MEG II experiment:
Commissioning of Liquid Xenon Detector
towards Start of Physics Run (1)

Kazuki Toyoda on behalf of the MEG II Collaboration
19-Sep-2019
JPS autumn @Yamagata Univ.
Outline

➢ Introduction
  o $\mu \rightarrow e\gamma$
  o MEG II
  o Liquid Xenon Detector
  o pre-Engineering Run

➢ Photo-Sensor Monitoring
  o MPPC
  o PMT
  o Energy Scale
  o Prospect
Charged Lepton Flavor Violation

- practically forbidden in Standard Model by tiny neutrino mass
- but many predictions by new physics are within experimental reach
  - eg. SUSY with GUT/Seesaw

\[ \mu \rightarrow e \gamma \] search

- Signal
  - both 52.8 MeV/c
  - back to back
  - same timing

- Dominant Background: Accidental

\[ \mu \rightarrow e \gamma \]
MEG II

- goal sensitivity: $6.0 \times 10^{-14}$ in 60 weeks
  - compared to MEG I result:
    \[ Br(\mu \to e\gamma) < 4.2 \times 10^{-13} \]
    (sensitivity: $5.3 \times 10^{-13}$)

- key concept:
  - high $\mu$ intensity: $7 \times 10^7 \mu/s \text{ @PSI}$
  - high resolution detectors

- talks
  - overall status: 19pT22-2
  - timing counter: 17pT12-1,2,3
  - radiative decay counter: 18pT12-1
Liquid Xenon Detector

- 900 L liquid Xe scintillator (VUV-light ~175 nm)
- PMTs on γ incident surface are replaced to MPPCs

→ improved uniformity and granularity

- energy resolution: 2% @MEG I → 1% @MEG II (expected)
- position resolution: 5 mm @MEG I → 2.5 mm @MEG II (expected)
Commissioning of Xe Detector

- **pre-Engineering Run 2018**
  - sensor calibration by LED, $^{241}$Am $\alpha$ source
  - 17.6 MeV $\gamma$ from $p$-Li reaction
  - background $\gamma$ from $\mu$ beam ($\mu \rightarrow e\nu\nu\gamma$, $ee \rightarrow \gamma\gamma$)
  - limited to $\frac{1}{4}$ of full readout electronics

- **talks**
  - MPPC PDE issue: 17aT12-4,5
  - energy resolution:
    - sensor monitoring: 19pT14-6 (this talk)
    - background spectrum: 19pT14-7
    - $p$-Li reaction: 19pT14-8
Outline

- Introduction
  - $\mu \rightarrow e\gamma$
  - MEG II
  - Liquid Xenon Detector
  - pre-Engineering Run

- Monitoring of Photo-Sensor
  - MPPC
  - PMT
  - Energy Scale
  - Prospect
charged = N_{photon} \cdot PDE_\lambda \cdot gain \cdot ECF

- weak LED
- Strong LED: response for visible light
- charge from scintillation by α from $^{241}\text{Am}$
- current from scintillation by γ from μ

Charge follows “Poisson + correlated noise” distribution

\[
gain \cdot ECF = \frac{\text{mean}}{\mu \text{ (expected # of primary discharge)}}
\]

estimated from pedestal fraction:

\[
P(0 \text{ p.e.}) = e^{-\mu}
\]
\[ \text{charge} = N_{\text{photon}} \cdot QE \cdot CE \cdot \text{gain} \]

- LED of different intensity

- Strong LED: response for visible light
- charge from scintillation by \( \alpha \) from \( ^{241}\text{Am} \)
- current cannot be read out

\[ \text{gain} = \frac{\text{variance}}{\text{mean}} \]

- Charge follows Poisson distribution

QE: Quantum Efficiency
CE: Collection Efficiency
gain: charge from 1 photoelectron

LED

\( ^{241}\text{Am} \alpha \) source
Photo-Sensor Monitoring

MPPC: Visible Light

- gain looks stable < 0.5%
- LED response decrease ~ 1-2%

Gain ECF charge from LED
MPPC: VUV Light

- Current behavior is not simple
- Indicates ∼10% decrease of PDE for VUV in ∼150 h @MEG II intensity
- Response for VUV light is decreasing much faster than for visible light

Current from $\gamma$ (from $\mu$)

Charge from $\alpha$

# of muon (normalized)
### Photo-Sensor Monitoring

**PMT**

- **Gain & CE depends on B-field configuration**
- **All behavior is consistent within ~ 1%**
- **Gain decrease ~ 7%**

#### Graphs:

1. **Top graph:**
   - **x-axis:** Dates
   - **y-axis:** a.u.
   - Symbols:
     - hollow circle: gain (no B-field)
     - filled square: LED (B-field config. 1)
     - filled triangle: alpha (B-field config. 2)
   - The data points show the behavior of gain and CE across different dates.

2. **Bottom graph:**
   - **x-axis:** Dates
   - **y-axis:** # of muon (normalized)
   - The graph tracks the normalized number of muons over time, showing a consistent trend.

---

Kazuki Toyoda

JPS autumn 2019
Validation by $\gamma$ from $p$-Li Reaction

- 0.4-1 MeV $p$ by Cockcroft-Walton accelerator
- Li$_2$B$_4$O$_7$ target
- 17.6 MeV $\gamma$ from $^7$Li($p$, $\gamma$)$^8$Be
  - first time in MEG II
    → detail in following talk
- 3 runs
  - 30th Nov
  - 10th Dec
  - 17th Dec

\[ ^{12}\text{C} \rightarrow ^{12}\text{C} + \gamma \]
\[ ^{19}\text{F}(p, \alpha \gamma)^{16}\text{O} \quad ^{11}\text{B}(p, \gamma)^{12}\text{C} \quad ^7\text{Li}(p, \gamma)^8\text{Be} \]
Validation by $\gamma$ from $p$-Li Reaction

- 3 runs (30 Nov, 10 Dec, 17 Dec)

- Energy scale shift ~ 5%
- Should be within 1%
- Should be checked more frequently
Summary & Prospect

- **MPPC**
  - PDE for VUV light looks decreasing
    - under investigation (17aT12-4,5)
  - cannot follow the change by frequent LED calibration

- **PMT**
  - gain seems decreasing although it can be recovered by increasing HV
  - but faster than expected → lab. test is going on

- **Engineering Run 2019**
  - more stable long-term beam irradiation
  - frequent $\alpha$ calibration (thanks to improve of DAQ speed)
  - frequent $p$-Li runs to firmly confirm monitoring precision
Backup
**About XEC**

**Figure 59** An MPPC signal waveform (upper) and a PMT signal waveform (lower) for the same $\alpha$-event digitised at a sampling frequency of 700 MSPS.

**Figure 62** (Top) Response functions for the SiPMs with different total pixel numbers measured for a 40 ps laser pulses $[135]$. (Bottom) The number of photoelectrons expected from a $12 \times 12$ mm$^2$ MPPC versus conversion depth in the MEG II MC simulation.
XEC Performance (1)

Figure 71 Position resolution in the horizontal (top) and vertical (bottom) directions as a function of the first conversion depth. The resolutions in MEG are shown with red markers, and those in MEG II are shown with blue markers.

Figure 73 Energy PDFs for \( E = 52.83 \text{ MeV} \) photons converting in the MEG (left) and the MEG II (right) LXe photon detectors. The response to shallow (top) and deep (bottom) events are shown separately.
XEC Performance (2)

Figure 74: Energy response functions with various assumptions of additional fluctuation (0, 0.7 and 1.3%) and that of the 2009 data.

(a) $w \leq 2$ cm

(b) $w \geq 2$ cm

Figure 75: Reconstructed energy spectrum obtained for different beam intensities. The horizontal axis shows energies in GeV without unfolding pile-up photons (a) and the same after unfolding and subtracting the energy of pile-up photons (b). Green, black, blue and red lines show the spectrum at muon stopping rates of 1.0, 3.0, 3.3 and $8 \times 10^7 \mu /a$, respectively. The spectra are normalised by the number of events in the range 48-58 MeV; the scaling factors are consistent with the muon stopping rate on the target. A difference in the low energy part below 42 MeV is due to different effective trigger thresholds; a difference in the high energy part is due to the different ratio between the photon backgrounds and the cosmic ray background.
Requirement for Sensor Calibration

图 5.11 MPPC の PDE の測定誤差と位置・エネルギー分解能の関係 [37]。左)MPPC の PDE の測定誤差の増加に伴って位置分解能が悪化する。右)MPPC, PMT の PDE の測定誤差の増加によってエネルギー分解能が悪化する。
### Estimation of Radiation

<table>
<thead>
<tr>
<th>推定radiation</th>
<th>推定量</th>
<th>根拠</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ</td>
<td>$1 \times 10^{-2}$ Gy</td>
<td>シミュレーション</td>
</tr>
<tr>
<td>neutron</td>
<td>$2.7 \times 10^6$ n/cm²</td>
<td>実験ホールにおける過去の測定</td>
</tr>
<tr>
<td>photon (Xe scintillation)</td>
<td>$\sim 10^{15}$ photon ($10^{13-14}$ p.e.)</td>
<td>シミュレーション: 1e6 p.e. /s 電流の実測値: 1e7 p.e. /s ビーム期間: 150時間</td>
</tr>
</tbody>
</table>
Individual Difference

• Individual difference of measured PDE:
  • MPPC: 1.0%(636 channels)
  • PMT: 5.2%(364 channels)

\[
\sigma_{obs} \sim \sqrt{\sigma_{true}^2 + \sigma_{resolution}^2}
\]
CW

Backup

Kazuki Toyoda
Depth Dependence of Energy

# of photon

MPPC

PMT

30 Nov

10 Dec

17 Dec

depth [cm]
Position Dependence of Decrease @MEG I

Decrease Rate
$[10^{-2}\%$/day$]$
Position Dependence of Decrease Rate @ MEG II

Decrease Rate [%/day]
Estimation in 2012
HV Estimation based on Different Models

$$\text{Gain} = a(V - V_0)^k$$

due to a

due to $V_0$: Zener diodes, cable loss

due to $k$: dynode material