# VUV-sensitive MPPCs for liquid xenon detector in MEG II experiment

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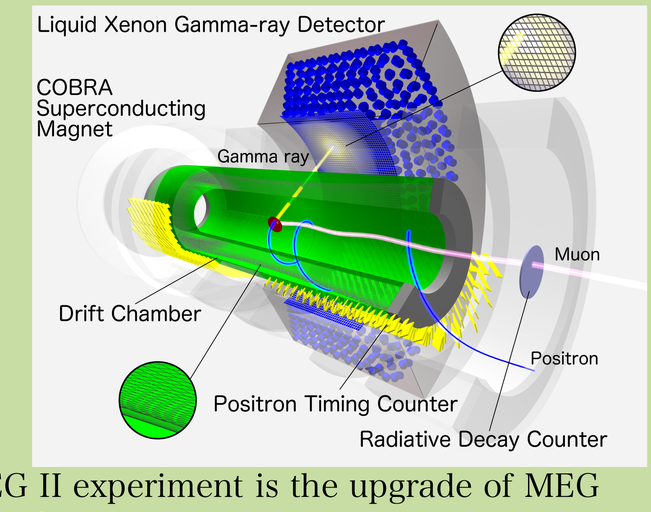
Abstract: A large area MPPC which is sensitive to xenon scintillation light in VUV range has been successfully developed for MEG experiment upgrade. Evaluated performance including a recent result is reported.

## 1. MEG II Experiment

MEG experiment have searched for lepton flavor violating decay of muon, $\mu^+ \to e^+ \gamma$.

- BR upper limit (90% C.L.): $4.2\times10^{-13}$ (A.M.Baldini et.al., Eur. Phys. J. C(2016) 76:434 1-30)



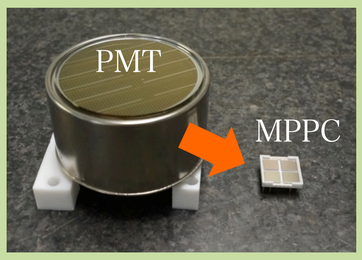

MEG II experiment is the upgrade of MEG experiment.

- Expected BR sensitivity (90% C.L.): $4\times10^{-14}$
- Higher beam rate
- LXe gamma-ray detector with MPPC readout
- Pixelated positron timing counter
- Cylindrical drift chamber for positron tracking
- Radiative decay counter for background identification

## 2. LXe Detector Upgrade

Goal is to achieve **better resolutions for signal $\gamma$-ray** to reduce accidental background.

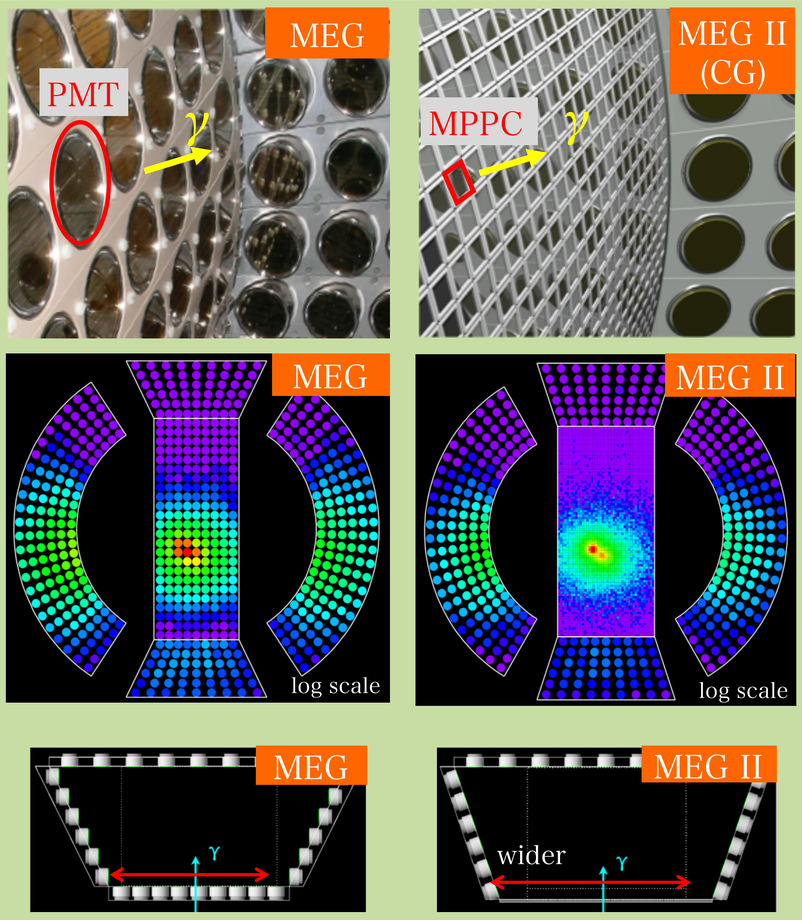
- Replace 216 2'' PMTs on $\gamma$-ray inner face with **4092 VUV-sensitive MPPCs**
- Modified PMT layout at lateral face
- Wider inner face




- **Better uniformity of photon collection**
  - Better energy resolution
- **Higher granularity of scintillation readout**
  - Better position resolution
- Better detection efficiency

**Detector performance for signal $\gamma$-ray**

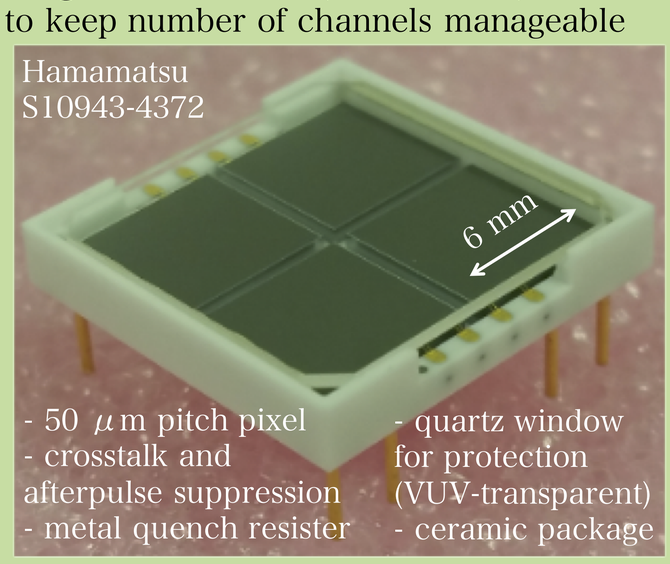
| | MEG (measured) | MEG II (simulated) |
|---|---|---|
| Efficiency | 65% | 70% |
| Position | ~ 5 mm | ~ 2.5 mm |
| Energy | ~ 2% | 0.7 - 1.5% |
| Timing | 67 ps | 40 - 60 ps |




## 3. VUV-Sensitive MPPC for MEG II

**Large area VUV-sensitive MPPC** has been developed in collaboration with Hamamatsu Photonics K.K.

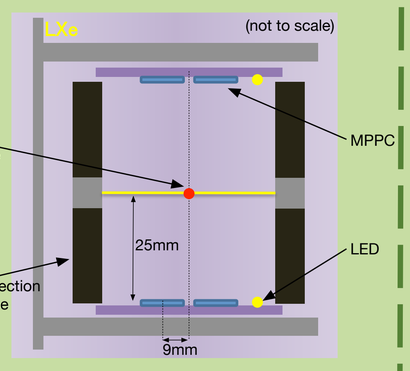
- **Sensitive to Xe scintillation light ($\lambda$=175 nm)** in VUV range
- **Large sensitive are (12×12 mm²)** to keep number of channels manageable




### ◆ Performance test

The performance is tested in LXe.

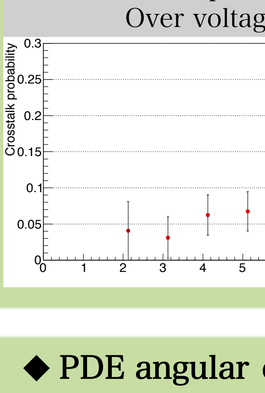
- Alpha source ($^{241}$Am) as a point light source of scintillation light.
- LED for 1p.e. calibration
- Anti-reflection tube to reduce the reflection from the cryostat wall.



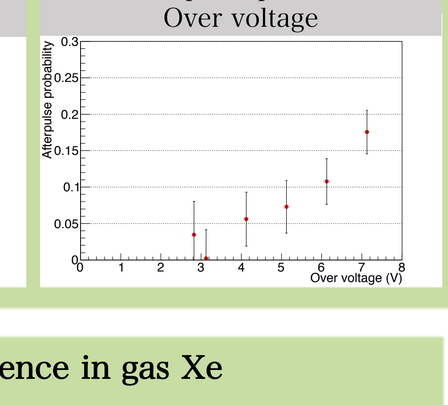

### ◆ Single photoelectron waveform

Our MPPC is a discrete array of four 6×6 mm² chips, and they are connected in series to suppress longer time constant coming from larger sensitive area.

"Hybrid" connection



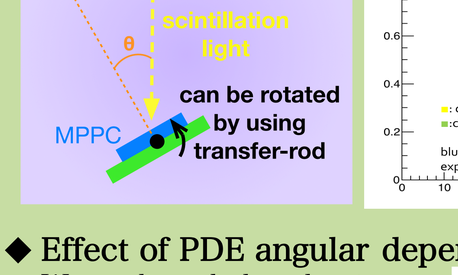

Measured 1 p.e. waveform



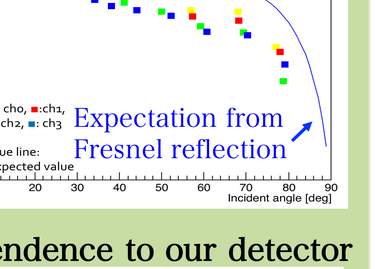

### ◆ Gain

Single p.e. peak is clearly resolved thanks to the small dark count rate at LXe temperature.
Sufficient gain ($10^5$/ V) is achieved.

Charge distribution using LED



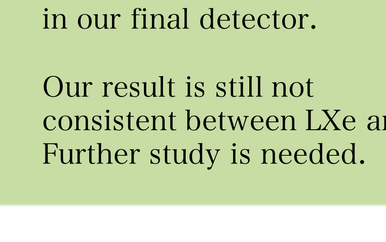

Gain vs. Over voltage



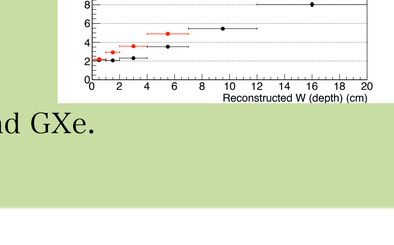

### ◆ Crosstalk & After pulse probability

Small crosstalk & afterpulse probability is achieved thanks to the suppression technique.

Crosstalk prob. vs. Over voltage




After pulse prob. vs. Over voltage

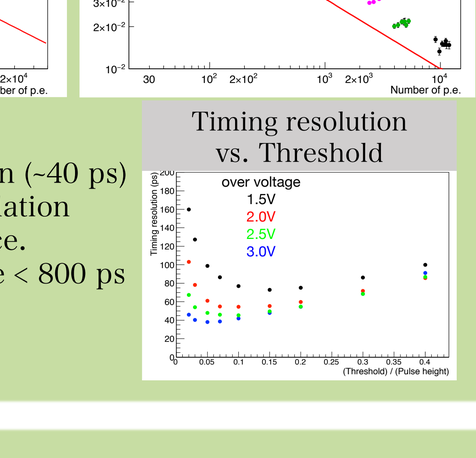



### ◆ PDE for VUV light

Sufficient PDE (>15%) is achieved for Xe scintillation light ($\lambda$=175 nm).
This is realized by

- removing the protection layer of resin
- optimizing optical matching b/w LXe and sensor surface
- thinning contact layer

PDE vs. Over voltage

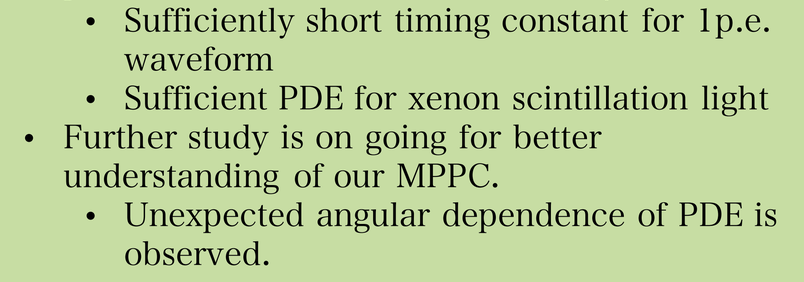



Large systematics for absolute PDE value comes from the estimation of impinging number of photons to MPPC.

### ◆ Energy resolution

Energy resolution is confirmed to improve as $1/\sqrt{(\#\text{ of p.e.})}$.
We observed larger excess noise factor (1.2-1.3) for VUV light. This is acceptable level for us, as energy resolution of our final detector is not limited by statistics.

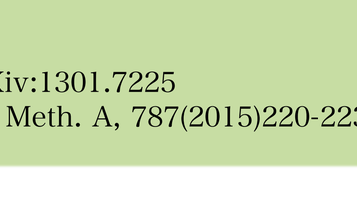
Energy resolution. vs. Photoelectron statistics




### ◆ Timing resolution

Good timing resolution (~40 ps) is achieved for scintillation light from alpha source.
TTS is estimated to be < 800 ps for VUV light.

Timing resolution vs. Threshold




## 4. For further understanding of our MPPC

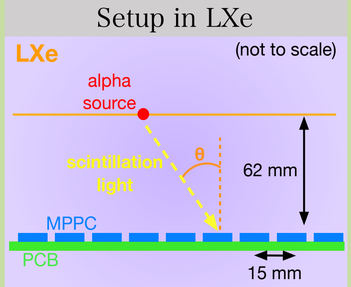
Further study of our MPPC characteristics is on going **for better understanding of our MPPC**.

- Absolute value of PDE
- Variation of MPPC characteristics.
- Angular dependence of PDE.

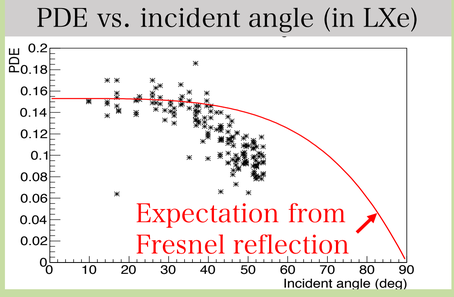
We have observed
**an unexpected angular dependence of PDE.**

### ◆ PDE angular dependence in liquid Xe

Setup in LXe




PDE vs. incident angle (in LXe)




### ◆ PDE angular dependence in gas Xe

Setup in GXe

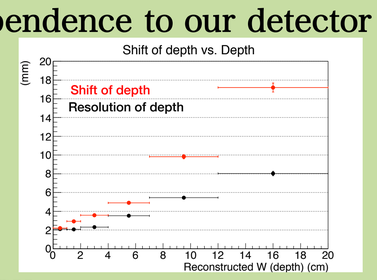



PDE vs. incident angle (in GXe)




### ◆ Effect of PDE angular dependence to our detector

Wrong knowledge about PDE angular dependence will bias depth reconstruction in our final detector.




Our result is still not consistent between LXe and GXe.
Further study is needed.

## 5. Summary

- Liquid xenon gamma-ray detector with MPPC readout is under construction for the MEG II experiment.
- Large are VUV-sensitive MPPC has been successfully developed, and an excellent performance has been confirmed by out test.
  - Sufficiently short timing constant for 1p.e. waveform
  - Sufficient PDE for xenon scintillation light
- Further study is on going for better understanding of our MPPC.
  - Unexpected angular dependence of PDE is observed.

**Reference**
[1] MEG Upgrade Proposal, arXiv:1301.7225
[2] W.Ootani et.al., Nucl. Instr. Meth. A, 787(2015)220-223