MEG II実験2022年物理ランにおける液体キセノンガンマ線検出器の較正

松下 彩華 (東大理), 他MEG IIコラボレーション

Ayaka Matsushita on behalf of MEG II Collaboration

The University of Tokyo

日本物理学会 2022年秋季大会

7aA442-4

Outline

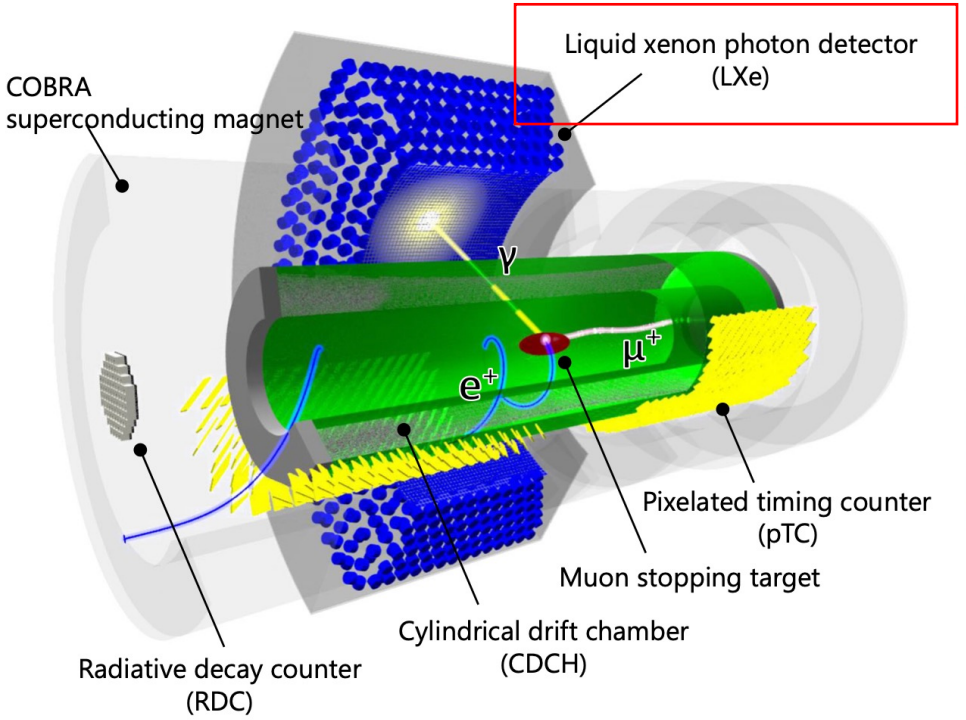
- MEG II Experiment
- Calibration of LXe Detector
- PMT Gain Monitoring
- PMT Gain Adjustment
- Gain Shift
- PDE Decrease
- PDE in 2022 Physics Run
- Level of LXe
- Energy Uniformity and Stability
- Summary

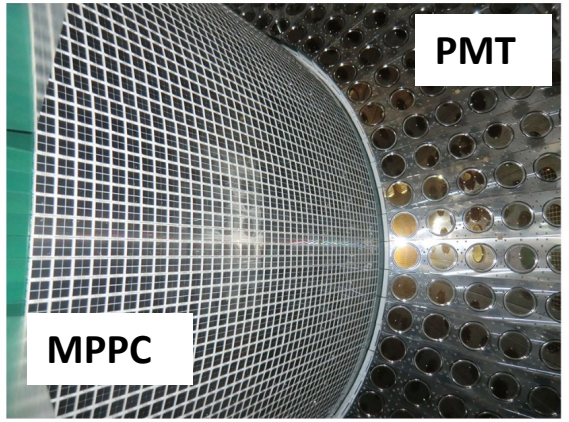
MEG II Experiment

MEG II experiment searches $\mu \rightarrow e\gamma$.
Goal : $\mathcal{B}(\mu \rightarrow e\gamma) \sim 6 \times 10^{-14}$

The most intense μ^+ beam at Paul Scherrer Institute

Physics data taking started in 2021.





Liquid Xenon(LXe) Gamma-ray Detector

LXe detector measures the position, energy and timing of the gamma-ray.

Scintillation light from 900 L LXe is read out by photosensors.
4092 VUV-sensitive MPPCs + 668 PMTs

Accurate event reconstruction by a higher read-out granularity

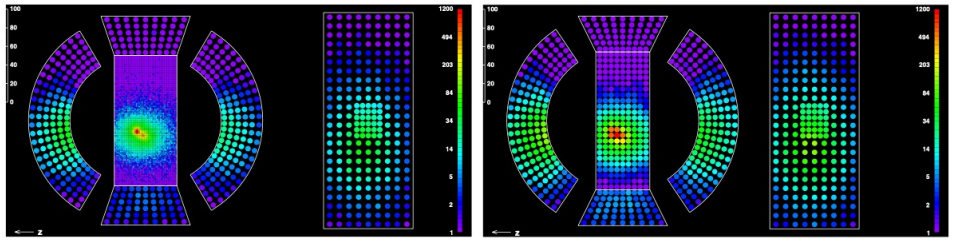


Fig. 58 Example of scintillating light distributions detected by photo-sensors in case of (left) PMTs and (right) smaller photo-sensors (12 × 12 mm^2) on the inner face for the same MC event

Calibration of LXe Detector

Various parameters, such as gain and PDE, are required to reconstruct events in LXe detector.

Parameters fluctuate over time.

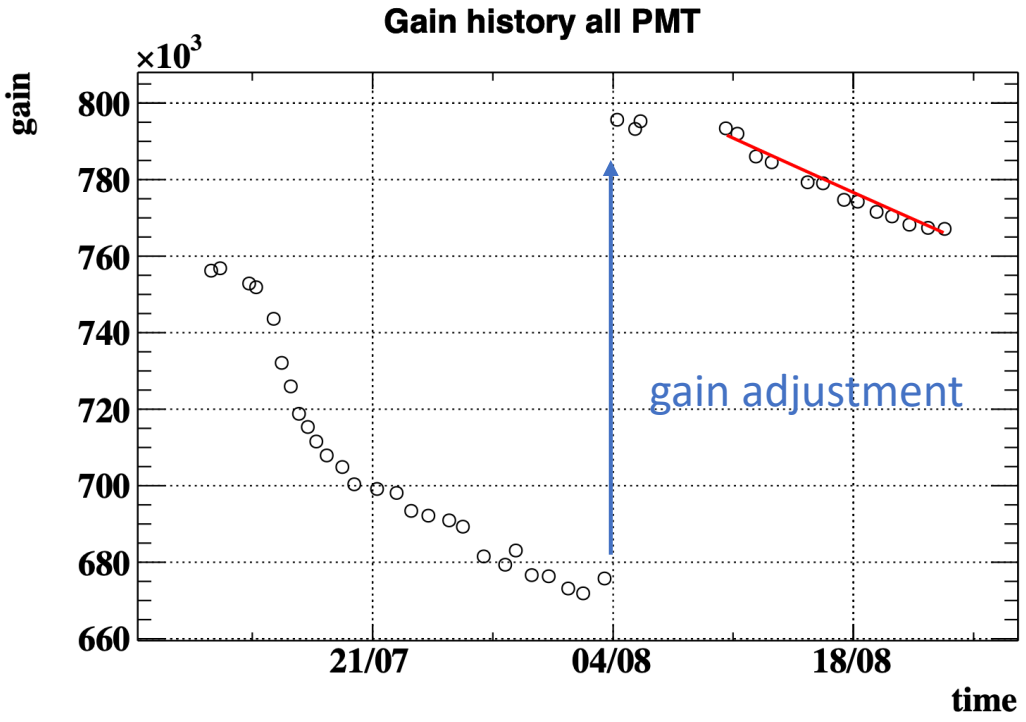
Calibration is necessary to ensure energy resolution.

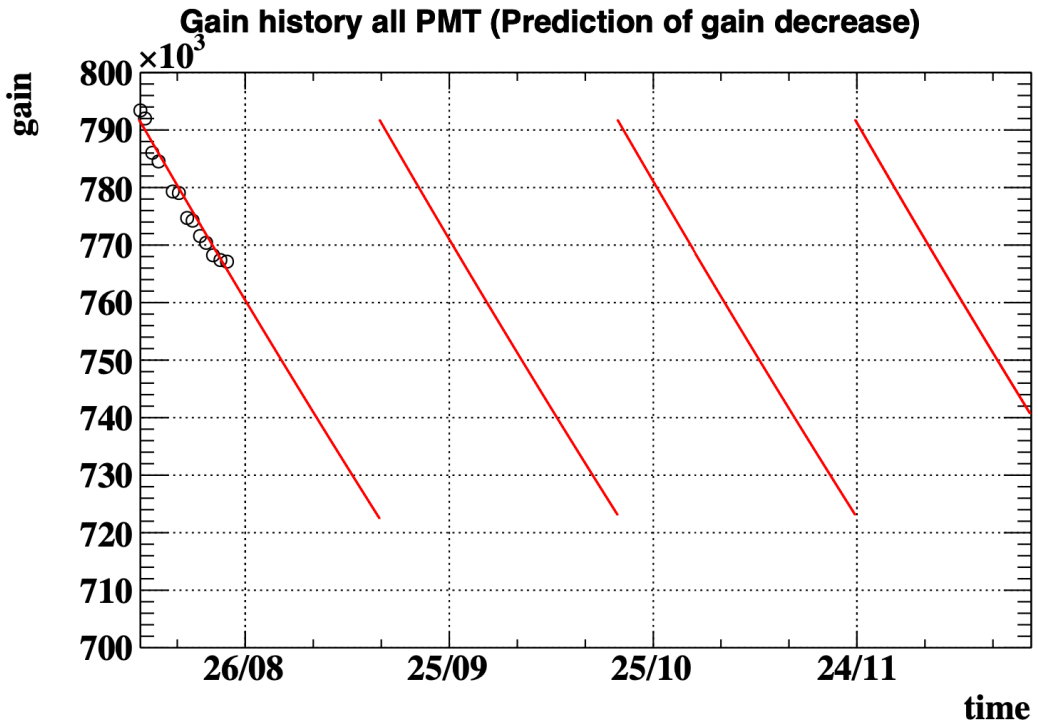
Physics data cannot be taken if detector is not properly calibrated.

Run type	Frequency	Purpose
Pedestal	Once a day	Noise check. Update templates if necessary.
Strong LED	Once a day	PMT gain calibration
Beam blocker(BB) open/close	Every BB operation	Correction of gain shift during BB opening/closing
Weak LED	3 times a week	MPPC gain calibration
Alpha	Once a day	MPPC PDE calibration
Cosmic-ray	3 times a week	Energy scale check
17.6 MeV gamma-ray from $^{7}\mathrm{Li}(p,\gamma)\,^{8}\mathrm{Be}$	3 times a week	Energy scale calibration
9 MeV gamma-ray from $^{58}\mathrm{Ni}(\mathrm{n},\gamma)^{59}\mathrm{Ni}$	3 times a week	Energy scale calibration

PMT Gain Monitoring

Gain decreases during beamtime.
The trigger threshold and PMT HV are adjusted.
Detector can be operated between 0.7 M and 0.8 M if gain is adjusted at intervals of one month or one and a half months.





PMT Gain Adjustment

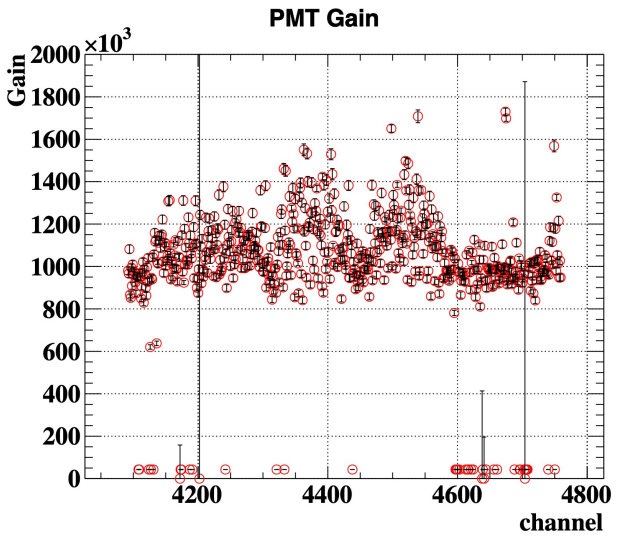
PMT gain was adjusted to 0.8M at the begging of this year's DAQ.

The spread of the gain distribution is 4%.

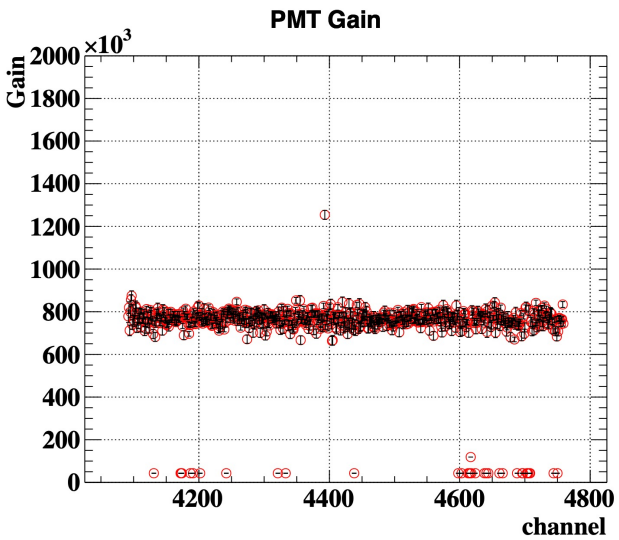
Purpose of gain adjustment

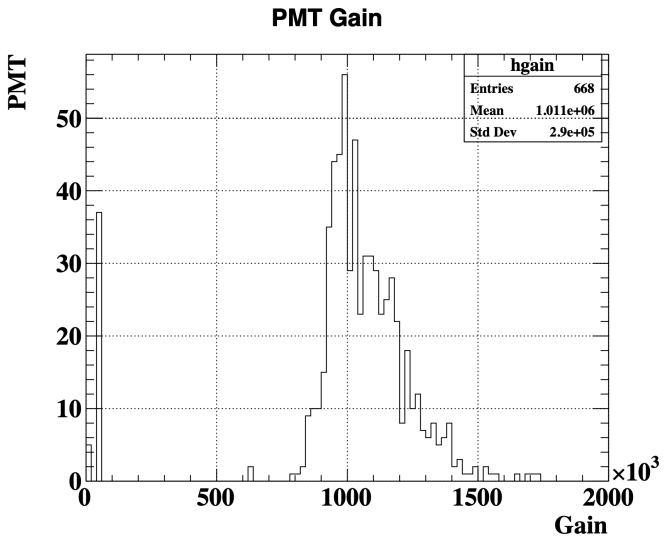
- Uniformity of PMT performance such as timing response
- Keep pulse height within the dynamic range of the readout electronics

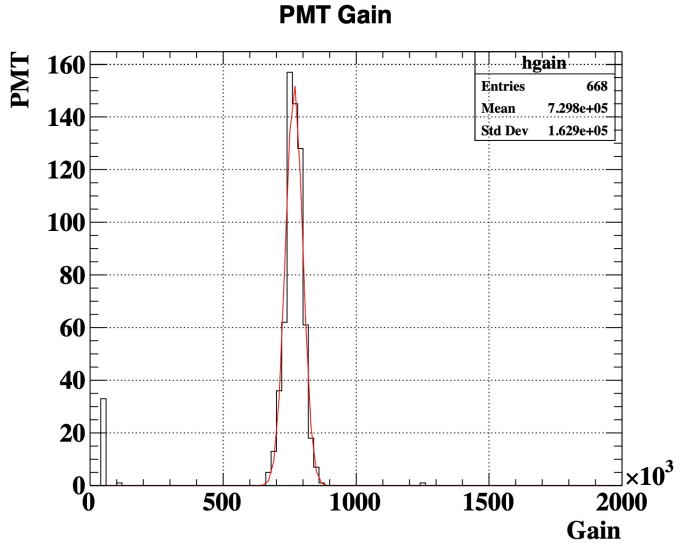
Before adjustment



After adjustment



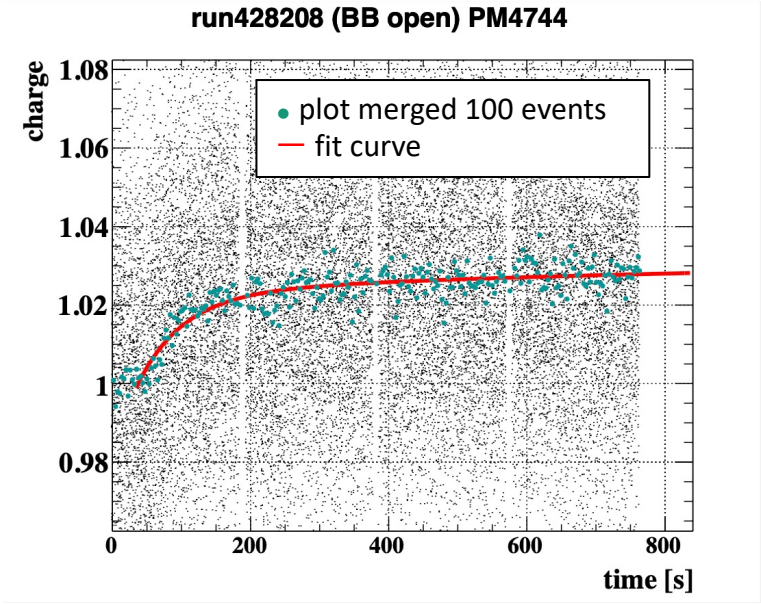




Gain Shift

Calibration data is taken at least once a day with μ^+ beam shut off.
Gain of PMT fluctuates over a short period of time as a beam blocker (BB) opens or closes.
Energy scale is modified due to gain shift.
It is necessary to compensate gain shift to use the data just after BB is opened.

LED is installed in the detector, and the LED events are used to measure gain shift.



Start DAQ → 1000 events acquisition → BB open/close → 23000 events acquisition

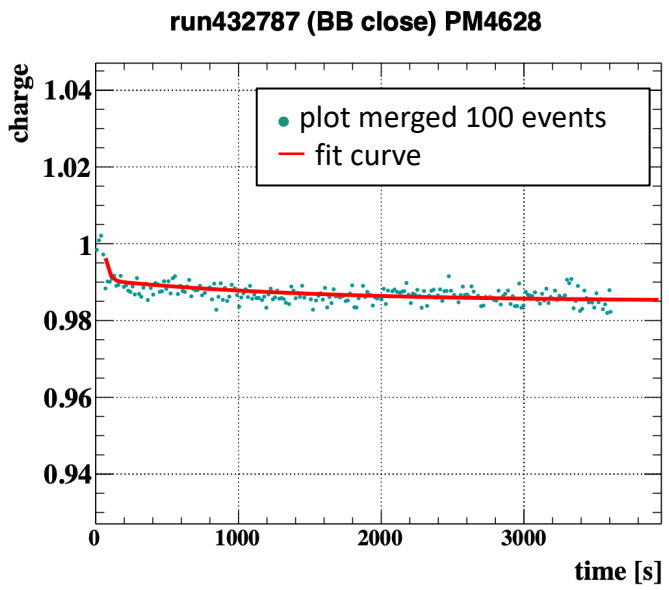
the average of charge of the first 1000 events is set to 1

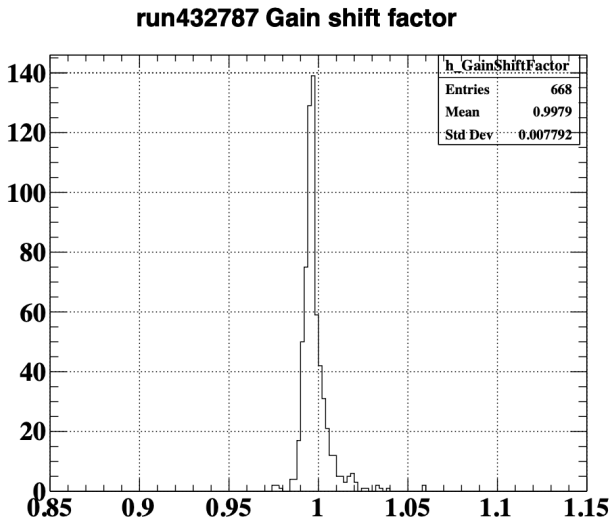
Gain Shift

Fitting function

$$f(x) = 1 + A\left(1 - \exp\left(-\frac{t - t_{BB}}{\tau_1}\right)\right) + B\left(1 - \exp\left(-\frac{t - t_{BB}}{\tau_2}\right)\right) + C\left(1 - \exp\left(-\frac{t - t_{BB}}{\tau_3}\right)\right)$$

Gain shift factor (BB open) = $1 + A + B + C$
Gain shift factor (BB close) = 1 / Gain shift factor (BB open)





Most PMT gains don't shift, but about 100 PMTs shifts more than 1%.

DAQ of 800 seconds is not sufficient to fit with 3 exp function.
Long gain shift run is used for the correction.

PDE Decrease

- It was found in pre-engineering run that PDE decreases during beamtime due to radiation damage.

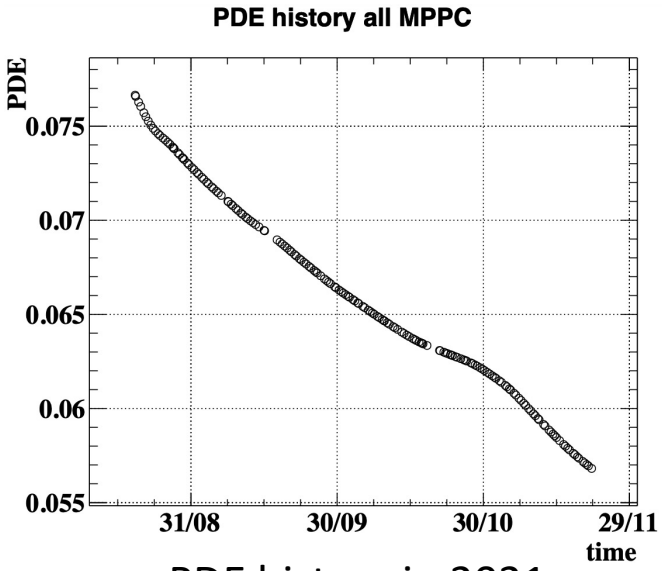
- PDE decreased from 7.7% to 5.6% during 2021 beamtime.

- PDE of at least a few percent is requires for DAQ.

  →The beam rate and beam time are limited by PDE.

- MPPCs were annealed after last year's beamtime.

  PDE recovered to 11.5%, which is sufficient to start 2022 physics run.



PDE history in 2021

It is important to monitor and predict PDE trend.

PDE in 2022 Physics Run

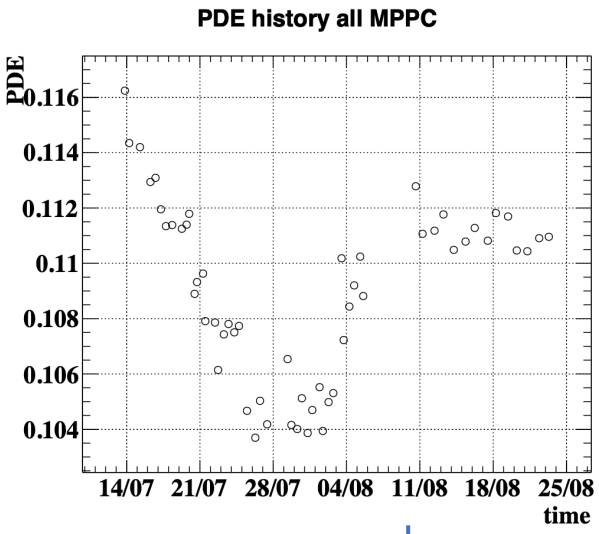
Apparent PDE decrease seems to be suppressed due to purification of xenon.

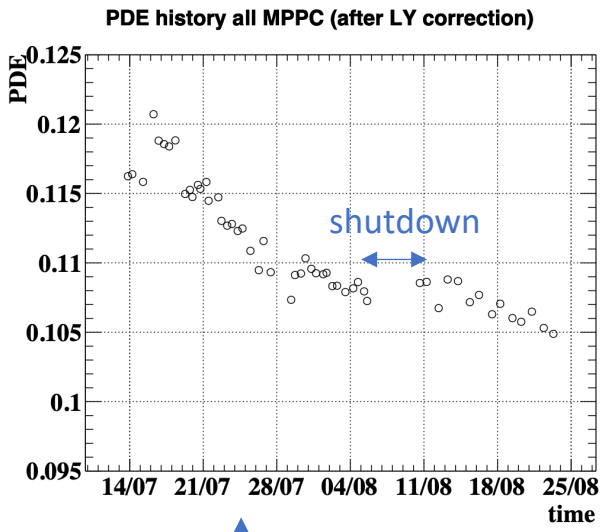
PDE corrected by LY decreases over beamtime.

PDE at the end of the beamtime is estimated to be ~7.5% using the same beam rate.

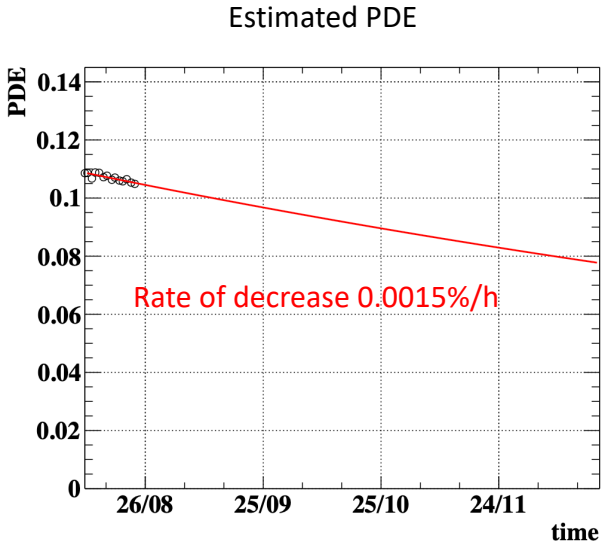
DAQ can be continued until the end of beamtime!

Remaining beamtime ~2200 h
Beam rate 3×10^{7}





PDE is corrected by LY



Level of LXe

LXe may not have reached the top of the detector in the last year's run.

LXe level in last year : 83 cm

Low LXe level may cause non-uniformity in light collection efficiency.

Xenon was added to raise the liquid level, and LXe level rose.

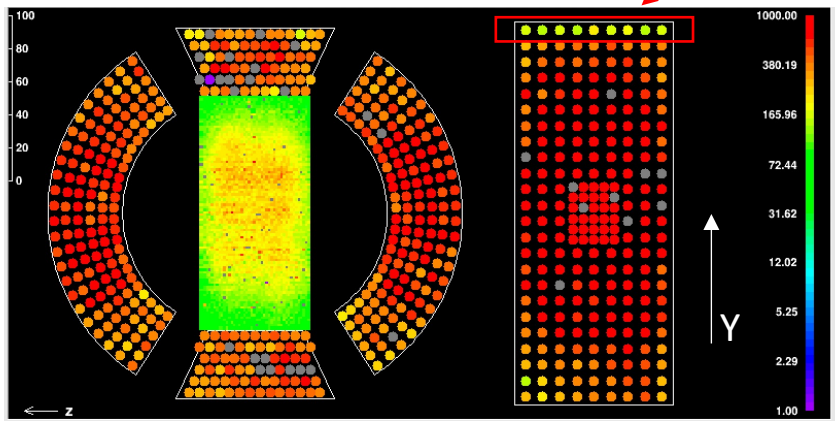
Top part of the detector (a PMT row) is not filled with LXe.

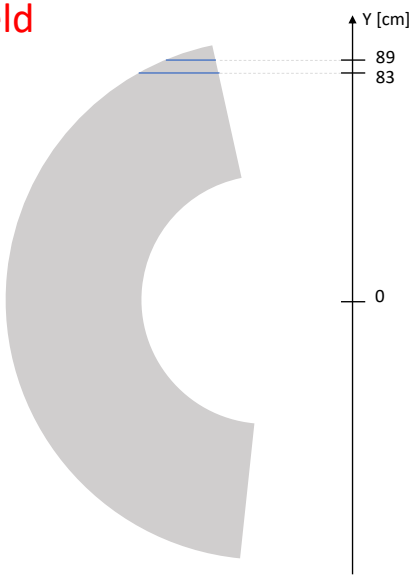
LXe level in this year : 89 cm

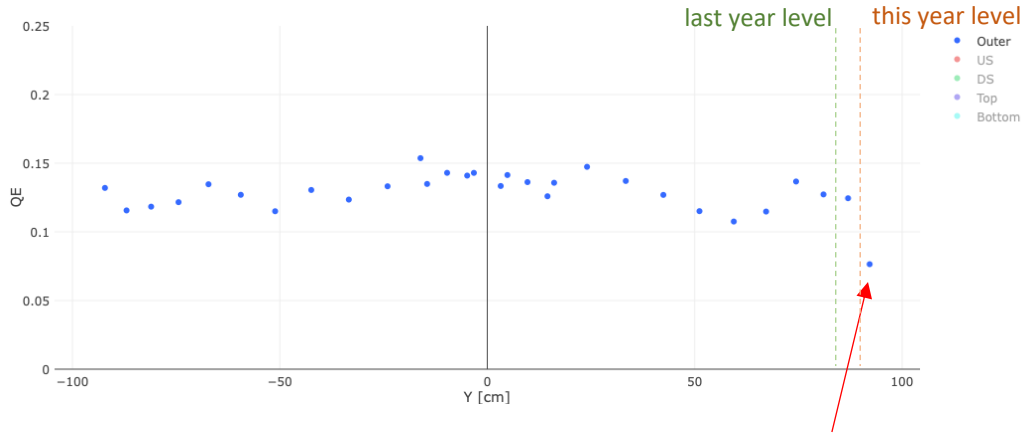
→ Symmetry of energy response is expected to improve.

Response of the senser when LEDs installed inside the detector is turned on.

Low light yield

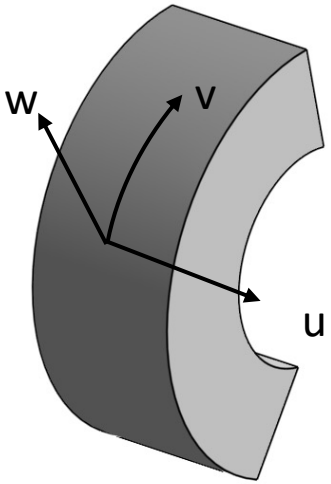






small apparent QE

Energy Uniformity and Stability

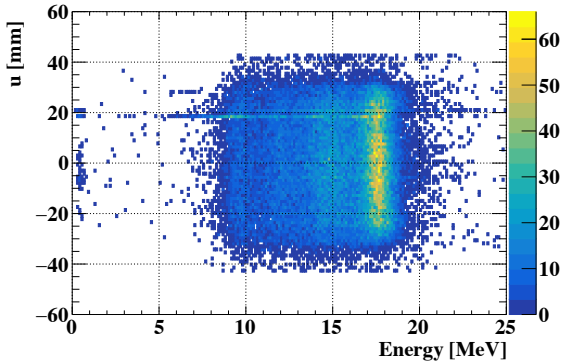


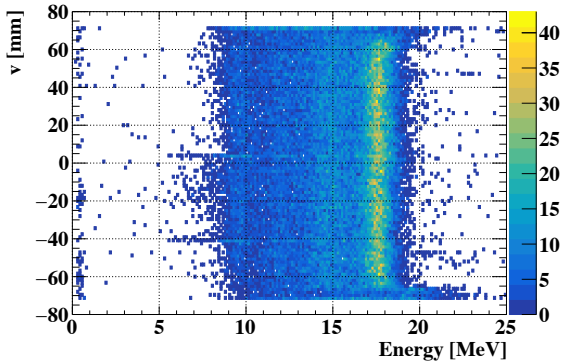
Energy scale is monitored by 17.6 MeV gamma-ray from $^{7}_{3}\mathrm{Li}(p,\gamma)^{8}_{4}\mathrm{Be}$.

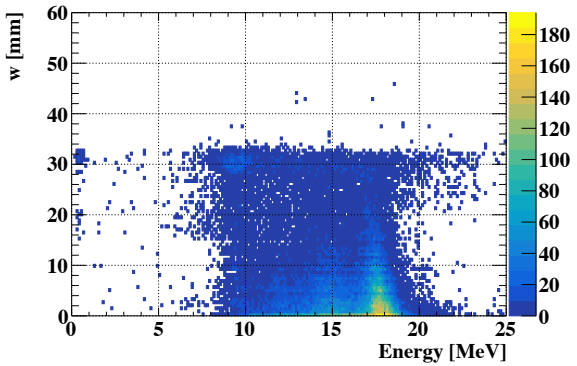
Energy uniformity is confirmed.

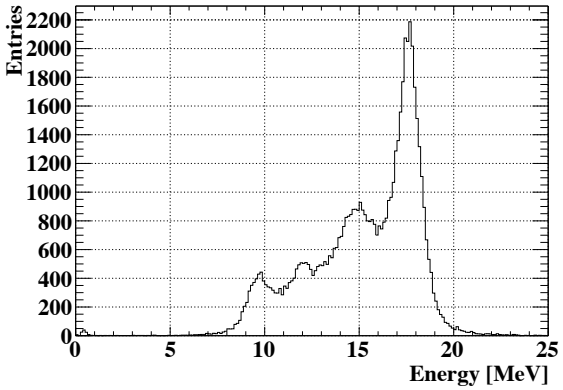
Online energy resolution is 4%.

Energy distribution is uniform and stable, and physics data can be taken.









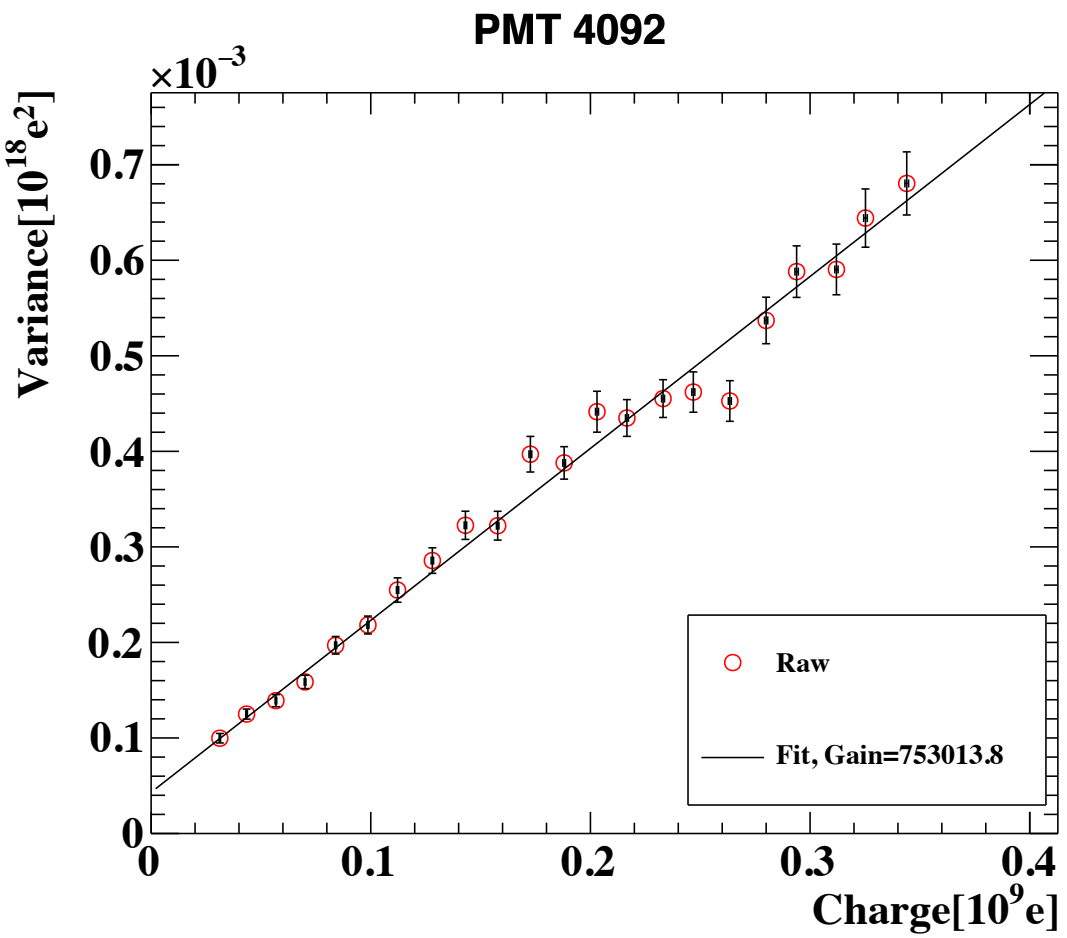
Summary

- Stable energy reconstruction needs daily calibration because the parameters of each photo sensor fluctuate over beamtime.
- Gain is adjusted, and the detector response is uniform.
- Gain shift data was taken to used the data immediately after opening BB.
- Sufficient PDE was ensured by annealing in the long shutdown period.
  Measured QE and PDE suggests that xenon is being purified.
  DAQ can be continued until the end of the beamtime in the current PDE decrease speed.
- Xenon was added to raise the liquid level, but the uppermost PMTs are above xenon level.
  However, there is no problem if uniformity is corrected in offline analysis.
- Energy uniformity is confirmed, and physics data can be obtained.

Physics data is taken keeping data quality through daily calibration.

Backup

Gain calculation (Strong LED)



$$\overline{N_{pe}} = \overline{N_{LS}} \times \Omega \times PDE$$

Integrate in wider range than wave form

$$q = G \cdot e \cdot N_{pe}$$

$$\bar{q} = G \cdot e \cdot \overline{N_{pe}}$$

$$\sigma_q^2 = (G^2 + \sigma_G^2) \cdot e^2 \cdot \left(\sigma_{pe}^2 + \sigma_{LED}^2\right) + \sigma_0^2$$

When σ_G and σ_{LED}^2 is small,

$$\sigma_q^2 = Ge\bar{q} + \sigma_0^2$$

PDE, QE Calibration (Alpha)

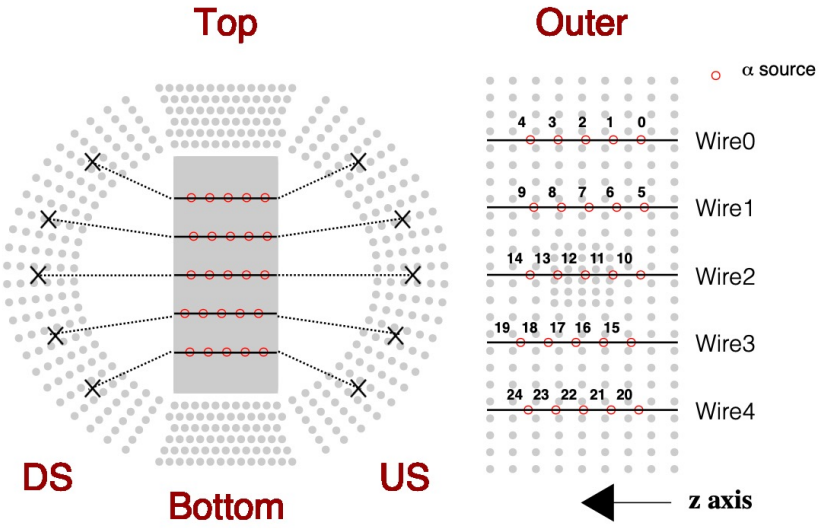
- PDE and QE are measured with alpha-ray from $^{241}\mathrm{Am}$.

$$PDE_{data} = PDE_{MC} \times \frac{\lambda_{data}}{\lambda_{MC}} \times LY$$

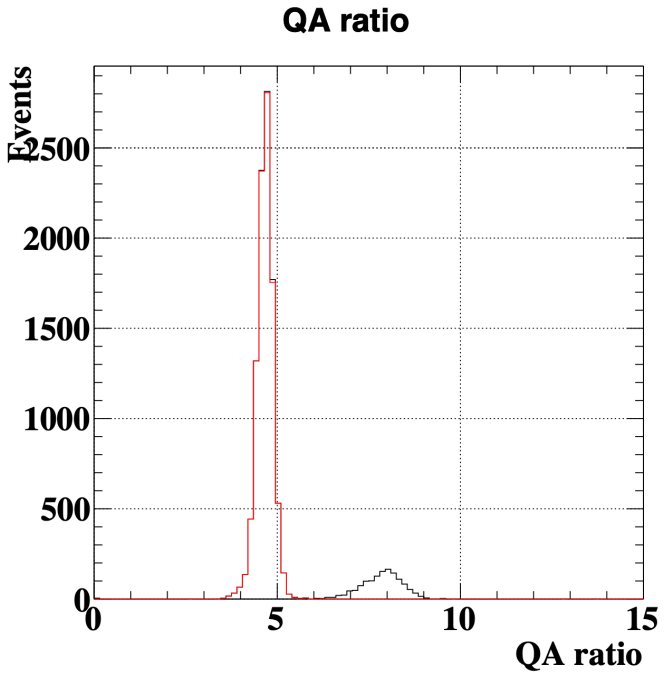
λ_{data} : the number of detected photoelectrons

λ_{MC} : the number of detected photoelectrons in MC simulation

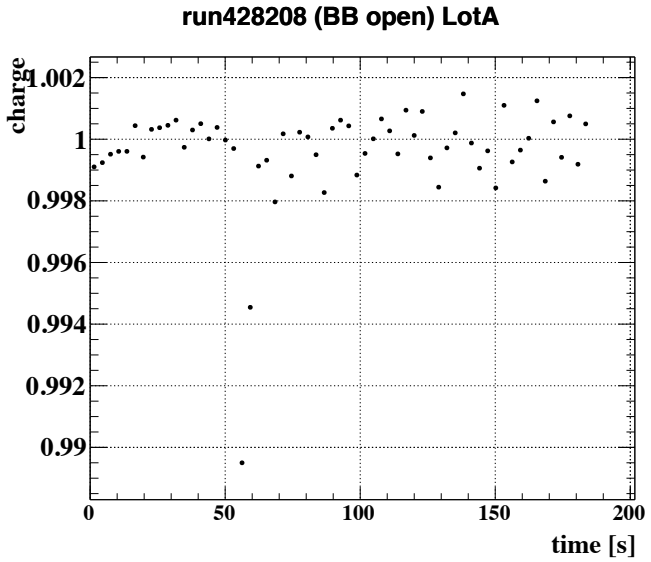
LY : Light yield of LXe

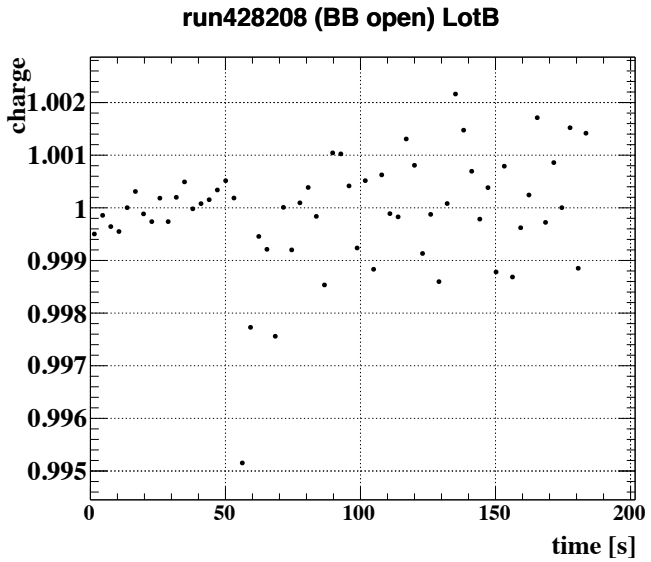


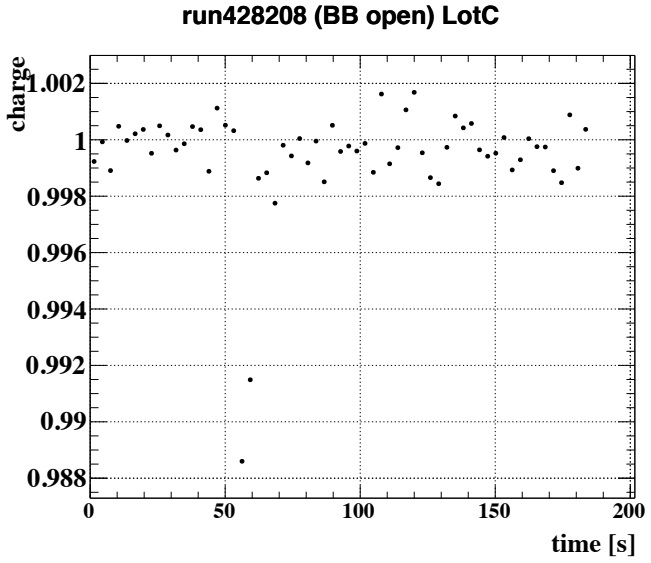
- Separate the event of alpha-ray from one of cosmic ray by QA ratio.

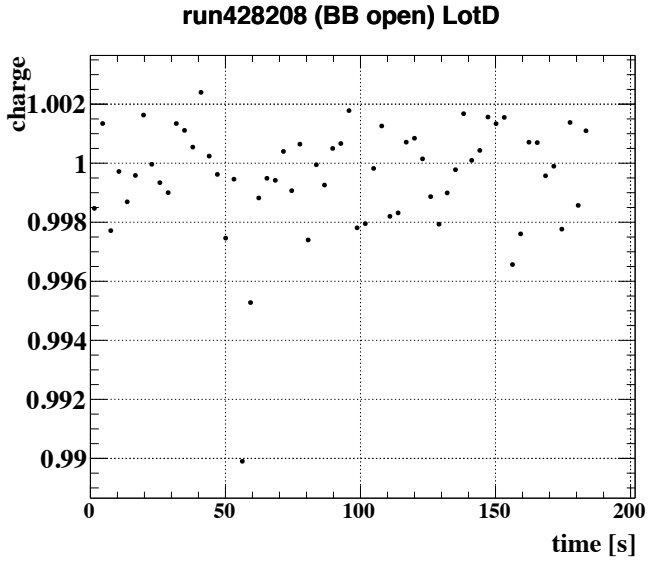


Gain shift of MPPC









The average of the charges before opening BB is 1.

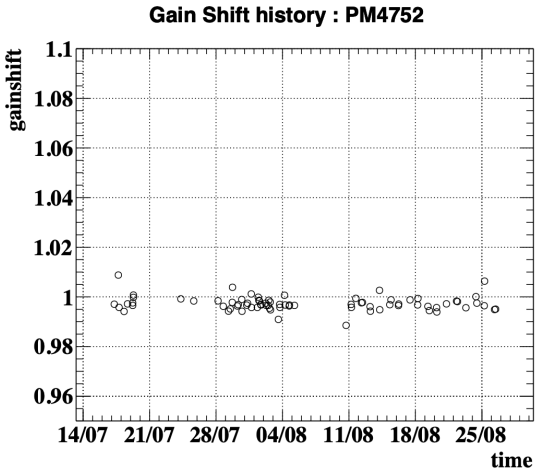
The average of the data for each lot was plotted.

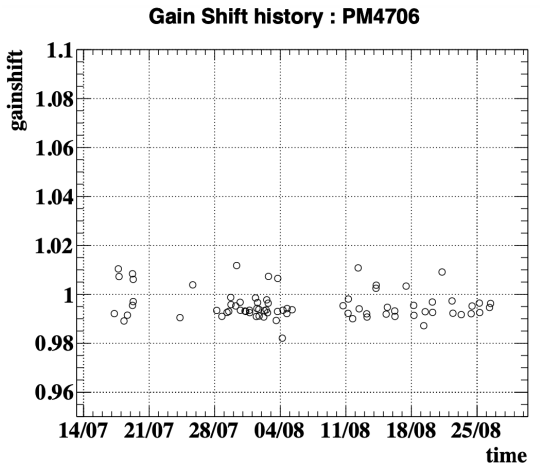
The 100 plots were merged to make one plot.

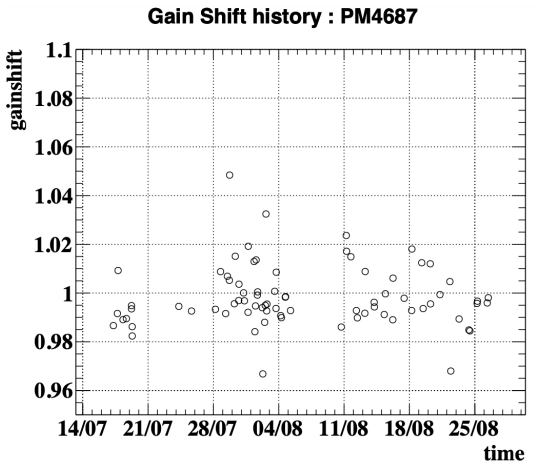
Gain decreases sharply by about 1% immediately after opening BB.

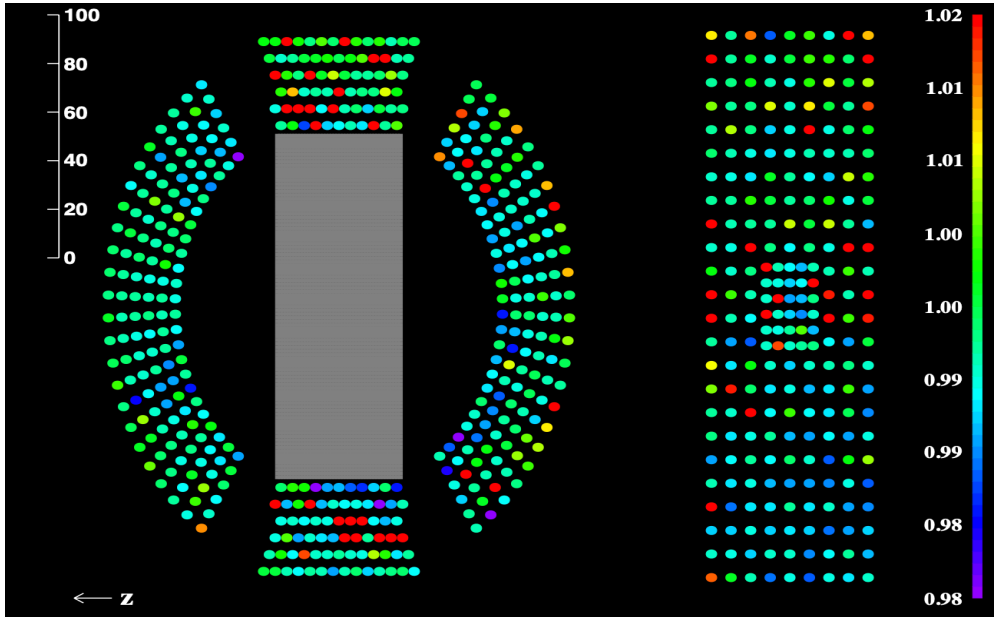
Gain recovers in 20~30 seconds, but charge fluctuates greatly after BB operation.

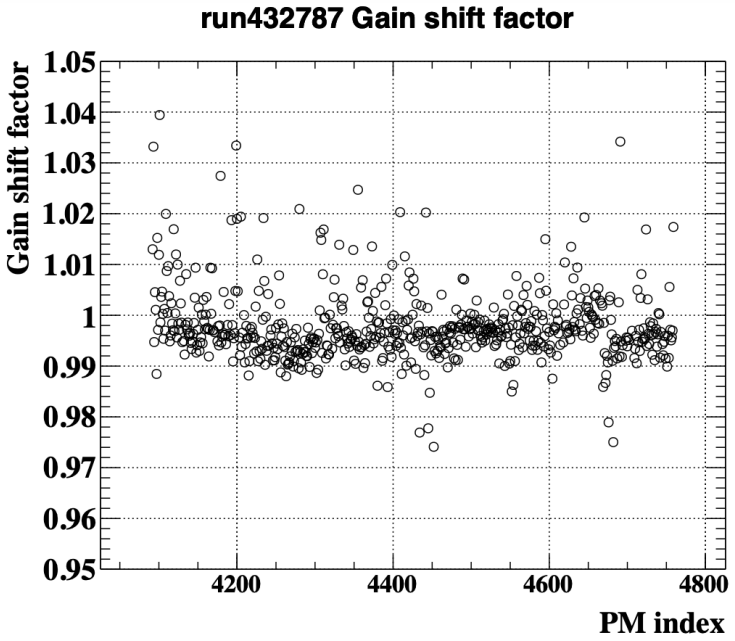
Gain shift


Gain Shift history : PM4752
gainshift
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
14/07 21/07 28/07 04/08 11/08 18/08 25/08
time


Gain Shift history : PM4706
gainshift
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
14/07 21/07 28/07 04/08 11/08 18/08 25/08
time

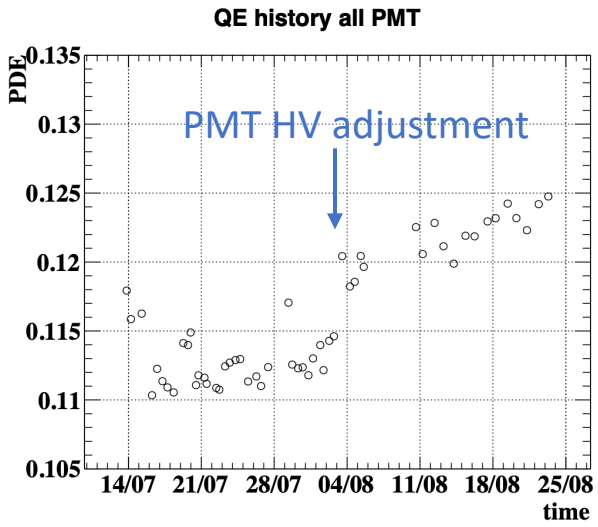

Gain Shift history : PM4687
gainshift
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
14/07 21/07 28/07 04/08 11/08 18/08 25/08
time

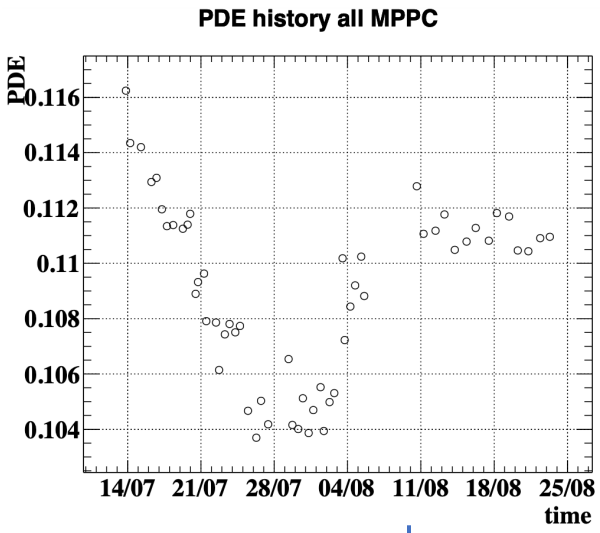

100
80
60
40
20
0
z
1.02
1.01
1.01
1.00
1.00
0.99
0.99
0.98
0.98

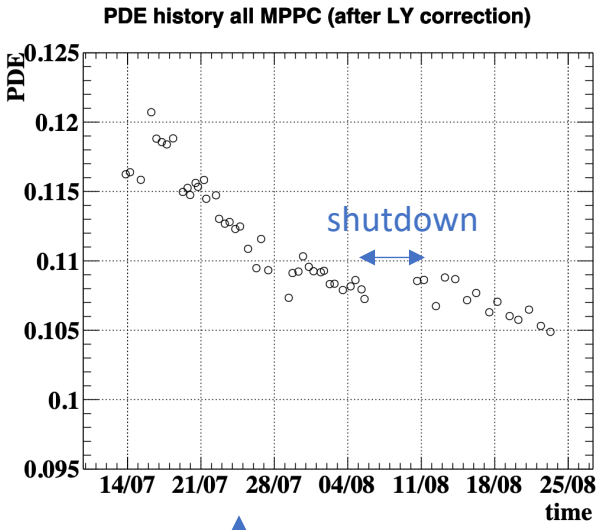

run432787 Gain shift factor
Gain shift factor
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
4200
4400
4600
4800
PM index

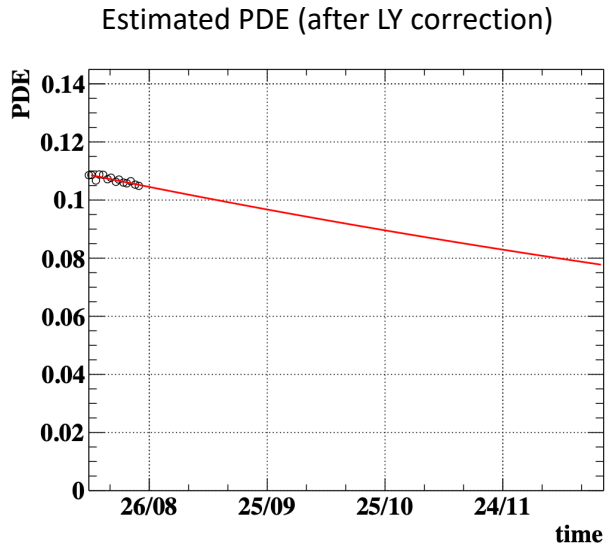
MPPC PDE in 2022 Physics Run

Radiation damage decreases PDE of MPPC.
PDE was recovered by annealing during the long shutdown period.
PDE of at least a few percent is requires for DAQ. →The beam rate is also limited by PDE.
The increase of PMT QE is likely because of the purification of Xe.
Assuming that the actual QE has not changed, and the change of QE is only due to LY, PDE was corrected.
PDE at the end of the beamtime is estimated to be ~7.5% using the same beam rate.
DAQ can be continued until the end of beamtime!



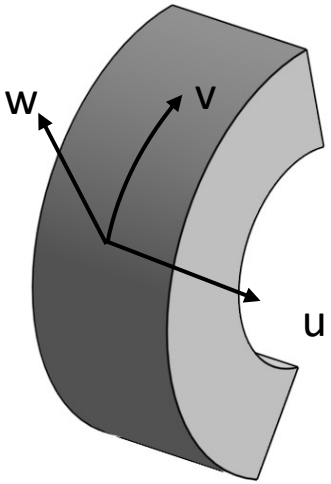




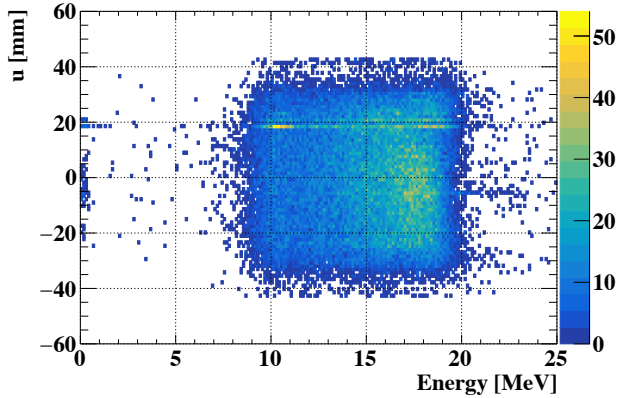


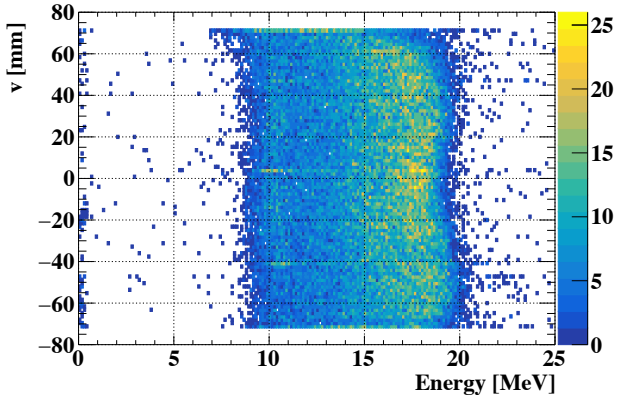
PDE is corrected by LY estimated from QE of PMT

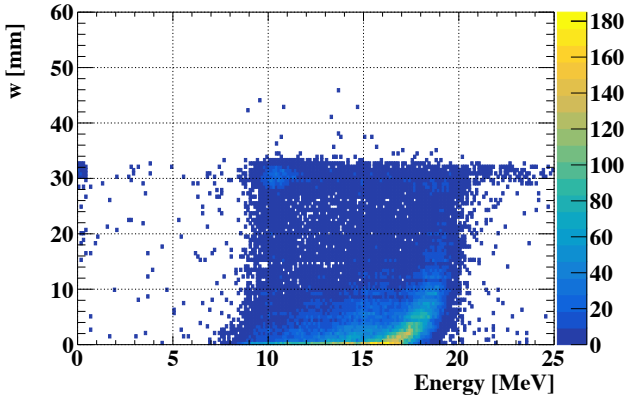
Energy Uniformity and Stability



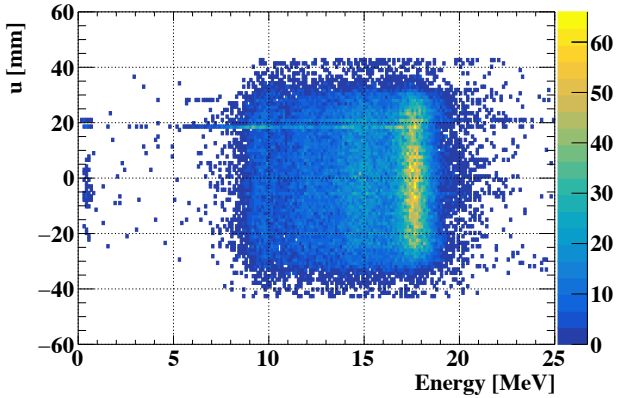
Before weight correction

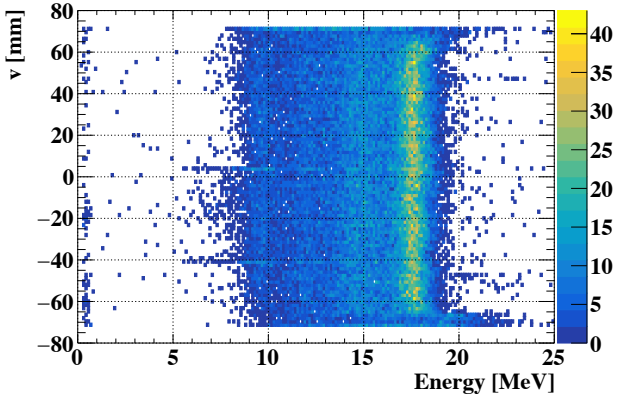


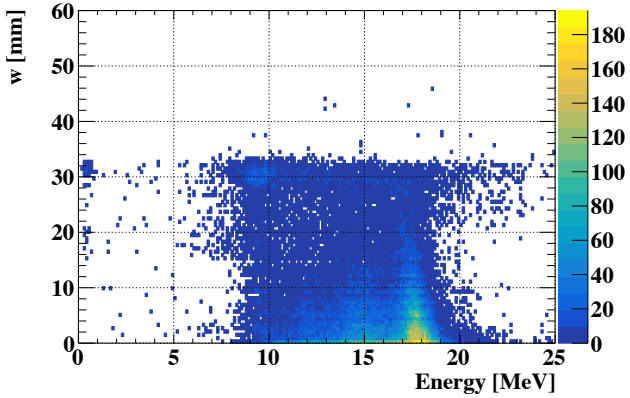




After weight correction







LXe Reconstruction