MEG II実験における陽電子再構成アルゴリズムの開発

Development of positron reconstruction algorithm in MEG II experiment

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大阪大学（豊中キャンパス）

Content

- Introduction of the MEG II Experiment
- Positron Spectrometer
- Positron Time Reconstruction
- TC Tracking
- Prospect and Summary

MEG II Motivation

In MEG II experiment we aim to search for charged lepton flavor violation (cLFV), $\mu^+ \rightarrow e^+\gamma$ **decay**.

- The SM strongly suppress cLFV .
- However sizable branching ratio is expected by many bSMs.

- Most stringent upper limit of the branching ratio is given by the MEG experiment.

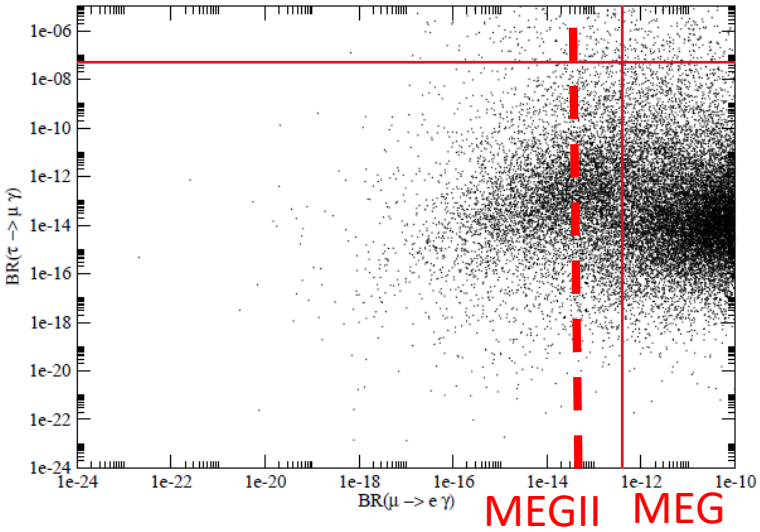
$$4.2 \times 10^{-13} \text{ 90\% C.L.}$$

(Eur. Phys. J. C 76 (2016) no.8, 434)

- Target sensitivity of MEG II is

$$\sim \mathbf{4 \times 10^{-14}}$$

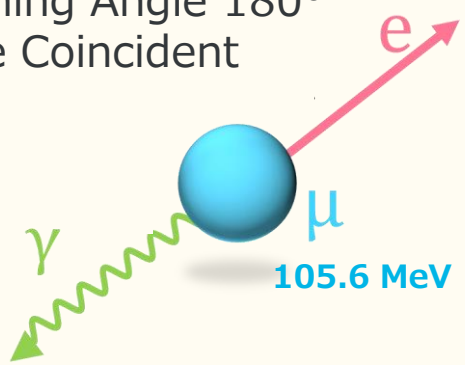
Simplest Little Higgs Model (arXiv:1610.01266v2)



MEG II Requirement

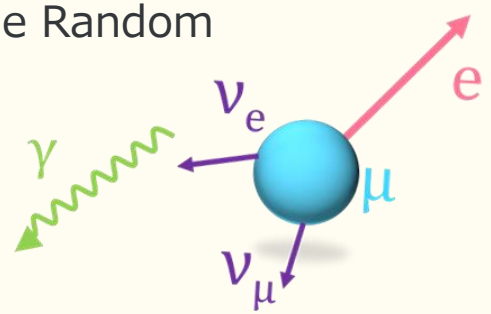
Signal: two-body decay

- 52.8 MeV
- Opening Angle 180°
- Time Coincident



Dominant BG: accidental

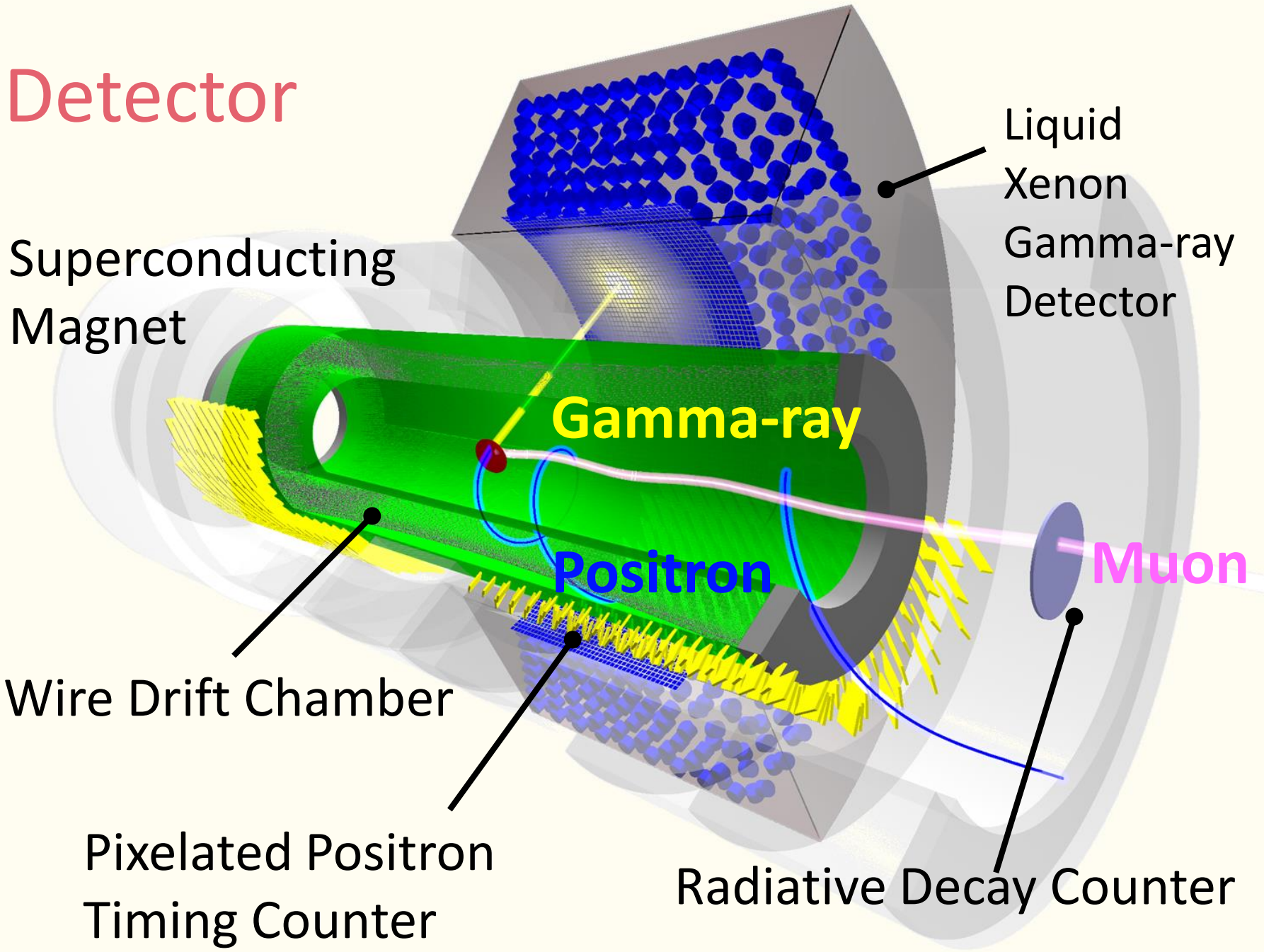
- <52.8 MeV
- Any angle
- Time Random



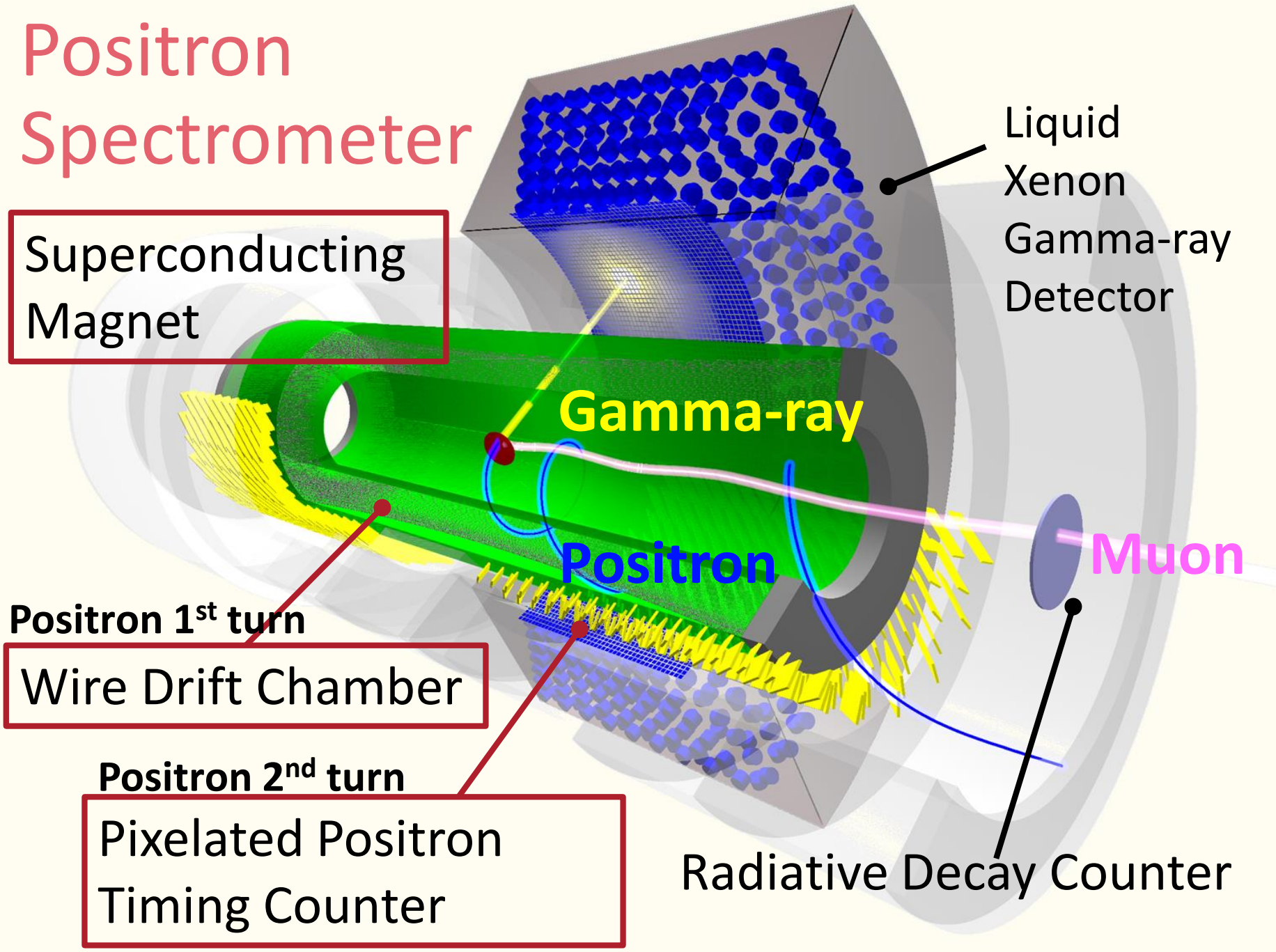
Precise measurement of emission angle, energy, and timing of both positron and γ is essential.

⇒ Today's topic is performance of positrons time reconstruction.

Detector


Liquid
Xenon
Gamma-ray
Detector
Superconducting
Magnet
Gamma-ray
Positron
Muon
Wire Drift Chamber
Pixelated Positron
Timing Counter
Radiative Decay Counter

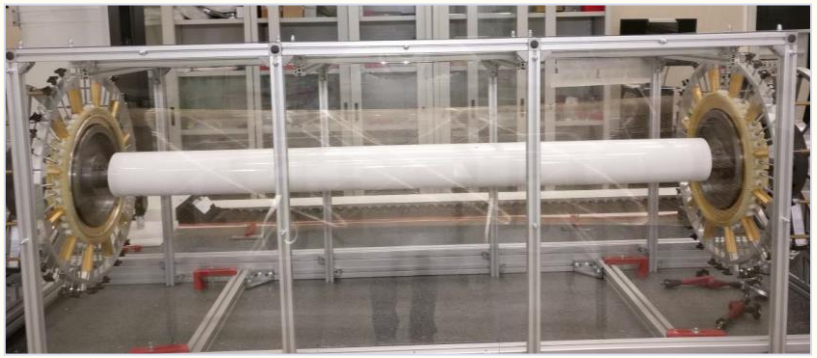
Positron Spectrometer



Positron Measurement

Wire Drift Chamber (DCH)

- Single volume, low-Z gas mixture ($He:iC_4H_{10}$ = 85:15)
- 1200 sense wires (2 m long, 20 μm diameter)
- Stereo angle (7°) configuration



Pixelated Positron Timing Counter (TC)

- 512 fast plastic scintillator counters (120x40/50x5 mm^3)
- 6 SiPMs (AdvanSiD) are attached on both side of the counters.

DCH reconstructs

✓ Momentum and vertex

✓ Track length from vertex to TC

TC reconstructs

✓ Positron passing time through each counter

Reconstruct positrons in each detector, then check matching

Performance Study with MC

- Check the performance of positron spectrometer in detail with **full analysis chain** of the positron reconstruction.

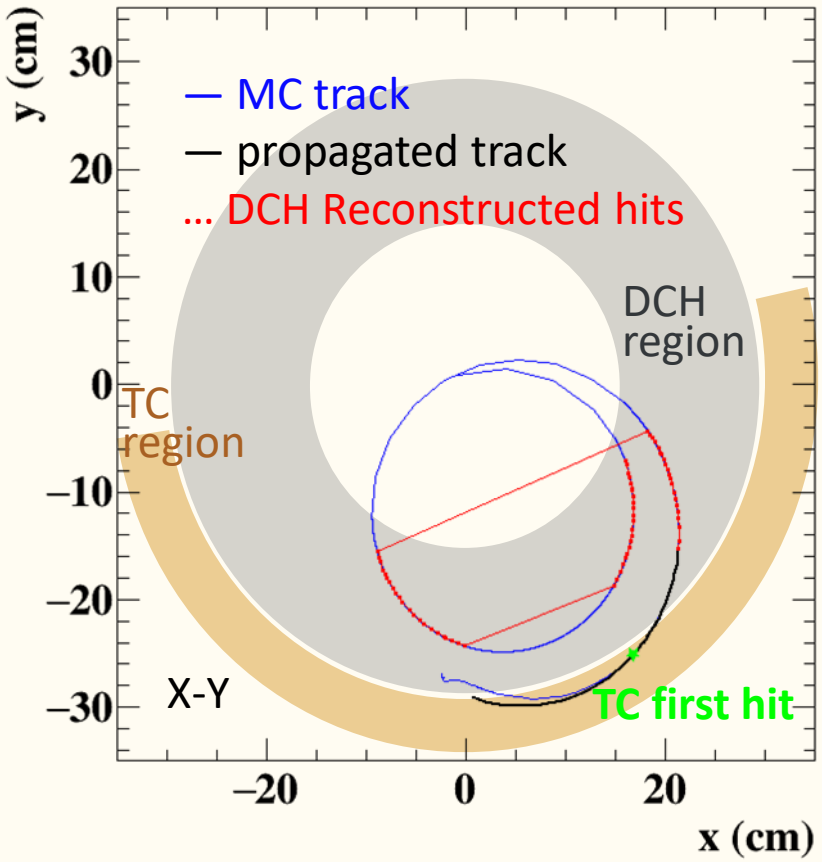
- Set up
  - Geant4
  - Signal positron mixed Michel positron @ 7×10^7
  - TC: Hit smeared by their resolutions
  - DCH: waveform simulation

(TC Waveform simulation study
Usami's talk 20aA12-1)

In this talk we'll focus on timing reconstruction.

Positron Timing Reconstruction

An example with signal event (w/o pile up)



1. DCH reconstructs track from vertex to TC first hit. (L_{DCH})
2. TC reconstructs time at first hit by each counter.

Measured time by i^{th} counter

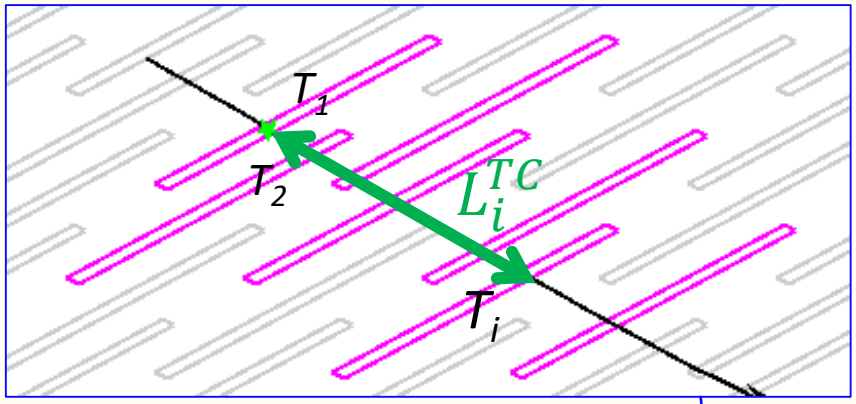
$$T_{\mathrm{TC}} = \sum_{i}^{N} (T_i - L_i^{TC}/c)/N$$

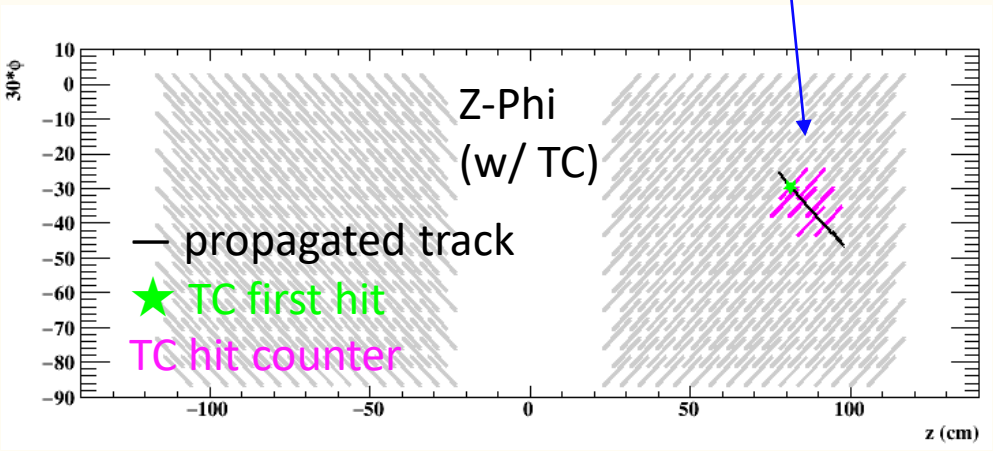
Path length from a first counter to i^{th} counter

$$T_{e^+} = T_{\mathrm{TC}} - L_{\mathrm{DCH}}/c$$

Positron Timing Reconstruction

An example with signal event (w/o pile up)





1. DCH reconstructs track from vertex to TC first hit. (L_{DCH})
2. TC reconstructs time at first hit by each counter.

Measured time by ith counter

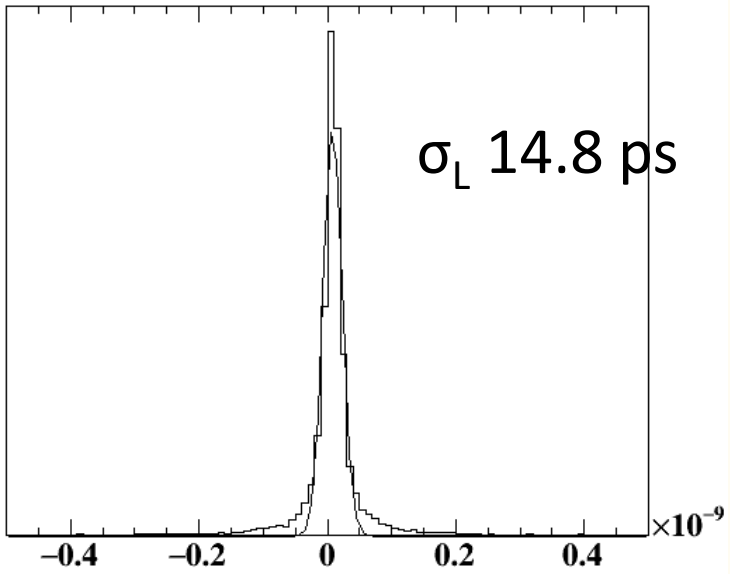
$$T_{\mathrm{TC}} = \sum_i^N (T_i - L_i^{TC}/c)/N$$

Path length from a first counter to ith counter

$$T_{e^+} = T_{\mathrm{TC}} - L_{\mathrm{DCH}}/c$$

Time Resolution from Each Detector

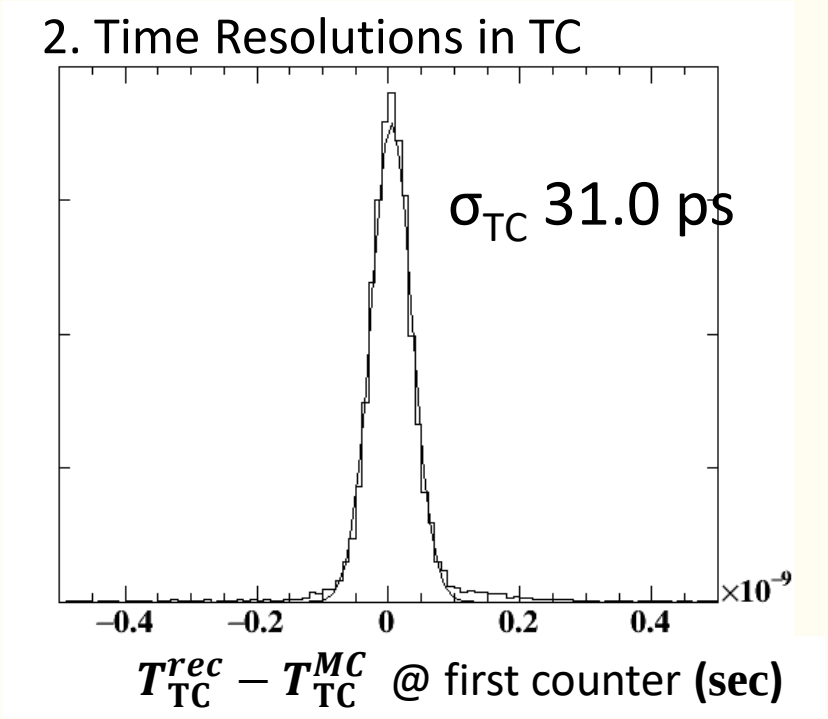
1. Flight Time b/w Target and TC



- Resolution coming from Track reconstruction is 14.8 ps.

  (75 ps in MEG)

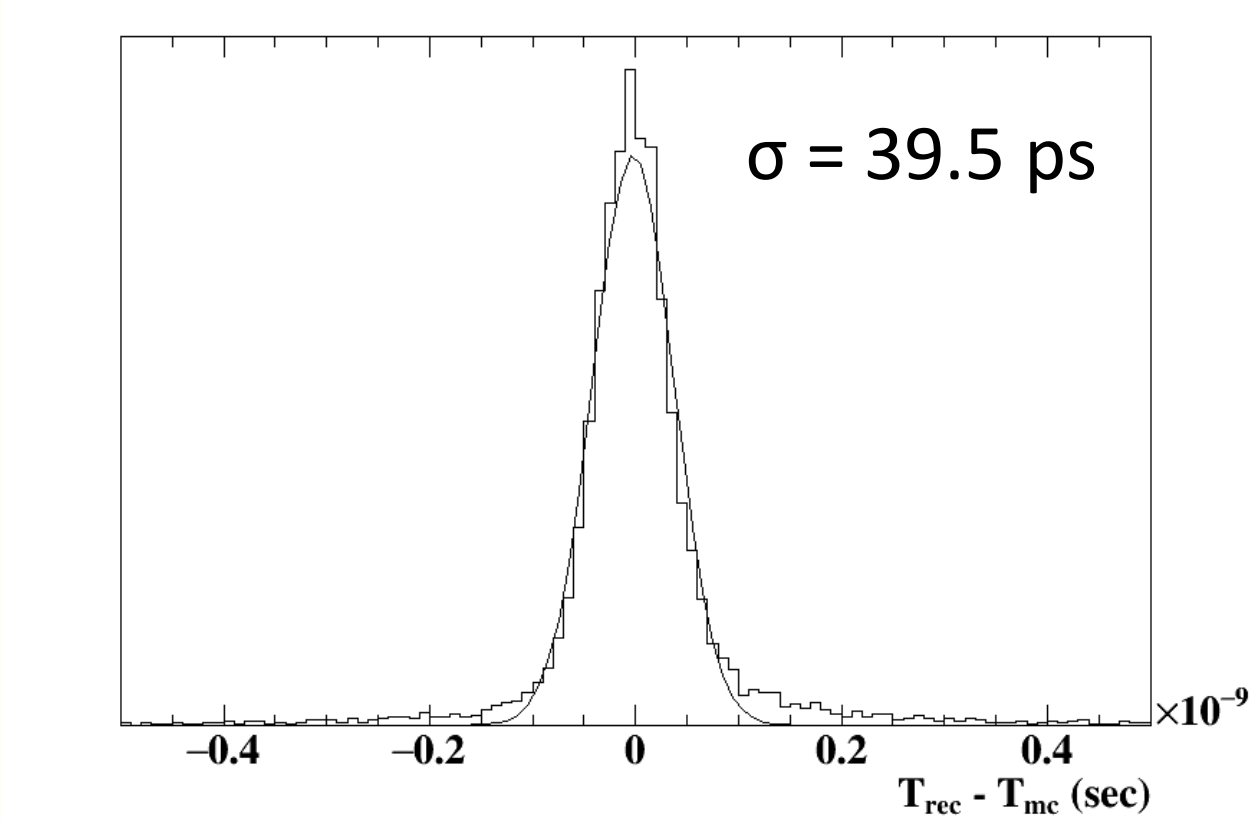
2. Time Resolutions in TC



- TC resolution is 31.0 ps.

  (76 ps in MEG)

Overall Positron Time Resolution

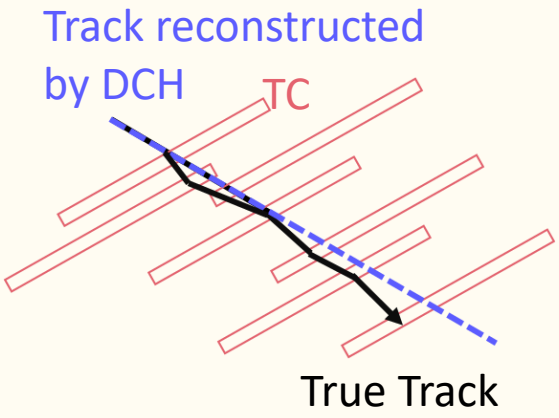


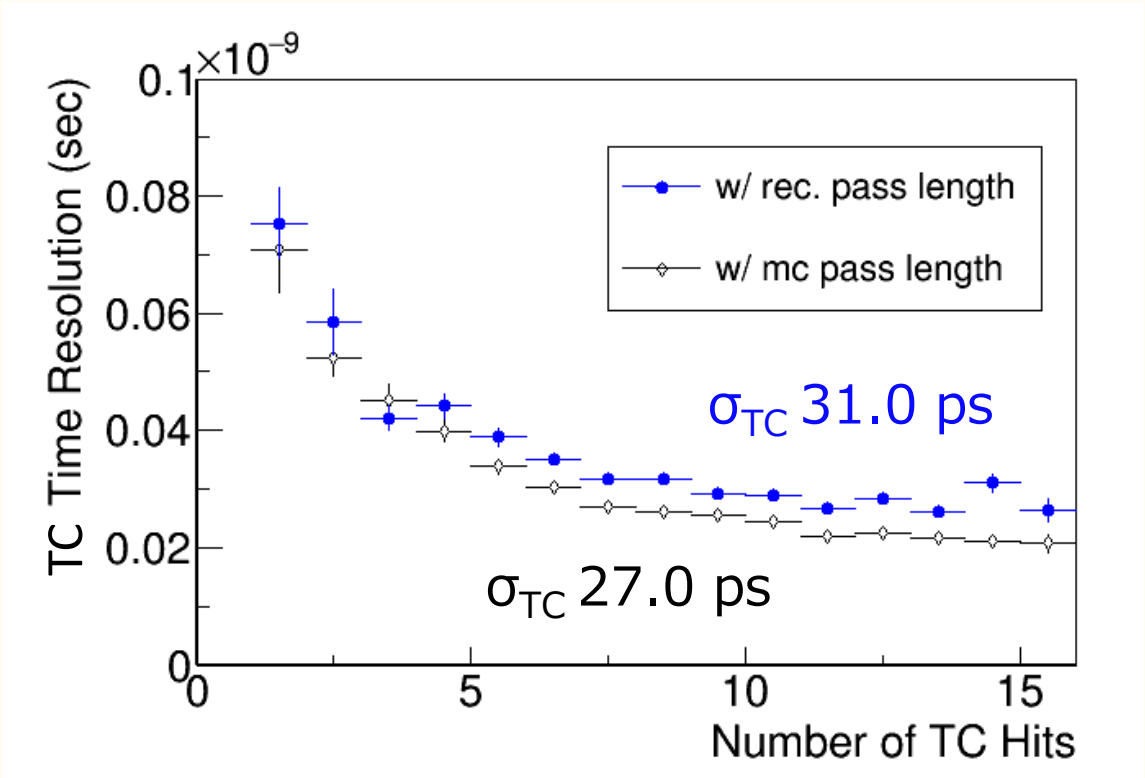
- Overall positron time resolution is 40 ps.

(It was 108 ps in the MEG experiment.)

More Development

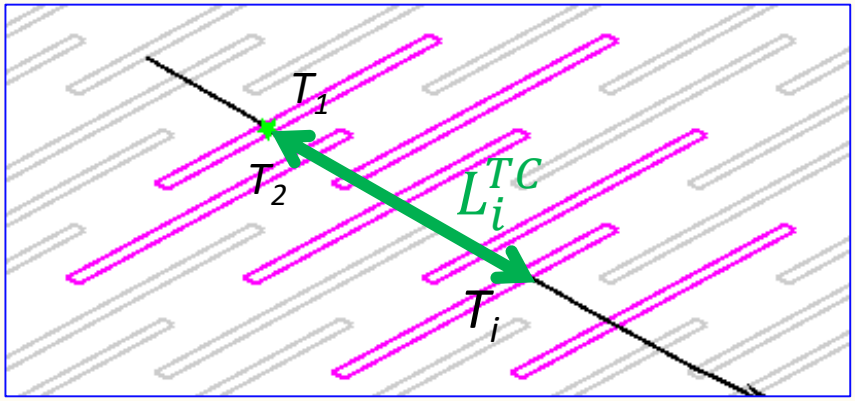
Effect of Multiple Scattering in TC

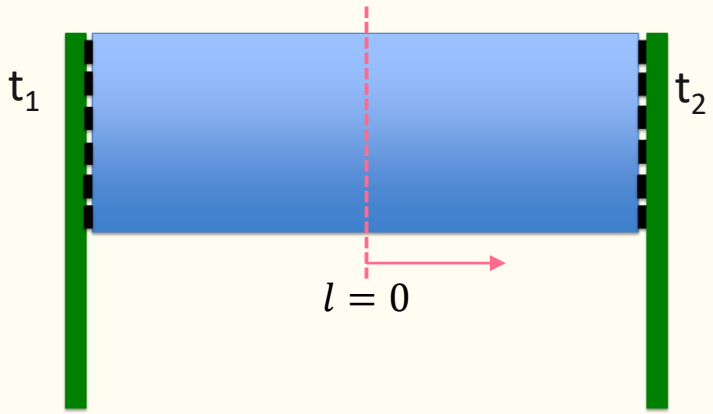




The effect of multiple scattering **in TC** is not so large, but if we'll estimate them more accurate the time resolution should be better.

TC Tracking



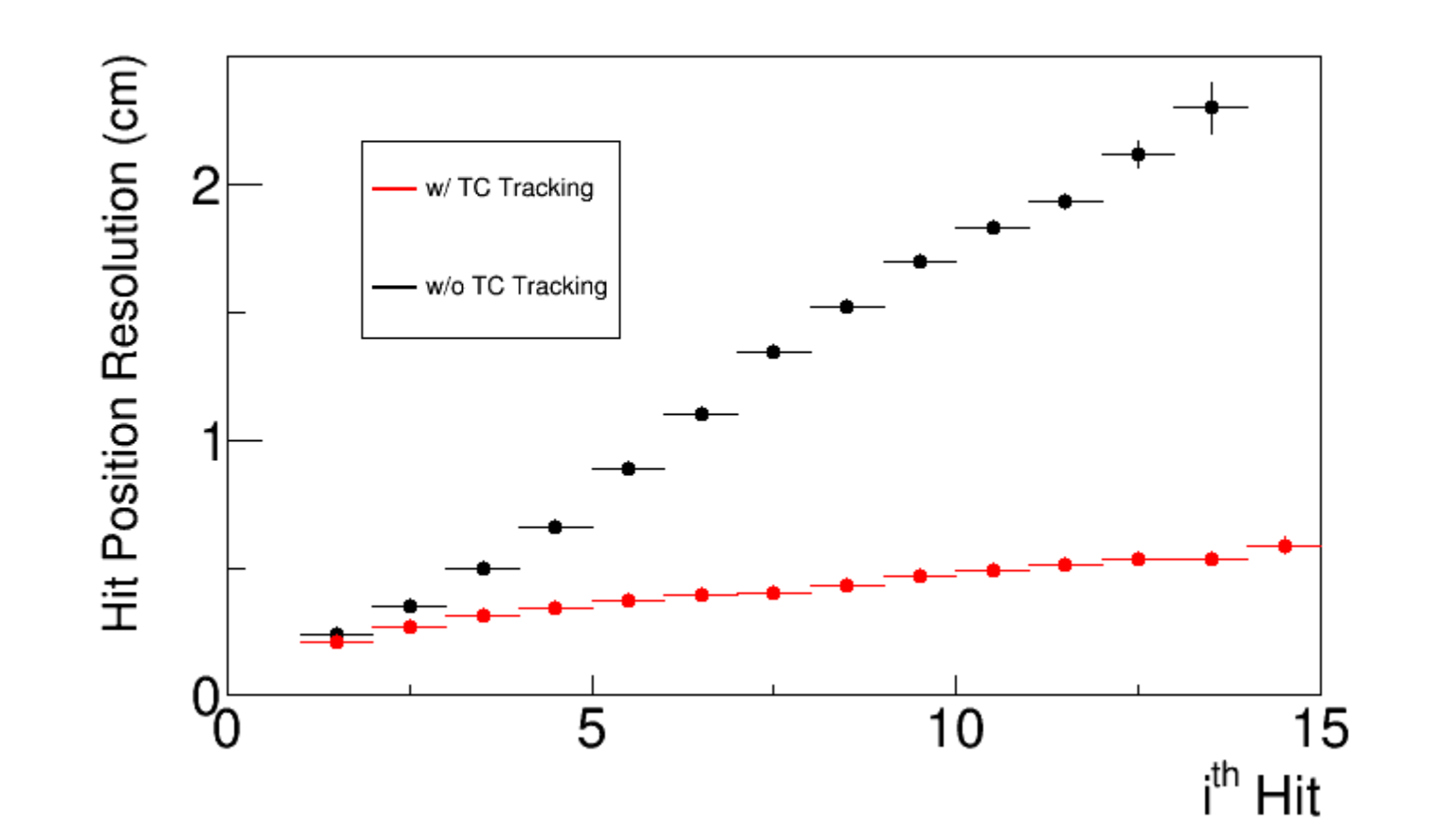


$$T_{counter} = (t_1 + t_2)/2$$

$$l = v_{eff}(t_1 - t_2)/2$$

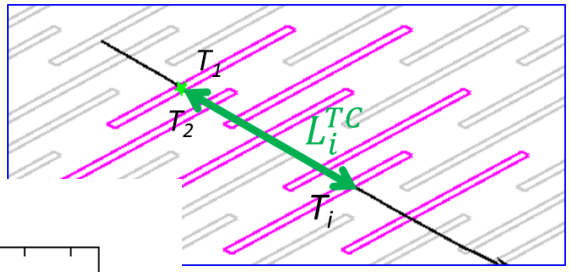
- Motivation is more precise estimation of path length in TC.
- TC reconstructs hit position along length.
- GENFIT: DAF(Deterministic Annealing Filter) is used.
  - It is almost **Kalman Filter** but with reweighted measurements against outlier hypothesis.
- Initial information is a track reconstructed by DCH.

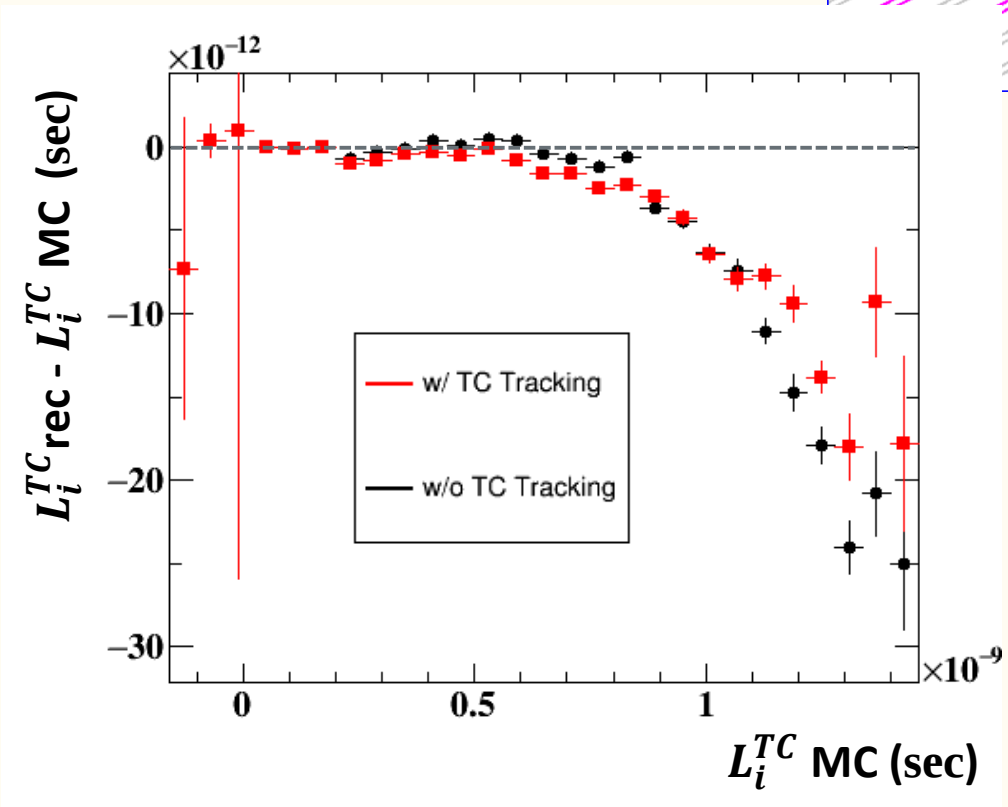
Hit Position Resolution



TC tracking recovers the effects of multiple scattering.

Time of Flight in TC



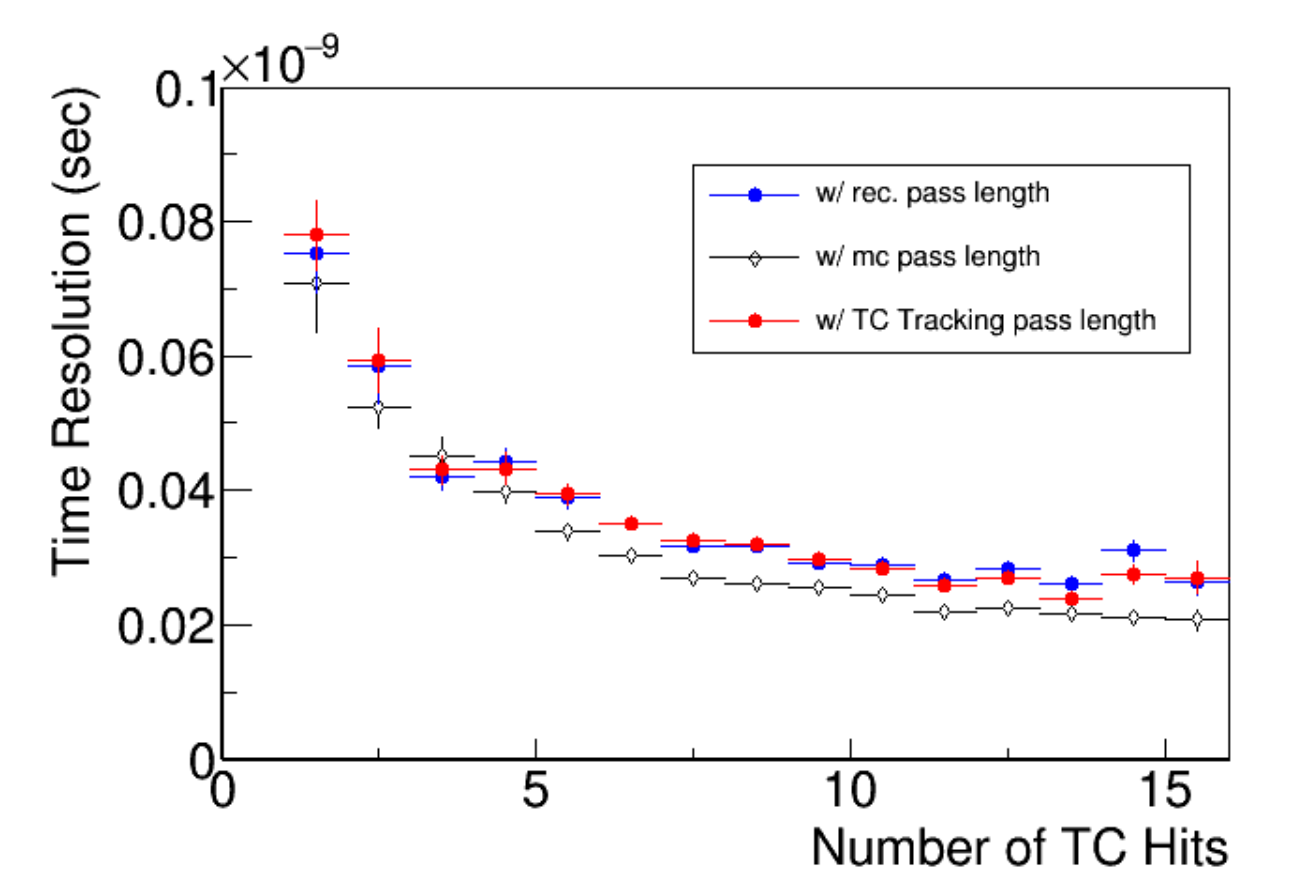


However reconstructed path length does not change so much.

GENFIT does not have time fit.

More development is need.

Impact on Time Resolution



In this time, time resolution does not improve so much, because calculation of path length does not improve.

Summary

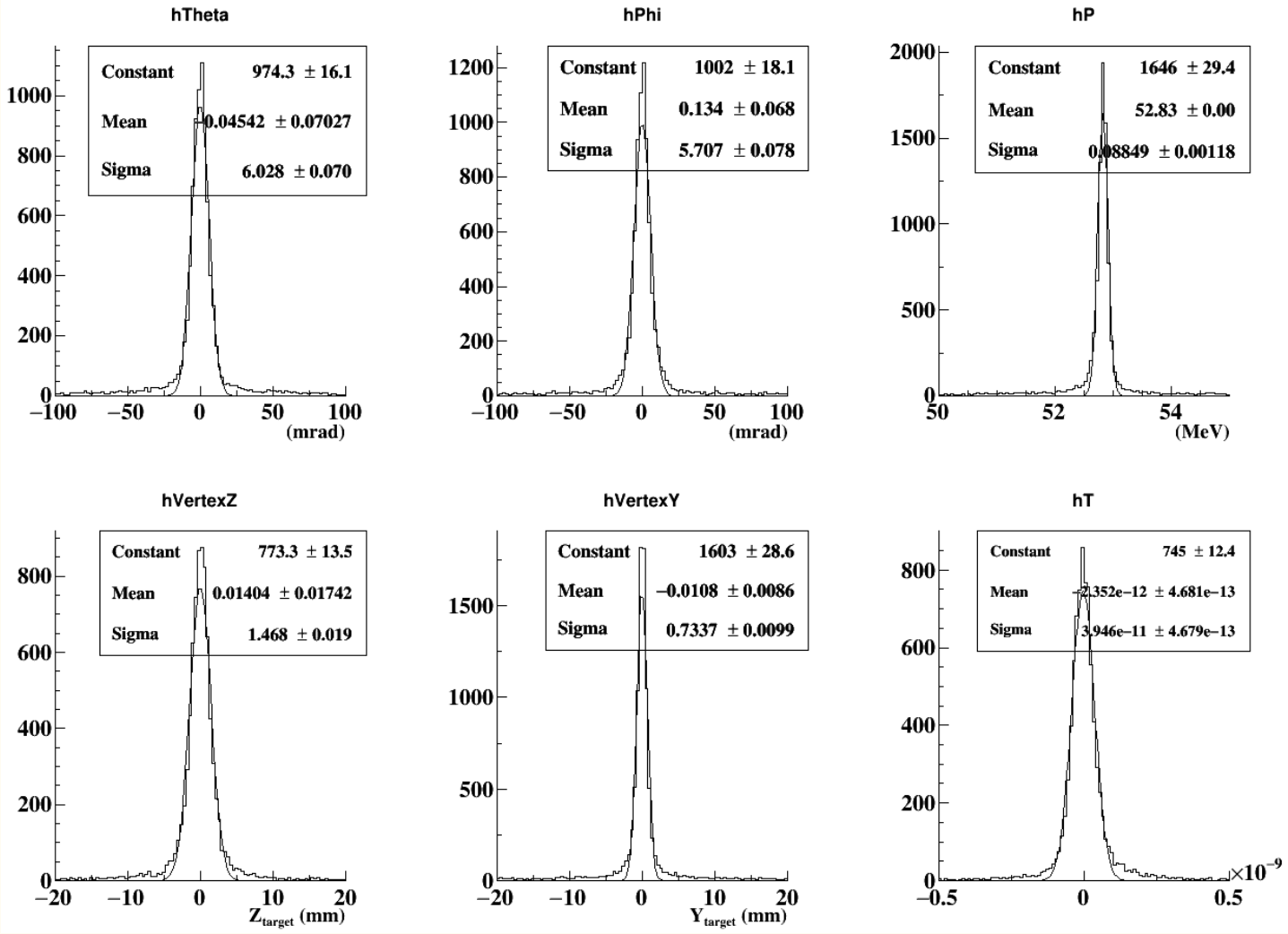
- The MEG II experiment aim to search for $\mu^+ \rightarrow e^+\gamma$ decay.
- Positrons are reconstructed by DCH and TC.

- Full chain of positron reconstruction algorithm is prepared and estimate overall performance.
  - Overall positron time resolution is improved to 40 ps from 108 ps in MEG.

- There is room for improvement and it's ongoing.

Back Up

Mix overall resolutions



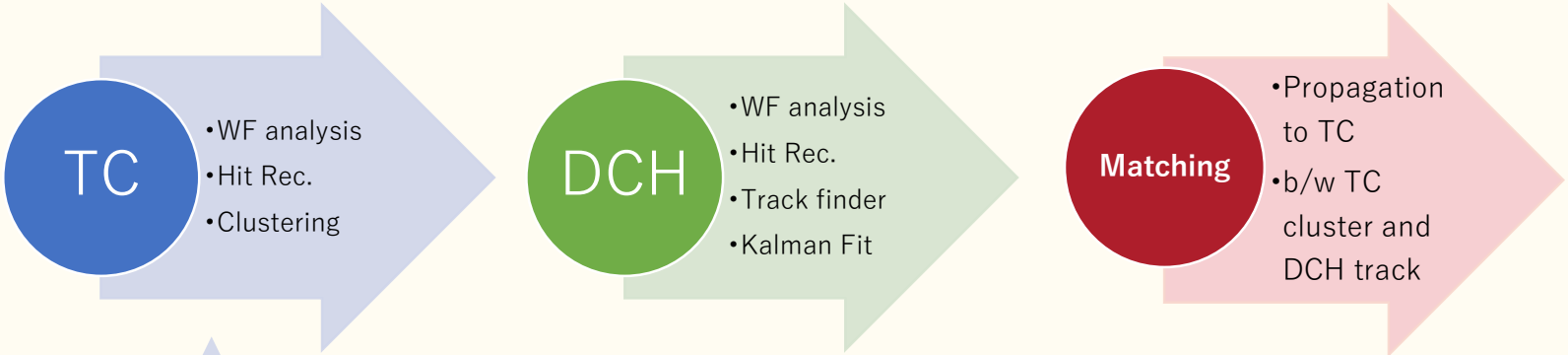
Positron Detection Efficiency

Preliminary

- Overall Efficiency: **71.1 %**
  - DCH Efficiency: 81.0 %
    - Propagation miss to TC (Dominant ~50 %)
    - Contamination
    - Vertex reconstruction miss
  - TC Efficiency: 90.6 %
    - No Hit (9.2 %)
    - Clustering contamination > 40% in a cluster (the rest)
  - Matching Inefficiency (if both reconstruction is succeeded): 7.6 %
    - in the same turn (20.9 %)
    - Turn difference is just 1. (58.1 %)

} 6 % in matching inefficiency

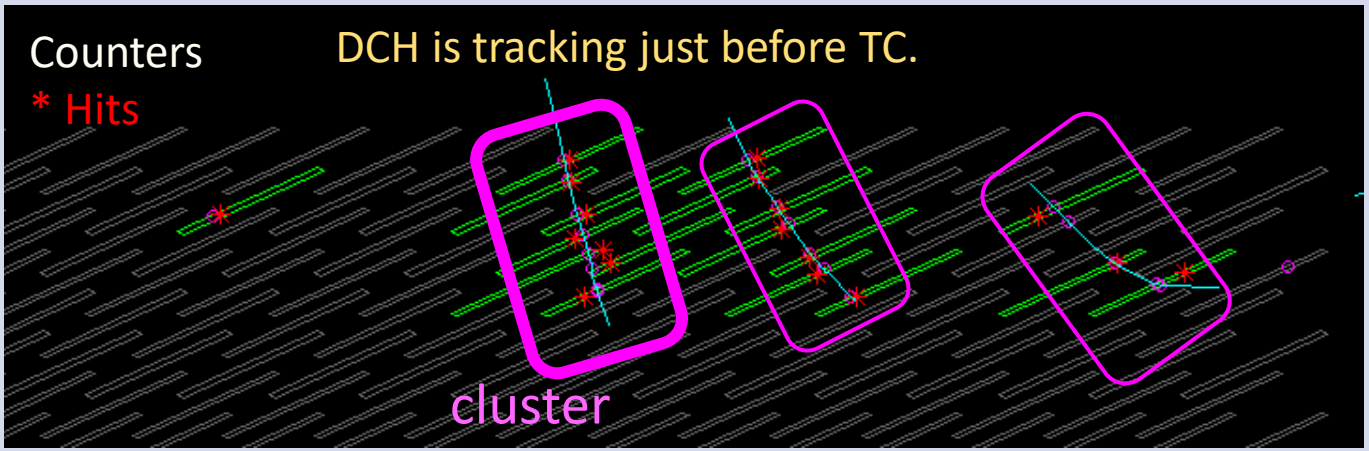
Positron Reconstruction Chain



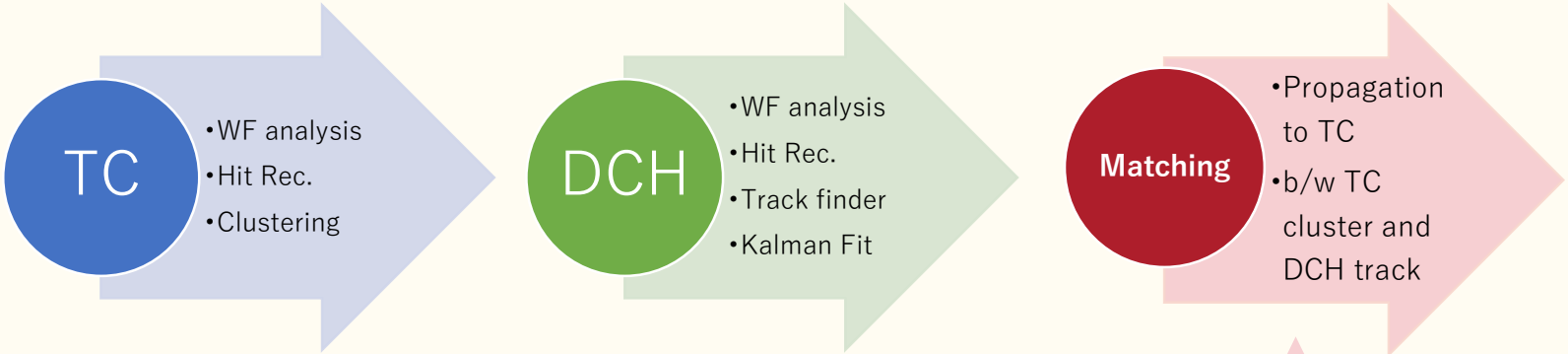
Previous JPS

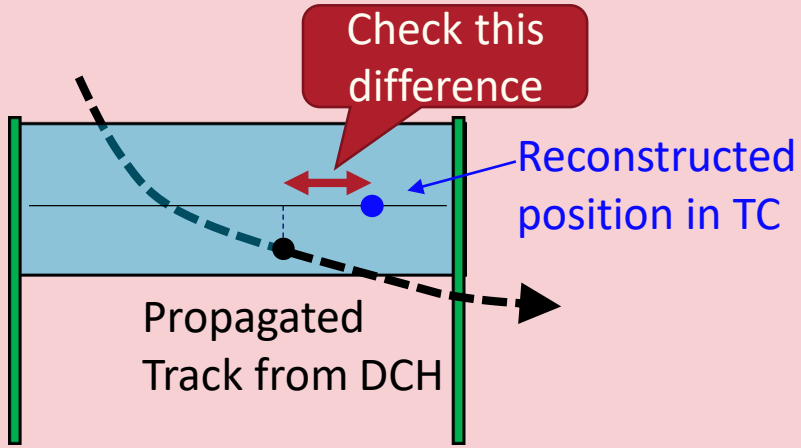
- TC is pixelated by 512 scintillator counters.
- Positron comes to the TC in high rate. (a few MHz in the TC region.)

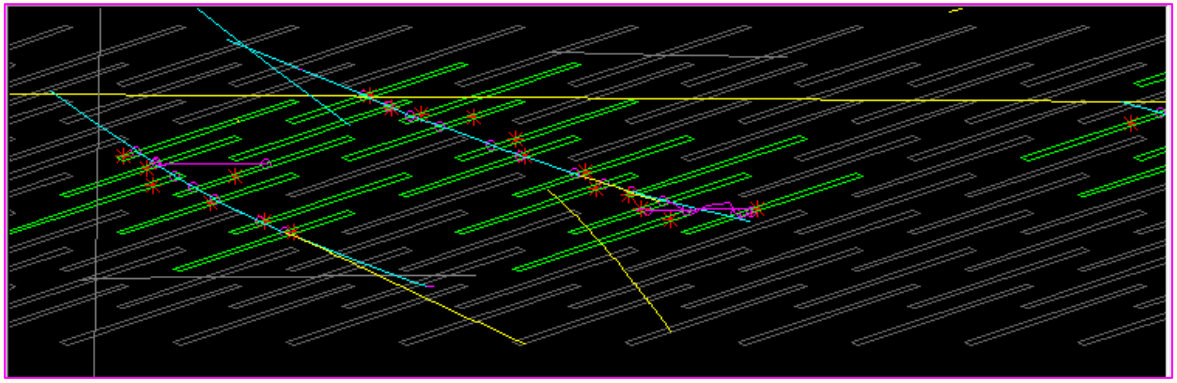
→ Clustering of TC hits was developed.



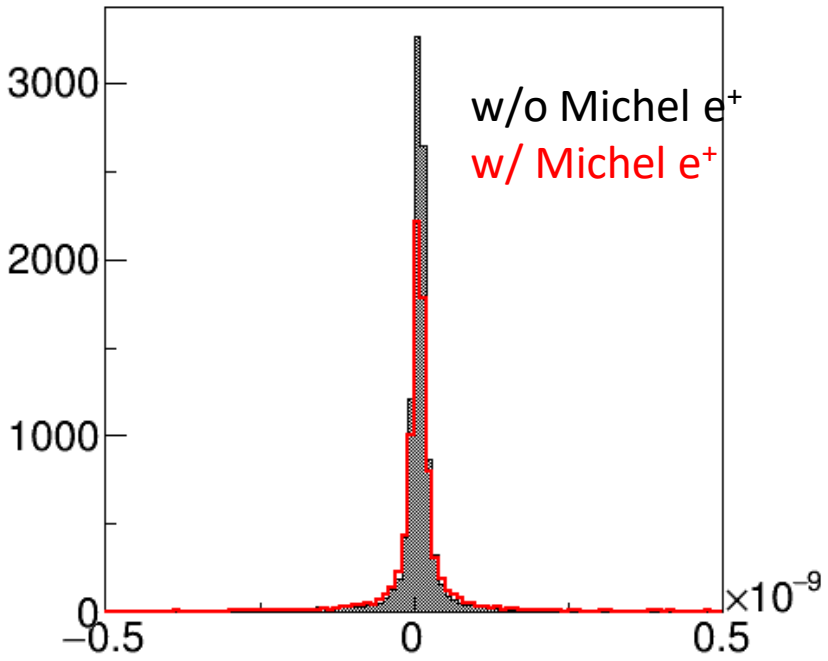
Positron Reconstruction Chain



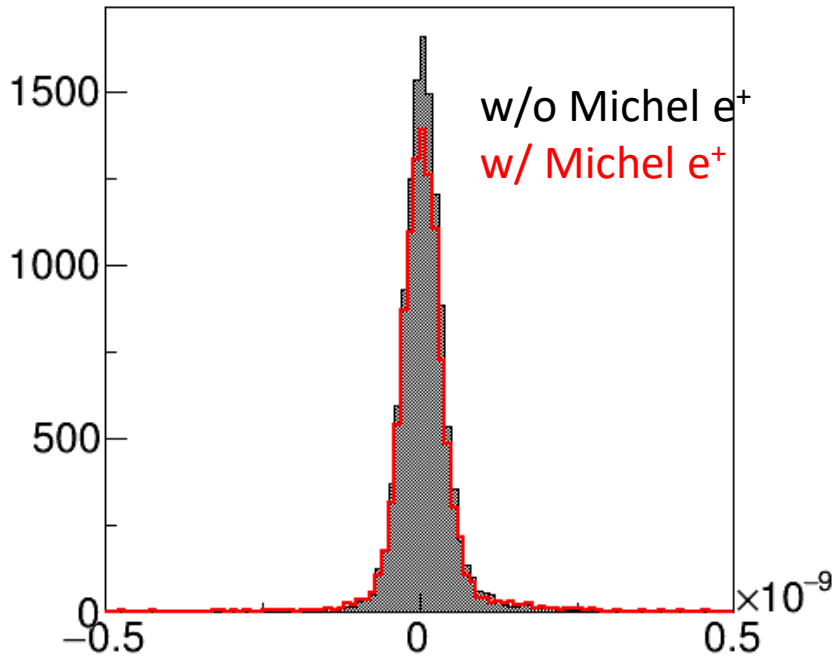




Time of Flight b/w Target and TC



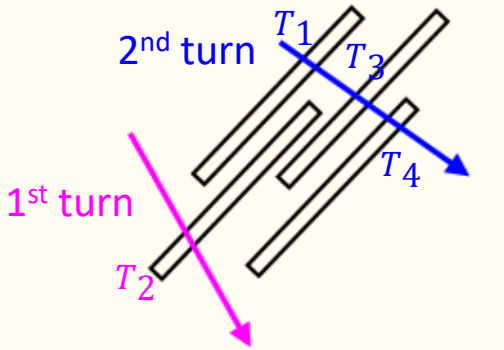
Time Resolutions in TC



Tails are almost the same. These tails come from signal itself.
Multi turn or delta ray may be the reason.

Tail events from multi turn

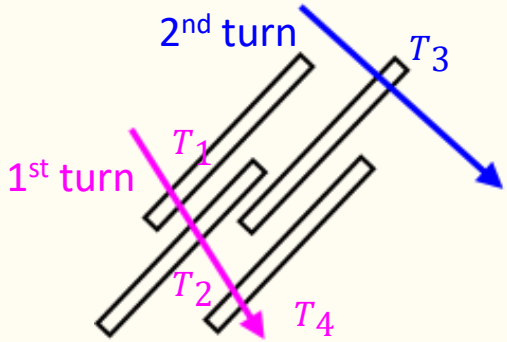
- Tail in events come from hits from different turns of the same positron.
  - They affect final time measurement.
- These kind of hits should be separated by
  - Tracking
  - More precise cut in clustering



$$\frac{T_1 + T_2 + T_3 + T_4}{4} - T_1^{MC}$$

⇒ make negative tail.

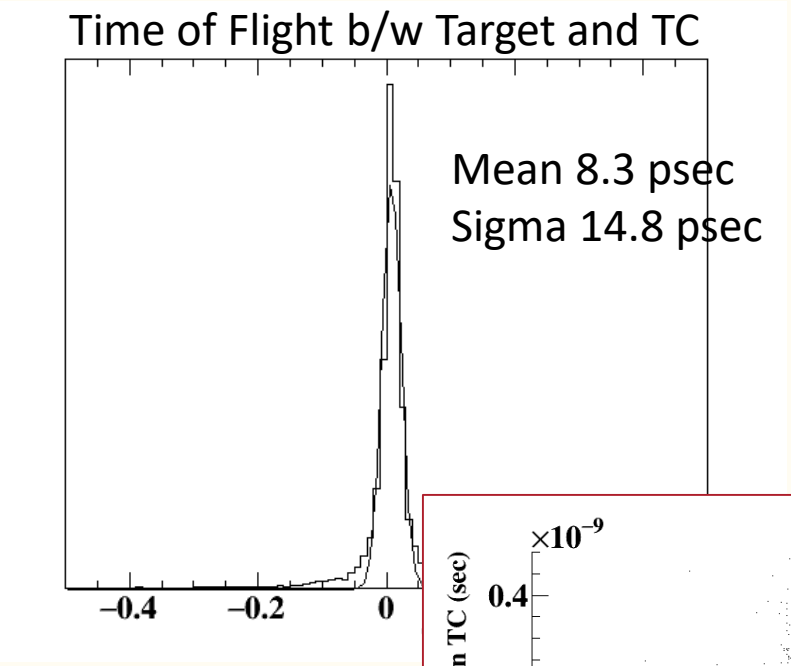
<

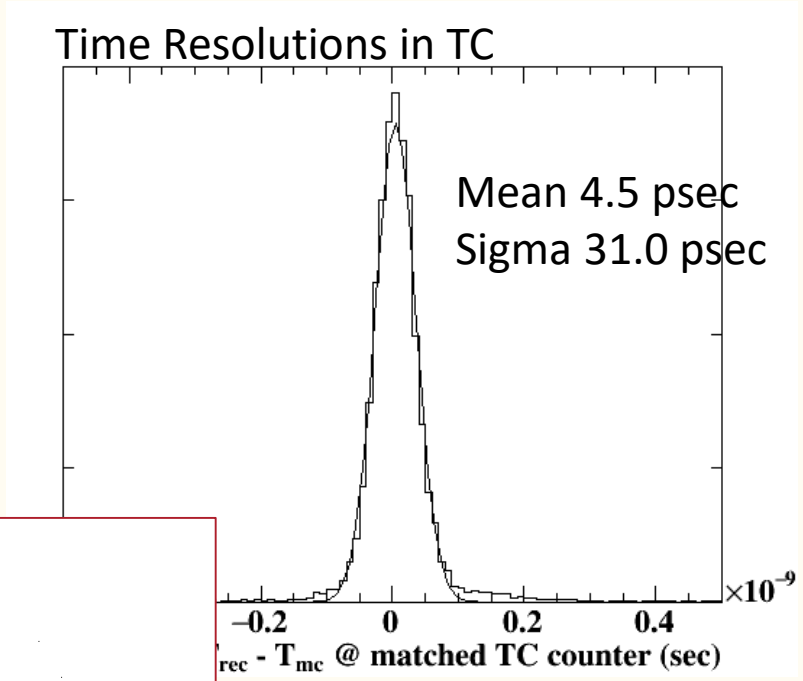


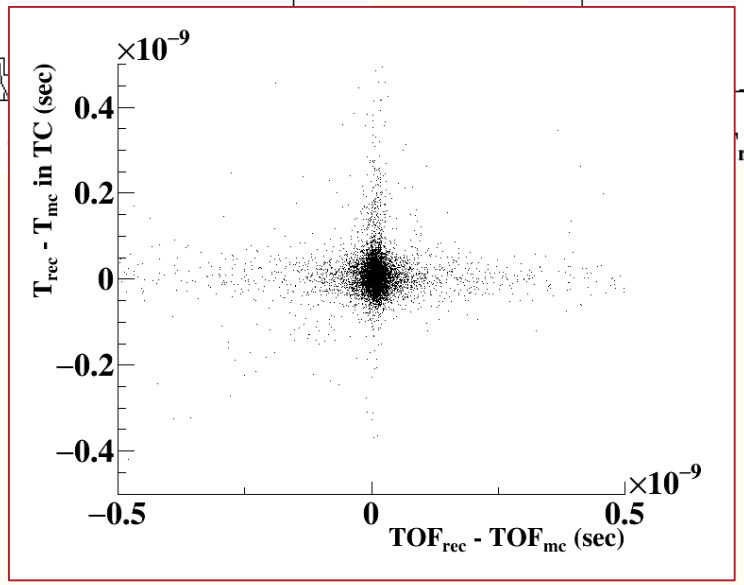
$$\frac{T_1 + T_2 + T_3 + T_4}{4} - T_1^{MC}$$

⇒ make positive tail.

Time Resolution from Each Detector

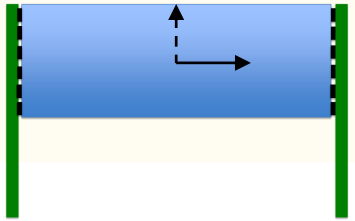




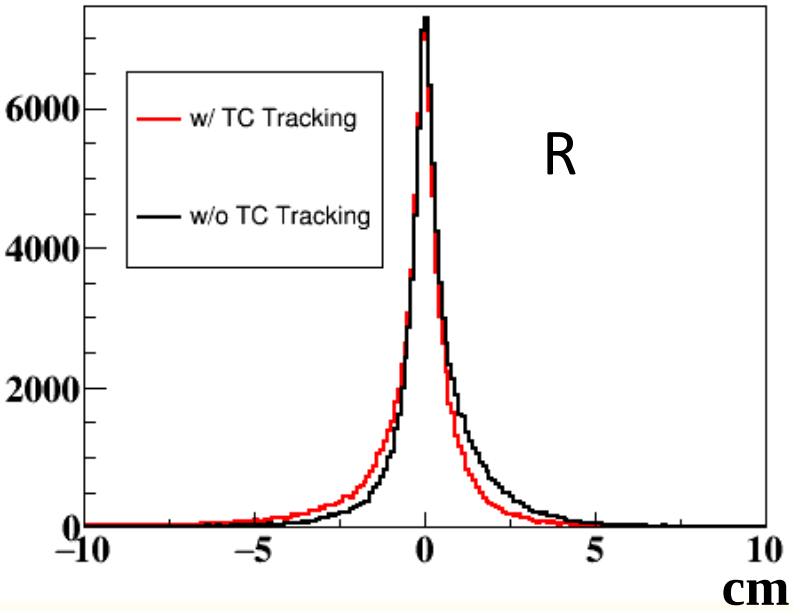


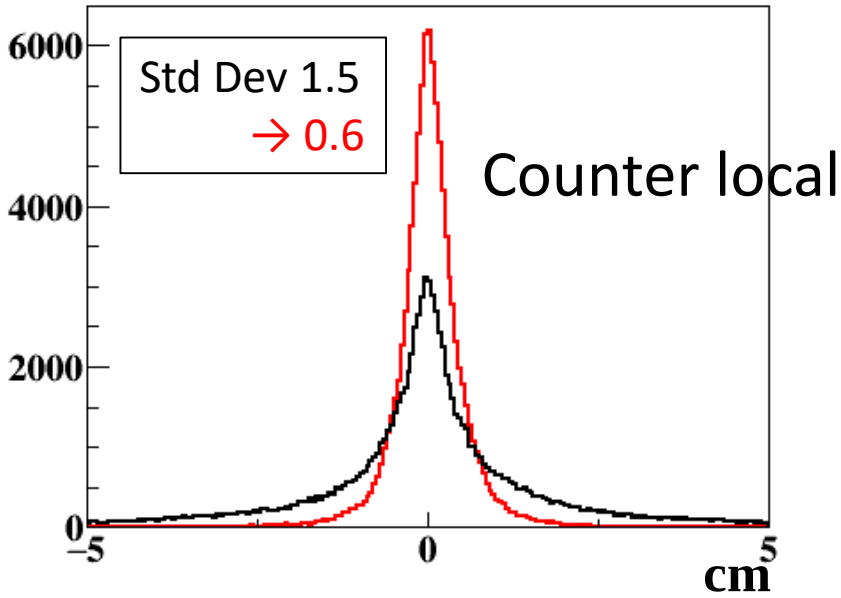
Since these two reconstructions does not have correlation, .

Hit Position Reconstruction

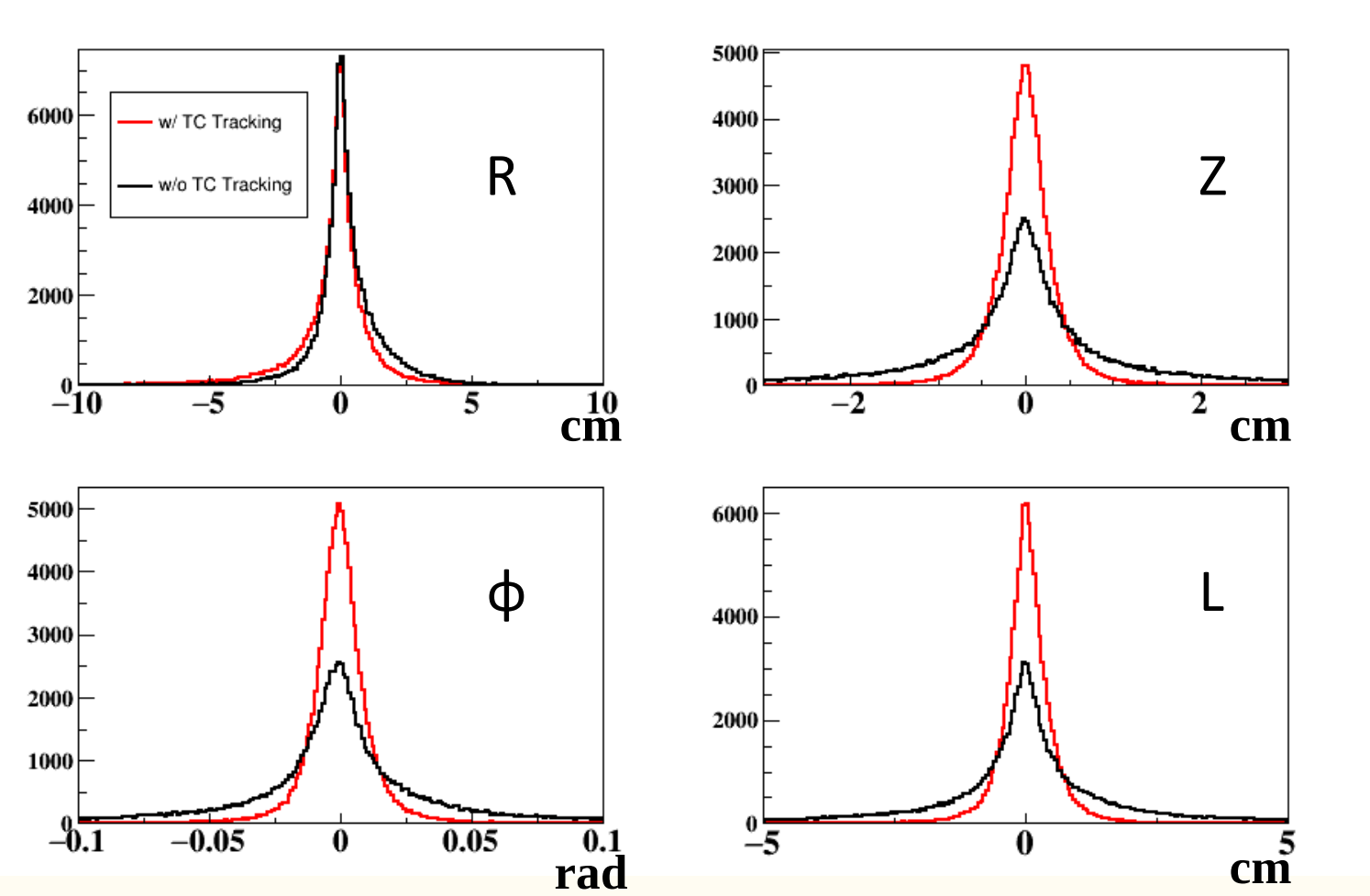


Reconstructed position – mc position

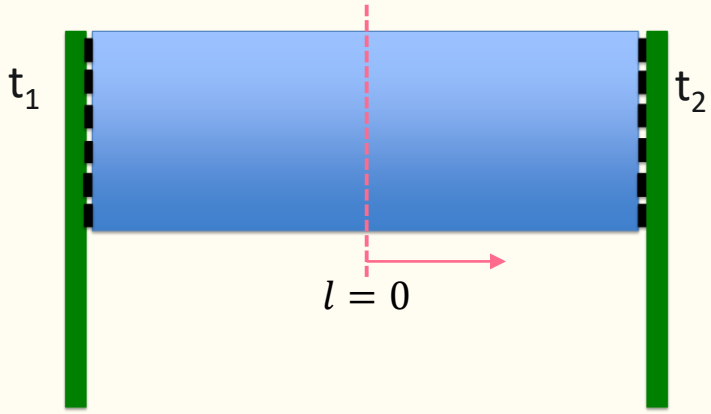




Hit Position Reconstruction



Prospects



$$T_{counter} = (t_1 + t_2)/2$$

$$l = v_{eff}(t_1 - t_2)/2$$

- Weighted hit time by reconstructed hit position
  - Closer channel should have larger light amount than the other channel have.
- Contamination cut