Effect of the photo sensor deterioration to the MEG II Liquid Xe detector performance

小川真治、他 MEG II コラボレーション
@日本物理学会 2019年秋季大会
2020.03.16
LXe detector in MEG II

- LXe γ-ray detector has been upgraded for MEG II to significantly improve the performance.
  - measure energy, hit position, and timing of 52.8MeV γ from $\mu \to e\gamma$.

216 2-inch PMTs  4092 $12 \times 12$ mm$^2$ MPPCs

- Detector commissioning on going.
- On 2018 Dec., Pre-Engineering run 2018 was conducted.
  - Monochromatic γ-source for calibration.
  - BG γ-ray from muon beam.
Effect of smaller MPPC PDE

- MPPC PDE for VUV is found to be decreasing under MEG II beam. (16pG22-11)
- Annealing will recover its degradation. (16pG22-12)

↓

Can we carry out MEG II experiment with this degradation?

- Smaller MPPC PDE may affect sensor calibration precision, online resolution of $\gamma$, and offline resolution of $\gamma$.
- This talk will focus on offline $\gamma$ resolution.
  - Smaller MPPC PDE
    → Larger statistical fluctuation, Worse S/N ratio.
    → Worse resolution of $\gamma$ energy, hit position and hit timing.
    → Degradation of significance of Signal to BG.
    → Degradation of MEG II physics sensitivity.
  - Effect to physics sensitivity is estimated from
    - Degradation speed of MPPC PDE.
    - Detector resolution in MC simulation at smaller MPPC PDE.
Degradation speed of MPPC PDE

- Still many uncertainties on the PDE in the future.
  - We do not know the shape on degradation.
  - Degradation speed in 2017-2018 is faster than that in 2019.
  - PDE before irradiation is worse than PDE after recovery by annealing, and PDE measured before installation.

- In the best case, degradation of PDE will saturate at some point.
  - Saturation of degradation observed at another VUV irradiation test at room temperature. (Ref: 17aG22-7)

- In the worst case, PDE goes to 0% after 70 days from annealing.

---

**History of MPPC VUV PDE**

(Measured data & expectation in the future)

<table>
<thead>
<tr>
<th>Days @ MEG II environment</th>
<th>Data</th>
<th>Expectation from 2019 Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>Linear model</td>
</tr>
<tr>
<td></td>
<td>2018</td>
<td>Exponential model</td>
</tr>
<tr>
<td></td>
<td>2019</td>
<td></td>
</tr>
</tbody>
</table>

**PDE before installation**

**PDE after annealing**
Possible scenarios

- Planned MEG II run: 140 days / year (summer - winter) x 3 years.

- There are several possibilities depending on the number of annealing process needed to keep PDE at a “reasonable” level.
  - Scenario A. (no need for annealing)
    - Degradation of PDE saturated at some point.
  - Scenario B. (annealing once / year)
    - Annealing can be performed during the shutdown period every year.
      → No effect on the statistics of physics run.
  - Scenario C. (annealing more than once / year)
    - Annealing has to be performed also during data taking period.
      → One cycle of annealing will take 1-2 month.
      This will reduce the statistics of physics run.
Hit position of $\gamma$ is reconstructed from the # of p.e. distribution on MPPCs.
Worse MPPC PDE will increase statistical fluctuation of observed distribution, and leads to worse position resolution.

Slight resolution degradation expected at smaller MPPC PDE down to 2%
- more obvious at deep event due to their small # of p.e. statistics on inner face.
Position resolution

- Worse position resolution leads to worse signal to BG significance on opening angle of e-\(\gamma\) (\(\Theta_{e\gamma}\)).
- Degradation of MEG II sensitivity is estimated based on Signal and BG PDF.
  - For simplicity, only considering the significance of PDFs, and neglecting single event sensitivity.
- Sensitivity degradation of 5% by MPCP PDE 22->2%.

Signal & BG PDF of opening angle between e-\(\gamma\)

\(\Theta_{e\gamma}\) PDF
- Signal (PDE 22%)
- Signal (PDE 2%)
- BG

MEG II sensitivity by \(\gamma\) position vs MPPC PDE

- 5% degradation by smaller MPPC PDE
Energy resolution

- Energy is reconstructed from sum of # of p.e. of all MPPC/ PMT.
- If we have smaller MPPC PDE, Poisson statistics contribution will become larger.
- Poisson statistics term of MPPC is not dominant contribution, thus effect is limited.
Energy resolution

• In addition to that, we have not yet achieved energy resolution in MC.
  – Energy resolution (Data) = Energy resolution (MC) + 1.4% (for 52MeV gamma)
  – Known from MEG I, and seems to be existing also in MEG II.

• Effect of PDE degradation will be further smaller.

• 5-10 % degradation by MPPC PDE 22->2%.

![MEG II sensitivity by γ energy vs MPPC PDE](image)
Timing reconstruction

- Timing is reconstructed by the weighted average of hit timing of all MPPC/PMTs.
- Dominant contribution to timing resolution is the sum of timing precision of all channel.
  - Total Precision = \( \Sigma \) “Precision of a MPPC/PMT” x “number of MPPC/PMT in a event”.
- If we have smaller MPPC PDE, total precision of MPPC will get worse.
  - Part of the degradation can be recovered by increasing S/N ratio by larger amplifier gain, as long as signal amplitude will not exceed dynamic range of the readout.

### Timing precision of a MPPC

<table>
<thead>
<tr>
<th>Amplifier Gain</th>
<th># of MPPC (avg.) in a Signal event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2.5, 5, 10</td>
<td>PDE 22, 16, 12, 8, 6, 4, 2%</td>
</tr>
</tbody>
</table>

1/sqrt(# of p.e.)
• Precision of MPPC timing will become larger at small PDE, and precision of PMT timing will define detector timing resolution.
• 5 % sensitivity degradation by MPPC PDE 22->2%.
• Still better than design resolution thanks to improvement of the offline analysis.
(Ref: JPS 2016s 22pAN-4)
Summary

- MEG II LXe detector will improve its performance by installing newly developed VUV MPPC. Degradation of VUV PDE under MEG II beam and recovery of degradation by annealing is observed.

- Effect of this degradation to the MEG II experiment has been discussed.

- Some degradation of $\gamma$–ray resolutions are expected at very small MPPC PDE of 2%, but its effect to the MEG II physics sensitivity is found to be limited (+20%).

- If the degradation will saturate at PDE above ~6%, we may not need annealing.

- Even in the worst case (PDE goes to 0% in 70 days), we can operate our detector by keeping PDE above 2%.
  (This will reduce DAQ day from 140 days/year → 80 - 110 days/year)
Upgrade of MEG experiment

- Searches for $\mu \rightarrow e\gamma$.
- Dominant BG: accidental BG
- More statistics
  - $x2.3$ muon beam rate
  - $x2$ positron efficiency
- Better separation of signal event from BG
  - $x2$ for all detector resolutions
  - New detector for background tagging will be introduced

Expected sensitivity: $6 \times 10^{-14}$

- One order of magnitude better than MEG

Engineering run from 2020

- Followed by physics data taking.

Reference:
MEG II Sensitivity vs DAQ time

- 90% C.L. MEG 2011
- 5σ Discovery
- 3σ Discovery
- 90% C.L. Exclusion

MEGII in 3 years