MEG実験2010 現状と展望

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東京大学 素粒子物理国際研究センター
内山 雄祐
Contents

• 2010 status
  - Run schedule
  - Detector condition

• Update, modification
  - DRS timing tune
  - Mott scat data
  - Neutron generator

• Performance
• Sensitivity 2010

• Further prospects
### 2010 Schedule

**RUN2010 : MEG3年目の物理ラン**

<table>
<thead>
<tr>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
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<tr>
<td>LXe transfer</td>
<td>Calibration &amp; monitor</td>
<td>Purification</td>
<td>π⁰</td>
<td>Installation</td>
<td>Cosmic</td>
<td>e⁺Mott</td>
<td>Beam study</td>
<td>Analysis of 2009</td>
</tr>
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</tbody>
</table>

- Re-install spectrometer after repair & maintenance work (~1 month delay)
- Positron beam test
- Beam optimization
- MEG RUN 2010- I
- Pi0 calibration run
- MEG RUN 2010-II

Total **117 days** for physics data taking

cf. 43 days in 2009 x 2.7
New things, modifications

- Beam optimization
- Replaced 5 Drift Chamber modules with new ones
- Z-measuring Timing Counter integration
- Electronics (waveform digitizer) timing tuning
- New calibration method (feasibility test, mounting)
  - Positron mott scattering
  - Neutron generator for 9 MeV gamma
Beam optimization

- Beam intensity
- Stopping distribution
- Degrader, momentum slit
- Event distribution (asymmetry)
- Optimize S/N

- Originally planed before 2009 run
  - 1st half of 2009 data shows strong asymmetry (200µm degrader)
    - Less stopping efficiency (~65% of that with 300µm degrader)
    - Higher BG
  - Changed degrader setting during run2009
    - $T_{\text{live}}^{200} : T_{\text{live}}^{300} = 37 : 63$
    - $N_{\text{stop}}^{200} : N_{\text{stop}}^{300} = 29 : 71$

- This study shows the setting of 2nd half of 2009 was optimal
  - Tuned beam center for this setting
  - Rate was adjusted to $3.6 \times 10^7 \mu$/sec at center $\rightarrow R_{\text{stop}} = 2.9 \times 10^7 \mu$/sec

This year
More efficient and less BG beam condition for all period
Detector condition

• Drift chamber
  − Replaced 5 modules with new ones
  − 30 layers (out of 32) working at nominal voltage
  − (still) large noise on cathode readout

• Liquid xenon
  − Slightly higher light yield (full (updating best record))
  − A few PMTs becoming dead
    • Continuous decrease of PMT gain
    • Total 7 dead channels

• Timing counter
  − Phi-bars working fine (for this 3 years)
    • Optimization of thresholds for better timing resolution are ongoing
  − Z-fibers just integrated into our DAQ
    • Conditioning, noise study, readout tuning under way
    • Integrating into trigger is under study
**Detector condition**

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- **Integrating into trigger is under study**

---

13pSM-1 : He/C$_2$H$_6$ を用いたドリフトチェンバーの高頻度照射下でのエイジング 西口創
Detector condition

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  - A few PMTs becoming dead
    - Continuous PMT gain decrease
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- Continuous PMT gain decrease

- Timing counter
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~1.5% / week

µ⁺ beam  π⁻ beam
Detector condition

- Drift chamber
  - Replaced 5 modules with new ones
  - 30 layers (out of 32) working at nominal voltage
  - (still) large noise on cathode readout

- Liquid xenon
  - Slightly higher light yield (full, updating best record)
  - A few PMTs becoming dead
  - Continuous PMT gain decrease (up to 5%)

- Timing counter
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  - Z-fibers just integrated into our DAQ
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    - Integrating into trigger is under study

Two-layer (orthogonal)
- Z-fiber
- Phi-bar

Online resolution
- ~5cm → ~2.5cm

5x5mm$^2$ fiber

Beam-dir (z-axis)
Electronics Timing Accuracy

- In 2009, we introduced new version of waveform digitizer (DRS4)
  - Low noise, better linearity
  - Sampling frequency is regulated by PLL
  - However, found to have worse timing accuracy
  - 2009 timing resolution was largely worsened by the electronics
- Modification during shutdown period
  - Reduce digital noise on acquisition board
  - Optimize PLL regulation circuit to minimize jitter

Time difference of two gamma from $\pi^0$ decay

![Graph showing time difference of two gamma from $\pi^0$ decay](image)
MEG calibrations

$\pi^{-} p \rightarrow \pi^{0} n$

$\pi^{0} \rightarrow \gamma \gamma$
55, 83, 129 MeV
monochoro

$\pi^{0} \rightarrow \gamma e^{+} e^{-}$
Relative timing
Similar topology

Radiative Decay
$\mu \rightarrow e \nu \nu \gamma$
Relative timing
Similar topology

Michel Decay
$\mu \rightarrow e \nu \nu$

Complementary for completeness
Duplicative for cross check
MEG calibrations

- What's missing?
  - Monochromatic positrons
  - Gamma source used in beam ON
  - Angle calibration

Alpha
- Am source on wire
- PMT QE

C-W accel.
- Li(p,γ)Be
  - 18MeV γ
- B(p,γ)C
  - 4,11MeV 2γ

AmBe
- 4.4MeV γ source

CosmicRay
- DC alignment
- TC uniformity
- LXe monitor

Radiative Decay
- μ → eννγ
- Relative timing
- Similar topology

Michel Decay
- μ → eνν

Complementary for completeness
Duplicative for cross check
New calibration method 1

- **Spectrometer calibration with e⁺ Mott scattering**
  - Coherent elastic scatter of e⁺ on light nuclei
    - Precisely known cross-section
  - e⁺ beam
    - High intensity @ PiE5 beamline
      - For MEG, e⁺ are separated and rejected
    - Monochromatic, and momentum tunable
      - Select momentum with low momentum bite (~100keV)
  - **Target** (light nuclei → Carbon is best solution)
    - MEG target (thickness of 205µm)
    - Dedicated target
      - Pure CH2 (thickness of 2mm)
      - Mounted inside COBRA magnet

- **Calibrate and study**
  - Momentum resolution
  - Efficiency and uniformity
    - Cross section & angular distribution well known

First test in May (feasibility test)
Analysis underway → Modification, optimization
Mounted (May 2010)
New calibration method 2

- **9 MeV gamma** from n-Ni reaction
  - Thermal neutron capture on Ni
  - Unique possibility of calibrating LXe with gamma under *beam ON*.

- **Neutron generator** as n-source
  - D-D reaction
  - Pulsed operation (better S/N under beam condition)
  - Easy to switch ON/OFF
    - Frequent monitoring (any time)

Installed (June 2010)
2010 Expectations
### Expected performance

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009 (preliminary)</th>
<th>2010 (preliminary estimate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma energy (%)</td>
<td>2.0 (w&gt;2cm)</td>
<td>←</td>
<td>1.5 (w&gt;2cm)</td>
</tr>
<tr>
<td>Gamma timing (psec)</td>
<td>80</td>
<td>&gt;67</td>
<td>68</td>
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<tr>
<td>Gamma position (mm)</td>
<td>5(u,v) / 6(w)</td>
<td>←</td>
<td>←</td>
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<td>63</td>
<td>58</td>
<td>←</td>
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<td>Positron momentum (%)</td>
<td>1.6</td>
<td>0.74 (core)</td>
<td>0.7</td>
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<td>&lt;125</td>
<td>&lt;95</td>
<td>←</td>
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<td>Positron angle (mrad)</td>
<td>10(φ) / 18 (θ)</td>
<td>7.4(φ, core) / 11.2(θ)</td>
<td>8(φ) / 8(θ)</td>
</tr>
<tr>
<td>Positron efficiency (%)</td>
<td>14</td>
<td>40</td>
<td>40</td>
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<tr>
<td>e+-g timing (psec)</td>
<td>148</td>
<td>142 (core)</td>
<td>120</td>
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<tr>
<td>Muon decay point (mm)</td>
<td>3.2(R) / 4.5(z)</td>
<td>2.3(R) / 2.8(z)</td>
<td>1.4(R) / 2.5(z)</td>
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<td>Trigger efficiency (%)</td>
<td>66</td>
<td>84</td>
<td>84-94</td>
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<tr>
<td>DAQ time/Real time (days)</td>
<td>48 / 78</td>
<td>35 / 43</td>
<td>95 / 117</td>
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For detail,
→ 13pSM3 “MEG実験液体キセノン検出器の性能”白雪
→ 13pSM2 “MEG実験用電子スペクトロメータの性能評価”藤井祐樹
Expected statistics & sensitivity

- 3.1-3.5倍の統計(2009比)
  - 2.7 beam time × 1.15 stopping eff, × trigger eff

- Sensitivity : \((2.0-2.2) \times 10^{-12}\)
  - cf. \(S_{2009} = 6.1 \times 10^{-12}\)
  - Current best UL = \(1.2 \times 10^{-11}\) (MEGA 1999)

Preliminary estimation
## Summary table

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<td>84</td>
<td>84-94</td>
</tr>
<tr>
<td>Stopping muon rate (/sec)</td>
<td>$3 \times 10^7(300\mu\text{m})$</td>
<td>$2.8 \times 10^7(300\mu\text{m})$</td>
<td>$2.9 \times 10^7(300\mu\text{m})$</td>
</tr>
<tr>
<td>DAQ time/Real time (days)</td>
<td>48 / 78</td>
<td>35 / 43</td>
<td>95 / 117</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>$1.3 \times 10^{-11}$</td>
<td>$6.1 \times 10^{-12}$</td>
<td>$(2.0-2.2) \times 10^{-12}$</td>
</tr>
<tr>
<td>BR upper limit (obtained)</td>
<td>$2.8 \times 10^{-11}$</td>
<td>$1.5 \times 10^{-11}$</td>
<td>-</td>
</tr>
</tbody>
</table>
Further prospects, Discussion

- We will run at least until 2012
  - Another two-year full run.
  - No clear schedule for further years
    - We will clarify the situation (2009 result) by ourselves with long term stable data taking

- Our goal is a sensitivity of a few \( \times 10^{-13} \)

- To achieve the goal
  - Gaining statistics is crucial
  - Must reduce BG by improving analysis
Further improvement

- Efficiency and data statistics
  - DAQ and Trigger efficiency by double buffering
    - Current DAQ eff ~ 82%
    - Current TRG eff = 84%
    - → 99x95 %
  - Possibility in our system has been considered since this spring
    - Study underway
    - Possibly implemented from next year
  - $e^+$ tracking efficiency
    - Even if the full operation of DC, eff is limited to <50% due to detector material.
    - Improvement under consideration
      - Use thinner cables, upto 15% improvement
      - Feasibility and design underway, possibly from 2012
  - Drastic improvement requires major upgrade of detector
- Analysis
  - Gamma energy
  - Positron tracking
Strategy for analysis improvement

- Positron tracking
  - Reduce noise, hardware and software
  - Fine tuning of track fitting algorithm

- Gamma energy
  - Understand LXe optical properties
    - MC
      - Reflection with polarization, etc.
    - Improve QE measurement
    - Detail understand of detector
    - Optimize analysis with MC training
  - Fine calibration
    - Stable and better quality data of pi0 run with BGO
    - Uniformity calibration for high energy gamma
  - Develop more sophisticated reconstruct algorithms
  - Possibility of replacing bad PMTs with new ones (2012?)
Summary

• 8月頭から既に物理ランを再開
  - 3年目、スムーズに。
  - 色々最適化を進めている。

• 新しいキャリブレーション方法を試行

• 期待される実験感度の見積もり
  - ~3倍の統計を貯められる。(2009比)
  - 期待感度:~2 x 10^{-12}

• 今後の長期ランで2009結果の状況をはっきりさせることができる
  - 最低3年走る。
  - 目標感度に到達するには、統計を如何に稼ぐかが非常に重要。
  - BGを落とすために解析を鋭意改善
Quality factor for Beam optimization

\[
QF = \frac{N_{GOOD}}{N_{TC\text{ - Clusters}}} \cdot \frac{N_{TOT\text{ - TRG }#22}}{\langle I_p \rangle \cdot T_{TOT}} \cdot \sqrt{\frac{N_{GOOD}}{N_{TC\text{ - Clusters}}}}
\]

TC trigger

\[
QF = \left(\frac{N_{GOOD}}{\langle I_p \rangle \cdot T_{TOT}}\right) \cdot \frac{N_{TOT\text{ - TRG }#18}}{(N_{TRG \#18})_{REC}} \cdot \sqrt{\frac{N_{GOOD}}{(N_{TRG \#18})_{REC}}}
\]

DC trigger
Improve pi0 data with BGO

- Use BGO instead of NaI
  - Higher efficiency, better resolution (位置, エネルギー)
  - First test done with 16 crystals on Sep. 2010

<table>
<thead>
<tr>
<th></th>
<th>LXe</th>
<th>LAr</th>
<th>NaI(Tl)</th>
<th>CsI(Tl)</th>
<th>BGO</th>
<th>LSO(Ce)</th>
<th>PbWO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm²)</td>
<td>2.98</td>
<td>1.40</td>
<td>3.67</td>
<td>4.51</td>
<td>7.13</td>
<td>7.40</td>
<td>8.3</td>
</tr>
<tr>
<td>Radiation length (cm)</td>
<td>2.77</td>
<td>14</td>
<td>2.59</td>
<td>1.86</td>
<td>1.12</td>
<td>1.14</td>
<td>0.89</td>
</tr>
<tr>
<td>Molière radius (cm)</td>
<td>4.2</td>
<td>7.2</td>
<td>4.13</td>
<td>3.57</td>
<td>2.23</td>
<td>2.07</td>
<td>2.00</td>
</tr>
<tr>
<td>Decay time (ns)</td>
<td>45</td>
<td>1620</td>
<td>230</td>
<td>1300</td>
<td>300</td>
<td>40</td>
<td>30/10¹</td>
</tr>
<tr>
<td>Emission peak (nm)</td>
<td>178</td>
<td>127</td>
<td>410</td>
<td>560</td>
<td>480</td>
<td>420</td>
<td>425/420¹</td>
</tr>
<tr>
<td>Relative output</td>
<td>75</td>
<td>90</td>
<td>100</td>
<td>165</td>
<td>21</td>
<td>83</td>
<td>0.083/0.29¹</td>
</tr>
</tbody>
</table>

¹ slow/fast component

MC study
NaI (赤)
BGO (青, 黄)
Relative alignment with CR

- Alignment of detectors
  - Optical survey
  - Photogrammetric survey
  - Farogauge
  - Michel positron for spectrometer
  - Relative alignment b/w Lxe and spectrometer
    - Took CR w/o magnetic field (May 2010)
  - Reduce uncertainty of relative angle.