Fourth Italian Workshop on Physics at High Intensity

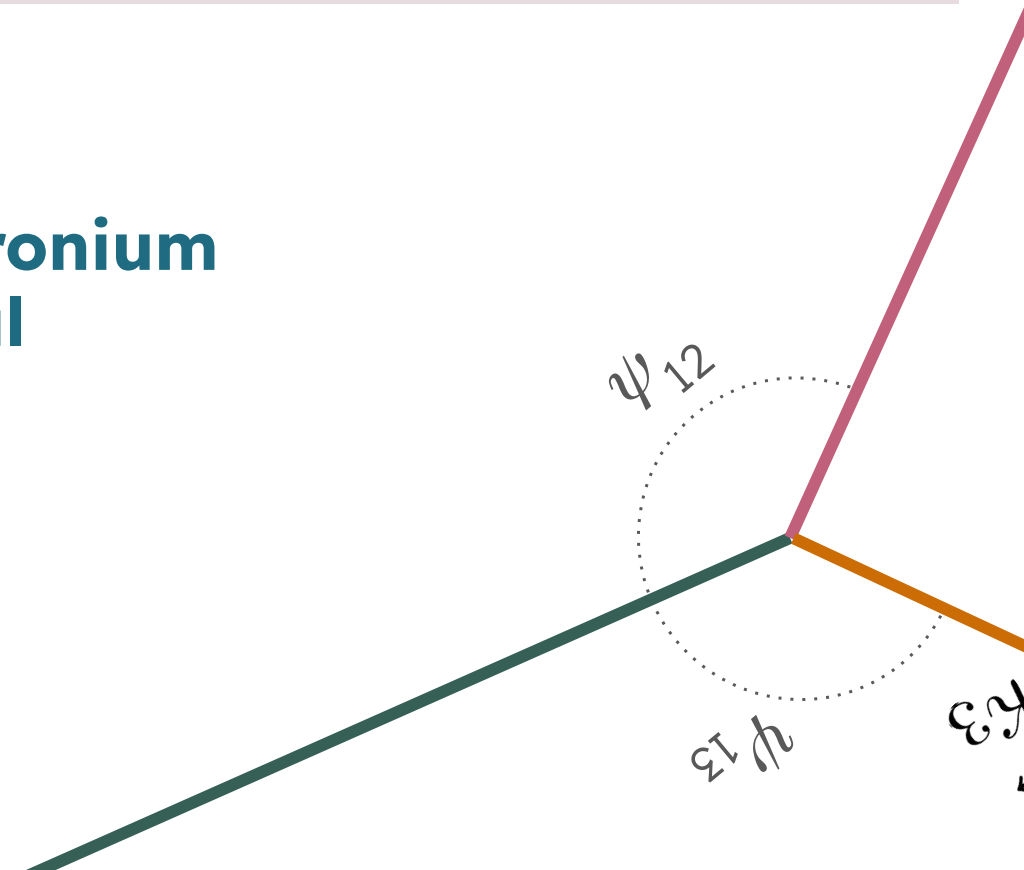
Development of a CP Symmetry Violation Measurement System

J. Nascimento, J. R. B. Oliveira

INFN
IFUSP Instituto de Física da USP
CNPq
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO
GOVERNO FEDERAL BRASIL UNIÃO E RECONSTRUÇÃO

Outline

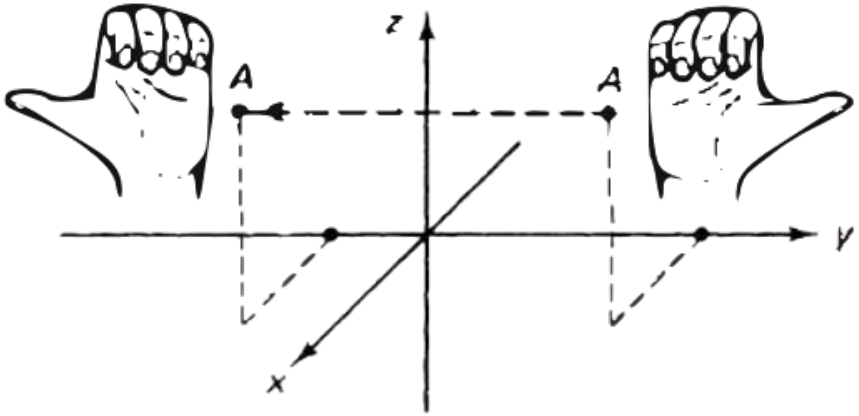
- ★ Introduction
- ★ CP Violation in Positronium
- ★ Methods and Material
- ★ Obtained Data
- ★ Conclusion
- ★ Future Steps

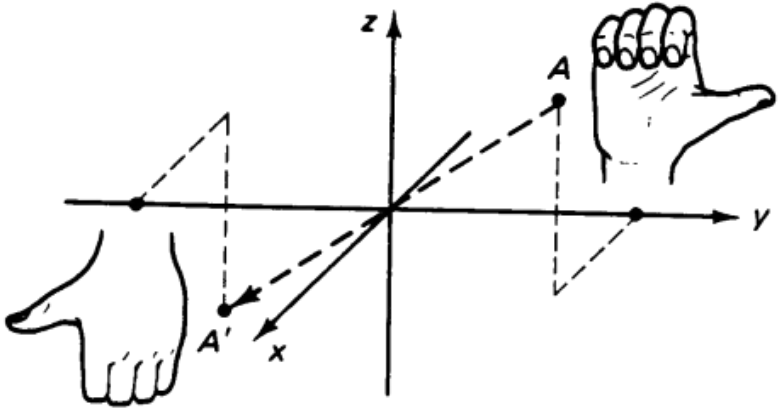


Introduction

The discrete symmetries are represented by the following operators:

- ★ **Charge Conjugation (C):** relates particles to their antiparticles.
- ★ **Time Reversal (T):** reverses the direction of time.
- ★ **Parity (P):** reflects spatial coordinates (mirror inversion).





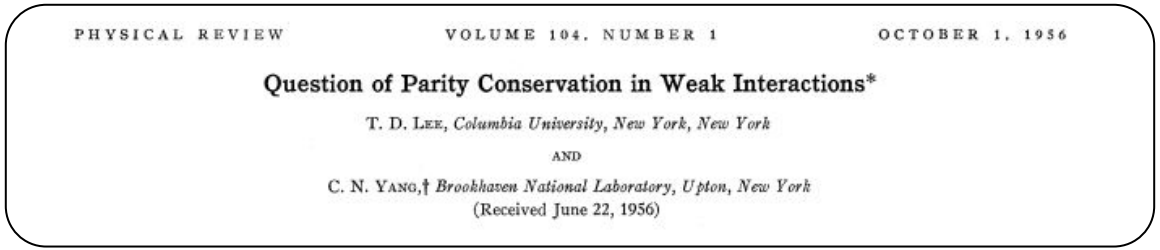
Introduction

The "**Θ-τ puzzle**":

- ★ Same mass, spin, charge…
- ★ One of them decays into **two pions** and the other into **three pions**.

$$\Theta^+ = \pi^+ + \pi^0$$

$$\tau^+ = \left\{ \begin{matrix} \pi^+ + \pi^0 + \pi^0 \\ \pi^+ + \pi^+ + \pi^- \end{matrix} \right\}$$



PHYSICAL REVIEW VOLUME 104, NUMBER 1 OCTOBER 1, 1956

Question of Parity Conservation in Weak Interactions*

T. D. LEE, *Columbia University, New York, New York*

AND

C. N. YANG,† *Brookhaven National Laboratory, Upton, New York*

(Received June 22, 1956)

Introduction

The "**Θ-τ puzzle**":

★ Madame Wu experiment
★ **P violated** in weak interactions

$$\Theta^+ \rightarrow P = (-1)^2 = +1$$

$$\tau^+ \rightarrow P = (-1)^3 = -1$$

Experimental Test of Parity Conservation in Beta Decay*

C. S. Wu, *Columbia University, New York, New York*

AND

E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson,
National Bureau of Standards, Washington, D. C.

(Received January 15, 1957)

VOLUME 13, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JULY 1964

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey

(Received 10 July 1964)

CP Violation in Positronium

The **Positronium**:

★ The **singlet state:**
- *Para-positronium* (p-Ps):
  - Antiparallel
  - Two gamma rays

$$|0,0\rangle = \frac{1}{\sqrt{2}}(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$$

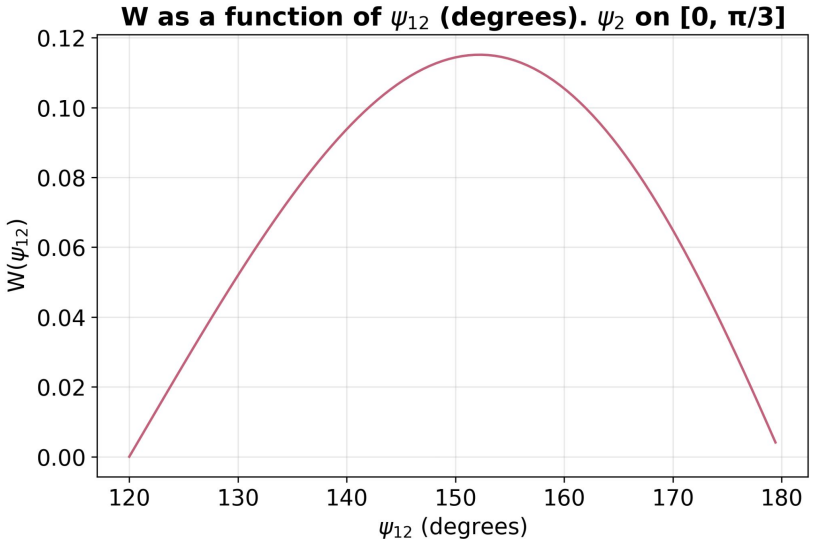
★ The **triplet state**
- *Ortho-positronium* (o-Ps):
  - Parallel
  - Three gamma rays

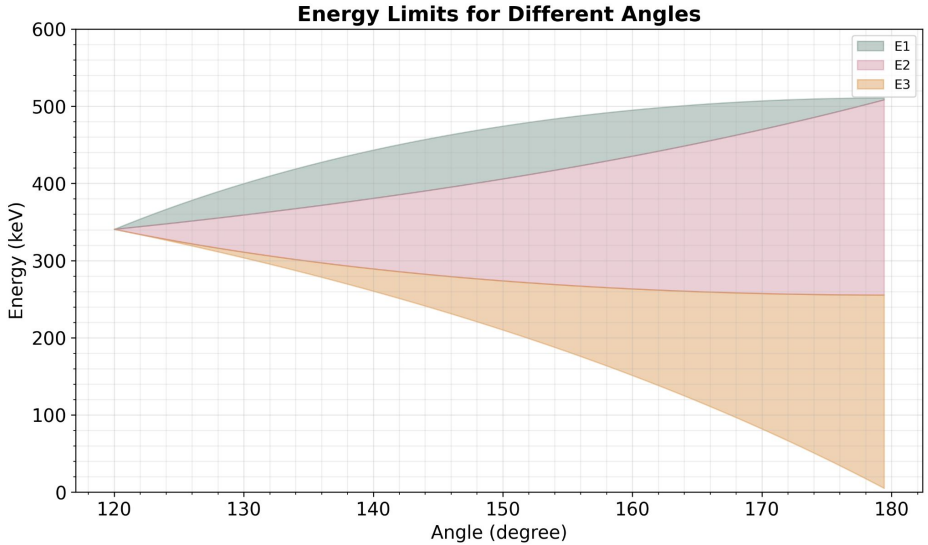
$$\vec{k_1} > \vec{k_2} > \vec{k_3}$$

$$\begin{cases} |1,1\rangle = |\uparrow\uparrow\rangle \\ |1,0\rangle = \frac{1}{\sqrt{2}}(|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle) \\ |1,-1\rangle = |\downarrow\downarrow\rangle \end{cases}$$

CP Violation in Positronium

★ **Angular correlation**:

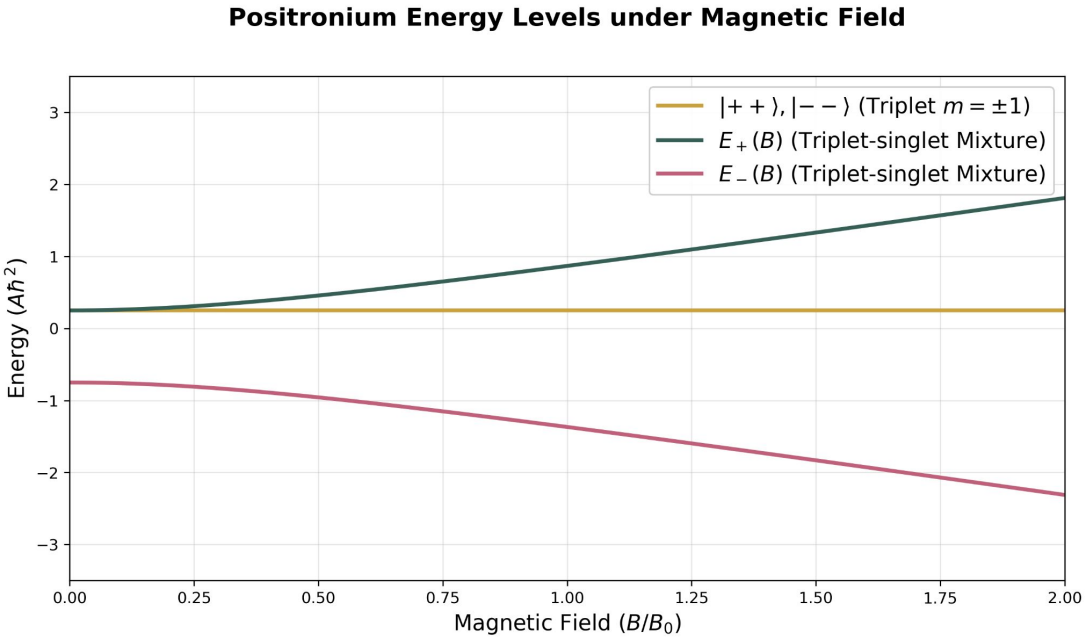




Methods and Materials

★ Under a **Magnetic Field**:

$$|\Psi_+\rangle = \cos\theta\,|1,0\rangle + \sin\theta\,|0,0\rangle$$
$$|\Psi_-\rangle = \cos\theta\,|0,0\rangle - \sin\theta\,|1,0\rangle$$



Methods and Materials

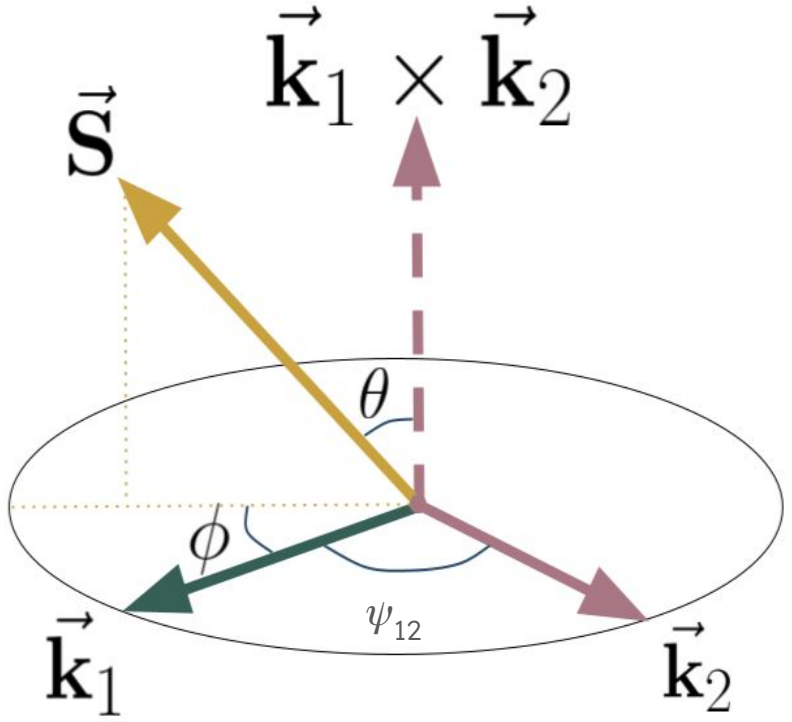
The Experiment:

★ The CP Violation will occur when:

$$Q = C_{CP}\left(\vec{S}\cdot\vec{k_1}\right)\left(\vec{S}\cdot\vec{k_1}\times\vec{k_2}\right)$$
$$= C_{CP}\left(\frac{P_2}{2}\cdot\sin(2\theta)\sin\psi_{12}\cos\phi\right)$$

★ **Polarization tensor:**

$$P_2 = \frac{N_{+1} - 2N_0 + N_{-1}}{N_{+1} + N_0 + N_{-1}}$$



Methods and Materials

★ **Mesured C_{CP}:**
- 0.0013 ± 0.0021(stat.) ± 0.0006(sys.)

Search for CP-violation in Positronium Decay

T. Yamazaki, T. Namba, S. Asai, and T. Kobayashi
Department of Physics, Graduate School of Science,
and International Center for Elementary Particle Physics,
University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
(Dated: November 2, 2018)

Methods and Materials

The *Nossa Caixa* spectrometer device

★ Arranged in a compact geometry with a temporal resolution of ≈ 3.7(5) ns
- ±45°, ±90° and ±135°
- 38% of a 4π solid angle

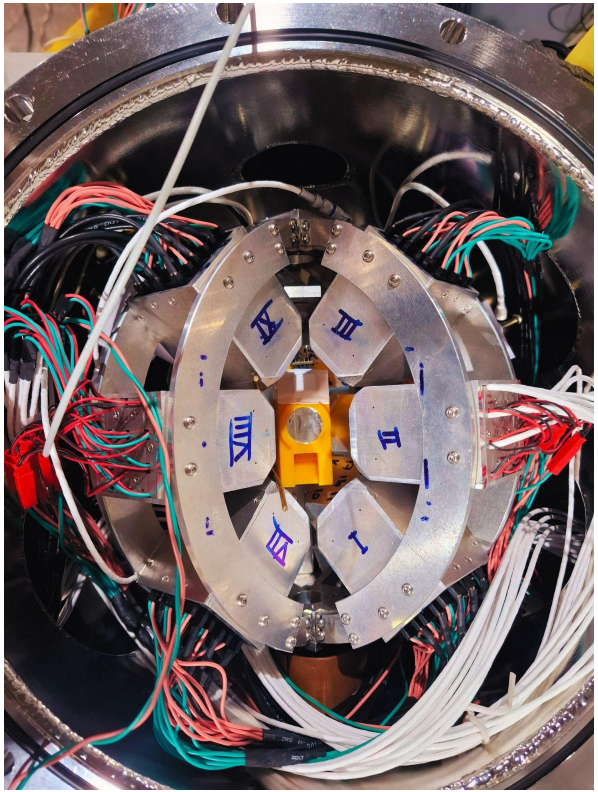
New spectrometer projects for challenging particle-gamma measurements of nuclear reactions

To cite this article: J R B Oliveira *et al* 2018 *J. Phys.: Conf. Ser.* **1056** 012040

Testes do novo espectrômetro gama Nossa Caixa com a reação de $^{10}B + ^{120}Sn$

Caio Eduardo Cabral de Vasconcellos

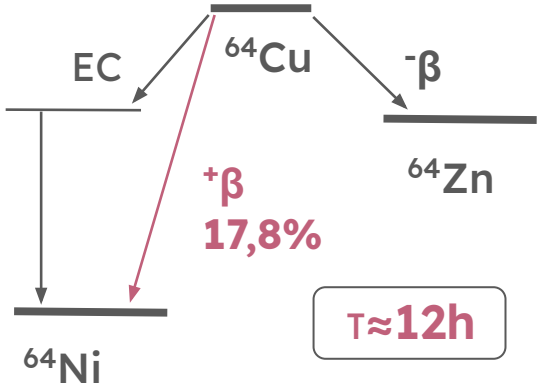
Master's thesis

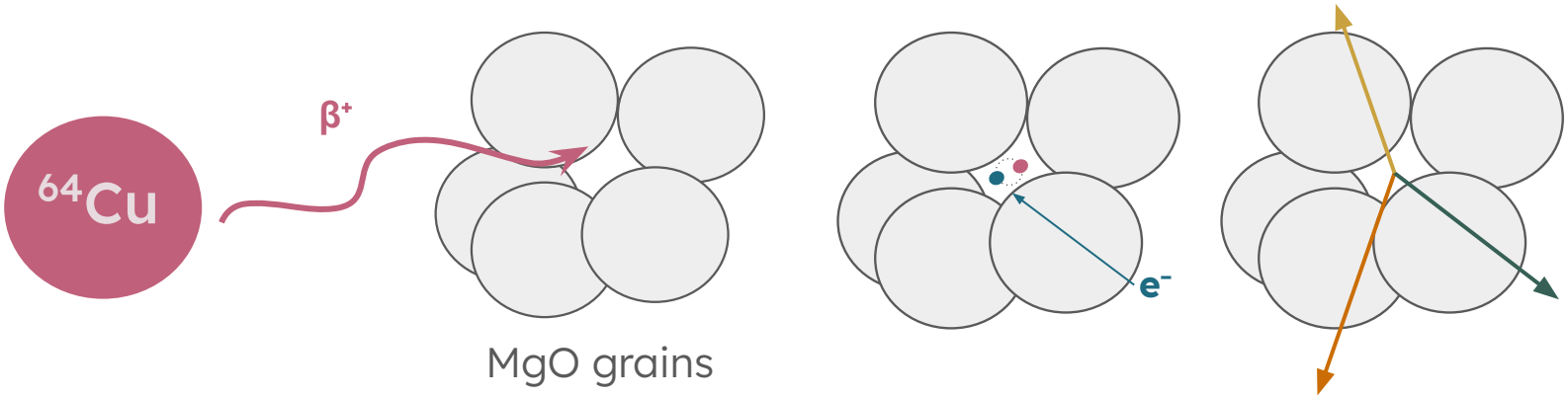


Methods and Materials

Formation of Positronium in MgO:

- ★ Thousands of collisions with the grains
  - ○ Capturing a surface electron
  - ○ Energetically forbidden to re-enter a grain
- ★ Short-range repulsive forces:
  - ○ Create small void gaps



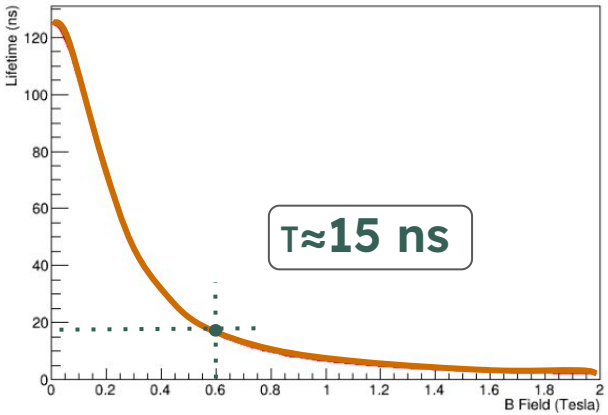


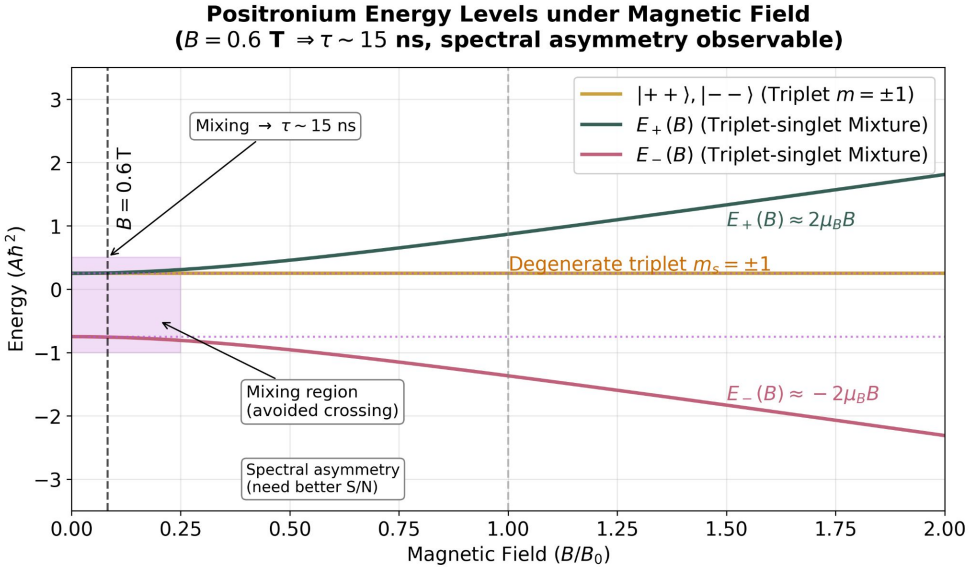
Methods and Materials

Under a magnetic field ($\vec{B}$):

★ Mixing the $m_s = 0$ states:

- Changing the properties
- Allows the manipulation of th
  half-life of the $m_s = \pm 0$

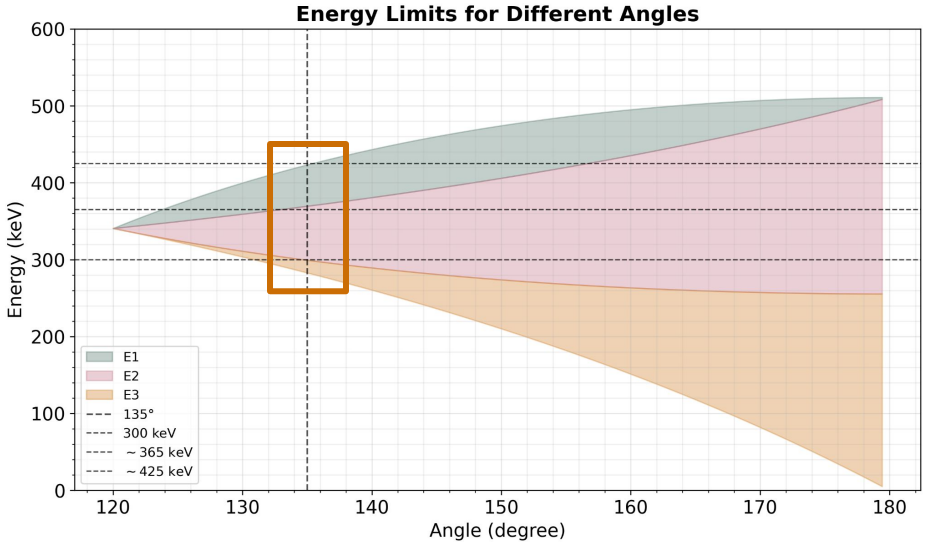


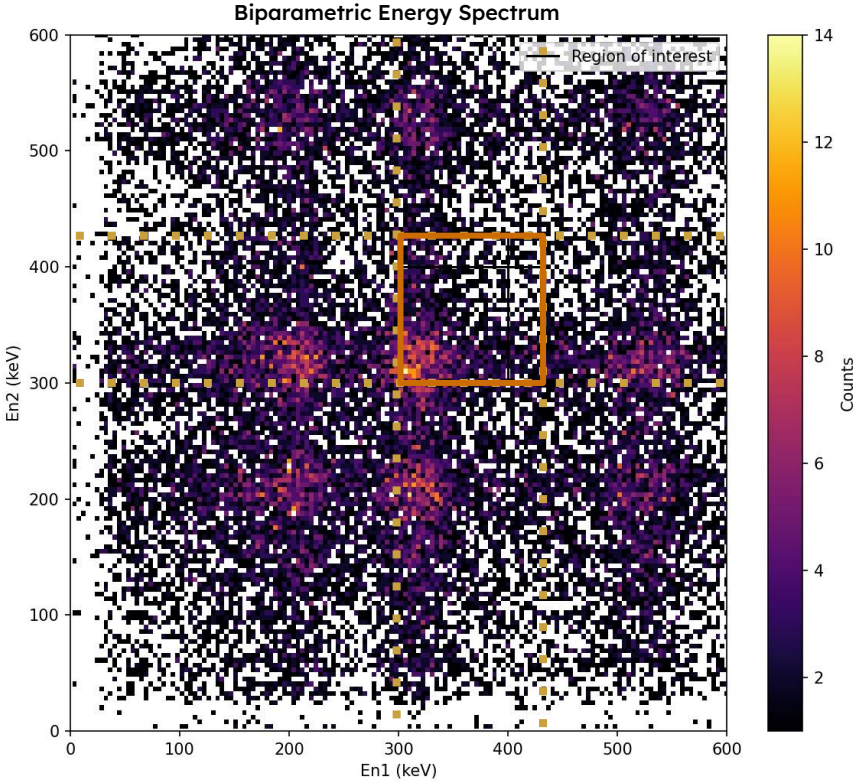


Search for CP-Violation in ortho-Positronium Decay
T.E. Haugen1, E.A. George2, O. Naviliat-Cuncic1,3, P.A. Voytas2

Obtained Data

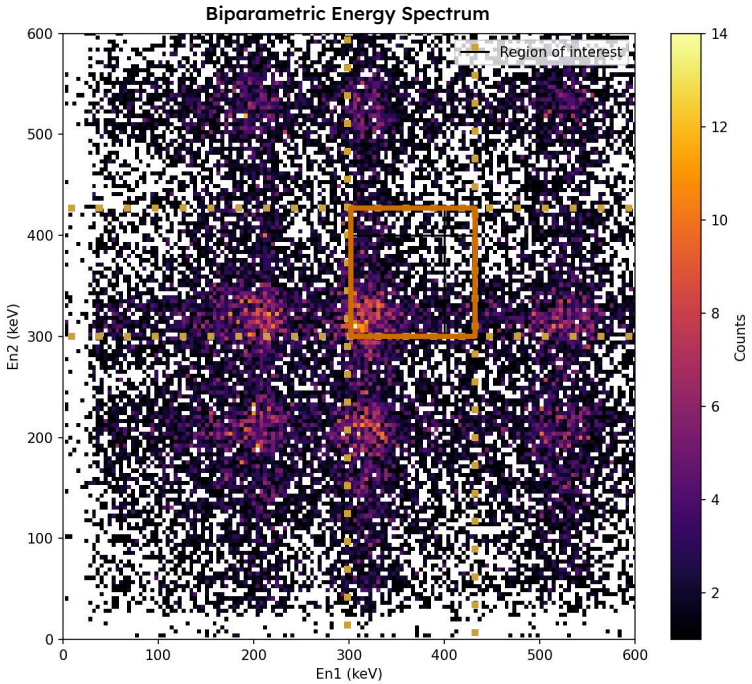
Biparametric Energy Spectrum:

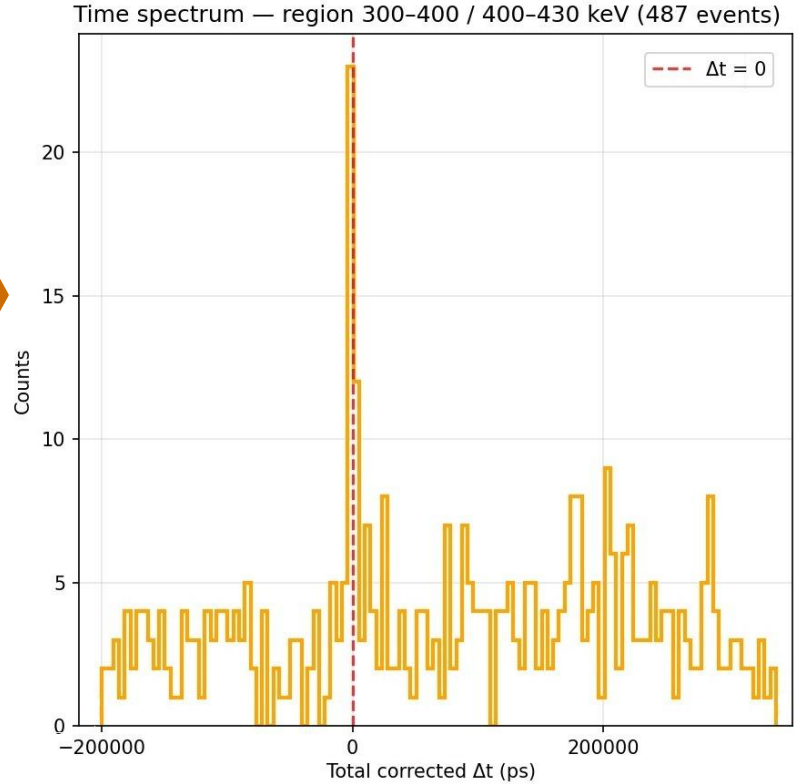




Obtained Data

Time resolution: ~4ns.





Conclusion and Future Steps

★ **Conclusion:**
- **Limited statistics**
  - **24 hours** of experimental run
  - ^{64}Cu: $\tau \sim 12$ hours
  - The count's in the region of interest was limited

★ **Future steps:**
- **Finalize** the simulation in **Geant4**
- **Repeat the experiment**
  - ^{22}Na: $\tau \sim 2.6$ years


Thanks for your
attention!!

Back-up

Introduction

★ The **Standard Model** allows CP Violation through:
- Phases Mixing Matrices
  - CKM and PMNS

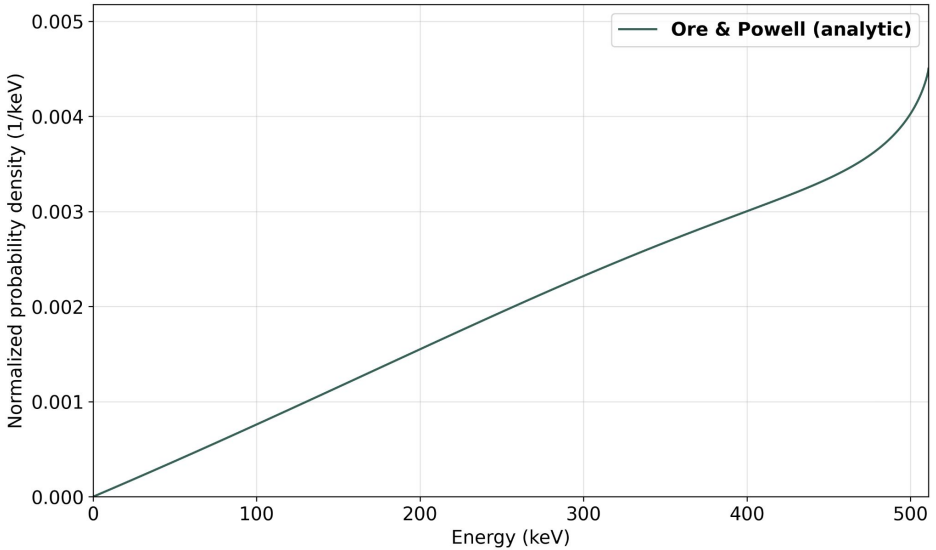
★ **Clean Signals**:
- Neutral systems:
  - Kaons
  - B-Mesons
  - Z-Bosons

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

CP Violation in Positronium

★ A. Ore and J. L. Powell:
- C=+1 →two gamma rays
- C=-1 →three gamma rays

$$\begin{cases} \vec{k_1} + \vec{k_2} + \vec{k_3} \approx 0 \\ \vec{k_1} > \vec{k_2} > \vec{k_3} \end{cases}$$



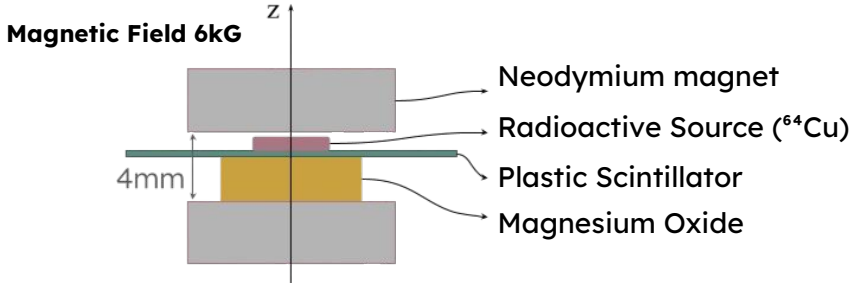
PHYSICAL REVIEW VOLUME 75, NUMBER 11 JUNE 1, 1949

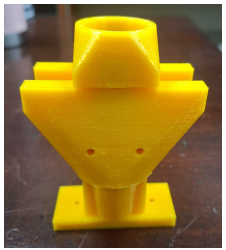
Three-Photon Annihilation of an Electron-Positron Pair

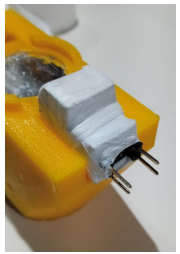
A. Ore* and J. L. Powell*
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
(Received January 12, 1949)

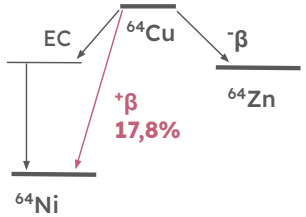
Methods and Materials

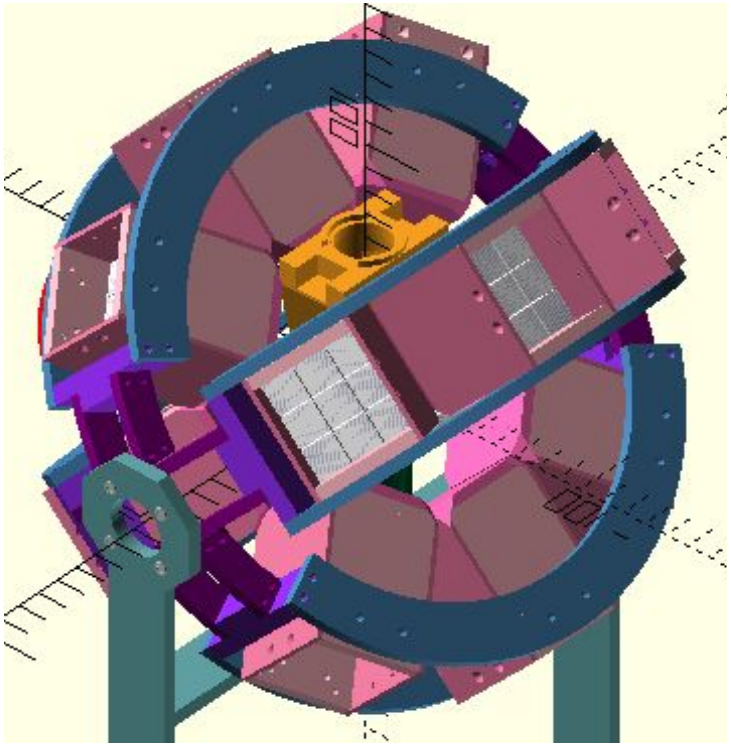
The experiment:
The positron is produced by a copper source and combines with an electron trapped between the grains of magnesium oxide.







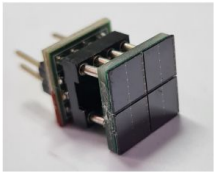
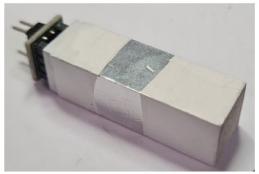


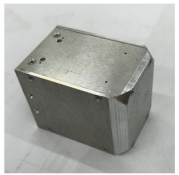
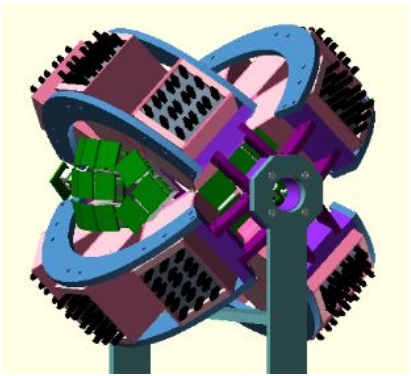
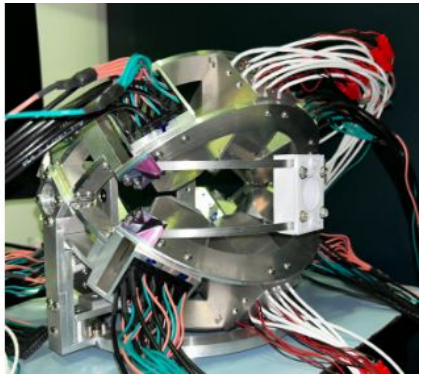


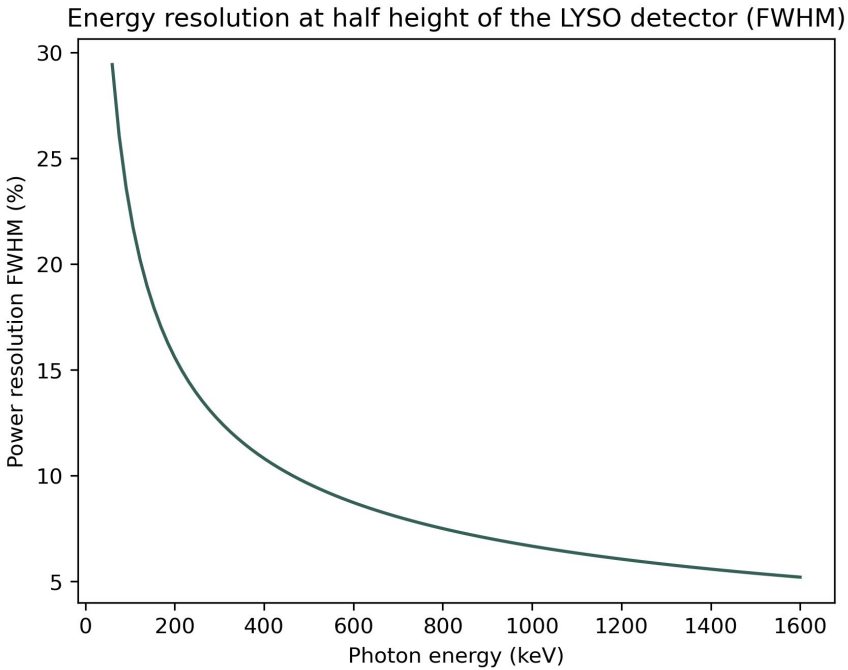
Methods and Materials

The *Nossa Caixa* spectrometer device

★ Two orthogonal rings:
- 12 LYSO(Ce) scintillators
- 3×3 pixels coupled to SiPMs

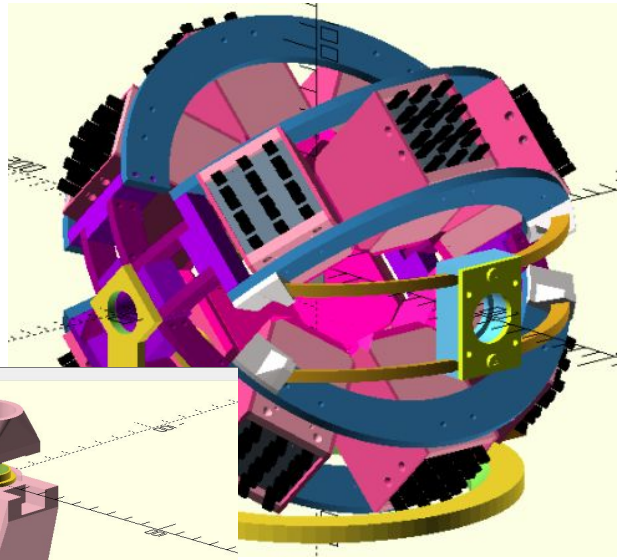


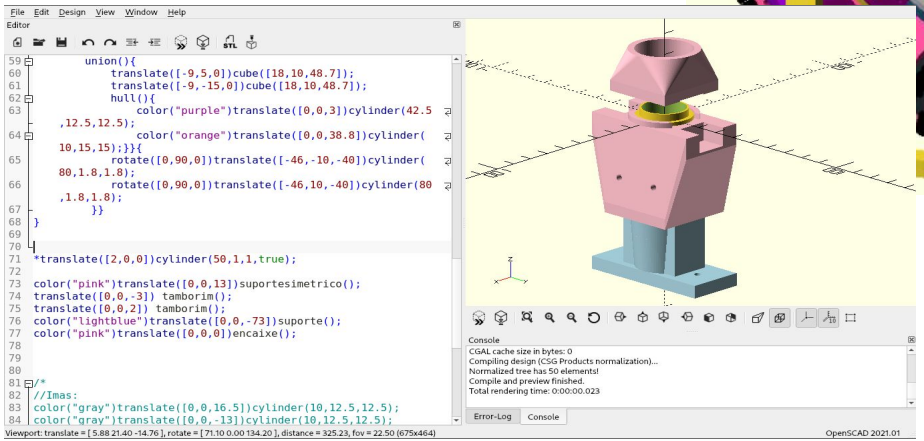
$$FWHM(\%) = e^{f\cdot(5.04-0.48ln(E_\gamma))}$$

Methods and Materials

Open SCAD:

- ★ Intuitive
  - Script Based
  - Descriptive language
  - Parametric Control
- ★ Easy to learn
- ★ **Free**

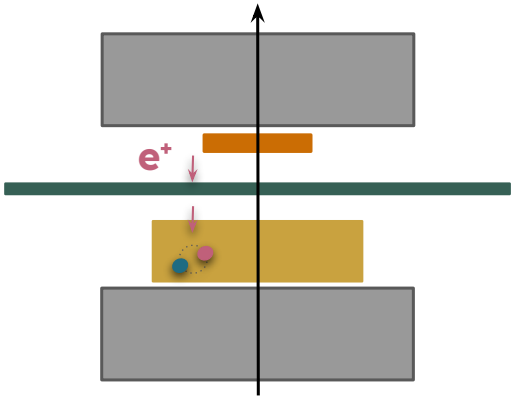




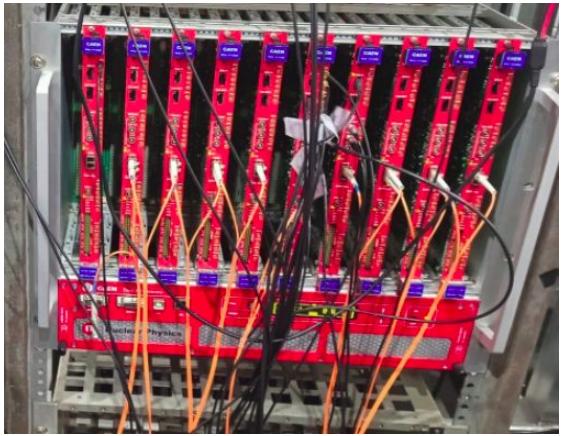
Methods and Materials

CoMPASS:

- ★ Developed by CAEN
- ★ Module control and operation
- ★ Master/Slave
- ★ Graphical interface

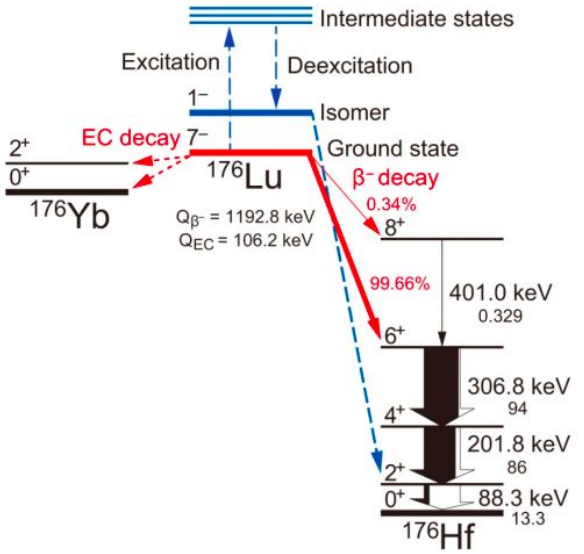


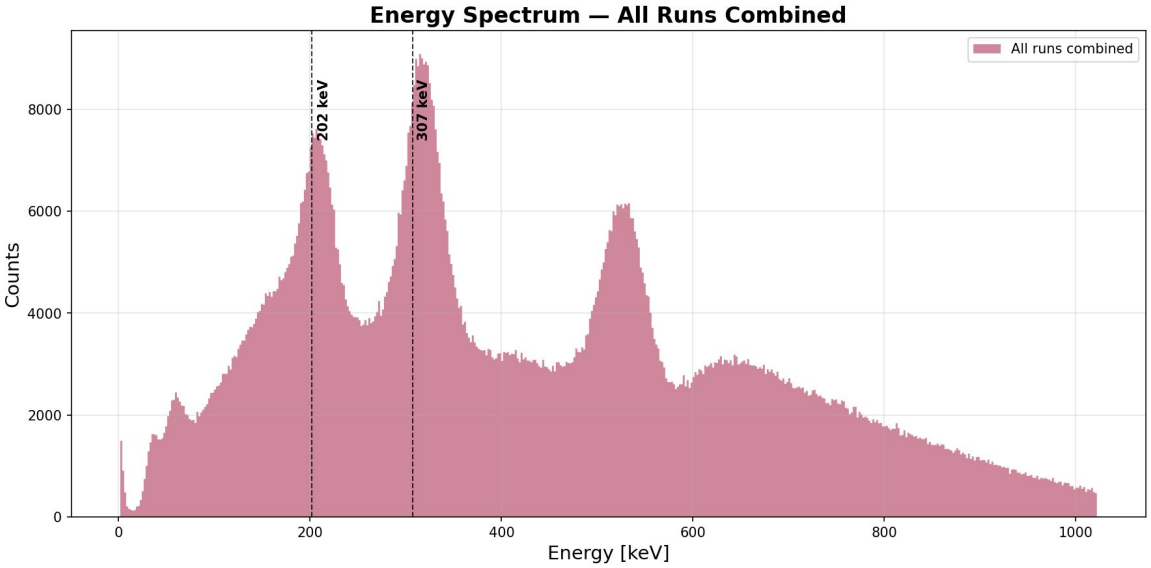
Trigger → Channel Ref



Obtained Data

Energy Spectrum:

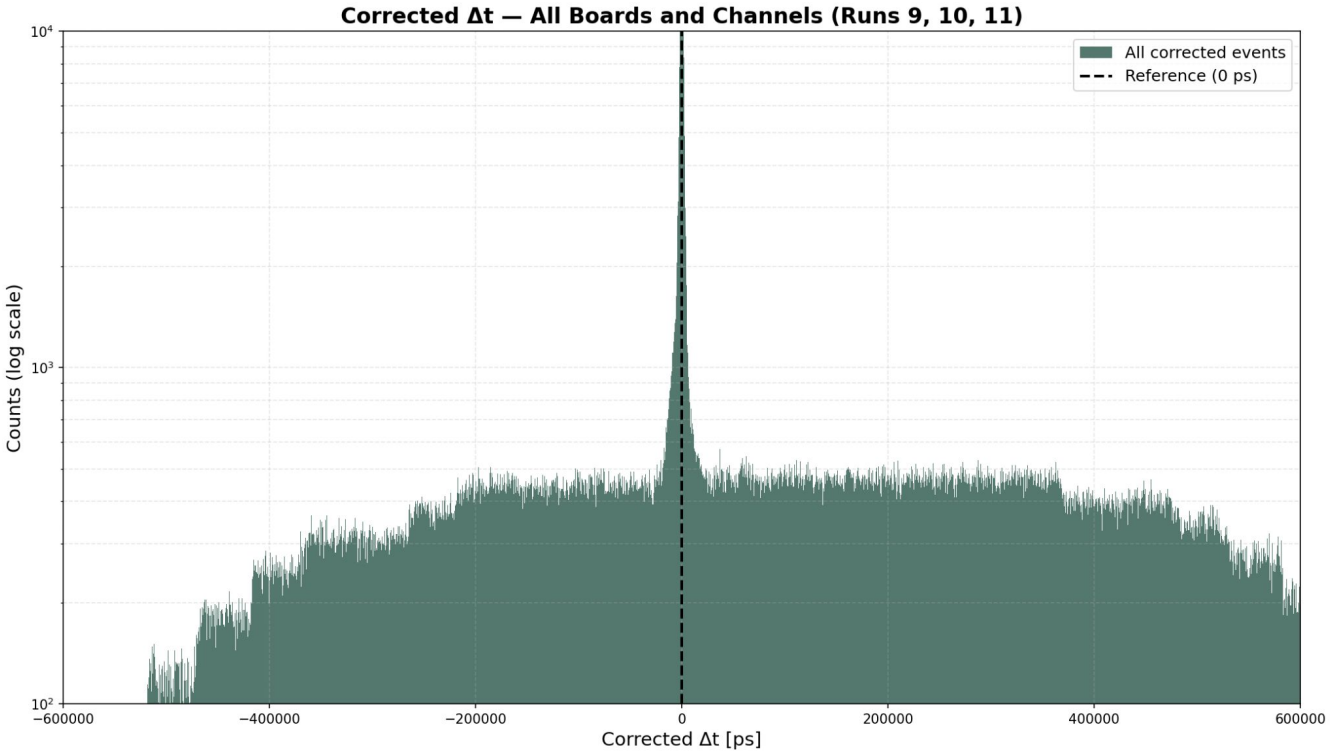




Obtained Data

Time Spectrum:

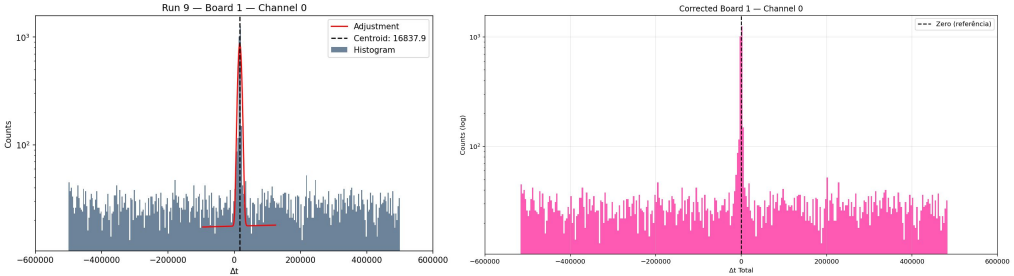
★ All energies

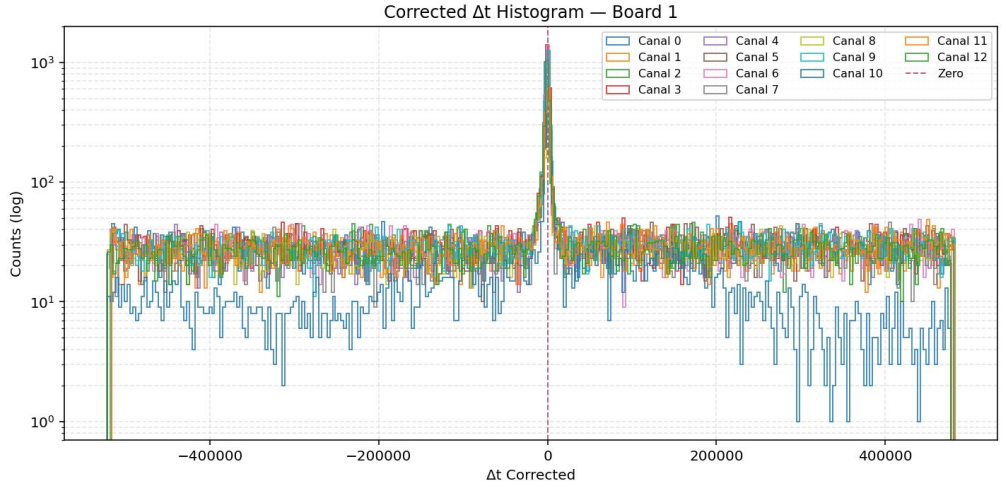


Obtained Data

Time Spectrum:

- ★ Boards and Channels:
  - ○ time lag between themselves
- ★ timing corrections





Obtained Data

★ Other ongoing experiments **aim to increase** sensitivity.

Search for CP-Violation in ortho-Positronium Decay

Tom-Erik Haugen[1,*], *Elizabeth A.* George[2], *Oscar* Naviliat-Cuncic[1,3], and *Paul A.* Voytas[2]

[1]Facility for Rare Isotope Beams, and Department of Physics and Astronomy, Michigan State University, East Lansing, Mi, USA
[2]Wittenberg University, Springfield, Oh, USA
[3]Laboratoire de Physique Corpusculaire de Caen, and Université de Caen Normandie, Caen, France