MEG II実験液体キセノン検出器で用いられる光検出器の実機環境における応答の評価

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On behalf of MEG II collaboration
The University of Tokyo
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Introduction
  · The motivation of searching $\mu \rightarrow e\gamma$
  · Overview of MEG II

MPPC
  · MPPC PDE decrease
  · Surface damage by VUV light

Measurement of PDE decrease
  · Measurement flow
  · Setup
  · Result
  · Summary
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The motivation of searching $\mu \rightarrow e\gamma$

- Neutrino oscillation was discovered (1998)
  - Shows that neutrinos have mixing
  - Indicates charged lepton mixing

- $\mu \rightarrow e\gamma$ in the standard model

$$\text{Br}(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{ii}}{M_W^2} \right|^2 \approx 10^{-54}$$

  - Cannot be observed

- $\mu \rightarrow e\gamma$ in a new physics e.g. SUSY GUT
  - Assume unknown heavy particle

$$\text{Br}(\mu \rightarrow e\gamma) = \mathcal{O}(10^{-12}) - \mathcal{O}(10^{-14})$$

  - Can be observed
Overview of the MEG II experiment at Paul Scherrer Institut

- The world's most intense $\mu$ beam $7 \times 10^7 \mu$/sec
- Muons are stopped at the target
- Two-body decay

- The photon energy, interaction point position and time are measured by LXe

\[\begin{align*}
52.8\text{MeV} & \quad \gamma \quad \mu \quad e^+ \\
180^\circ & \quad \text{Radiative decay counter (RDC)} \\
& \quad \text{Cylindrical drift chamber (CDCH)}
\end{align*}\]
Overview of the MEG II experiment at Paul Scherrer Institut

- Detect the scintillation ($\lambda = 175 \text{nm}$)
- 4092 MPPCs, 668 PMTs at 160K~165K
- Energy and position resolutions will be improved as compared with MEG by a factor of two
- Under commissioning since 2017
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VUV-sensitive MPPC PDE decrease

- Degradation of MPPC VUV-sensitivity → quite fast ~0.05%/hour (under MEG II beam intensity $7 \times 10^7 \mu$/sec)

- MEG II DAQ time (design): 140 days/year, 3 years → This degradation is a serious problem

- A possible cause: Gamma, Neutron irradiation → In lab test, no effect on PDE was observed
Possible cause: surface damage by VUV light

- Electron-holes are generated in SiO2 by VUV light
- Holes are trapped at interface SiO2-Si
- The electric field near the boundary of the two surfaces will be reduced by the holes
  → Collection efficiency will be reduced
- Degradation may be accelerated at low temperature
  → Holes hardly move
  → Anealing is one of solutions
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Overview of the measurement

- Previous research: Irradiation measurement was done at room temp
  - Degradation speed was much lower than LXe detector

- In this measurement: Approached to actual environment
  - Temperature: Used refrigerator and heater control to keep ~160K

- Irradiation source: Xe-lamp is used
  - To reach the dose level of LXe detector in realistic time
Measurement flow

1: Measure PDE for UV and visible
   - To observe difference of PDE b/w UV and visible
2: Irradiate VUV-MPPC for 24h at room/low temp
3: Measure PDE for UV and visible again
4: Compare the PDE decrease b/w room and low temp

Irradiation source

Xe flash lamp
HAMAMATSU - L9455 series

Graph showing:
- Quartz glass
- UV glass

Allows over 185nm
There is little VUV
Setup for charge measurement

- Charge was measured by oscilloscope to observe PDE decrease

- Irritate MPPC by Xe-lamp w/ filter and PDE for UV was observed
  - UV : 185nm~400nm

- Irritate MPPC by LED w/o filter and PDE for visible was observed
  - Visible : ~450nm

- 4 chips of VUV-MPPC was used
  - Two MPPCs are used separately room/low temp
  - Non irradiated MPPC was also used as a reference
Setup for irradiation

- MPPC is mounted on pulse tube refrigerator
- Xe-lamp is fixed in Dewar
  - Irradiate MPPC directly
  - 3cm away from the lamp window
    → total dose level of UV will reach 2019run in ~10sec
- Make $N_2$ flow
  - Prevent dew formation
- 2ch current monitor
  - MPPC’s response to irradiation light was monitored w/o HV

※ Room temp
  - Basically the same as Low temp
  - Prevent Xe-lamp temp rising
Temperature control

Refrigerator: Aisin TAC 101J
- Pulse-tube type
- Can only cool

To keep temp stable we performed PID control
- Using heater and thermometer
→ succeeded at keeping temp of 161K - 162K
Result

- UV PDE decrease at low temp was larger than at room temp
  - Low: 14.8%
  - Room: 10.4%
- At low temp, UV PDE decrease was larger than visible
  - UV: 14.8%
  - Visible: 5.2%
Summary

- In MEG II LXe detector, PDE decrease for VUV was observed
  - May be accelerated at low temp

- We performed irradiation by Xe-lamp at room temp and low temp
  - UV PDE decrease at low temp was larger than at room temp
    - Low temp effect was observed
  - But, degradation speed was much lower than LXe detector
  - We need to irradiate with VUV

<table>
<thead>
<tr>
<th></th>
<th>Xe-lamp</th>
<th>MEG II LXe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dose level</td>
<td>4.5e16 photon</td>
<td>4.4e12 photon</td>
</tr>
<tr>
<td>PDE decrease</td>
<td>14.8%(UV)</td>
<td>9%(VUV)</td>
</tr>
</tbody>
</table>
Main purpose: Understand the situation of PDE decrease in MEG II LXe detector

- We don’t know how PDE decrease in a few years

- Xe-lamp window is UV glass
  - Not allow under 185nm photon (LXe scintillation: 175nm)
    → Xe-lamp with quartz window

- Bandpass filters
  - Filters have transmittance peak at ~190nm
  - But 300nm~400nm photons couldn’t be rejected
    → more filters, another light source

- Optical system
  - We need to move Xe-lamp b/w PDE measurement and irradiation
  - There may be changes in optical system and it can cause change of reference PDE
    → use two light sources
Backup slides
Dose level of Xe-lamp at 45cm w/ bandpass filter 25%*25% and φ1mm slit

- \( N_{phe,VUV} = 60 \text{ p.e./mm}^2 \cdot \text{pulse} \)
  \[
  \rightarrow N_{pho,VUV} = 400 \text{photon/mm}^2 \cdot \text{pulse} \quad \text{if PDE = 15%}
  \]

  \[
  \rightarrow N_{pho,VUV} = 400 \times 144 \div (0.25)^2 \times 500 \text{Hz} \times \left( \frac{3 \text{mm}}{1 \text{mm}} \right)^2 \times \left( \frac{42 \text{cm}}{3 \text{cm}} \right)^2 \text{photon/ch}
  \]

  \[
  = 2.1 \times 10^{12} \text{photon/ch} \cdot \text{sec}
  \]

- \( N_{pho,2019} = 1.0 \times 10^{13} - 2.5 \times 10^{13} \text{photon/ch} \)

It will take \(~10\text{sec}\) to reach 2019 run at low-temp
Reached LXe temp

- Apply grease b/w connecting part
- Efficiently transfer low temp from refrigerator to MPPC
- Cover Xe-lamp and refrigerator with insulator
- Prevent low temp from being taken by $\text{N}_2$ gas
Setup for irradiation at room temp

- MPPC is mounted on refrigerator
  - refrigerator not running
- Make $N_2$ flow
  - make the same condition as at low temp
- 2ch current monitor
- $N_2$ gas hit Xe-lamp directly
- Dewar $\rightarrow$ Chamber
  - prevent temperature of Xe-lamp increase
Current decrease was observed during 24h irradiation
Probably represents the PDE decrease
Temp (~160K) is stable
PDE decrease for UV is larger than visible
PDE decrease of the channels in front of Xe-lamp window (ch1,4) are larger than other two channels(ch2,3)
Charge measurement results are as written below

<table>
<thead>
<tr>
<th></th>
<th>Visible</th>
<th>UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ch1</td>
<td>0.95</td>
<td>0.79</td>
</tr>
<tr>
<td>ch2</td>
<td>0.97</td>
<td>0.86</td>
</tr>
<tr>
<td>ch3</td>
<td>0.95</td>
<td>0.86</td>
</tr>
<tr>
<td>ch4</td>
<td>0.96</td>
<td>0.82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Visible</th>
<th>UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ch1</td>
<td>1.02</td>
<td>0.97</td>
</tr>
<tr>
<td>ch2</td>
<td>1.01</td>
<td>0.99</td>
</tr>
<tr>
<td>ch3</td>
<td>1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>ch4</td>
<td>1.01</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Result

- Current decrease was observed during 24h irradiation
- Rate of decrease is larger than at low temp
- $N_2$ flow rate change affected current decrease rate
- Temperature changed
- There was no significant difference b/w PDE decrease for UV and visible

<table>
<thead>
<tr>
<th></th>
<th>Irradiated</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch1</td>
<td>0.91</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Ch2</td>
<td>0.92</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Ch3</td>
<td>0.94</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Ch4</td>
<td>0.93</td>
<td>0.92</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Non-Irradiated</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch1</td>
<td>0.97</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td>Ch2</td>
<td>0.94</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Ch3</td>
<td>0.93</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Ch4</td>
<td>0.96</td>
<td>1.02</td>
<td></td>
</tr>
</tbody>
</table>

(Normalized with charge before irradiation)
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