PROCEEDINGS OF SCIENCE

Commissioning of liquid Xe detector with VUV-MPPC readout for MEG II experiment

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MEG II experiment is an upgrade of MEG experiment to search for charged lepton flavor violating decay of muon, $\mu \to e\gamma$. Target sensitivity of MEG II is 6×10^{-14} at 90% C.L., which is one order of magnitude better than MEG. Liquid xenon detector was used to detect 53 MeV signal γ-ray in MEG, and this detector has been upgraded for MEG II. Replacement of 216 PMTs on the entrance face with 4092 newly developed VUV-sensitive MPPCs has been carried out to have better granularity and uniformity of the scintillation readout.

In 2017, commissioning of this detector has been started. Sufficient performance has been confirmed for most of the MPPCs. Pilot run of this detector with muon beam was performed, and γ-ray near signal energy has been successfully detected. By the even-odd analysis of the obtained data, good timing resolution (44 ps for 50 MeV γ-ray) has been achieved.

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1. LXe γ-ray detector in MEG II experiment

Charged lepton flavor violating decay of muon, $\mu \to e\gamma$, has never been observed, and prohibited in the Standard Model. On the other hand, detectable branching ratio is predicted by many new physics. Current best upper limit is 4.2×10^{-13} at 90% C.L. given by MEG experiment [1]. For the further improvement of the sensitivity by one order of magnitude, upgrade of MEG experiment, called MEG II, is in preparation at Paul Scherrer Institut (PSI) [2]. All detectors will be upgraded to achieve twice better resolution, and muon beam rate will also be doubled.
Liquid xenon (LXe) detector was used in MEG to detect monochromatic 53 MeV γ-ray from the signal event, and this detector has been upgraded for MEG II. Most important upgrade is to replace 216 2-inch Photo Multiplier Tubes (PMTs) on the γ-ray entrance face with 4092 $12 \times 12\,\mathrm{mm}^2$ Multi-Pixel Photon Counters (MPPCs) (Fig.1), to have better granularity and uniformity of the scintillation readout. Expected detector performance is summarized in Table 1. Position and energy resolution will be improved by a factor of 2.

Table 1: Performance of LXe detector for the signal 53 MeV γ-ray.

	σ (position)	σ (energy)	σ (timing)	Efficiency
MEG (measured)	$\sim$ 5 mm	$\sim$ 2%	67 ps	63%
MEG II (simulated)	$\sim$ 2.5 mm	0.7 – 1.5%	50 – 70 ps	69%

MPPC used for this detector has to be operated in LXe temperature, and has to be sensitive to Xe scintillation light ($\lambda = 175\,\mathrm{nm}$) in VUV range. Since there was no MPPC which satisfied our requirements, we have developed a new MPPC in collaboration with Hamamatsu Photonics K.K [3]. Photon detection efficiency over 15% for Xe scintillation light has been achieved by removing the protection layer of resin, and optimizing optical matching at sensor surface. Our MPPC package is a discrete array of four $6 \times 6\,\mathrm{mm}^2$ chips. Those four chips are connected in series to reduce long time constant caused by large capacitance due to large sensitive area.

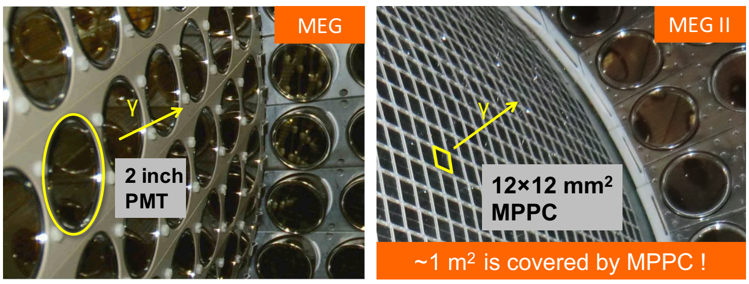

Figure 1: Picture of γ-ray incident face of LXe detector for MEG (left) and MEG II (right).

2. Commissioning of LXe detector

Detector commissioning has been started just after we completed detector construction in 2017 April. Goal of 2017 was to carry out pilot run with MEG II nominal intensity muon beam.

2.1 Preparation for pilot run

For the operation of LXe detector, it is needed to achieve good and stable condition of LXe purity, since impurity such as water and oxygen can cause quenching and absorption of the scintillation light. Purification of Xe has been performed. Purification system in MEG is reused.
Purity has been monitored by two types of events. One is the scintillation light from calibration alpha source (^{241}Am) installed inside cryostat, whose light distribution can be used to measure total light yield and absorption length. The other is the cosmic ray muon, whose waveform time constant can be used to monitor quenching effect from . Fig.2 shows detected number of photons from ^{241}Am. After a few months of purification, sufficient light yield for our detector operation was achieved.
Calibration of photo sensors have been done. Sufficient performance was confirmed for most of our sensors (Table 2). Stability of sensor performance is also confirmed for a month.
Alignment of MPPC was carried out by measuring scintillation light of collimated X-ray beam injected from the outside of the cryostat. Detail is summarized in [4].

Table 2: Performance of photo sensors. (MPPC HV: $\Delta V = 7\,\mathrm{V}$. PMT HV: adjusted to have uniform gain.)

Variable	Method	Measured value (average)
Gain of MPPC	single p.e. peak	8×10^5
Gain of PMT	Poisson statistics of p.e. from LED	1.6×10^6
Excess charge factor of MPPC	p.e. distribution from weak LED light	1.2 - 1.4
PDE for VUV (Premilinary)	number of p.e. from ^{241}Am	12% (MPPC), 15% (PMT)

2.2 Pilot run with muon beam

Pilot run with MEG II nominal intensity muon beam was performed, and data taking of γ-ray mainly from radiative muon decay ($\mu \to e\nu\bar{\nu}\gamma$) has been successfully carried out. Signal from photo sensors were read out by electronics developed for MEG II, called WaveDREAM. Because the number of readout channel was limited, only the quarter of our detector was read out. Trigger was generated based on the amplitude of the sum of MPPC waveforms, and energy threshold was set to roughly 42 MeV. Fig 3 shows an example of event display, where light distribution can be clearly seen with improved granularity realized by MPPC.
Timing resolution is estimated from the obtained data. Hit timing of γ-ray is reconstructed from the weighted average of the timing of each photo sensor waveforms. Tuning of the waveform analysis and dedicated noise subtraction algorithm is performed in offline analysis to achieve good resolution. Detector timing resolution is estimated by "even-odd analysis", where photo sensors are grouped into two, and resolution is calculated from the difference of the reconstructed timings of each groups.
Timing resolution for 50 MeV γ-ray is measured to be 44 ps, which is 30% better than the MEG II design value. This will lead to 15% improvement of MEG II physics sensitivity. Timing resolution by even-odd analysis does not include the precision of the γ-ray propagation time which is dominated by hit position resolution. It may also not include the effect of correlated noise. Thus another measurement using coincident two γ from π^0 decay is being planned to check those effect.

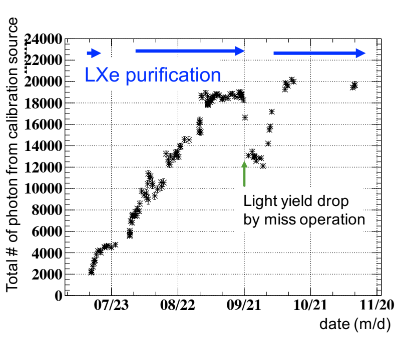

Figure 2: History of total light yield.

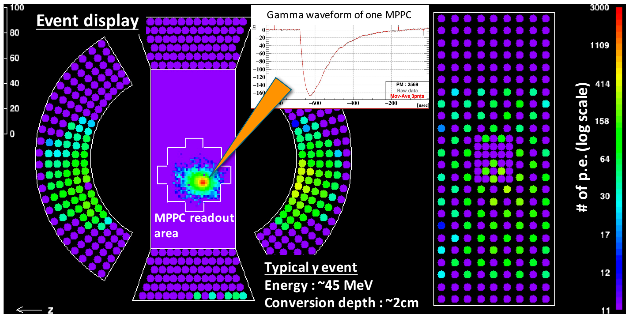

Figure 3: Typical event display of γ-ray. (Only the quarter of our detector was read out.)

Another purpose of this pilot run is to find out possible issue before the engineering of our detector. Coherent noise on the readout electronics was observed, and this can limit our energy resolution, since energy of incident γ-ray is reconstructed from the sum of the integrated charge of all photo sensors. Observed noise level can be comparable to our goal of energy resolution. Investigation and reduction of this noise is ongoing.

3. Summary

LXe detector for MEG II has been upgraded by utilizing newly developed VUV-MPPC. Commissioning of this detector has been started. Sufficient performance has been confirmed for most of the MPPCs. Data taking of γ-ray has been carried out, and good timing resolution has been achieved. Found issues are under investigation towards the detector engineering planned in 2019.

Acknowledgements

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