MEG II実験陽電子スペクトロメータにおける検出効率改善のための再構成アルゴリズムの研究

宇佐見正志、他 MEG II コラボレーション

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Introduction

- Introduction
  - MEG II experiment
  - Positron spectrometer
- Performance study on positron spectrometer
- Summary and prospect
μ → e γ search

- Charged Lepton Flavor Violation (cLFV);
  - Prohibited in standard model
    - Even with neutrino oscillation, Br(μ → eγ) ~ O(10⁻⁵⁴)
  - Predicted in beyond standard model
    - Many models (SUSY-GUT, Extra-dimension etc…), Br(μ → eγ) ~ O(10⁻¹⁴)

- To discover μ → eγ means to discover the new physics!

![Diagram 1](image1)
![Diagram 2](image2)

Expected branching ratio is within the reach of experiment.
Current upper limit (MEG, 2016):
Br(μ → eγ) < 4.2 × 10⁻¹³ (90% C.L.)
Target sensitivity of MEG II:
Br(μ → eγ) ~ 6 × 10⁻¹⁴


MEG II Experiment Detectors

- **Overall talk:** 14aS20 (Finished)
- **Positron spectrometer:** 15pS28 4-5
- **LXe gamma-ray detector:** 16aS41 7-8
- **Radiative decay counter:** 16aS41 5


DCH: Taken by DCH group in Dec.

RDC: 2017年秋季大会大強度μ粒子ビーム中で動作する MEG II実験測定用同定用カウンターの開発, K Ieki
MEG II Experiment Detectors

- Drift Chamber
- Timing Counter
- Superconducting magnet

- e\(^+\) turns in the detector region
- Constant bending radius
- Low momentum e\(^+\) does not enter TC region

**Positron Spectrometer:**
- Superconducting magnet + Drift Chamber + Timing Counter
- Superconducting magnet & magnetic field measurement: Next talk
**Positron Spectrometer Detectors**

- **Cylindrical one-volume**
- **~2 m**
- **~7 mm square drift cell**

**Drift Chamber (CDCH)**
- Ultra-low mass (90% helium based gas mixture + 10% isobutene) cylindrical drift chamber with stereo wires
- 192 drift cell (~7mm x 7mm) in each layer
- The most outer layer was reduced (10 -> 9 layers design) to be on schedule for commissioning
- Detector construction completed. Detector will be installed in this year.

**Pixelated Scintillation Counter**
- 12 cm

**Timing Counter (TC)**
- Composed of 512 scintillation counters
- Each counter has 6-series connected SiPMs on both sides of scintillator (BC 422)
- Using multiple hit information
- Cooling system is updated to suppress radiation damage effect (dark current increase)
- Ready for physics run.

Requirement for $e^+$ Spectrometer

- **Upgrade from MEG:**
  - × 2 higher beam intensity: $3 \times 10^7 \rightarrow 7 \times 10^7 \, \mu/s$
  - × 2 better detector resolution: See result page
  - × 2 positron reconstruction efficiency: 30% → 70%

- **Challenging**
  - Background events drastically increased ($BG_{accidental} \propto (Beam \ rate)^2$)
  - 3-4 times hit occupancy in CDCH cell compared with MEG case
    - 1.7—0.8 MHz/cell
    - $<N_{hit}> \sim 650$ in event in 250 ns
  - Higher radiation environment

- Understanding and upgrading more effective analysis are essential to achieve target sensitivity!
Positron Reconstruction

- Introduction on MEG II experiment
- Performance study on positron spectrometer
  - Overview
  - Analysis review
  - Final result
- Summary and prospect
Analysis Overview

Track Reconstruction from CDCH hits

Timing Reconstruction from TC cluster

CDCH-TC Matching & Refinement

Positron Reconstruction
Positron Reconstruction

TC Cluster Reconstruction
CDCH Hit Reconstruction

Drift circles
TC hits

Track Finding

Fitted track

purple wires are not shown in 2D
Positron Reconstruction

- Difficulty comes from
  - ~1MHz Hits/cell in CDCH
  - Short track information
Efficiency @ 2018 Spring

- Track Reconstruction from CDCH hits
- Timing Reconstruction from TC cluster
- CDCH-TC Matching & Refinement
- Positron Reconstruction

Below the target efficiency (70%)!

**Signal only case**
Efficiency: 76.4 % @ 10 layer

**Signal + Background (BG)**
Efficiency: 56.1% @ 10 layer
-> ~50% @ 9 layer
~10% Efficiency loss by reducing layer!

Reference: Positron Timing Measurement to Search for Lepton Flavor Violating Decay in MEG II, Miki Nishimura, May 2018, Doctor thesis (The Univ. of Tokyo)
Analysis Review

- Introduction on MEG II experiment
- Performance study on positron spectrometer
  - Overview
  - Analysis review
  - Final result
- Summary and prospect
Updates Summary

- **CDCH tracking reconstruction**
  - 9 layer scheme
  - Broken wire effect investigation
  - z reconstruction by time difference
  - Additional seeding combination
  - Shared hits comparison in tracks
  - TOF correction and recalculation

- **Information matching**
  - Added Timing information
  - Backward matching
  - Refinement

- **TC Cluster Reconstruction**
  - Added position information
  - CDCH independent tracking for seed

- And many more updates during this summer!
TC Cluster Reconstruction

- TC cluster reconstruction was done based on “time”
- This time we added “position information” for criteria
  - Sometimes small radius turn positrons after scattering makes tail events. Based on hit position, we remove those hits.
Track Reconstruction

- **Tracking Strategy:** Local method (Track following) based on Kalman Filter technique
  - Track is started from track seed
  - Track is prolonged by Kalman Filter to add hits through layers from seeds
  - Fit the segments with GENFIT

**Kalman Filter**
Efficient recursive algorithm to estimate the state vector and its covariance matrix based on previous states.

**GENFIT**
A generic toolkit for track reconstruction for experiments in particle and nuclear physics.
**Track Reconstruction**

**Basic seed process:**
1. Timing from possible TC cluster or nearest 3 wires
2. 2 consecutive hits (pair) in the same layer is picked up
3. 2 pairs from nearest layer is combined
4. Start track following

**Additional seeding patterns**
1. More T0 pattern
2. Seed w/ 2 gap
3. 3 unused wires (Default unused option)
4. Seed from TC cluster track (under development)

TOF (Path Length)

- TOF calculation is one of main improvement from MEG
  - 75 ps in MEG
  - 14.8 ps were reported by MC study in Spring
- We iterated the calculation with smoothed track (used smoothed track trajectory for calculation) and it became ~ 7 ps resolution. × 10 improvement from MEG

2018 Spring

\[ \sigma_L = 14.8 \text{ ps} \]

2018 Autumn

\[ \sigma_L = 7.2 \text{ ps} \]
CDCH-TC Matching

- CDCH track and TC cluster is matched based on extrapolated “position”
  - $< 5 \sigma$ difference b/w CDCH and TC
- We also added timing difference b/w tracks and TC for criteria
  - 15 ns timing window
  - Roughly $\sim 30\%$ background matching cut, avoid fake matching event
CDCH-TC Refinement

- After matching we recalculate the drift distance based on TOF calculated from CDCH track length and timing from TC cluster
  - More precise drift time can be calculated
- By using more precise drift distance, we can get more precise track
  - Currently we succeed in improving re-calculation of drift distance, but not yet completed the fitting & extrapolation process

Blue: Before
Red: Recalculation
$\sigma$ became
99 $\mu$m $\rightarrow$ 71 $\mu$m

Point time = $T_0$ - TOF - time offset
Result

- Introduction on MEG II experiment
- Performance study on positron spectrometer
  - Overview
  - Analysis review
  - Result
- Summary and prospect
Efficiency and resolutions @2018 Autumn

- **Signal only case**
  - Efficiency: 76.4%
  - 10 layer configuration

- **Signal + BG**
  - Efficiency: 56.1% (~50%)
  - 10 (9) layer configuration

- **Signal only case**
  - Efficiency: 80±1%
  - 9 layer configuration

- **Signal + BG**
  - Efficiency: 60±1%
  - 9 layer configuration

- Though CDCH layer was reduced, **60±1%** efficiency was obtained from analysis development.

- Better efficiency is expected by…
  - More seeding pattern (from TC cluster track)
  - Hit reconstruction optimization, additional global track finding etc…
# Resolutions

<table>
<thead>
<tr>
<th>Positron Resolution</th>
<th>MEG</th>
<th>Design (10 layer)</th>
<th>Updated (9 layer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theta (mrad)</td>
<td>9.4</td>
<td>5.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Phi (mrad)</td>
<td>8.7</td>
<td>3.7</td>
<td>5.3 ※A</td>
</tr>
<tr>
<td>Momentum (keV)</td>
<td>380</td>
<td>130</td>
<td>83</td>
</tr>
<tr>
<td>Vertex Z (mm)</td>
<td>2.4</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Vertex Y (mm)</td>
<td>1.2</td>
<td>0.7</td>
<td>0.72</td>
</tr>
<tr>
<td>Positron time (ps)</td>
<td>108</td>
<td>46</td>
<td>49 ※B</td>
</tr>
</tbody>
</table>

※A. Correction based on theta and phi correlation is not applied, though expected value include it.
※B. 1 year radiation damage effect is roughly simulated, w/o cooling condition. \( \sigma(T_{\text{calib}}) \sim 10 \text{ ps} \), \( \sigma(T_{\text{WDB-sync}}) \sim 25 \text{ ps} \) is added.


- Good resolutions were obtained compared with expected values
- Better resolution is expected from...
  - Tracking: Iteration fitting with re-calculated drift distance etc...
Summary & Prospect

- Positron spectrometer
  - Detectors are ready for commissioning in this winter
  - CDCH+TC positron reconstruction algorithms are being developed, aiming at 70% reconstruction efficiency (designed value)
  - Currently we simulated 60±1% efficiency with 9 layer CDCH
    - Great progress & encouraging result in each reconstruction step during this summer by positron analysis group!

- To improve the reconstruction efficiency, what can we do?
  - Additional seeding pattern (TC tracking w/o CDCH information)
  - Try global pattern recognition methods in addition to local method
  - Re-calculation of drift distance, iterate the fitting process
  - Hit reconstruction optimization etc….
Backup
Resolution Histograms
10 Layer
## 10 Layer vs. 9 Layer @ Autumn

<table>
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<tr>
<th>Positron Resolution</th>
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<td>48</td>
<td>49 ※B</td>
</tr>
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65±1%
10 layers -> 9 layers: -8% effect