

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



Neha Chug
On behalf of the J-PET collaboration
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9 November, 2022



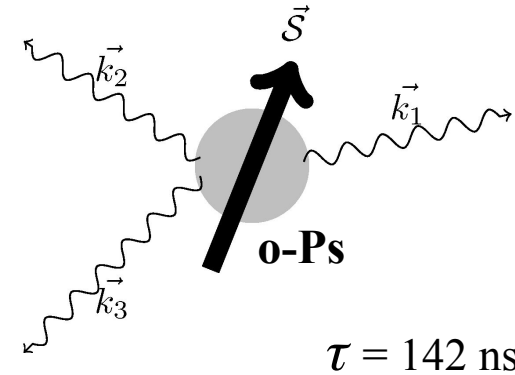
CPT symmetry test in $o\text{-Ps} \rightarrow 3\gamma$ decay

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

Testing CPT symmetry using the **angular correlations** between spin and decay plane of $o\text{Ps} \rightarrow 3\gamma$.

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

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



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

$$\langle O_{CPT}^{(-)} \rangle \stackrel{?}{=} 0$$

$$|\vec{k}_1| > |\vec{k}_2| > |\vec{k}_3|$$

CPT symmetry test in $o\text{-Ps} \rightarrow 3\gamma$ decay

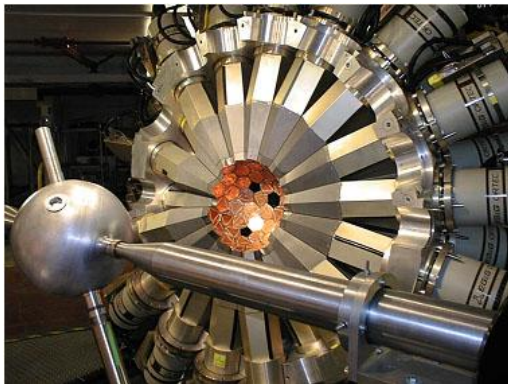
Experimental search for CPT violating decay processes in positronium using $\vec{S} \cdot (\vec{k}_1 \times \vec{k}_2)$

Gammasphere detector

Search for CPT violation

$$C_{\text{CPT}} \sim 10^{-3}$$

(PRL 91, 263401)

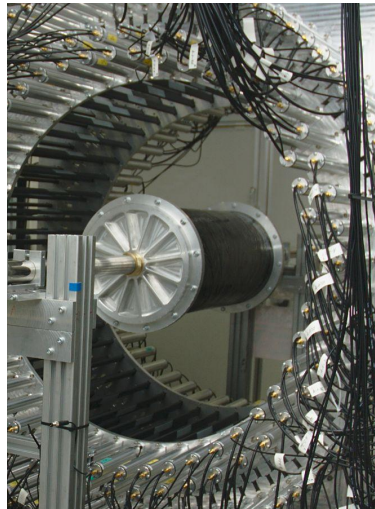
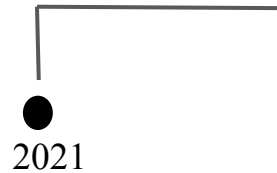


J-PET

Search for CPT violation

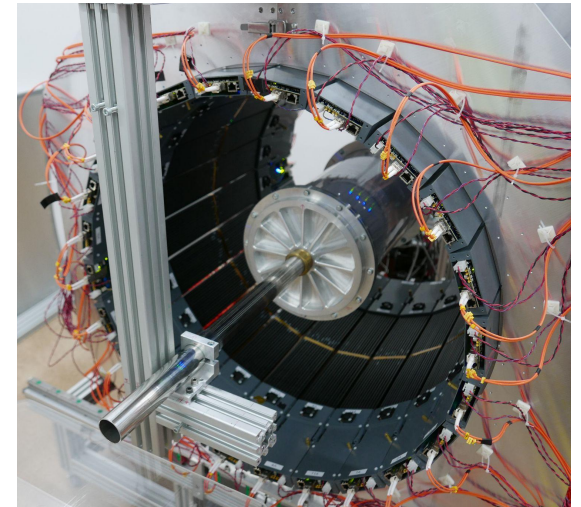
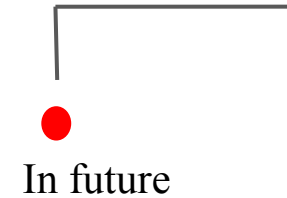
$$C_{\text{CPT}} \sim 10^{-4}$$

Nat. Commun 12, 5658

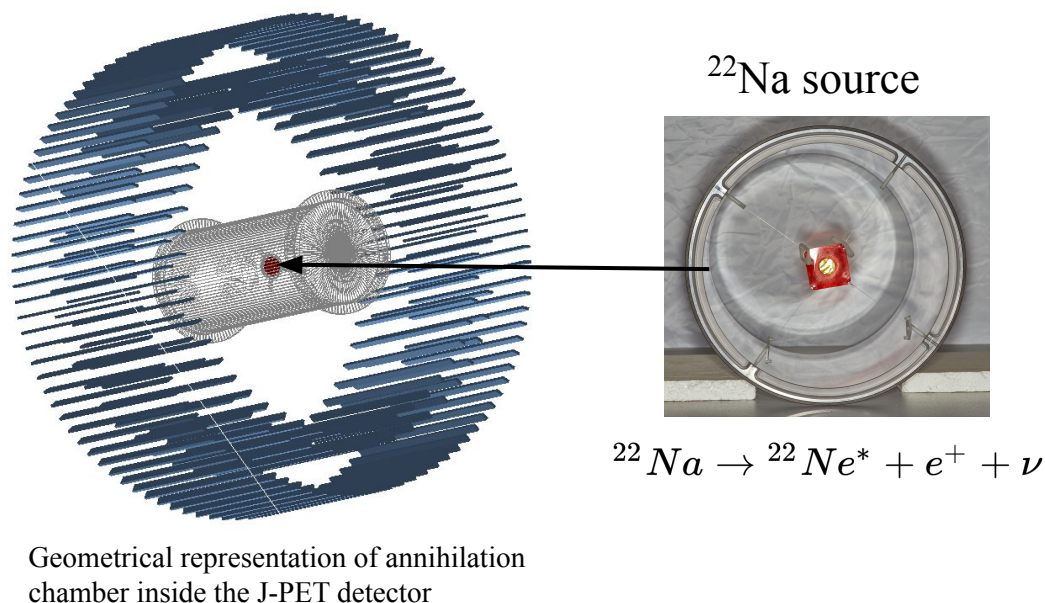
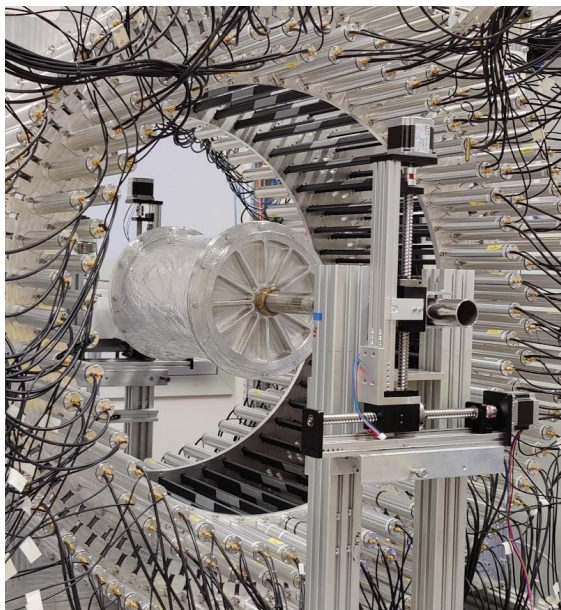


J-PET

To extend the sensitivity to 10^{-5}



CPT odd operator study with J-PET



Jagiellonian Positron Emission Tomograph

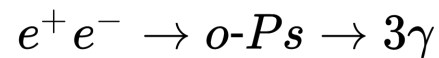
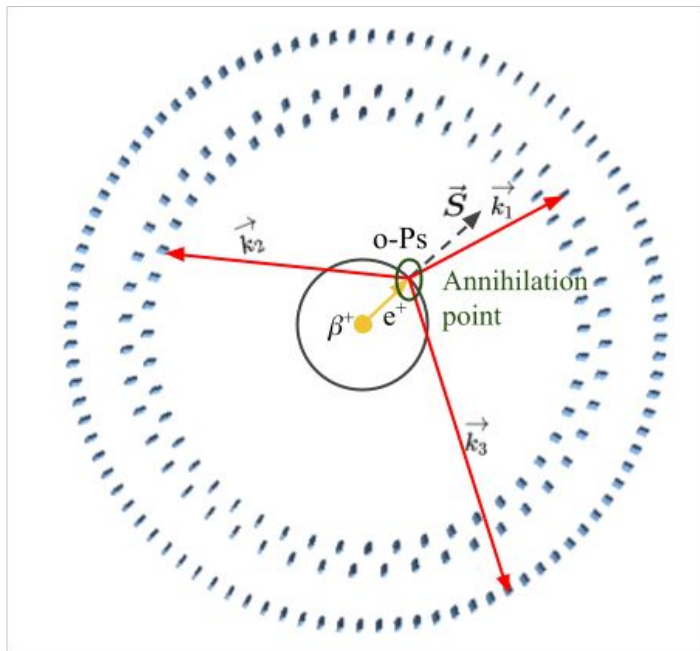
- ❑ A cost-effective PET scanner built from **192 plastic scintillators**.
- ❑ Time resolution ~ 250 ps & Angular resolution $\sim 1^\circ$

Talk by Eryk Czerwiński

Annihilation chamber

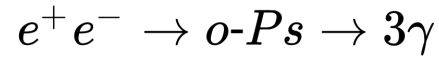
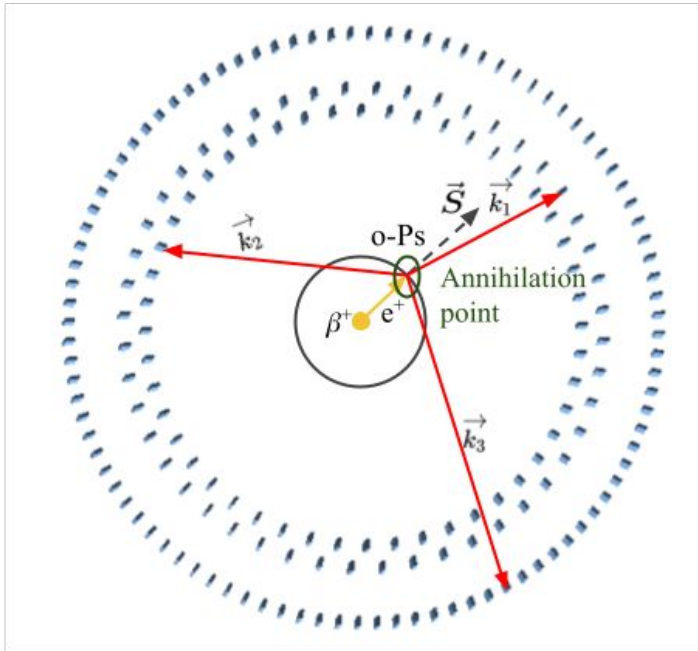
- ❑ **β^+ emitter** source placed at the center of chamber.
- ❑ Coating of porous silica on the inner walls of chamber to **enhance positronium (Ps)** formation.
- ❑ Annihilation chamber is **vacuumized**

CPT odd operator study with J-PET



- **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

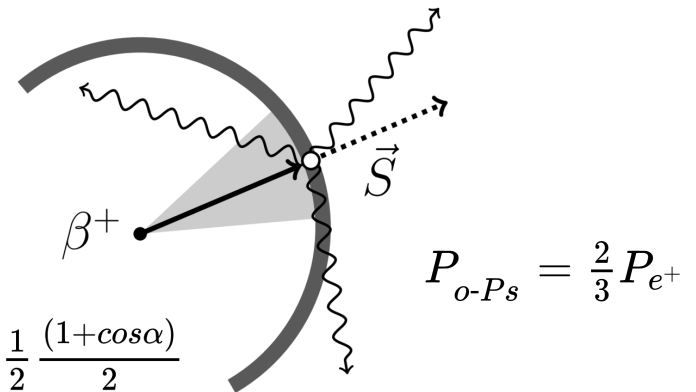
CPT odd operator study with J-PET



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$$O_{CPT} = \hat{S} \cdot \frac{(\vec{k}_1 \times \vec{k}_2)}{|\vec{k}_1 \times \vec{k}_2|} = \cos\theta$$

$$C_{CPT} = \frac{\langle O_{CPT} \rangle}{P}$$



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

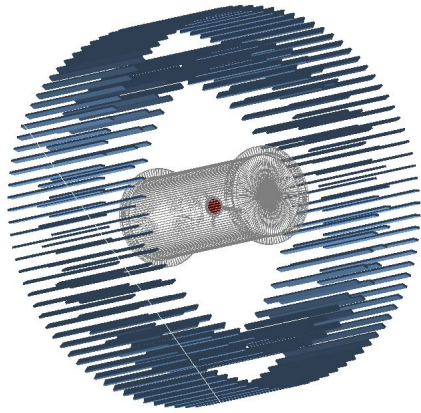
$$P_{o\text{-Ps}} = \frac{2}{3} P_{e^+}$$

C_{CPT} : amplitude of CPT violating effect

P: Analyzing power (dominated by polarization)

Testing CPT invariance in $o\text{-Ps} \rightarrow 3\gamma$ decay with J-PET

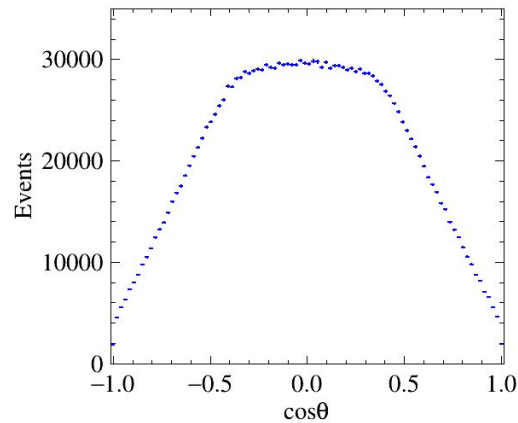
J-PET



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

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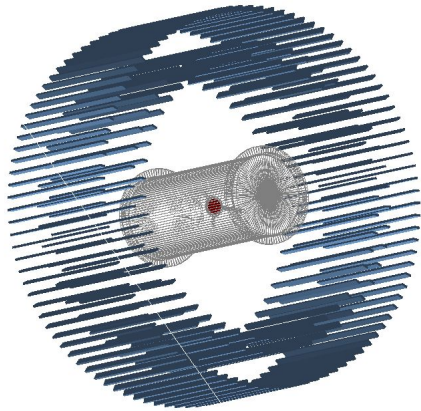


$$C_{CPT} = 0.00067 \pm 0.00095$$

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

Testing CPT invariance in $o\text{-Ps} \rightarrow 3\gamma$ decay with J-PET

J-PET

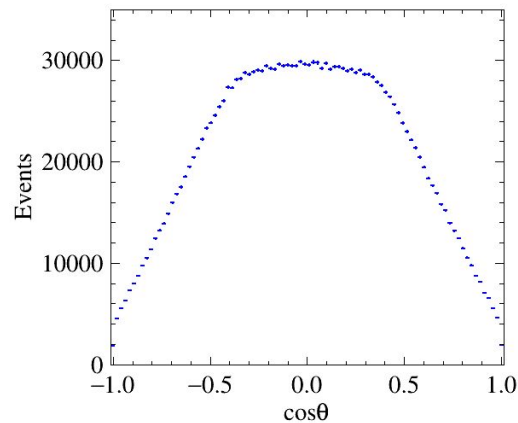


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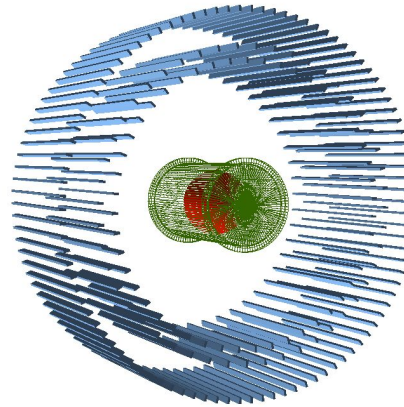
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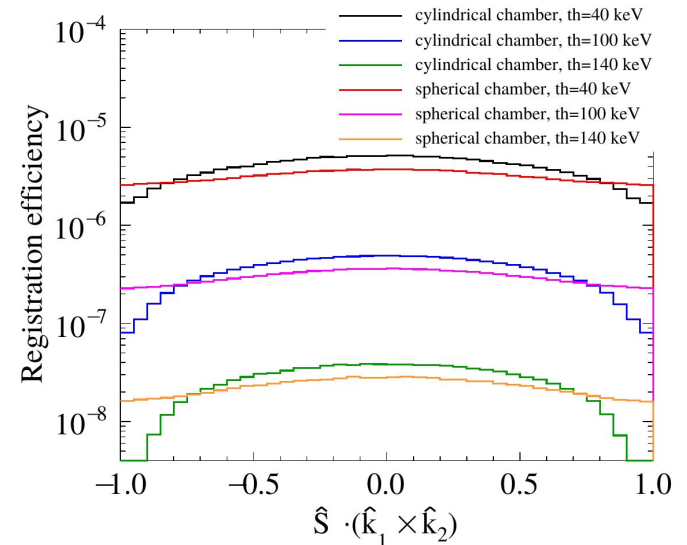
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Improved CPT test with J-PET



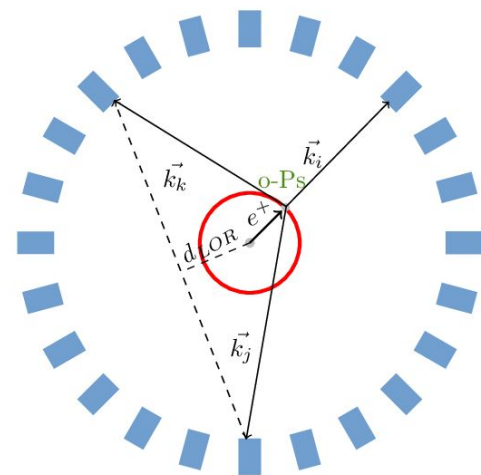
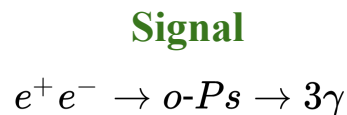
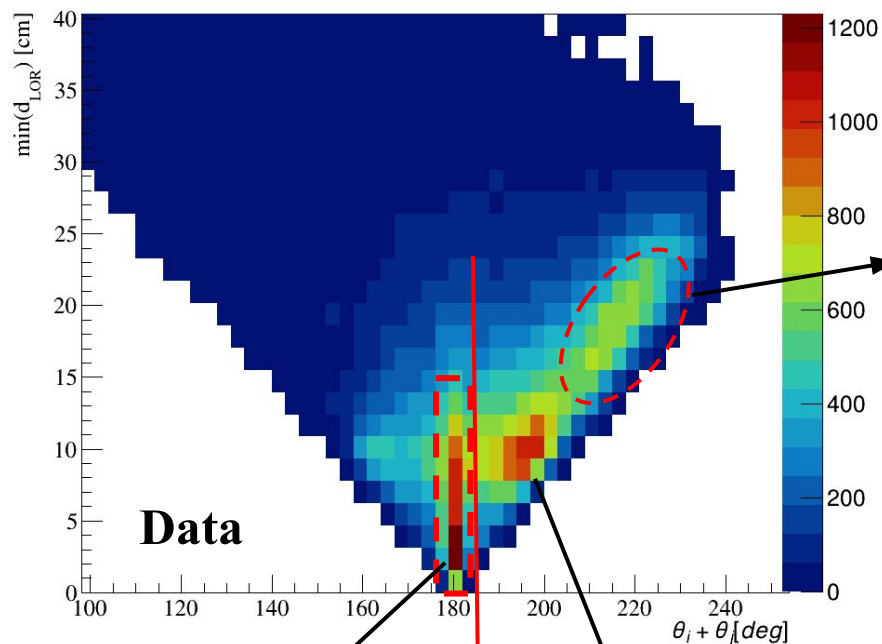
- **Spherical annihilation chamber** is used to increase positronium formation
- 4 MBq source activity
- Around 1 year of data taking



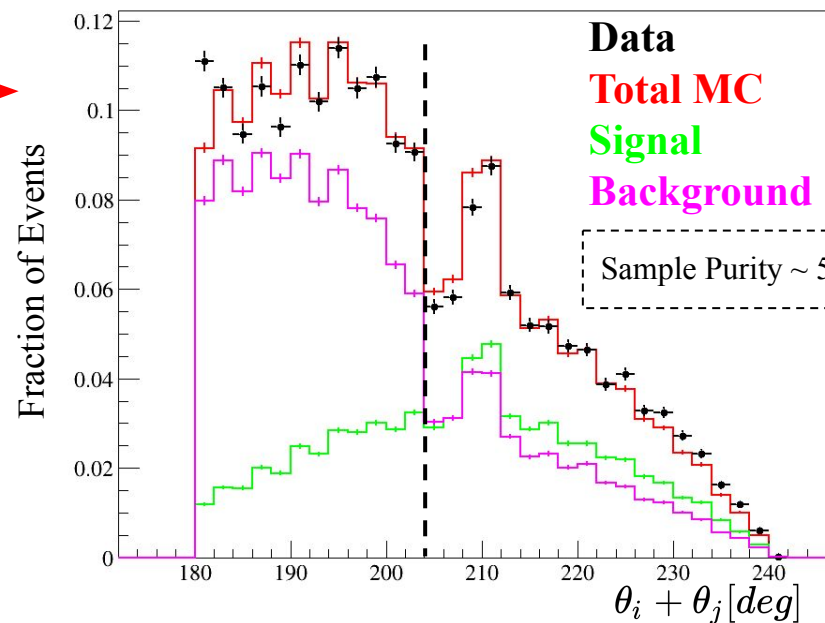
Total Efficiency of registration of $o\text{-Ps}$ events in J-PET

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

Studies with spherical annihilation chamber + J-PET detector

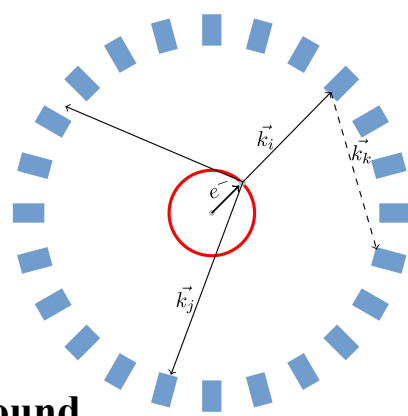
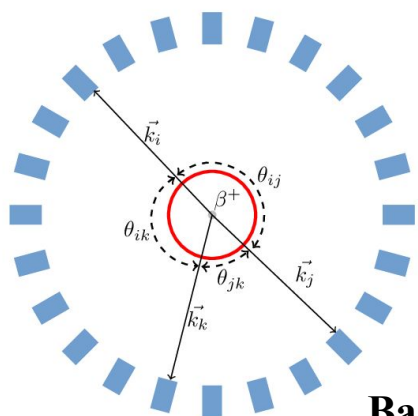


Projection on x-axis



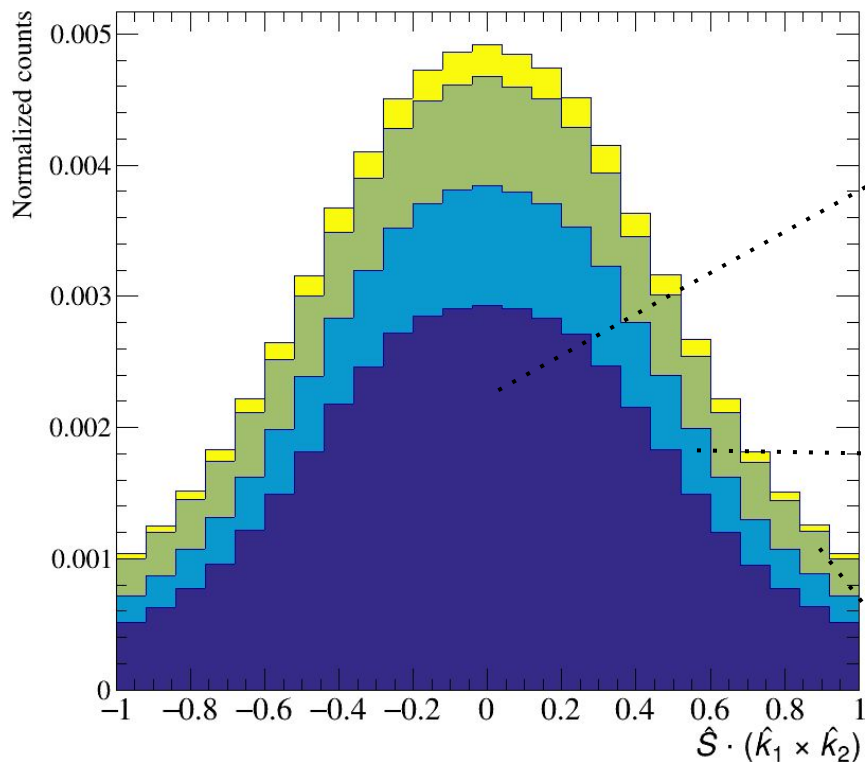
Direct 2γ annihilations

Secondary scatterings



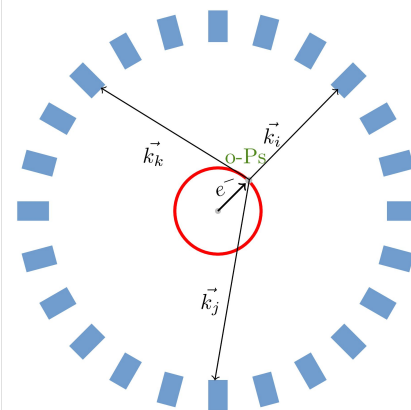
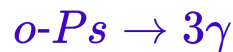
Background

CPT-asymmetric angular correlation operator plot (MC)



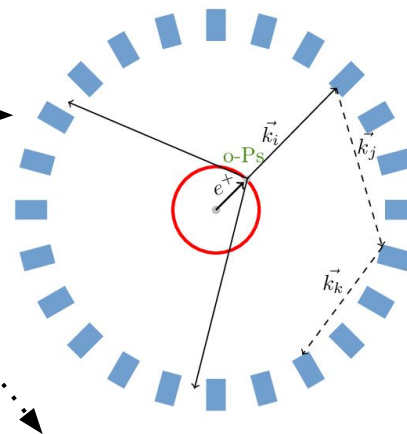
Plot obtained from only a part of target statistics that we expect to have in data

Signal events



Events with multiple secondary scatterings

16%



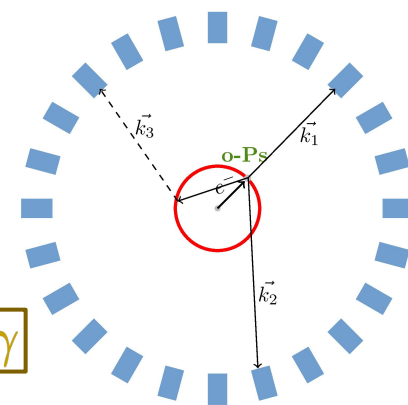
Photons scattered on chamber material from:



14%

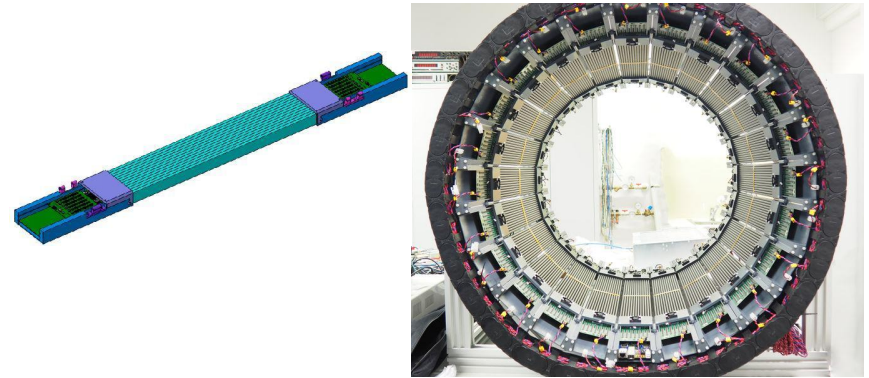


8%



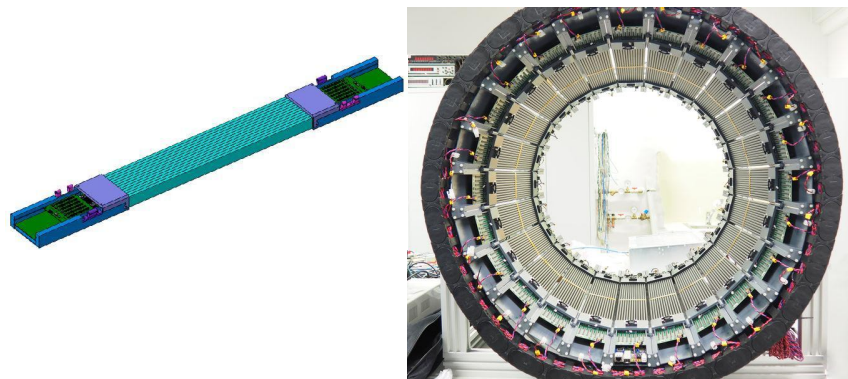
Improving the sensitivity for CPT symmetry tests to 10^{-5}

- **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

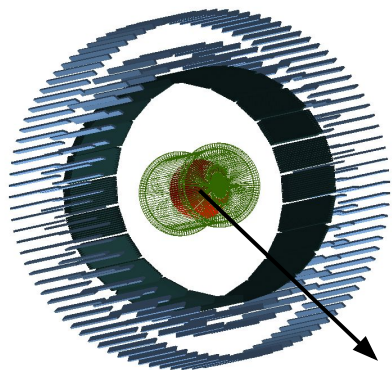


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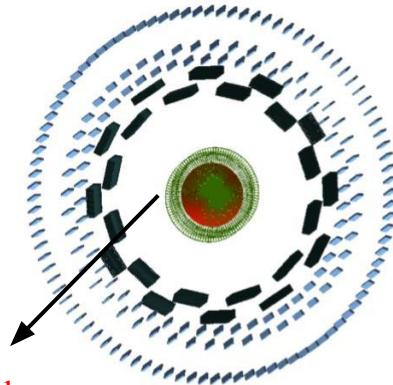


J-PET + 24 Modular J-PET



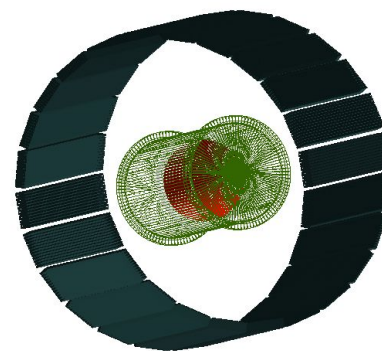
*Efficiency ~ 21
w.r.t present J-PET
*Scattering background: 37%

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



Efficiency ~ 75
w.r.t present J-PET
Scattering background: 28%

24 Modular J-PET



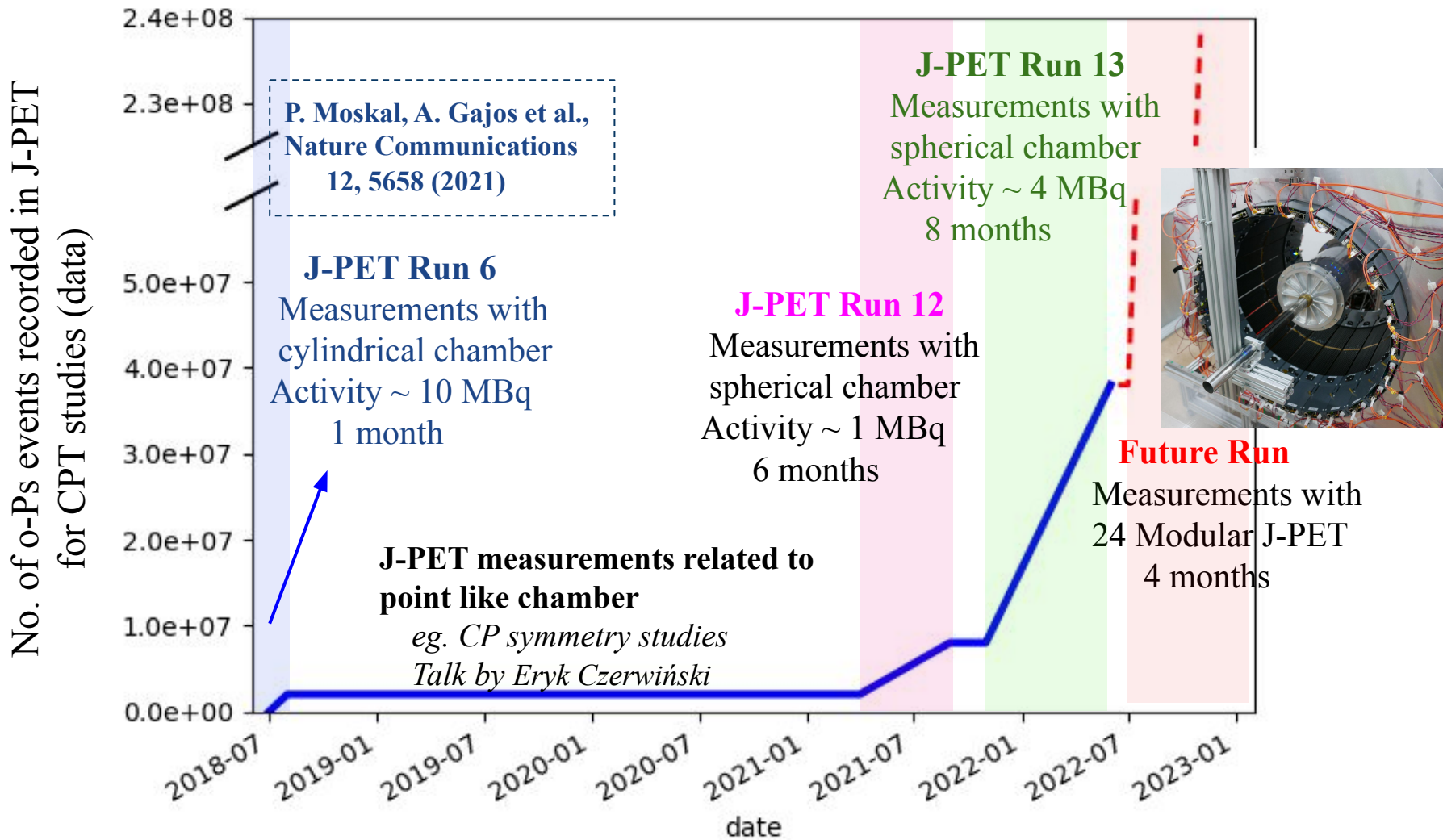
Efficiency ~ 11
w.r.t present J-PET
Scattering background: 7%

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 \rightarrow 3y events in detector (based on MC simulations)

Outlook



Thank You