# **Improving the CPT Symmetry test** towards 10<sup>-5</sup> level

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### **Motivation**

- Search for the discrete symmetry violation in leptonic sector.
- Positronium is used for the tests of CP and CPT in J-PET.
- Gammasphere detector : CPT symmetry test reached a sensitivity of order of 10<sup>-3</sup> [1].
   J-PET: reached up to 10<sup>-4</sup> [2].

• Towards 10<sup>-5</sup> :

Spherical annihilation chamber To increase the rate of formation of positronium atoms from  $\beta^+$  source.

#### Modular Layer

To increase the detector efficiency of recording photons from o-Ps.

[1] P. A. Vetter and S. J. Freedman, Phys. Rev. Lett. 91, 263401 (2003).
[2] M. Mohammed, Doctoral thesis, Jagiellonian University (2020).

## **Study of Operators**



 $\vec{S}$ .  $\vec{k_1}$ CP and CPT violation sensitive $\vec{S}$ .  $(\vec{k_1} \times \vec{k_2})$ T and CPT violation sensitive $|\mathbf{k_1}| \ge |\mathbf{k_2}| \ge |\mathbf{k_3}|$  $\vec{S}$ : Spin of decaying o-Ps atom<br/> $\vec{k_1}$ ,  $\vec{k_2}$ ,  $\vec{k_3}$ : momentum direction of

annihilated photons.

o-Ps ->  $3\gamma$  $\vec{S}$  $\vec{k}_3$   $\vec{k}_2$   $\vec{k}_1$ 

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### **CPT Symmetry Test**

This study would be carried out by considering the decay of o-Ps into 3gamma events and observing the correlation between positronium spin and a gamma quanta originating from its annihilation.



Spin: Estimated to be along the direction of flight of positron. Annihilation Point: Reconstructed from Trilateration Method

A. Gajos et al., NIM A 819 (2016), 54-59

#### **Experimental Set-up - First attempt**





Left: Geometrical representation of large annihilation chamber placed inside the detector setup in Geant4. Right: Experimental setup

- Cylindrical chamber made of Polycarbonate material.
- Source <sup>22</sup>Na, glued between two layers of Kapton foil, placed at centre of chamber using a metal holder.
- **Porous silica** (positronium production medium) is coated on inner walls of cylinder.
- Pressure system is used to create vacuum in chamber.

Reached the sensitivity to  $10^{-4}$  for CPT symmetry test.

### **Spherical Annihilation Chamber**

- Spherical chamber (R = 10 cm) made of plexiglass material.
- Source <sup>22</sup>Na placed at centre of chamber using plastic string holder.
- **Porous silica** is coated on inner walls of sphere (positronium production medium).
- Outer cylinder is vacuumised.
- 4 Bolts (polyoxymethylene) and a outer ring (polycarbonate) used to place sphere inside the cylinder.



Geometrical representation of spherical annihilation chamber in the J-PET detector in Geant4



Increase in the fraction of positrons forming o-Ps in the sensitive area of J-PET detector.

Geometrical representation of a spherical chamber with outer ring and Bolts.

#### **Plots for Generated Events - MC**



Visualisation of XY distribution of simulated Annihilated Points using MC.

Annihilation Points are expected to be on the walls of spherical chamber.



E1 and E2 of generated events

Energy distribution of gamma quanta from decay of o-Ps to  $3\gamma$ .

#### **Modular J-PET**

- 24 modules of plastic scintillators.
- 13 scintillators in each module.
- $50 \times 2.4 \times 0.6 \text{ cm}^3$
- SiPM is used for readout from both sides of detector.





- Array of 4 SiPM on each side of scintillator ( $6 \times 0.6 \text{ mm}^2$ ).
- Allow to improve the time resolution of recorded gamma interaction in the detector.

P Moskal, Phys. Med. Biol. 61 2025 (2016)

Diagramatic view of Modular layer inside J-PET detector.

Dense layer of scintillators that can increase the probability of recording photons.





#### 24 Modular J-PET

Efficiency of registration of single photon including fourth layer is about 3.5 larger than the three layers of J-PET.

To improve the CPT symmetry : Modular Layer + Spherical Annihilation Chamber

First measurements with spherical annihilation chamber --- Expected to be in beginning of 2021.



#### Summary

Upgrades:
 Annihilation chamber : to increase the rate of produced o-Ps -> 3γ events in J-PET.
 Modular layer: to increase the detection efficiency for registration of annihilated photons from o-Ps.

- □ Studies from simulation of J-PET and J-PET + Modular layer shows that there is an improvement in efficiency of about 3.5 times after adding modular layer to J-PET.
- □ With this improvements, J-PET expects to reach the sensitivity of discrete symmetry test at the level of 10<sup>-5</sup>.
- Currently simulations are being prepared and measurements are planned for 2021.

# **Thank You**