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対する影響の評価

米本 拓、他MEG IIコラボレーション

2020年3月17日

日本物理学会2020年年次大会@名古屋大学

講演番号: 17aG22-10
Contents

• Introduction
  - $\mu \rightarrow e + \gamma$
  - MEG II experiment
  - Pixelated Timing Counter
  - pTC alignment

• Alignment
  - Flowchart
  - Scan data
  - Results
  - Discussion

• MC study
  - TOF from reconstructed track
  - Results
  - Discussion

• Summary & Prospect
\[
\mu \rightarrow e + \gamma
\]

- 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 $\mu^+ \rightarrow e^+ + \gamma$
  $\mu^+$: most intense beam at PSI (10$^8$ $\mu^+/s$)
  $\gamma$: detected by LXe
  $e^+$: bent by COBRA magnet,
  detected by pTC & CDCH

• expected sensitivity:
  $B(\mu^+ \rightarrow e^+ + \gamma) \sim 6 \times 10^{-14}$
MEG II - Pixelated Timing Counter

- a highly segmented (256 tiles × 2) scintillation detector on two semi-cylindrical super-modules.
- each counter consists of a 120mm × 40mm (50mm) × 5mm plastic scintillator.
- read by series connection of 6 SiPMs attached to both side of the scintillator.
- time resolution ~ 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 $\rightarrow$ Track reconstruction and Time-of-Flight calculation
  ... has been investigated by MC study

- Position of whole pTC $\rightarrow$ $e^+$ detection efficiency
  ... will be investigated
Contents

• Introduction
  - $\mu \rightarrow e + \gamma$
  - MEG II experiment
  - Pixelated Timing Counter
  - pTC alignment

• MC study
  - TOF from reconstructed track
  - Results
  - Discussion

• Summary & Prospect
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
Scan data - handling

- 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:

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

- Counter position from the center position is shown in green, whereas designed one is in blue.

Gray : Data points  
Red : Extracted data points as a top side  
Blue : Designed position of a counter  
Green : Measured position of a counter
Scan data – Data selection

• Top side widths
  
y width: \( |y_{\text{max}} - y_{\text{min}}| \)
  
z width: \( |z_{\text{max}} - z_{\text{min}}| \)

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

<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>

*US = up stream  
DS = down stream
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 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.
Contents

• Introduction
  - $\mu \rightarrow e + \gamma$
  - MEG II experiment
  - Pixelated Timing Counter
  - pTC alignment

• Alignment
  - Flowchart
  - Scan data
  - Results
  - Discussion

• MC study
  - TOF from reconstructed track
  - Results
  - Discussion

• Summary & Prospect
TOF from reconstructed track

- In the past, there are no detailed studies on effects of misalignment of pTC.
- Misalignment would worse 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 $\sim$ 7 ps)
  2. designed geometry  (std. dev $\sim$ 7.8 ps)

$\rightarrow$ 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:

$$\frac{\sqrt{\left(\sigma_{\text{single}}^2 + 7.8^2\right) \times N}}{N} \approx 1.0006 \sim 1.0007$$

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

- **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

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 $\sim 7.1$ ps)
  2. Design geometry (Red, std. dev $\sim 16$ ps)

$\rightarrow$ 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:
  \[\sum_{i=2}^{12} (\text{resolution} \times \text{rate of } i \text{ hit events})\]

  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
Taku Yonemoto
"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対する影響の評価"