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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日本物理学会 第72回年次大会
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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.
  
  $4.2 \times 10^{-13}$ 90\% C.L.  
- Target sensitivity of MEG II is
  
  $\sim 4 \times 10^{-14}$


**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.
Positron Measurement

Wire Drift Chamber (DCH)
- Single volume, low-Z gas mixture (He:C₄H₁₀ = 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 mm³)
- 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 @ $7 \times 10^7$
  - TC: Hit smeared by their resolutions
  - DCH: waveform simulation

In this talk we’ll focus on timing reconstruction.
An example with signal event (w/o pile up)

1. DCH reconstructs track from vertex to TC first hit. \( (L_{\text{DCH}}) \)

2. TC reconstructs time at first hit by each counter.

\[
T_{\text{TC}} = \sum_{i}^{N} \left( T_i - \frac{L_{i}^{\text{TC}}}{c} \right)/N
\]

\[
T_{e^+} = T_{\text{TC}} - \frac{L_{\text{DCH}}}{c}
\]
Positron Timing Reconstruction

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

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

$$T_{e^+} = T_{TC} - \frac{L_{DCH}}{c}$$
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 is 40 ps. (It was 108 ps in the MEG experiment.)
More Development
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

- 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.

\[ T_{\text{counter}} = \frac{(t_1 + t_2)}{2} \]
\[ l = \frac{v_{\text{eff}}(t_1 - t_2)}{2} \]
TC tracking recovers the effects of multiple scattering.
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.
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

- **hθ**
  - Constant: $974.3 \pm 16.1$
  - Mean: $0.04542 \pm 0.07027$
  - Sigma: $6.028 \pm 0.070$

- **hϕ**
  - Constant: $1002 \pm 18.1$
  - Mean: $0.134 \pm 0.068$
  - Sigma: $5.707 \pm 0.078$

- **hP**
  - Constant: $1646 \pm 29.4$
  - Mean: $52.83 \pm 0.00$
  - Sigma: $0.8849 \pm 0.00118$

- **hνZ**
  - Constant: $773.3 \pm 13.5$
  - Mean: $0.01404 \pm 0.01742$
  - Sigma: $1.468 \pm 0.019$

- **hνY**
  - Constant: $1603 \pm 28.6$
  - Mean: $-0.0108 \pm 0.0086$
  - Sigma: $0.7337 \pm 0.0099$

- **hT**
  - Constant: $745 \pm 12.4$
  - Mean: $2.352e-12 \pm 4.681e-13$
  - Sigma: $3.046e-11 \pm 4.679e-13$
Positron Detection Efficiency

- 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

TC
- WF analysis
- Hit Rec.
- Clustering

DCH
- WF analysis
- Hit Rec.
- Track finder
- Kalman Fit

Matching
- Propagation to TC
- b/w TC cluster and DCH track

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.

DCH is tracking just before TC.
Positron Reconstruction Chain

TC
- WF analysis
- Hit Rec.
- Clustering

DCH
- WF analysis
- Hit Rec.
- Track finder
- Kalman Fit

Matching
- Propagation to TC
- b/w TC cluster and DCH track

Check this difference

Propagated Track from DCH
Reconstructed position in TC
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 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

\[
\frac{T_1 + T_2 + T_3 + T_4}{4} - T_1^{MC} \Rightarrow \text{make positive tail.}
\]

\[
\frac{T_1 + T_2 + T_3 + T_4}{4} - T_1^{MC} \Rightarrow \text{make negative tail.}
\]
Time Resolution from Each Detector

Time of Flight b/w Target and TC

Mean 8.3 psec
Sigma 14.8 psec

Time Resolutions in TC

Mean 4.5 psec
Sigma 31.0 psec

Since these two reconstructions do not have correlation, .
Hit Position Reconstruction

Reconstructed position – mc position

Counter local

Std Dev 1.5 → 0.6
Hit Position Reconstruction

- $R$ distribution with and without TC tracking
- $Z$ distribution with and without TC tracking
- $\phi$ distribution with and without TC tracking
- $L$ distribution with and without TC tracking
Prospects

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

- Contamination cut

\[ T_{\text{counter}} = \frac{(t_1 + t_2)}{2} \]
\[ l = v_{\text{eff}} \frac{(t_1 - t_2)}{2} \]