Calibration of VUV-sensitive MPPCs of MEG II Liquid Xenon Gamma-ray Detector

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0. Abstract

We have developed calibration methods of VUV(Vacuum Ultraviolet)-sensitive MPPCs of MEG II liquid xenon gamma-ray detector. Gain, Excess Charge Factor(ECF) and Photon Detection Efficiency(PDE) have been constantly monitored under high intensity muon beam environment.
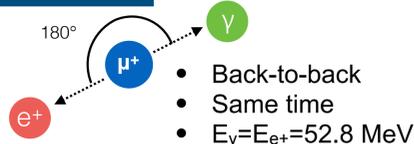
1. MEG II Experiment

$\mu \rightarrow e\gamma$ decay search at PSI.
- Forbidden in Standard Model
- Observable in BSM($Br(\mu \rightarrow e\gamma) \sim 10^{-14}$).

Kinematics

180°
μ^+
γ
e^+
- Back-to-back
- Same time
- $E_\gamma = E_{e^+} = 52.8$ MeV

Key concepts[1]
- High intensity μ beam available at PSI.
  - $7 \times 10^7 \mu/s$
- High resolution detectors for e^+ and γ

COBRA superconducting magnet
Pixelated timing counter (pTC)
Muon stopping target
Cylindrical drift chamber (CDCH)
Radiative decay counter (RDC)
Liquid Xenon gamma-ray detector
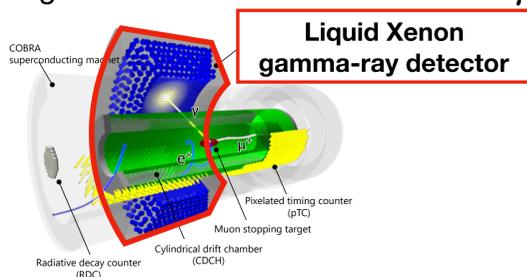
2. Liquid Xenon Gamma-ray Detector

LXe scintillator coupled with VUV-sensitive photosensors.

LXe scintillator(900 L)
- Fast & large response
- Vacuum Ultraviolet scintillation
  - Wavelength $\lambda \sim 175$ nm

+

4760 Photosensors
- **4092 MPPC(Multi-pixel Photon Counter)**
  - Newly developed for MEG II[2]
- 668 PMT(Photo Multiplier Tube)

In 2018, 640 MPPCs have been operated under high intensity muon beam environment.
- The number of MPPCs is limited due to the limited readout channels.
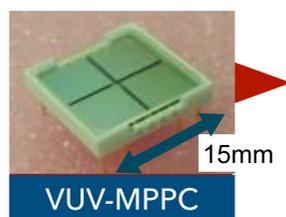- Over voltage: 7 V, Temperature: 165 K

Photosensor Calibration

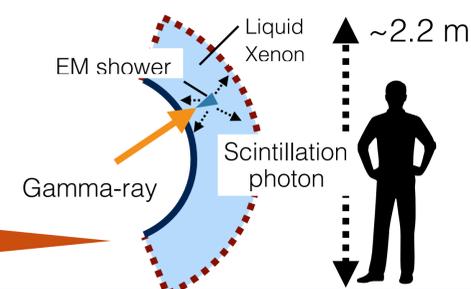**O(1)% precision is essential for detector performance.**

$$N_{photon} = Charge/(G \times ECF \times PDE)$$

Gain — Excess Charge Factor: Cross-talk, After pulsing — Photon Detection Efficiency

Designed Resolution	
Position	2.5 mm
Energy	**0.7~1.5%**

4092 MPPCs   668 PMTs
VUV-MPPC   15mm
Inside Detector
EM shower   Liquid Xenon   ~2.2 m
Gamma-ray   Scintillation photon

3. Gain & ECF

Method

Measure subtle blue LED light.

Gain = Charge of 1 photo-electron.

$$Gain = Q_{1\ p.e.} - Q_{0\ p.e.}$$

Excess Charge Factor(ECF):
Deviation from Poisson distribution

$$ECF = \overline{Q_{observed}}/\overline{Q_{Poisson}}$$

$$\overline{Q_{Poisson}} = Gain \times (-\ln(R_{0\ p.e.}))$$

Fraction of pedestal events

LED (covered with Teflon)

Charge Spectrum
Gain
Sufficient S/N to resolve peaks
Charge[$10^9 e$]
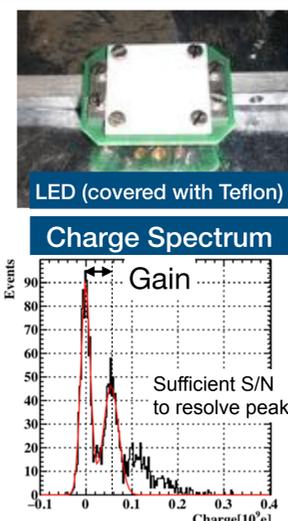
Result

Gain & ECF were successfully measured for all MPPCs.
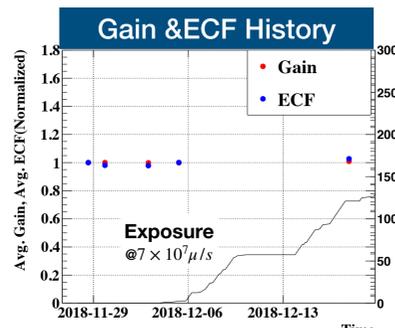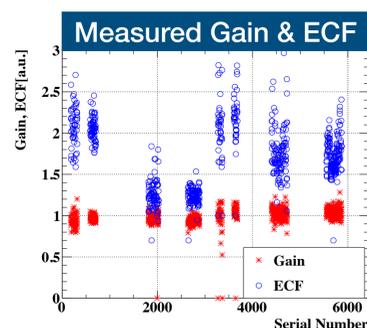Gain: 1.6×10^6(average), precision: 1%
ECF: 1~2.5(depending on production lot)
- Relative uncertainty: 3~4%(channel by channel)

► Precision meets the requirement.
Stability under muon beam environment has been checked.

Measured Gain & ECF
Gain, ECF[a.u.]
Gain
ECF
Serial Number

Gain & ECF History
Avg. Gain, Avg. ECF(Normalized)
Gain
ECF
Exposure @$7 \times 10^7 \mu/s$
2018-11-29 2018-12-06 2018-12-13
Time

4. Photon-detection efficiency(PDE)

Method

Measure α-ray events from ^{241}Am sources[3].
- 25 point sources mounted on 5 wires.
- 5.5 MeV α-ray at ~100 Hz.

The expected number of incident photons is evaluated using MC simulation.

^{241}Am source

$$PDE = N_{phe,measured}/N_{pho,expected}$$

# of measured photo-electrons   # of expected Incident photons
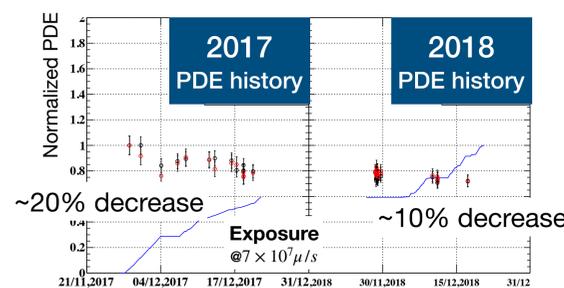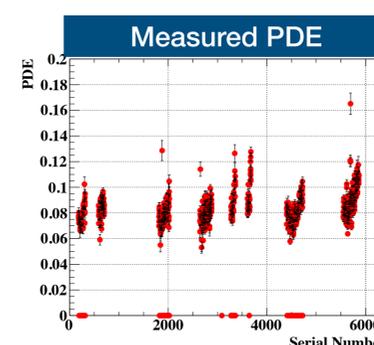
Detector Condition
- Light yield of LXe
- Absorption in LXe
- Reflection at walls

Result

Measured PDE: 8.6 % (average)
- Relative uncertainty: 4%(channel by channel)
- Lower than the previous measurement(~18%)[2]
~30 % PDE drop under muon beam (370 hours@$7 \times 10^7 \mu/s$).

► Precision meets the requirement.

Measured PDE
PDE
Serial Number

Normalized PDE
2017 PDE history   **2018 PDE history**
~20% decrease   ~10% decrease
Exposure @$7 \times 10^7 \mu/s$
21/11,2017 04/12,2017 17/12,2017 31/12,2017 30/11,2018 15/12,2018 31/12

5. Summary

- VUV-sensitive MPPC has been developed and installed in MEG II liquid xenon gamma-ray detector.
- We have developed calibration methods that realizes O(1)% precision on gain, ECF and PDE.
- Intrinsic response of MPPC has been stable under high intensity muon beam environment.

6. Acknowledgement

7. Reference

[1] Baldini, A.M. et al., "The design of the MEG II experiment" ,Eur. Phys. J. C (2018) 78: 380.
[2] K, Ieki et al., "Large-area MPPC with enhanced VUV sensitivity for liquid xenon scintillation detector" , Nucl. Instrum. Methods A 925 (2019) 148-155
[3] Baldini, et al., "A radioactive point-source lattice for calibrating and monitoring the liquid xenon calorimeter of the MEG experiment", Nucl. Instrum. Methods A 565 (2006) 589–598