MEG実験
陽電子スペクトロメータの性能評価

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2010年9月13日
日本物理学会 秋季大会
九州工業大学戸畑キャンパス
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Introduction

- MEG experiment started to hunt the muon rare decay which indicate the cLFV ($\mu \rightarrow e + \gamma$) in 2008
- Requirements to get a few$^*10^{-13}$ branching ratio
  - High intensity DC muon beam
    - Realized by most intense proton accelerator @ PSI
  - Good resolution gamma detector --> see next talk
    - Using large LXe calorimeter (~ 900 litter)
  - Good resolution and less material positron spectrometer
    - COBRA magnet, drift chamber (for tracking) and timing counter (for trigger) constitute the MEG spectrometer to get this requirements
Run 2009

- Stable data acquisition succeeded
- Waveform digitizers for DCH were replaced from DRS2 to DRS4
  - DRS internal noise were reduced
- Spectrometer performance improved by solving discharge problem which suffered some drift chamber modules in 2008
- Higher spectrometer efficiency and better resolution were expected than in 2008
Spectrometer performance in 2009

<table>
<thead>
<tr>
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<th>2009</th>
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<tbody>
<tr>
<td>e+ timing (psec)</td>
<td>125&lt;</td>
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<td>e+ momentum (%)</td>
<td>1.6</td>
<td>0.74 (core)</td>
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<td>10 (φ) / 18 (θ)</td>
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<td>3.2 (R) / 4.5 (Z)</td>
<td>2.3 (R) / 2.8 (Z)</td>
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- **Calculated by #of Michel positron mixed in MEG trigger**
- **Estimated by radiative muon decay indirectly**
- **Extract from residuals of two turn track**

**Momentum resolution from 2turn method**
Run 2010

- MEG data taking started in Aug. \(\rightarrow\) 2.7 times longer than in 2009
- 5 chambers replaced to new one \(\rightarrow\) almost all chambers working fine
- Remaining problems for positron spectrometer
  - Noisy waveform baseline
    - Large periodic noise found around 14 MHz (related to HV supply modules) \(\rightarrow\) replaced after this years run
    - try to reduce by offline analysis for this run \(\rightarrow\) in this talk
  - Materials between DCH and TC affect low efficiency (\(~ 40\%\))
    - hardware update is needed (will be done in 2012 hopefully)
- Update for 2010
  - Mott scat. analysis (to calibrate and estimate performance) \(\rightarrow\) in this talk
  - Digitizers for Timing counters were changed from DRS3 to DRS4
  - TC Z-fibers started to work (under studying)
Run 2010

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Expected performance

- Assuming lower noise level
  - Noise makes ~2 times worse Z resolution
  - Z resolution related to θ resolution strongly
  - Lower noise bring better vertex resolution too
- TC Z-fibers will bring more precisely position information

### Expected Performance

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Mott scattering analysis

- Introduction of Mott scattering
- Mott scattering is coherent and elastic
  - It has well known distribution monochromatic e+ for calibration and checking performances!
  - Further, momentum of positron is tunable with O(100keV)
- Mott target placed COBRA center position and MEG target moved to “parking position”
  - Setup
  - Slant angle: ~ 50° for beam axis
  - Thickness: 2 mm
  - Material: pure CH₂

Mott cross section @ 50 MeV
Mott scattering analysis

- 50 MeV monochromatic positron beam with 160 keV momentum byte
- MEG fiducial volume $70^\circ - 110^\circ$
- Background source
  - Cloud muons Michel decay (forward direction dominant)
  - Mott scat. from MEG target (on its “parking position”)
- Background data (w/o target) was also taken
  - Michel positron from cloud muons can be subtracted
Mott scattering analysis

- Energy spectrum
  - Selection criteria
    - generated on the target plane
    - MEG fiducial volume
    - $35 \, \text{MeV} < E_{\text{positron}} < 65 \, \text{MeV}$
    - # of turn < 3

- Subtract the background energy spectrum
  - Red line, very small contribution
  - Forward dominant
    - Michel $e^+$ form cloud muons

- After that, Mott peak and Mott background form MEG target remain
Mott MC comparison

- MC status
  - w/o cloud $\mu^+$ & MEG target
  - Simulation also has tail and asymmetry, but it is sharper than data
  - asymmetry: Energy loss in target
  - tail: From analysis

- $\theta \rightarrow$ almost same shape

- Few differences may be from uncalibrated detector resolutions and MEG target (on "parking position")
Preliminary result of Mott analysis

- It is important that positron tracks were reconstructed by assuming MEG target centered.
- Energy spectrum fitted by double gaussian (considering asymmetry and tail).
- Although DCH has not been calibrated yet, momentum resolution estimated approximately 1.7 % ($\sigma_{\text{core}}$) for 50 MeV.
  - 0.84 % ($\sigma_{\text{core}}$) from Michel data.
- Need better understanding about tail and influence of MEG target.
  - After that, we can use it as a “signal like” calibration source.

$\sigma_{\text{core}} \approx 850 \text{ [keV]}$
Offline noise reduction

All data taken as a “waveform” in our experiment

- It may be possible to reduce the noise by offline analysis
- Result of FFT
  - Clearly periodic noise exist around 14 MHz
  - Previous peak can be seen at FFT analysis result
  - This sample figure shows event by event and channel by channel FFT results
Offline noise reduction

• Fitting needs huge amount of time to analyze
  • nonrealistic solution

• Filtering
  • Need to divide signals and noise clearly
    • At the point of frequency, signal cannot divide from noise easily → see right figure

• Subtraction
  • Less time for analysis but need to adjust timing between each channels and need pedestal channels
  • How to adjust phase ??

Result of Fourier transform for all channels few events accumulation (peak → coherent noise)
Prospects

- Improvement of performance predicted by some updates
  - Reduce noise in terms of hardware
    - It will be replaced to new HV modules after this years run
    - Better grounding, Gain optimization ...
  - To reduce materials between DCH and TC, we will change thinner cables and new design support structure hopefully
    - After that, we expected spectrometer efficiency will be improved about 15 % (40 → 46 %)
Summary

- Feasibility check for monochromatic calibration started
  - Momentum resolution from Mott is \( \sim 2.3 \) times worse than in 2009
    - However it from Michel is already nearly equal to last year’s one
  - DCH calibration has not been finished yet
  - Need more study to use for calibration as a “signal like event”

- To get better performance, offline noise reduction needed
  - Noise components are analyzed by Fourier transform
    - We need fast algorithm except the filtering method
  - \( 1/3 \) noise suppression bring the improvement numbers below ...
    - Momentum [%] : 0.74(core) → 0.7 Angle [mrad] : 11.2(\( \theta \)) → 8(\( \theta \))
    - Vertex point [mm] : 2.3(R)/2.8(Z) → 1.4(R)/2.5(Z)

- Planning for further improvement is underway

- Better spectrometer performance will realize better sensitivity
Backup
測定原理(1)

- Waveform analysis
  - MEG実験ではすべてのdrift chamber cellでwaveform digitizer(DRS4)によってデータ収集を行っている。
  - Waveformから
    1. Charge
    2. Drift time

の情報を得ることができる
測定原理(2)

• Hit reconstruction
• Z方向: charge division
  • Vernier methodにより1mm以下のZ resolutionを達成する

• XY方向: drift時間

\[ A = \frac{Q_d}{Q_u + Q_d} \]
Detector performance

• Efficiency
  – Spectrometer Efficiency
  – Drift Chamber Tracking Efficiency

• Resolution
  – Drift Chamber Position Resolution
  – Momentum Resolution
  – Angular Resolution
  – Vertex Resolution
Efficiency

• Michel positron trigger mixed in MEG physics run
• Spectrometer efficiency: 再構成されたMichel positronの数と、targetに止まったmuon数から計算できる
• Target muonの数はproton beamのcurrentから見積もりることができる

- \( N_{\text{obs}} = 6.677 \times 10^{10} = N_{\text{stop}_{\mu}} \times \Omega_{\text{acc}} \times \varepsilon_{(e+)} \)
- \( N_{\text{stop}_{\mu}} \times \Omega_{\text{acc}} = (15.5 \pm 0.7) \times 10^{10} \)

\[ \varepsilon_{(e+)} \approx (43 \pm 2)\% \]
\[ \varepsilon_{\text{DCH}} \approx (93 \pm 4)\% \]

\( \varepsilon_{(\text{matching})} \approx 46\% \)

In 2008:
\[ \varepsilon_{(e+)} \approx 14\% \]

3 times larger!
Resolution

- Z resolution
- R resolution

Drift chamber’s intrinsic position resolution

Momentum resolution

- Angular resolution
- Vertex resolution

Spectrometer performance
Z/R resolution

- Z resolution: charge divisionで再構成されたZとZ in Trackの残差
- R resolution: drift timeから再構成されたRとR in Trackの残差
- Tailを考慮して2 gaussianでfitする

\[
\Delta Z
\]
\[
\sigma_z \text{ core} = 784\mu m
\]
\[
\sigma_z \text{ eff.} = 1297\mu m
\]

\[
\Delta R
\]
\[
\sigma_R \text{ core} = 239\mu m
\]
\[
\sigma_R \text{ eff.} = 515\mu m
\]
Momentum resolution

- Michelの理論的なスペクトルに選択効率の関数と分解能をかけたものが実際の\(e^+\)エネルギースペクトルとなる
  → Michel Energy spectrum から分解能を評価することができる
- Resolution function として 3 つのガウシアンを用いる
- 結果: \(\sigma_{\text{p eff.}} = (0.57 \pm 0.02)\ [\text{MeV}]\)
- 52.8 [MeV] に対しては 1.08 % の分解能となる

今後MCとの比較等、quality checkを行う

JPS meeting @ Kyuteck
Angular resolution

- Angular resolution is estimated by double turn track
  - Compare 1st turn and 2nd turn
- MCによるstudyから、2 turn methodではθの角度分解能を実際より少し悪く見積もっていることがわかっている
  → これを補正する

\[ \sigma_{\phi}/\sqrt{2} = 8.3 \text{[mrad]} \]

\[ \sigma_{\theta}/\sqrt{2} = 14 \text{[mrad]} \]
Angular resolution

- Trackをtargetまで戻した時の角度分解能をTrack自身から求める
  - 2 turn method
- MCによるstudyから、2 turn methodでは角度分解能を実際より少し悪く見積もっていることがわかっている
  → これを補正する

\[
\sigma_\phi \left/ \sqrt{2} \right. = 8.3 \text{[mrad]} \\
\sigma_\theta \left/ \sqrt{2} \right. = 14 \text{[mrad]} \\
\rightarrow 11 \text{[mrad]}
\]
Vertex resolution

**Hole method**
- Target上にあけている穴を再構成されたvertexがどれほど再現できるかで、target上でのposition resolutionを見積もることができる
**Vertex resolution**

- **Hole method**
  - Target上にあけている穴を再構成されたvertexがどれほど再現できるかで、target上でのposition resolutionを見積もることができる

\[ \sigma_Y = 2.7 \text{[mm]} \]

\[ \sigma_z = 3.1 \text{[mm]} \]
Noise

- 現在、drift chamberの分解能はnoiseによって強く制限されている

Noise levelを1/3まで落とせばZ resolutionが2倍良くなる(MC simulation)
- Z resolutionが良くなればθ resolutionも良くなる
- MEG実験ではdrift chamberからの信号をwaveformとして取得しているため、offline analysisで取り除ける可能性がある
Future prospects

• Calibrationが完璧では無いので、2009年の resolutionはまだ改善の余地あり
• 放電問題の解決によりEfficiency, Resolutionが改善した現在、Resolutionを主に制限しているのは noiseである
• Ground 強化等、hard面でnoiseの低減を行う
• Drift chamberは先に述べたようにすべてのデータをwaveformとして収集しているため、offlineで noiseを低減することも可能で、現在そのための studyを進めているところである
Summary

- 2009年runでの陽電子スペクトロメータの性能評価を行った
- 各値の2008年runとの比較を表に示す

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<td>Z/R resolution (μm)</td>
<td>819/202</td>
<td>784/239</td>
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- これらの結果はpreliminaryなものであり、calibrationや解析方法の改善等により、向上する可能性がある
- さらにresolutionを向上させるために現在soft wareによるnoise reduction algorithmのtestを進めているところである