Liquid xenon detector with VUV-sensitive MPPCs for MEG II experiment

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ON BEHALF OF THE MEG II COLLABORATION

Table of contents

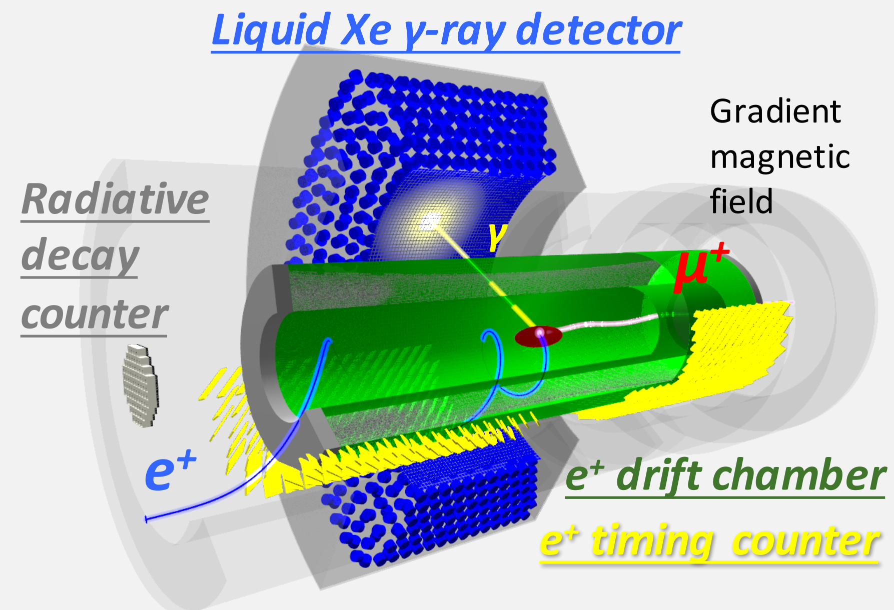
MEG II experiment

Searches for a cLFV decay of muon, μ→e+γ.

- Clear evidence of BSM.
- Detectable branching ratio ($O(10^{-12} \sim 10^{-15})$) is predicted by some BSM models.

Upgrade of MEG experiment

- Doubled μ^+ beam intensity
- Doubled detection efficiency
- Resolutions of all detectors will become half
- Expected sensitivity of MEG II: 4×10^{-14}
  - MEG final result: $Br(\mu \to e+\gamma) < 4.2 \times 10^{-13}$ (90% C.L.)



Radiative decay counter : R.Iwai (talk in Wed)
e+ timing counter : M.Nakao (talk in Thu)

Liquid Xe γ-ray detector

- To detect monochromatic 52.8 MeV γ-ray from μ→e+γ.
- Measuring the hit position, energy, and timing of γ-ray with good resolution is important to efficiently suppress the accidental background.

MEG LXe γ-ray detector

LXe γ-ray detector was successfully operated in the MEG experiment.

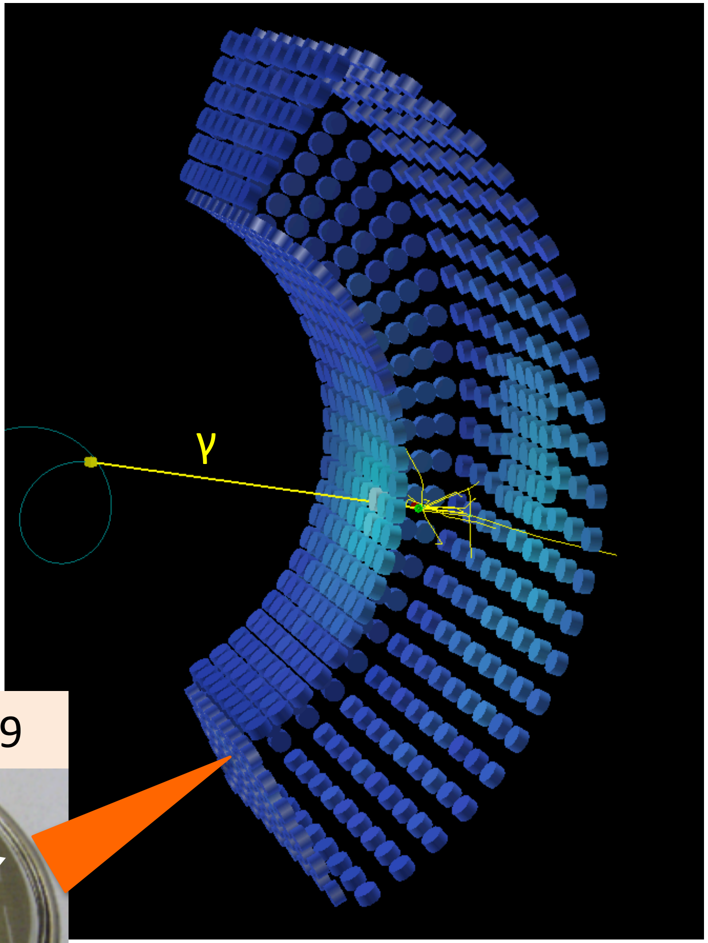
- 900 ℓ LXe.
- Scintillation light readout by 846 PMTs

Advantages of LXe

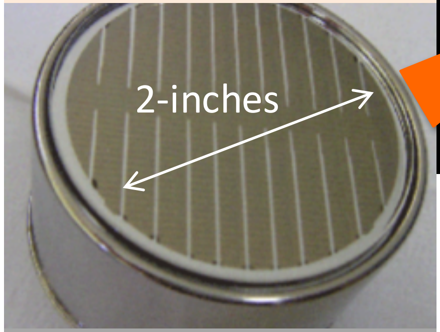
- High light yield (~75% of NaI)
- Fast (τ_{decay} = 45ns for γ-ray)
- High stopping power (X_0=2.8cm)
- Uniform (liquid)

Disadvantages of LXe

- *VUV (Vacuum Ultraviolet) scintillation light (λ=175nm)*
- High purity is needed
- Low temperature (165K) is required



Hamamatsu R9869



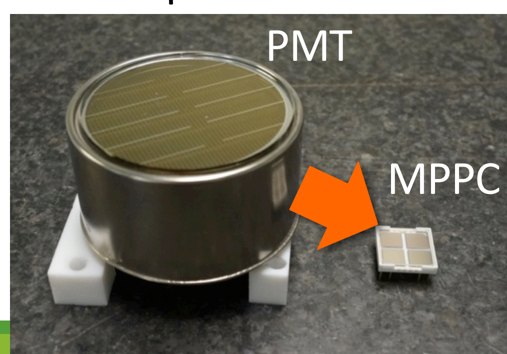
16% QE for λ=175nm

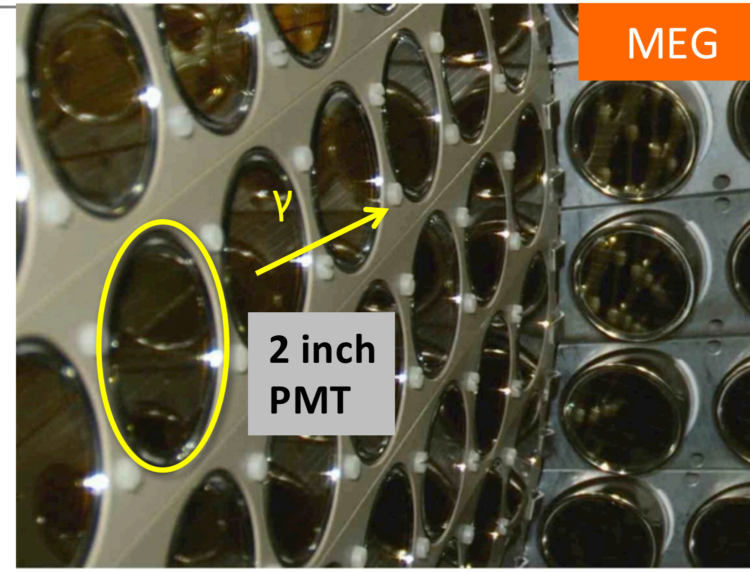
LXe detector upgrade

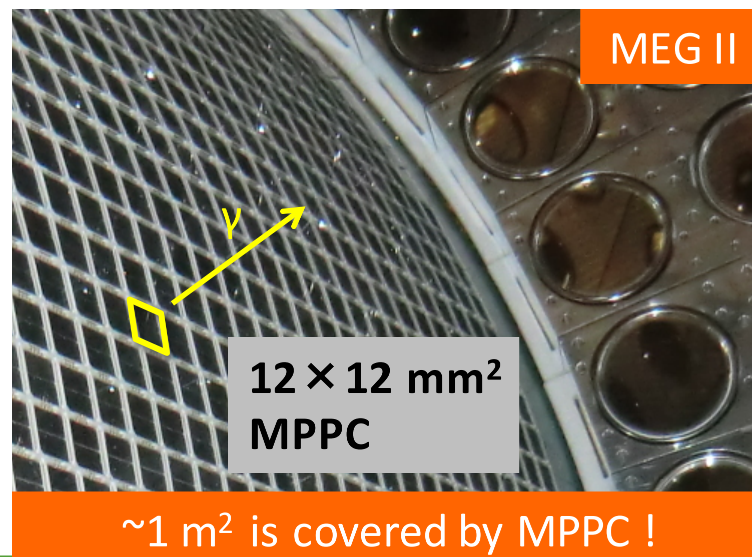
We are **upgrading LXe detector for MEG** II to significantly improve the performance.

We have **replaced 216 2-inch PMTs** on the γ-entrance face **with 4092 12 × 12 mm² MPPCs.**

- **Better position resolution**
  from higher granularity.
- **Improved energy resolution**
  from better uniformity of scintillation readout.
- **Better timing resolution**
  from TOF estimation with better accuracy and larger statistics from larger sensitive area.
- **Increased detection efficiency**
  from reduced material of the γ-entrance face.







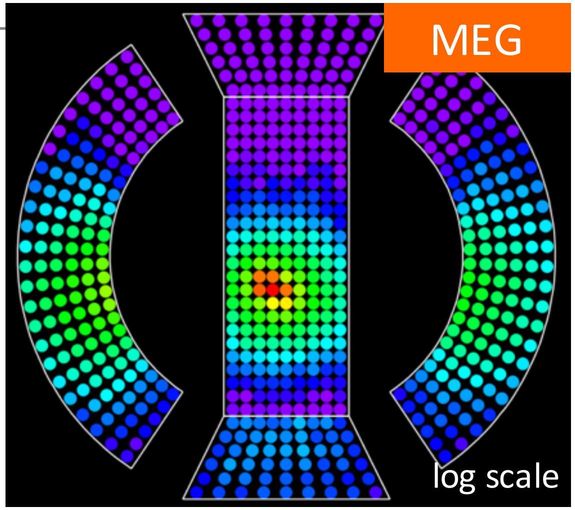
Expected performance

Significant improvement is expected for resolutions and efficiency.

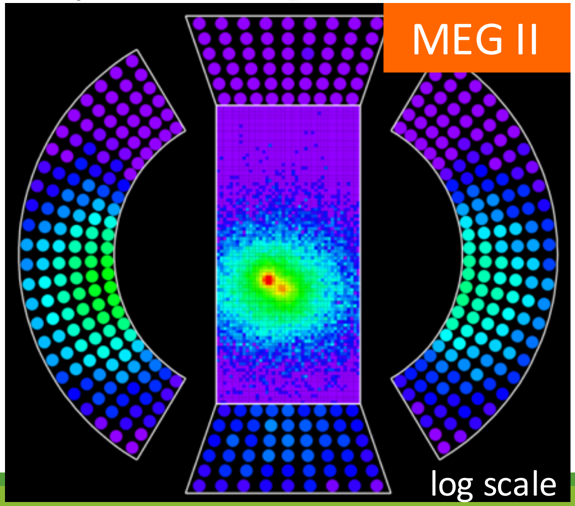
Detector performance for signal γ-ray

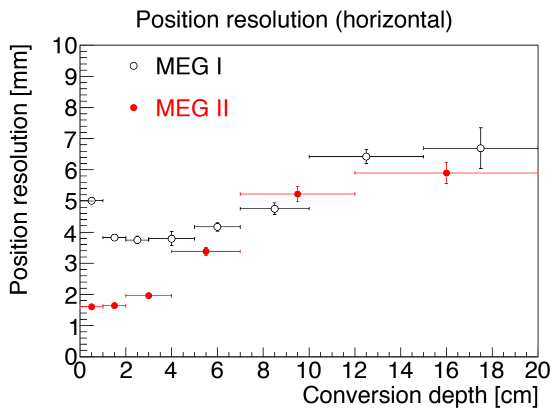
	MEG (measured)	MEG II (simulated)
σ (position)	~5 mm	~2.5 mm
σ (energy)	~2%	0.7 - 1.5%
σ (timing)	67 ps	50 - 70 ps
Efficiency	65%	70%

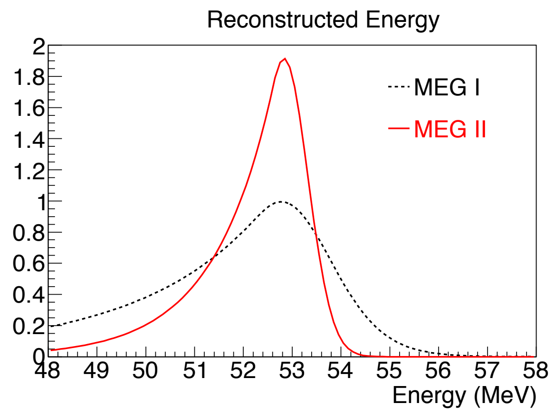
improve by a factor of **2**!



Imaging power improves







LXe detector status

finished **R&D**

finished **Production**

finished **Assembly**

on going **Commissioning**

R & D

- ✓ **VUV-sensitive large area MPPC**
- ✓ **Signal transmission system**

Production

- ✓ **MPPC mass production**
- ✓ **MPPC mass test**
- ✓ Signal transmission system
  - ✓ Cable, PCB, feedthrough
- ✓ Modified PMT holders
- ✓ Refrigerator

Assembly

- ✓ **MPPC & PMT installation**
- ✓ Sensor position survey
- ✓ Cabling & connection check
- ✓ Calibration source installation

1. LXe γ-ray detector in MEG II experiment
2. R&D for LXe detector
3. Detector construction
4. Summary

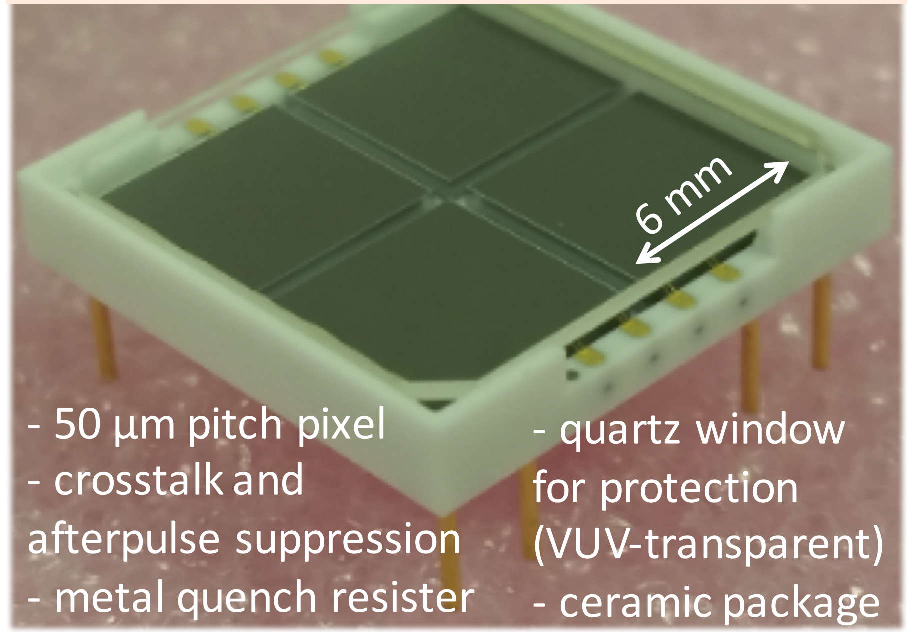
VUV-sensitive large area MPPC

MPPC for MEG II LXe detector has been developed in collaboration with Hamamatsu Photonics K.K.

VUV-sensitive (PDE (λ=175nm) > 15%)

- Scintillation light of Xe is in VUV range
- Realized by removing the protection layer of resin, optimizing optical matching b/w LXe and sensor surface, and thinning contact layer.

Hamamatsu S10943-4372



Large sensitive area (12 × 12 mm^2)

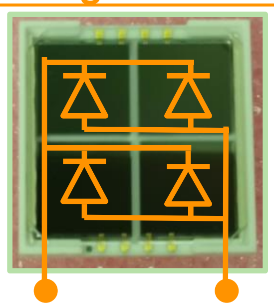
- To keep the number of readout channels manageable
- Discrete array of four 6 × 6 mm^2 chips
- Four chips connected in series at readout PCB to reduce long time constant.

Performance test of our MPPC

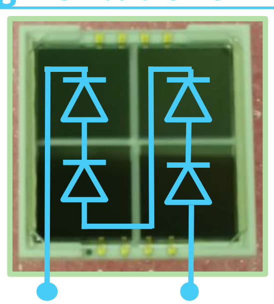
We have tested MPPC in LXe, and **an excellent performance has been confirmed.**

- **Sufficiently short timing constant** has been achieved by series connection.
- **Single p.e. peak is clearly resolved** for large sensitive area.
- Gain: 8.0×10^5 (@ Vover=7V, series connection)
- Low crosstalk & after pulse probability (~15% each @ Vover = 7V)

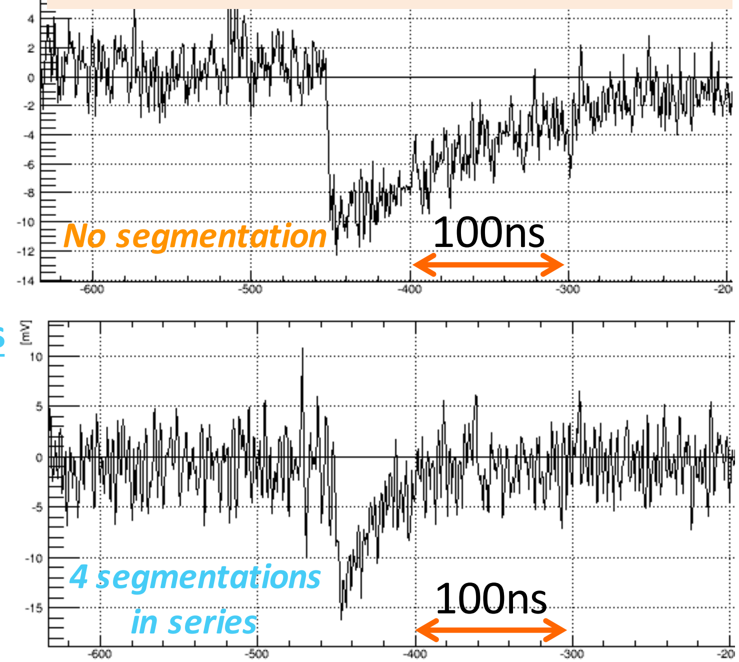
No segmentation



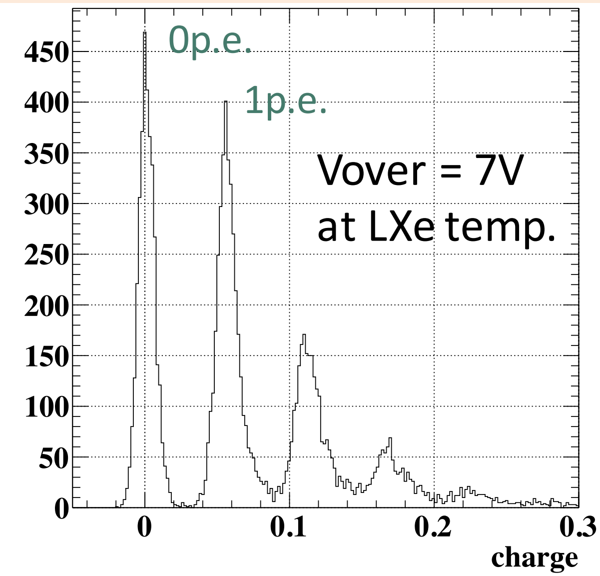
4 segmentations in series



Measured waveform



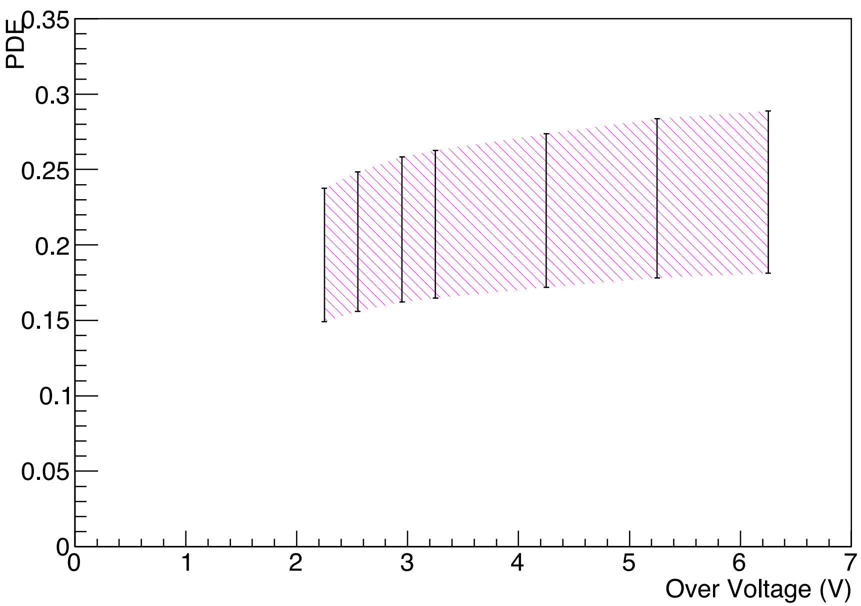
Charge distribution using LED



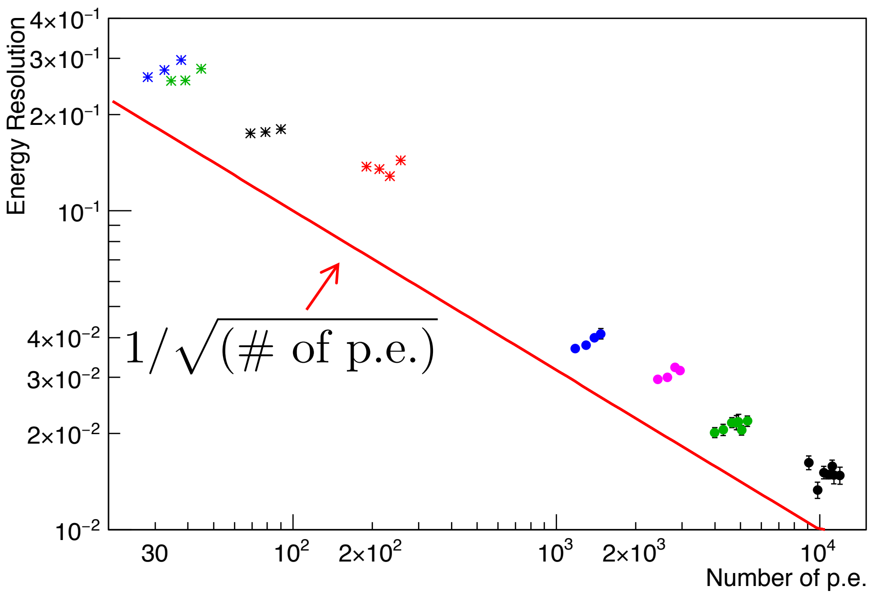
Performance test of our MPPC

We have tested MPPC in LXe, and **an excellent performance has been confirmed.**

- **Sufficient PDE (>15%)** for Xe scintillation light
- **Good energy resolution down to O(1%)** (@10^4 p.e. , α scintillation light)
- Good timing resolution down to 40ps (@2000 p.e. , α scintillation light)



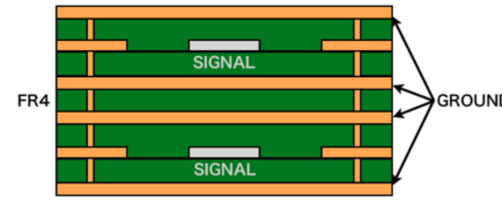
Energy resolution vs. Photoelectron statistics

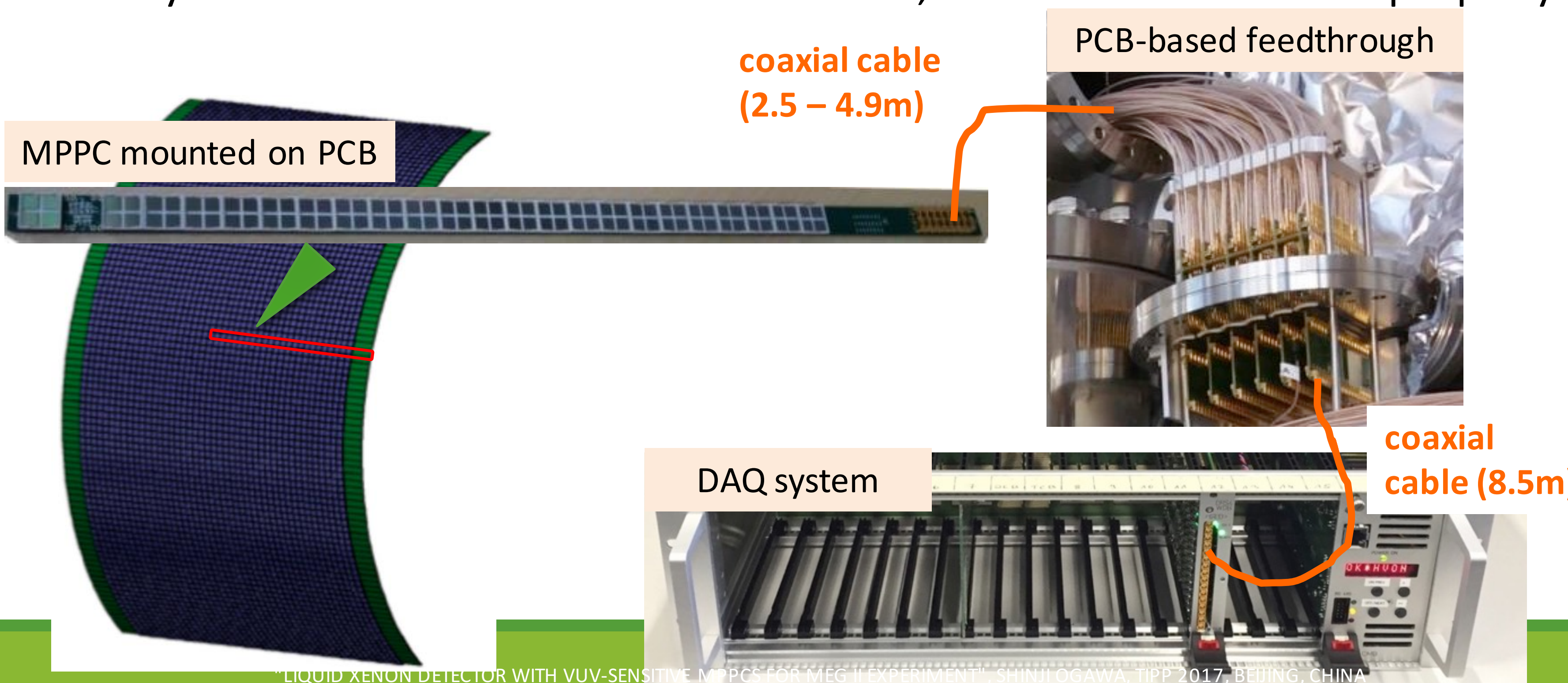


Signal transmission system

- We have developed signal transmission system.
  - It can transmit ~5000 ch signals.
  - Long cable (~12m) before signal amplification.
  - PCB has coaxial-like structure for impedance matching (50Ω), good shielding from external noise, high bandwidth, and low crosstalk.
  - Feedthrough is based on PCB to realize high density transmission.
- This system has been tested in LXe for 600 ch, and confirmed to work properly.

"Coaxial-like structure" PCB



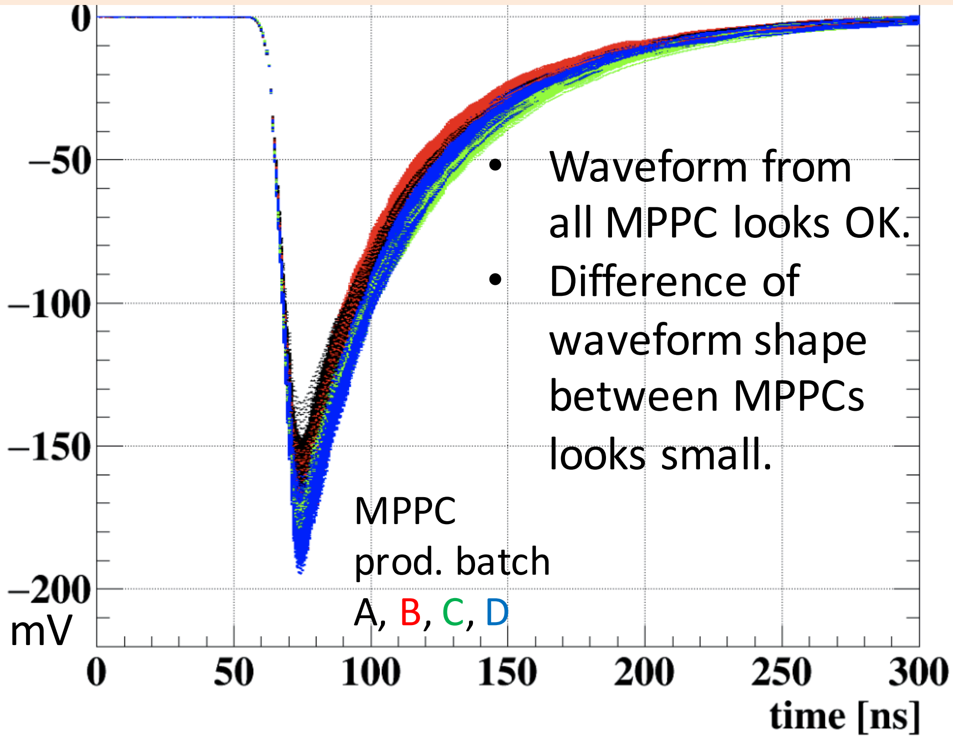


1. LXe γ-ray detector in MEG II experiment
2. R&D for LXe detector
3. Detector construction
4. Summary

Mass production/test of MPPCs

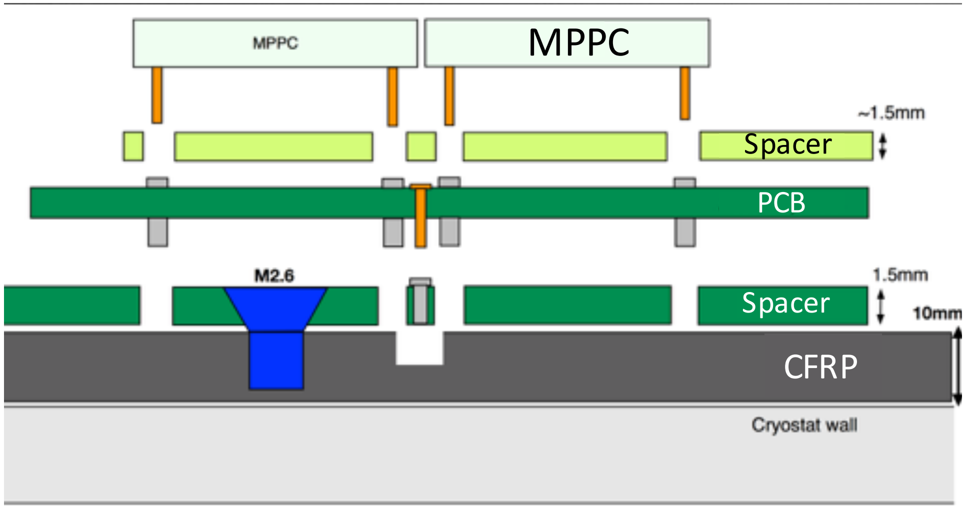
- Production of 4200 MPPCs was completed.
- All of them were tested at room temperature to reject bad MPPC.
  - I-V curve and breakdown voltage were checked.
  - Waveform from LED light was checked.
- We found only 0.2% bad chips (31 out of 4180 × 4 chips).

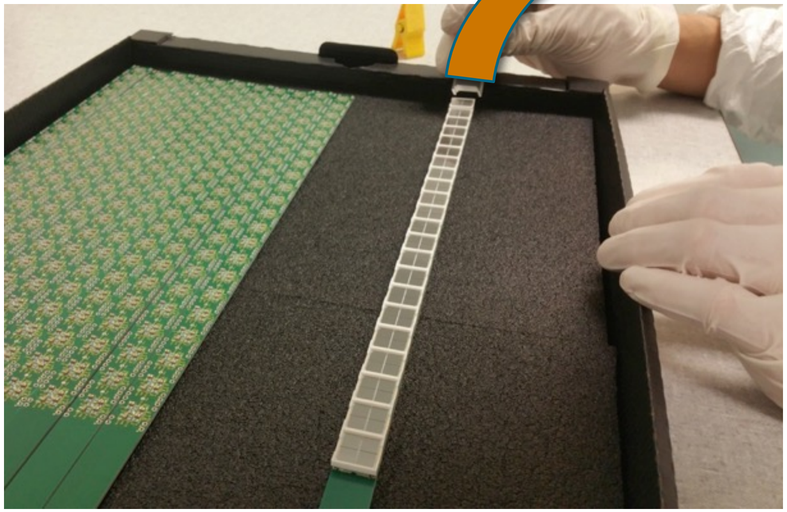
Waveforms of all 4180 MPPCs with LED light

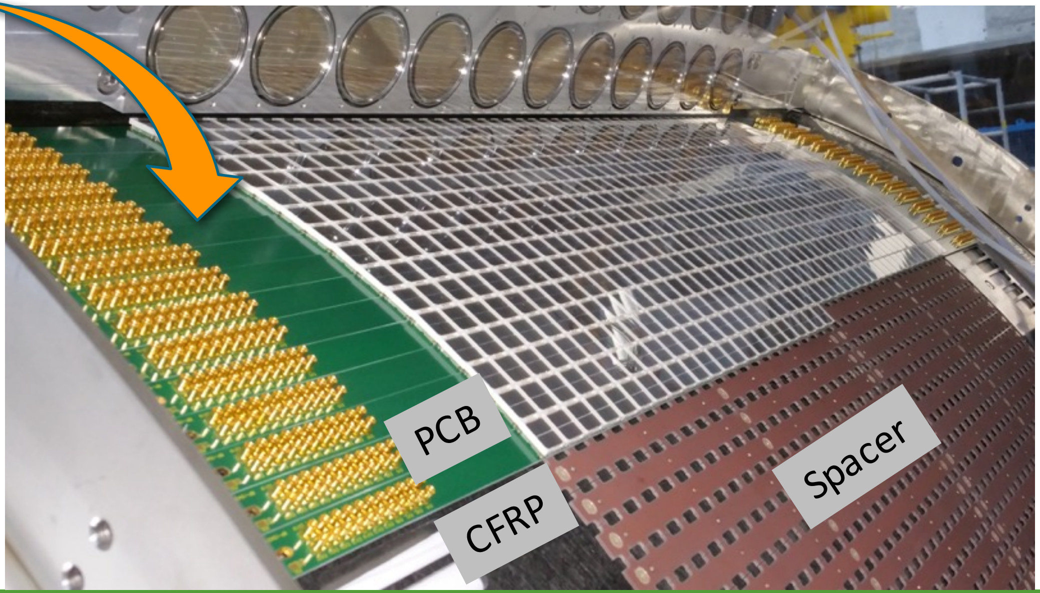


MPPC installation to the cryostat

- MPPCs are mounted on PCBs.
  - for signal readout and alignment.
  - PCBs are fixed on CFRP support structure which is attached on cryostat.
- These support are designed to minimize the material.
  - Thin support structure with low mass material
  - Spacers to reduce LXe.





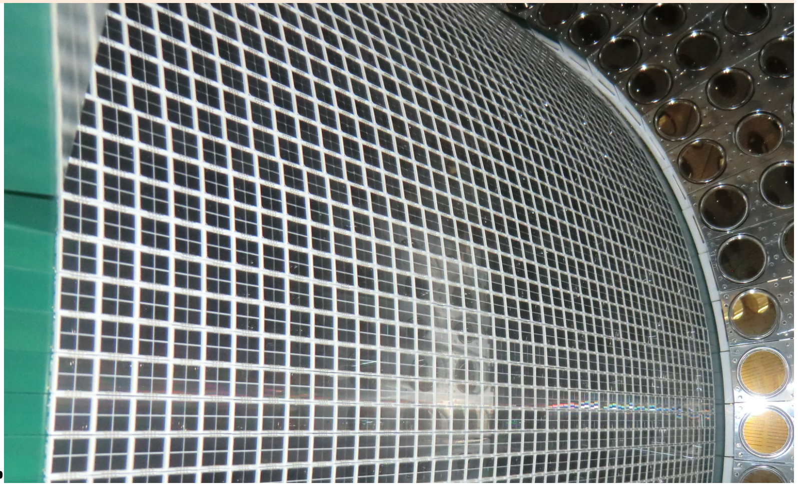


Detector assembly

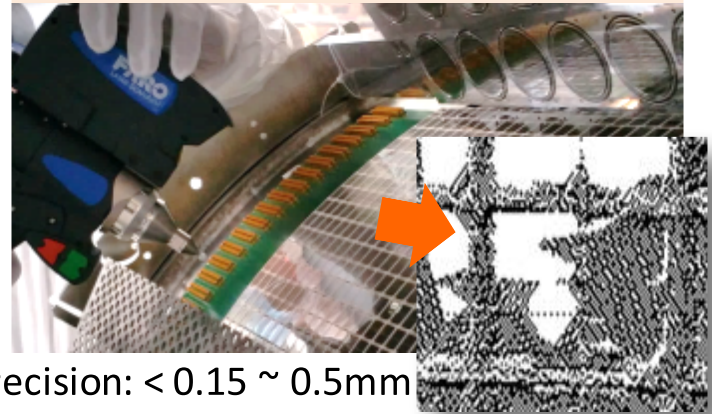
- Detector assembly has been completed.
  - Photo-sensor installation
  - Cabling
  - Connection check for all sensors.
  - Sensor position measurement by 3D Laser scanner (FARO)
  - Calibration source (LED, α source) installation.

→**Detector construction: Finished (Apr.2017).**

Photo-sensor installation

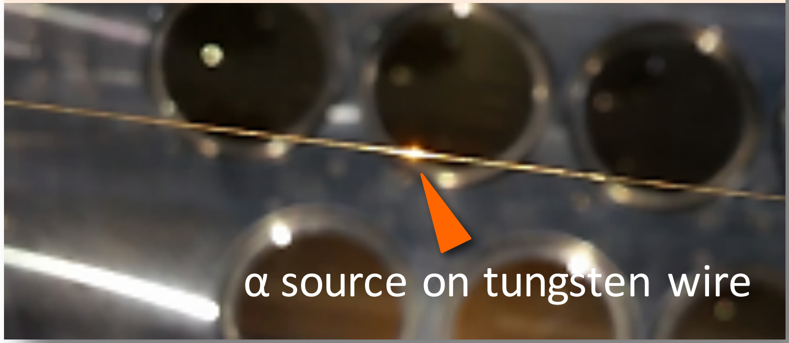


Position measurement by 3D laser scanner



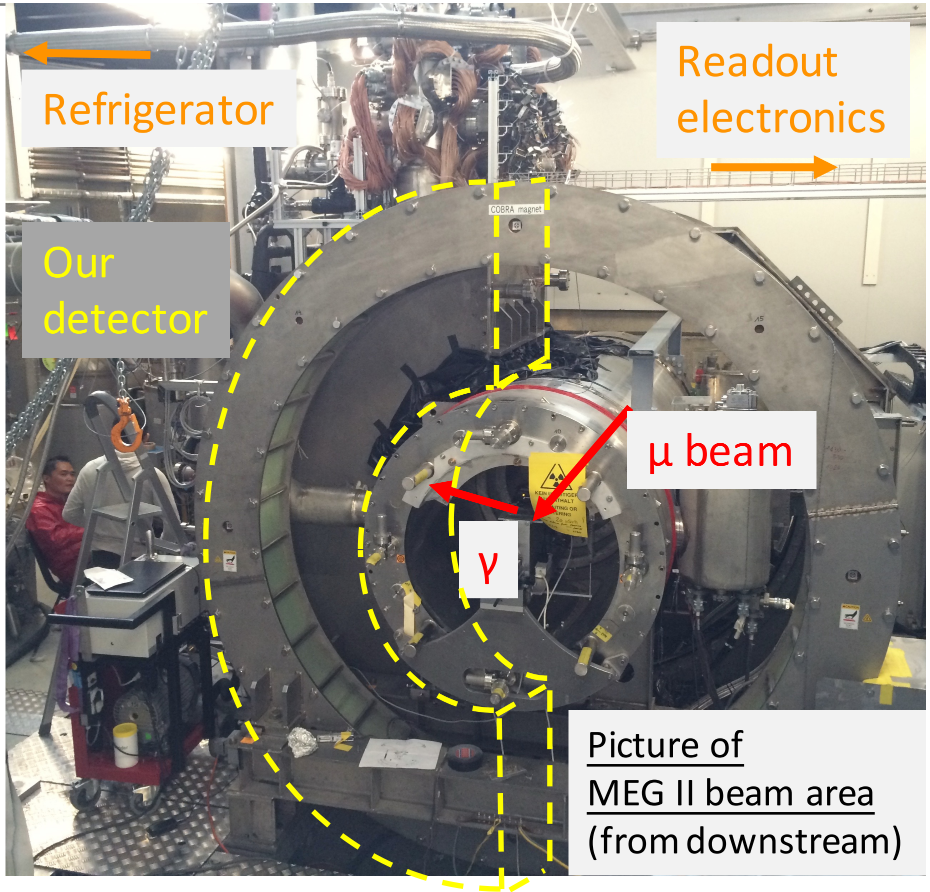
Precision: < 0.15 ~ 0.5mm

Calibration source (α , ^{241}Am)



Status and Prospects

- **<u>Detector construction</u>** : Finished
- **<u>Detector commissioning</u>** : Ongoing
  - ✓ Installation to the beam area
  - Xenon liquefaction & purification : in a few weeks
  - Photo-sensor calibration
  - Detector response calibration
  - Detector performance evaluation with calibration γ-source
- **<u>Pilot run</u>** : 2017 Nov. – Dec.
  - 7 weeks DAQ with muon beam in MEG II environment



<u>Picture of</u>
<u>MEG II beam area</u>
(from downstream)

- **<u>Engineering & physics DAQ with all MEG II detectors</u>** : 2018

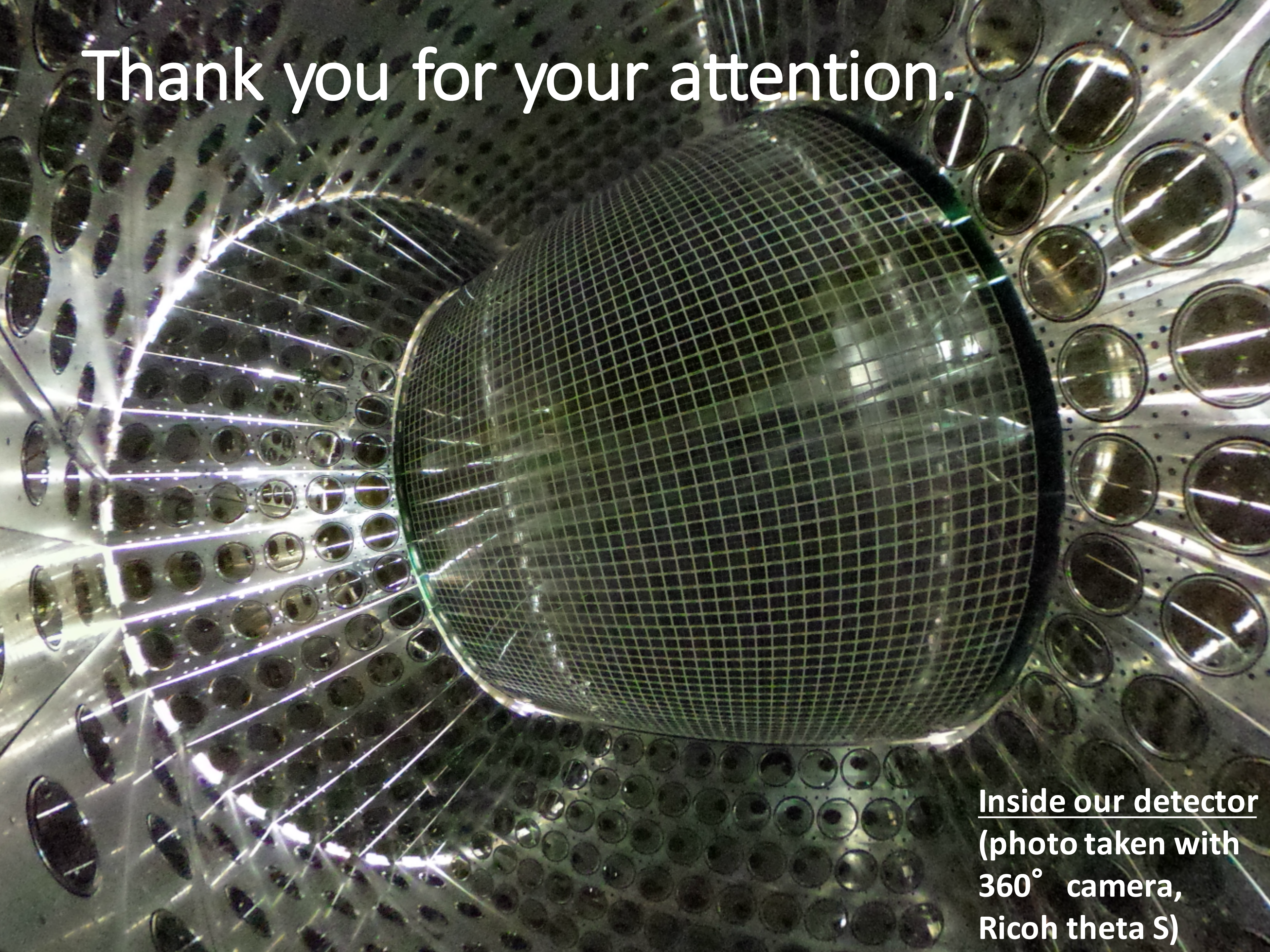
Summary

- The MEG II experiment will search for $\mu \to e + \gamma$ decay with the sensitivity of 4×10^{-14}.
- Upgraded LXe γ-ray detector will play an important role to sensitivity improvement.

- Large area VUV-sensitive MPPC has been successfully developed.
- Detector construction of LXe detector has been finished.

- Detector commissioning is ongoing. Pilot run of the detector in MEG II environment is planned this winter.
- Engineering and physics DAQ of MEG II will start from 2018.

Thank you for your attention.

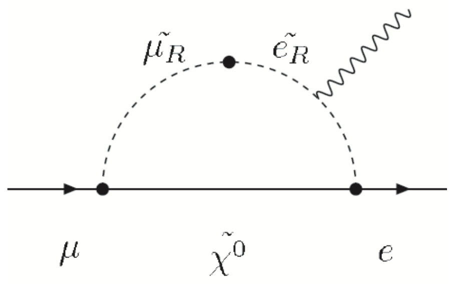


Inside our detector
(photo taken with 360° camera, Ricoh theta S)

BACKUP

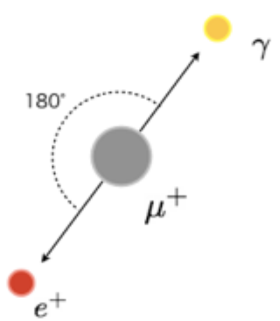
μ→eγ search

We search for charged lepton flavor violating decay of muon, μ->e+γ.
Prohibited in SM, detectable branching ratio in some BSM model
Main background is the accidental background.
Detector resolutions, **especially energy resolution of γ-ray**, are important to effectively distinguish the signal event from the accidental background



Signal

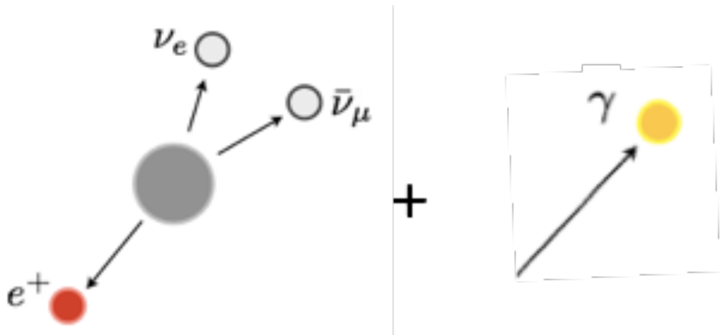
Signal decay



- E=52.8MeV
- back-to-back
- coincident

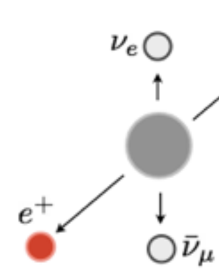
Background

Accidental background



- **Dominant background**
- E < 52.8MeV
- not back-to-back

Radiative muon decay



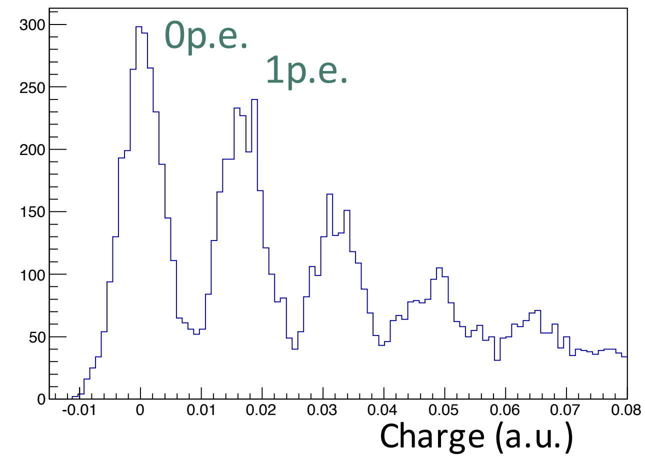
- E<52.8MeV
- not back-to-back
- coincident

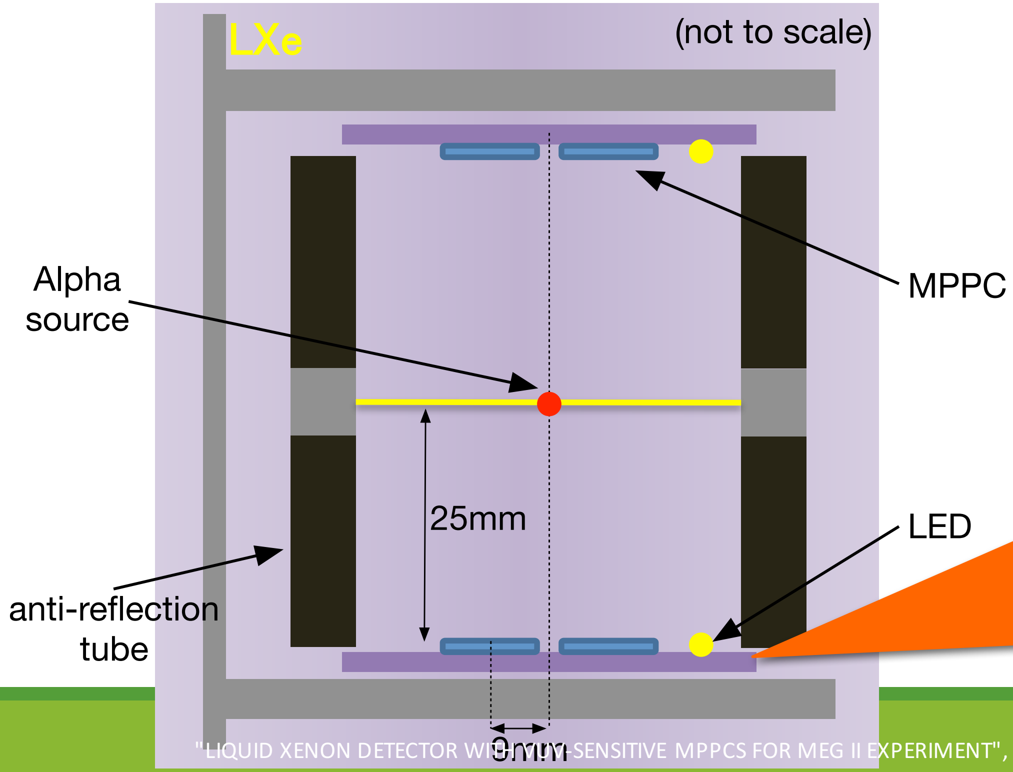
MPPC Performance measurement

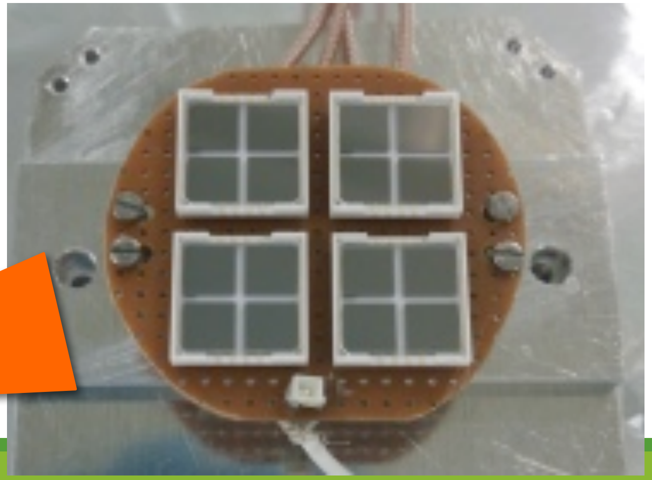
Basic performance of MPPC have been measured by using 2ℓ LXe chamber.

- LED and alpha source are used as light sources
- 1 p.e. peak is clearly resolved for large area (12×12 mm^2) MPPC.
  - Thanks to the very low dark rate (~5 Hz/mm^2) at LXe temperature.

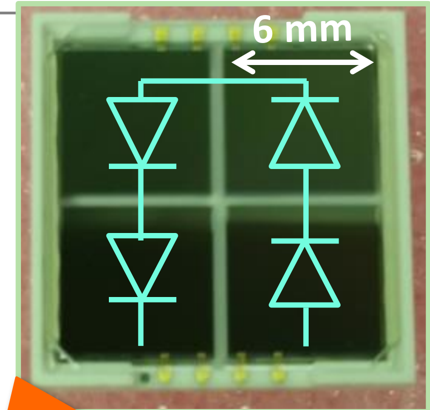
Example of the charge distribution using LED







Waveform with series connection



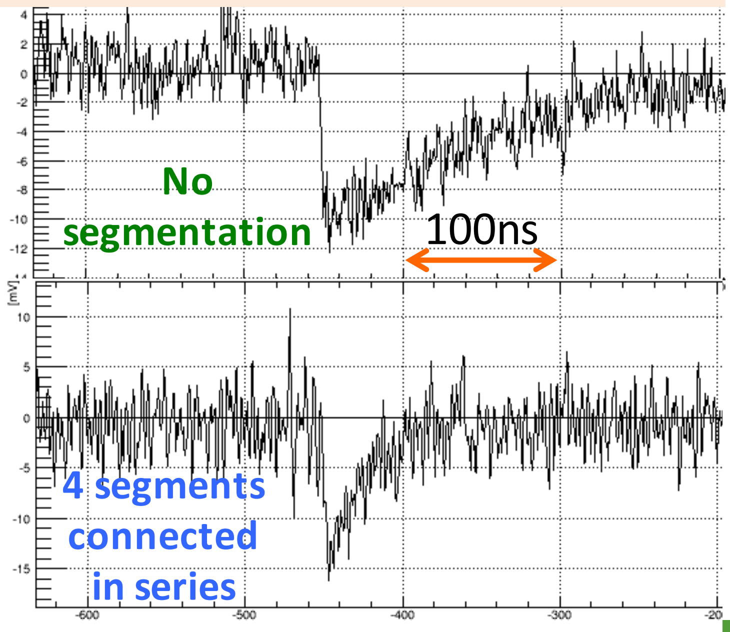
Large sensitive area leads to longer time constant

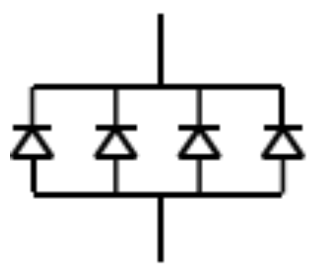
- Timing resolution and pileup elimination performance of our final detector can be affected.

We have achieved sufficiently short timing constant by connecting 4 segments in series.

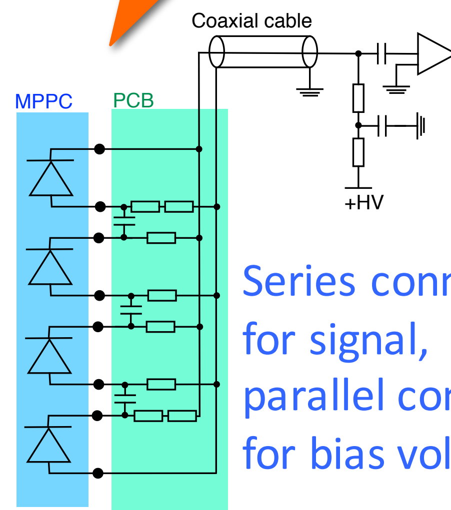
- A dedicated series connection (hybrid connection) is used.

Measured waveform





No segmentation



Series connection for signal, parallel connection for bias voltage

4 segments with Hybrid connection

Test of signal transmission

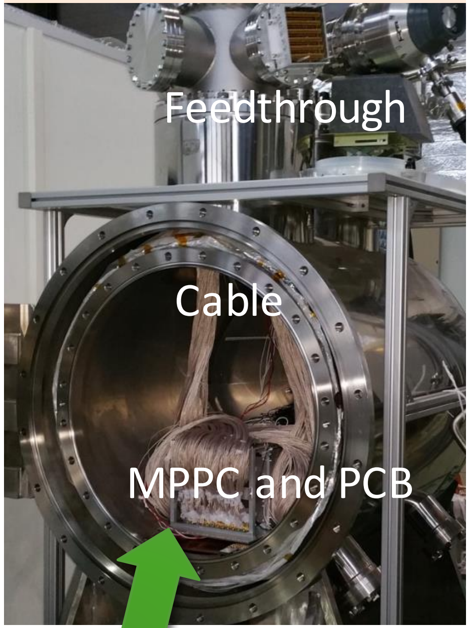
Signal transmission system has been tested in LXe.

- Signal from ~600 MPPCs in LXe are read out with the same scheme as final detector.

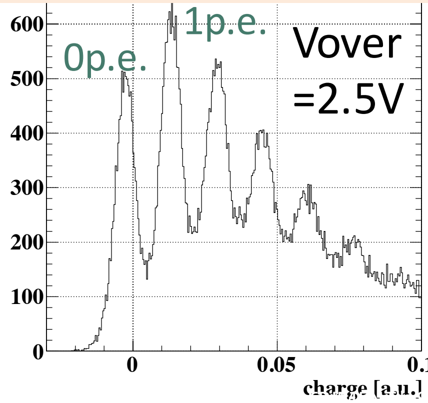
We confirmed that MPPC, PCB, and feedthrough work properly in LXe for most of the channels.

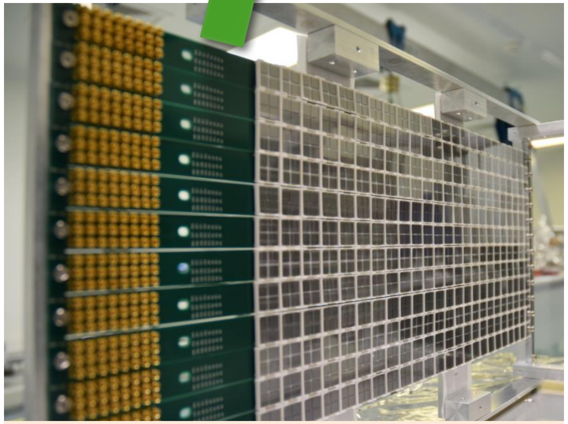
- A clear 1 p.e. peak from weak intensity LED can be seen.

Prototype chamber



Example of the charge distribution using LED

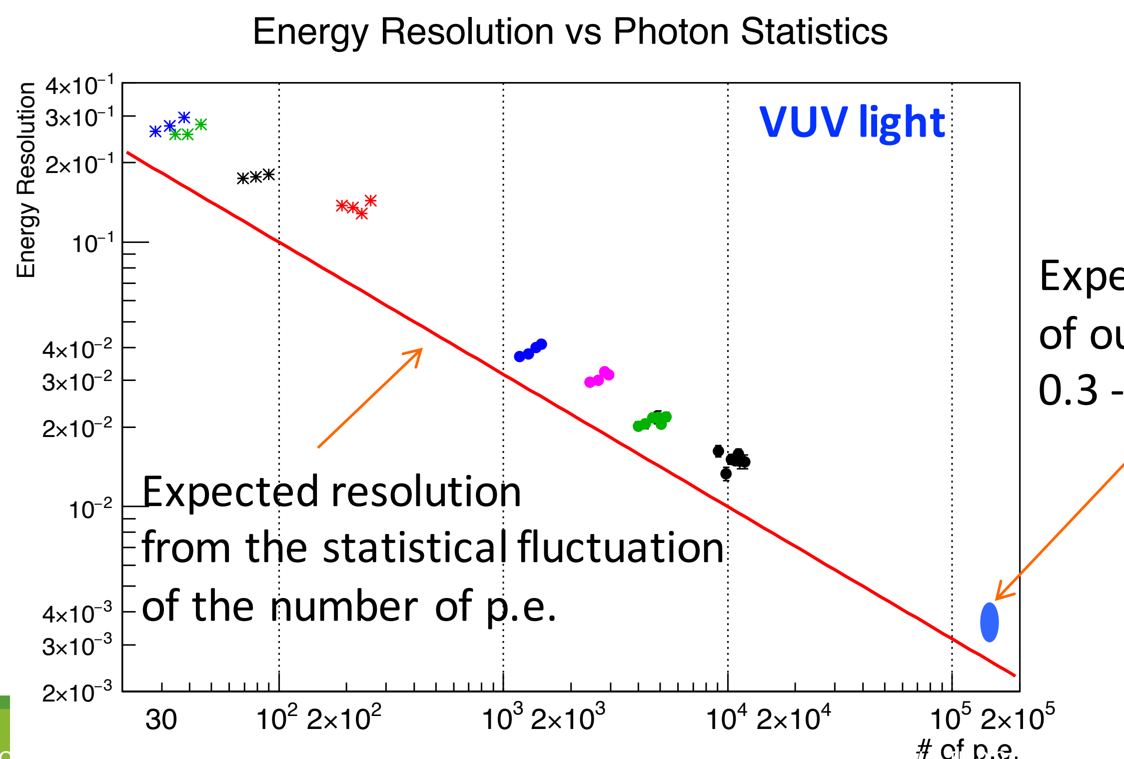




MPPCs mounted on PCBs

Energy resolution

- Energy resolution for VUV light has been measured as a function of # of p.e
  - using a scintillation light from α source.
  - by changing geometrical acceptance with several setups.
- Energy resolution improves as $1/\sqrt{(\#\ \text{of p.e.})}$
  - at least down to ~10^4 p.e.
  - excess noise factor: 1.2 - 1.3 (reason has not yet been understood.)

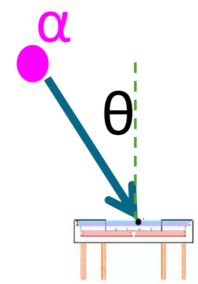


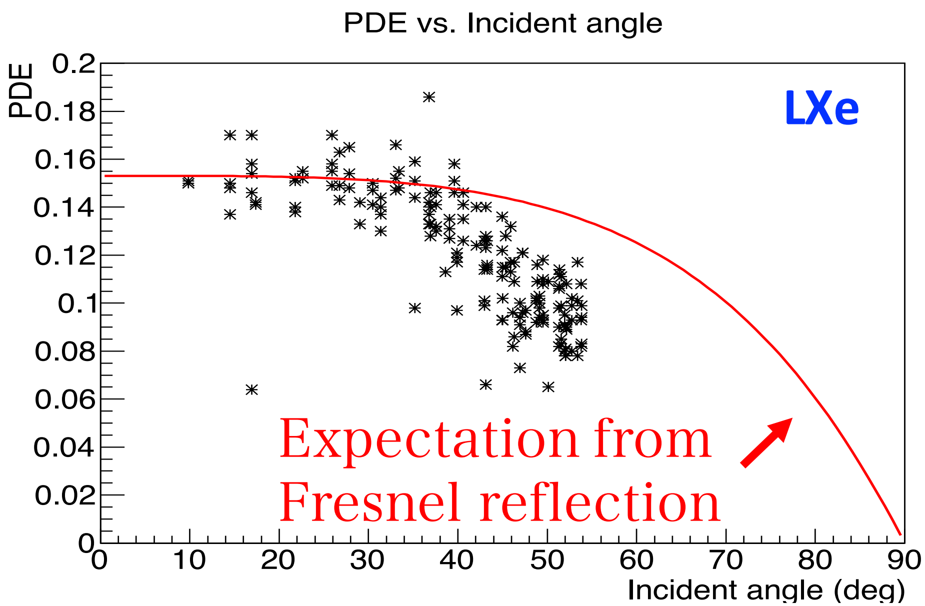
Expected statistical term of our final detector 0.3 - 0.4%

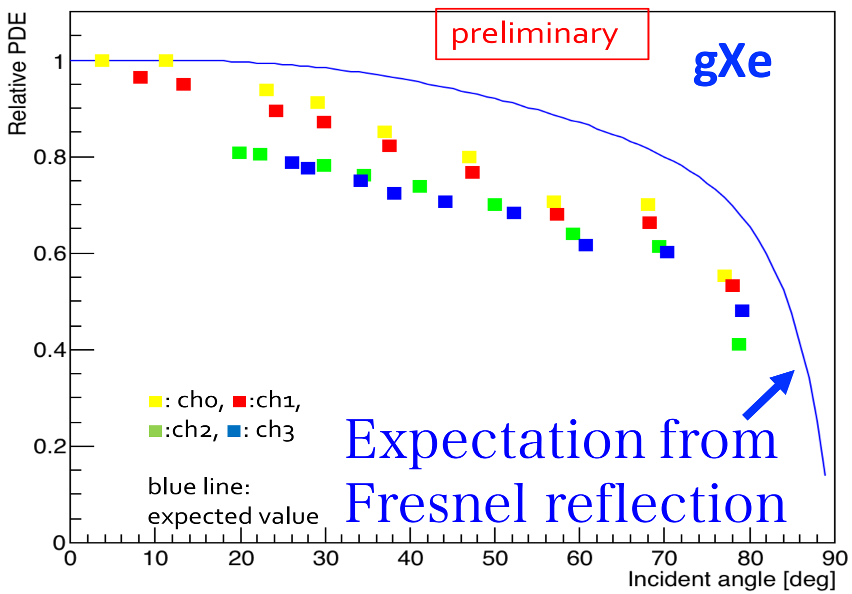
Angular dependence of MPPC PDE

We observed an unexpected angular dependence of PDE both in LXe, and gXe.

- Result in LXe and gXe is not consistent. Systematics is being estimated.
- Result of these dependence will be used in the final detector to reconstruct γ hit position accurately.







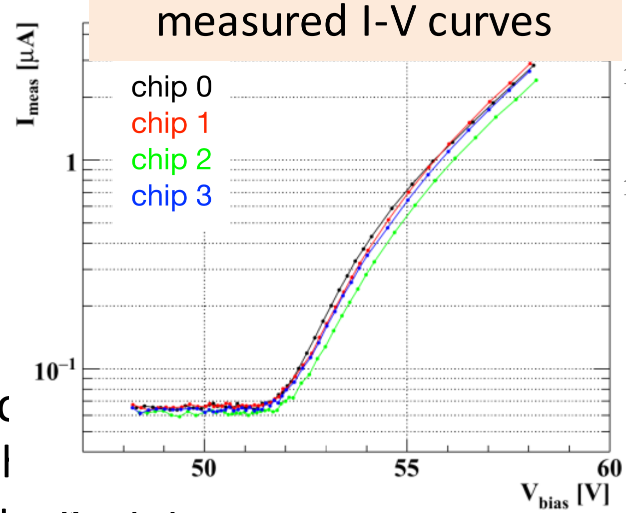
Mass test @ Room temp.

We confirmed the normal I-V curves and breakdown voltages for most of the channels.

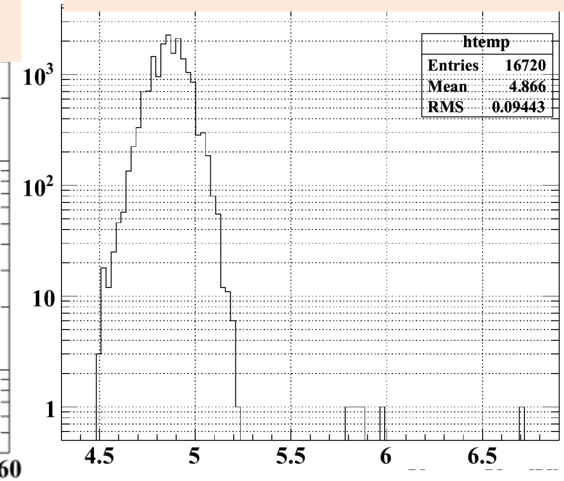
We found 31 bad chips (0.2% c

- There are three kinds of bad cl
- Bad chips will not be used in the final detector.

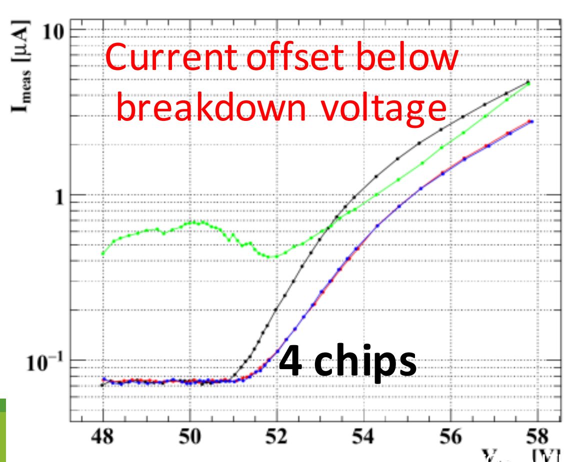
Example of measured I-V curves

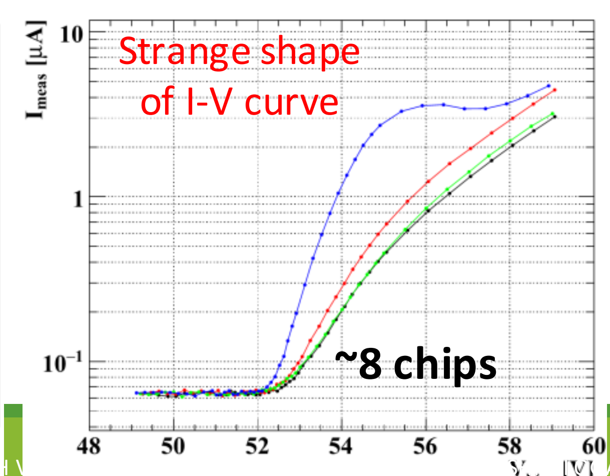


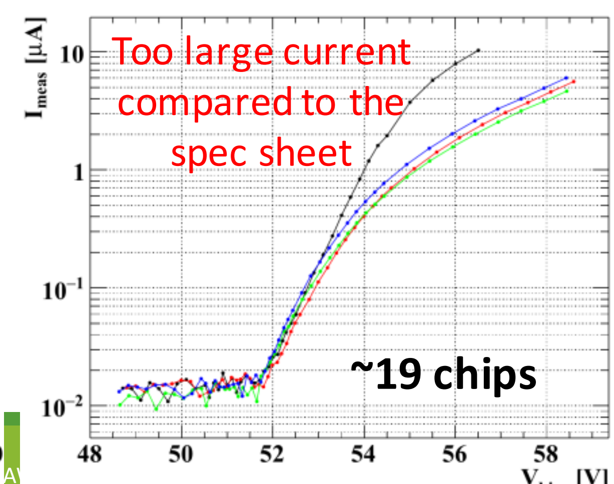
Breakdown voltage



V(breakdown) - V(recommended by HPK)







Calibration & monitoring tools

LEDs and α wires are installed as we did in MEG.
Some LEDs are added for calibration of SiPMs.
(Calibration tools with accelerator are not shown here.)