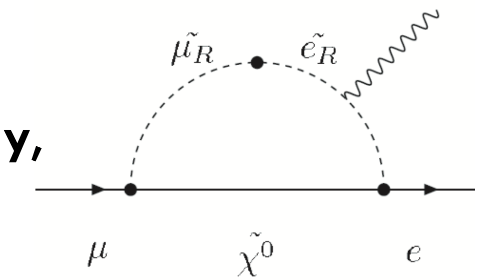
Liquid xenon calorimeter for MEG II experiment with VUV-sensitive MPPCs

Shinji Ogawa on behalf of the MEG II Collaboration

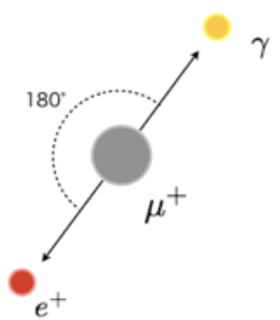
$\mu \rightarrow e \gamma$ search

- We search for charged lepton flavor violating decay of muon, $\mu \rightarrow e + \gamma$.
- 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

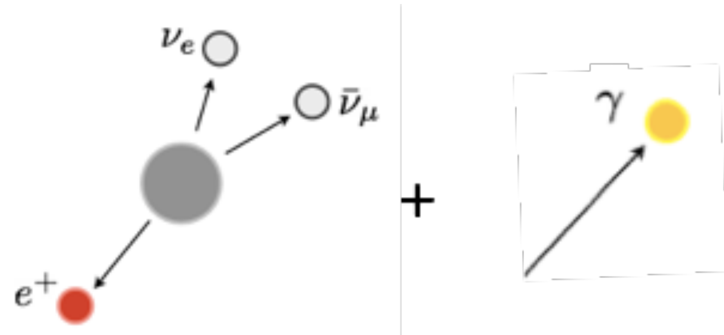
Signal decay



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

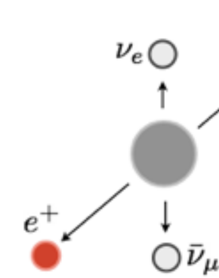
Background

Accidental background



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

Radiative muon decay

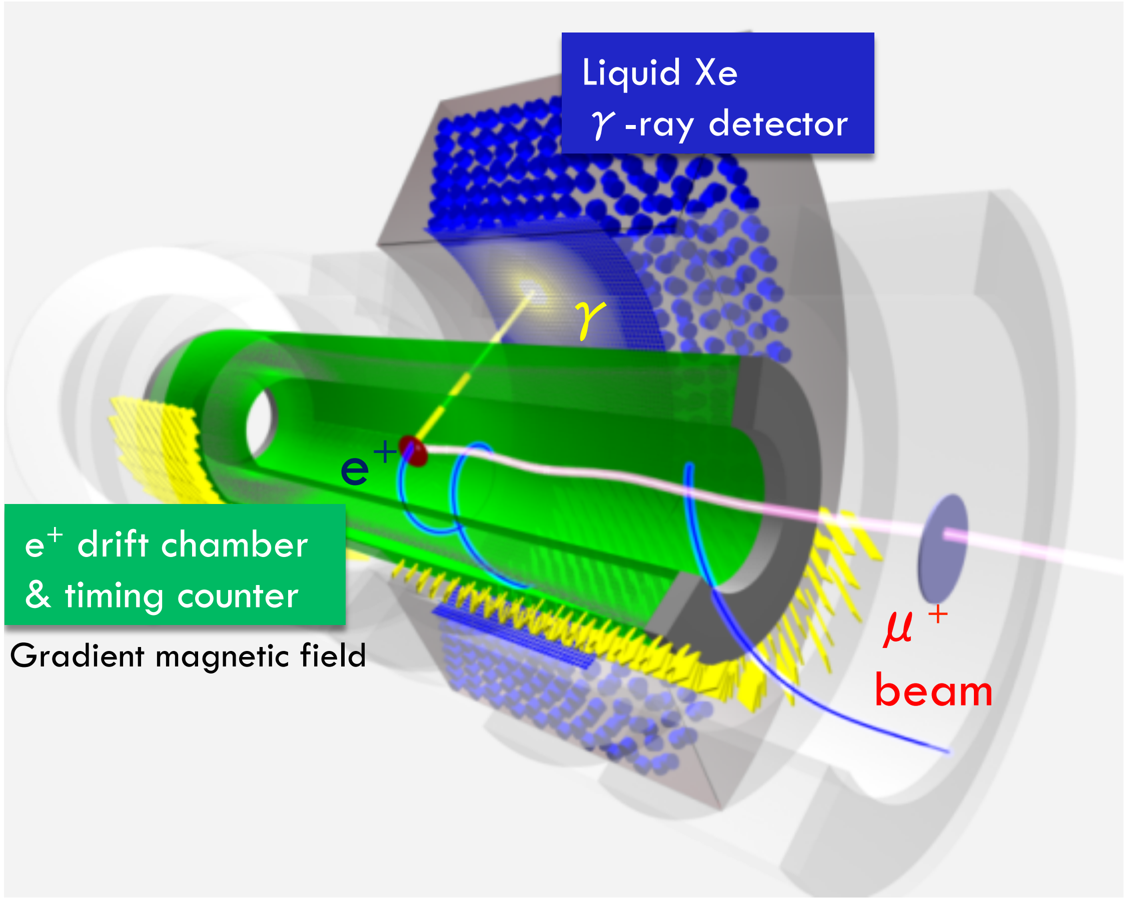


- E<52.8MeV
- not back-to-back
- coincident

MEG II experiment

Upgrade of MEG experiment

- μ^+ stopping rate will be doubled
  - $3\times10^7\ \mu/s \rightarrow 7\times10^7\ \mu/s$
- Detection efficiency will improve.
- Resolutions of all detectors will become half.
- New detector for background tagging will be introduced



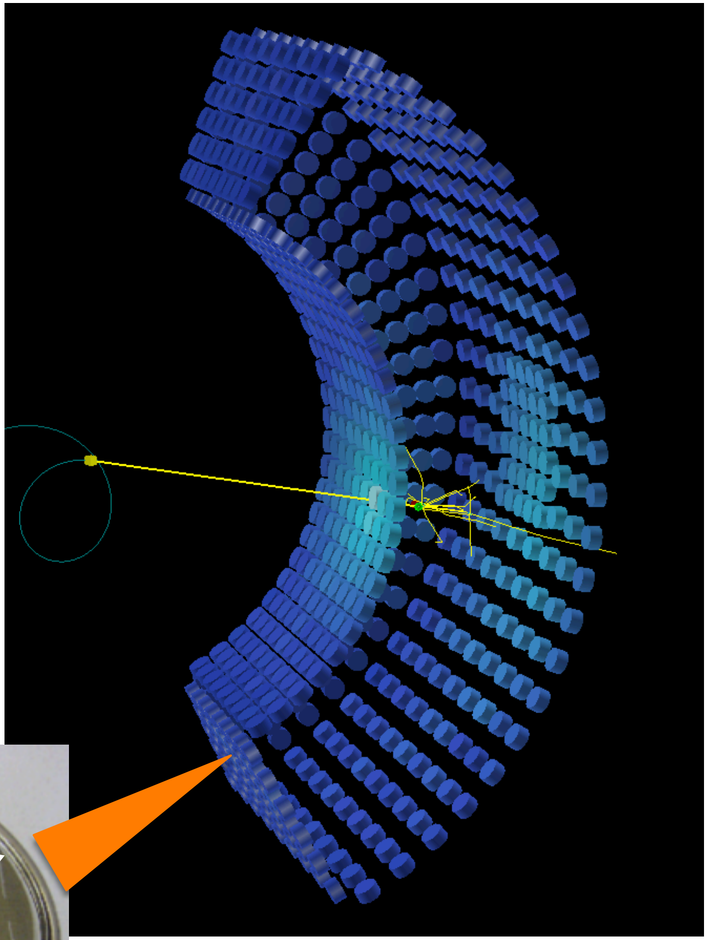
Expected sensitivity: 4×10^{-14}

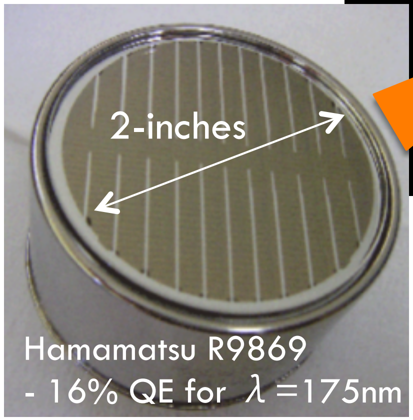
- One order of magnitude better than MEG

1. MEG II experiment
2. LXe γ-ray detector
3. R&D of MPPC
4. Detector construction
5. Summary

MEG LXe γ -ray detector

- LXe γ -ray detector was successfully operated in the MEG experiment.
  - 900 ℓ LXe detector
  - 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 (Vaccum UltraViolet) scintillation light (λ =175nm)
  - High purity is needed
  - Low temparature (165K) is required

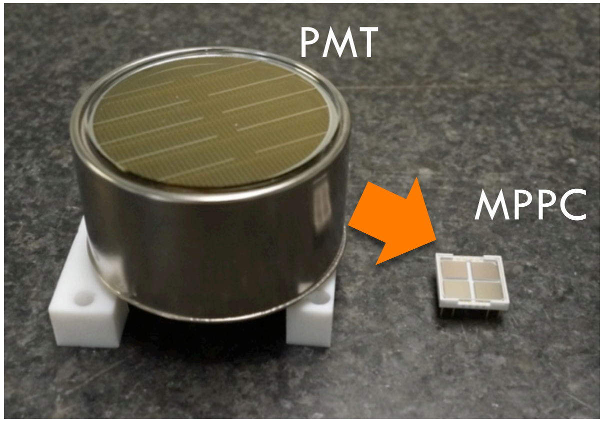


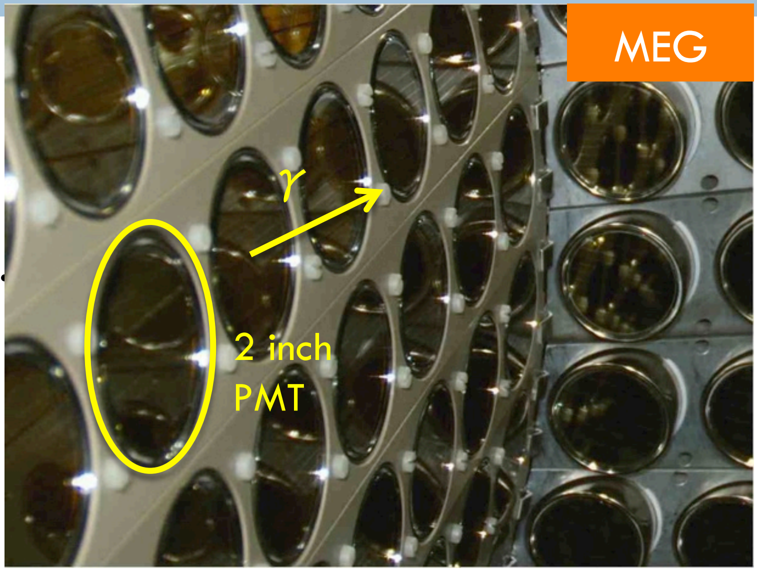


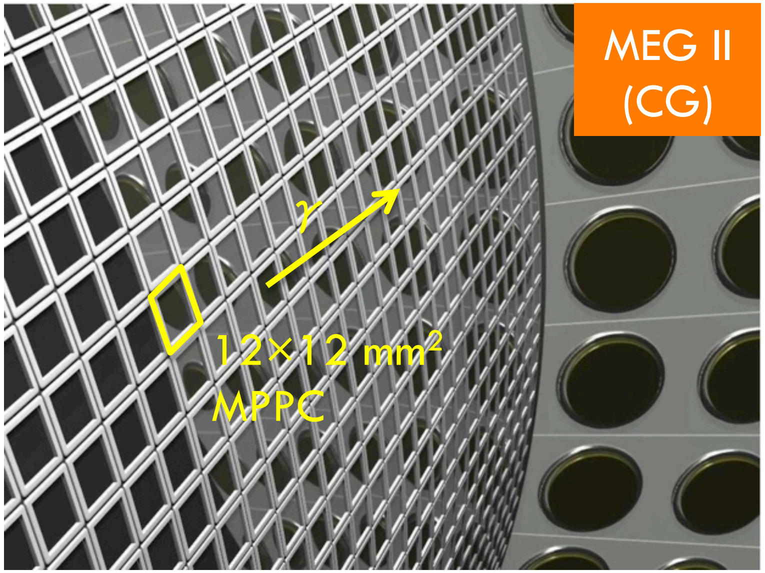
LXe Detector upgrade

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

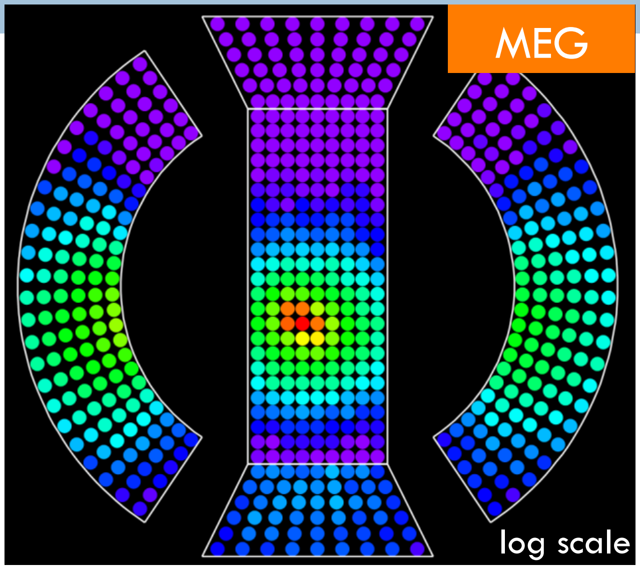
- We will replace 216 2-inch PMTs on the γ-entrance face with 4092 12×12 mm^2 MPPCs.
  - Better granularity
    - Better position resolution
  - Better uniformity of scintillation readout
    - Better energy resolution
  - Less material of the γ-entrance face
    - Better detection efficiency



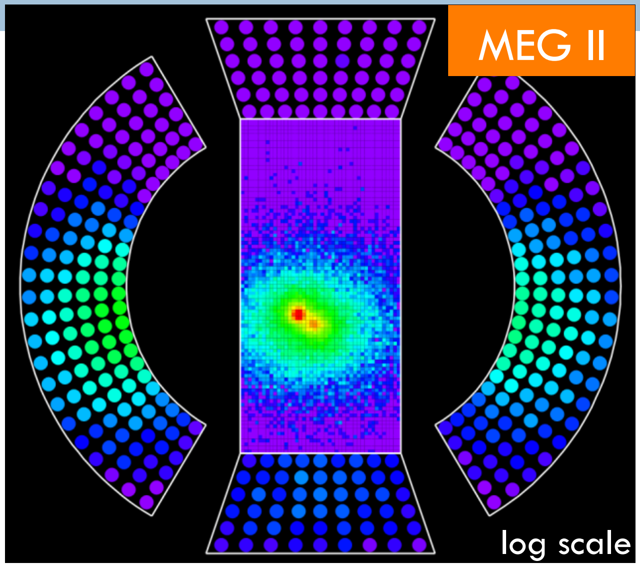




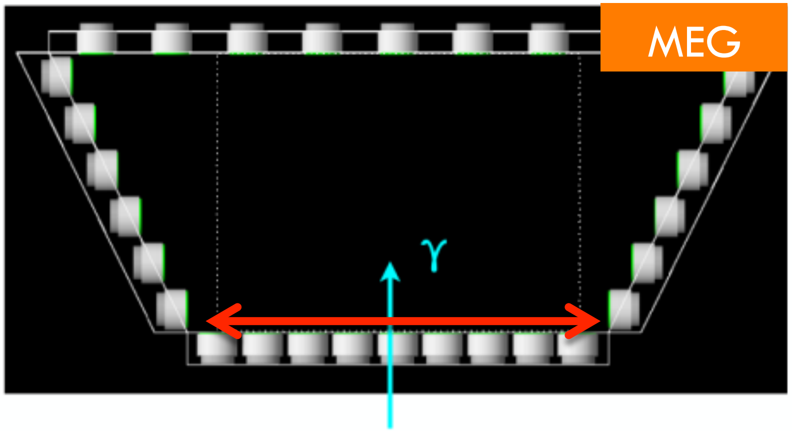
LXe Detector upgrade

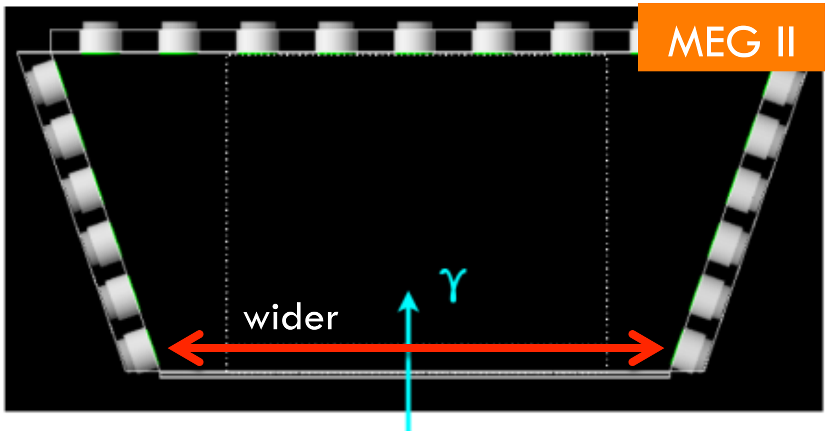


Imaging power improves



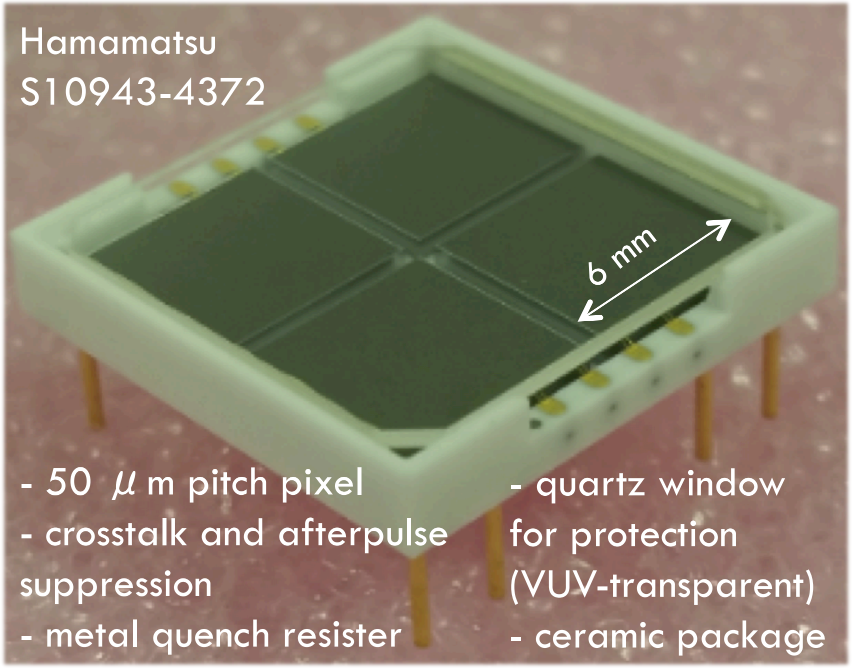
- Layout of the PMTs will also be changed
  - Improve the uniformity of the scintillation readout
  - Decrease energy leakage





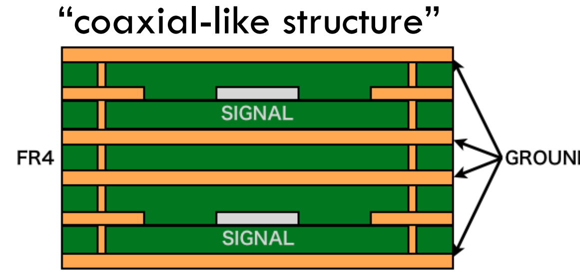
VUV-sensitive large area MPPC

- 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.
- 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.

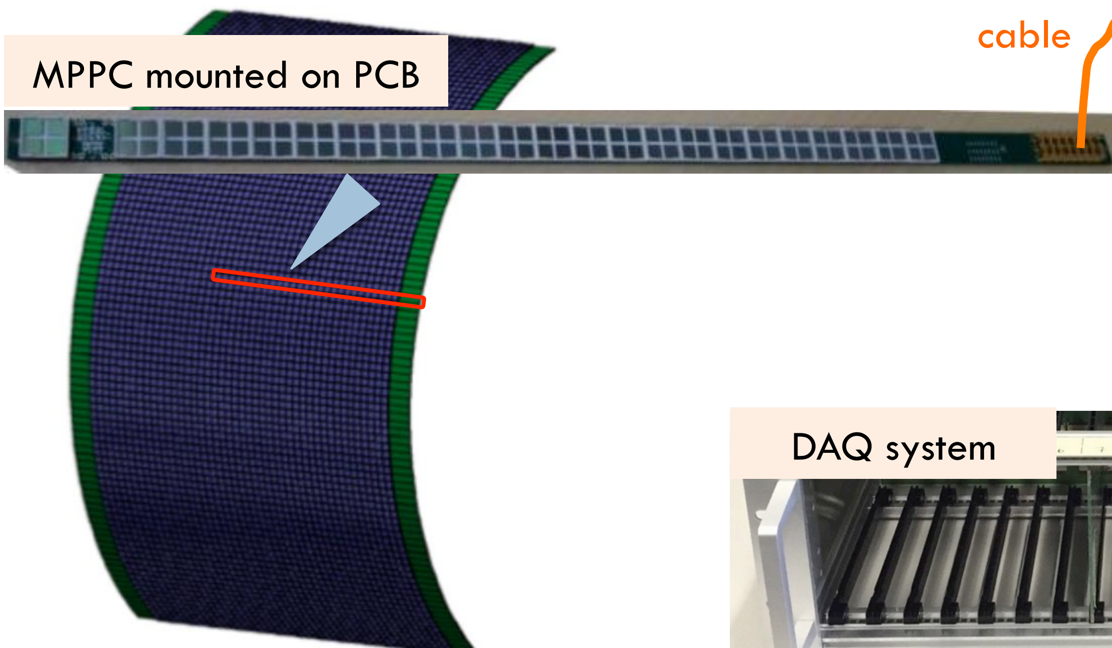


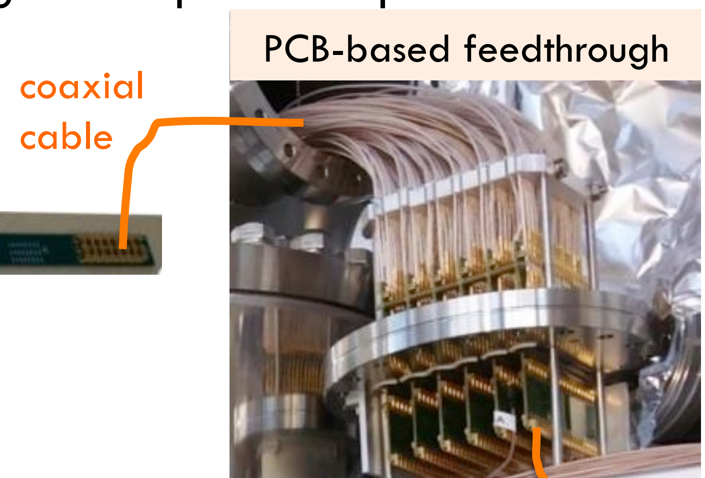
Signal transmission

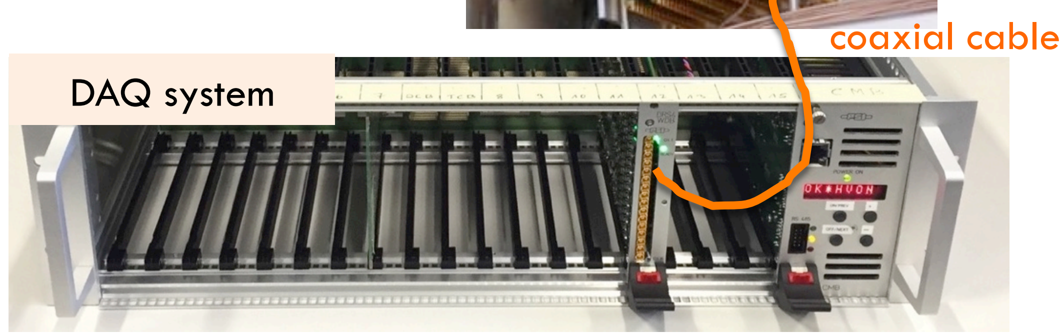
- We have developed signal transmission system.
  - It can transmit ~5000 ch signals.
  - PCB have coaxial-like structure for good shielding from external noise, high bandwidth, and low crosstalk.
  - Feedthrough is based on PCB to realize high density transmission.



- New DAQ board, WaveDREAM, is being developed to cope with increased number of channels.

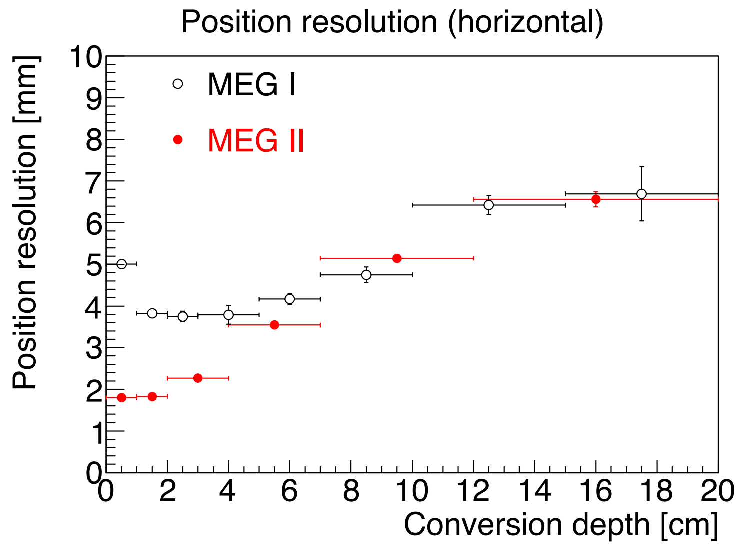






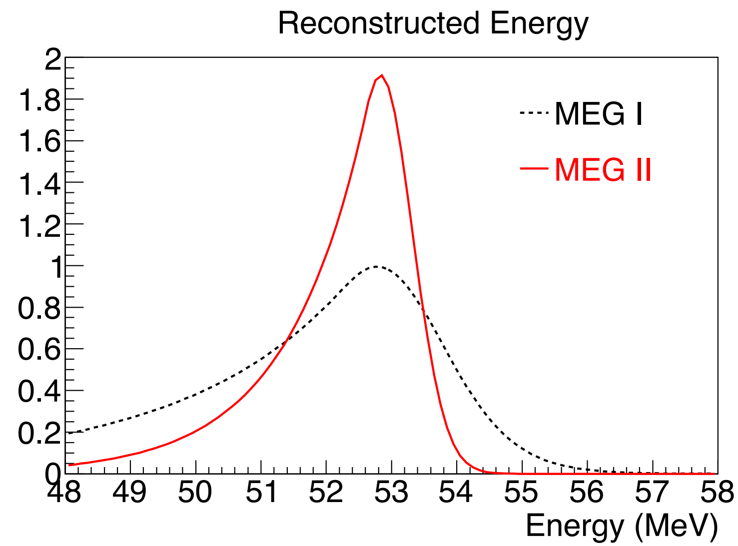
Expected performance

- Detector performance has been estimated by MC simulation.
- Reconstruction algorithm is optimized to MEG II.
- **Significant improvement of all resolutions and efficiency are expected.**



Detector performance for signal γ-ray

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



1. MEG II experiment
2. LXe γ -ray detector
3. R&D of MPPC
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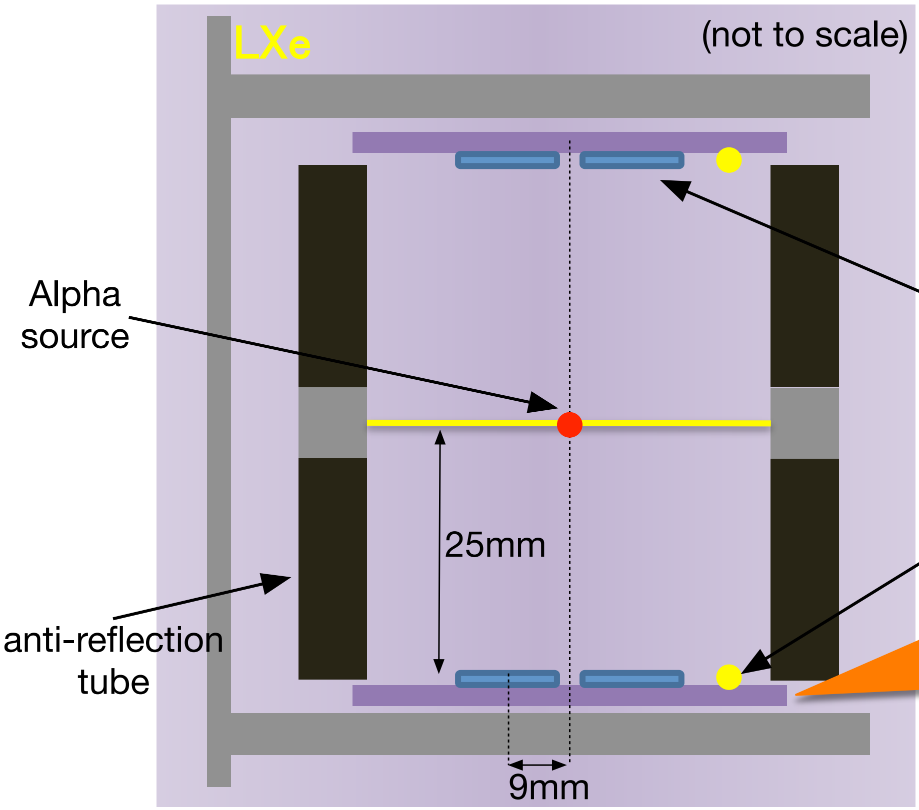
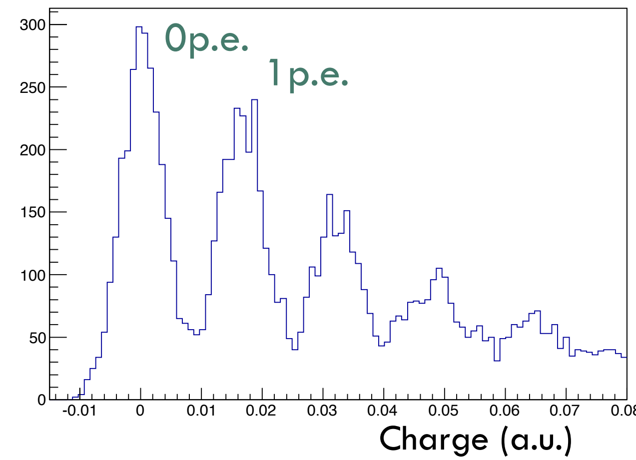
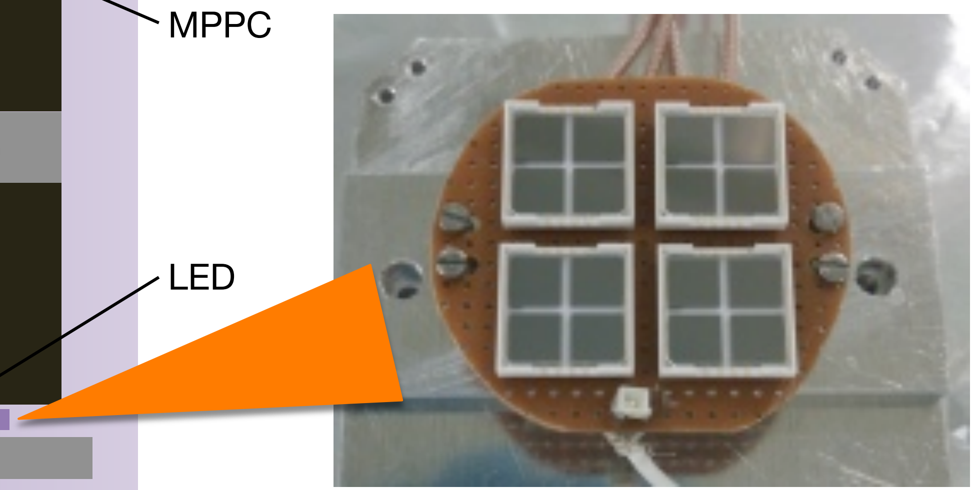
MPPC Performance measurement

- 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 clealy resolved for large area (12×12 mm^2) MPPC.



Example of the charge distribution using LED

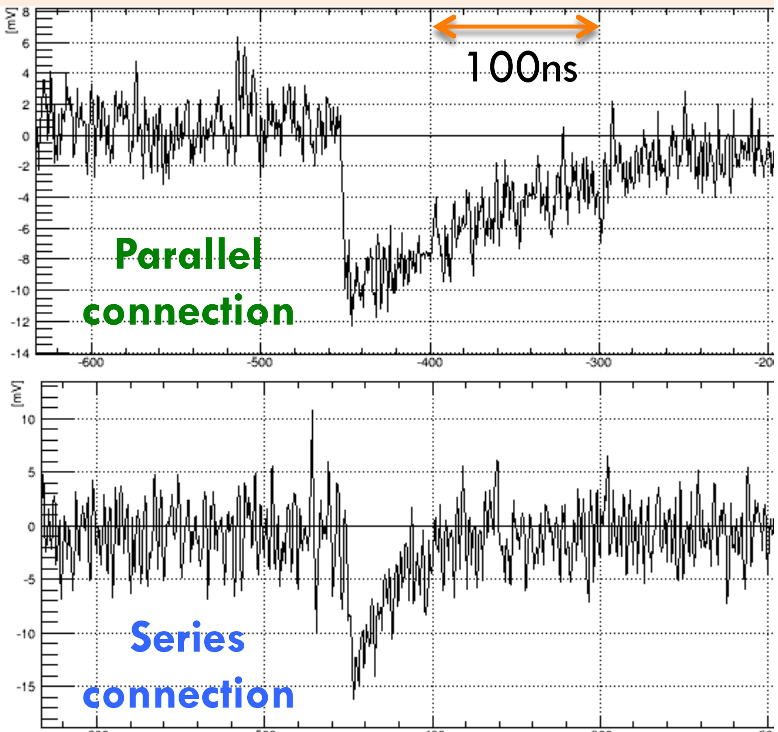


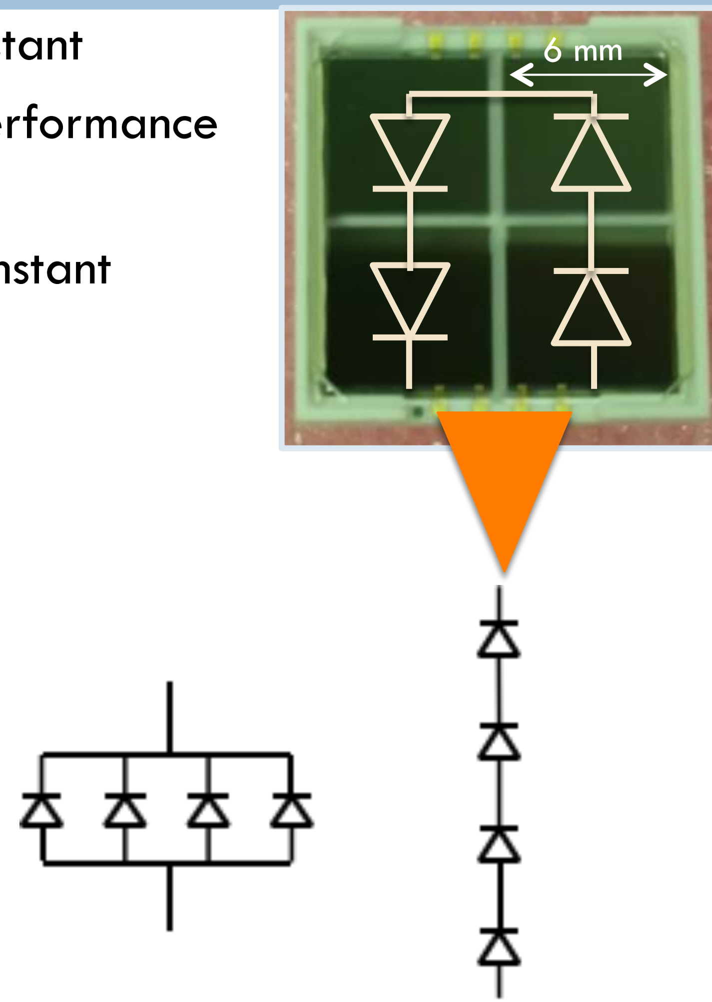


Series connection

- 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 using series connection.

Measured single p.e. waveform





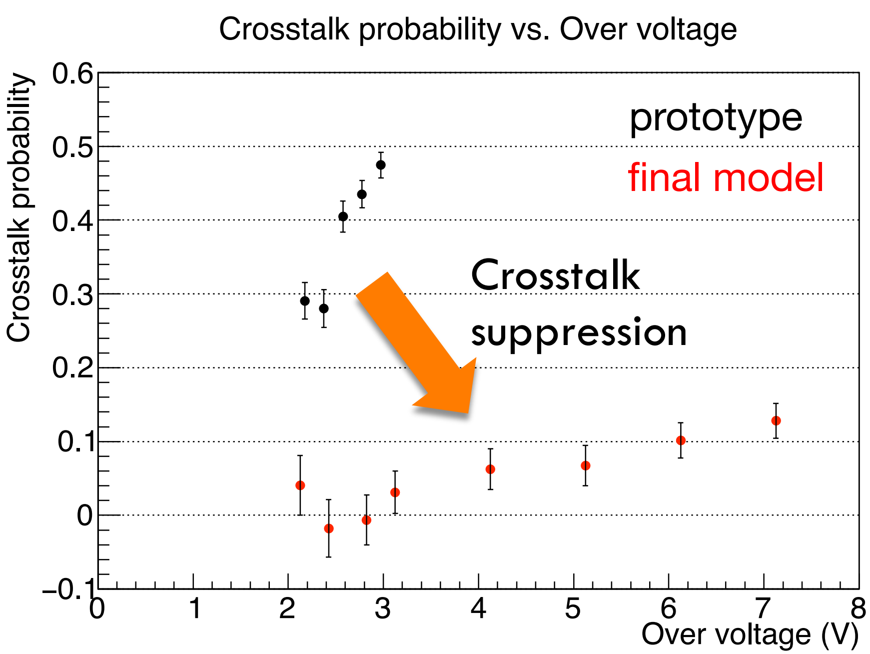
Parallel connection

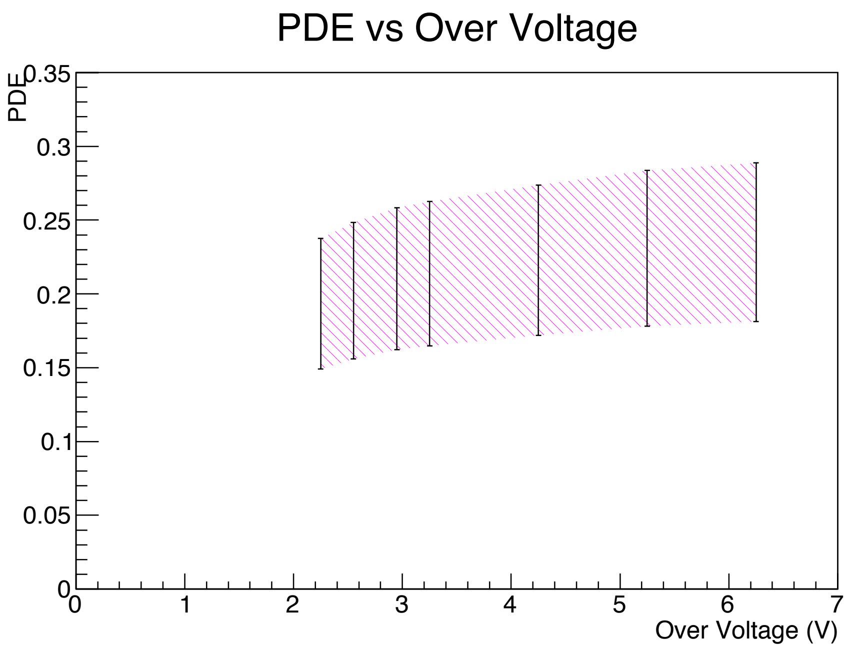
Series connection

Performance of MPPC

Excellent performance of MPPCs have been measured.

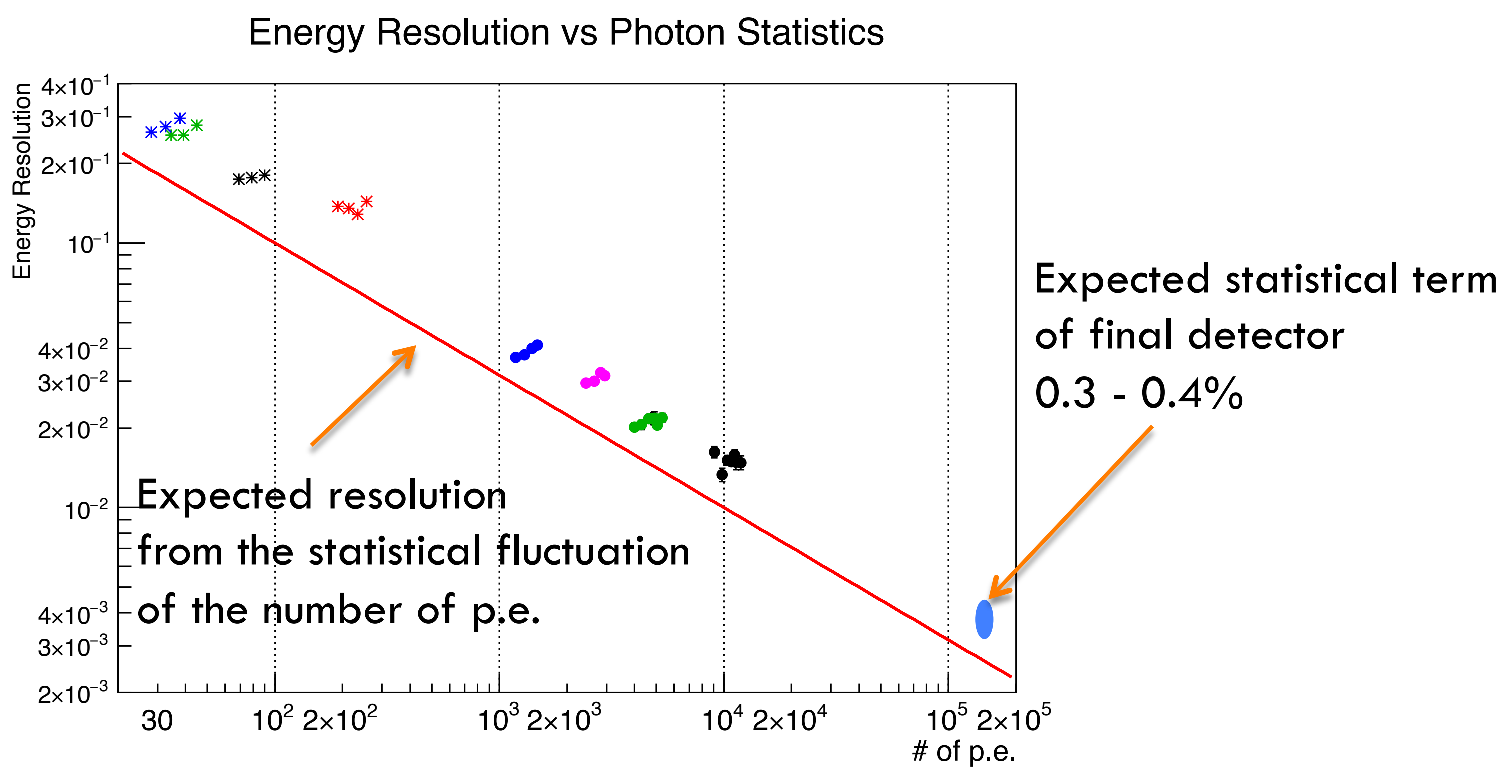
- Gain: 8.0×10^5 (@ Vover=7V, series connection)
- Low crosstalk probability (~15% @ Vover=7V) and wider operation voltage thanks to the crosstalk suppression
- Sufficient PDE for Xe scintillation light (PDE > 15%)





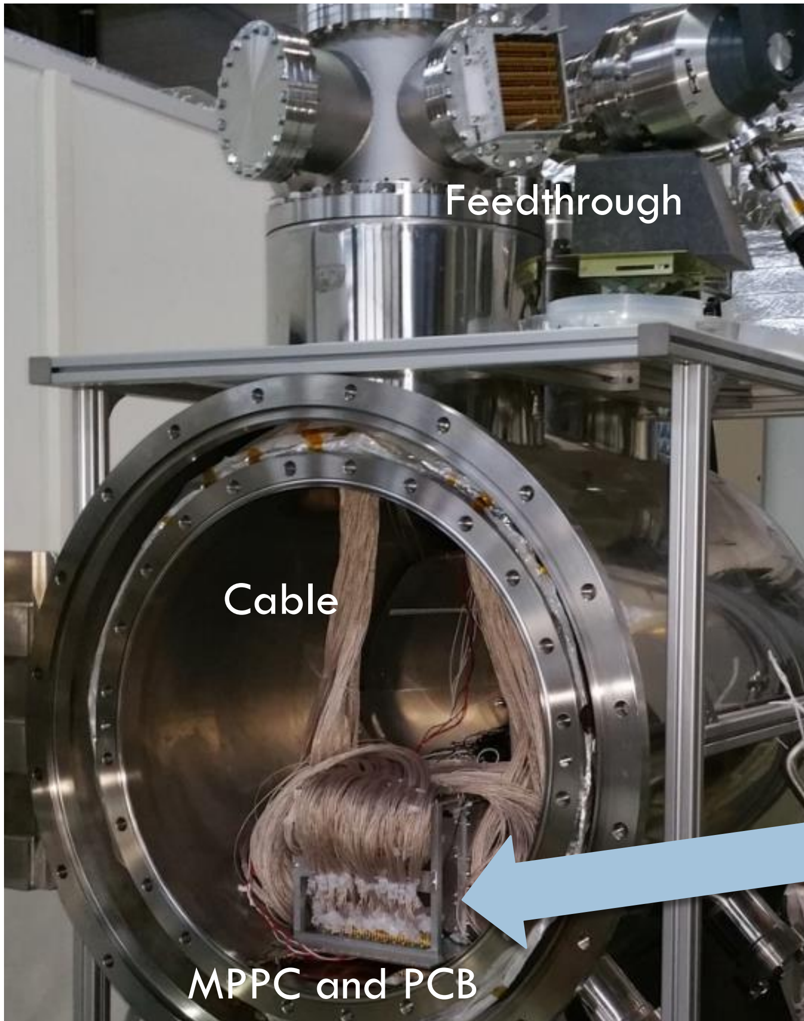
Energy resolution

- Energy resolution for scintillation light has been measured as a function of # of p.e by changing geometrical acceptance with several setups.
- We confirmed that energy resolution improves as 1/Sqrt(# of p.e.) at least down to 1.4% at ~10^4 p.e.
- Difference from the statistical expectation will NOT limit the performance of our detector.



Mass test in LXe

- 568 prototype MPPCs were tested in LXe
  - Check the properties of MPPCs
    - Breakdown voltage, gain, PDE
  - Test readout system
    - PCB, cable, feedthrough



Prototype chamber

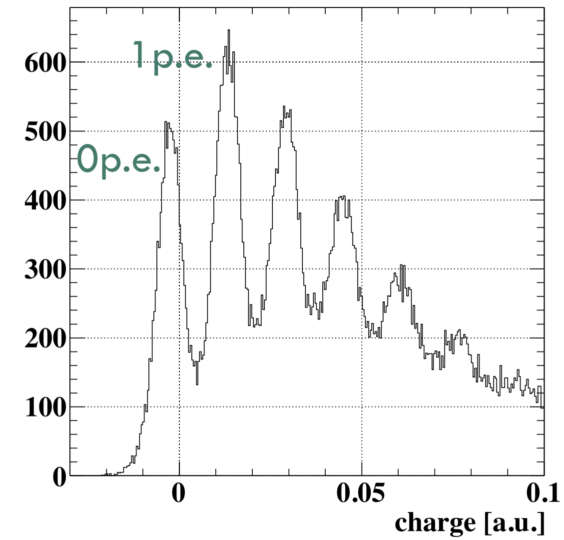
MPPCs mounted on PCBs

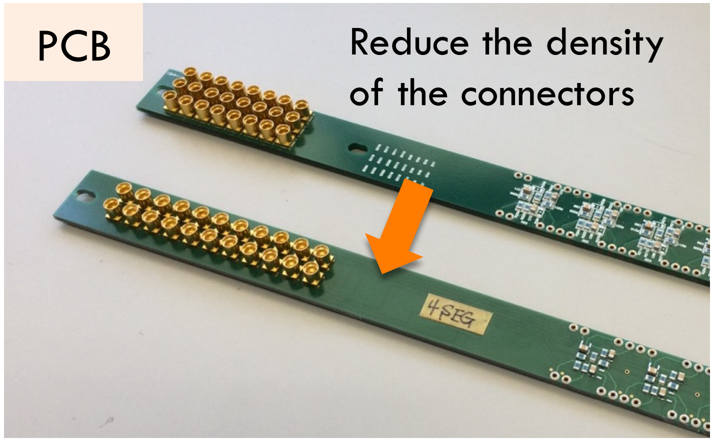
Result of mass test in LXe

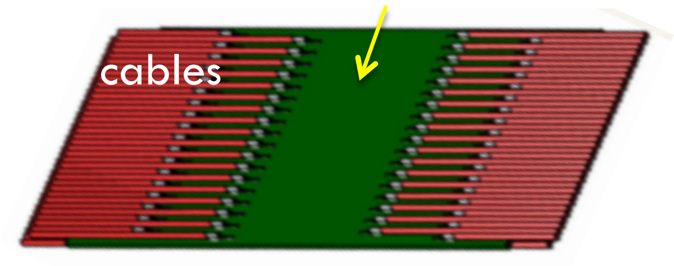
We confirmed that MPPC, PCB, and feedthrough work properly in LXe for most of the channels.

- We can see a clear 1 p.e. peak.
- Some bad channels were found.
  - Most of the bad channels are found to be due to the bad connection in the signal readout system (cables at connectors etc…).
  - We have improved the design and assembling procedure for the final detector.

Example of the charge distribution using LED



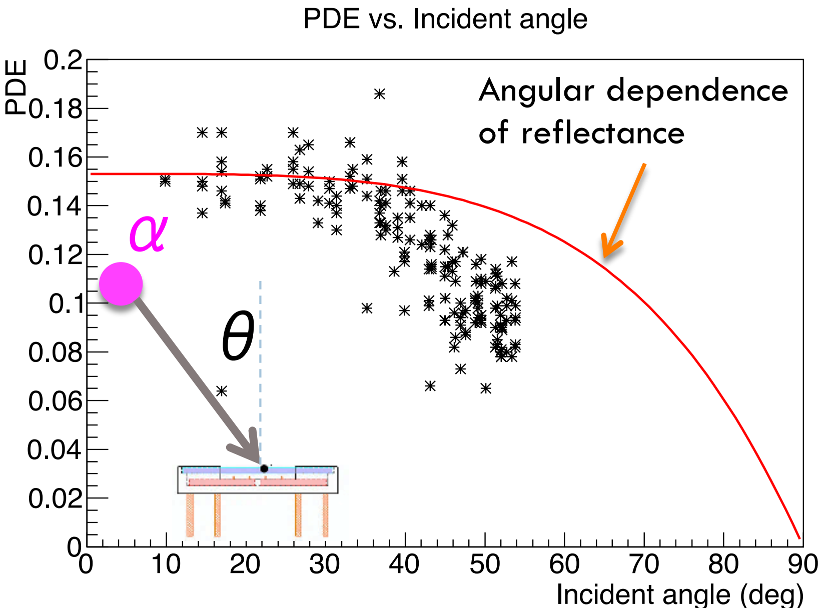


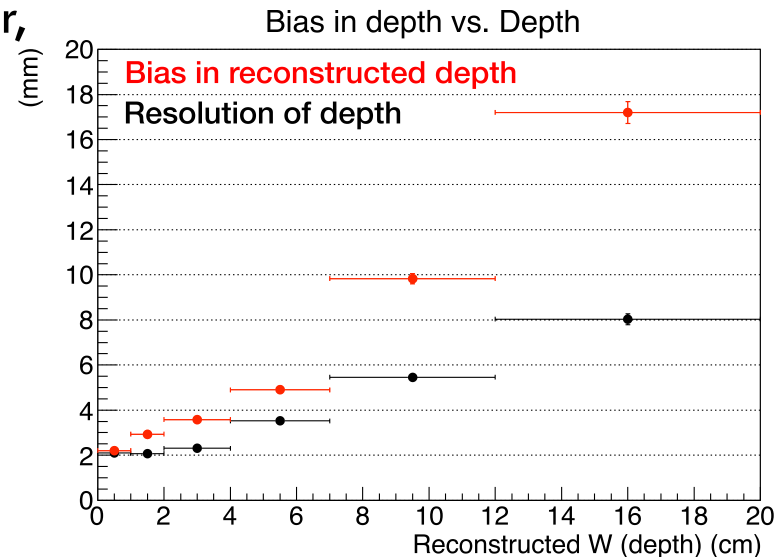


Direct soldering of the cables instead of connectors

Angular dependence of PDE

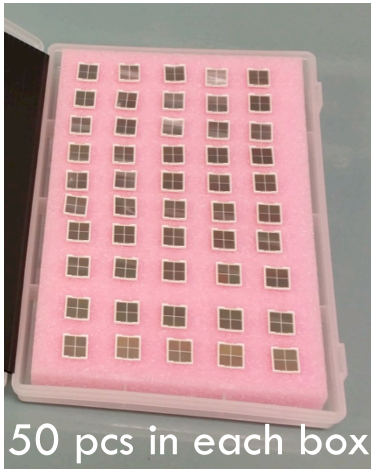
- We found that PDE has larger incident angle dependence.
  - Larger than the angular dependence of the reflectance at the Si surface.
- Effect to the final detector performance has been estimated by MC simulation.
  - Reconstructed depth is biased to shallower, if the larger angular dependence is NOT correctly included in the reconstruction.
  - We are planning to measure the angular dependence in a dedicated setup.





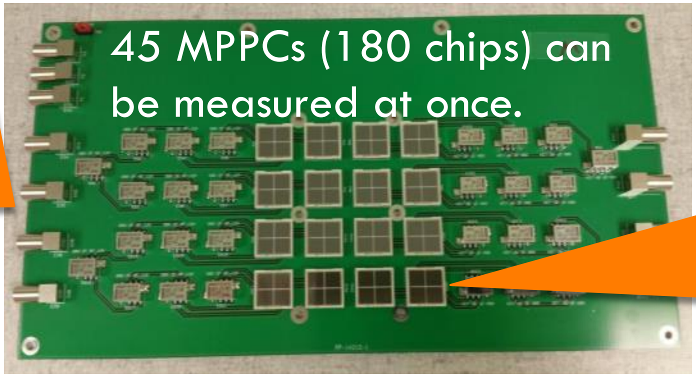
Mass production of MPPCs

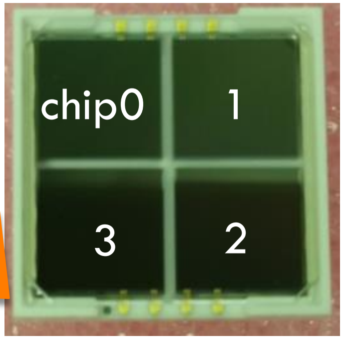
Production of 4200 final model MPPCs finished in October 2015.



We have measured I-V curve for all chips (4180x4) to reject bad MPPC.

- Breakdown voltage, Current @ Vover=5V, shape of I-V curve

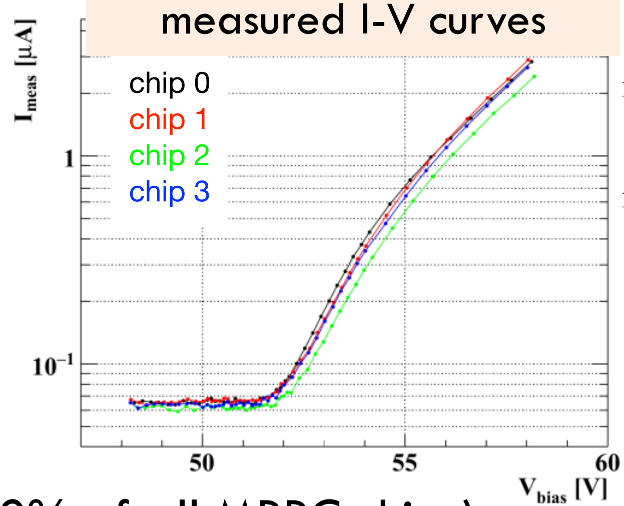




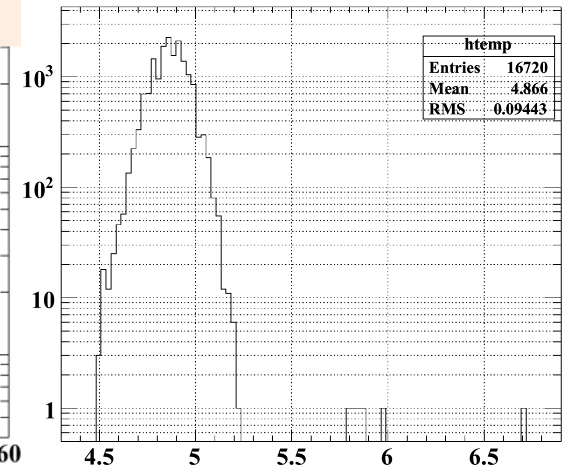
Result of the mass test

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

Example of measured I-V curves

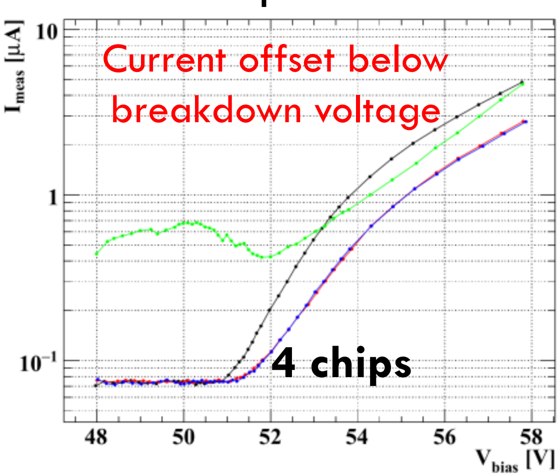


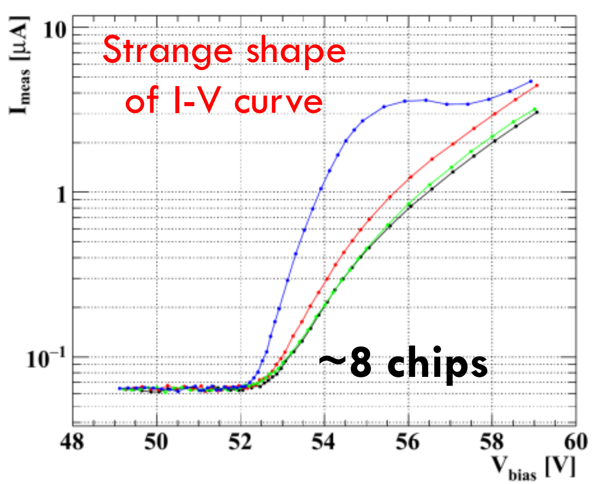
Breakdown voltage

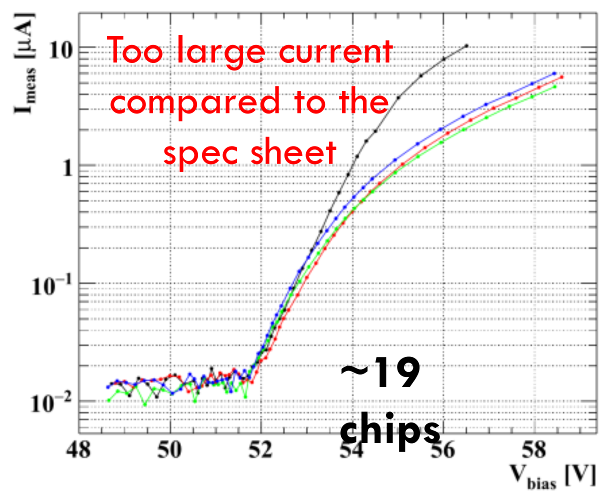


V(breakdown) - V(recommended by HPK)

- We found 31 bad chips (0.2% of all MPPC chips).
  - There are three kinds of bad chips.
  - Bad chips will not be used in the final detector.

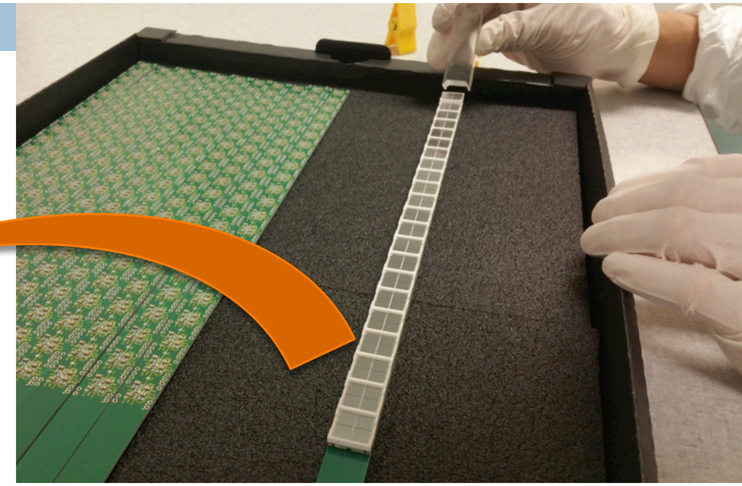


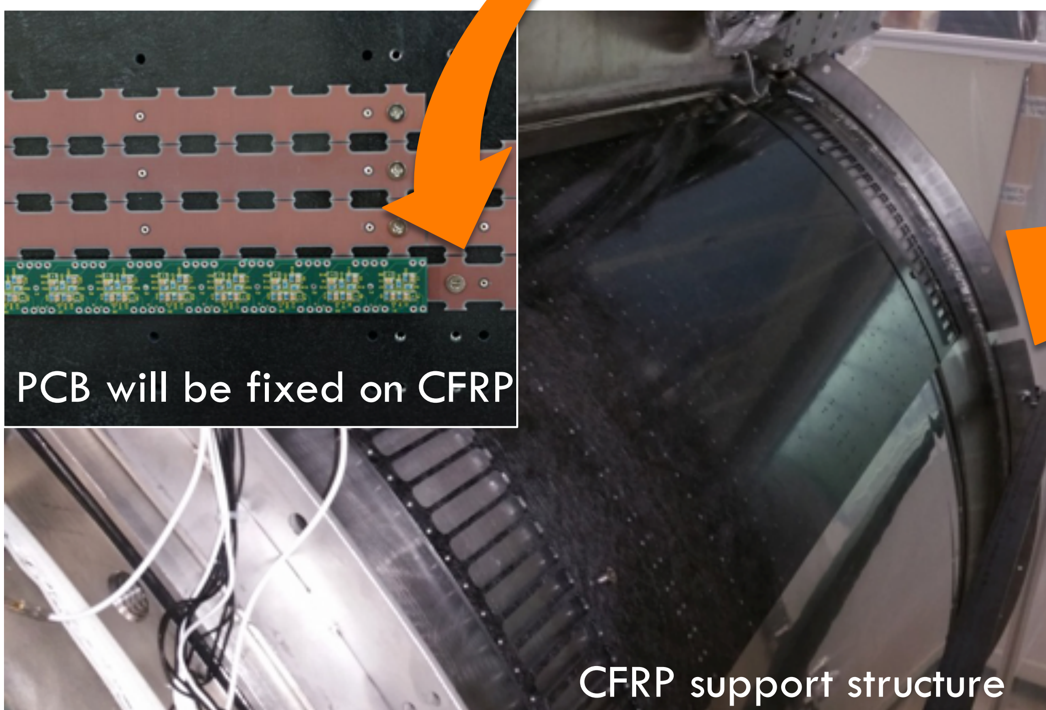




Detector construction

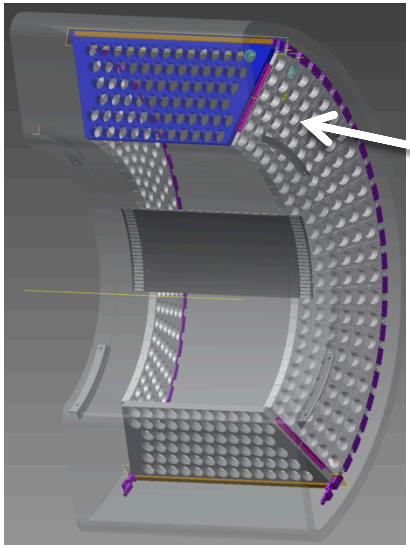
- Support structures for MPPC have already been produced.
- Detector assembling is on going.



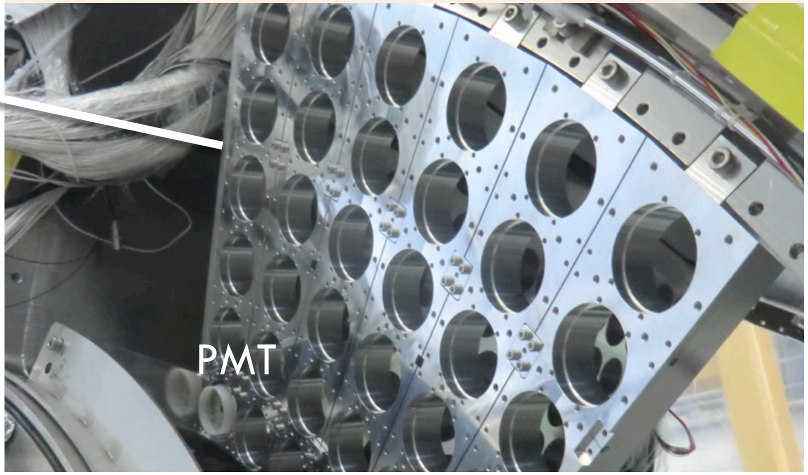


Detector construction

- Production of the support structure for PMT is in progress.



PMT support structure (Lateral face)



- External heat inflow is expected to increase due to ~4000 MPPC signal cables.
- New powerful refrigerator will be installed. Sufficient coling power (430W @165K) have been confirmed.

Summary

- The performance of the LXe detector in the MEG experiment will be greatly improved with a highly granular scintillation readout with MPPCs.

- We have developed a VUV-sensitive large area MPPC, and an excellent performance has been confirmed.

- The construction of the final detector will finish June. Liquefaction and purification of Xe will take 3-4 months. Operation test will start this autumn.