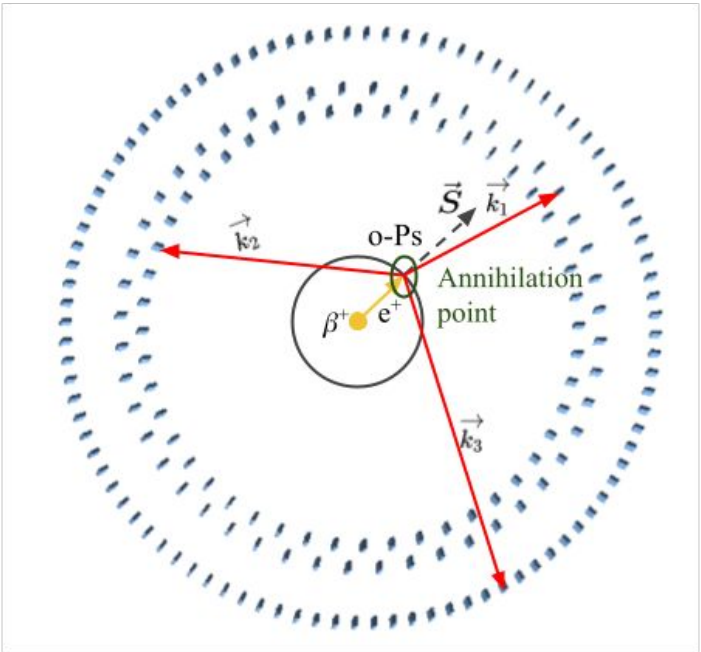


$$e^+e^- \rightarrow o\text{-}Ps \rightarrow 3\gamma$$

- Trilateration method: o-Ps annihilation point
- **Spin** of o-Ps is estimated event by event
- Direction of photons' momenta
- $\vec{S} \cdot (\vec{k_1} \times \vec{k_2})$: CPT - violation sensitive operator

A.Gajos, NIM A 819 (2016), 54

CPT odd operator study with J-PET



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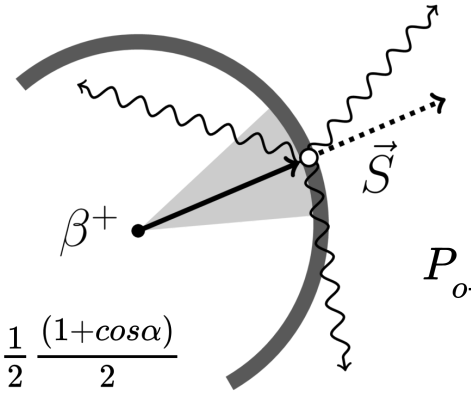
$$O_{CPT} = \hat{S}.\frac{(\vec{k_1}\times\vec{k_2})}{|\vec{k_1}\times\vec{k_2}|} = cos\theta$$

$$C_{CPT} = \frac{<O_{CPT}>}{P}$$



$$P_{o\text{-}Ps} = \frac{2}{3}P_{e^+}$$

$$P_{e^+} = \frac{v}{c} \cdot \frac{1}{2}\frac{(1+cos\alpha)}{2}$$

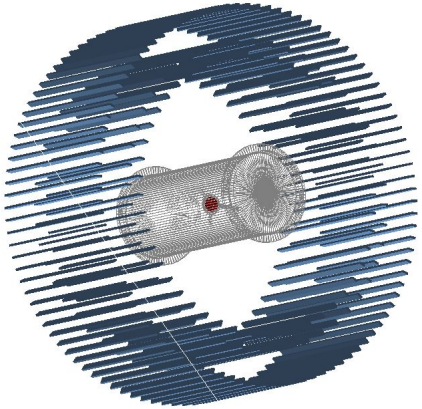
C_{CPT} : amplitude of CPT violating effect

P : Analyzing power (dominated by polarization)

A.Gajos, NIM A 819 (2016), 54

Testing CPT invariance in o-Ps→3γ decay with J-PET

J-PET



- **Cylindrical annihilation chamber**
- 10 MBq source activity
- 26 days of measurement

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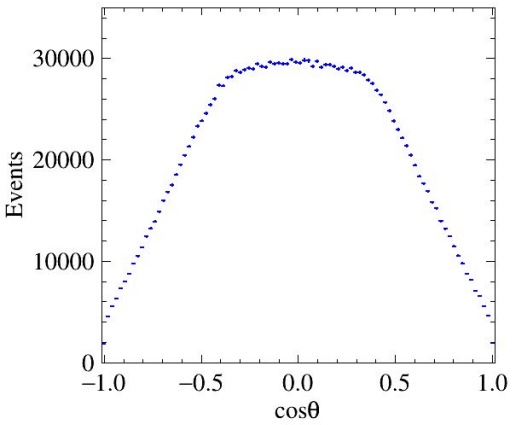
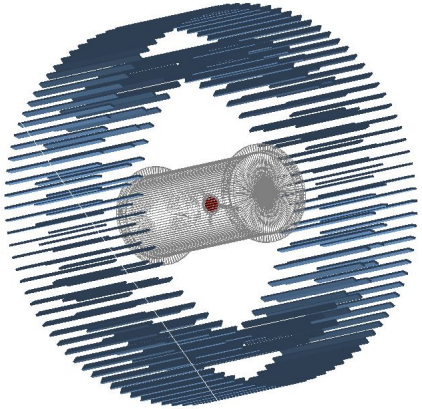


$$C_{CPT} = 0.00067 \pm 0.00095$$

P. Moskal et al.,
Nature Commun., 12, 5658 (2021)

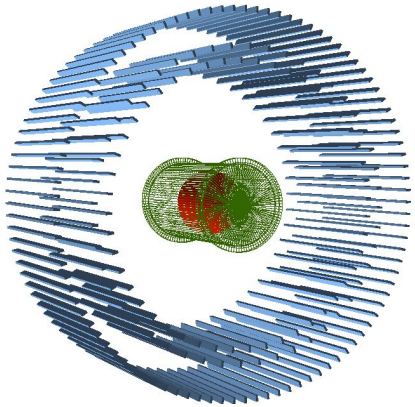
Testing CPT invariance in o-Ps→3γ decay with J-PET

J-PET



- **Cylindrical annihilation chamber**
- 10 MBq source activity
- 26 days of measurement

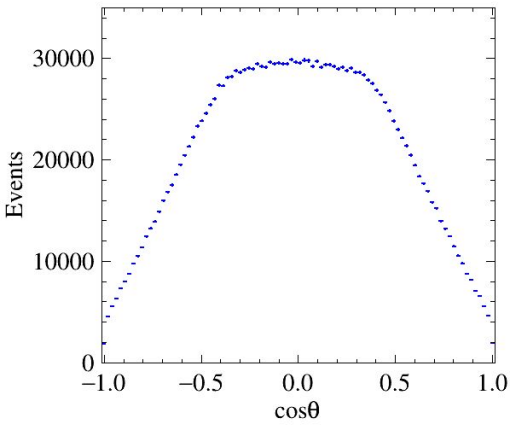
Improved CPT test with J-PET



- **Spherical annihilation chamber** is used to increase positronium formation
- 4 MBq source activity
- Around 1 year of data taking

$$O_{CPT} = \hat{S}.\frac{(\vec{k_1}\times\vec{k_2})}{|\vec{k_1}\times\vec{k_2}|} = cos\theta$$

$$C_{CPT} = \frac{<O_{CPT}>}{P}$$



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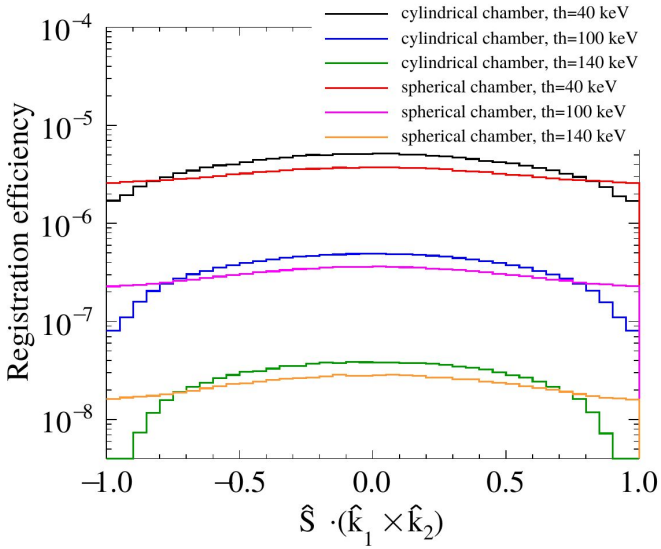
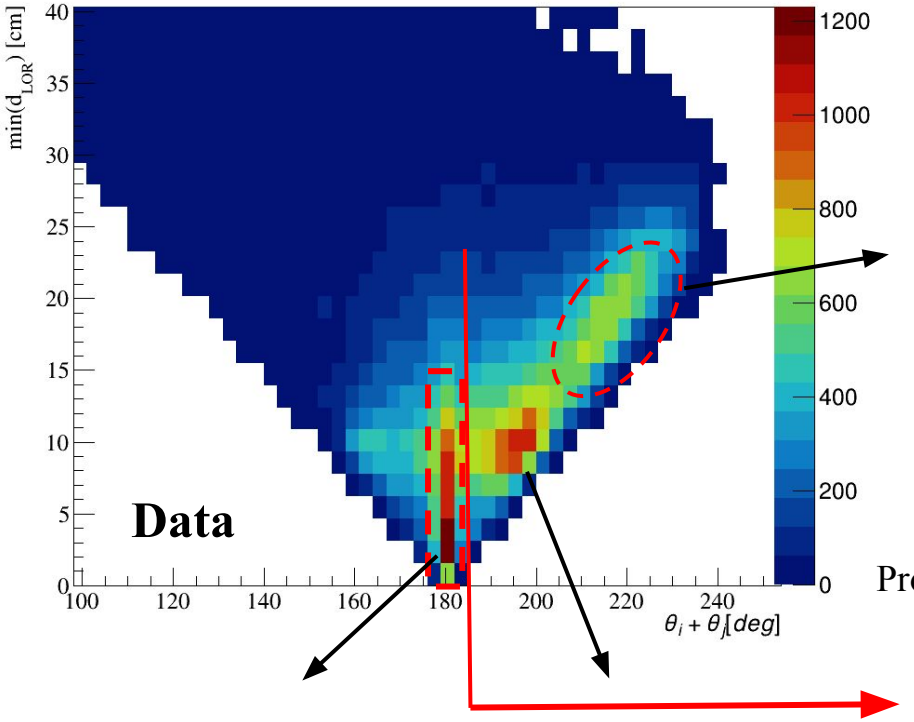


Total Efficiency of registration of o-Ps events in J-PET

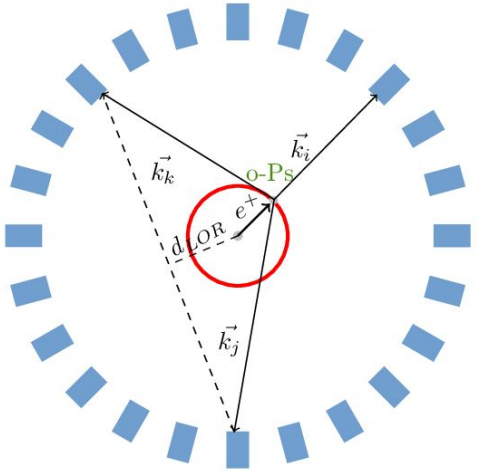
A. Gajos, *Symmetry* 2020, *12*(8), 1268

Studies with spherical annihilation chamber + J-PET detector

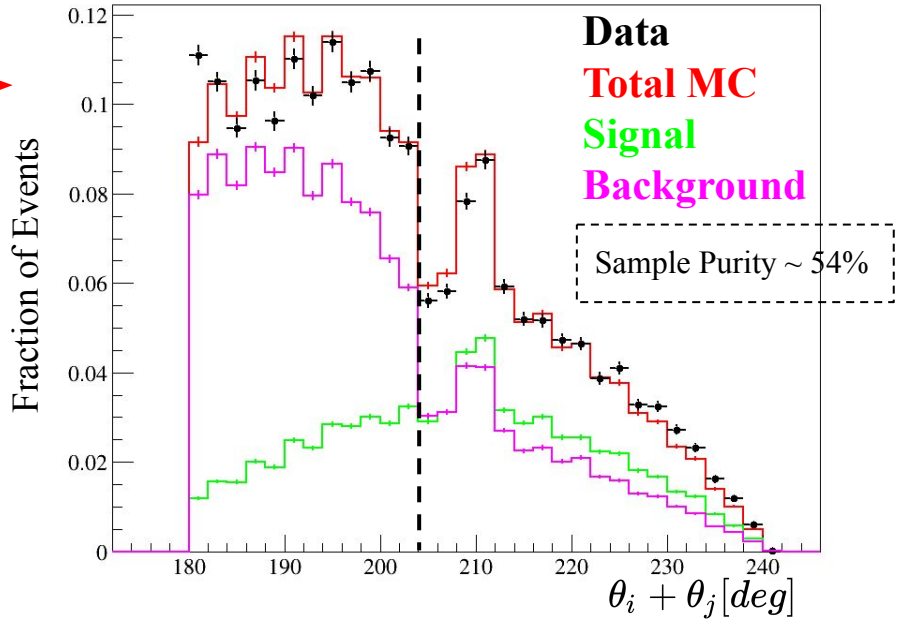


Signal

$e^+e^- \rightarrow o\text{-}Ps \rightarrow 3\gamma$

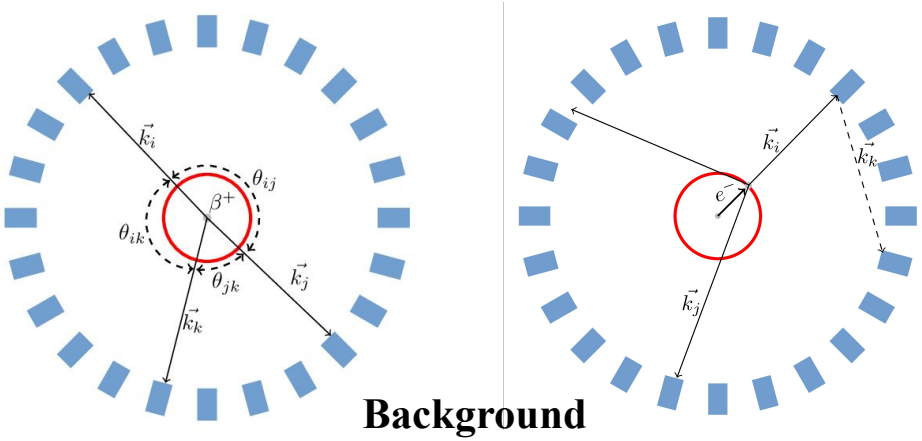


Projection on x-axis



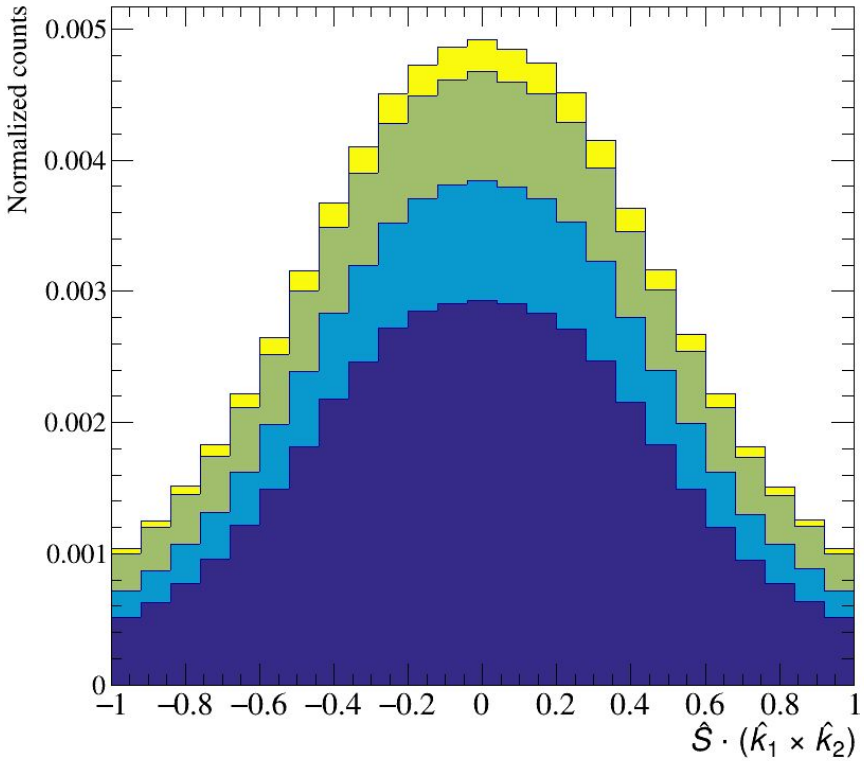
Direct 2γ annihilations

Secondary scatterings



Background

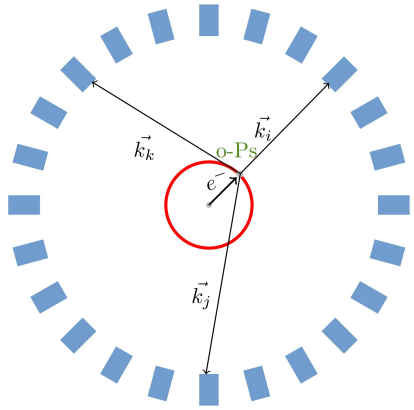
CPT-asymmetric angular correlation operator plot (MC)

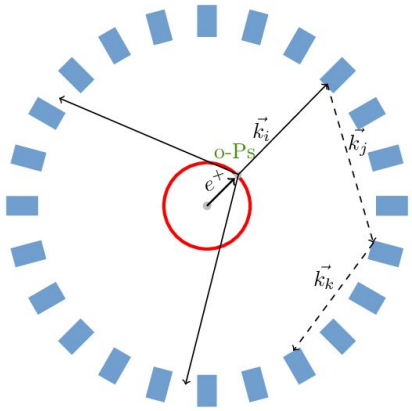


Plot obtained from only a part of target statistics that we expect to have in data

Signal events

$o\text{-}Ps \rightarrow 3\gamma$





Events with multiple secondary scatterings

16%

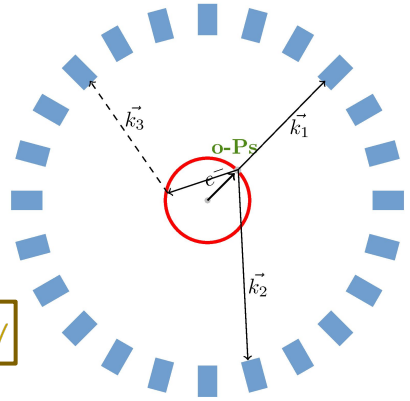
Photons scattered on chamber material from:

$o\text{-}Ps \rightarrow 3\gamma$

14%

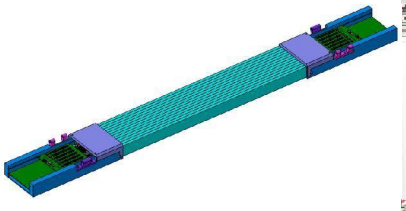
$e^+ + e^- \rightarrow 2\gamma$

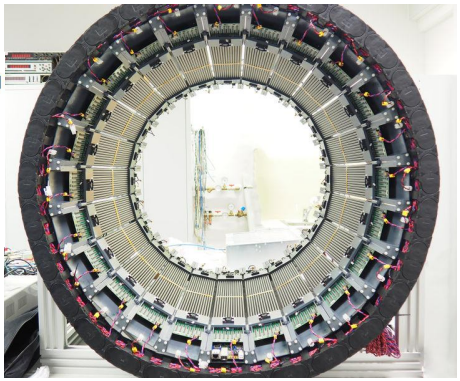
8%



Improving the sensitivity for CPT symmetry tests to 10^{-5}

- **Modular J-PET Detector:** 24 modules of densely packed plastic scintillators with SiPM readout.
- Increase the **detection efficiency** for registration of annihilation photons from o-Ps.
- Reconfigured in to **multiple layers**
- A **portable** device





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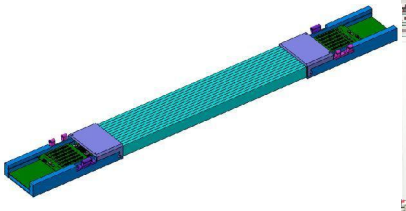
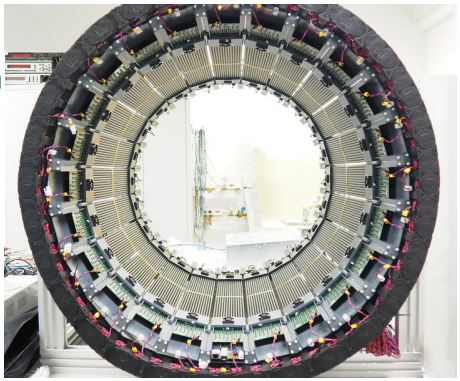
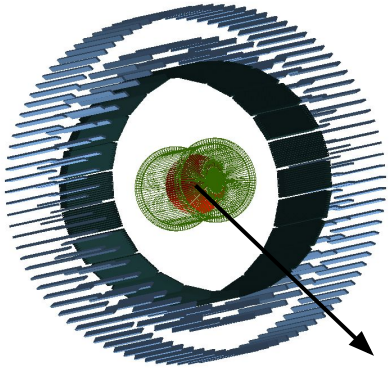




J-PET + 24 Modular J-PET

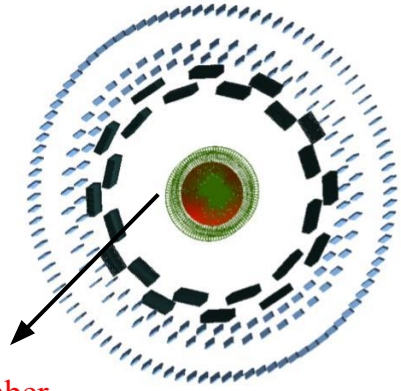


*Efficiency ~ 21
w.r.t present J-PET

*Scattering background: 37%

Spherical Chamber

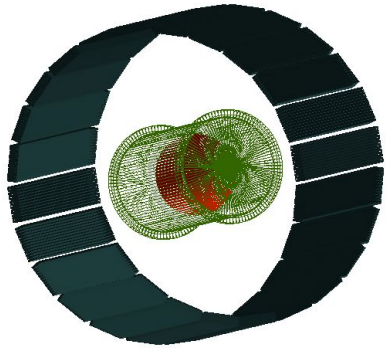
J-PET + (12 + 12) Modular J-PET



Efficiency ~ 75
w.r.t present J-PET

Scattering background: 28%

24 Modular J-PET



Efficiency ~ 11
w.r.t present J-PET

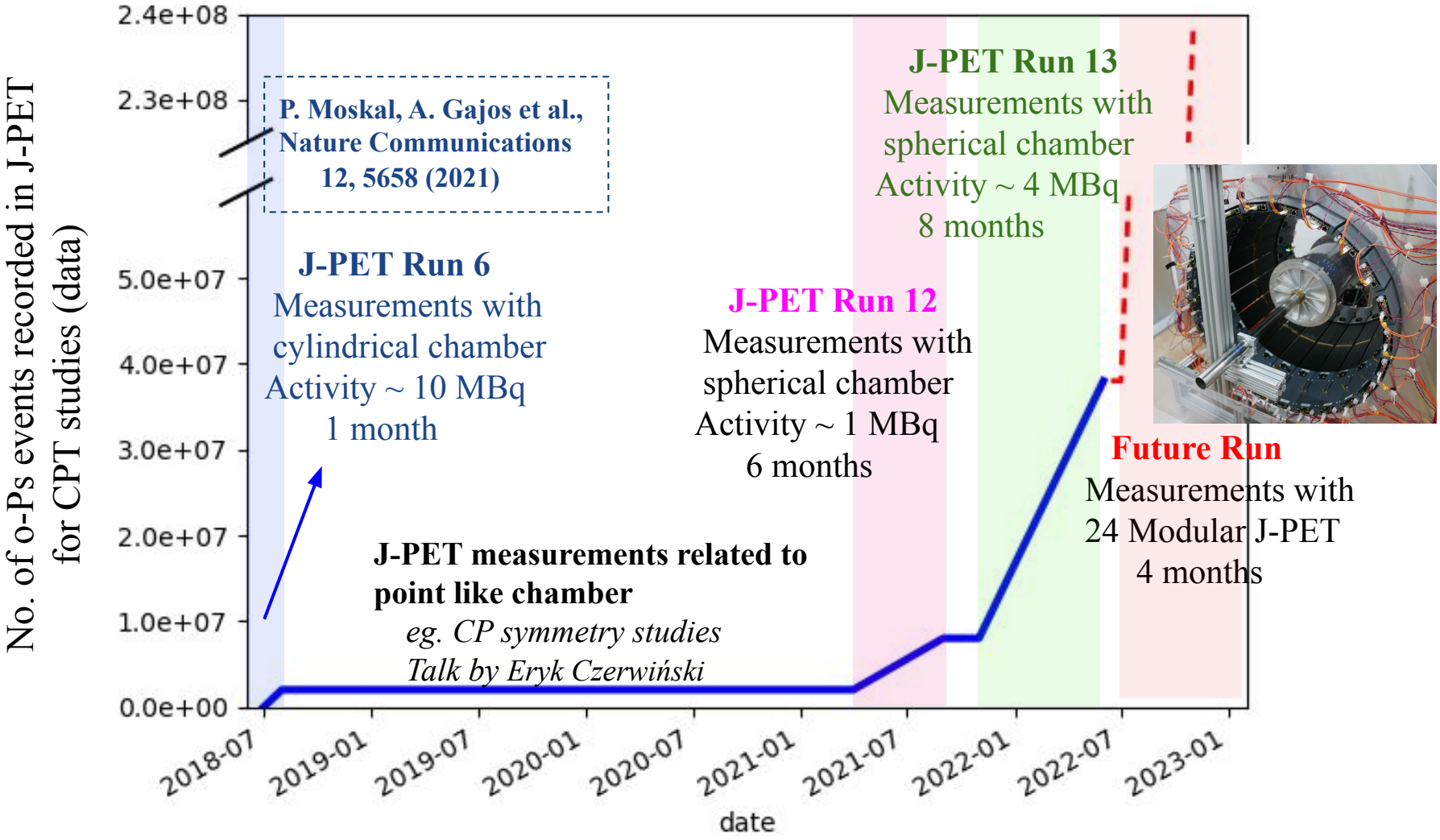
Scattering background: 7%

Future CPT Symmetry test with the J-PET detector

*Secondary background: Fraction of secondary scattering events (based on MC simulations)

*Efficiency of registration of o-Ps ➔ 3γ events in detector (based on MC simulations)

Outlook



Thank You