

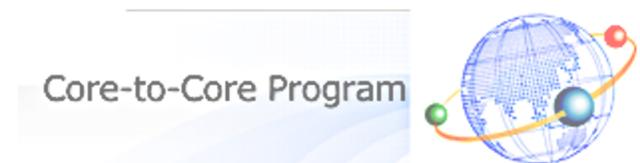
MEG II実験陽電子タイミンングカウンターの 位置較正及び時間分解能に対する影響の評価

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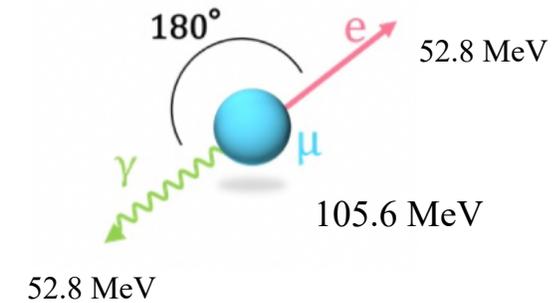
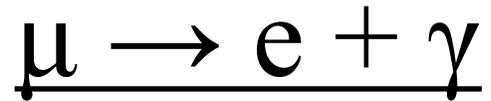
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 - $\mu \rightarrow e + \gamma$
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- One of charged lepton flavor violating decays, which is forbidden in the Standard Model.
- Many of the new physics beyond the Standard Model predict that the branching ratio is $\mathcal{O}(10^{-13})$ – $\mathcal{O}(10^{-14})$ mediated by an undiscovered particle in $\mathcal{O}(10)$ TeV.
- Considering the high energy scale particle and the small branching ratio, high intensity muon beam is effective to search the decay.
- Upper limit on the branching ratio: $\mathcal{B}(\mu^+ \rightarrow e^+ + \gamma) < 4.2 \times 10^{-13}$ (90% C.L.)
↑ Final results of the MEG experiment

MEG II experiment

- Upgrade of the MEG experiment

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

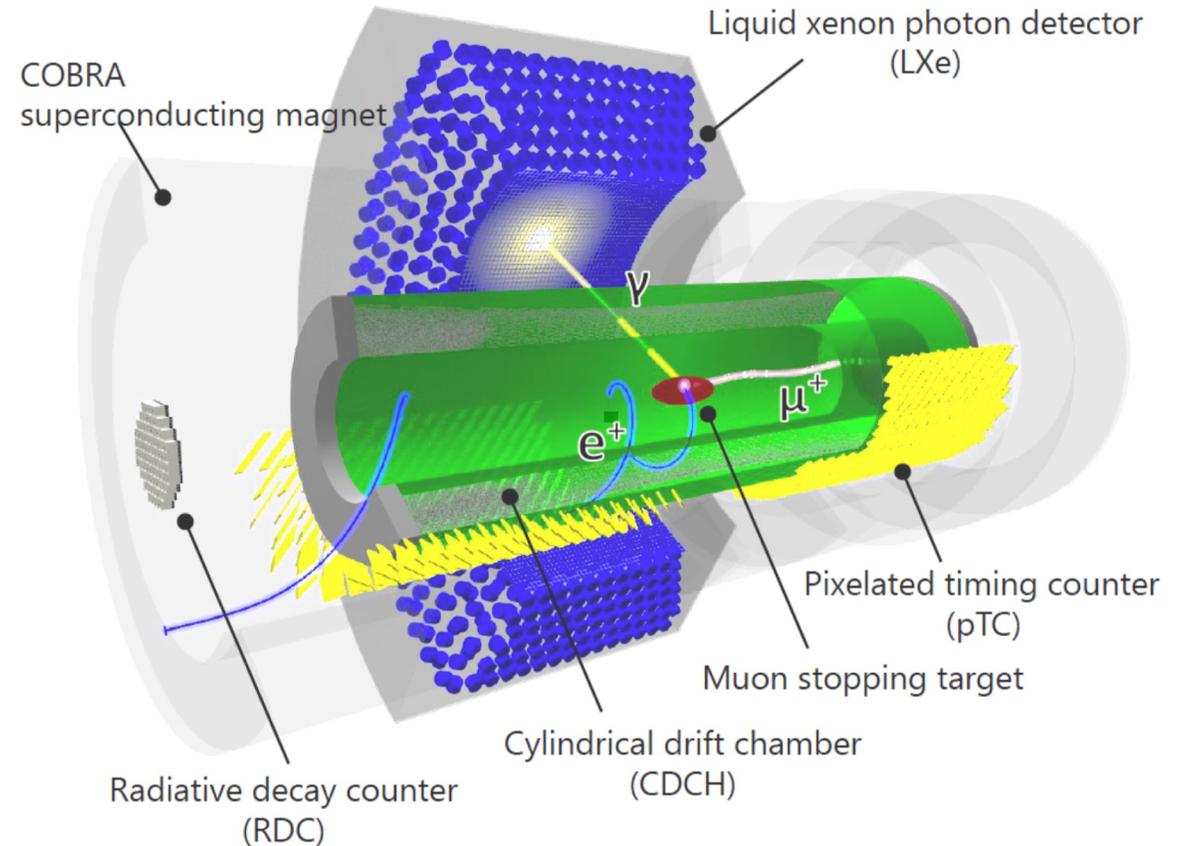
μ^+ : most intense beam at PSI ($10^8 \mu^+ / s$)

γ : detected by LXe

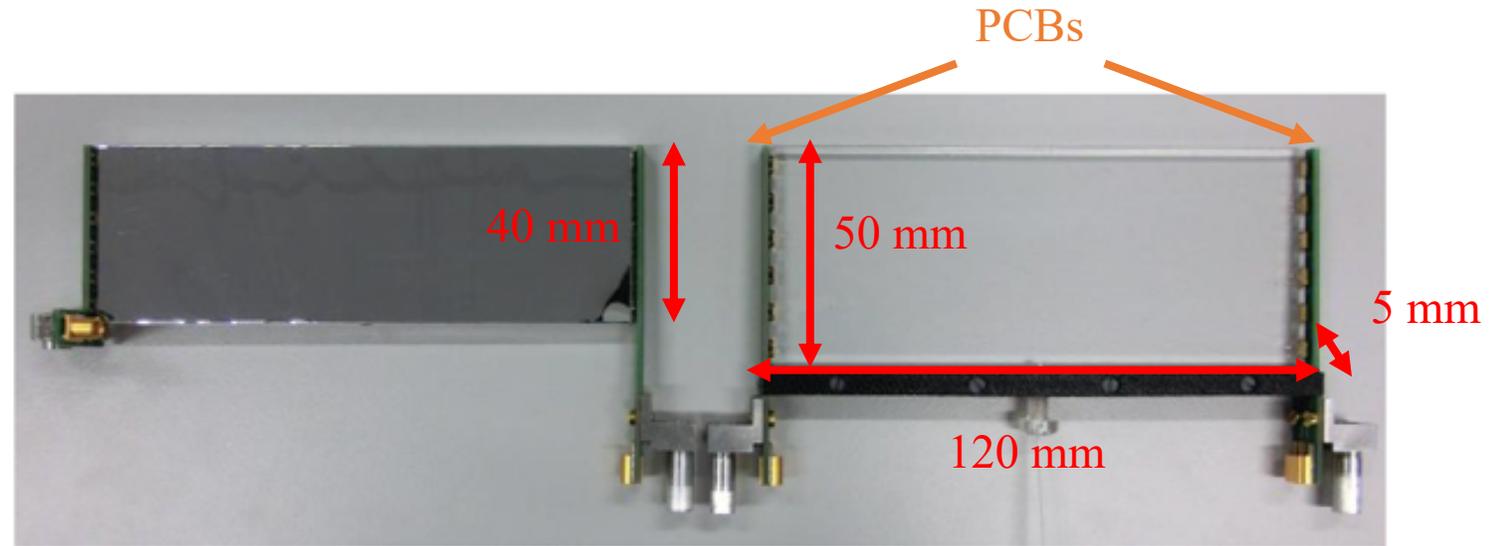
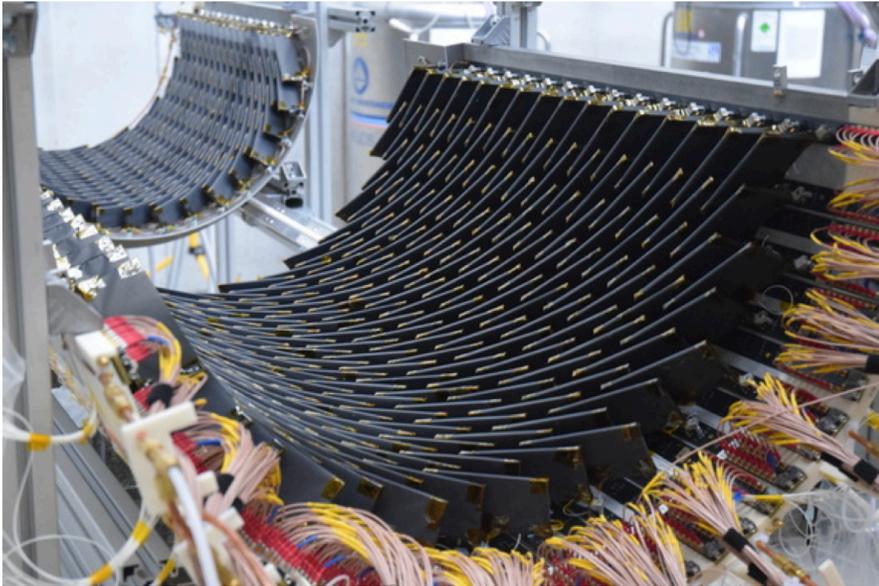
e^+ : bent by COBRA magnet,
detected by **pTC** & CDCH

- expected sensitivity:

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

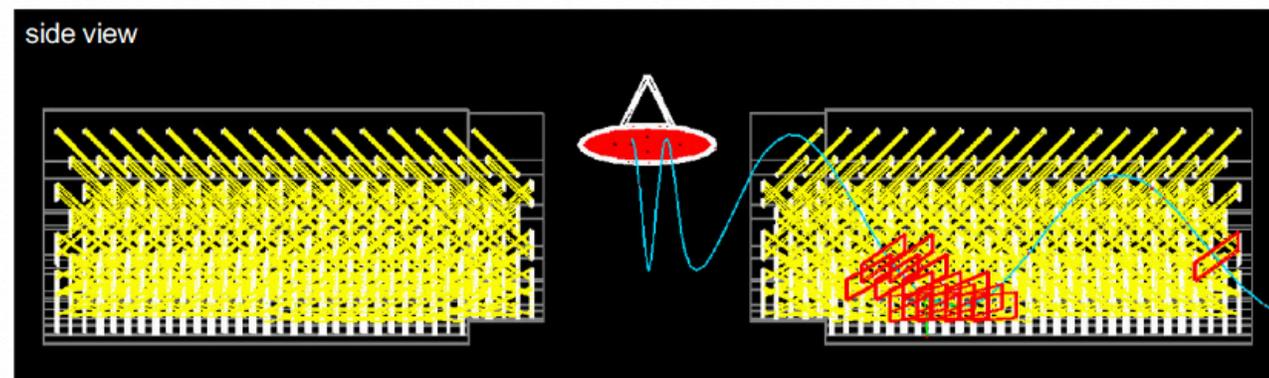


MEG II - Pixelated Timing Counter

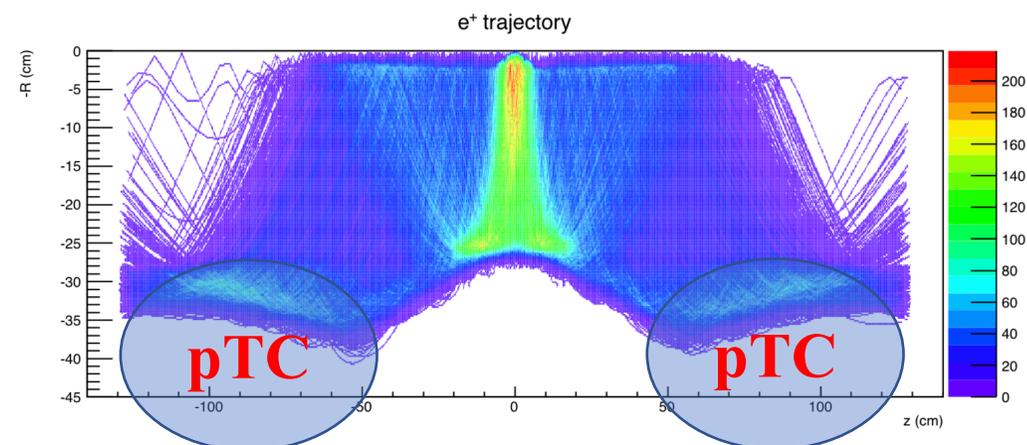


- a highly segmented (**256 tiles** \times 2) scintillation detector on two semi-cylindrical super-modules.
- each counter consists of a **120mm** \times **40mm** (**50mm**) \times **5mm** plastic scintillator.
- read by series connection of 6 SiPMs attached to both side of the scintillator.
- time resolution \sim **38 ps** for 9 hits (average number of hits for signal e^+), whereas 90~100 ps for a single hit.

pTC alignment



- Position difference among hit counters $\xrightarrow{\text{affects}}$ Track reconstruction and Time-of-Flight calculation
... has been investigated by MC study
- Position of whole pTC $\xrightarrow{\text{}}$ e^+ detection efficiency ... will be investigated



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Flowchart

3D scan by FARO 3D ScanArm (see Backup)

① Scan pTC and get scan data of the following (✓ Mar. 2019).

- 512 counters
- **laser tracker targets**



Laser survey by Leica laser tracker (see Backup)

② **Laser tracker targets** are measured in the MEG II global coordinates system (✓ Sep. 2019).



Calculate transform matrix by **laser tracker targets**

③ Counters in the 3D scanner coordinates system can be transformed into the MEG II global coordinates system.



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

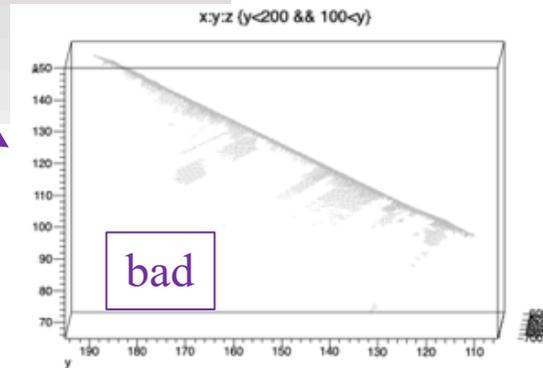
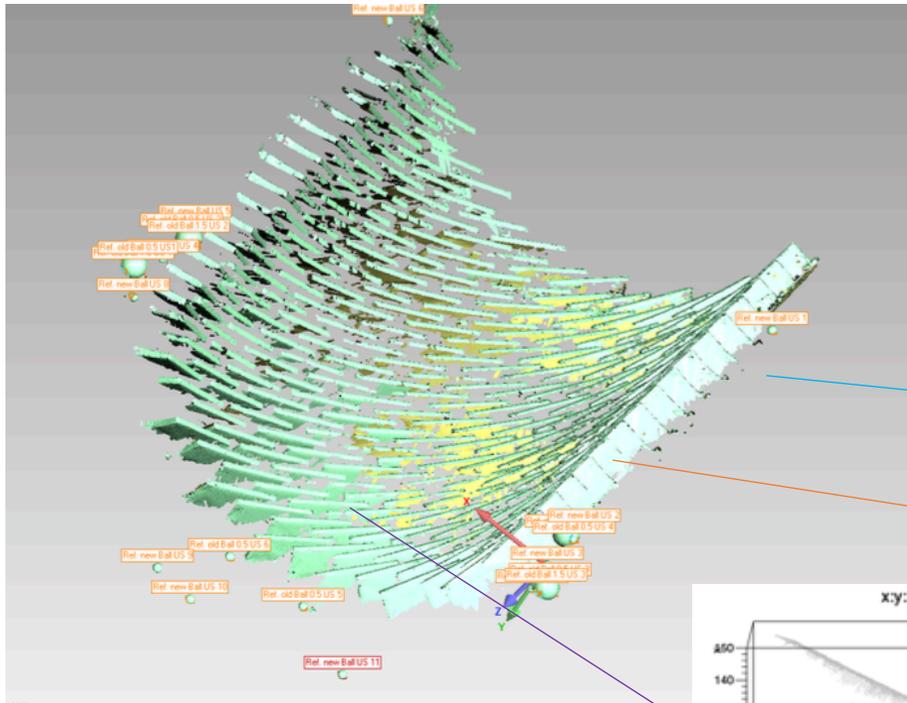
Design value of counter positions
(now used in MEG II software)

Measure deviations
(=Alignment)

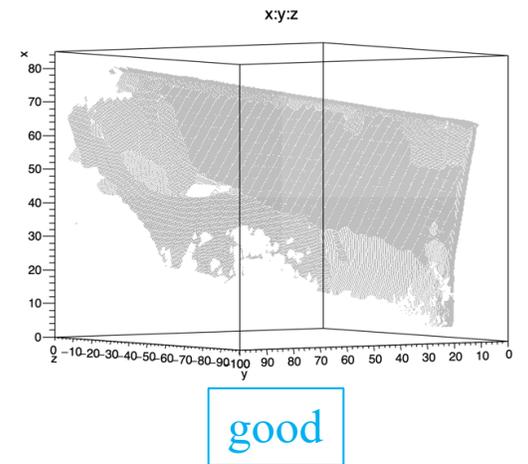
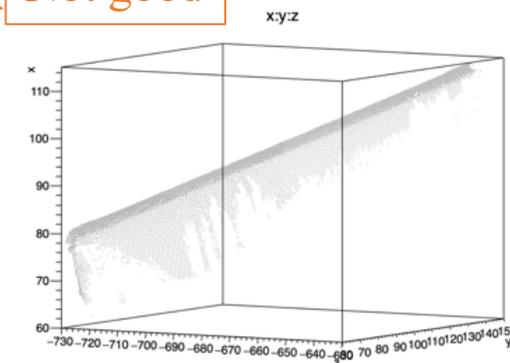
Get counter positions in the MEG II
global coordinates !

Scan data - overview

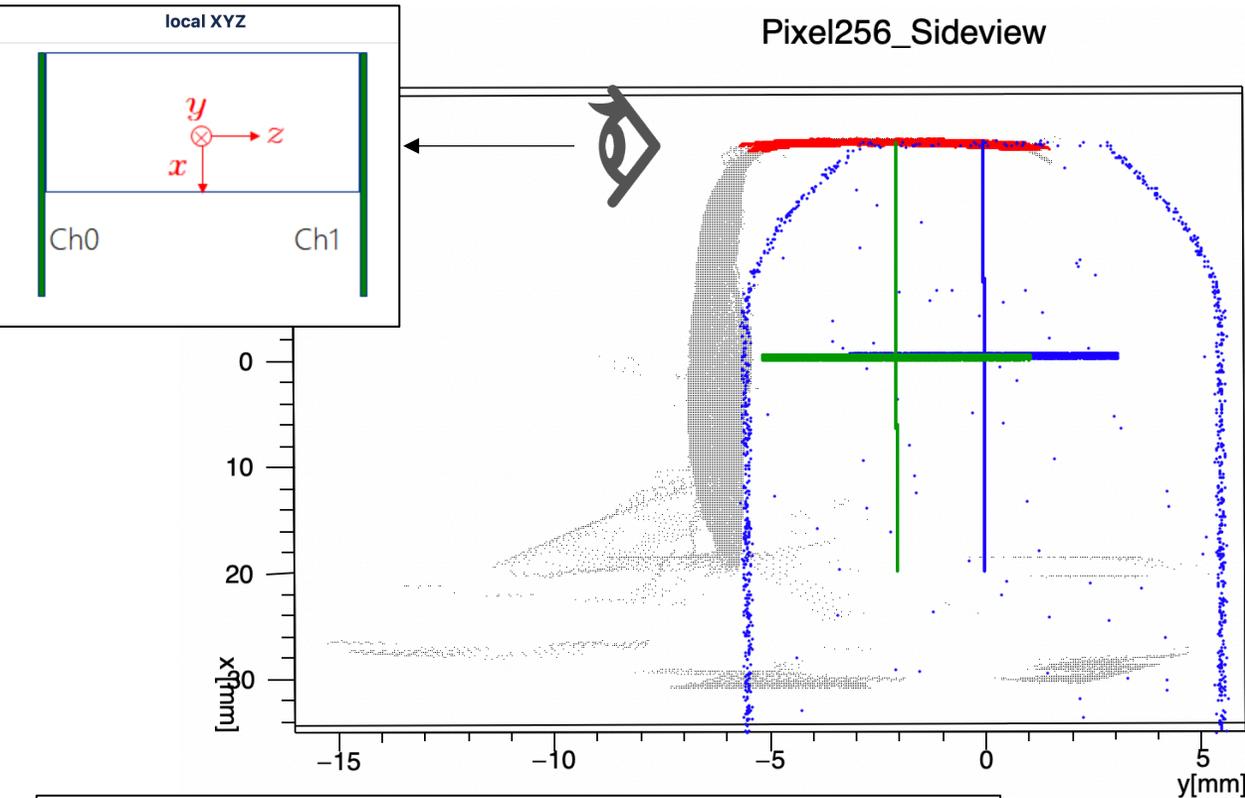
- Scan data are available as an array of (x,y,z) points
- Data is lacking because the light of 3D scanner could not reach
- 77 counters from 512 counters are excluded from analysis due to bad data condition



Not good



Scan data - handling



Gray : Data points

Red : Extracted data points as a top side

Blue : Designed position of a counter

Green : Measured position of a counter

- Design values are used as initial values to transform counters into counter-local XYZ
- Top side of counters, mostly scanned in good condition, are manually extracted from data points. They are adopted as indicators of counter positions (shown in red).
- Center position of each counter is calculated from the maximum and minimum points from its top side:
$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} (x_{max} + x_{min})/2 \\ (y_{max} + y_{min})/2 \\ (z_{max} + z_{min})/2 \end{pmatrix}$$
- Counter position from the center position is shown in green, whereas designed one is in blue.

Scan data – Data selection

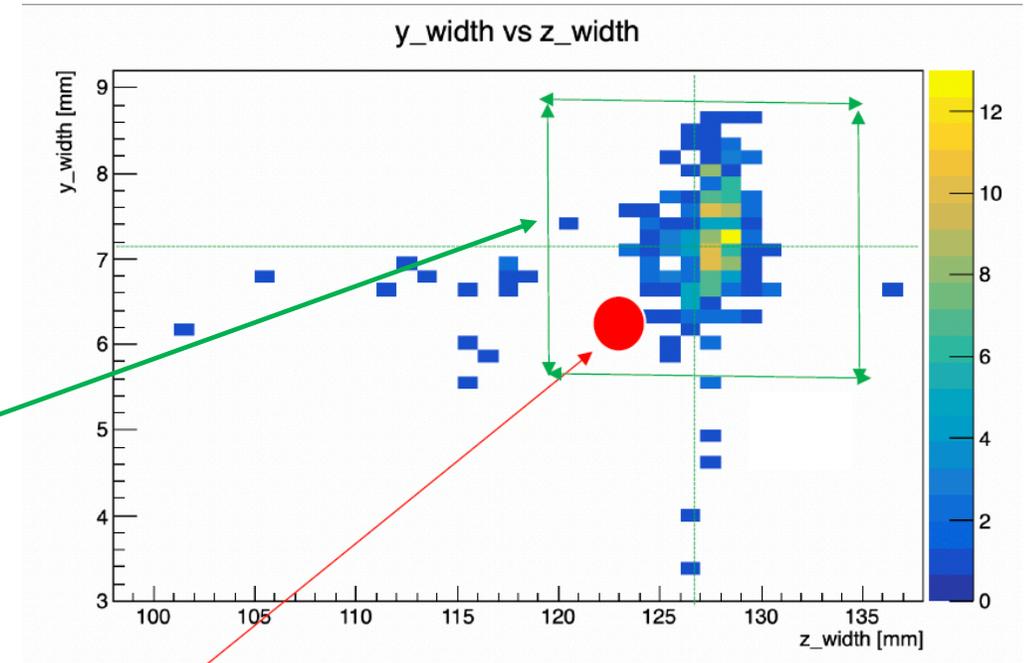
- Top side widths

y width: $|y_{max} - y_{min}|$

z width: $|z_{max} - z_{min}|$

are used as parameters for data selection.

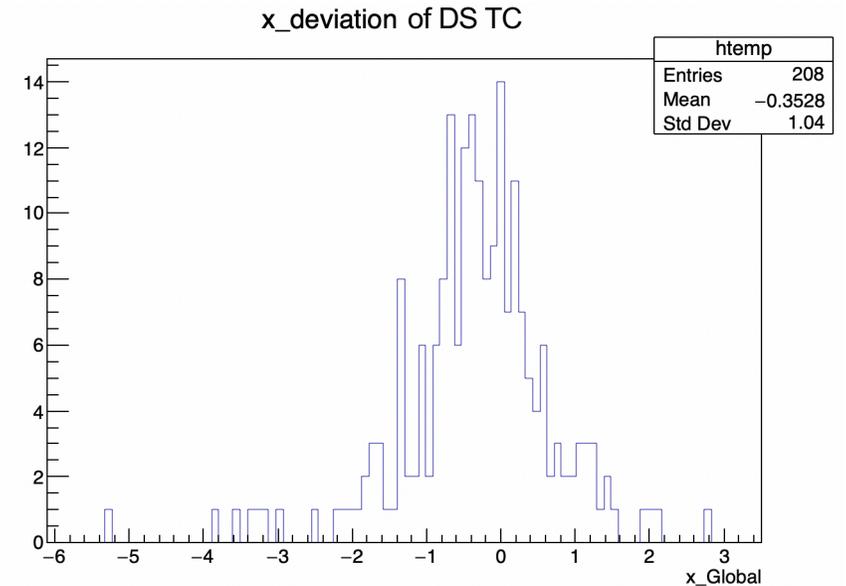
435 counters in
selected area



designed scintillator+SiPM+PCB size of top side

Results of alignment

- Mean value of deviations b/w are in ~ 1.1 mm
- All the standard deviation σ are in ~ 1.2 mm
- Maximum value of the deviation is ~ 5.5 mm



*US = up stream
DS = down stream

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

Discussion of alignment

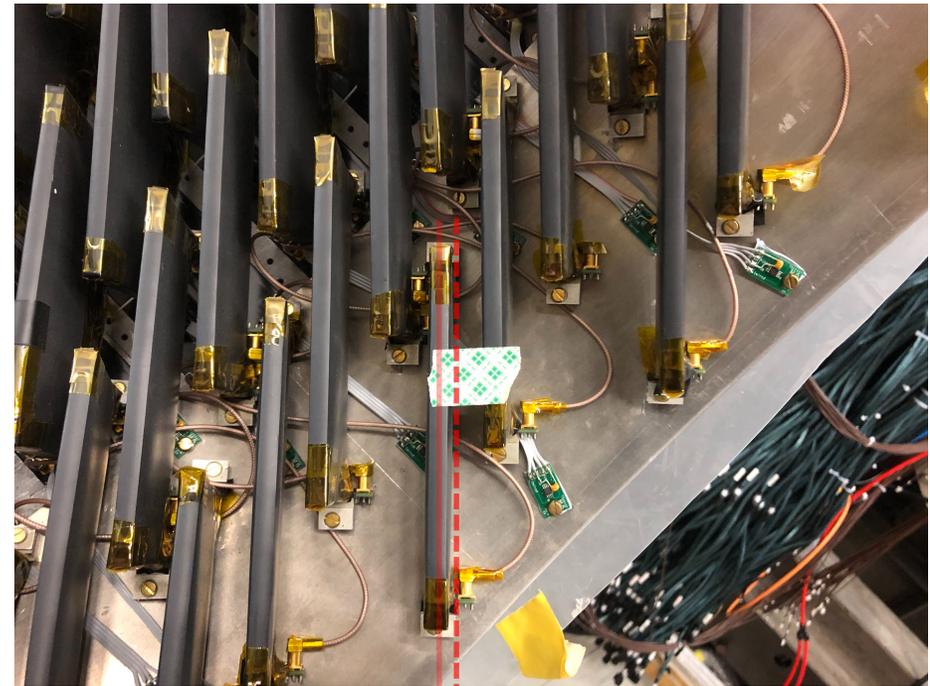
- We aim to measure geometrical error of pTC construction, assembly or installation.

→ Several millimeters.

- The results also reflect accuracy of the alignment method.

→ The alignment has done in 1.2 mm accuracy
(maximum std. dev)
for each x,y,z axis.

- * Counters with large deviations from design
 - More than 3mm misaligned counters can be confirmed by sight or with a ruler
 - We can check whether excluded 77 counters have large deviations from design or not.



real position | designed (expected)



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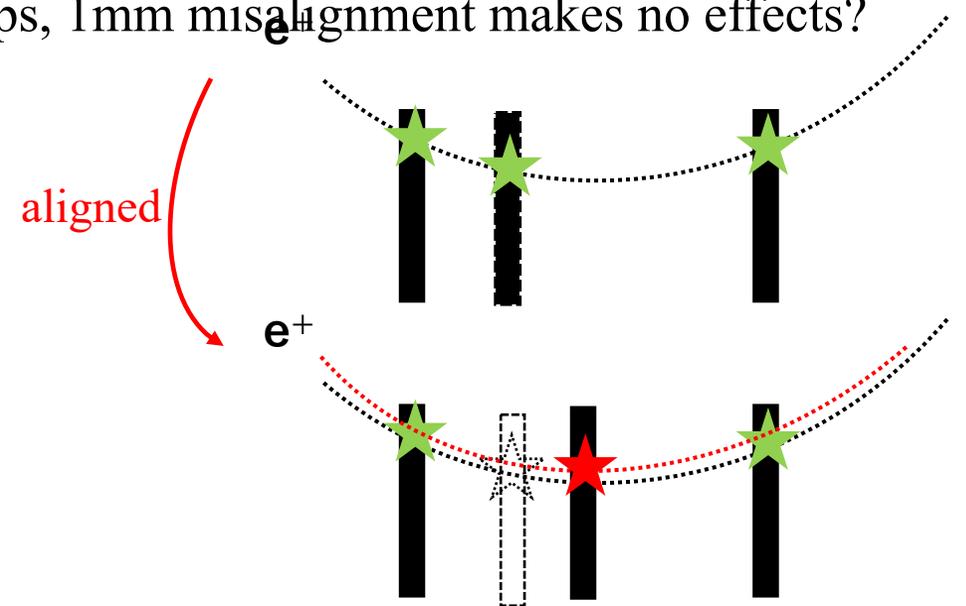
TOF from reconstructed track

- In the past, there are no detailed studies on effects of misalignment of pTC.
- Misalignment would worsen track reconstruction. Then, calculation of Time of Flight (TOF) would be worsen.
- 1mm difference makes 3 ps difference at light speed.
→ Because time resolution for each counter alone is 90~100 ps, 1mm misalignment makes no effects?

MC study for deviated geometry

2 types of pTC geometrical setup

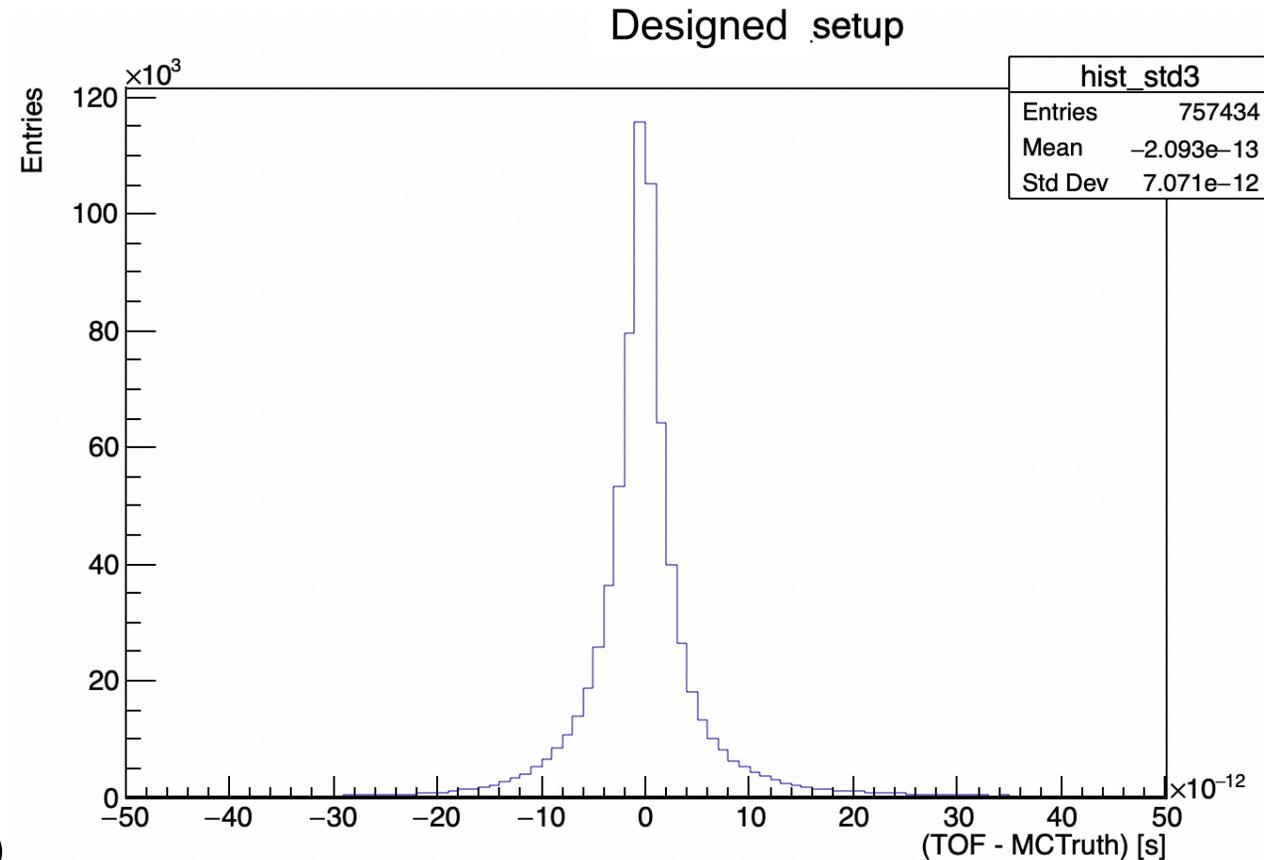
1. Designed setup (with no deviations)
2. Aligned setup (with measured deviations)



Results (1) Designed setup

- MC setup: designed geometry
- Reconstruction: designed geometry
- TOF from MC truth is subtracted from TOF from reconstructed track.

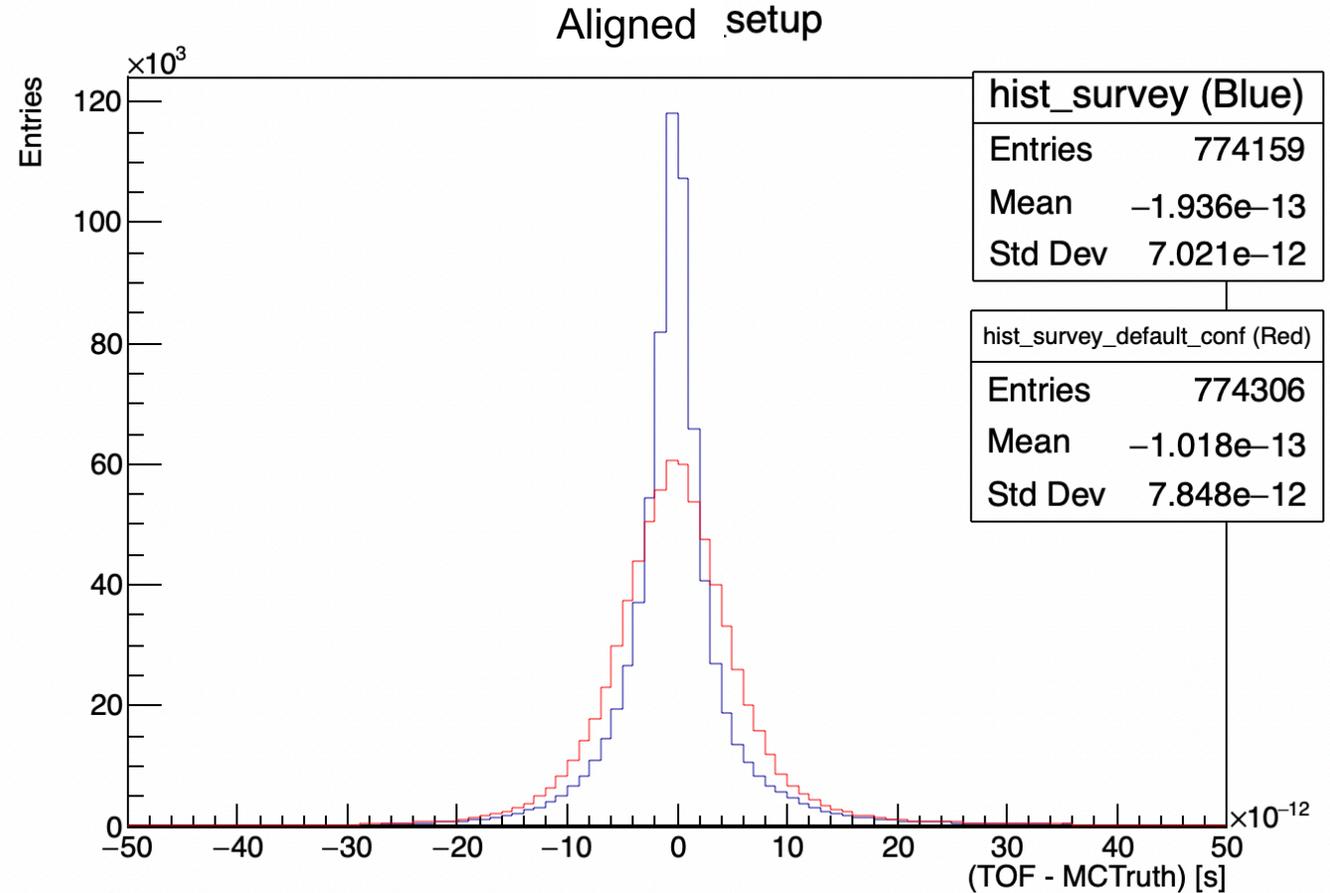
→ Ordinarily reconstructed. (**std. dev ~ 7.1ps**)



Results (2) Aligned setup

- MC setup: aligned geometry
- Reconstruction:
 1. **aligned geometry** (std. dev ~ 7 ps)
 2. **designed geometry** (std. dev ~ 7.8 ps)

→ 0.8ps better reconstructed by the aligned geometry



Discussion of MC study

- Measured deviations worsen accuracy of the calculation by **0.8 ps**.
- **The realistic situation should be intermediate** b/w completely knowing the deviation and not knowing them.
- Maximum effect on the time resolution for reconstructed time from track TOF is estimated:

$$\frac{\frac{\sqrt{(\sigma_{single}^2 + 7.8^2) \times N}}{N}}{\frac{\sqrt{(\sigma_{single}^2 + 7^2) \times N}}{N}} \cong 1.0006 \sim 1.0007$$

$\sigma_{single} = 90 \sim 100 \text{ ps}$

Summary

- Alignment for pixelated timing counter was done with 3D scanner and laser tracker, and its accuracy is in 1.2mm.
- From MC simulation, measured geometrical deviations have worsen the time resolution for reconstructed time from track by 0.06~0.07%.

Prospect

- We will manually check 77 counters excluded from analysis of the alignment.
- More precise alignment will be done with new laser tracker targets.

Back up

Instruments - 3D scanner

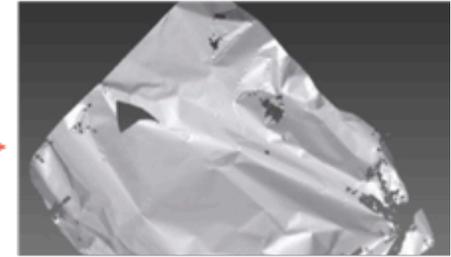
3D Scanner (FARO Edge ScanArm HD)



Picture



Scan Data



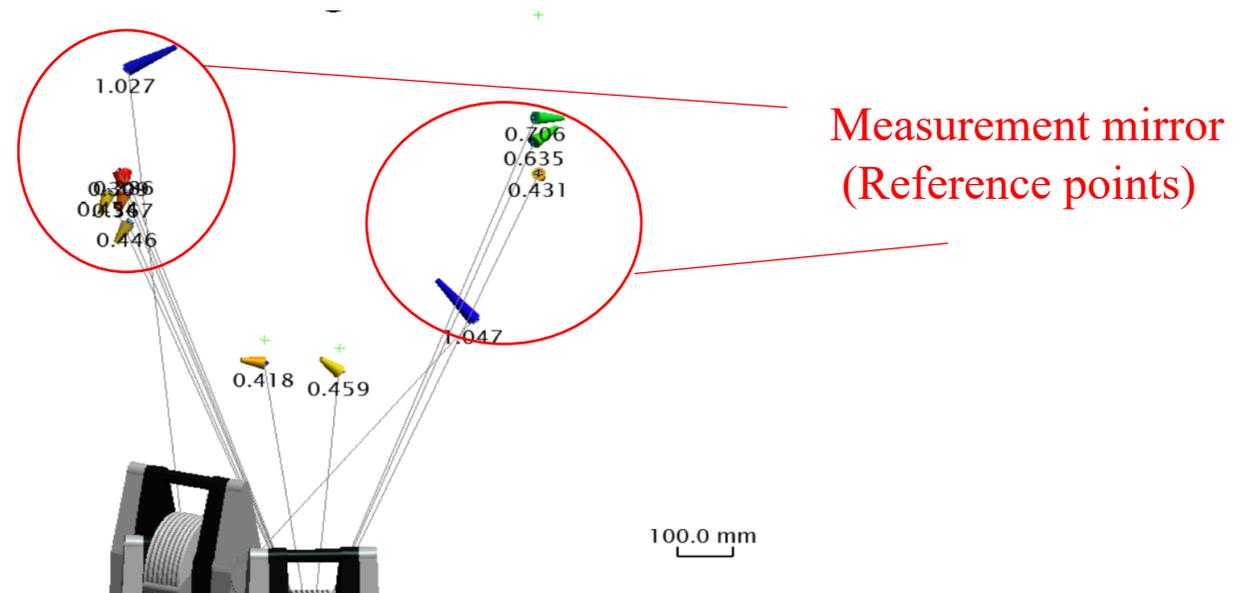
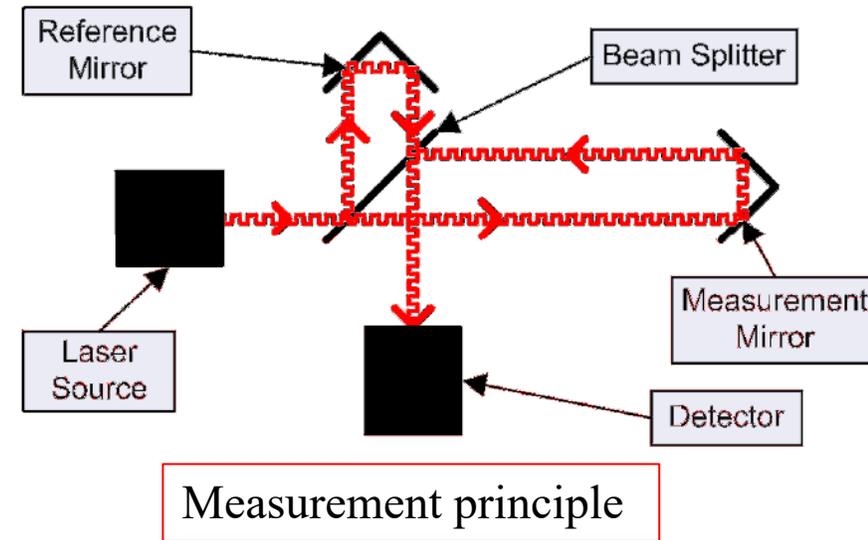
- Accuracy $\pm 25\mu\text{m}$
- Scan rate : 560,000 points/sec
- Cited from <https://www.faro.com/resource/faro-edge-scanarm-hd/>

Instruments - Laser tracker

Leica Absolute Tracker AT401



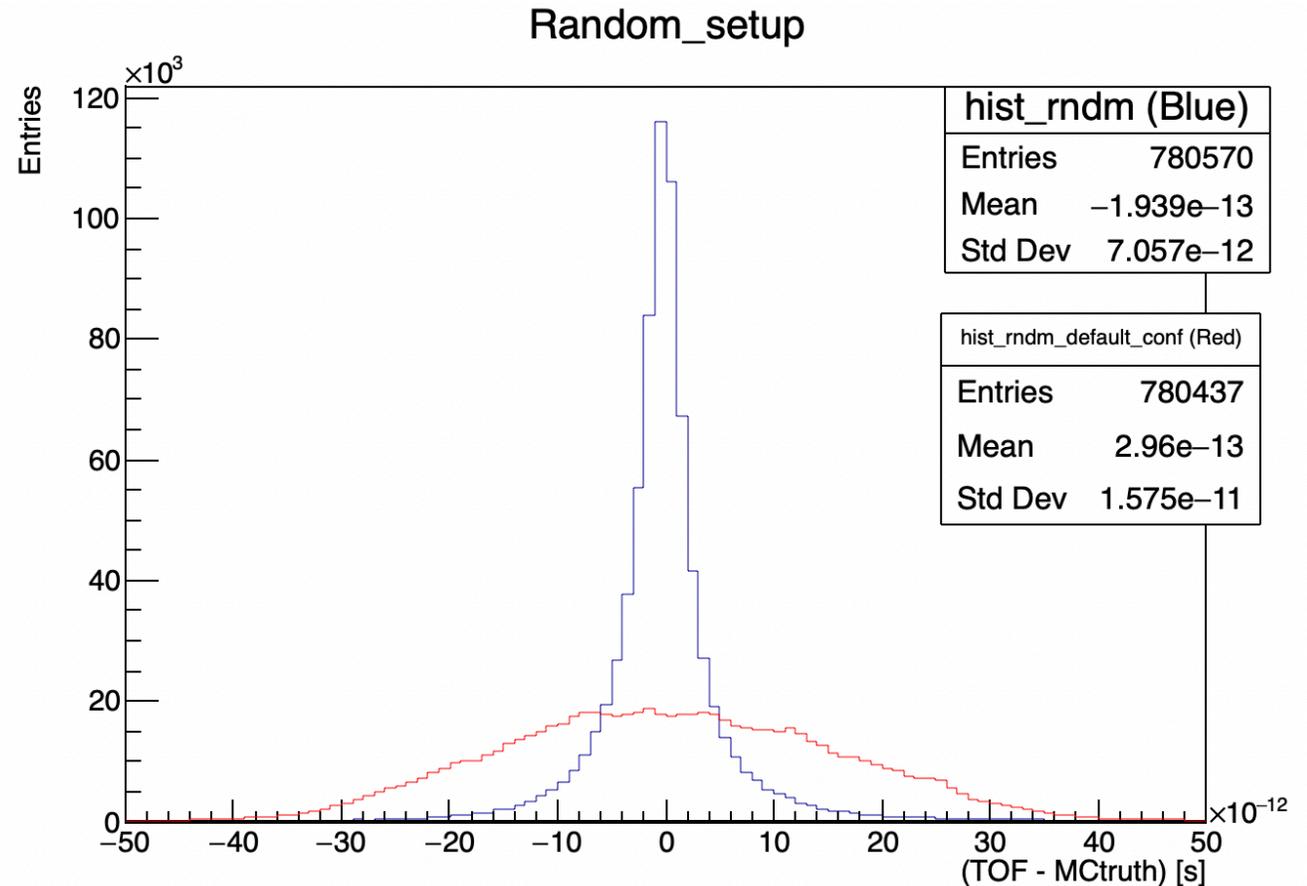
• https://w3.leica-geosystems.com/downloads123/m1/metrology/at401/brochures/leica%20absolute%20tracker%20at401_en.pdf



Results (3) Random setup

- Randomly deviated from design
 - Uniform random numbers
 - $|dx_i| < 5$ mm.
-
- Reconstructed with **2 types of geometrical configuration.**
 1. Adjusted geometry (Blue, std. dev ~ 7.1 ps)
 2. Design geometry (Red, std. dev ~ 16 ps)

→ More than twice better reconstructed by the adjusted geometry.



Results(4) Time resolution of multiple-hit

- TOF_{0n} from MC truth is subtracted from TOF_{0n} from reconstructed track
(0 / n stand for a first / last hit counter)

- Average time resolution:
 $\sum_{i=2}^{12}$ (resolution \times rate of i hit events)

standard setup : 60.2 ps

survey setup (adjusted/default config.): 61.0/60.9 ps

random setup (adjusted/default config.): 60.1/61.7 ps

