MEG II実験: 液体キセノン検出器の物理ラン開始に向けたコミッションング (3)

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$\mu \rightarrow e\gamma$ decay

MEG II experiment searches for cLFV decay, $\mu \rightarrow e\gamma$.

- Sensitivity goal: $6 \times 10^{-14}$
  (10 times better than MEG)
- BSM prediction: $\mathcal{O}(10^{-14})$
  (e.g. SUSY-seesaw)

If $\mu \rightarrow e\gamma$ is found -> Discovery new physics!
Key concepts:
- **High rate** continuous $\mu^+$ beam at PSI ($7 \times 10^7 \mu$/sec)
- **High resolution** detectors to distinguish $\mu \to e\gamma$ from accidental BG

$\mu \to e\gamma$ or $e^+e^- \to 2\gamma$

Back-to-back same timing $E_\gamma = E_e = 52.8$ MeV

**MEG II experiment**

900 l LXe detector

Cylindrical drift chamber + Timing counter

All detectors were installed in 2018! (w/ partial readout electronics)

BG detector

Signal

BG (Accidental)
LXe $\gamma$ detector

900L liquid Xe (LXe) scintillator to detect energy, position and timing of $\gamma$

In MEG II, $\gamma$ entrance face is replaced from 216 PMTs (2 inches) to 4092 MPPCs (12x12 mm$^2$)

Light collection uniformity and granularity improved! $\rightarrow$ x2 energy and position resolution improvement expected
Commissioning with 17.6 MeV $\gamma$

Monochromatic 17.6 MeV $\gamma$ from $^7\text{Li}(p,\gamma)^8\text{Be}$ is used for commissioning.

Energy resolution at 17.6 MeV:
$\sim 3\%$ (Data) $\Leftrightarrow$ $\sim 1\%$ (MC)

Resolution depends on statistical fluctuation of $N_{\text{pho}}$, EM shower shape etc.

Why Data disagree with MC?
- Problem in Data?
- MC is too good?

Li target ($\text{Li}_2\text{B}_4\text{O}_7$)

CW accelerator

$E_\gamma$ spectrum

17.6 MeV peak

14.8 MeV broad peak

(4 cm < conv. depth < 8 cm)
Problem in Data?

MC is too good?
Example of events

Distribution of $N_{\text{pho}}$ is compared between high energy event and low energy events.

No specific difference can be seen.
Energy reconstruction procedure

1. Charge integration of each channel
2. Charge $\rightarrow N_{\text{photon}}$ conversion with calibration constants
3. Calculate sum of $N_{\text{photon}}$
   \[ N_{\text{sum}} = \sum N_{\text{photon}}^i \cdot C_i \]
4. Convert to energy
   \[ E = C \times N_{\text{sum}} \times \text{(position dependent correction)} \]

$C_i$ is a coverage factor

\[ C_i = \frac{\text{assigned area}}{\text{sensor area}} \]

Possible reasons of bad $E$ resolution:
noise, calibration ...
Effect of coherent noise can be measured in random trigger data.
→ Fluctuation is 0.6% of 17.6 MeV. Much smaller than 3%.
Calibration?

- How much does resolution change if we make mistake in calibration?

  We compared two cases in MC
  Correct calibration:
   Use same calibration constants for all channels
  Wrong calibration:
   Apply calibration constants obtained in Data

Resolution become worse (1.2→1.3%) with (completely) wrong calibration, but it is not big enough to explain data (3%).
Stability?

Instability of gain, PDE might explain bad resolution.

Time dependence is found to be too small to explain bad resolution.
Fluctuation of sensor response?

There might be an event-by-event fluctuation in response of MPPC or PMTs (crosstalk + afterpulsing probability etc.)

To distinguish such effect from fluctuation of sum of $N_{\text{pho}}$, even-odd resolution is calculated like this:

$$\Delta E_{\text{even_odd}} = \Delta \left( \frac{E_\gamma(\text{even}) - E_\gamma(\text{odd})}{E_\gamma(\text{even}) + E_\gamma(\text{odd})} \right)$$

<table>
<thead>
<tr>
<th></th>
<th>Even-odd resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPPC Data</td>
<td>1.36%</td>
</tr>
<tr>
<td>MPPC MC</td>
<td>1.08%</td>
</tr>
<tr>
<td>PMT Data</td>
<td>1.00%</td>
</tr>
<tr>
<td>PMT MC</td>
<td>0.92%</td>
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</tbody>
</table>

Such fluctuation does not seem to be big enough compared to MC to explain bad resolution in Data.
PMT or MPPC?

We checked $N_{pho}$ sum distribution for both MPPC and PMT. (Especially for PMT.)

Resolution looks bad for both MPPC and PMT.

<table>
<thead>
<tr>
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<th>$\Delta E_{\text{data}}/\Delta E_{\text{MC}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPPC</td>
<td>1.55</td>
</tr>
<tr>
<td>PMT</td>
<td>1.93</td>
</tr>
</tbody>
</table>
Problem in Data?

MC is too good?
Is CW peak really monochromatic?
→ width is only ~12 keV.

If the target is thin enough and the energy deposit of proton on target is negligibly small, γ energy fluctuation is negligible.
Physics parameters in MC?

Is there any parameters in MC which affect the resolution?
We tried changing settings as follows:

- Optical photon simulation
  - Reflection at PMT holders → off/on
  - LXe Absorption length 400cm → 100cm
  - LXe Rayleigh scattering length 45cm → 20cm
  - Cherenkov light
- Angular dependence of MPPC PDE → off/on
- Physics model
  - EM model → precise model option
  - Photo-nuclear effect → off/on

None of these settings helped reproducing resolution of Data.
Intrinsic resolution of LXe?

Resolution depends on (at least) four parameters:

\[ Resolution^2 = R_{stat}^2 + R_{shower}^2 + R_{non-prop}^2 + R_{escape}^2 \]

Non-proportional scintillation response to electron energy may worsen resolution.

Effect is expected to be \(~0.5\% \) @ \( 17.6 \) MeV.

Number of escape electron may cause additional fluctuation.

Effect on resolution is not known above \(~10\) MeV.

(K Ni et al 2006 JINST 1 P09004)
What do we expect at signal energy (52.8 MeV)?

Energy dependence of resolution is not fully understood. In MC, resolution simply depends on statistical fluctuation and EM shower shape fluctuation. However, an unknown component which we observed in MEG might still exist.

Resolution was ~1.2% with MEG prototype LXe detector, so the intrinsic resolution is expected to be ~1% level or less.

Resolution vs. energy (MEG)

Energy resolution estimated from radiative muon decay spectrum was not bad (~1%), but we need to confirm it with 55 MeV $\gamma$ ($\pi^- p \rightarrow \pi^0 n, \pi^0 \rightarrow 2\gamma$) this year.
Summary

- Commissioning of MEG II LXe detector was done with 17.6 MeV monochromatic $\gamma$-source.

- Energy resolution was measured to be larger than what we expect from simulation.
  - Noise and calibration problem does not seem to explain the difference.
  - Both MPPC and PMT shows larger fluctuation
  - Changing parameter settings in simulation does not help

- Unknown component which affect resolution exists since MEG.
  - Resolution at $\sim$52.8 MeV needs to be checked this year with $\sim$55 MeV calibration $\gamma$ source.