Commissioning of Liquid Xenon Gamma-Ray Detector for MEG II Experiment

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Core-to-Core Program

1. Introduction

MEG II Experiment

MEG II experiment searches $\mu \to e\gamma$ using the most intense μ^+ beam at Paul Scherrer Institute.
$\mu \to e\gamma$ is a charged lepton flavor violation decay. If this decay is found, it would be evidence of new physics.
In MEG experiment, $\mathcal{B}(\mu \to e\gamma) = 4.2\times10^{-13}$ (90%C.L.) was obtained.
The goal is to search for 10 times better sensitivity by detector upgrade.

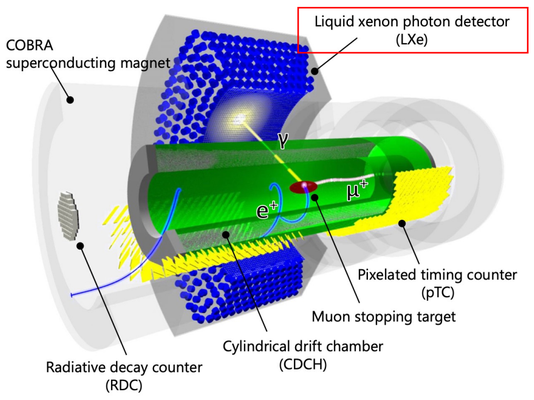

Fig.1 Detectors of MEG II experiment

Liquid Xenon Gamma-ray Detector (LXe)

LXe measures the position, energy and timing of the γ-ray.

- 900 L liquid xenon
- 4092 VUV-sensitive MPPCs (entrance face)
- 668 PMTs (other faces)

Readout of all channels started in 2021 engineering run.

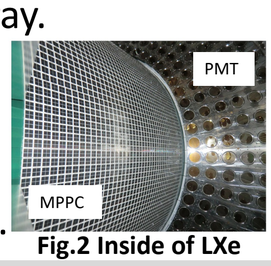

Fig.2 Inside of LXe

2. Start of Physics Data Taking

All kinds of the required calibration data were taken.
→Physics data taking started.

Calibrations

Sensor calibration with LED and α-ray

MPPC PDE Decrease

- Cause of the decrease is not known.
- PDE can be recovered by annealing.
- Physics run in 2022 can be started after the annealing.

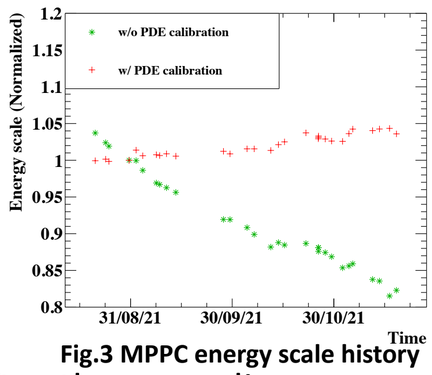

Fig.3 MPPC energy scale history

Energy scale stability

- 17.6 MeV and 14.6 MeV gamma-ray from Li(p,γ)Be
- 9 MeV gamma-ray from Ni(n,γ)Ni
- Cosmic rays

Energy monitoring by Li(p,γ)Be (Fig.3)

- PDE has an impact for energy scale.
- Energy scale is monitored stably with PDE calibration although some fluctuation is observed.

Radiative Muon Decay (RMD) $\mu \to e\nu\bar{\nu}\gamma$

- Trigger for $\mu \to e\gamma$ (MEG trigger) needs time coincidence of gamma-ray and positron.
- Gamma-ray and positron are emitted at the same time in RMD.
- The peak was observed.
  →MEG trigger is fired correctly.

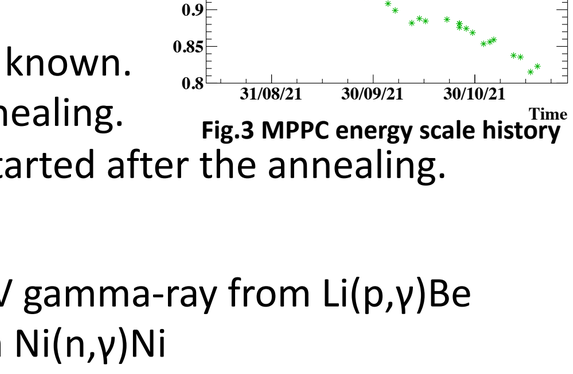

Fig.4 Time difference between gamma-ray and positron

Physics Data

- Physics data was taken in 2021 in some beam intensities.
- Analysis of physics data is ongoing.

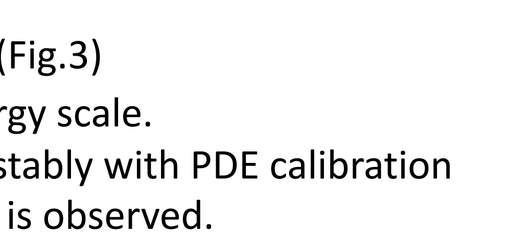

Fig.5 Accumulated number of muon stopped on target

3. Timing Resolution Evaluation in CEX Run

Charge Exchange reaction (CEX)

$\pi^- \mathrm{p} \to \pi^0 n$
$\pi^0 \to \gamma\gamma$ (Back-to-back γ-rays : 54.9 MeV and 82.9 MeV)
close to the energy of the signal event (52.8 MeV)

absolute timing resolution

$$\sigma_{\mathrm{abs}} = \sigma\left(T_{\mathrm{LXe}} - T_{\mathrm{ps}} - T_{\mathrm{TOF}}\right) \ominus \sigma_{\mathrm{ps}} \ominus \sigma_{\mathrm{vertex}}$$

σ_{vertex} smears the distribution of $(T_{\mathrm{xec}} - T_{\mathrm{ps}} - T_{\mathrm{TOF}})$ → σ_{vertex} should be measured

intrinsic timing resolution

Gamma-ray hit timing on pre-shower counter is used as reference.

$$\sigma_{\mathrm{int}} = \sigma(T_{\mathrm{PM,even}} - T_{\mathrm{PM,odd}})/2$$

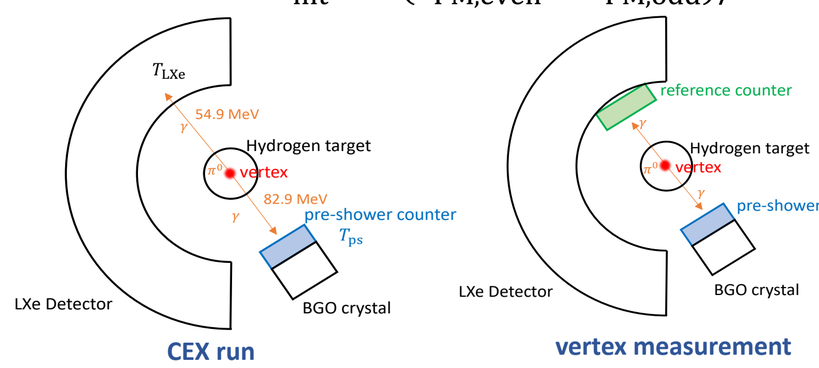

Fig.6 Setup for CEX run and vertex measurement

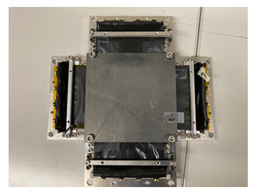

Fig.7 Pre-shower counter

$\pi^0 \to \gamma\gamma$ Vertex measurement

$$\sigma^2_{\mathrm{vertex}} = 2\sigma^2\left(\frac{T_{\mathrm{ps},0} + T_{\mathrm{ps},1}}{2} - \frac{T_{\mathrm{ref},0} + T_{\mathrm{ref},1}}{2}\right) - \frac{\sigma^2(T_{\mathrm{ps},0} - T_{\mathrm{ref},0}) + \sigma^2(T_{\mathrm{ps},1} - T_{\mathrm{ref},1}) + \sigma^2(T_{\mathrm{ps},0} - T_{\mathrm{ref},1}) + \sigma^2(T_{\mathrm{ps},1} - T_{\mathrm{ref},0})}{4}$$

$$\sigma_{\mathrm{vertex}(\pi^0 \to \gamma\gamma)} = 65.0 \pm 6.1 \text{ ps } (9.8 \pm 0.9 \text{ mm})$$

Measured vertex size is larger than expected.
(π^- beam size : 4 mm)

Timing resolution of LXe

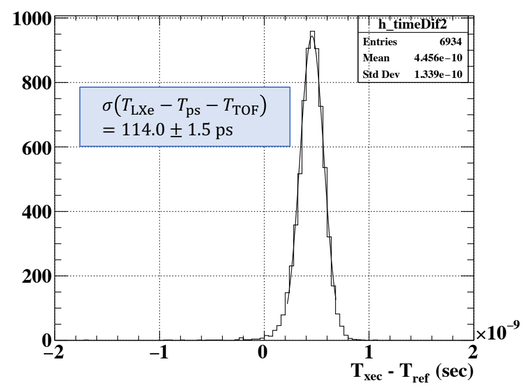

Fig.8 Time difference between LXe and pre-shower counter

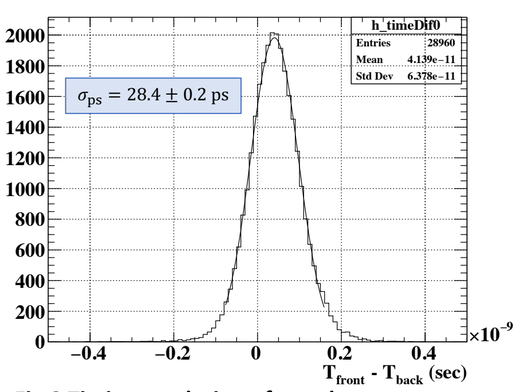

Fig.9 Timing resolution of pre-shower counter

$$\sigma_{\mathrm{abs}} = 85.4 \pm 5.1 \text{ ps (Preliminary result)}$$

	Measured	MC
σ_{abs} [ps]	85.4 (To be investigated)	57.3
σ_{int} [ps]	37.8	38.4

- $\sigma_{T_{e\gamma}}$ is limited by LXe resolution. ($\sigma_{T_e} \sim 40$ ps)
- Timing reconstruction and calibration method should be improved.
- The analysis of energy resolution with CEX run data is in progress.

4. Performance of LXe

	Resolution in MEG [1]		Resolution in MEG II
Position [mm]	5	4% sensitivity improvement [2] →	2.5 ± 0.2
Energy [%]	1.7 ~ 2.4	~10% sensitivity improvement [2] →	1.8 ± 0.1
Timing [ps]	64	To be improved	85.4 ± 5.1

[1] Baldini, A.M., Baracchini, E., Bemporad, C. et al. "The design of the MEG II experiment". Eur. Phys. J. C 78, 380 (2018). https://doi.org/10.1140/epjc/s10052-018-5845-6
[2] S.Ogawa, "Liquid xenon detector with highly granular scintillation readout to search for $\mu^+ \to e^+\gamma$ with sensitivity of 5×10^{-14} in MEG II experiment", The University of Tokyo, Ph.D. Thesis(2020)

5. Summary

- The full electronics were installed in 2021.
- All kinds of calibration data were taken, and physics data taking started.
- RMD peak was observed, so MEG trigger is working correctly.
- The cause of the large measured vertex is not known.
- Timing resolution of LXe is worse than MC. The further investigation is needed.
- LXe is ready for the long-term physics data taking, and the detector performance and stability will be improved furthermore.