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

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• Summary & Prospect
MEG II experiment

- Upgrade of the MEG experiment

- The search for $\mu^+ \rightarrow e^+ + \gamma$ (cLFV)
  - $\mu^+$: most intense beam at PSI ($10^8 \mu^+/s$)
  - $\gamma$: 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 counter, consists of two semi-cylindrical super-modules.
- \(120\text{mm} \times 40\text{mm} (50\text{mm}) \times 5\text{mm}\) plastic scintillator (BC422).
- read by 6 SiPMs on each PCB attached to both side of the scintillator.
- overall time resolution \(\sim 38\text{ ps}\) 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 $\rightarrow$ global timing
  - among hit pixels $\rightarrow$ pTC time calibration
for multiple hits of $e^+$. 
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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


Measurement principle

Measurement mirror (Reference points)
Analysis flow

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
  • 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.

*Every time we install TC, we will restart from ②
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
Scan data - handling

- Designed angles and center position are used for translating pixels to local x-y-z

- Estimated center of pixel is calculated:

\[
\begin{align*}
(x, y, z) &= \left( \frac{x_{\text{max}} + x_{\text{min}}}{2}, \frac{y_{\text{max}} + y_{\text{min}}}{2}, \frac{z_{\text{max}} + z_{\text{min}}}{2} \right)
\end{align*}
\]

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

• Mean value of deviations are in 1.1 mm
• All $\sigma$ of deviations are $\sim$ 1 mm
• All the deviations are in $\sim$ 5 mm

<table>
<thead>
<tr>
<th>value</th>
<th>dx (US)</th>
<th>dy (US)</th>
<th>dz (US)</th>
<th>dx (DS)</th>
<th>dy (DS)</th>
<th>dz (DS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>0.15 mm</td>
<td>0.65 mm</td>
<td>1.1 mm</td>
<td>-0.35 mm</td>
<td>0.43 mm</td>
<td>-0.33 mm</td>
</tr>
<tr>
<td>Std_dev</td>
<td>0.75 mm</td>
<td>0.86 mm</td>
<td>0.88 mm</td>
<td>1.0 mm</td>
<td>1.1 mm</td>
<td>1.2 mm</td>
</tr>
</tbody>
</table>

Conclusion of alignment

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

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

* Outlier
   - Pixels which show larger deviations than 3mm are visually confirmed to be deviated (→)
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• 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 \( (|dx_i| < 5 \text{ mm}) \)
- 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
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.
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
(a) $\mu^+ \rightarrow e^+ \gamma$
(b) $\mu^+ \rightarrow e^+ \nu_\mu \nu_e \gamma$ (Michel decay) (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

\begin{align*}
\text{dx}_{\text{mean}} &= 0.15 \text{ mm} \\
\sigma_x &= 0.75 \text{ mm} \\
\text{dy}_{\text{mean}} &= 0.65 \text{ mm} \\
\sigma_y &= 0.86 \text{ mm} \\
\text{dz}_{\text{mean}} &= 1.1 \text{ mm} \\
\sigma_z &= 0.88 \text{ mm}
\end{align*}
Results - DS

\[ dx_{\text{mean}} = -0.35 \text{ mm} \]
\[ \sigma_x = 1.0 \text{ mm} \]

\[ dy_{\text{mean}} = 0.43 \text{ mm} \]
\[ \sigma_y = 1.1 \text{ mm} \]

\[ dz_{\text{mean}} = -0.33 \text{ mm} \]
\[ \sigma_z = 1.2 \text{ mm} \]
Results (4) TC timing calibration

(1) no deviations
(2) random deviations
(3) measured deviations

- 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