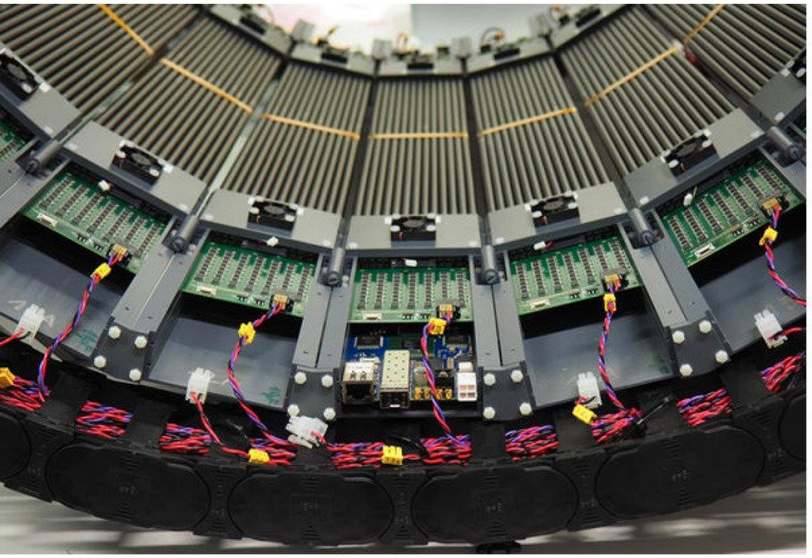
DISCRETE 2026

Pooja Tanty
Supervisor: Pawel Moskal
Jagiellonian University, Krakow, Poland

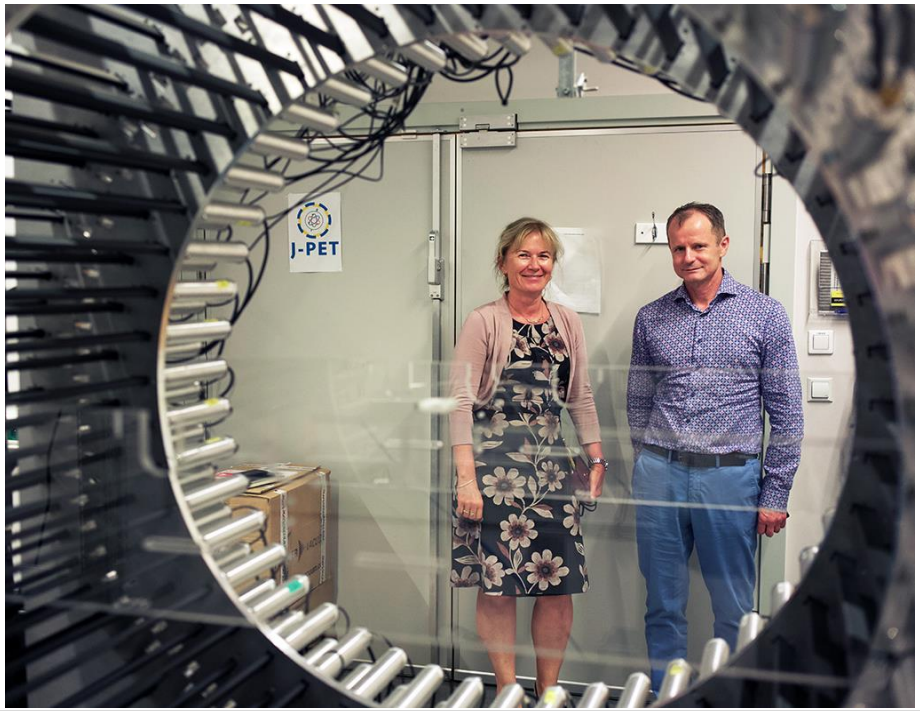


Precision test of discrete symmetries in positronium decays with the JPET detector

J-PET



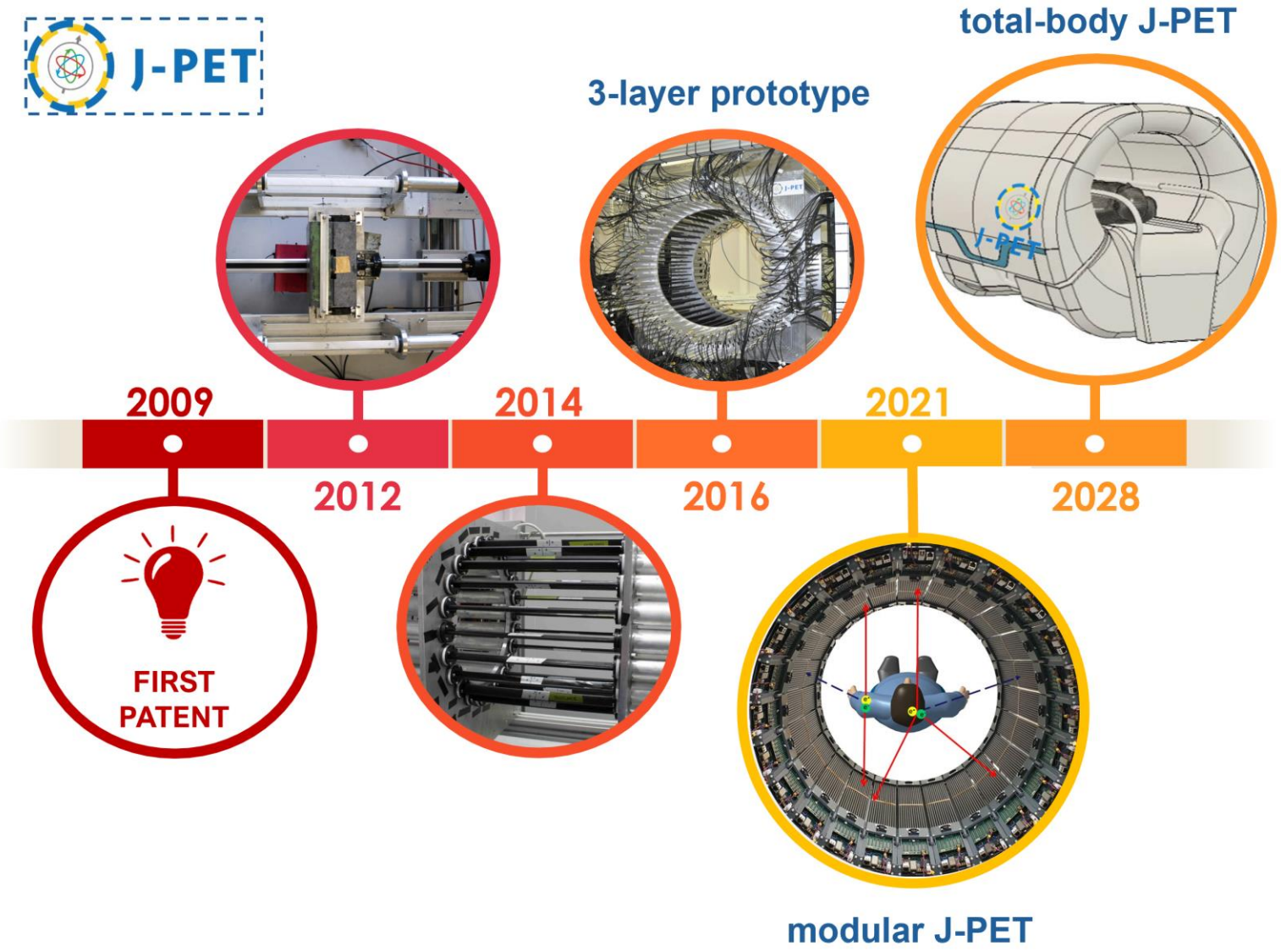
New twist on PET scans unlocks hidden signals for diagnosing disease



JPET: Science 389 (2025) 6761

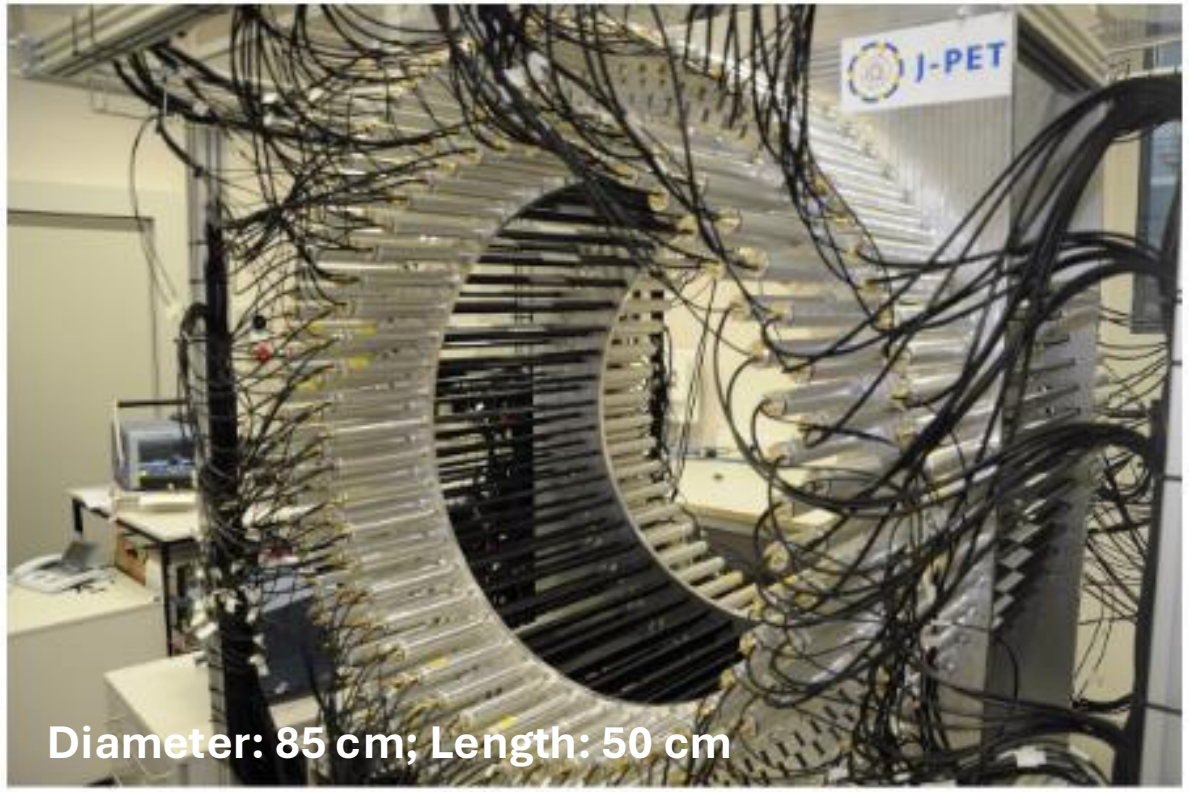
The family portrait

Unfolding the history.....

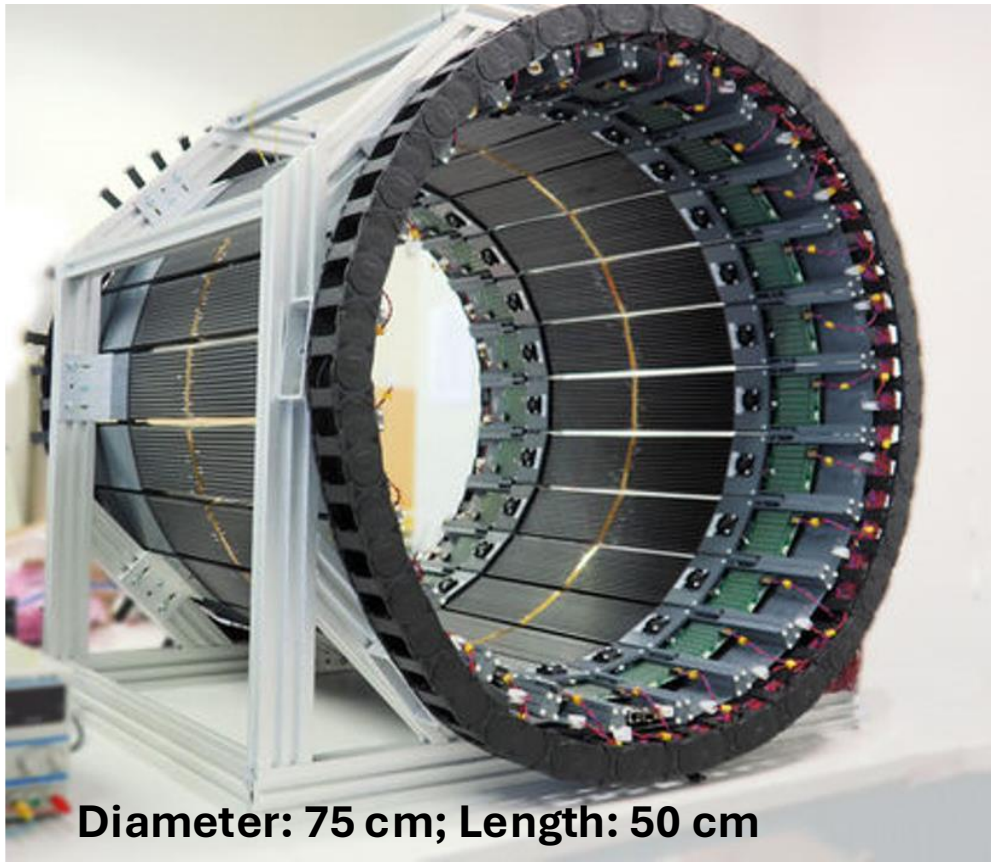


https://koza.if.uj.edu.pl/pet/

JPET: P. Moskal et al. Nucl. Instr. and Meth. A 764 (2014) 317-321



J-PET: P. Moskal et. al., Science Advances 10 (2024) eadp2840



JPET: G. Korcyl et al. Acta Phys. Polon. B 47 (2016) 491

3 layers

192 plastic scintillators with PMT readouts

Triggerless DAQ

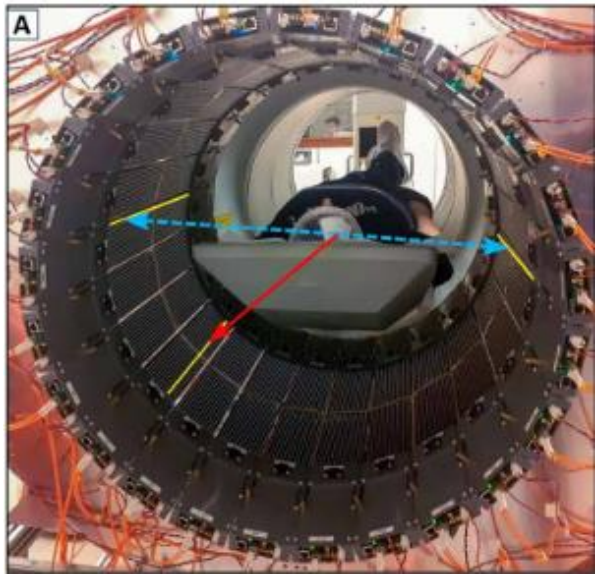
Cost effective

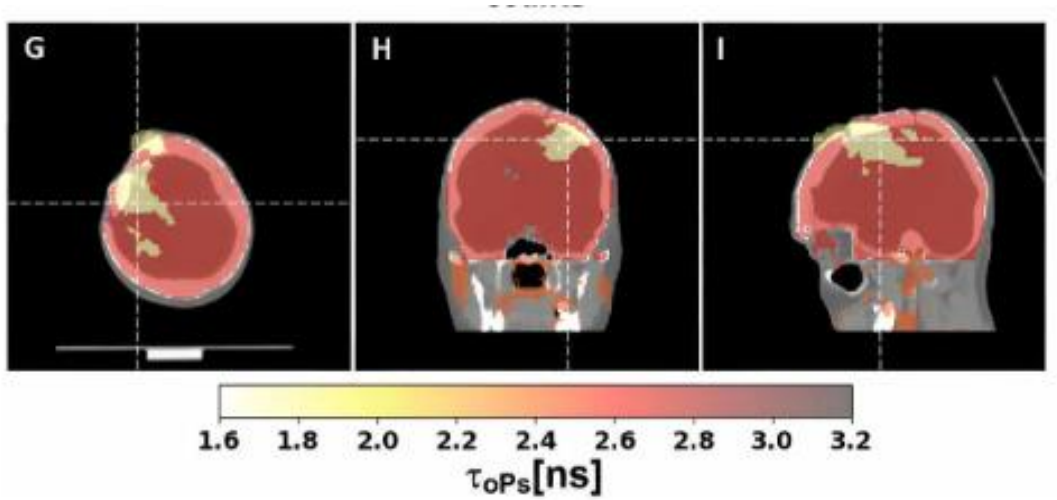
Modular design

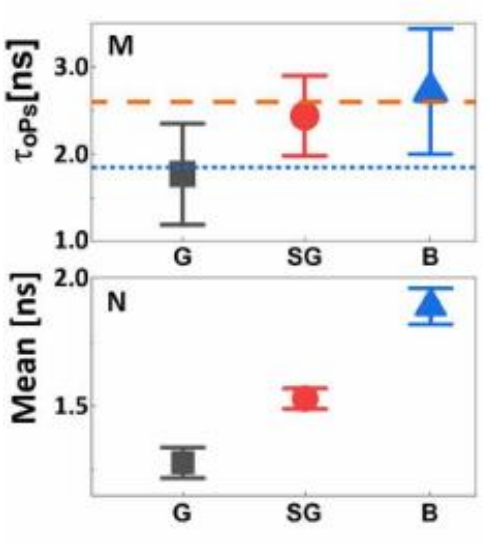
24 modules, 13 scintillators each module

Light weight - Portable

Reconfigurable







In-vivo positronium image of human brain using J-PET

https://koza.if.uj.edu.pl/pet/

J-PET: P. Moskal et. al., Science Advances 10 (2024) eadp2840

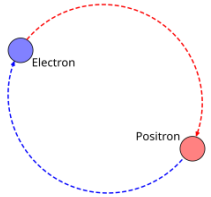
Positronium

S. D. Bass et al., Rev. Mod. Phys. 95, 021002 (2023)

Bound state of electron & positron

Cleanest system for testing QED

Can be used to test CPT, CP and C

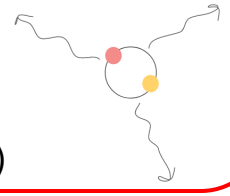


Para-Positronium (pPs)

Spin state: Singlet (S = 0) — spins antiparallel
C quantum number: C = +1
Lifetime: ~125 picoseconds
Dominant decay: p-Ps → 2γ (97.8%)



Spin state: Triplet (S = 1) — spins parallel
C quantum number: C = −1
Lifetime: ~142 nanoseconds
Dominant decay: o-Ps → 3γ (via QED)



Ortho-Positronium (oPs)

B. Jasinska, et al., Acta Phys. Polon. B 47 (2016) 453

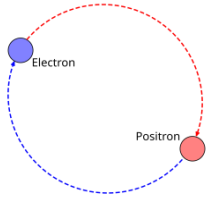
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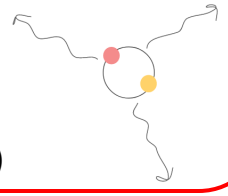


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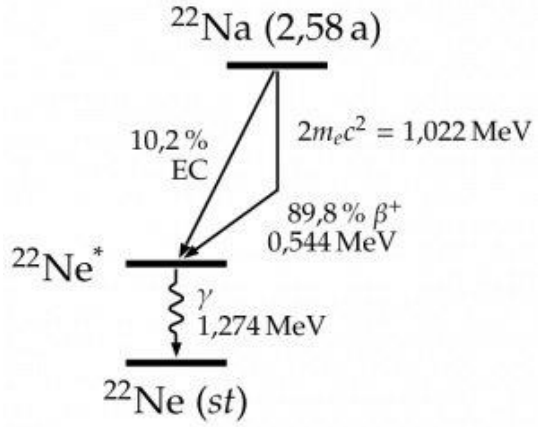


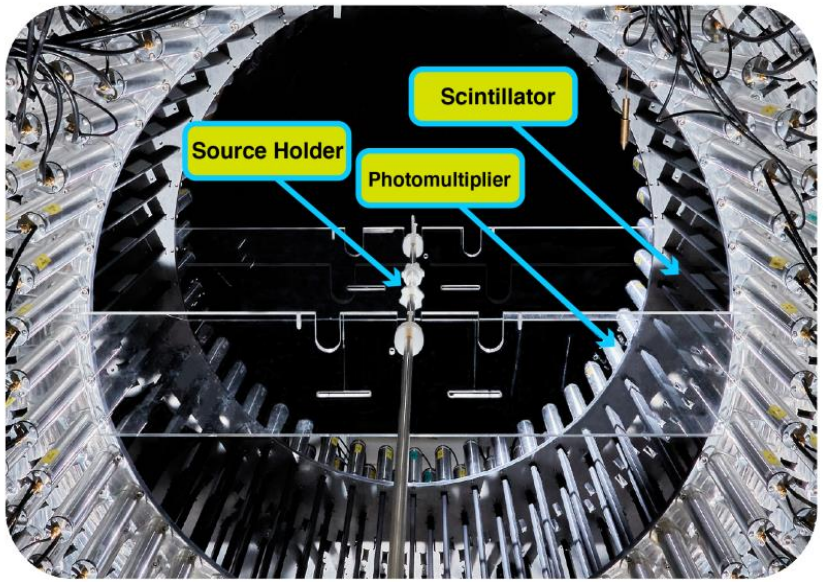
Spin state: Triplet (S = 1) — spins parallel
C quantum number: C = −1
Lifetime: ~142 nanoseconds
Dominant decay: o-Ps → 3γ (via QED)

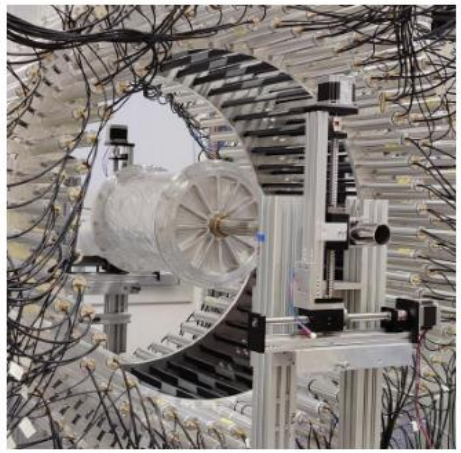


Ortho-Positronium (oPs)

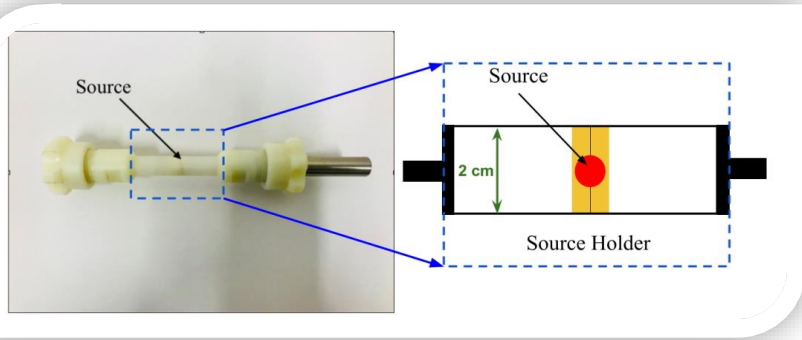
Positron Source – Sodium 22











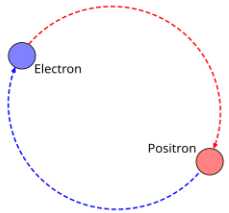
B. Jasinska, et al., Acta Phys. Polon. B 47 (2016) 453

Importance of oPs

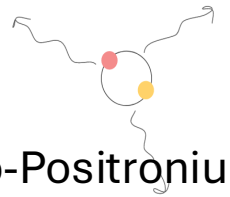
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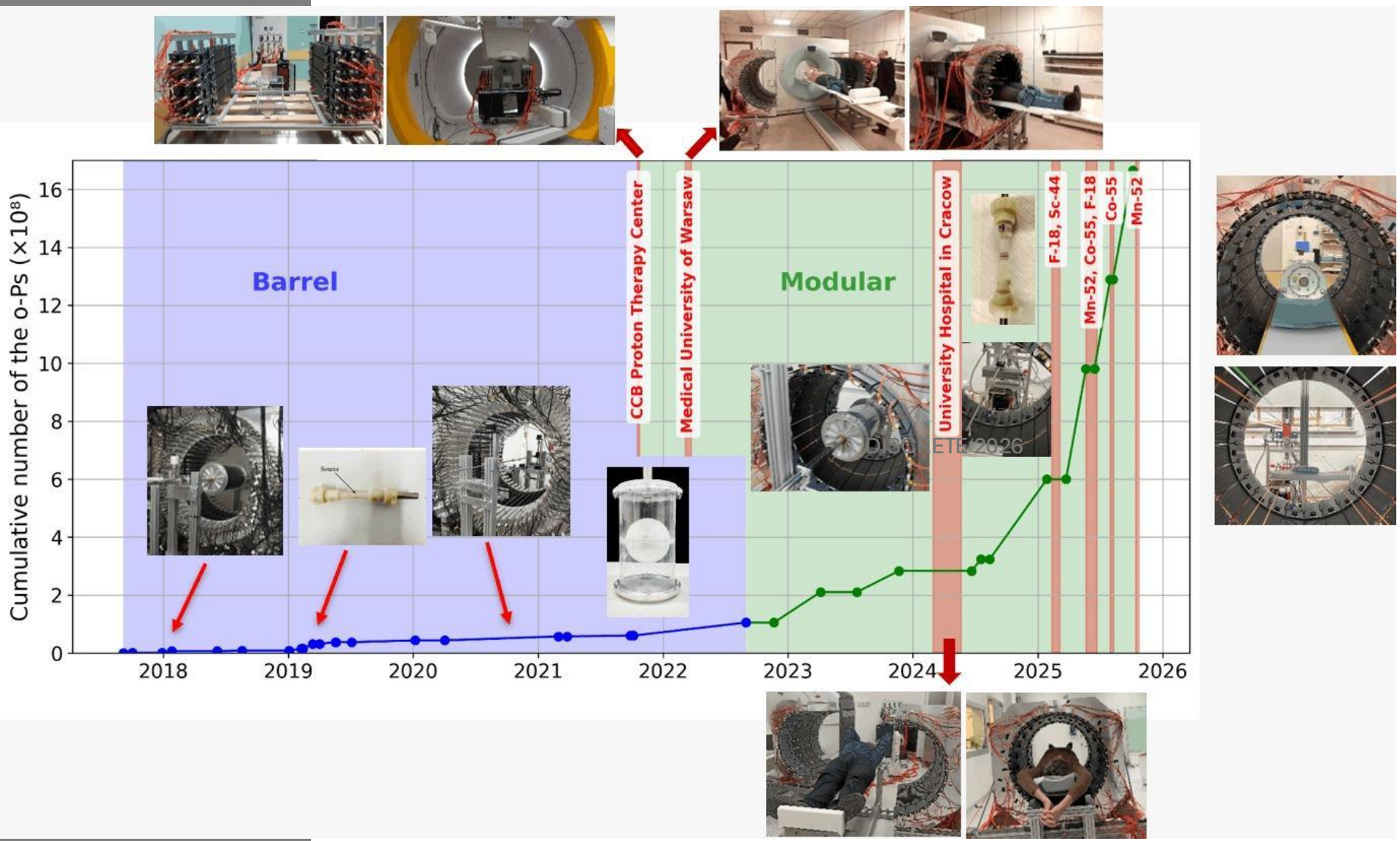
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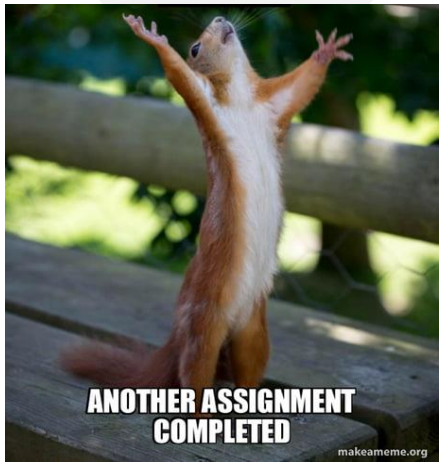
Ortho-Positronium (oPs)

Para-Positronium (pPs)

Spin state: Singlet (S = 0) — spins antiparallel
C quantum number: C = +1
Lifetime: ~125 picoseconds
Dominant decay: p-Ps → 2γ (97.8%)



1.6 billion o-Ps gathered so far....



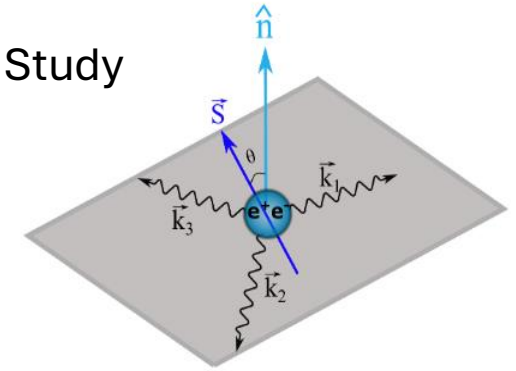
Discrete symmetries in leptonic system with J-PET

Measurement the expectation value of the symmetry odd-operators

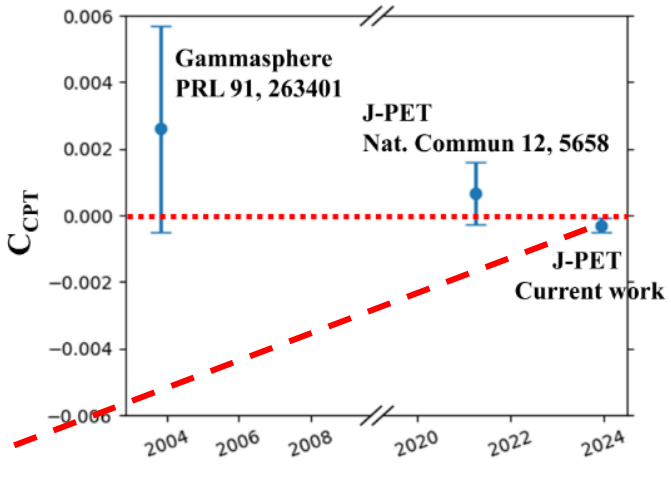
Operators are constructed out of the angular correlation of the out-going photons w.r.t the spin (oPs) and polarization vector

CP & CPT tested to a level of 10^{-4} precision

CPT Study



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



J-PET: N. Chug et al., Phys. Rev. D 113 (2026) 032003

JPET: P. Moskal et al. Nature Communications 12 (2021) 5658

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

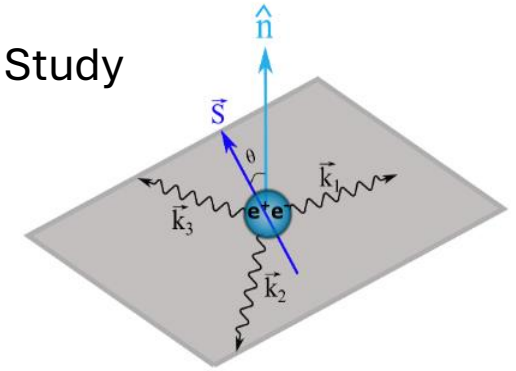
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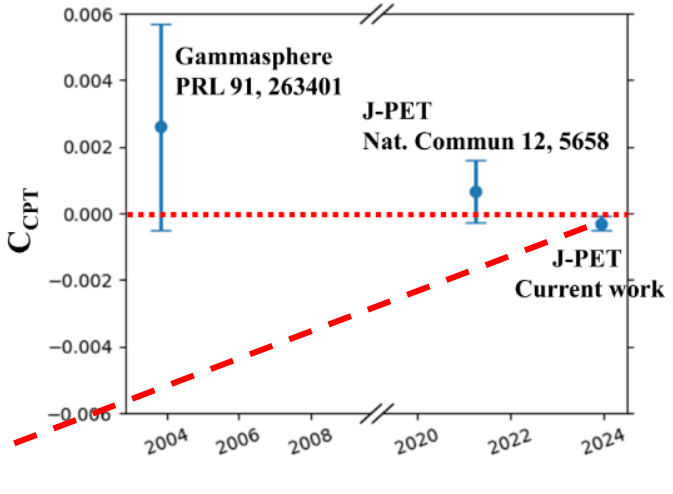
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CPT Study



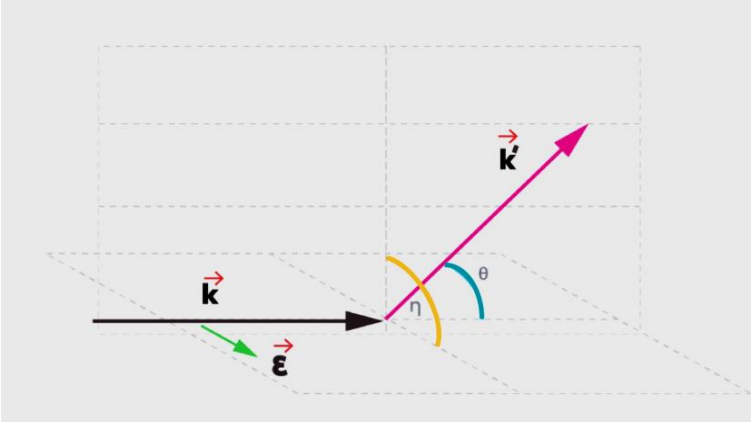
Operators	C	P	T	CP	CPT
$\vec{S}\cdot\vec{k}_1$	+	-	+	-	-
$\vec{S}\cdot(\vec{k}_1\times\vec{k}_2)$	+	+	-	+	-
$(\vec{S}\cdot\vec{k}_1)\,(\vec{S}\cdot(\vec{k}_1\times\vec{k}_2))$	+	-	-	-	+



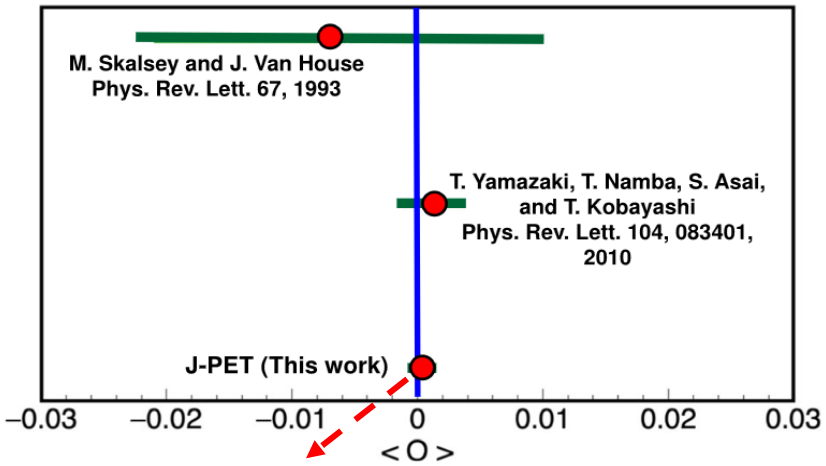
J-PET: N. Chug et al., Phys. Rev. D 113 (2026) 032003

JPET: P. Moskal et al. Nature Communications 12 (2021) 5658

CP Study



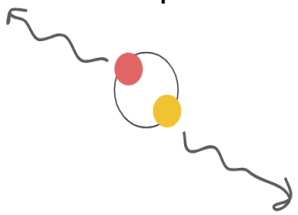
Operator	C	P	T	CP	CPT
$\vec{\epsilon_1}\cdot\vec{k_2}$	+	−	−	−	+



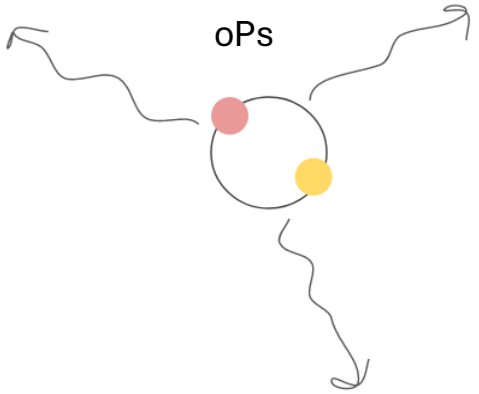
JPET: P. Moskal et al.Nature Communications 15 (2024) 78

Motivation: Charge conjugation invariance test

In EM decay, no. of photons in the final state – consequence of C-conjugation symmetry



Even no. Of photons
2γ, 4γ.....



Odd no. Of photons
3γ, 5γ.....

Deviation from the allowed no. Of photons in final state - an indication of C symmetry violation

S. D. Bass et al., Rev. Mod. Phys. 95, 021002 (2023)

Additional aid from Bose statistics

Mani and Rich. Phys. Rev. D, 4:122, 1971

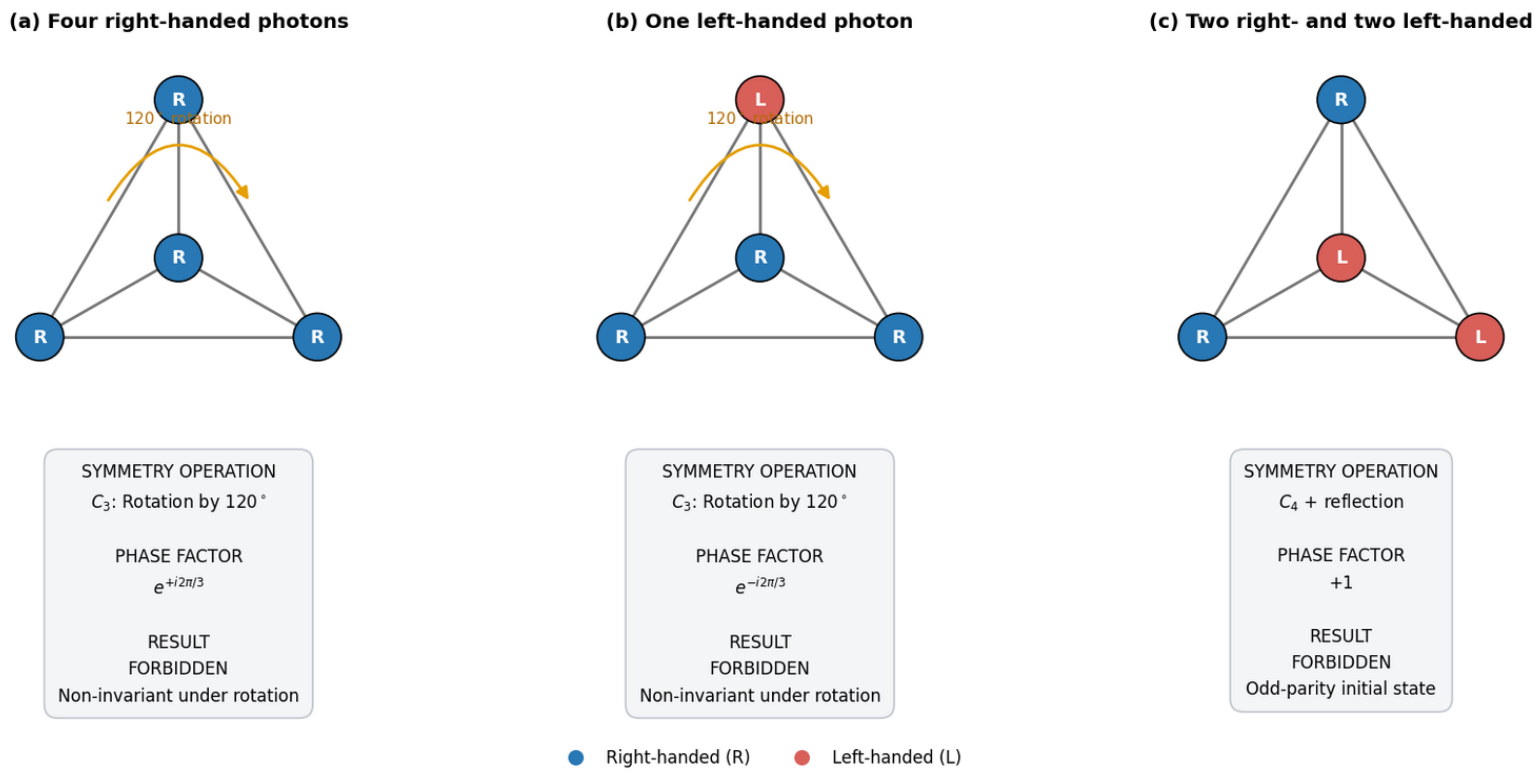
pPs --> 4γ possible

BUT

Not in a symmetric configuration of regular tetrahedron

pPs is rotationally invariant but,

are the final state photons consistent???



The final state photons have inconsistent polarization state w.r.t pPs.

Additional aid from Bose statistics

Mani and Rich. Phys. Rev. D, 4:122, 1971

pPs --> 4γ possible

BUT

Not in a symmetric con
tetrahedron

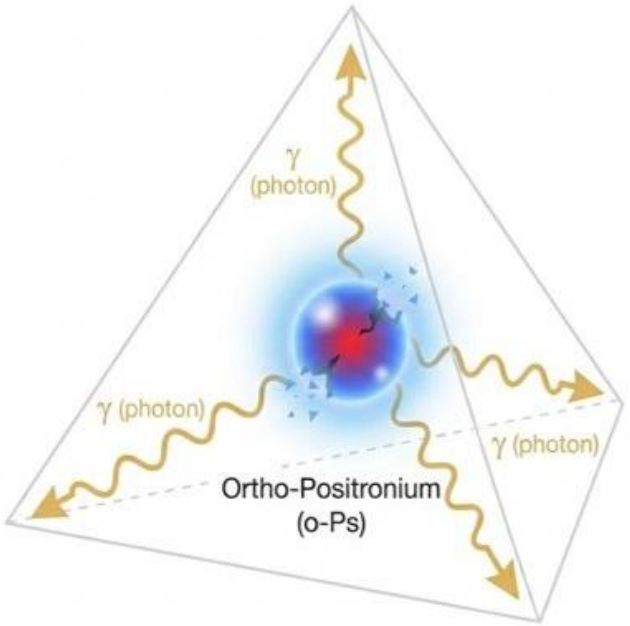
pPs is rotationally invar

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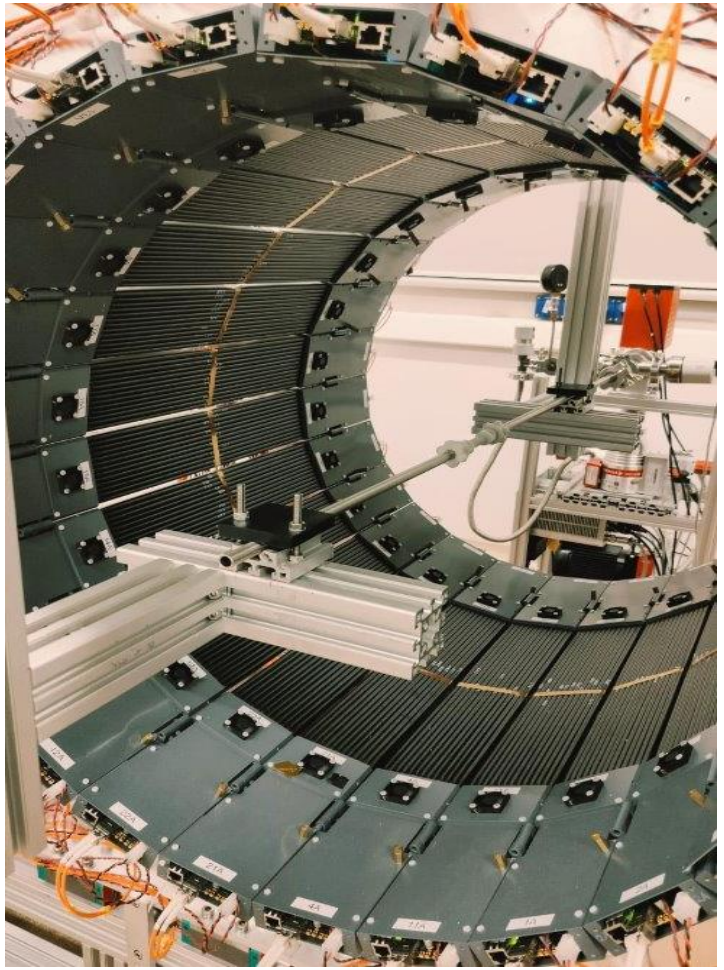


The final state photons have inconsistent polarization state w.r.t pPs.

Forbidden search with J-PET – Main goal

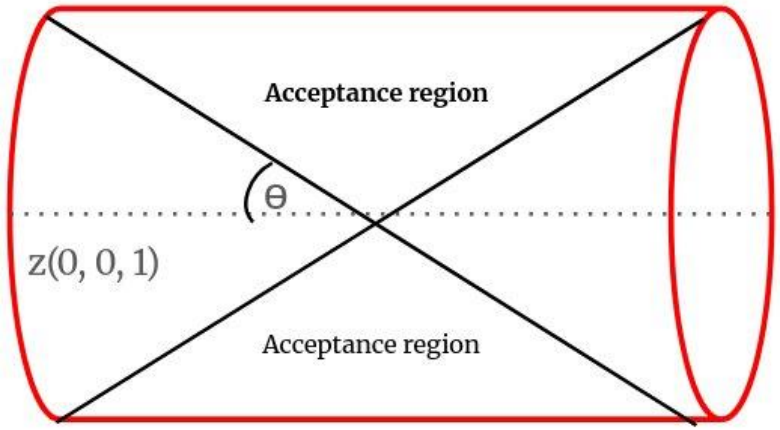


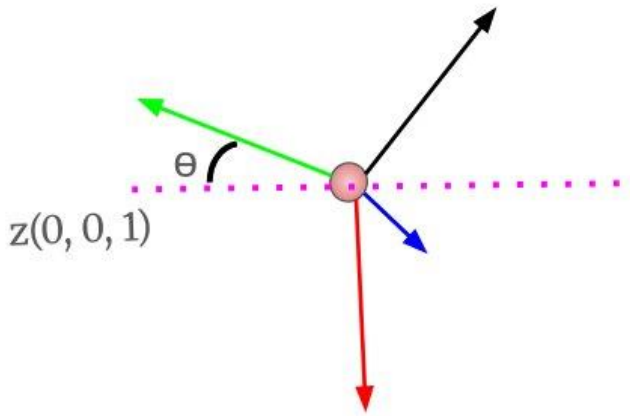
- 4 photons
- Photon energy: 255.5 keV
- Interangle: 109.5 deg.



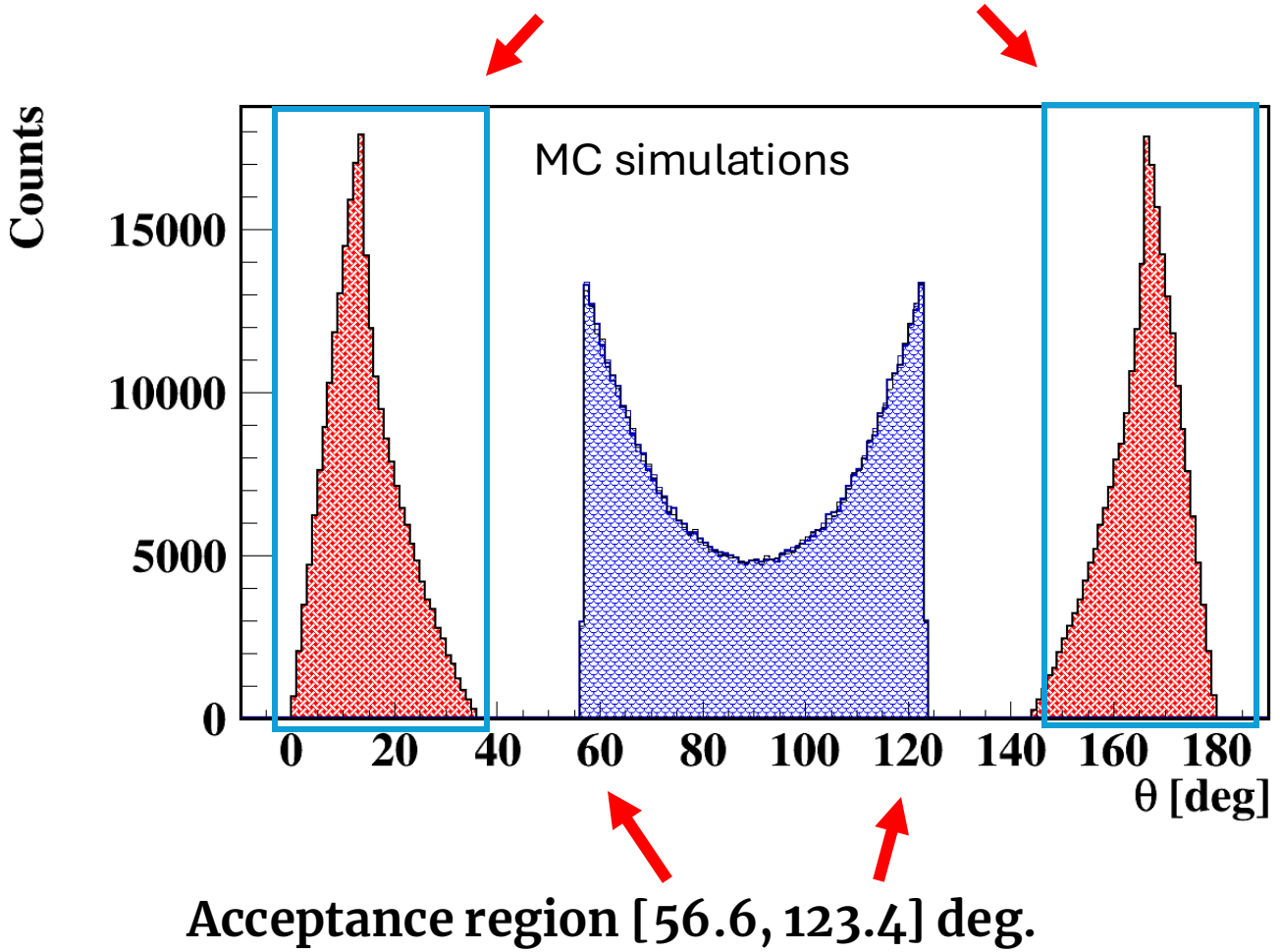
Geometrical Constraint

Length = 50 cm, Radius = 37.5 cm





Direction of 4th photon w.r.t the z(0,0,1) axis



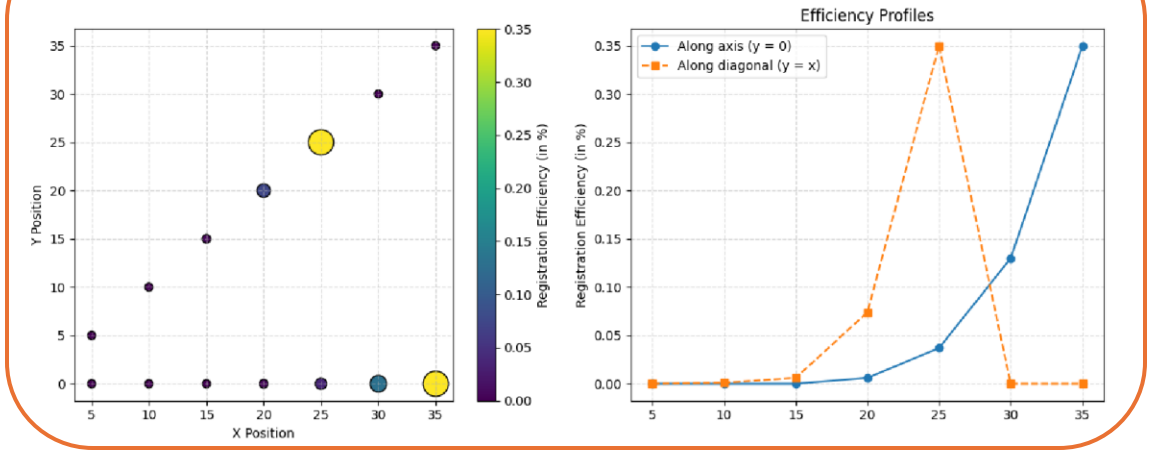
Acceptance region [56.6, 123.4] deg.

Alternatives!!

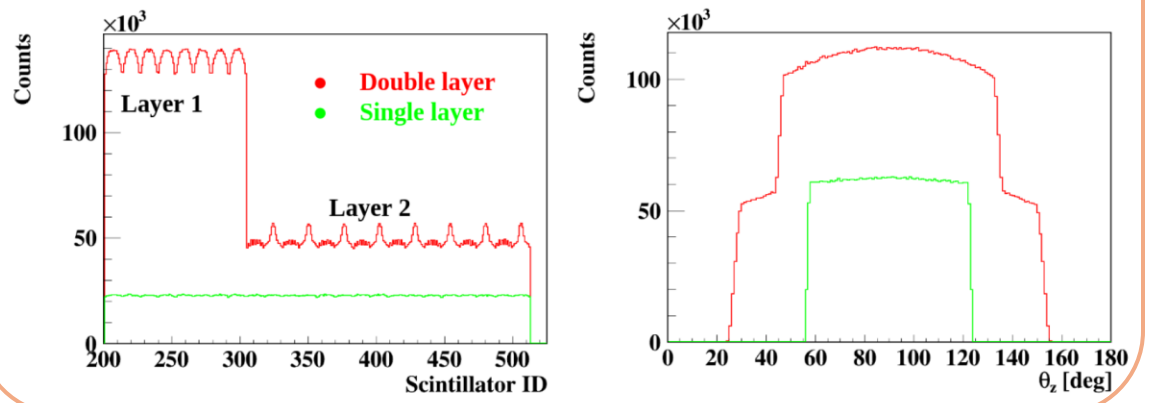
Displace the source position	• Simulation study carried out
Reconfigure the detector (Reduce the detector radius)	• Simulation study ongoing
User a longer Detector	• Total Body J-PET on the way
Use an extra detector at the endcaps with the existing detector	• Plan under consideration

Simulation studies

Displaced source



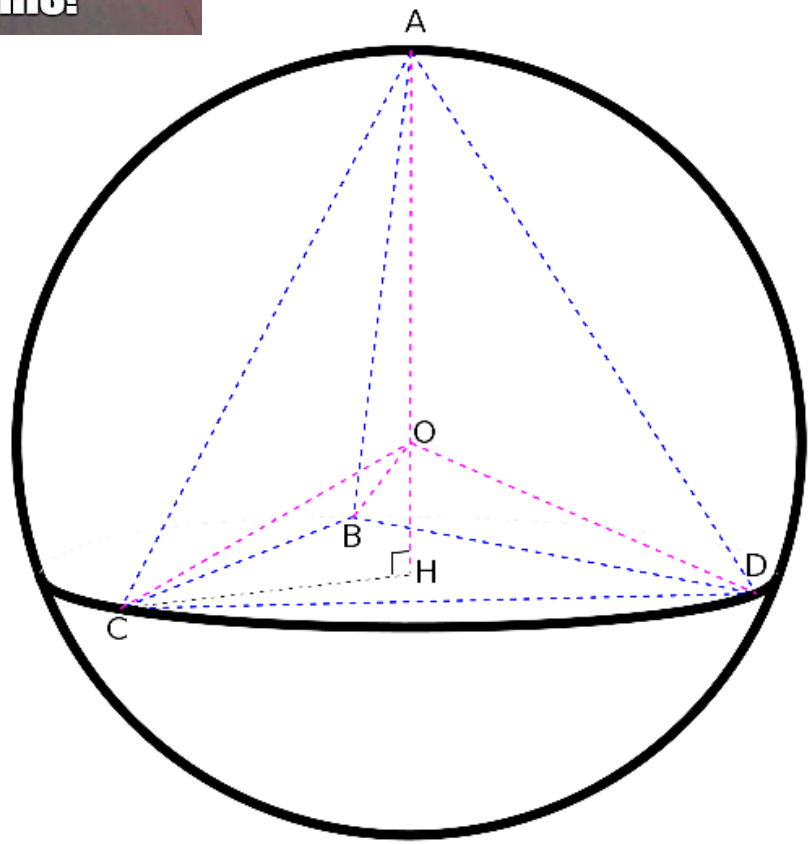
Reconfigured Detector

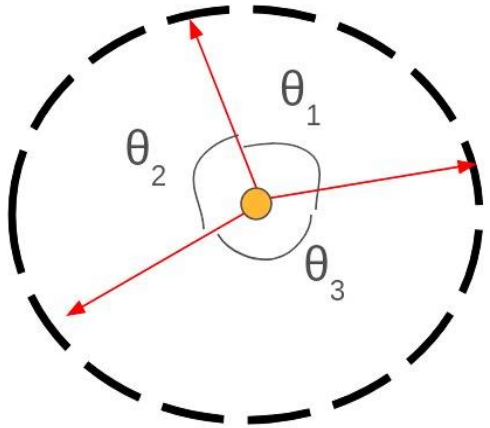


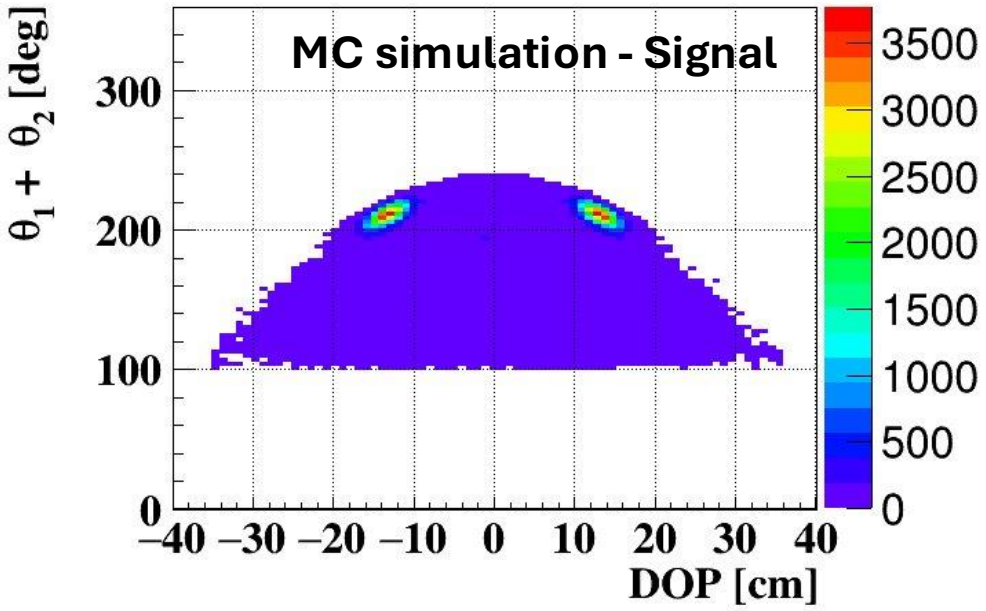


At present doable

Working with 3 photons instead of 4

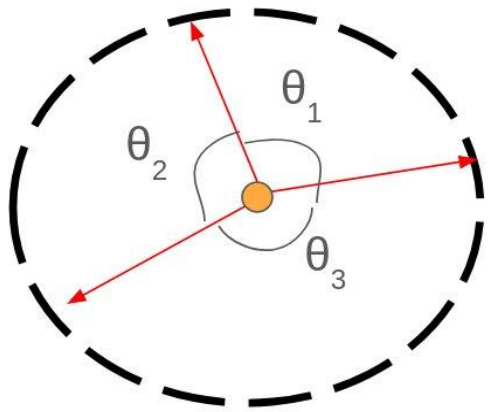


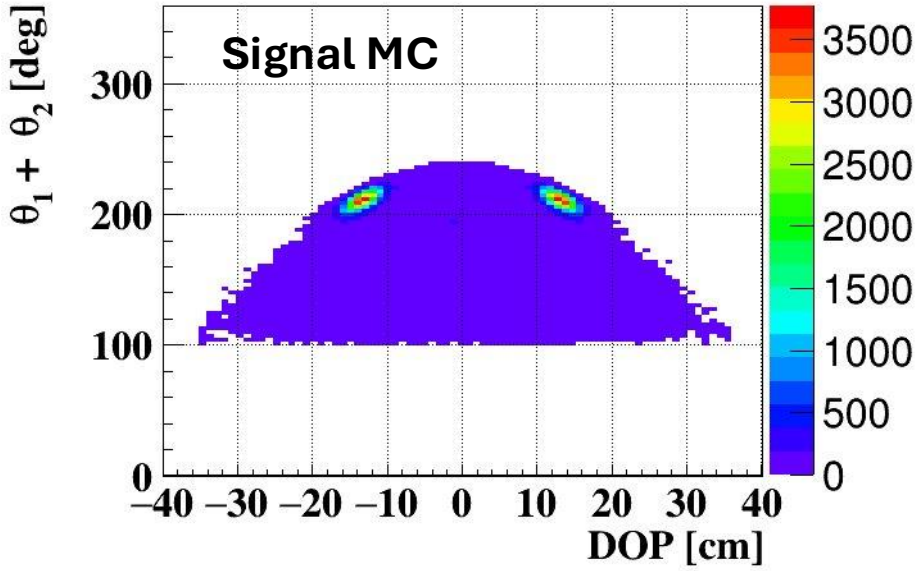


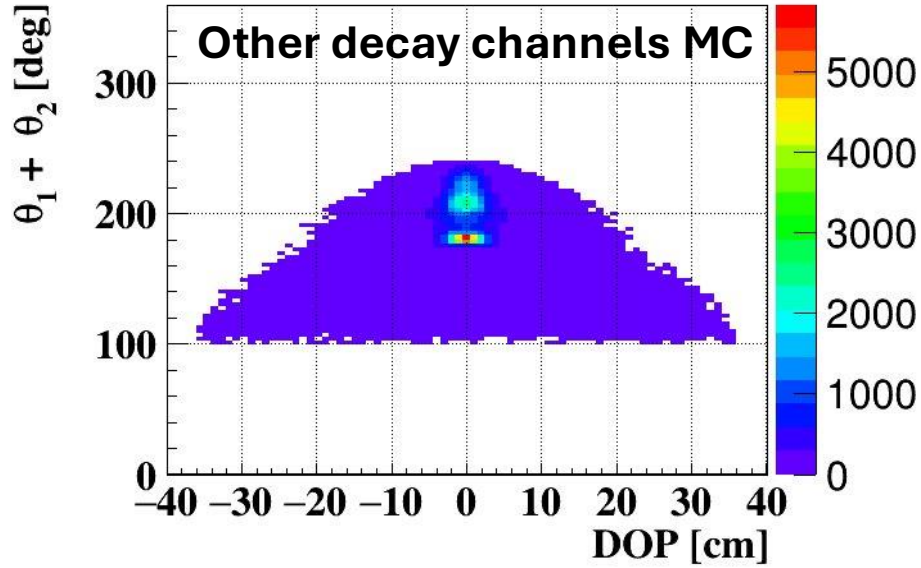


Distance of plane formed by 3 photons w.r.t annihilation point

Signal vs other dominant decay channels

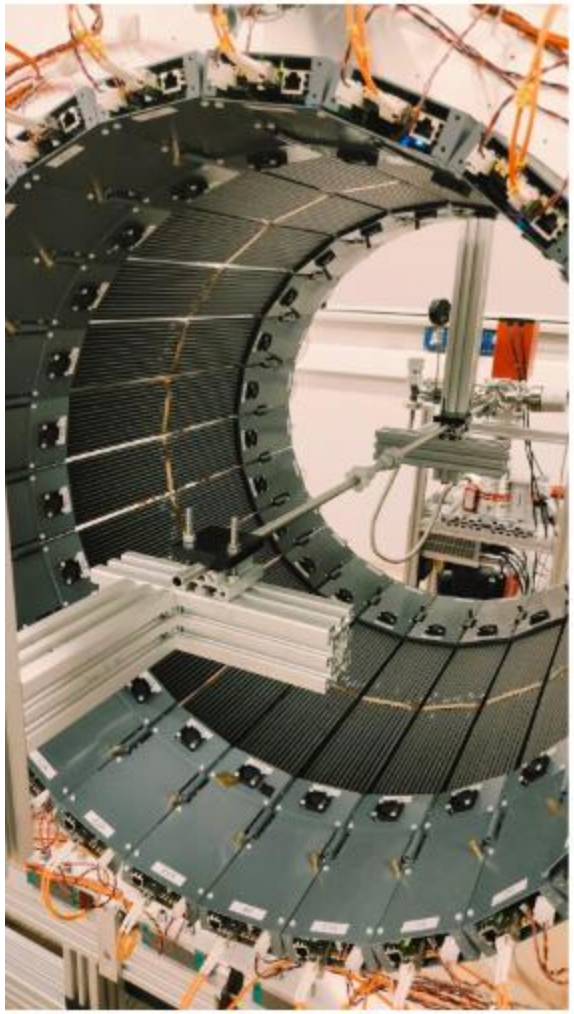






- 109.5 deg. - not the only characteristic of the signal
- Distance of plane from the annihilation point is also a distinct feature for signal selection

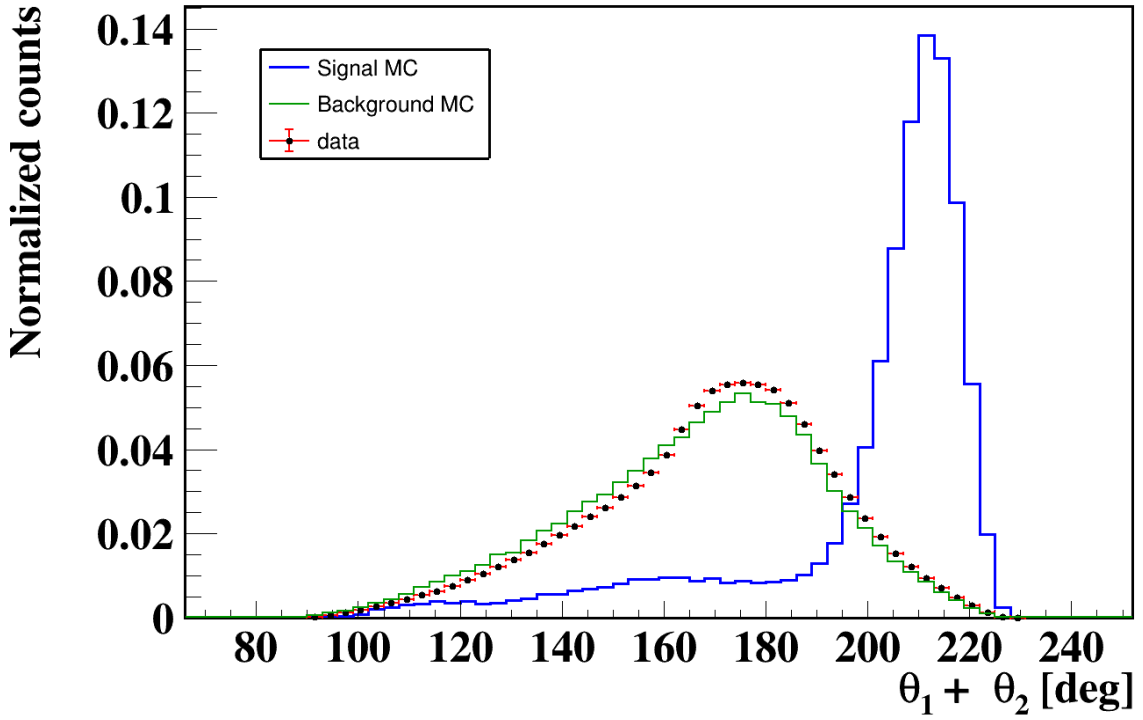
Search for forbidden decay of oPs



Preliminary!!

- 23 days of data
- Source: 1.209 MBq Sodium-22
- Small chamber

Signal MC not to scale

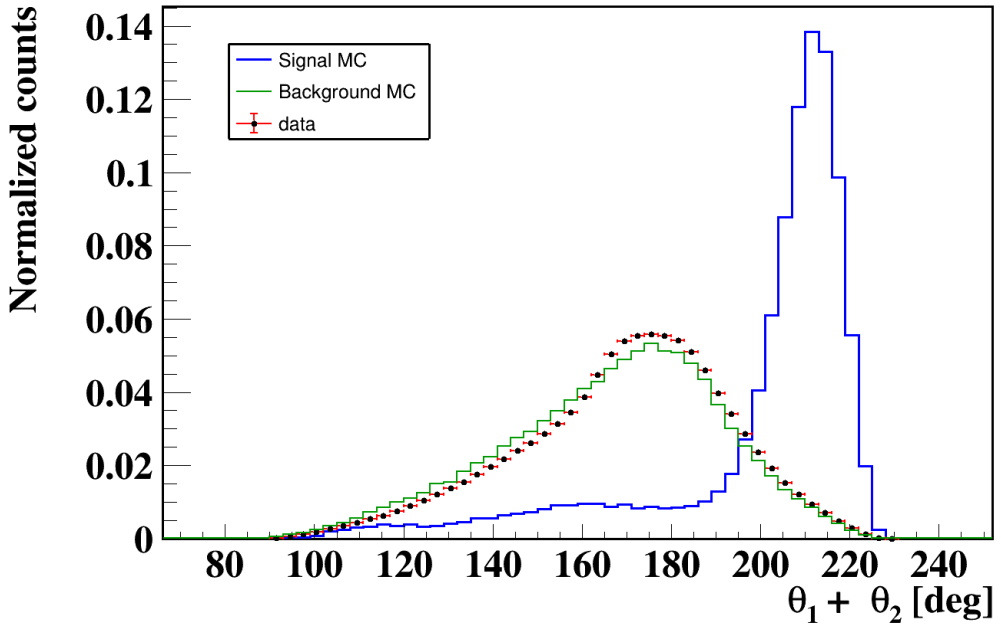


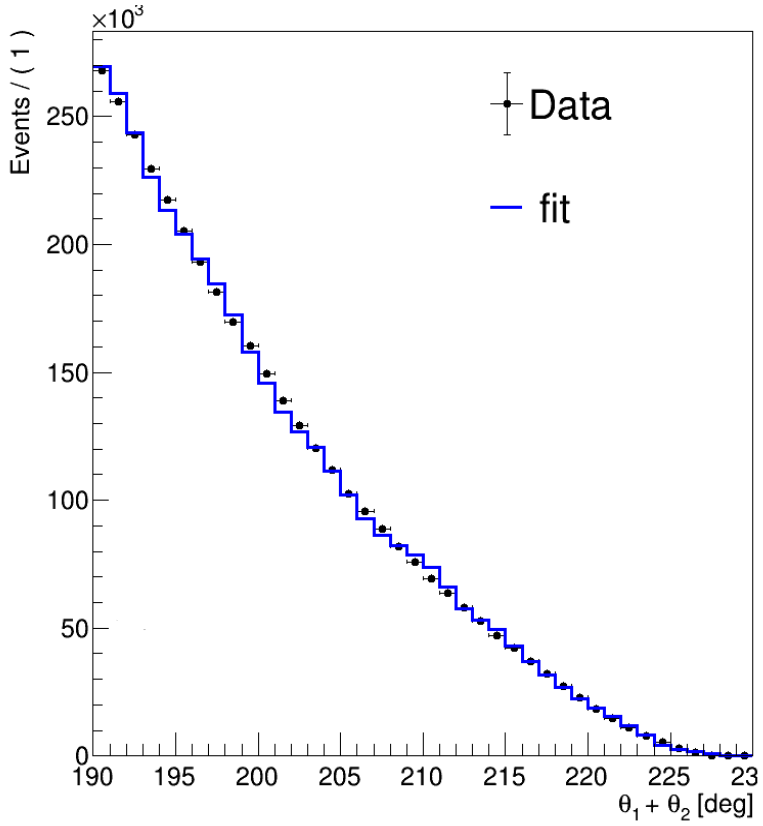
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- Small chamber

Signal MC not to scale

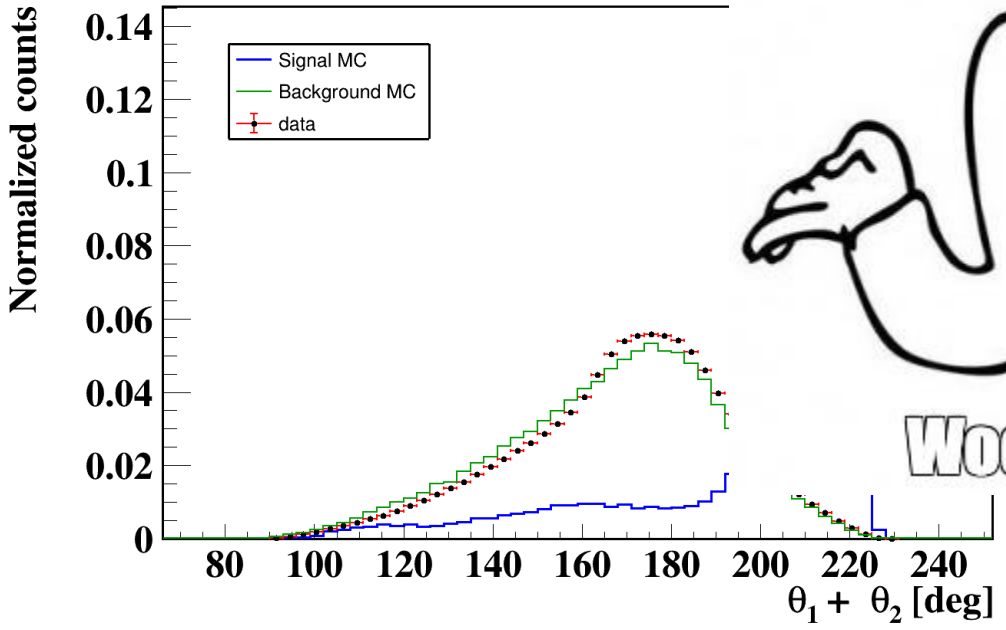




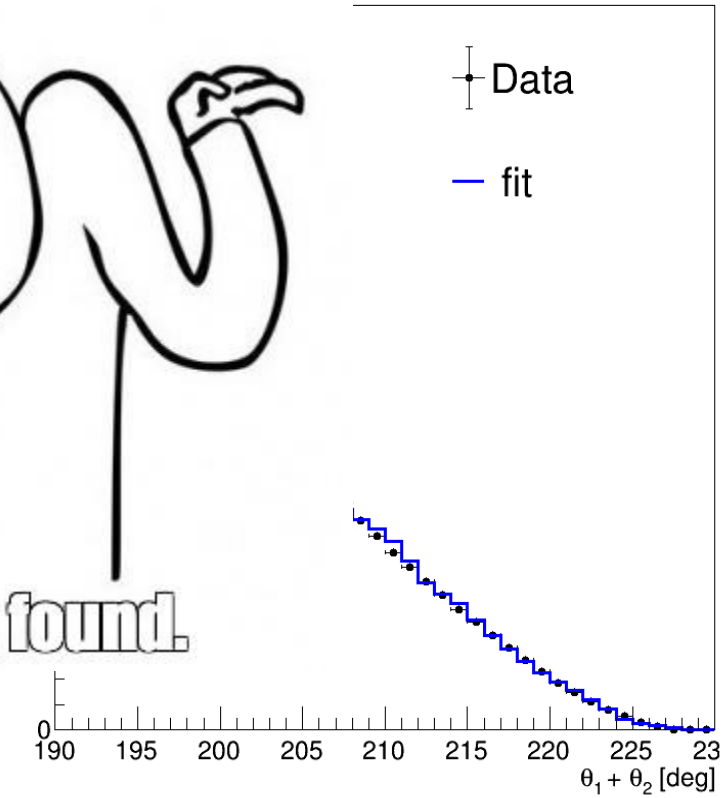
Search for forbidden decay

Preliminary!!

- 23 days of data
- Source: 1.209 MBq Sodium
  2
- S







Summary

- J-PET is a **multi-Purpose detector** which can be used in medical imaging as well as discrete symmetries.
- We have tested **CP & CPT** in pure leptonic system to the precision of 10^{-4} level.
- The detector can also be used to test the Charge conjugation invariance.
- Results from recent simulation studies and data are presented.
- Further development in background reduction is ongoing!!

Thank you for your attention!!

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