MEG II 実験2021年物理ランに関する報告
- ガンマ線測定の現状と課題-

日本物理学会
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ICEPP The University of Tokyo

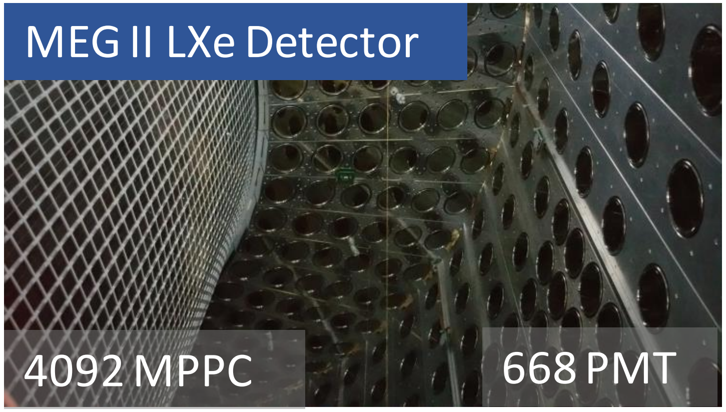
THE UNIVERSITY OF TOKYO

Core-to-Core Program

Outline

- Introduction
  - Liquid Xenon gamma-ray detector
- 2021 run
  - Goal
  - Non-uniformity of energy reconstruction
  - Systematics of PDE measurement
  - Data reduction
- Summary & Prospects

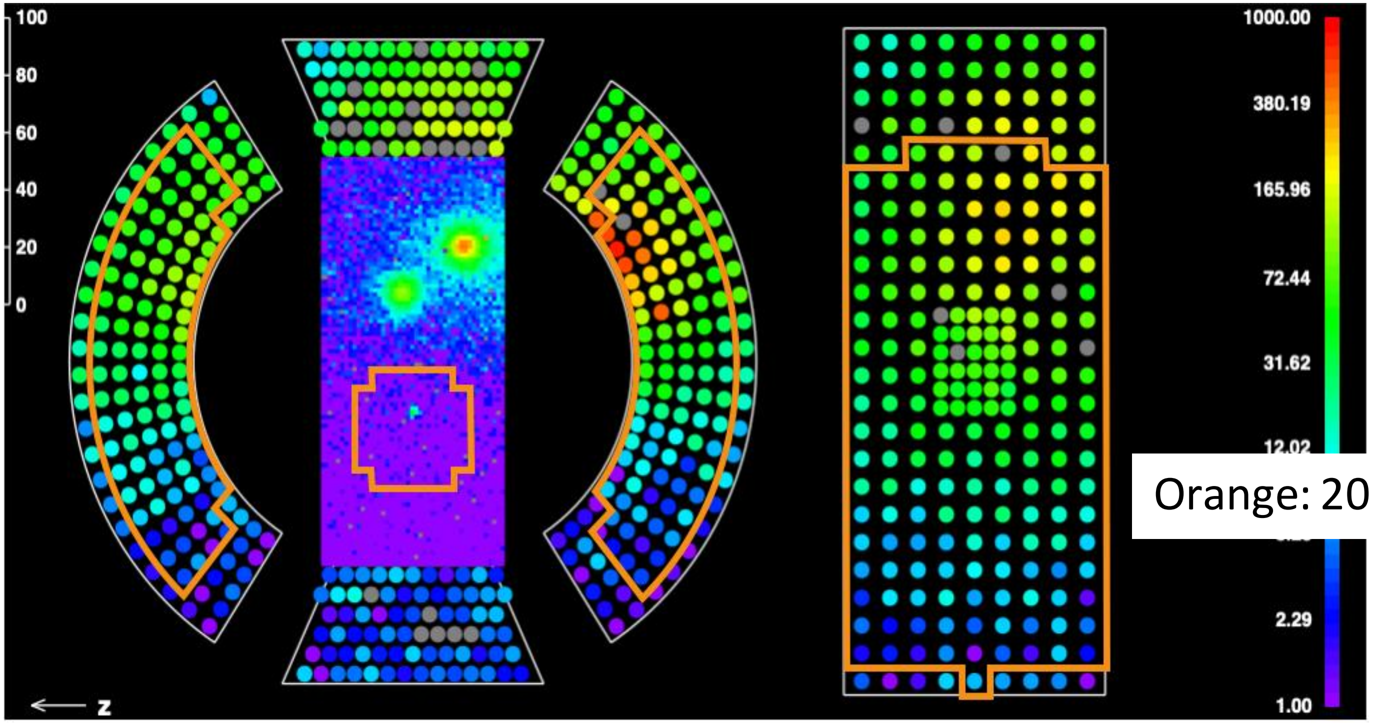
Liquid Xenon detector upgrade



Performance	MEG	MEG II (design)	MEG II (measured)
Position resolution[mm]	5 – 6	2.5	2.5
Energy resolution[%]	1.7 – 2.4	1.0-1.1	1.7-1.8
Time resolution[ps]	62	50 - 70	(80)
Efficiency[%]	63	69	-

- The entrance face is covered with 4092 VUV-sensitive MPPCs.
  - Improve uniformity of light collection, energy & position resolution.
- Improvement of position and energy resolution is observed.
- The full electronics are installed in 2021.
  - Before the installation, only ~1000 channels were read out.

2021 RUN – Goal -

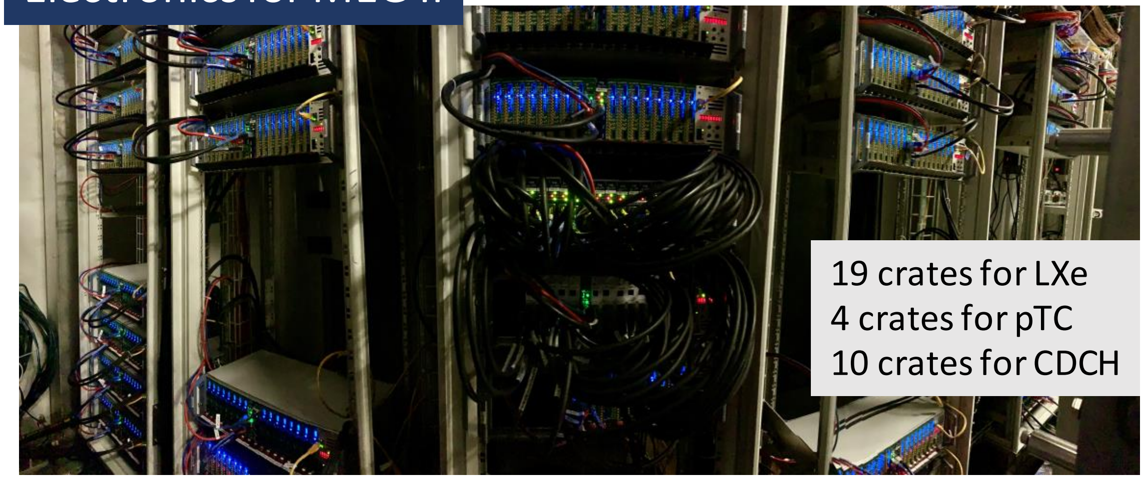


Orange: 2020 readout

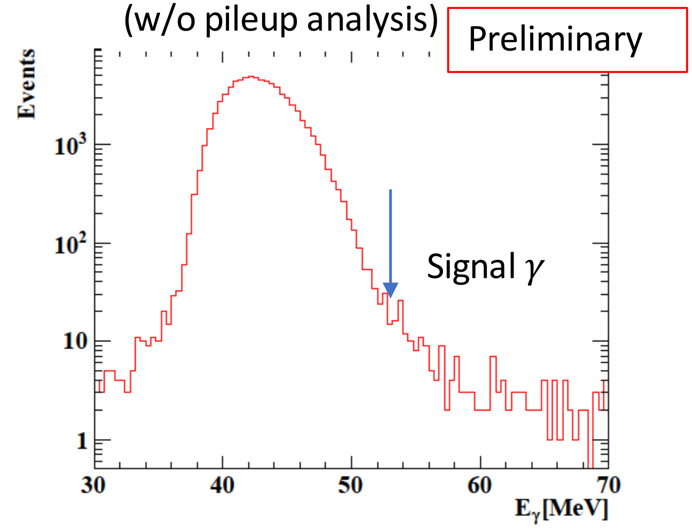
- Goal
  - Detector commissioning with the full electronics.
  - **Start a short physics data acquisition.**
  - Detector performance measurement.

Difficulties to start physics run

Electronics for MEG II

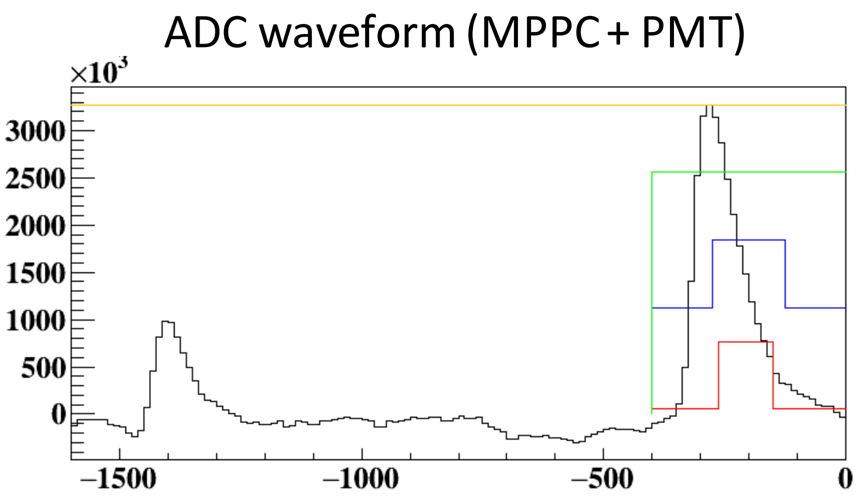


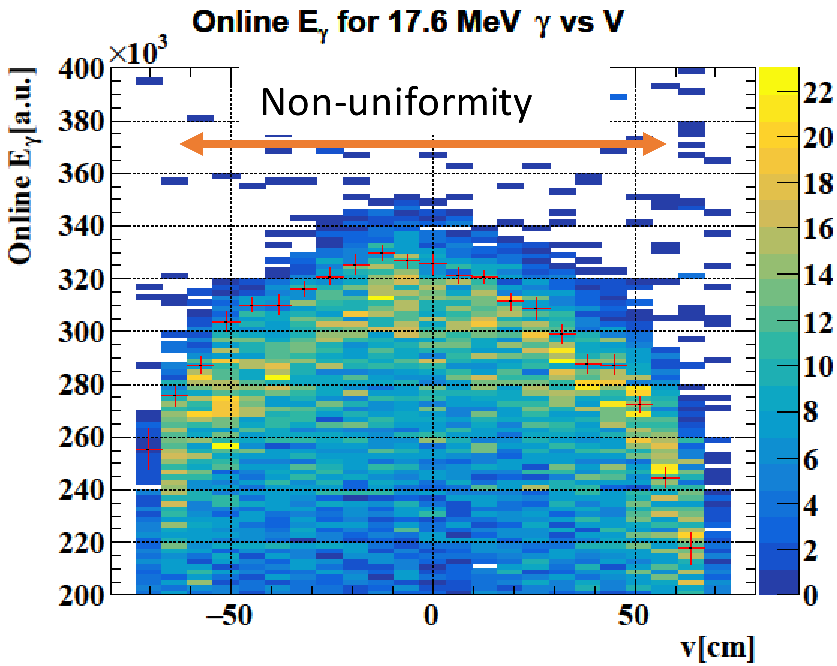
Energy spectrum
(w/o pileup analysis)



- Hardware requirement: data rate cannot exceed 100 MB/s.
  - 20 MB/s is the projected rate at the design phase.
- LXe detector has a dominant impact on the data rate.
  - MEG trigger rate heavily depends on gamma-ray energy threshold.
  - LXe detector has the largest number of channels (4760).
- Requirement for LXe detector
  - Good online energy uniformity and resolution.
  - Reduce data size per event: Data reduction.

Online Energy Reconstruction



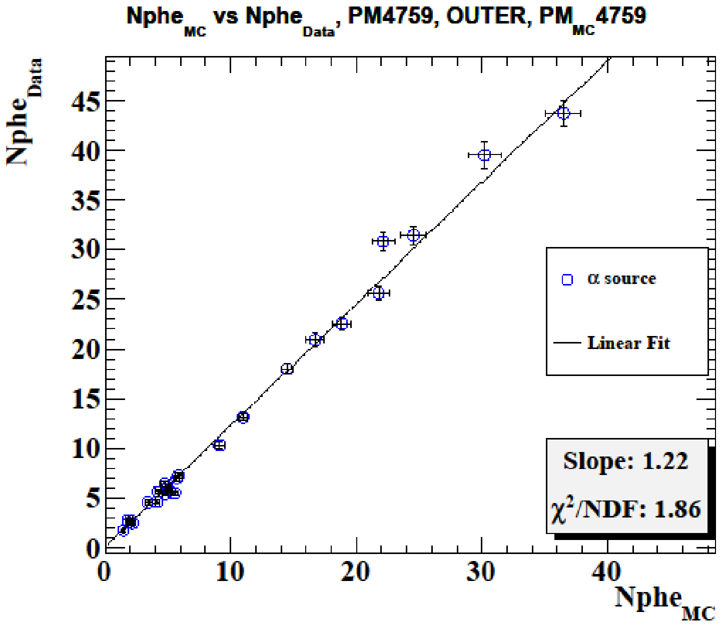


- Online energy reconstruction for trigger:
  - Use amplitude of sum waveform weighted with calibration constants
    - Gain & Photon Detection Efficiency: PDE.
- In 2021, a large non-uniformity of online energy was observed.
  - **Systematic bias of PDE calibration** was the most probable reason.
- In the beam time, it was temporarily solved by an iterative weight optimization.

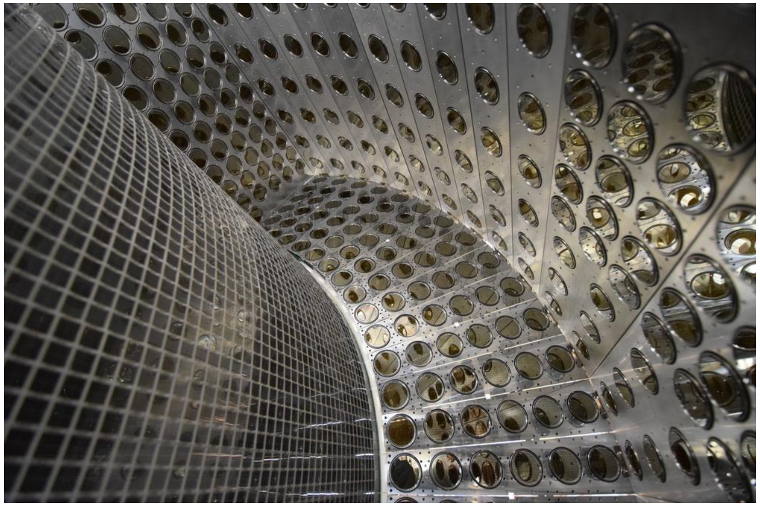
Systematics of PDE calibration

$$PDE \sim PDE_{MC} \times N_{phe,Data} / N_{phe,MC}$$

Number of photo-electrons

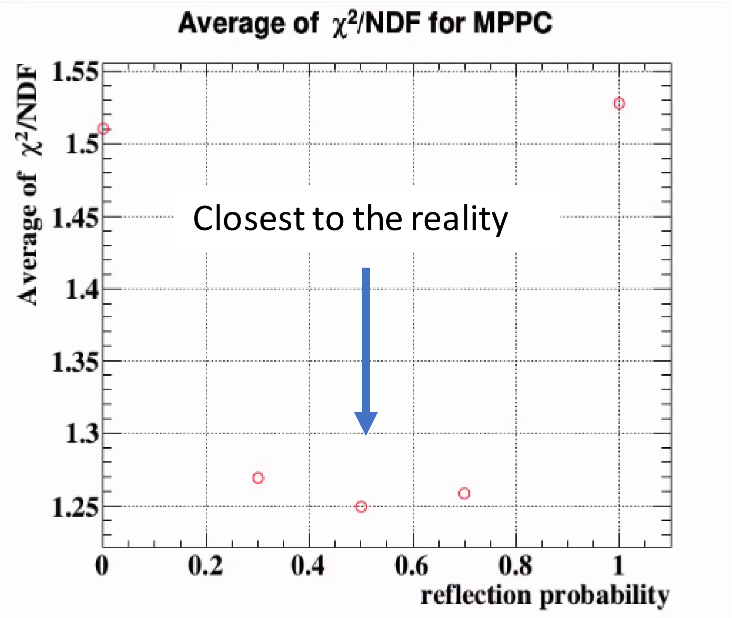


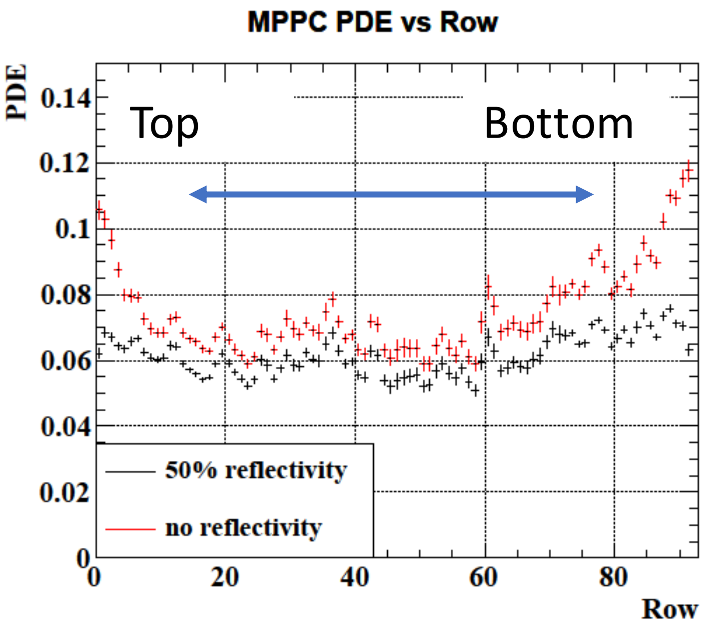
Detector inner wall



- PDE of MPPC and PMT is measured with ^{241}Am sources.
  - MC simulation is used to estimate the number of photo-electrons.
- Systematics comes from discrepancy between MC and reality.
- Default MC simulation had no reflection at Aluminum PMT holder.

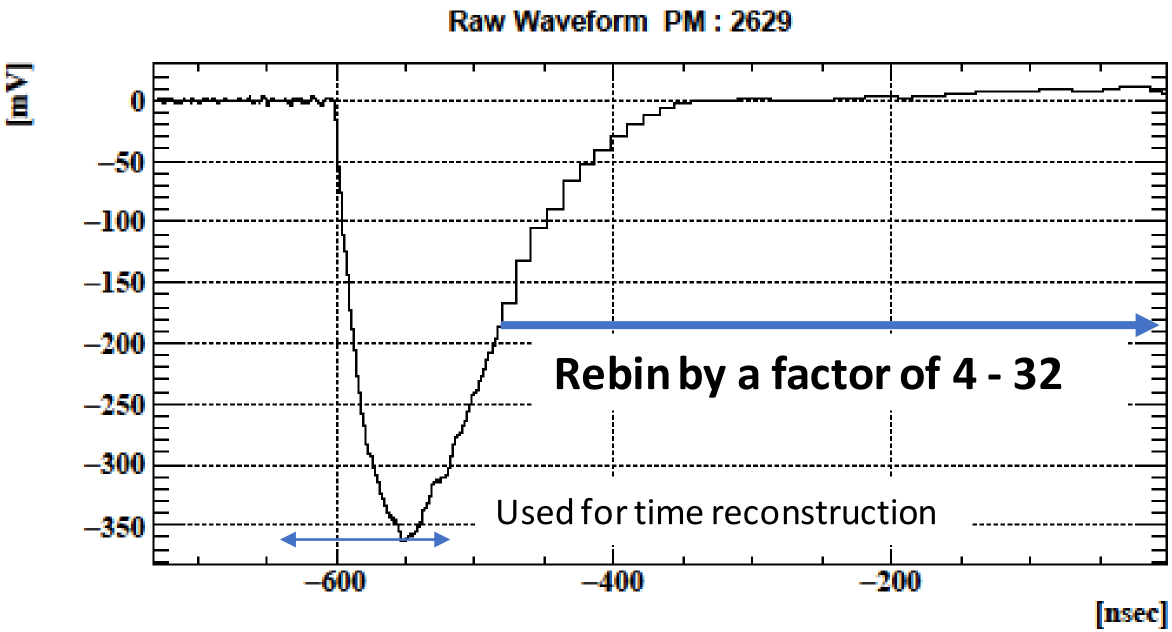
Systematics of PDE calibration





- Scanned reflectivity in MC simulation between 0 and 1.
  - Similarity of light distribution was defined with alpha dataset.
- 50% reflectivity was the best configuration to simulate the reality.
- Uniformity of MPPC PDE was improved with 50% reflectivity MC.
  - With default MC, MPPC close to edges had high PDE than central ones.

Data reduction



- Impact of data reduction was already studied (2017 spring JPS, 小川)
  - Negligible impact on pileup analysis & reconstruction.
- Waveform data was reduced down to ~30% by rebin.
  - Only the rising edge of large pulse matters for the time reconstruction.
  - Waveform with < 10 mV peak: entire waveform was rebinned by eight.
  - Waveform with > 10 mV peak: falling edge was rebinned by a factor of 4-32.

Summary

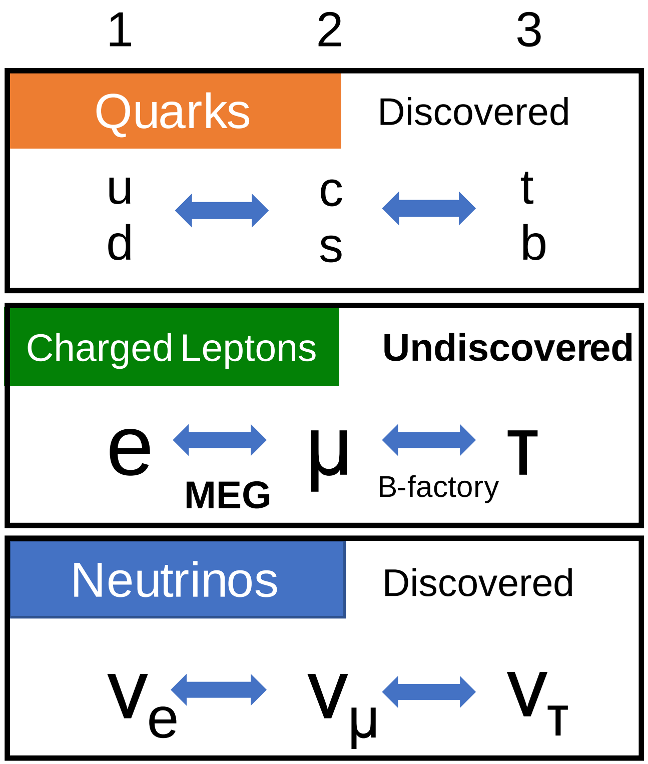
- MEG II started physics run to search for $\mu \rightarrow e\gamma$ in 2021.
- The hardware limitation of the data rate was a major difficulty to realize the physics run.
- DAQ at $5 \times 10^7 \mu/s$ was achieved with following solutions.
  - Data reduction by rebin.
  - Temporal solution to improve the uniformity of online energy.
- Systematic bias of PDE calibration derived from a discrepancy between data and MC was studied.
  - Uniformity was improved with optimized reflectivity of Aluminum PMT holder.

Prospects

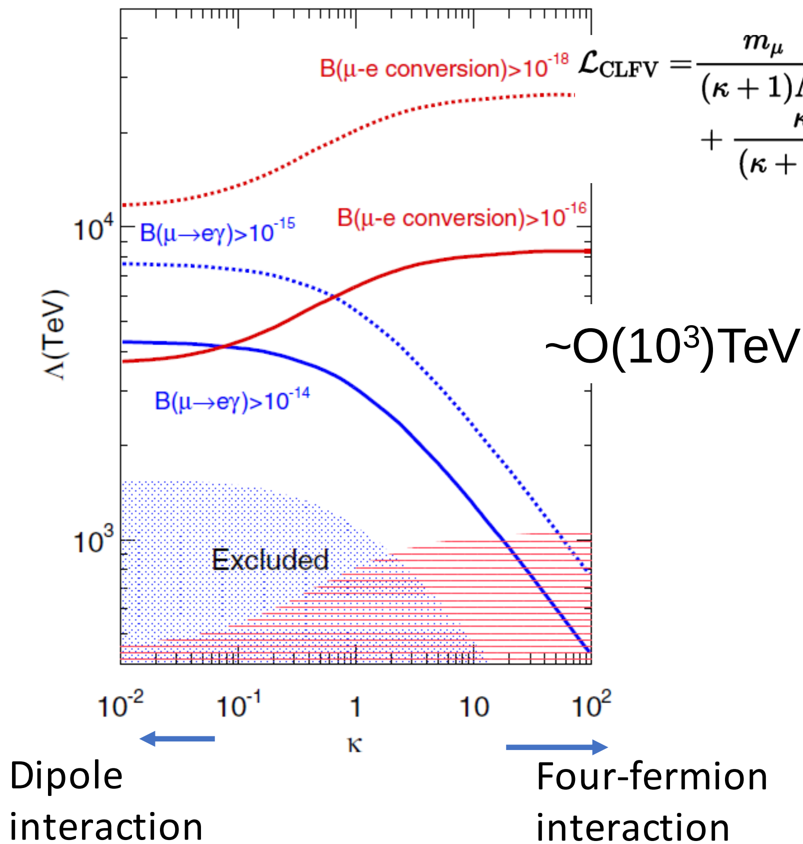
- Toward physics analysis :
  - Analysis on calibration measurements.
    - Radiation damage of MPPC: 17aA572-10, 吉田
  - Fix time and energy reconstruction & correction.
- In 2021, energy & time resolution were measured with the full electronics.
  - Analysis is in progress.
  - Time resolution measurement: 16aA573-9, 松下
- 2022 run requires PDE recovery by thermal annealing, and it is ongoing: 17aA572-10, 潘

Backup

Charged Lepton Flavor Violation



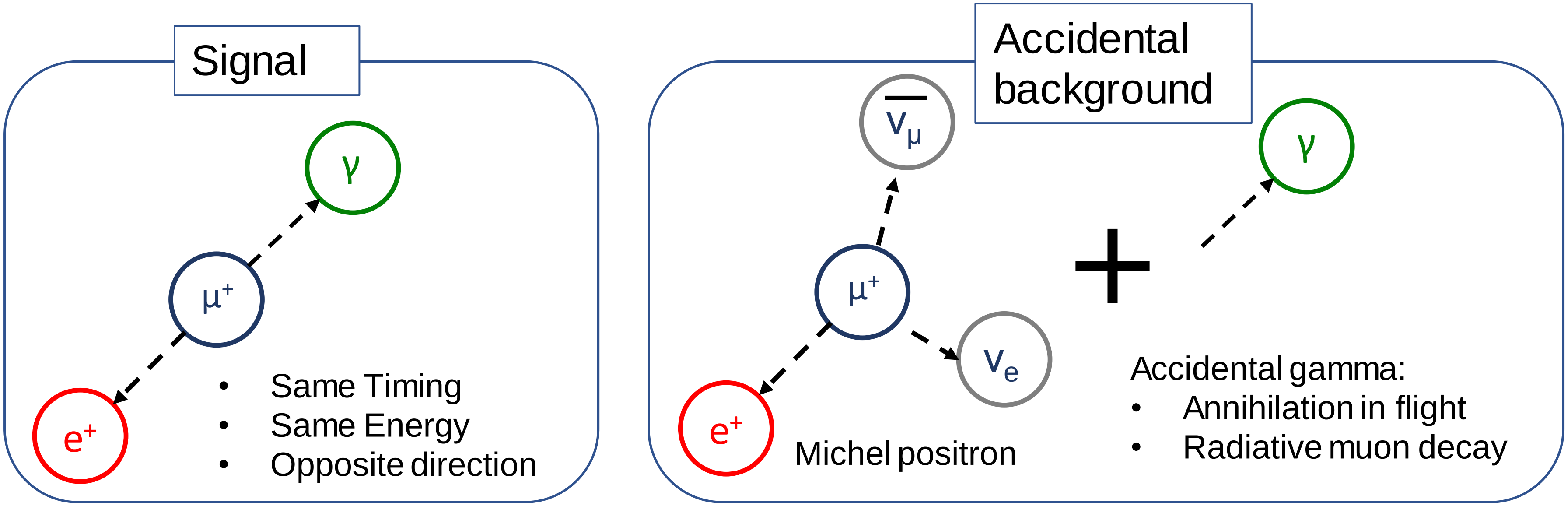
$$\mathcal{L}_{\mathrm{CLFV}} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_{\mathrm{R}}\sigma_{\mu\nu}e_{\mathrm{L}}F^{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}\bar{\mu}_{\mathrm{L}}\gamma_\mu e_{\mathrm{L}}(\bar{e}\gamma^\mu e)$$



Journal of the Physical Society of Japan 85, 091002 (2016)

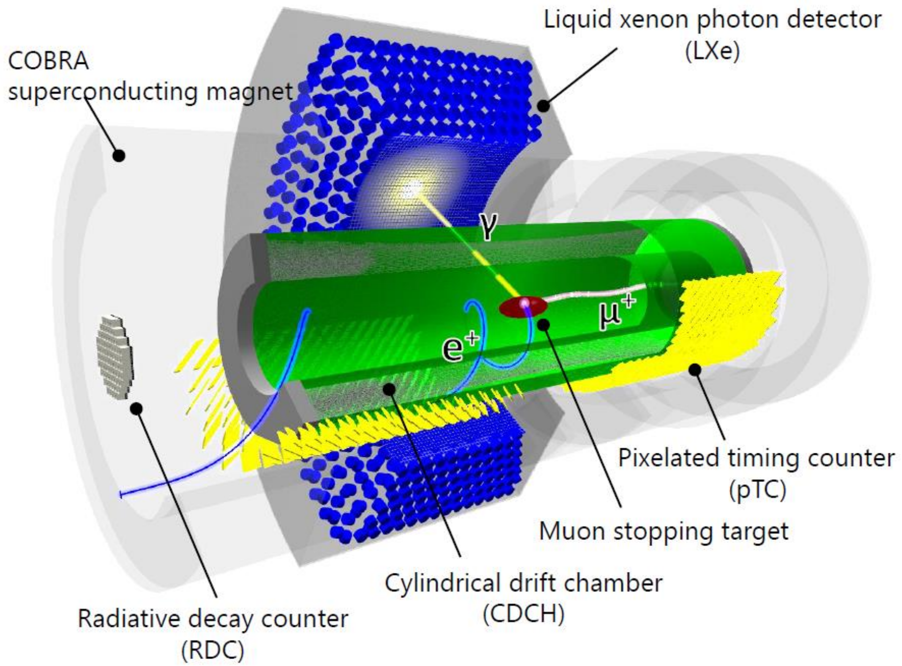
- Rates are too small ($Br(\mu \to e\gamma) \sim 10^{-54}$) in the SM.
- Large enhancement is predicted by new physics.
- High energy scale beyond LHC is indirectly accessible.

μ→eγ Search



- $\mu \rightarrow e\gamma$ decay: two-body decay
  - Main background: accidental
    - Positron from Michel decay + accidental gamma-ray.
  - Key: Precise measurement of positron + gamma-ray to discriminate signal and BG.

MEG II experiment



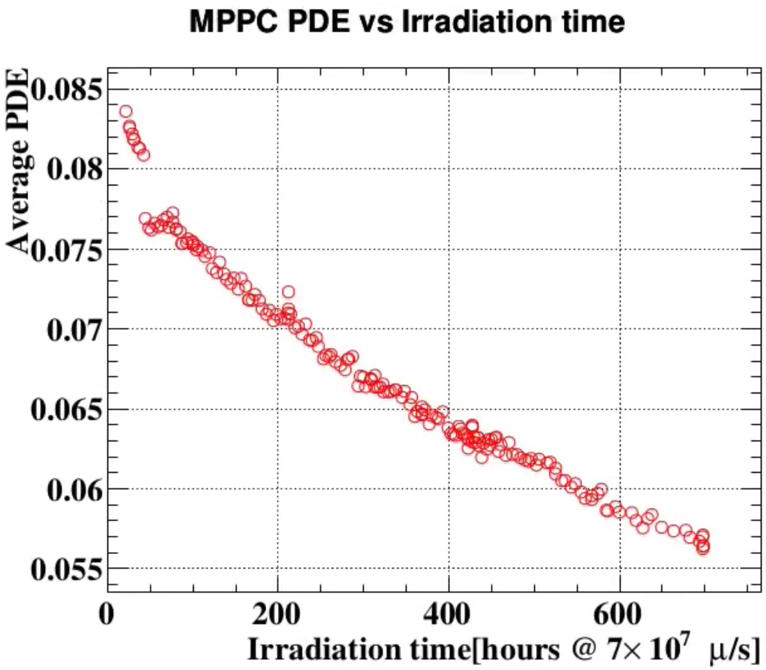
- MEG II will search for decay
  - Goal: Br(μ→eγ) ~ 6×10^{-14} in 3 years of data acquisition.
  - Even higher intensity muon beam ($7 \times 10^{7} \mu/s$)
  - Detector upgrade ($\times$ 2 resolution improvement for each detector)
- Liquid Xenon gamma-ray detector measures the position, energy, and timing of the incident gamma-ray.
  - 900 L liquid xenon + VUV-sensitive photosensor.

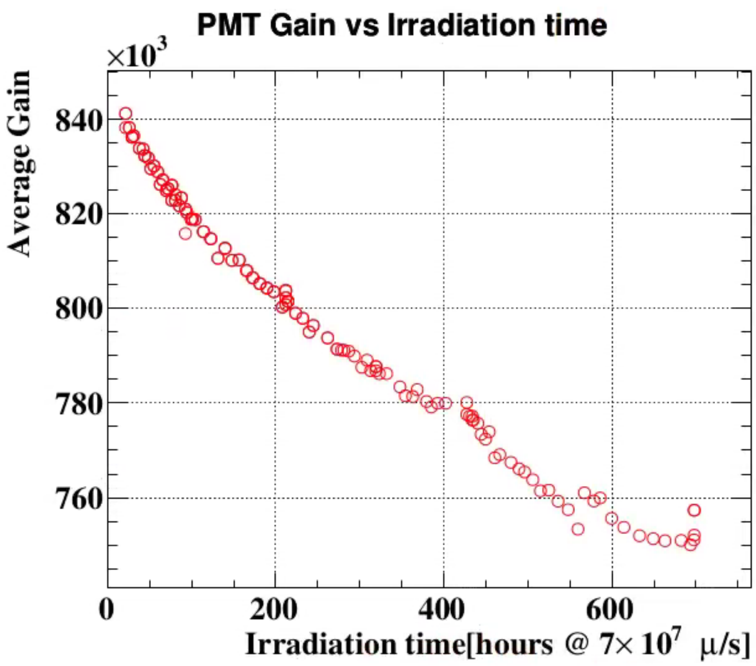
2021 RUN – Calibration Overview -

Source	Purpose	Frequency
LED	MPPC & PMT Gain	2 times per day
Alpha-ray from 241Am source	MPPC & PMT PDE	2 times per day
9 MeV gamma-ray	Light yield monitoring	5 times per week
17.6 MeV gamma-ray	Light yield monitoring	3 times per week
Cosmic-ray	Light yield monitoring	Daily

- Photo-sensor performance was monitored with intrinsic calibration sources (LED and Am source).
- Energy scale was monitored with gamma-ray sources and cosmic-ray.

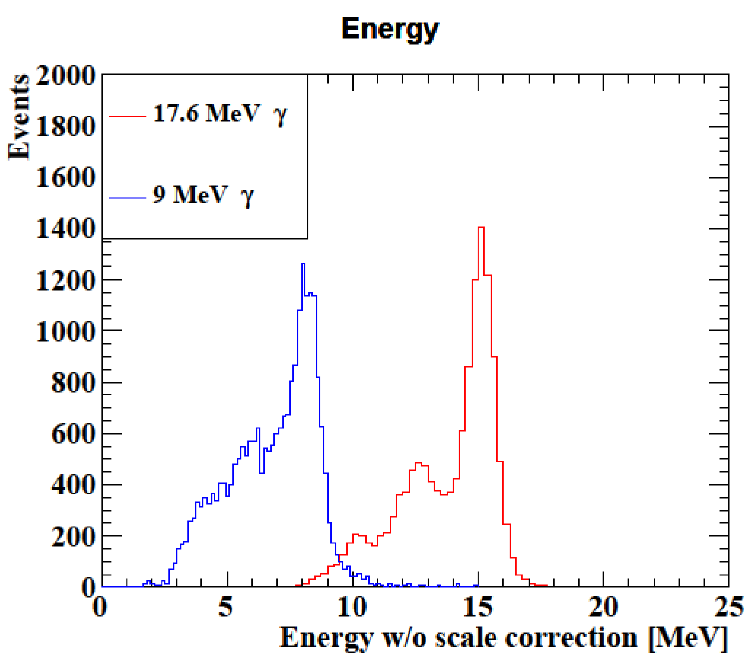
2021 RUN – Sensor Calibration -

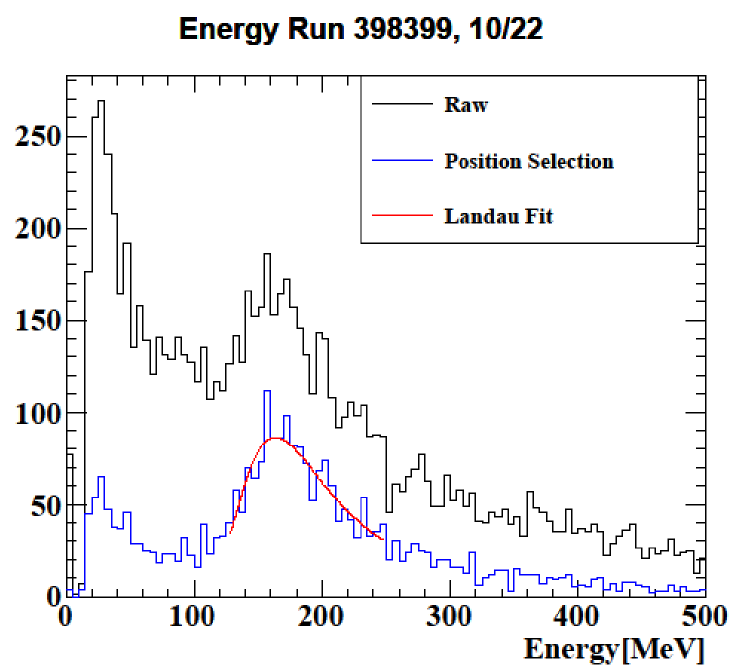




- Photosensor performance was frequently monitored with intrinsic calibration sources (LED and Am source).
- Radiation damage during 2021 run:
  - PMT gain: 840k -> 750k (11% decrease)
  - MPPC PDE: 8.4% -> 5.6%

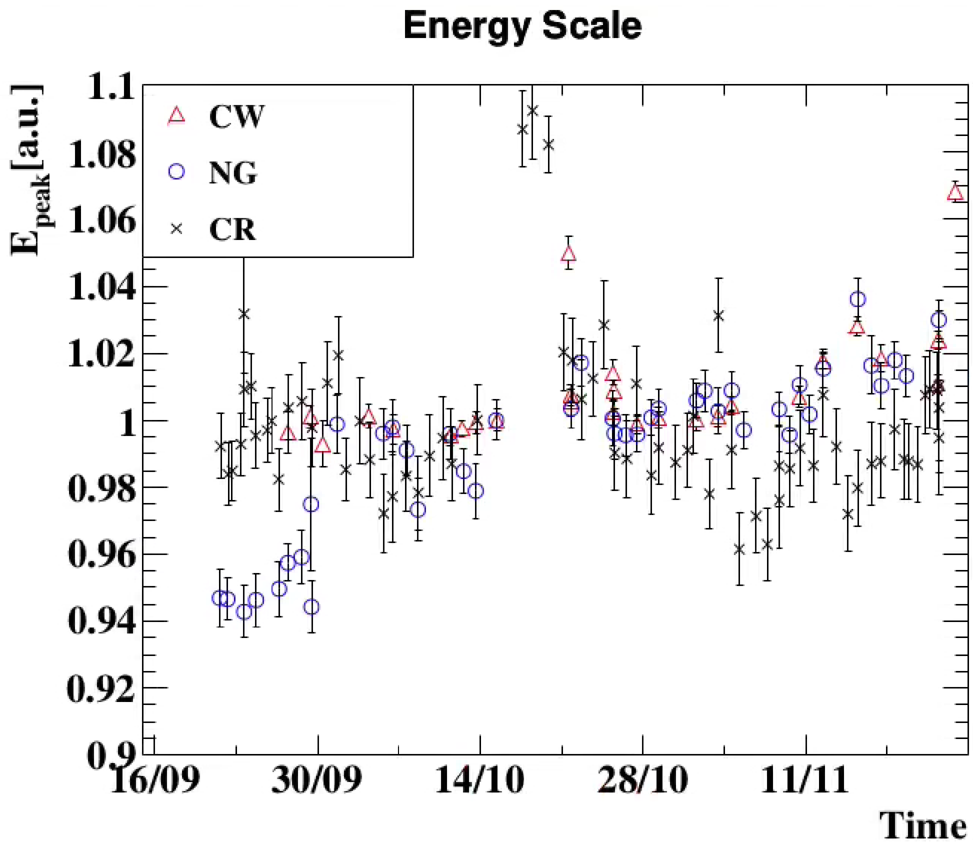
2021 RUN – Detector Response -





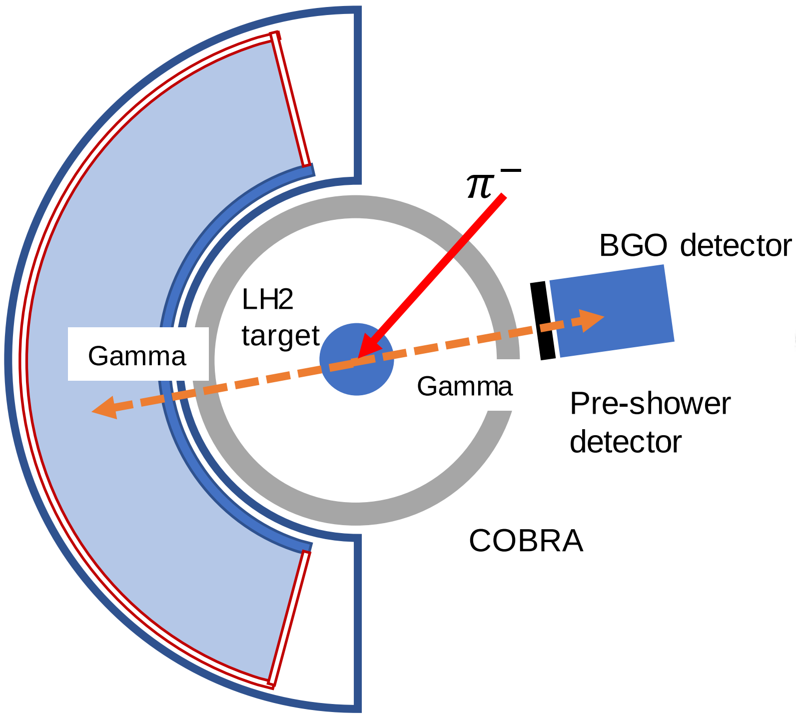
- The detector response during the beam time was monitored with
  - 9 MeV gamma-ray from thermalized neutron capture.
  - 17.6 MeV gamma-ray from
  - ~170 MeV Cosmic-ray energy peak.

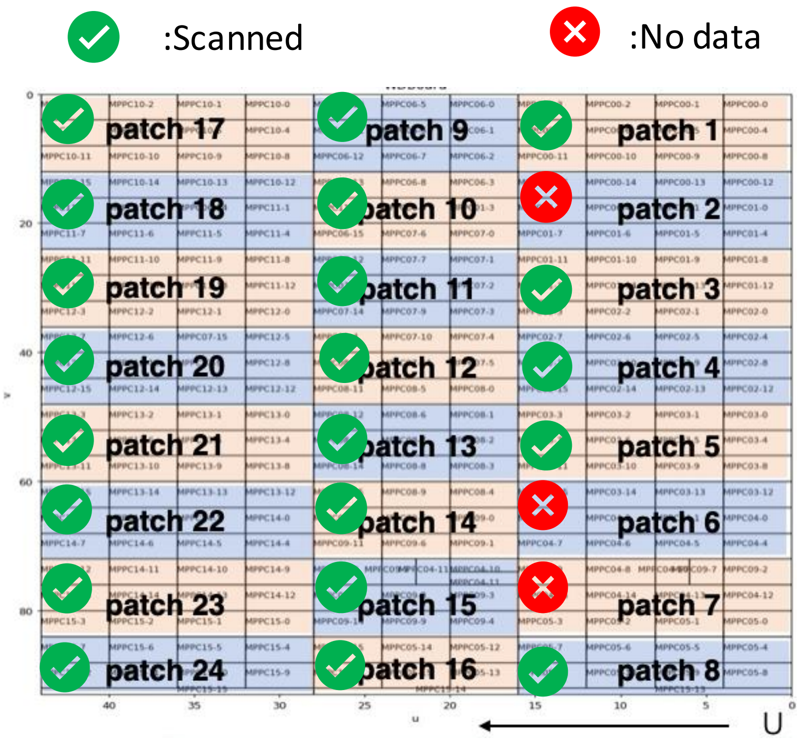
2021 RUN – Energy Scale -



- The energy scale must be measured with a better precision than the energy resolution (1.8%).

RUN2021: Charge Exchange(CEX) Measurement

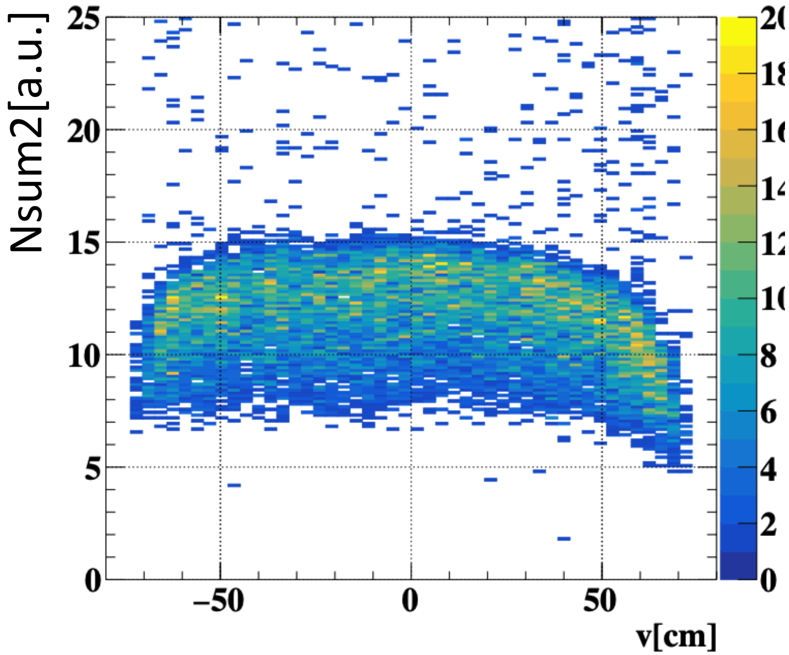


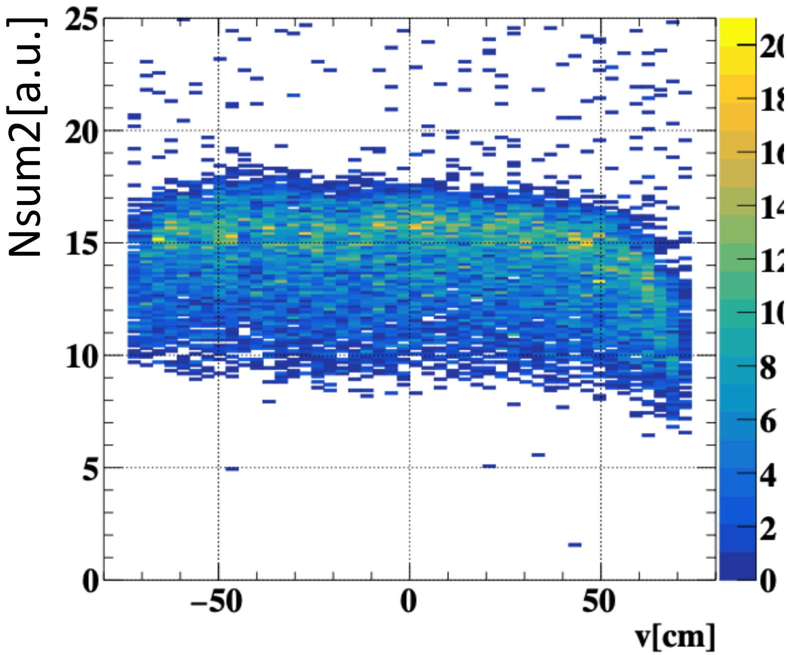


- Uniformity of the energy scale and energy resolution was measured with CEX setup.
- 21 out of 24 patches are scanned by moving the BGO detector.
- The full scan over the entire detector was not completed due to the short livetime of the LH2 target.
- The analysis of the energy resolution and efficiencies are in progress.

Energy reconstruction (CWLi data)

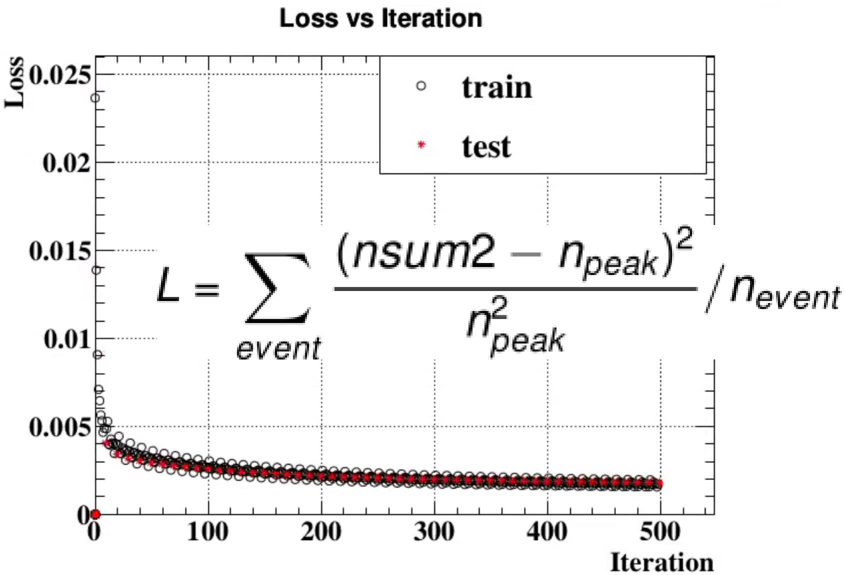
PDE based on Nominal MC (no reflection)	PDE based on Best fit MC (50% reflection)
Nsum2 vs v	Nsum2 vs v



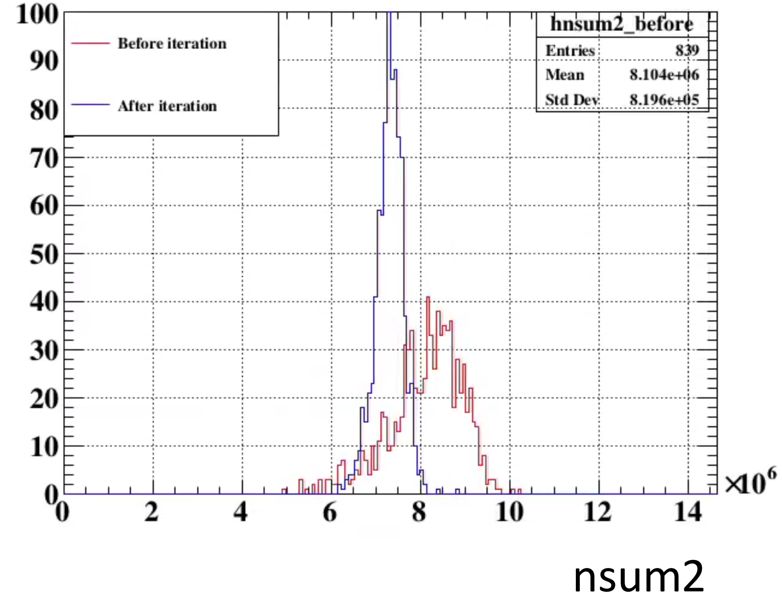


- Nsum2: weighted sum of the number of collected photons
- V-dependence is smaller with the PDE based on best-fit MC.

Method



$$L = \sum_{event} \frac{(nsum2 - n_{peak})^2}{n_{peak}^2} / n_{event}$$



- Update weights of all sensors iteratively so that they give a sharp monochromatic energy peak.
- Long CW data (#396904) are used.
  - The statistics are important to avoid over-fitting.
- Iteration: 500 steps (10 steps / 1 run).

Method – Iterative update of weight -

Loss

$$L = \sum_{event} \frac{(nsum2 - n_{peak})^2}{n_{peak}^2} / n_{event}$$

Weight update

Should be zero with an ideal set

$$w_{i,0} = 1$$

$$w_{i,j+1} = w_{i,j} - \lambda \boxed{\sum_{event} \frac{\partial L}{\partial w_{i,j}}}$$

$$= w_{i,j} - \lambda \sum_{event} n_{i,j}(n_{peak} - nsum2)$$

i: sensor

j: iteration step

- Iterative update to minimize Loss.
  - Loss: averaged distance between nsum2 and npeak(energy peak).

Data reduction

- Data size w/o reduction: 20 MB / event, 9 MB for LXe.
  - Reduction by a factor of 2-3 was necessary for 2021 run.