MEG II実験陽電子タイミングカウンターの位置較正及び時間分解能に与える影響の評価

Alignment and Effect Evaluation on the timing resolution of Positron Timing Counter in the MEG II Experiment

2020 / 2 / 16

第26回 ICEPP シンポジウム @ 志賀レークホテル

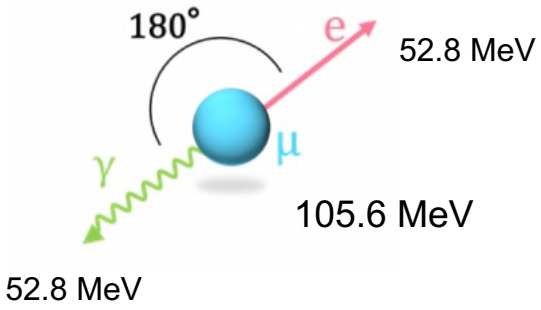
米本 拓 (ICEPP, 東京大学)

Core-to-Core Program

Contents

Contents

MEG II experiment



- Upgrade of the MEG experiment

- The search for $\mu^+ \rightarrow e^+ + \gamma$ (cLFV)

  μ^+ : most intense beam at PSI ($10^8\ \mu^+$ /s)

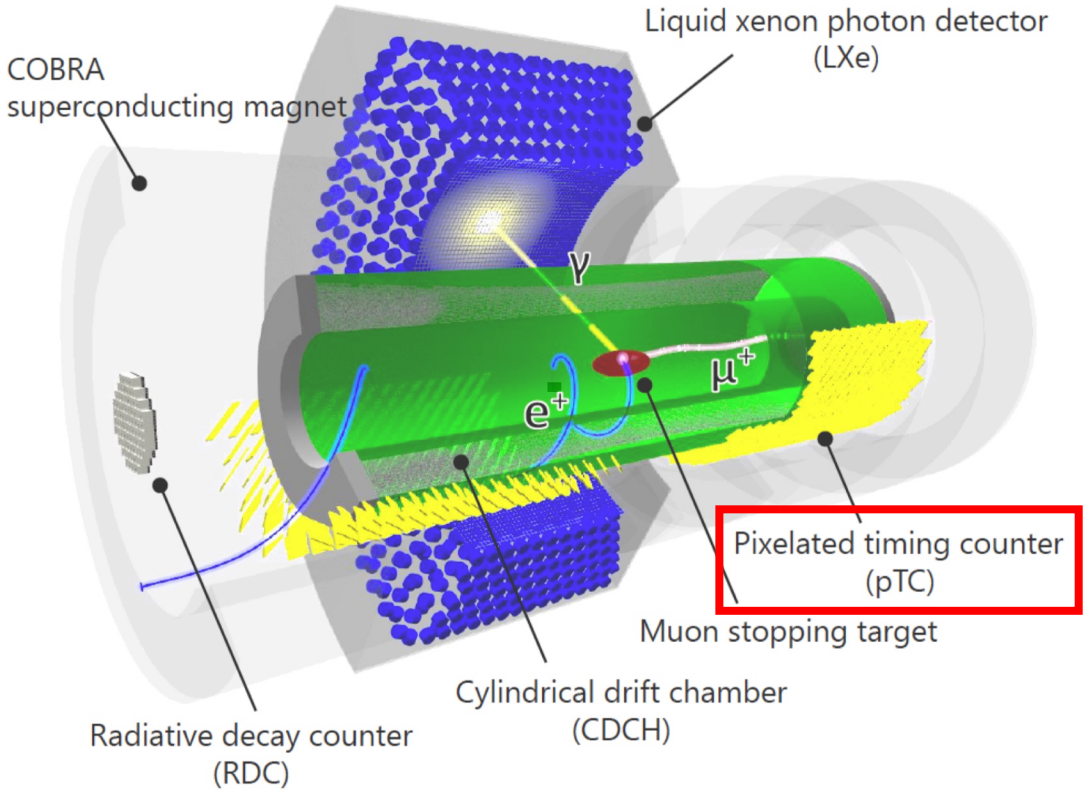
  γ : detected by LXe

  e^+ : bent by COBRA magnet,

  detected by pTC & CDCH

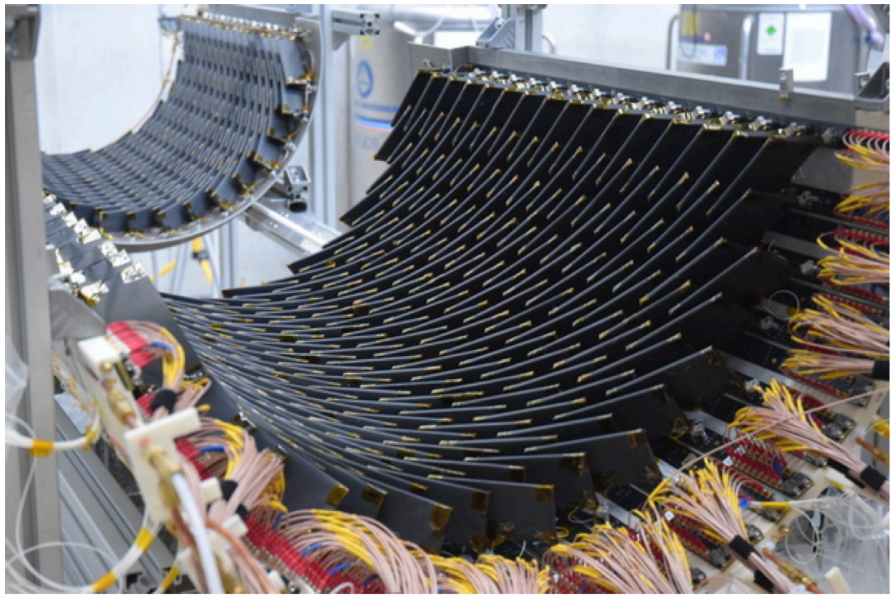
- expected sensitivity:

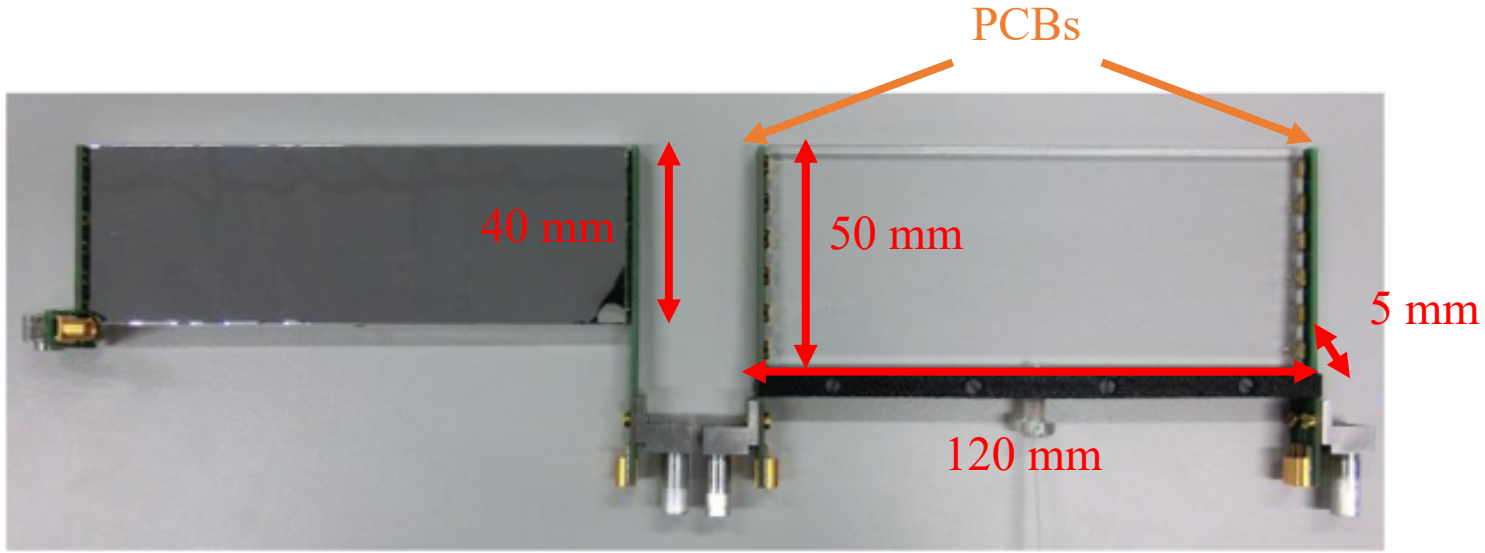
  $\mathcal{B}(\mu^+ \rightarrow e^+ + \gamma) \sim 6 \times 10^{-14}$



"The design of the MEG II experiment", Eur. Phys. J. C (2018) 78:38

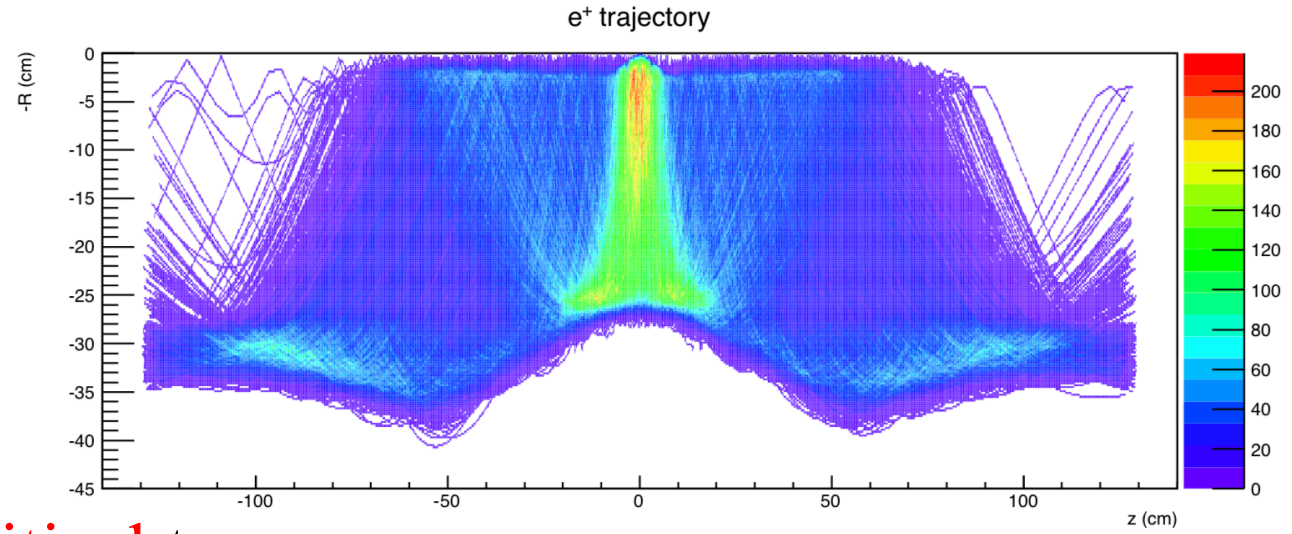
MEG II - Pixelated Timing Counter





- a highly segmented (256 tiles ×2) scintillation counter, consists of two semi-cylindrical super-modules.
- 120mm × 40mm (50mm) × 5mm plastic scintillator (BC422).
- read by 6 SiPMs on each PCB attached to both side of the scintillator.
- overall time resolution ~ 38 ps assuming 9 hits (average hits for signal e^+)

pTC alignment

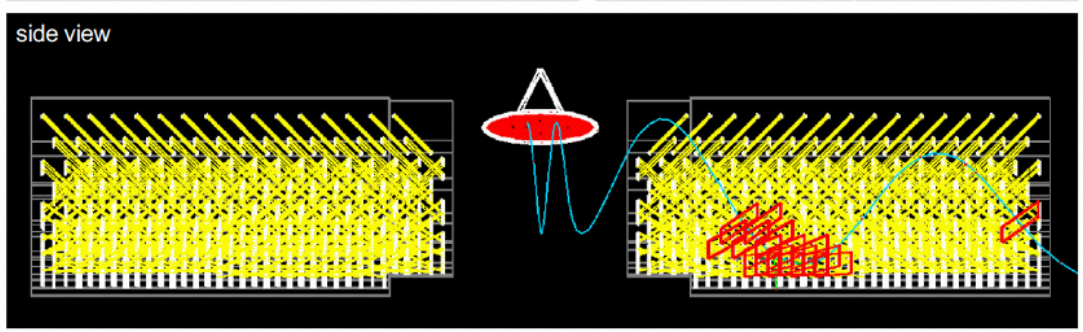


Real values of pixel positions are critical to

- e^+ detection efficiency
- Time-of-Flight

- for a first pixel → global timing
- among hit pixels → pTC time calibration

for multiple hits of e^+.



Contents

- Introduction
- MEG II experiment
- Pixelated Timing Counter
- pTC alignment

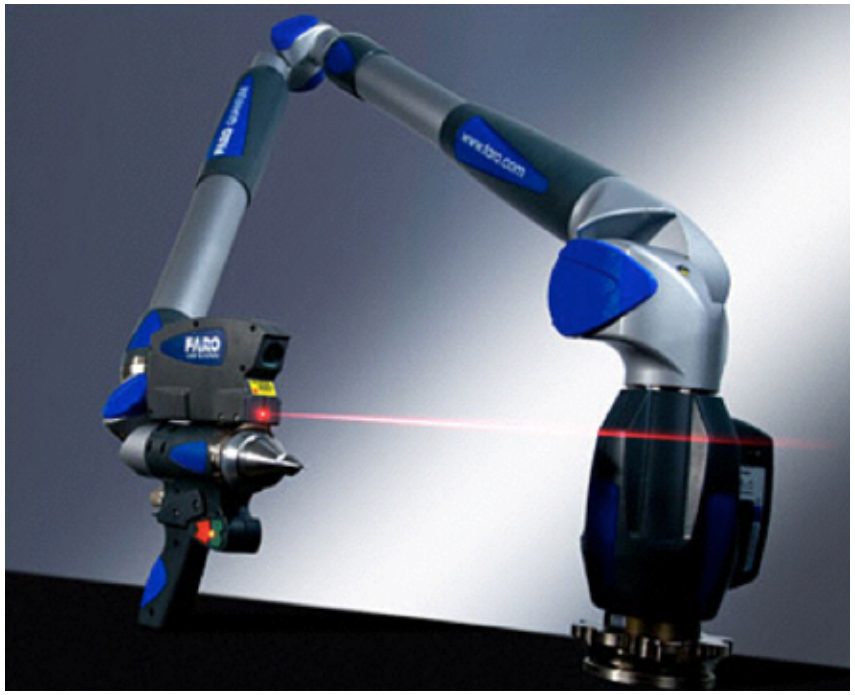
- Alignment
- Instruments
- Analysis flow
- Scan data
- Results
- Conclusion

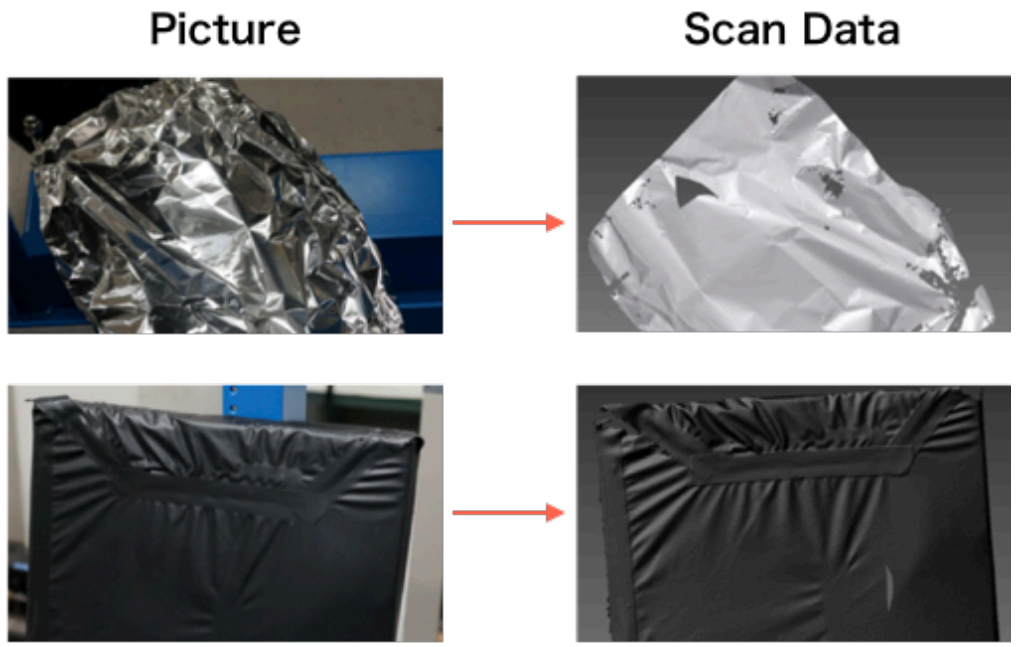
- MC study
- TOF from reconstructed track
- Results
- Conclusion

- Summary & Prospect

Instruments - 3D scanner

3D Scanner (FARO Edge ScanArm HD)



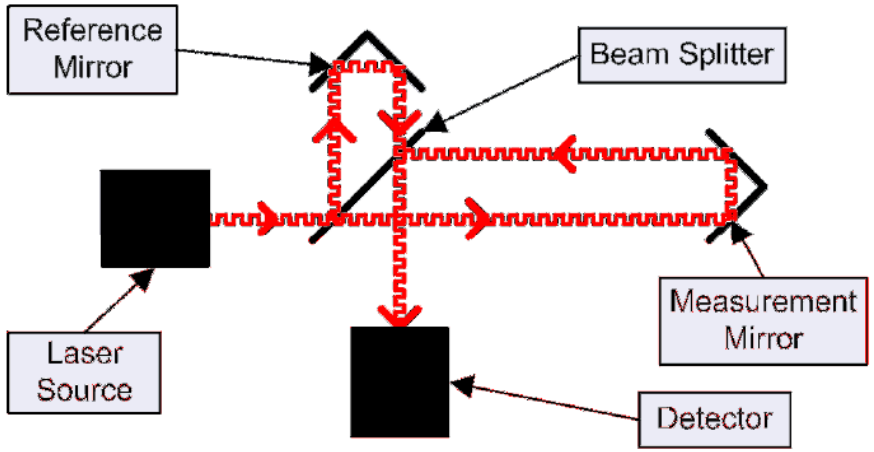


- Accuracy ± 25μm
- Scan rate : 560,000 points/sec
- Cited from https://www.faro.com/resource/faro-edge-scanarm-hd/

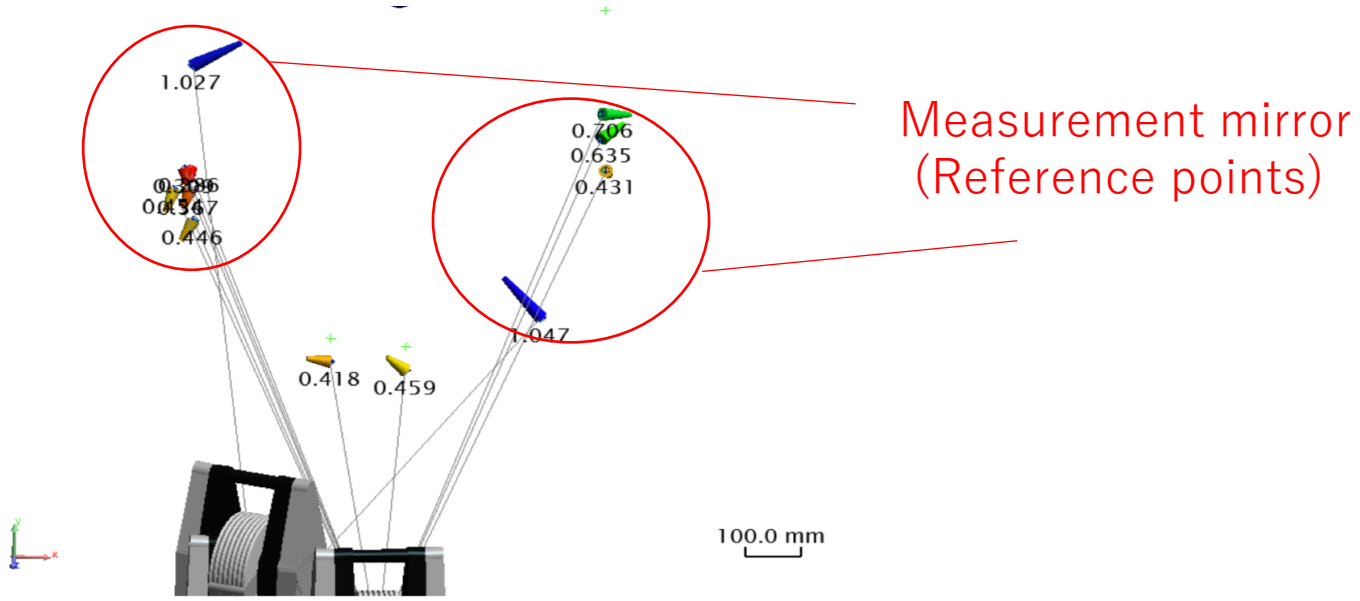
Instruments - Laser tracker

Leica Absolute Tracker AT401

・https://w3.leica-geosystems.com/downloads123/m1/metrology/at401/brochures/leica%20absolute%20tracker%20at401_en.pdf



Measurement principle



Measurement mirror (Reference points)

Analysis flow

*Every time we install TC, we will restart from ②

3D scan by FARO 3D scanarm

① Scan pixels and get the following data (✓ Mar. 2019).

- scan data
- reference points

Laser survey by Leica laser tracker

② Survey in piE5 (✓ 3rd Sep. 2019).

- reference points in global coordinates

Calculate transform matrix by reference points

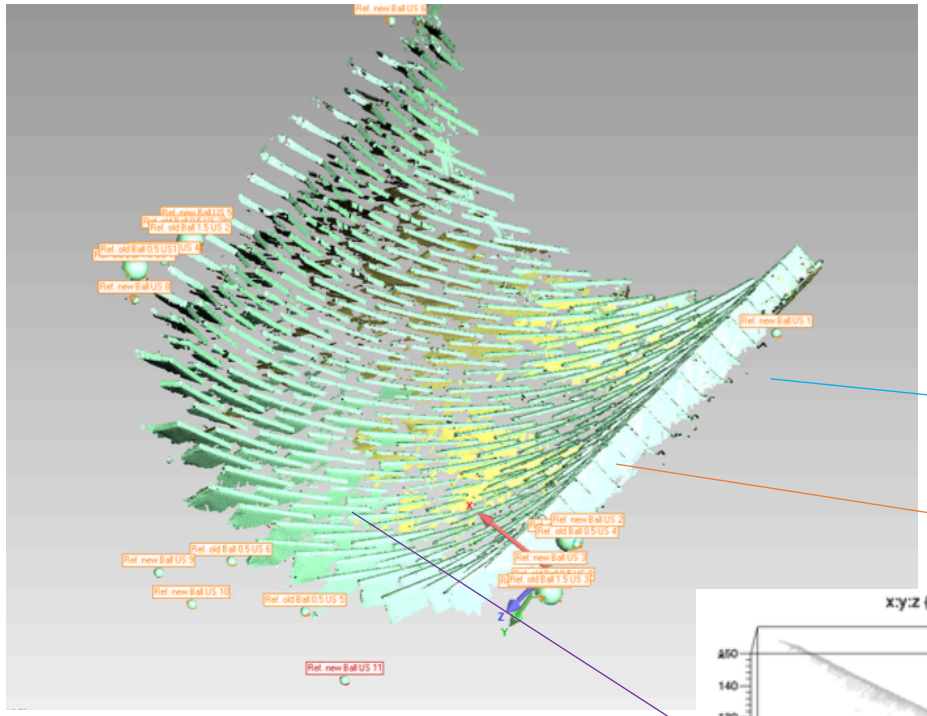
③ 3D scanner coordinates → global coordinates.

Designed position in global coordinates (now used in MEG II software)

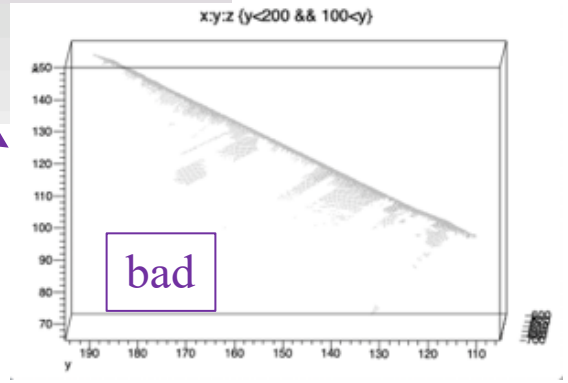
Get counter positions in global coordinates

④ Measure deviations from designed position.

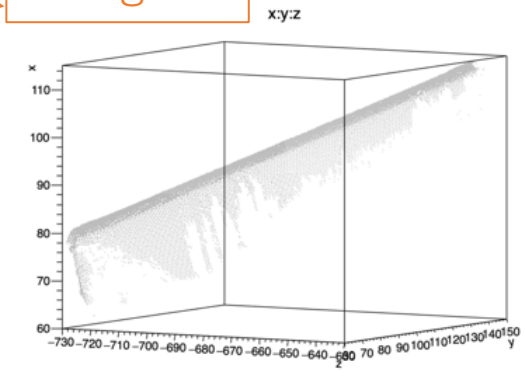
Scan data - overview

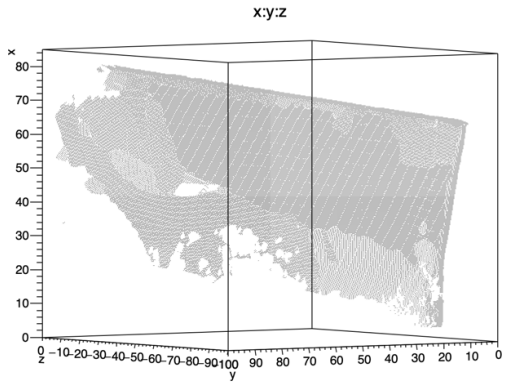


- Scan data are available as an array of (x,y,z) points
- Data is lacking because the light of 3D scanner could not reach
- 77 pixels from 512 pixels are excluded from analysis due to bad data condition



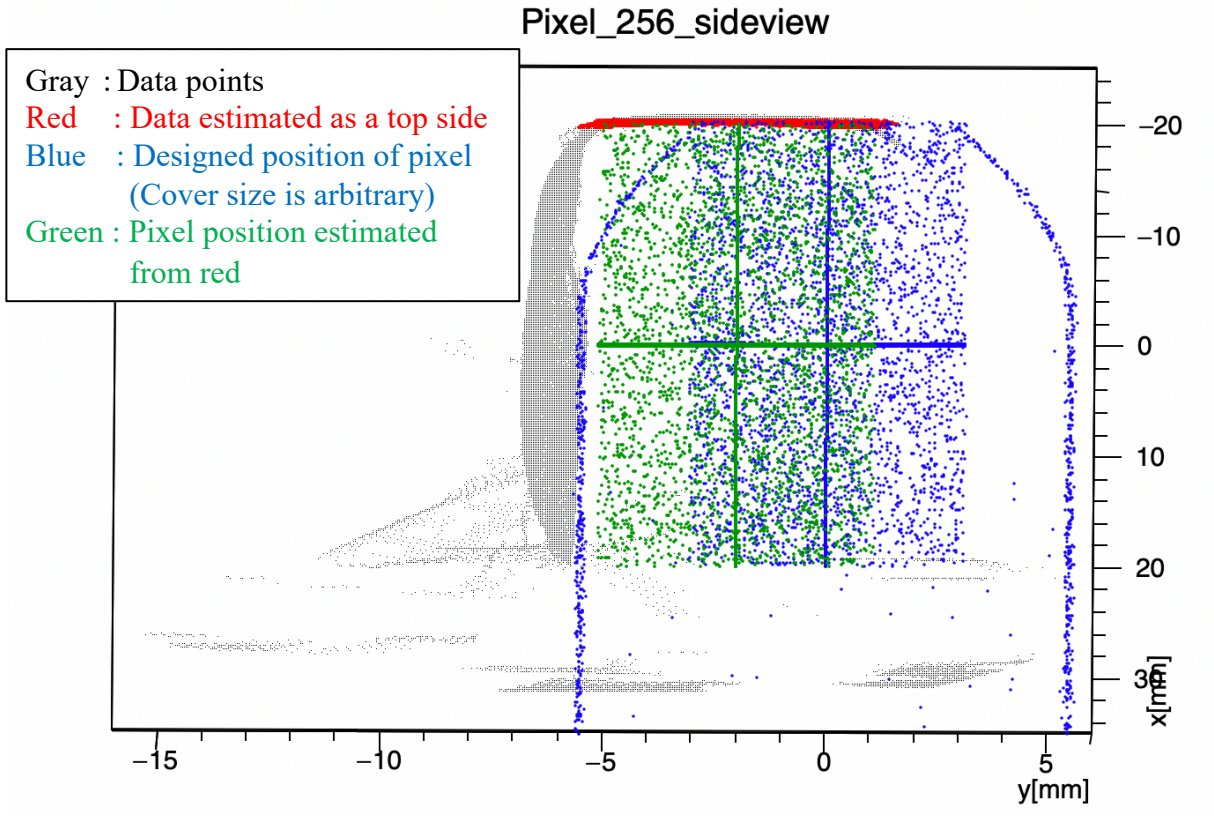
Not good





good

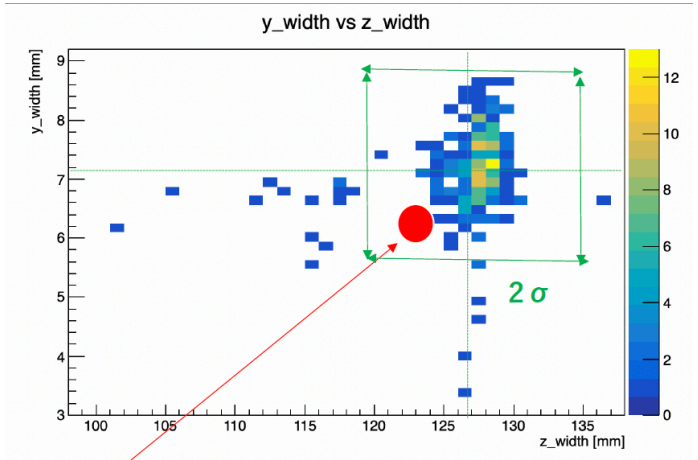
Scan data - handling



- Designed angles and center position are used for translating pixels to local x-y-z
- Estimated center of pixel is calculated:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} (x_{max} + x_{min})/2 \\ (y_{max} + y_{min})/2 \\ (z_{max} + z_{min})/2 \end{pmatrix}$$

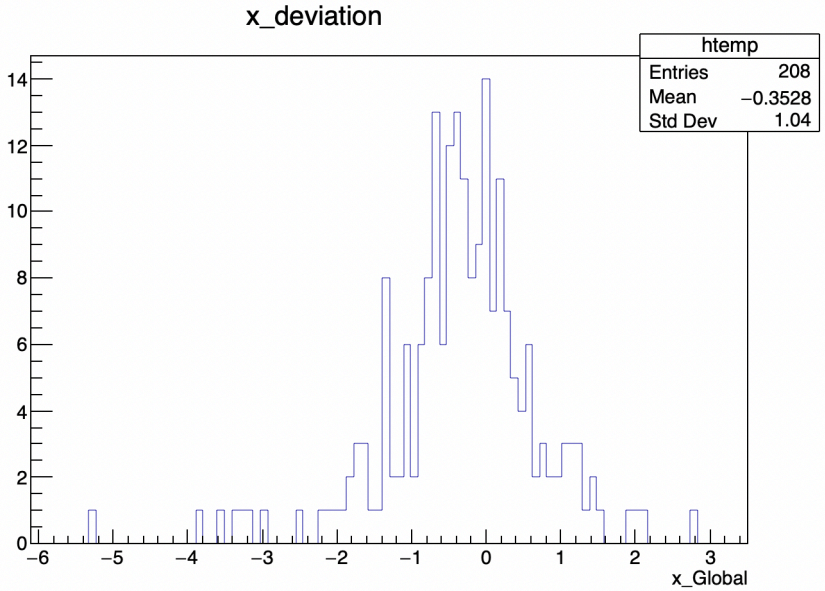
- Top side widths are used as parameters for data selection.



Results of alignment

- Mean value of deviations are in 1.1mm
- All σ of deviations are ~ 1 mm

- All the deviations are in ~ 5 mm



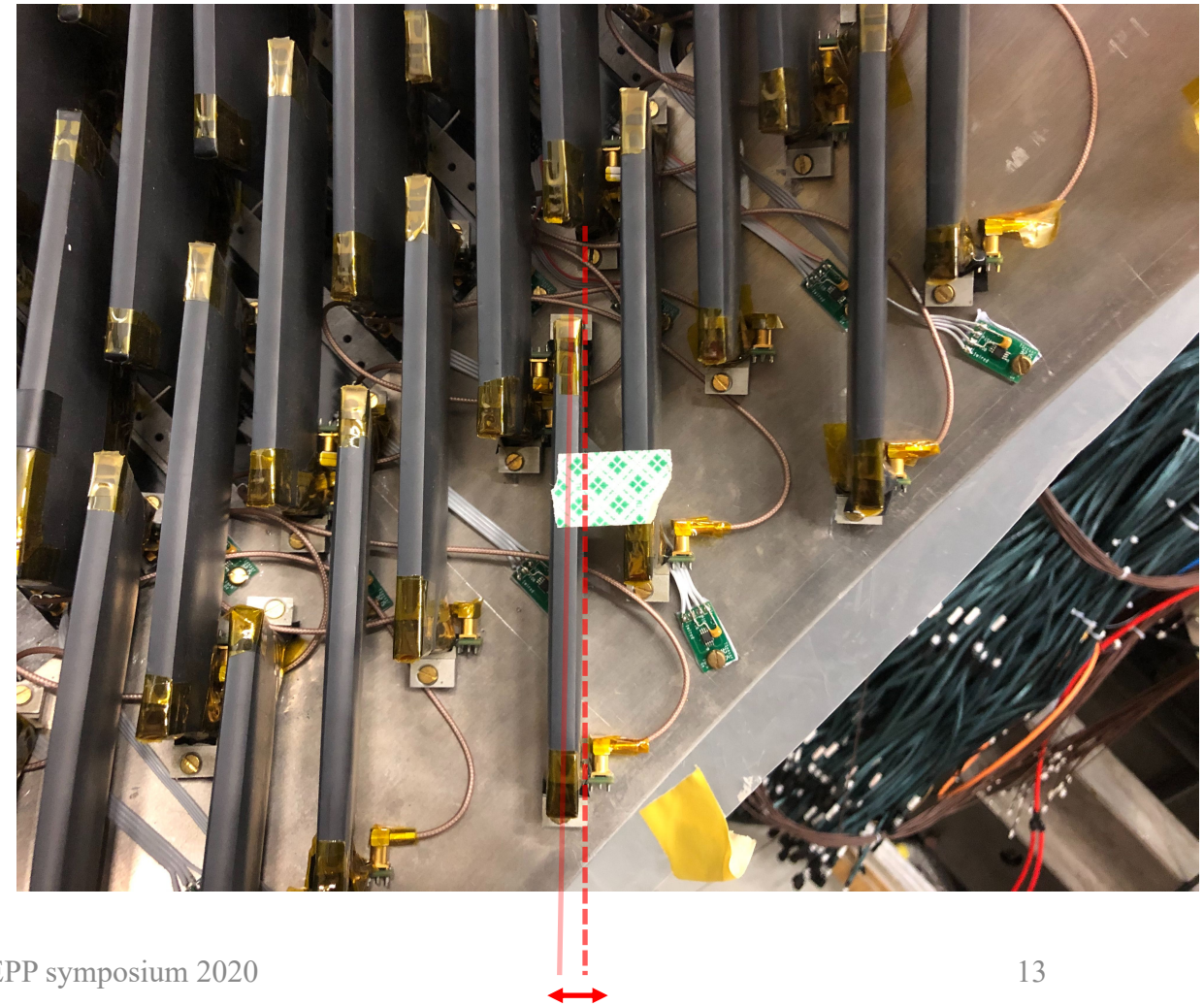
↑ x deviation of DS TC

value	dx (US)	dy (US)	dz (US)	dx (DS)	dy (DS)	dz (DS)
mean	0.15 mm	0.65 mm	1.1 mm	-0.35 mm	0.43 mm	-0.33 mm
Std_dev	0.75 mm	0.86 mm	0.88 mm	1.0 mm	1.1 mm	1.2 mm

Conclusion of alignment

- The results contain effects of alignment, construction and installation of pTC.

- Accuracy of this alignment can be estimated from $\sigma \sim 1$ mm $> \sigma_{\text{alignment}}$



* Outlier

- Pixels which show larger deviations than 3mm are visually confirmed to be deviated (→)

Contents

- Introduction
- MEG II experiment
- Pixelated Timing Counter
- pTC alignment

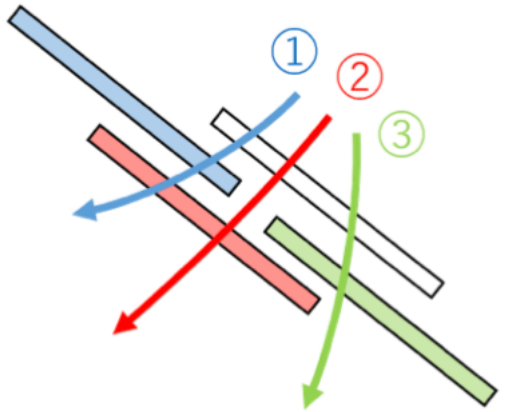
- Alignment
- Instrumentes
- Analysis flow
- Scan data
- Results
- Conclusion

- MC study
- TOF from reconstructed track
- Results
- Conclusion

- Summary & Prospect

TOF from reconstructed track

- Geometry changes affect on reconstructed track and Time of Flight (TOF) of particles.
- 1mm difference makes 3 ps difference for particle at light speed.
- TOF of background e^+ is used for TC time calibration.
- In the past, no study on effects by geometrical deviations



→ MC study for deviated geometry

3 types of TC geometry configuration

1. Designed geometry (No deviations)
2. Geometry with random deviations (0~5mm)
3. Geometry with measured deviations from alignment

Results (1) No deviations

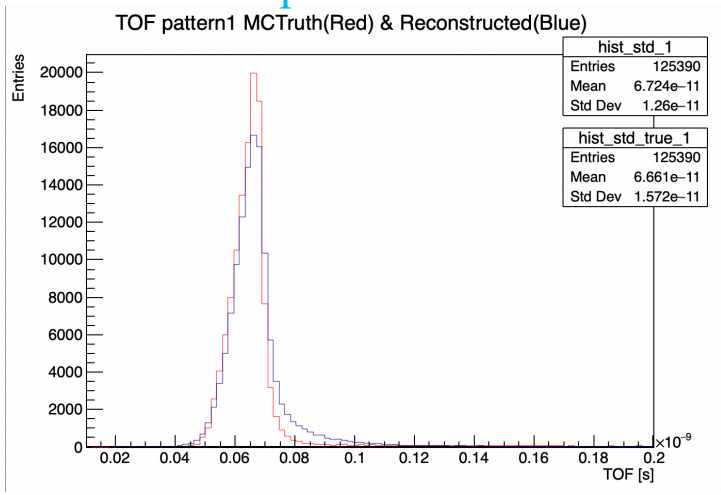
- Designed geometry
- Reconstruction with the same geometry

- Red: TOF from MC Truth

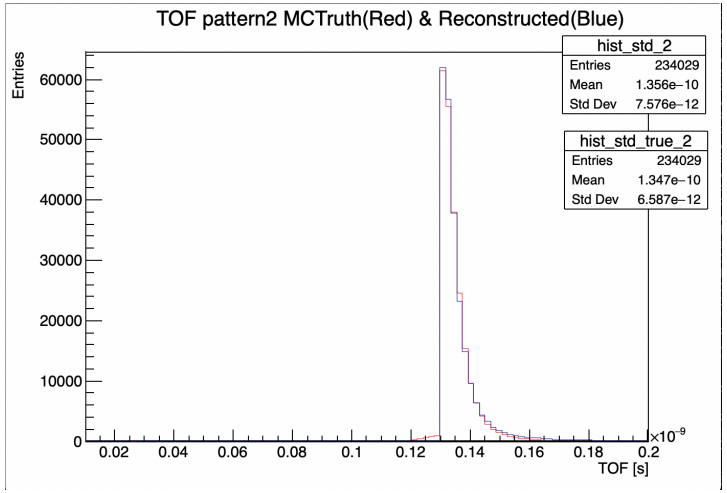
  Blue: TOF from reconstructed track

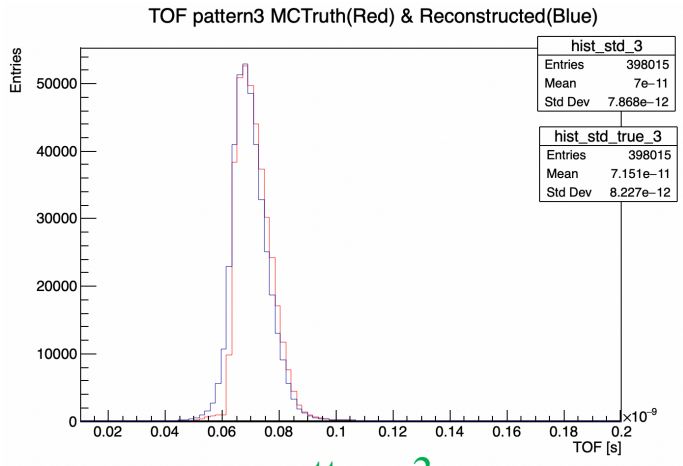
→ Well reconstructed

pattern 1



pattern 2





pattern 3

Results (2) Random deviations

- Randomly deviated from design

  ($|dx_i| < 5$ mm)

- Red: TOF from MC Truth

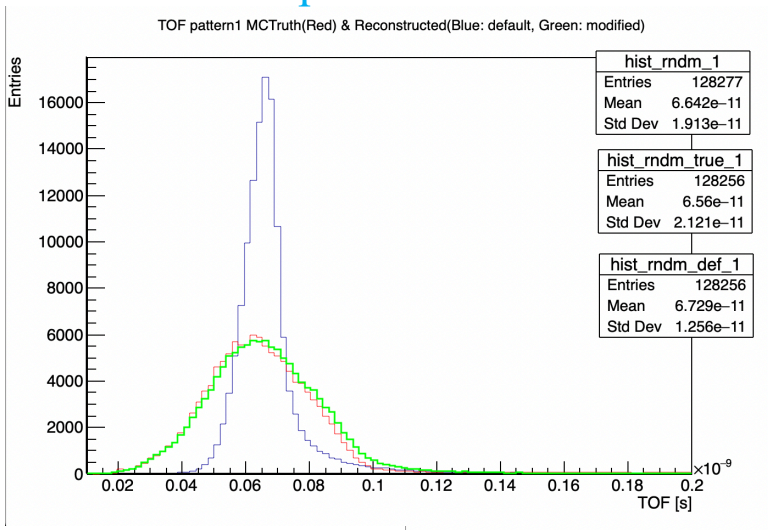
- Reconstruction with **2 types of geometry**

  1. Adjusted geometry (Green)

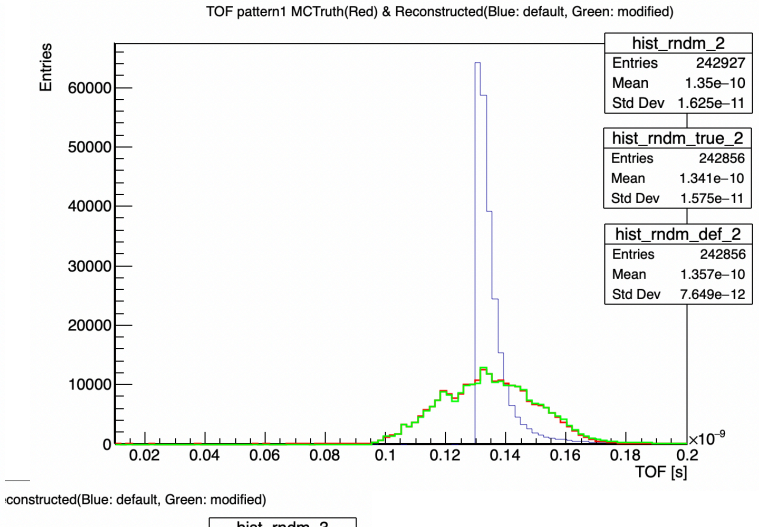
  2. Design geometry (Blue)

→ Well reconstructed by the adjusted geometry

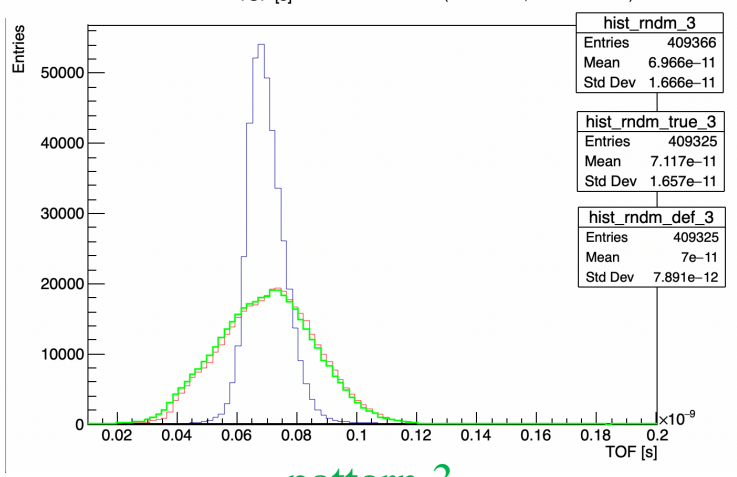
pattern 1



pattern 2



pattern 3



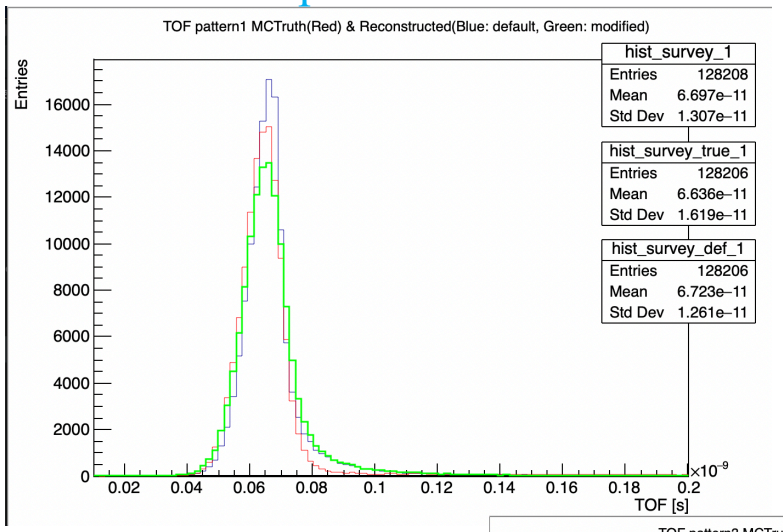
Results (3) Deviations from alignment

- Deviated with measured value from 3D scan
- Red: TOF from MC Truth

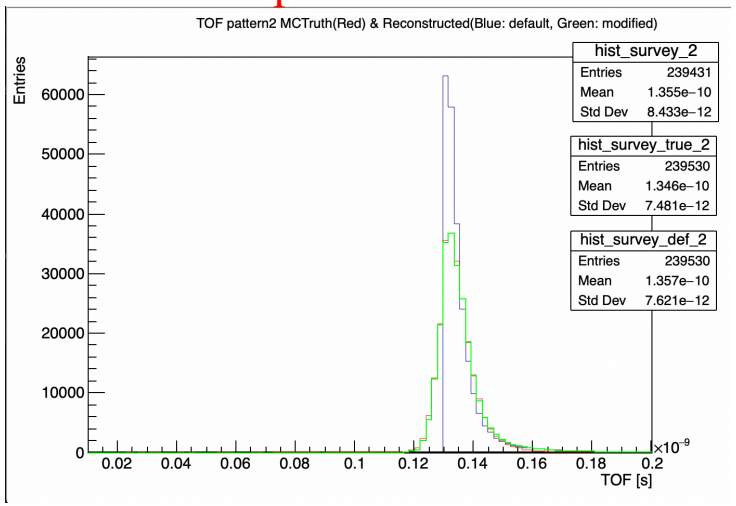
- Reconstruction with **2 types of geometry**
  1. Adjusted geometry (Green)
  2. Design geometry (Blue)

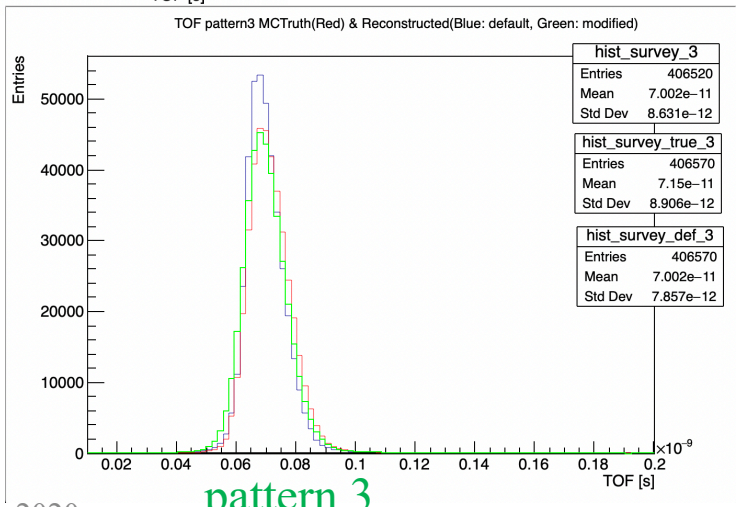
→ Well reconstructed by the adjusted geometry except for pattern 1.

pattern 1



pattern 2





pattern 3

Conclusion of MC study

- If every pixel has randomized 5mm deviation, the TOF distribution is apparently changed.
- On the other hand, measured deviations seems not affect so much.

→ Pixels with large deviations are rarely hit?

- TOF changes can be properly calculated with precise alignment.

→ Track reconstruction can be corrected by alignment.

Summary

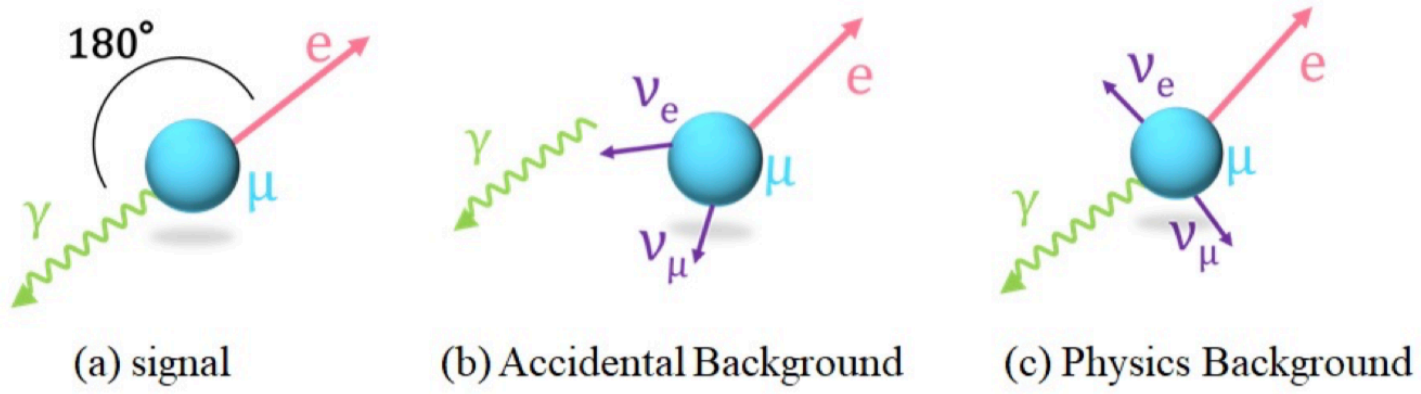
- Alignment for pixelated timing counter was done in 1mm accuracy with 3D scanner and laser tracker.
- The present alignment can improve track reconstruction.

Prospect

- Develop a method to measure direction angles for each pixel.
- More study for geometry change effects on event reconstruction.

Back up

$Mu^+ \rightarrow E^+ + Gamma$ decay



(a) signal (b) Accidental Background (c) Physics Background

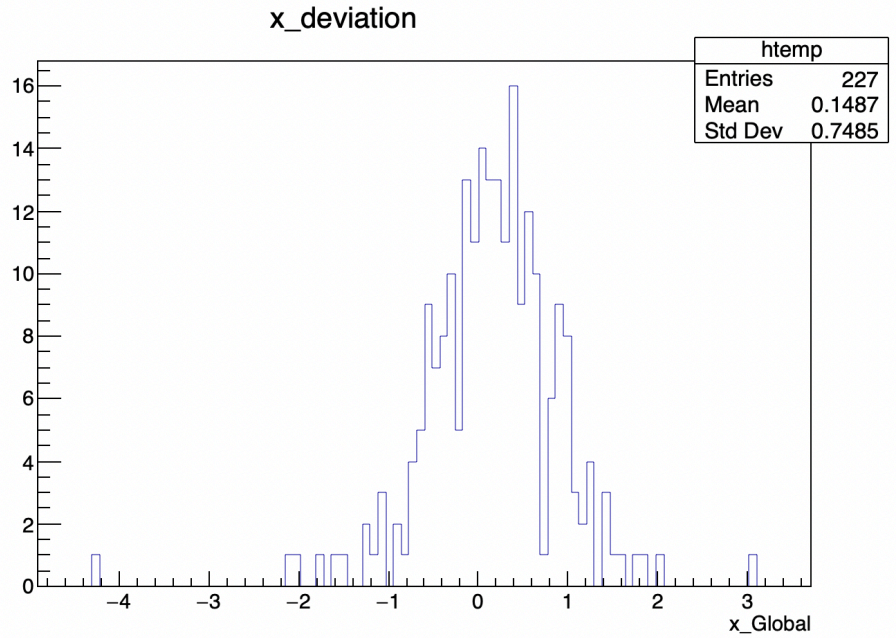
(a) $\mu^+ \rightarrow e^+ \gamma$

(b) $\mu^+ \rightarrow e^+ \nu_\mu \nu_e$ (Michel decay)
γ (photon from RMD, bremsstrahlung or AIF)

(c) $\mu^+ \rightarrow e^+ \nu_\mu \nu_e \gamma$ (Radiative Muon Decay (RMD))

In order to distinguish signal events from these background expected 4 times more than MEG, resolution of each detector should be totally upgraded.

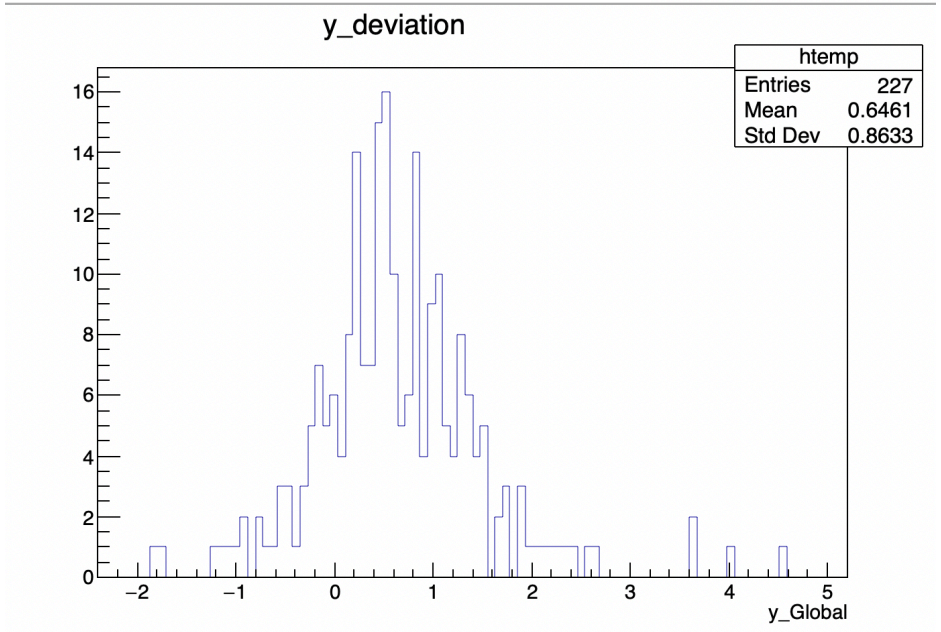
Results - US

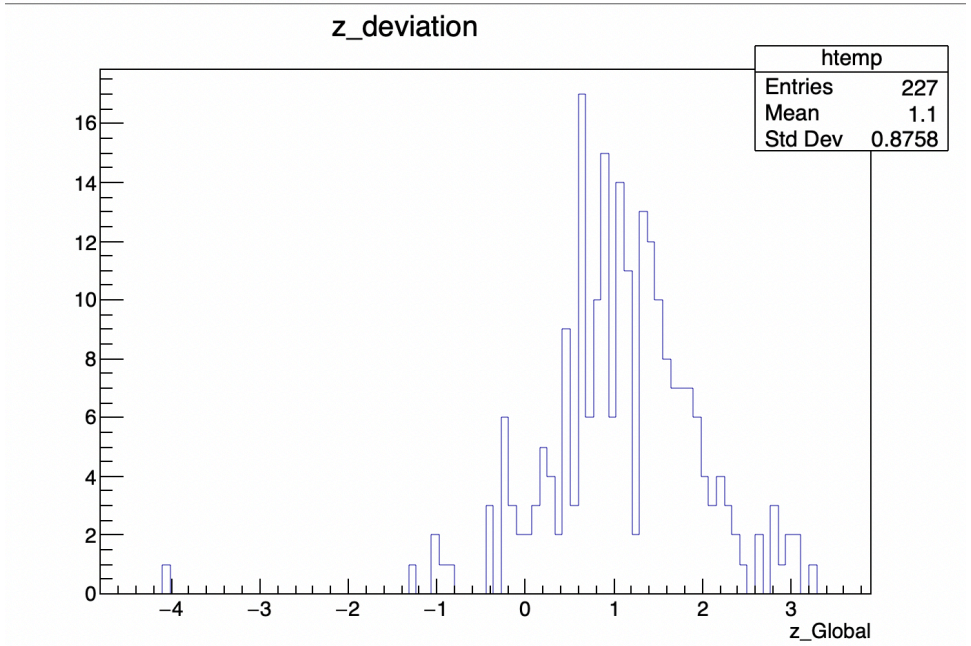


$dx_{mean} = 0.15$ mm
$\sigma_x = 0.75$ mm

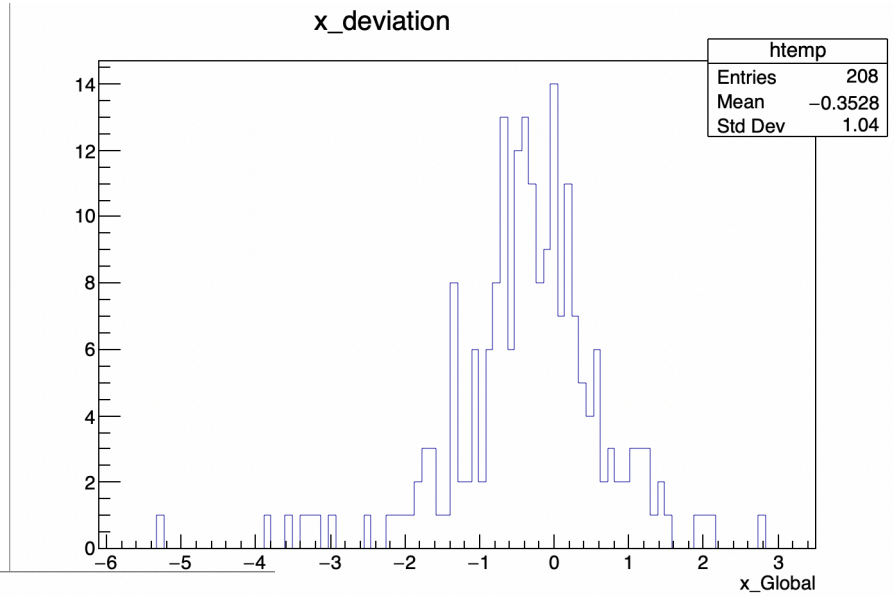
$dy_{mean} = 0.65$ mm
$\sigma_y = 0.86$ mm

$dz_{mean} = 1.1$ mm
$\sigma_z = 0.88$ mm





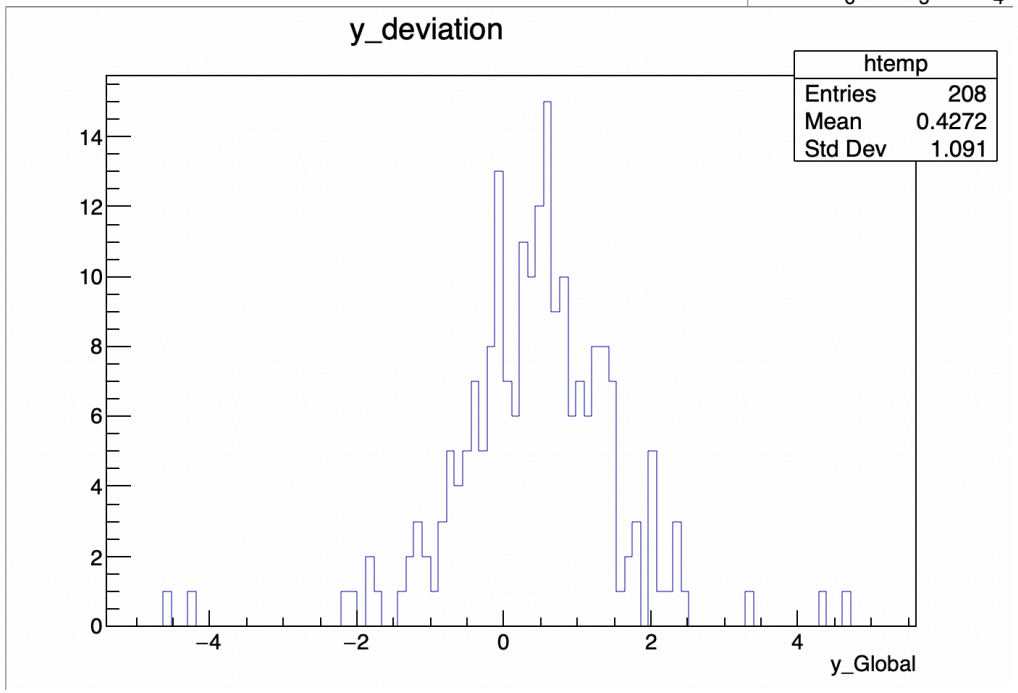
Results - DS

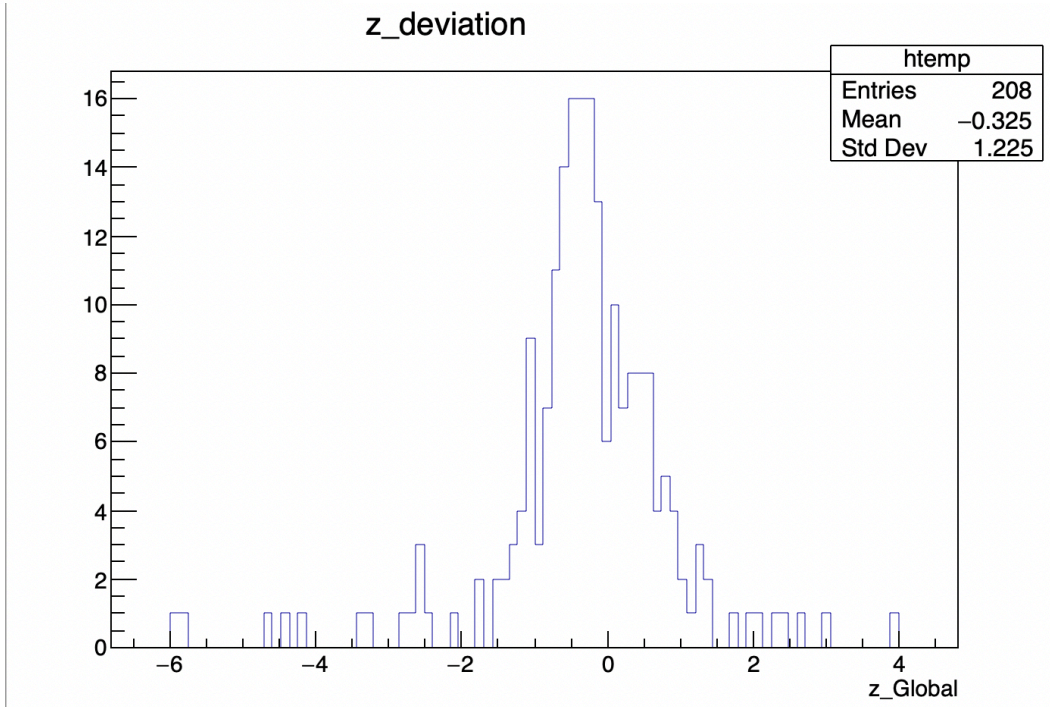


dx_{mean} = -0.35 mm
σ_x = 1.0 mm

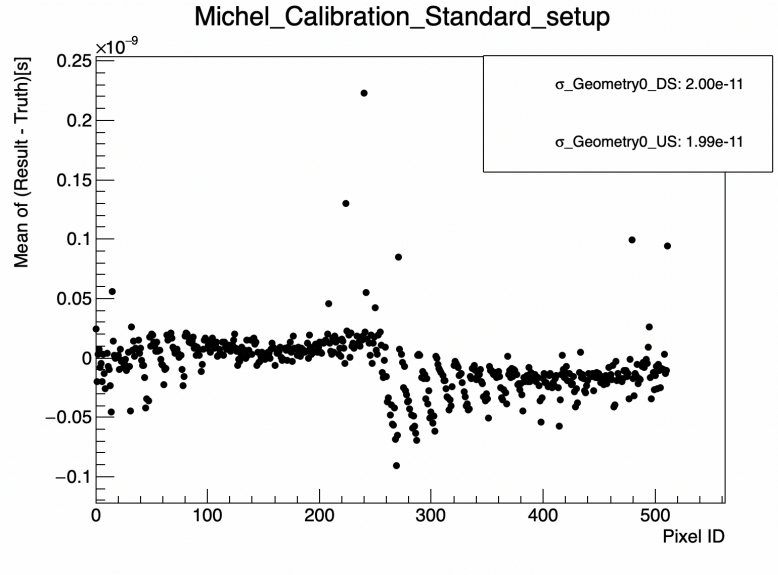
dy_{mean} = 0.43 mm
σ_y = 1.1 mm

dz_{mean} = -0.33 mm
σ_z = 1.2 mm

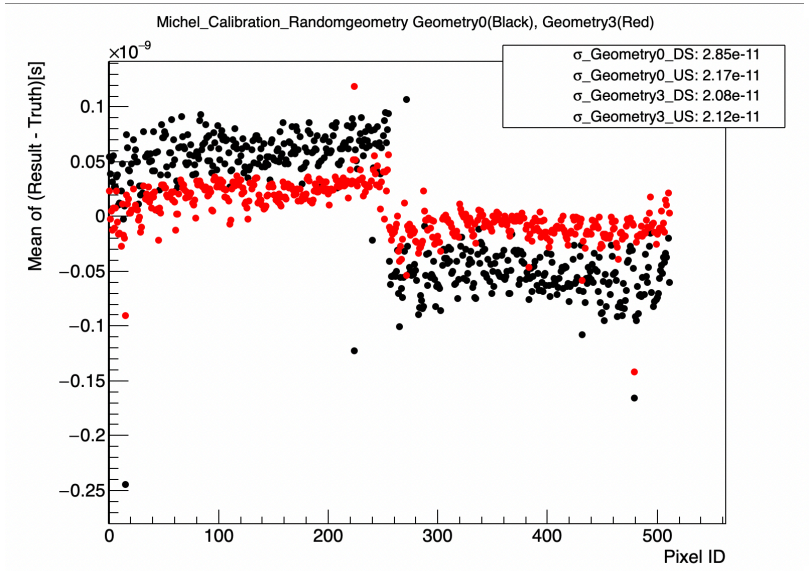




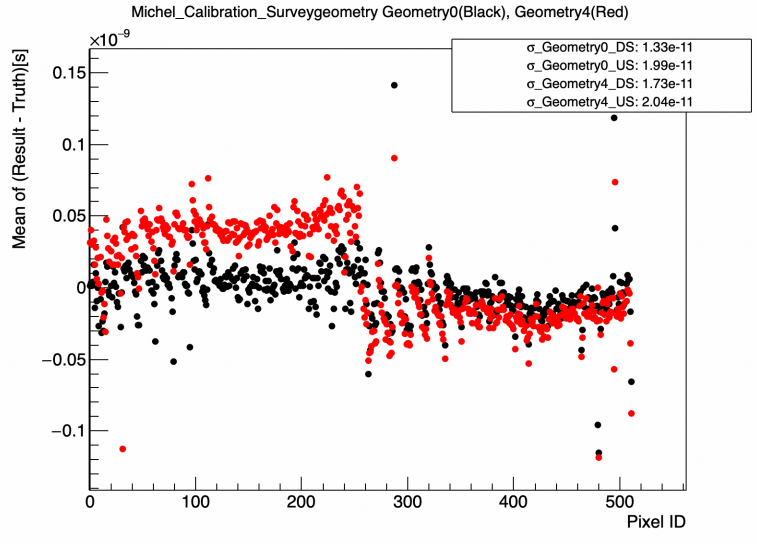
Results (4) TC timing calibration



(1) no deviations



(2) random deviations



(3) measured deviations

Black: reconstruction with designed geometry
Red: 〃 with adjusted geometry

- Y indicates: (calibration result) – (MCtrue time offset)
- Timing calibration is improved by adjusting geometry for (2), but not for (3)

Effect on pTC time resolution

- Standard setup – 4cm pixel: 27.3 ps
  5cm pixel: 35.1 ps
- Random deviations (< 5mm)

default analysis (not know the deviations) – 4cm pixel: 27.1 ps
5cm pixel: 35.0 ps

custom analysis (know the deviations) – 4cm pixel: 27.1 ps
5cm pixel: 35.0 ps

- Measured deviations

default analysis (not know the deviations) – 4cm pixel: 27.2 ps
5cm pixel: 34.7 ps

custom analysis (know the deviations) – 4cm pixel: 27.2 ps
5cm pixel: 34.7 ps