Tests of *CP* and *CPT* symmetry with positronium

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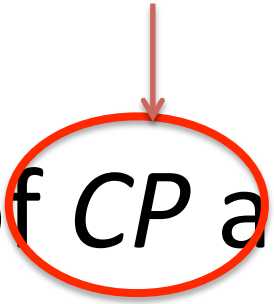
ICEPP, University of Tokyo

This talk is mainly focused on the *CP* test



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Introduction
CP asymmetry

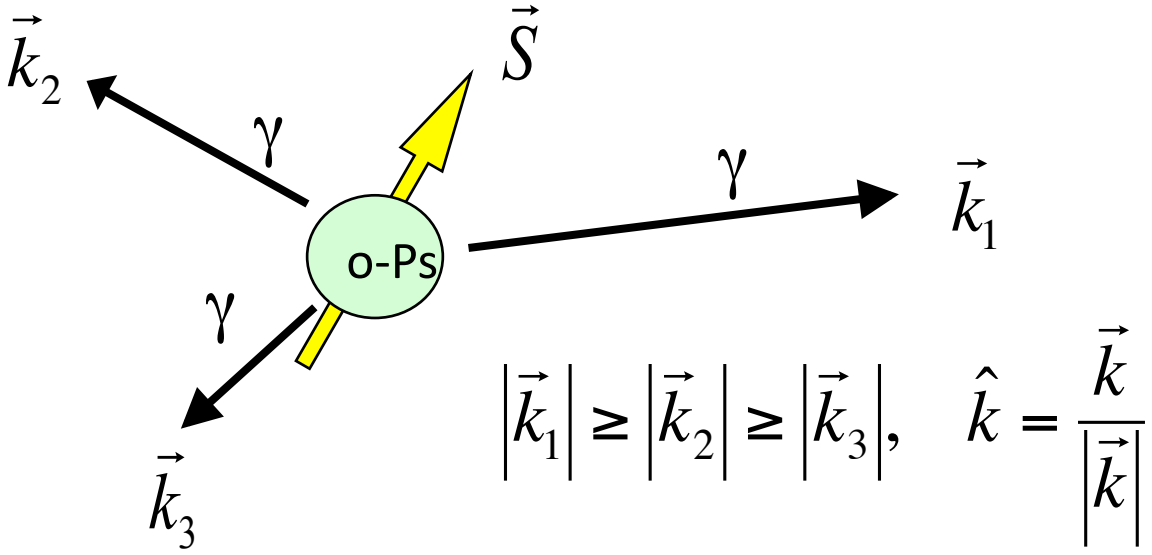
- *CP* asymmetry exists in the quark sector: ~10^{-3} level
- How about the lepton sector?
- No asymmetry discovered,

  but its uncertainty is ~10^{-2} level
- Need more precision test!
- Purpose of this experiment:

  Test *CP* symmetry with positronium at the 10^{-3} level

CP test with Positronium

- Angular correlations in o-Ps 3-γ decay:

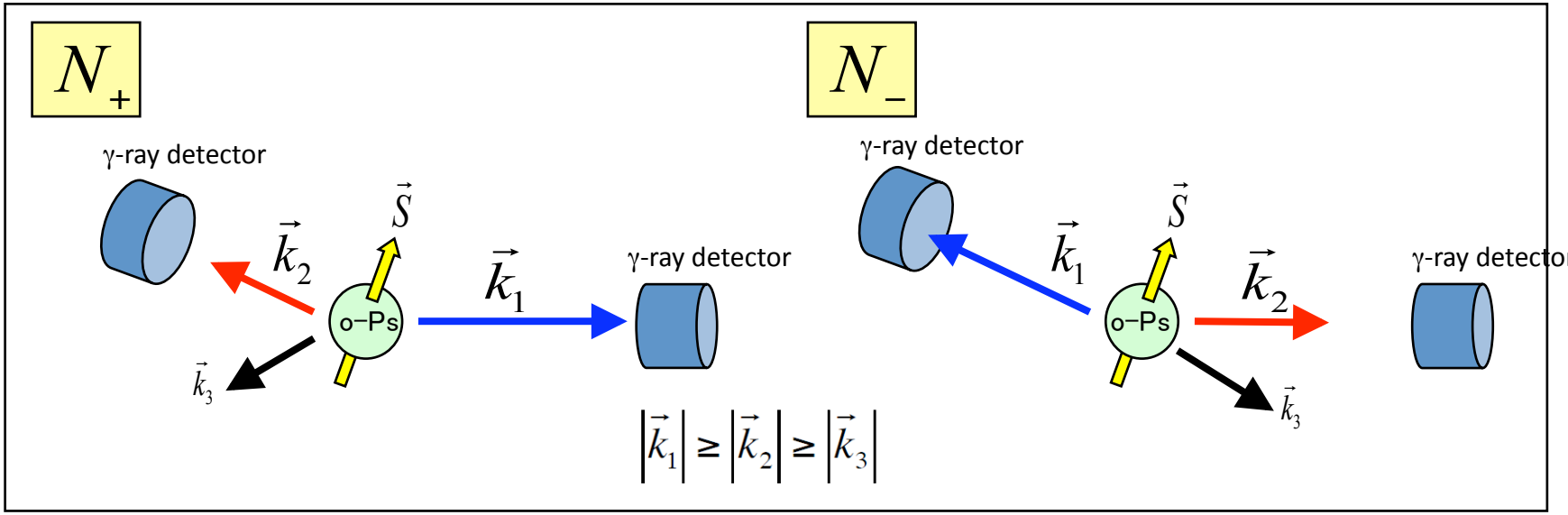


CP odd term! $\left(\hat{s}\cdot\hat{k}_1\right)\left(\hat{s}\cdot\hat{k}_1\times\hat{k}_2\right) \neq 0$ if *CP* violation

Need to measure the spin and γ-rays precisely

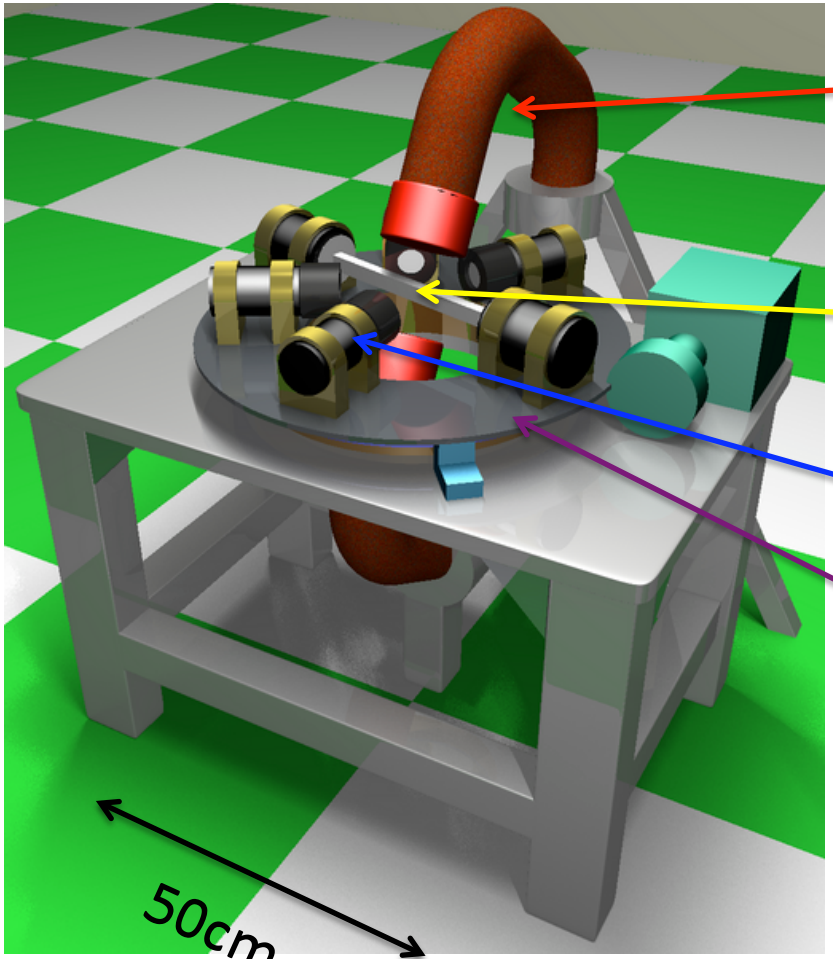
The simplest setup

- Spin aligned o-Ps source
- Two γ-ray detectors



- Count rate difference between N_+ and N_- means CP asymmetry

Our detector design



Magnet & return yoke

^{22}Na positron source
Silica aerogel stopper
Beta tagging system

Gamma ray detectors

Turntable

Magnet for the spin alignment

- Using Neodymium magnets (0.35T)
- Tensor polarization

$$\left(\hat{s}\cdot\hat{k}_1\right)\left(\hat{s}\cdot\hat{k}_1\times\hat{k}_2\right)$$

  (spin term appears twice in the angular correlation)
- Select m_z=±1 component

  (Eliminate m_z=0 component)

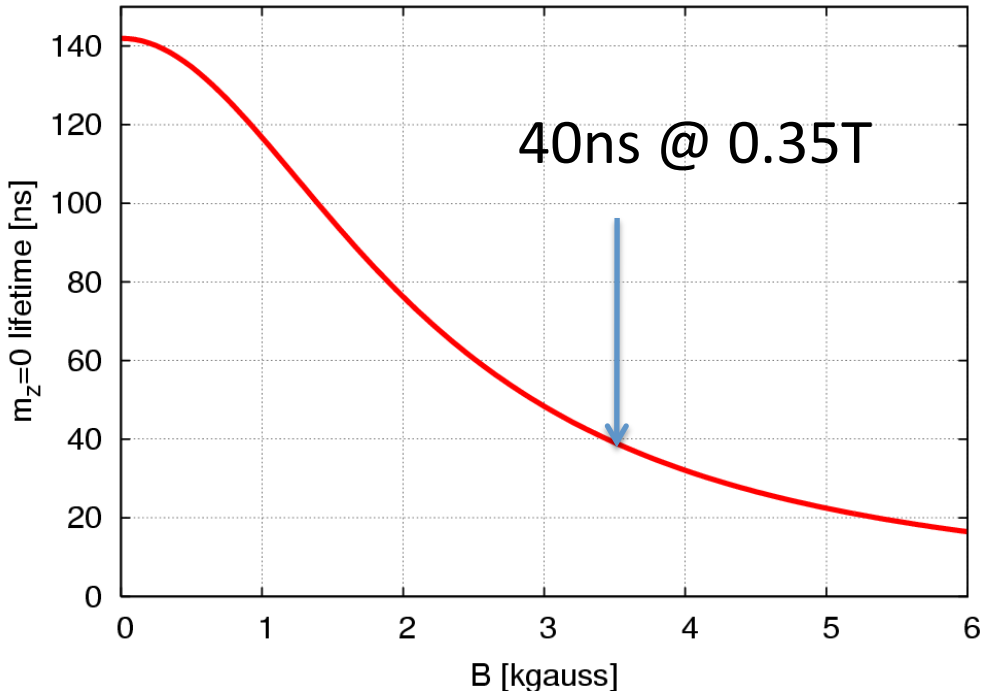
ortho-para mixing

ortho-para mixing under the magnetic field

- m_z=0 component of o-Ps mixes with p-Ps

  ⇒ m_z=0 has shorter Lifetime

- m_z=±1 component lifetime: no change



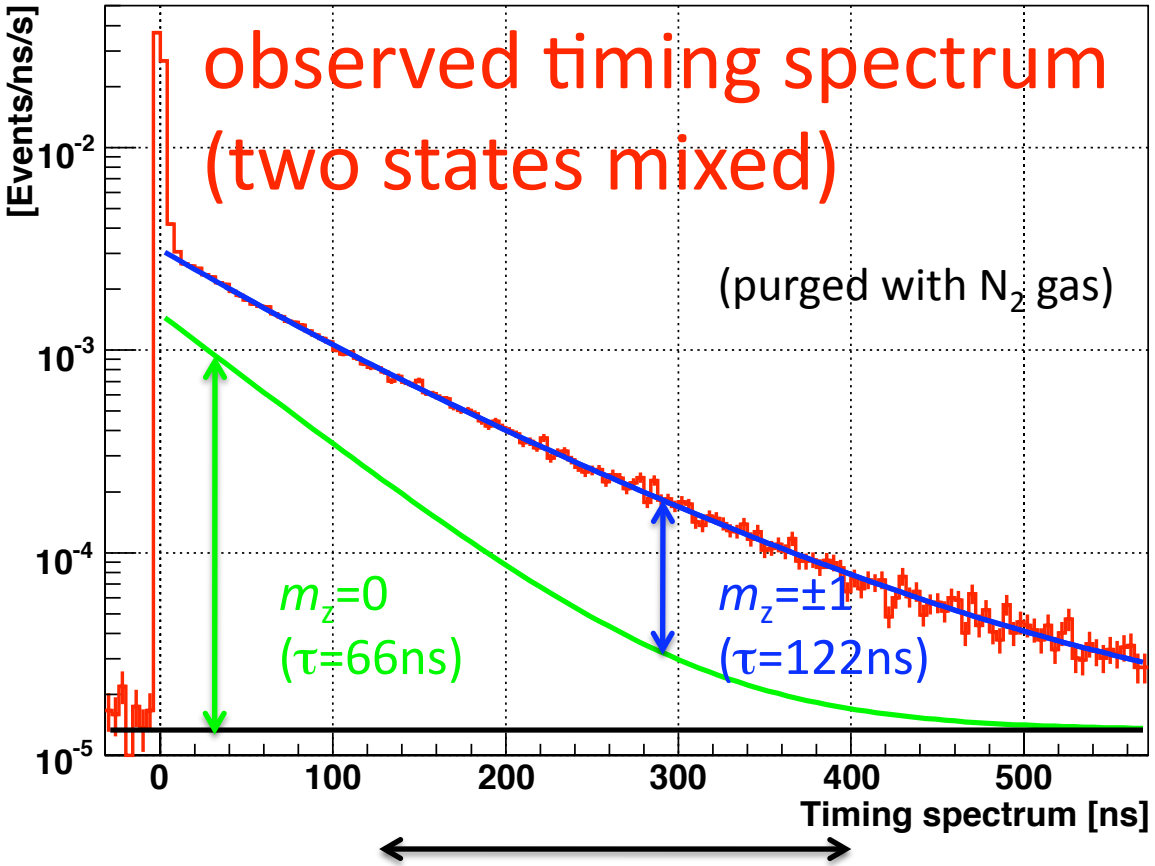
Make delayed timing window

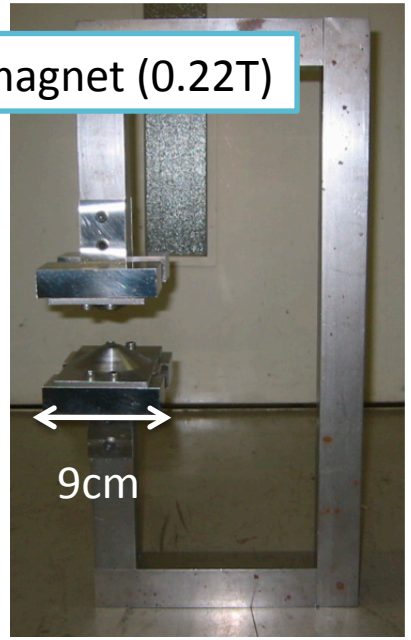
⇓

m_z=0: eliminated

m_z=±1: selected

o-Ps decay curve in a test setup (@ 0.22T)

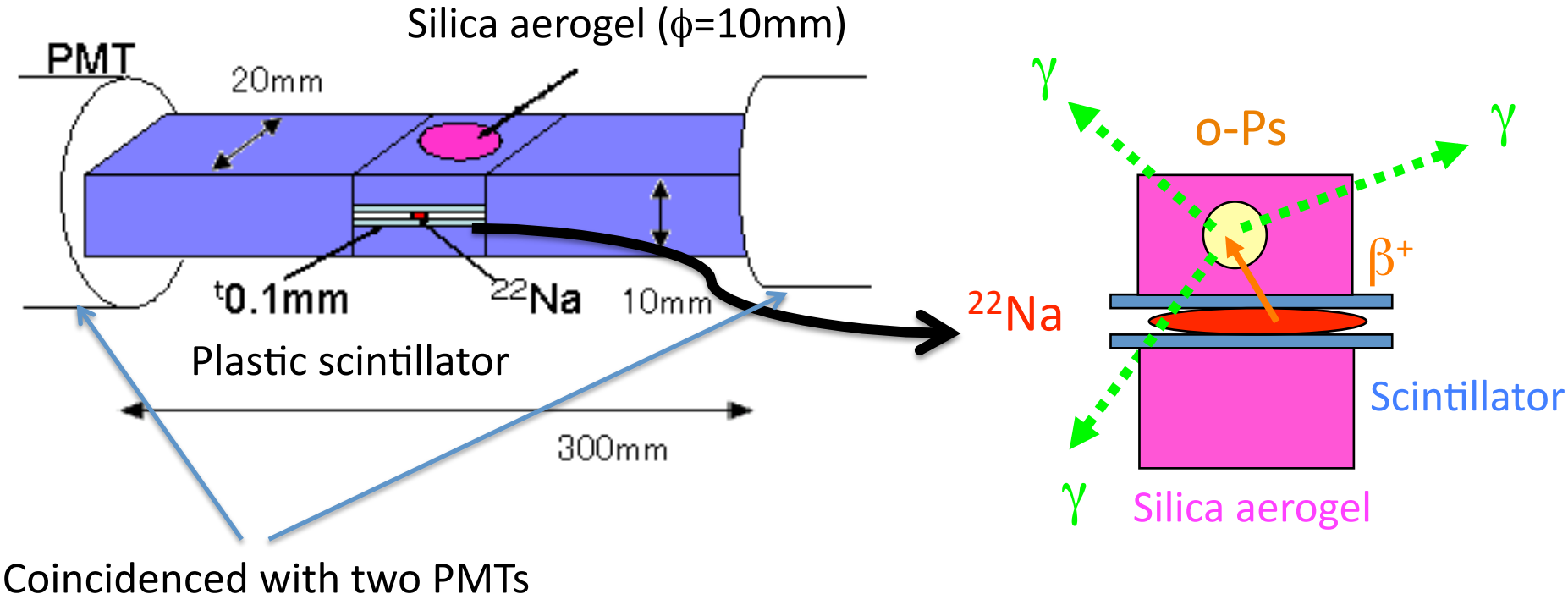




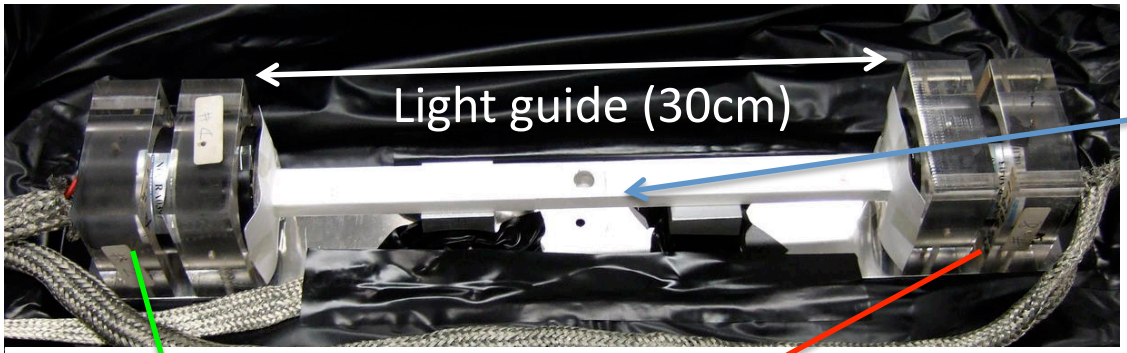
Better separation will be obtained in the final setup (0.35T)
m_z=0 contam. < 10%

o-Ps creation & tagging system

- β^+ source: ^{22}Na (E_{end}=546keV), 1MBq
- β^+ stopper & e^- supplier: Silica aerogel (ρ=0.1)
- Tag for the β^+ emission: t=0.1mm plastic scintillator



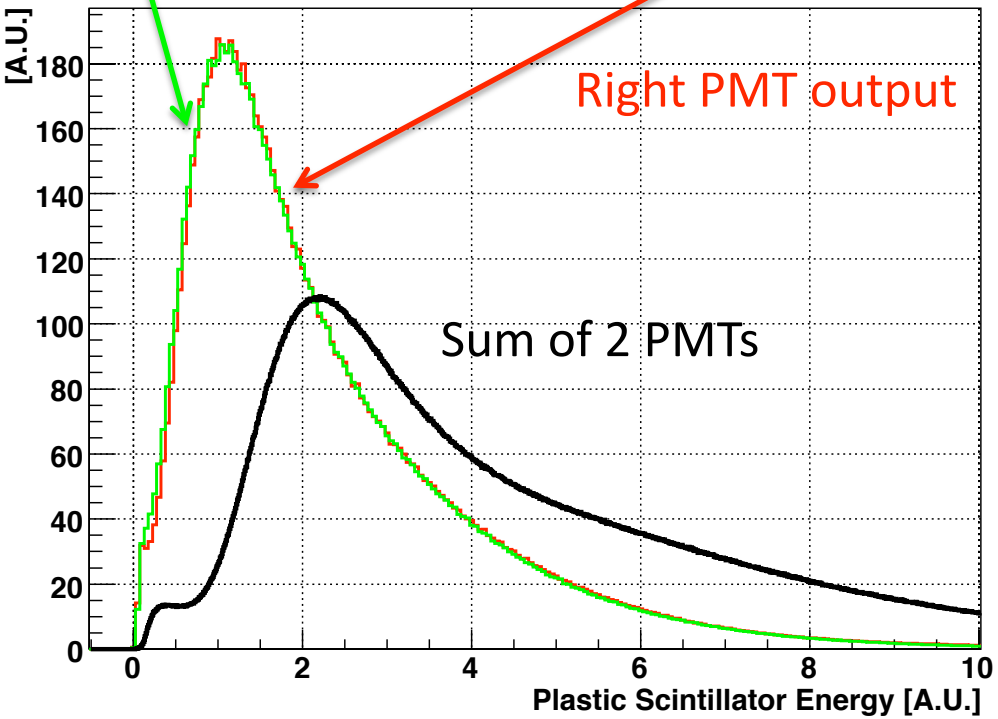
Observed spectrum with the tagging system



^{22}Na source
Plastic scintillator
Silica aerogel

Left PMT output

Right PMT output

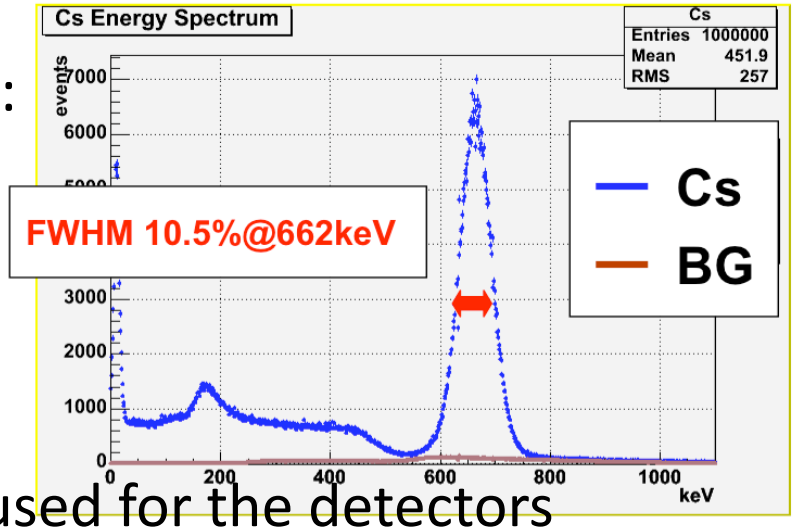


- Enough photoelectron collection for β^+ peak (25keV ~ 11 p.e.)

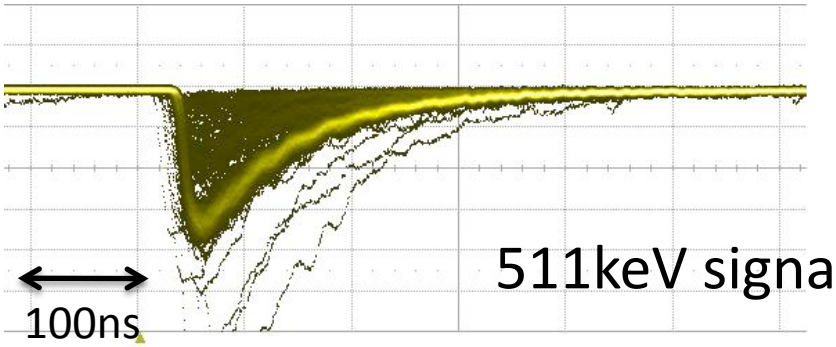
- Timing resolution: σ~0.85ns (for all coincidenced events)

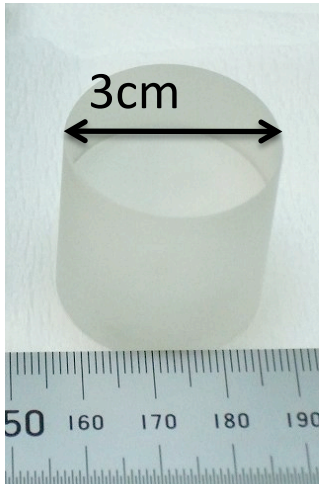
γ-ray detectors

- Requirements for the γ-ray detector:
  - Large stopping power for ~500keV γ's
  - Good energy resolution
  - Good timing resolution



- LYSO ($Lu_{1.8}Y_{0.2}SiO_5$) scintillators are used for the detectors
  - Large Z, high density (Atomic number of Lutetium=71, ρ=7.1)
  - ΔE=10% (FWHM) at 662keV
  - Short decay time 40ns
  - ΔT=150ps (σ) at 511keV





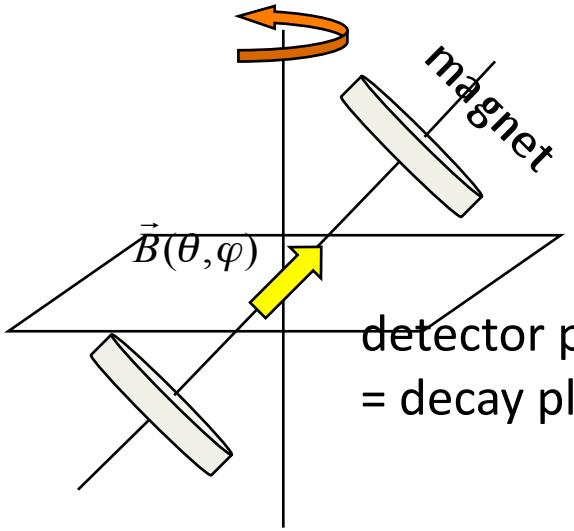
Turntable

- To reduce systematic errors, N_+/N_- should be compared with the same detector

  (10μm size difference can make critical asymmetry!)

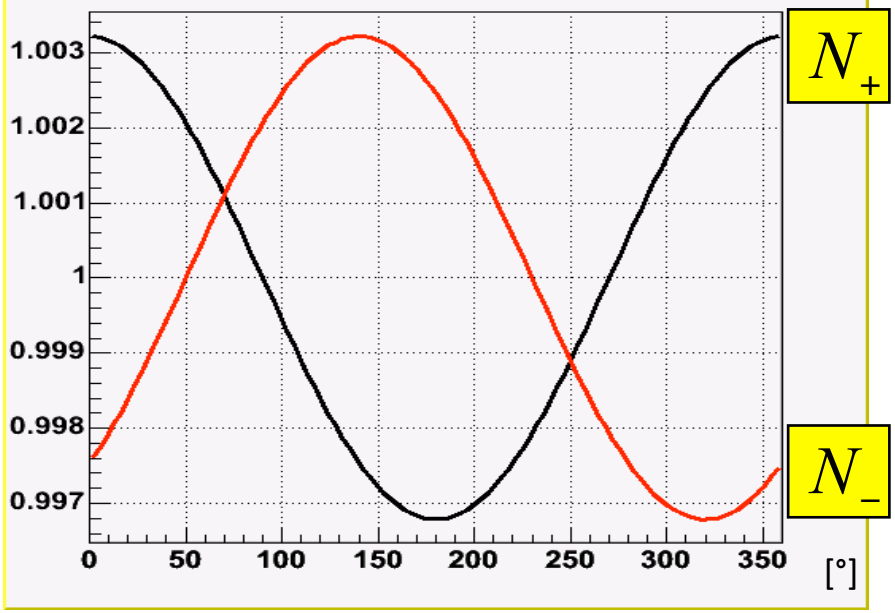
- Rotating magnetic field can change the CP violation term

rotating around the axis

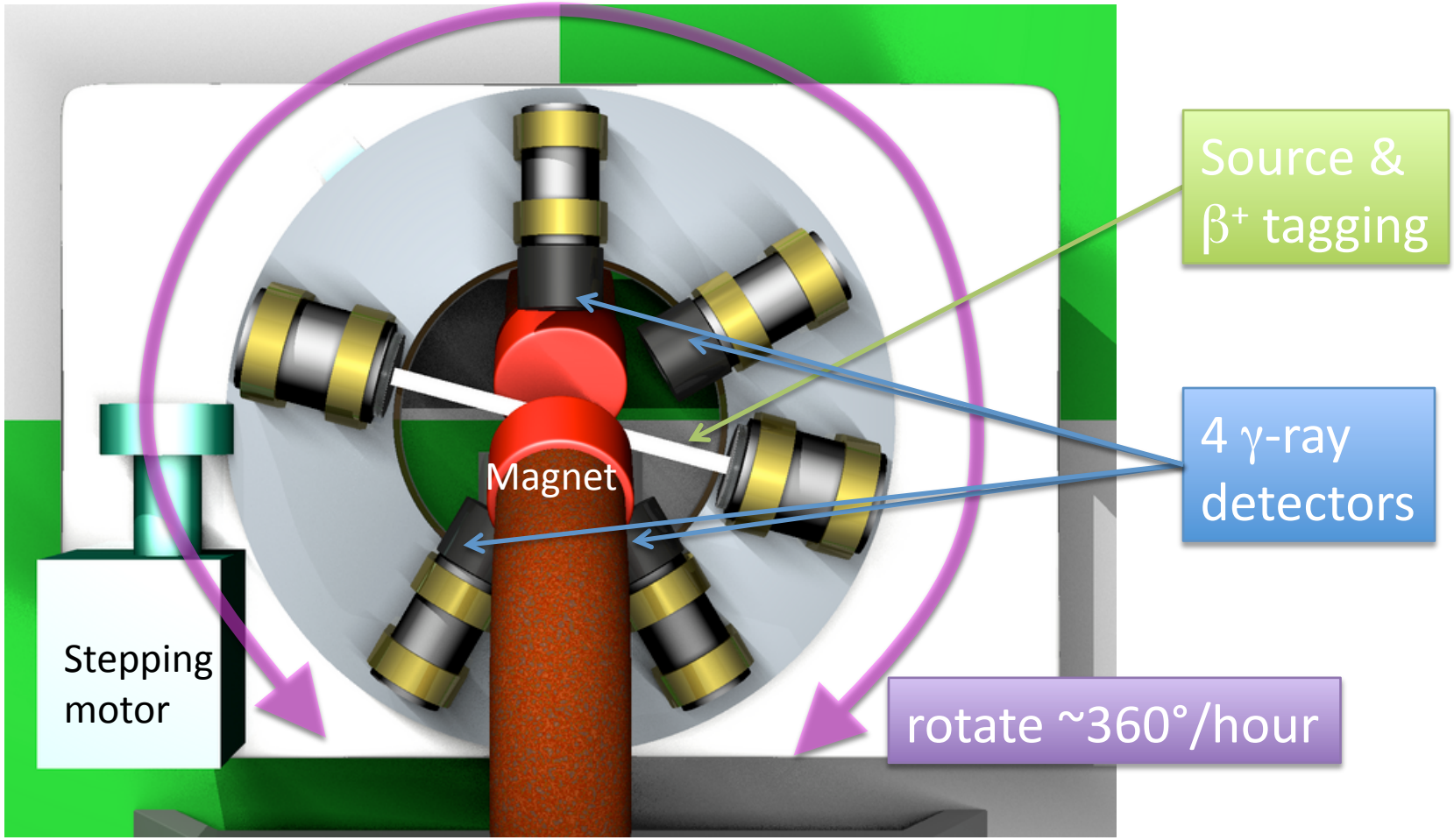


$$\left(\hat{s}\cdot\hat{k}_1\right)\left(\hat{s}\cdot\hat{k}_1\times\hat{k}_2\right)$$

In the case of the 10^{-2} asymmetry



In reality,
we rotate the detectors, not the magnet



Current status and future prospects

- o-Ps source & β^+-tagging system:
  - performance test was done & ready
- γ-ray detectors:
  - performance test was done & ready
- Magnet & return yoke:
  - Prototype (0.22T) was built and checked
  - Final design will be finished soon
- Turntable:
  - Final design was fixed, and now constructing the table
  - Motor control system is ready

DAQ will be started from this spring.
Estimated o-Ps event rate in the selection window~10Hz
10^8 events will be taken in 100 days

CP test at the 10^{-3} level will be done in this year

CPT test with a similar setup

- *CPT* violating angular correlations: $\hat{s} \cdot \left(\hat{k}_1 \times \hat{k}_2 \right)$
- Spin alignment (vector polarization):
  - Positrons from β^+ source are naturally polarized
  - <P>~90% (^{68}Ga source)
- For the γ-ray detection, same techniques can be used
  - LYSO scintillator pairs
  - Turntable for the systematic error reduction
- Will be measured after the *CP* test finished

Summary

- New experimental design to test *CP* symmetry
  - Magnet for tensor polarization
  - Plastic scintillator foils for β^+ tagging
  - LYSO crystals for γ detection
  - Turntable to reduce systematic errors
- Detector construction is almost done, and the 10^{-3} level test will be done in this year
- *CPT* can also be tested with similar setup