MEGII実験液体キセノン検出器 2022年データの解析状況

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The University of Tokyo

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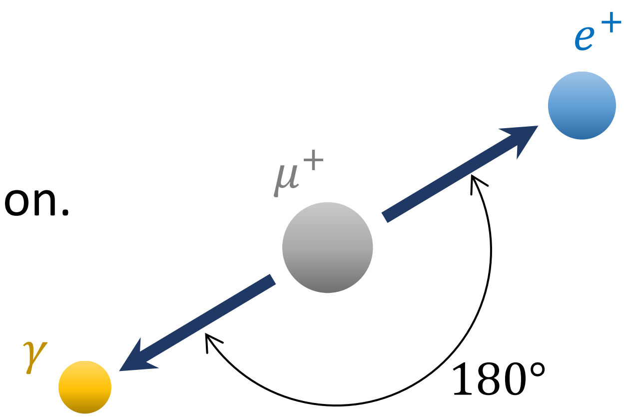
17aRA81-1

$\mu \to e\gamma$ search



- $\mu \to e\gamma$ is a charged lepton flavor violation decay.
- The decay is prohibited based on the Standard Model and ν oscillation.

$$\mathcal{B}(\mu \to e\gamma) : \ 10^{-54}$$

It can be observable in theories beyond SM.

$$\mathcal{B}(\mu \to e\gamma) : 10^{-11} \sim 10^{-14}$$

- Upper limit on the branching ratio was obtained by the MEG experiment.

$$\mathcal{B}(\mu \to e\gamma) < 4.2 \times 10^{-13} \ (90\% \ \mathrm{C.L.})$$

<u>Signal of $\mu \to e\gamma$</u>

e^+ and γ are emitted

- simultaneously
- back-to-back
- at monochromatic energy (52.8 MeV)

MEG II experiment

MEG II experiment searches $\mu \to e\gamma$.

Goal : $\mathcal{B}(\mu \to e\gamma) \sim 6\times10^{-14}$

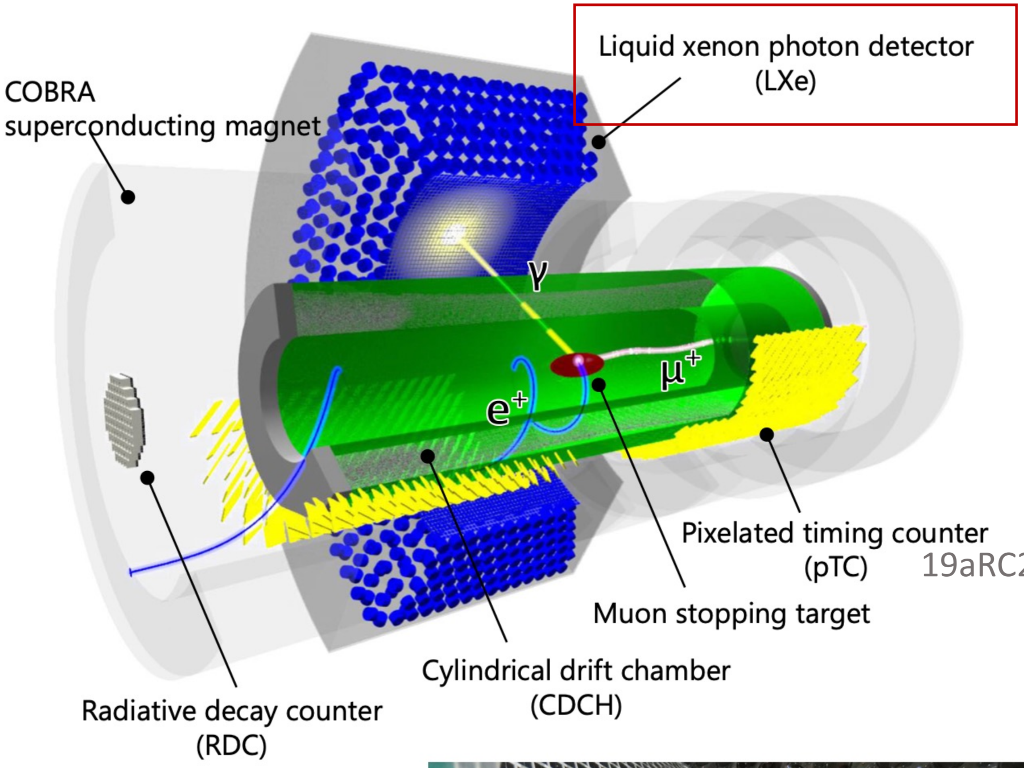
Physics data taking started.

1 month in 2021 engineering run → 18pRA34-7, 8

4 months in 2022 physics run → **(LXe) this talk**

2023 physics run is ongoing → (LXe) 17aRA81-2

(Overview of MEG II experiment → 18aRD11-6)

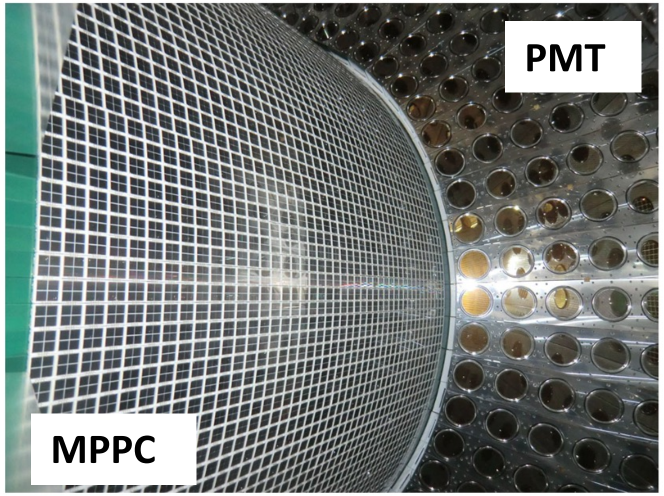


19aRC21-11

Liquid xenon (LXe) gamma-ray detector

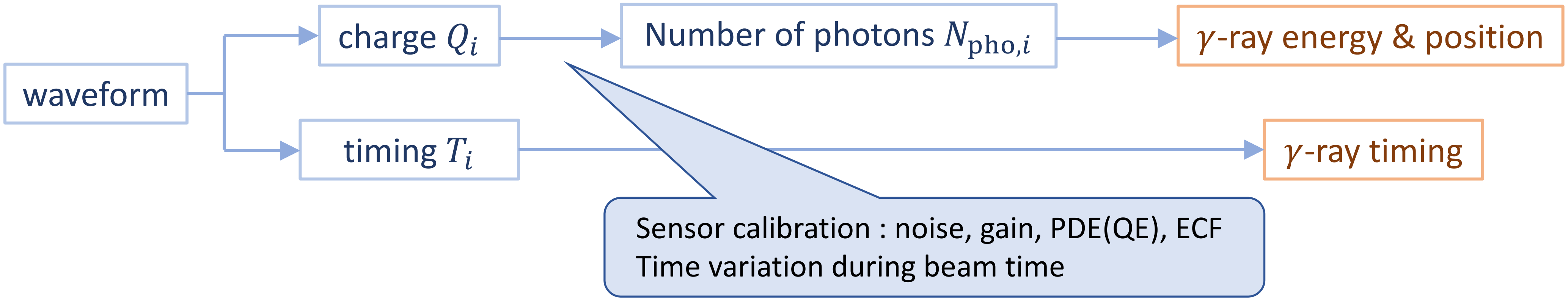
LXe detector measures the position, energy and timing of the gamma-ray.

4092 VUV-sensitive MPPCs (entrance face) + 668 PMTs (other faces)



Overview of LXe detector and 2022 physics run

Gamma-ray reconstruction



2022 physics run

① **Add new LXe**

LXe was not fully filled in 2021.
New LXe was added.
Impurities in new LXe → instability of the sensor calibration parameters

② **PMT HV adjustment**

To deal with PMT gain decrease
Twice during the physics run

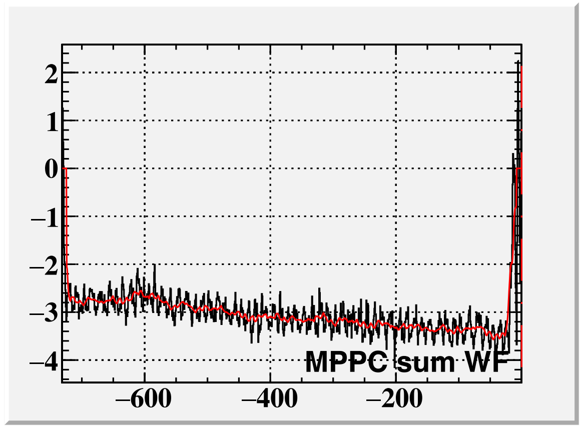
Noise reduction

Wave form of each channel is read out.

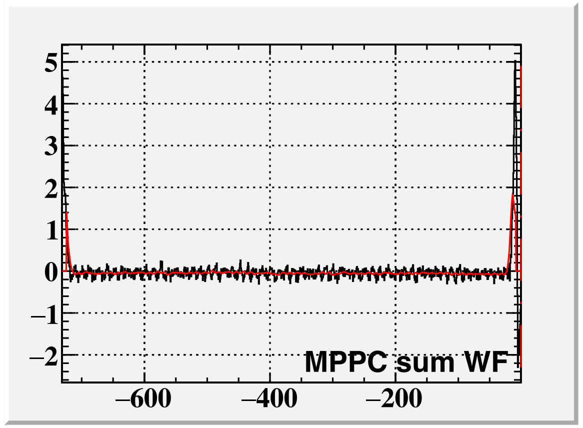
Pedestal run : periodic trigger without beam

→ Extract noise templates.

Subtract templates from the raw waveform.



w/o temperature dependent template

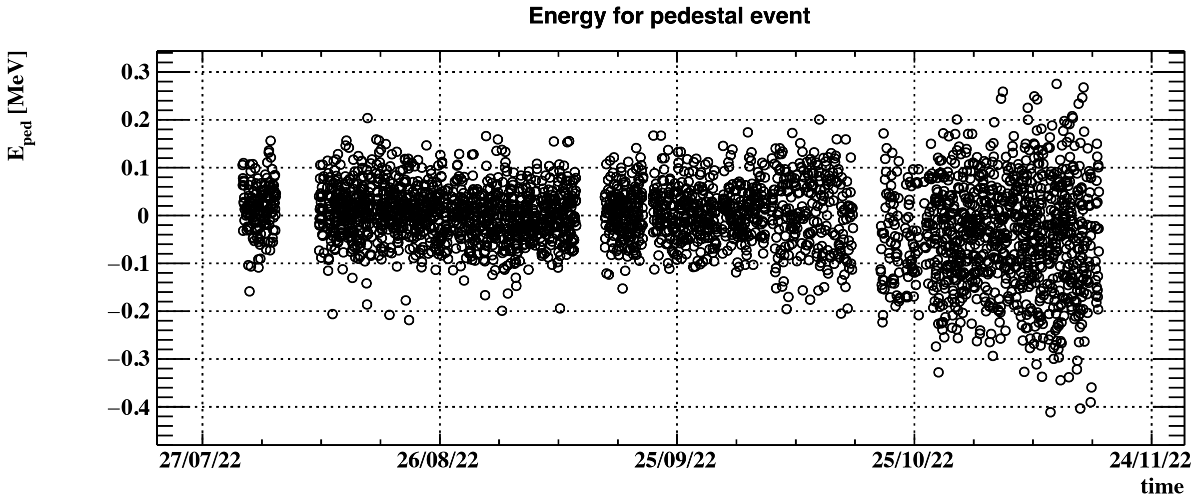


w/ temperature dependent template

Temperature dependent template

Leakage current in the readout electronics → temperature dependent slope in wave form

Time variation was observed in 2022 run and templates were updated every week.



E_{ped}:Reconstructed energy for pedestal events in physics runs

Noise effect : 0.5%

Enough smaller than energy resolution(2.6%).

Worsening noise conditions

possible cause : insufficient cooling

(No worsening trend in 2023)

PMT gain calculation

PMT gain can be calculated from LED intensity scan data.

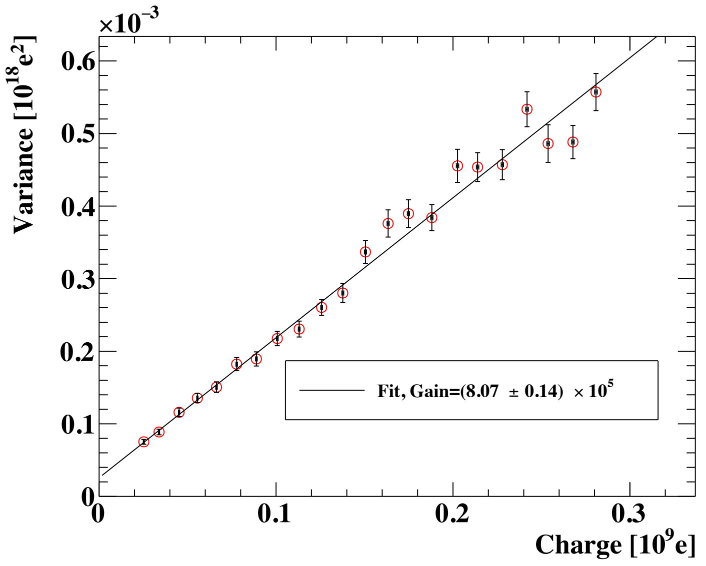
$$\boldsymbol{\sigma_q^2 = G \times e \times \bar{q} + \sigma_0^2}$$

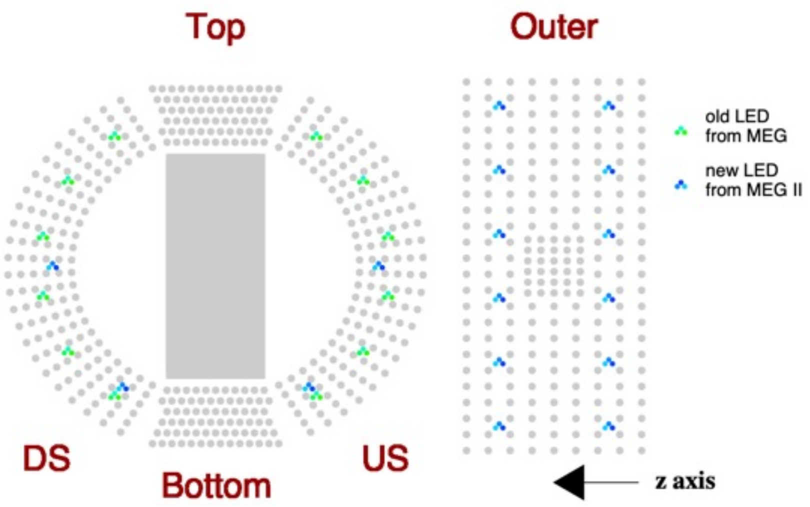
σ_q: spread of integrated charge distribution

G: gain

e: elementary charge

$\bar{q}$: mean of integrated charge





positions of LEDs inside LXe detector

How to create PMT gain history

① Absolute gain history

All plot are from absolute gain calculation

Stability is not good.

No effect from LED instability.

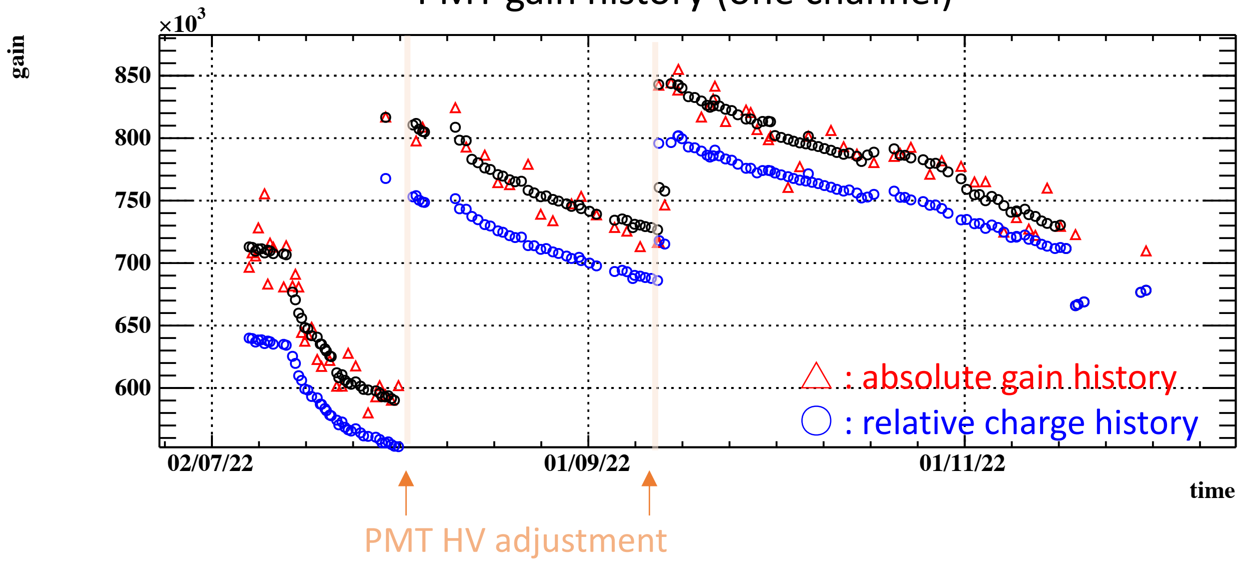
② Relative charge history

Scaled by one absolute gain plot.

Stability is better.

Include other effects. (LED instability)

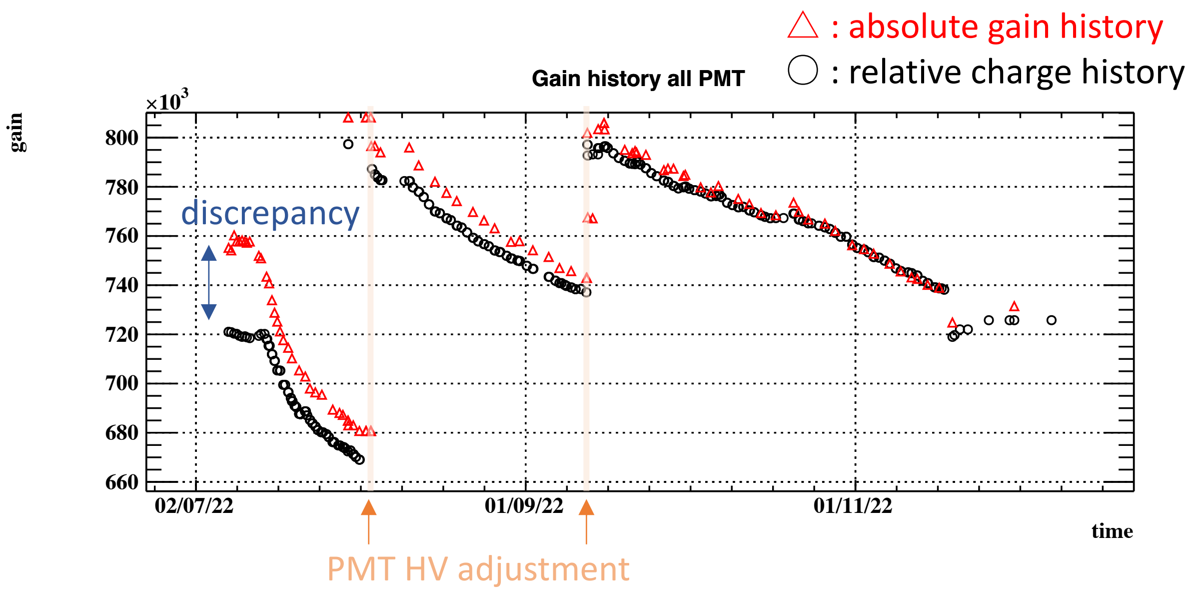
PMT gain history (one channel)

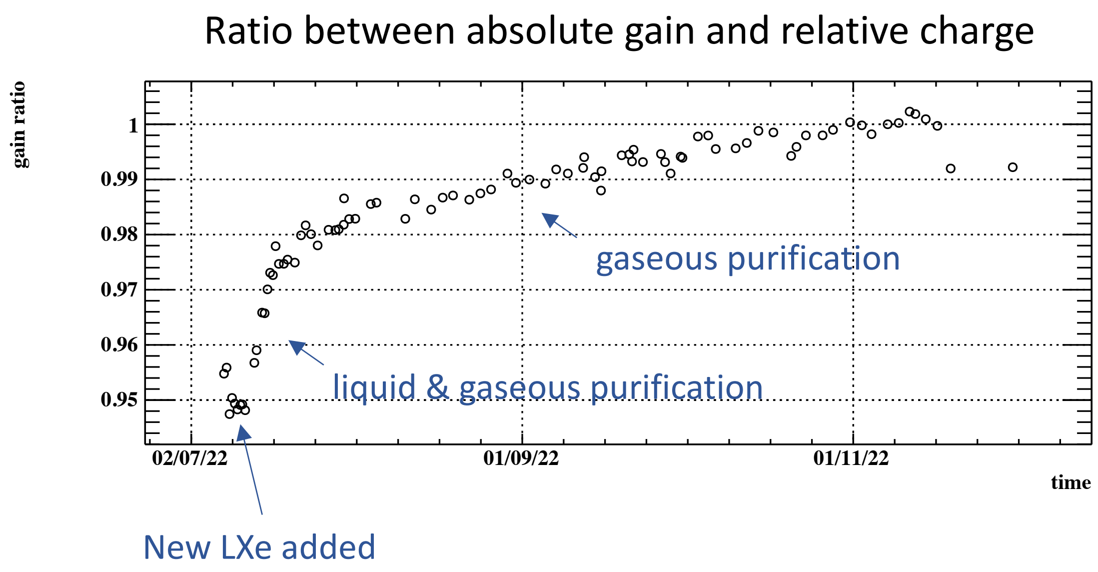


PMT gain decrease during the beam time due to the dynode surface damage
→ PMT HV adjustment

	stability	Effect from LED instability
Absolute gain history	×	○
Relative charge history	○	×

Discrepancy between absolute gain history and relative charge history

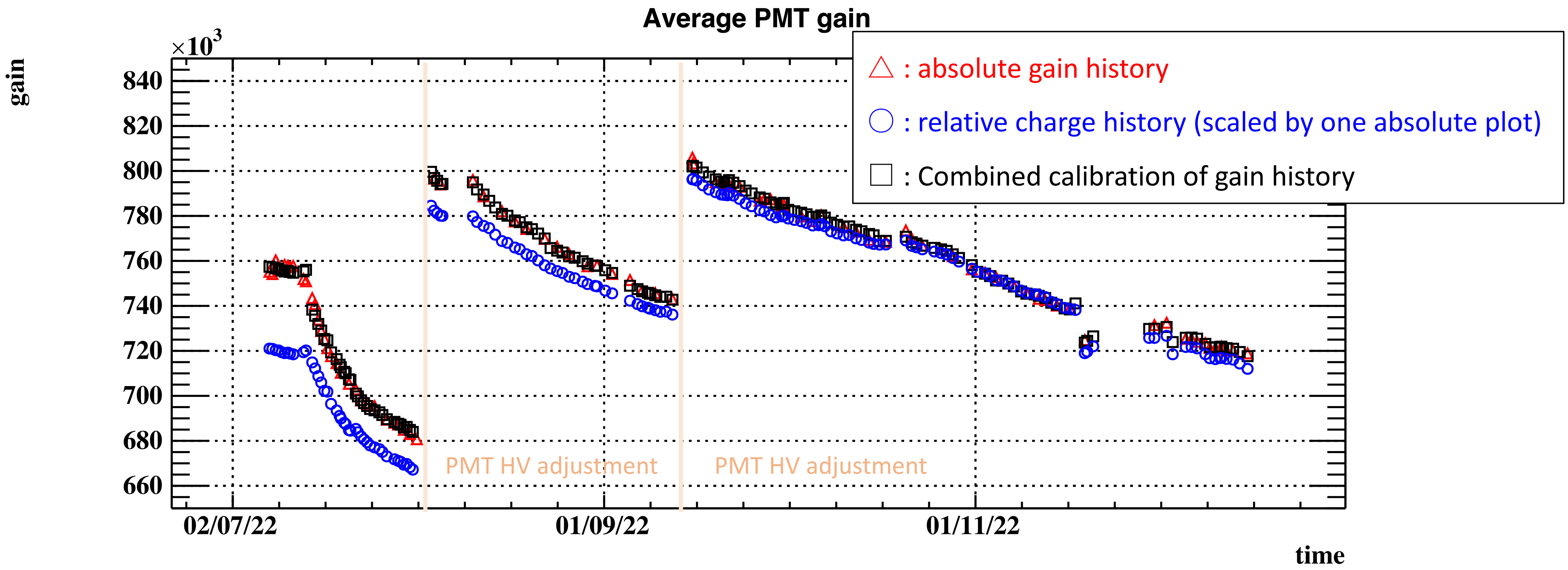




Large discrepancy at the beginning of the beam time.
Newly added xenon was contaminated with impurities.

Update method to combine absolute gain history and relative charge history.

Combined PMT gain history



Combine **absolute gain history** and **relative charge history**

→ **Combined gain history compensating the effect of impurity**

Relative charge history in which the effect of impurity is compensated will be used for the analysis.

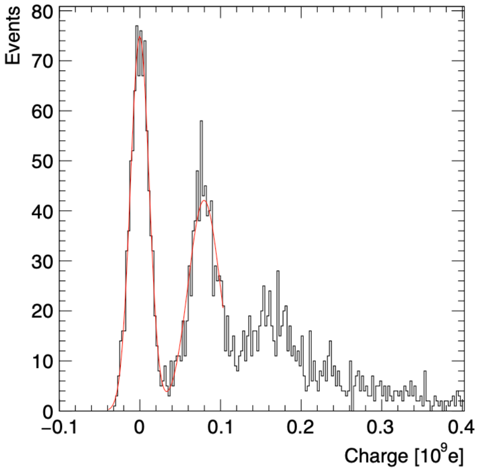
MPPC Gain and ECF calibration

- MPPC gain is calculated from 0 p.e. and 1 p.e. peak using LED data.

  Charge is calculated in multiple integration ranges

$$G(t) = G \times \left(1 - \exp\left(-\frac{t - t_0}{\tau_{\mathrm{fall}}}\right)\right)$$

τ_{fall}: time constant



example of charge distribution (integration range 70 ns)

- Excess Charge Factor (ECF)

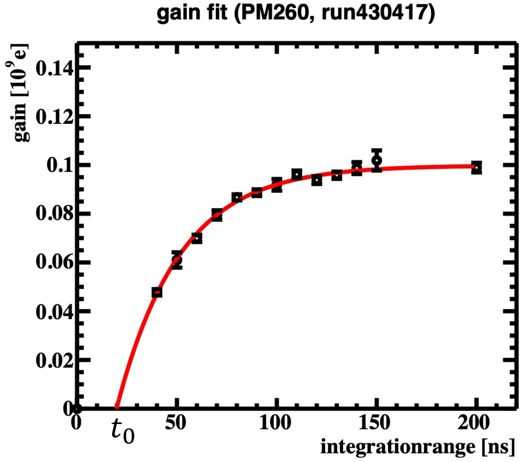
  Charge increase due to cross-talk or after-pulse.

  Calculated assuming the LED light is Poisson light.

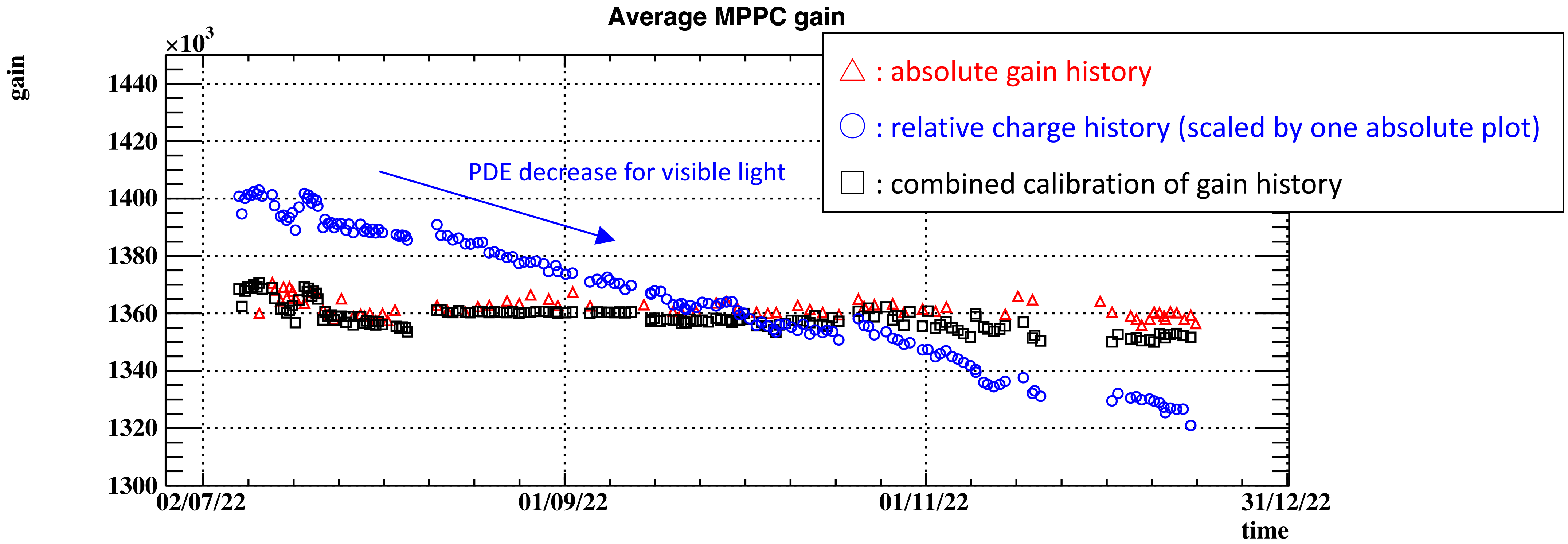
$$\mathrm{ECF} = \frac{\mu}{\lambda}$$

$$\mu = \frac{\bar{Q}_{measured}}{G}$$: Net average number of photoelectrons

$$\lambda = -\log\frac{N_{pedestal}}{N_{total}}$$: mean of Poisson distribution



MPPC gain history



PDE decrease for visible light in relative charge history
PDE will be calibrated after gain calibration.
Combine **absolute gain history** and **relative charge history**.
→ **Combined charge history without the effect of PDE decrease for visible light**

ECF is stable during the physics run (1.5%) and treated as a constant.

Summary

- Noise reduction

  Time variation of temperature dependent template was fond.

  Noise effect is enough smaller than energy resolution after every week template update.

- PMT gain

  Relative charge history includes the effect of impurity in LXe.

  Updated PMT gain history was prepared after compensating the effect from impurity.

- MPPC gain

  Updated MPPC gain history was prepared after compensating PDE decrease for visible light.

  ECF is stable during the physics run.

All calibrations for LXe detector are scheduled to be completed at the end of Nov.

Back up

Time offset difference in different PMT gain data

- PMT gain decreases during the beamtime.

  → Effect on timing resolution and time offset?

- Dedicated run for LXe detector calibration

  Back-to-back γ-rays from $\pi^0 \rightarrow 2\gamma$

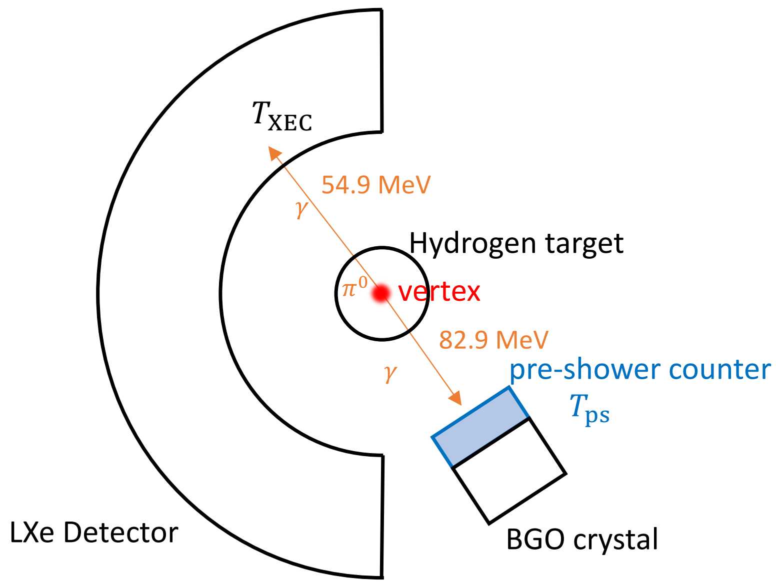
  Timing calibration and timing resolution estimation

  <u>Data was taken in 2 PMT HV configurations</u>

  ① average PMT gain 0.7M (original setting)

  ② average PMT gain 0.6M

  → Time offset difference : 0.1 ns



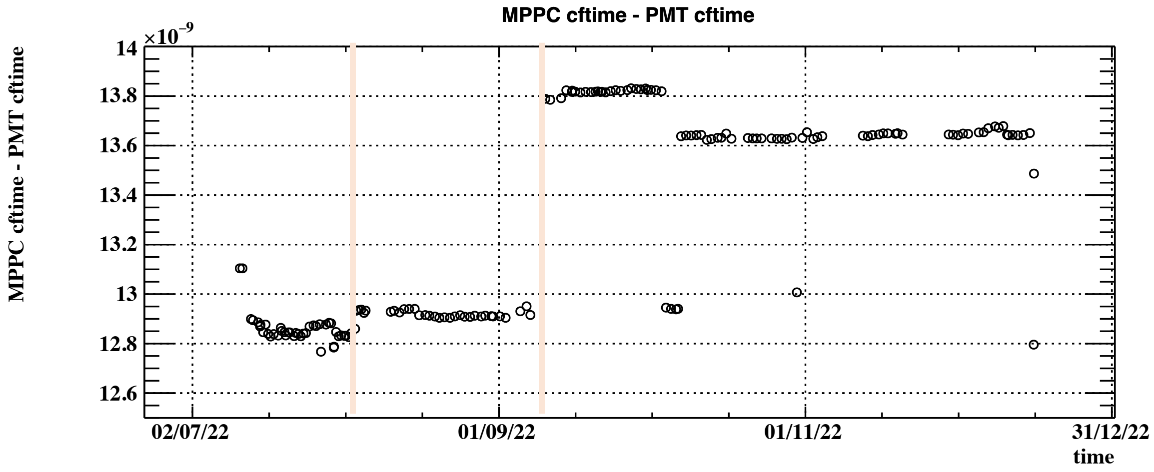
setup of the dedicated run

Stability of the time offset should be checked in long-term 2022 physics run.

Stability of time offset

What is the cause?

PMT gain itself or PMT HV?



PMT HV adjustment

Sensor by sensor time offset

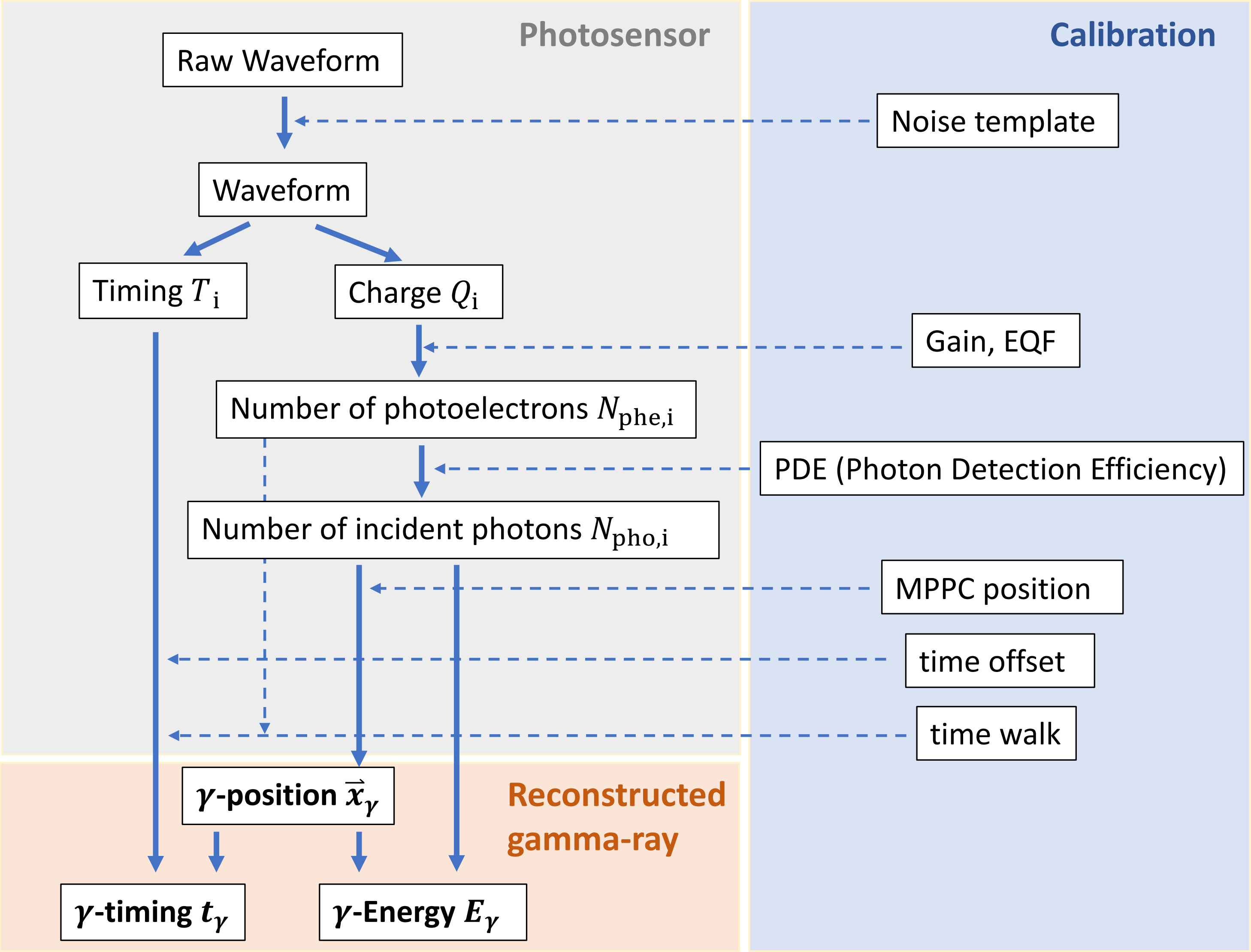
LED data for gain calibration is available.

Time consistency is required for the trigger of LED data.

Gap at PMT HV adjustment (but there is a gap without HV adjustment)

Details are under investigation.

Event reconstruction in LXe detector



Waveform data for each channel is read out.

Gain, EQF, and PDE are calibrated.

$N_{\mathrm{pho,i}}$ is calculated from charge of each sensor using calibration parameters.

Position and energy of gamma-ray is reconstructed using $N_{\mathrm{pho,i}}$.

Excess Charge Factor (EQF)
Effect of cross talk and after pulse

$$N_{\mathrm{pho}} = \frac{Q}{G \times PDE \times EQF}$$

Beam time in 2022

MPPC annealing

RMD run (8.7×10^5 μ^+/s)

Physics run (3×10^7 μ^+/s)

Physics run (4×10^7 μ^+/s)

Physics run (5×10^7 μ^+/s)

pion beam run

Jun.

(13/Jun.) Detector commissioning start

New LXe was added.
(LXe was not fully filled in 2021.)
→ Light yield drop due to impurities in new xenon.

Jul.

(14/Jul.) Physics run start

Aug.

(3/Aug.) PMT HV adjustment

Sep.

(15/Sep.) PMT HV adjustment

To deal with gain decrease
Continuous calibration is important!

Oct.

(27/Oct.) muon beam rate change

Nov.

(7/Nov.) muon beam rate change

(17/Nov.) physics run end

Dec.

(4/Nov.) pion beam run start

(16/Nov.) pion beam run end

pion beam run : dedicated run of LXe detector
(calibration + performance evaluation)

Physics run for 4 months was achieved!

Outline of 2022 LXe detector calibration

1st process → 2nd process → 3rd process

1st process

Sensor calibration
- Noise reduction
- Gain
- PED, QE

Energy calibration
- 17.6 MeV γ-ray from $^{7}\mathrm{Li}(\mathrm{p},\gamma)\,^{8}\mathrm{Be}$
- 9 MeV γ-ray from $^{58}\mathrm{Ni}(\mathrm{n},\gamma)^{59}\mathrm{Ni}$
- Cosmic-ray

2nd process

Sensor calibration
- Noise reduction
- Gain
- PED, QE

Energy calibration
- 17.6 MeV γ-ray from $^{7}\mathrm{Li}(\mathrm{p},\gamma)\,^{8}\mathrm{Be}$
- 9 MeV γ-ray from $^{58}\mathrm{Ni}(\mathrm{n},\gamma)^{59}\mathrm{Ni}$
- Cosmic-ray

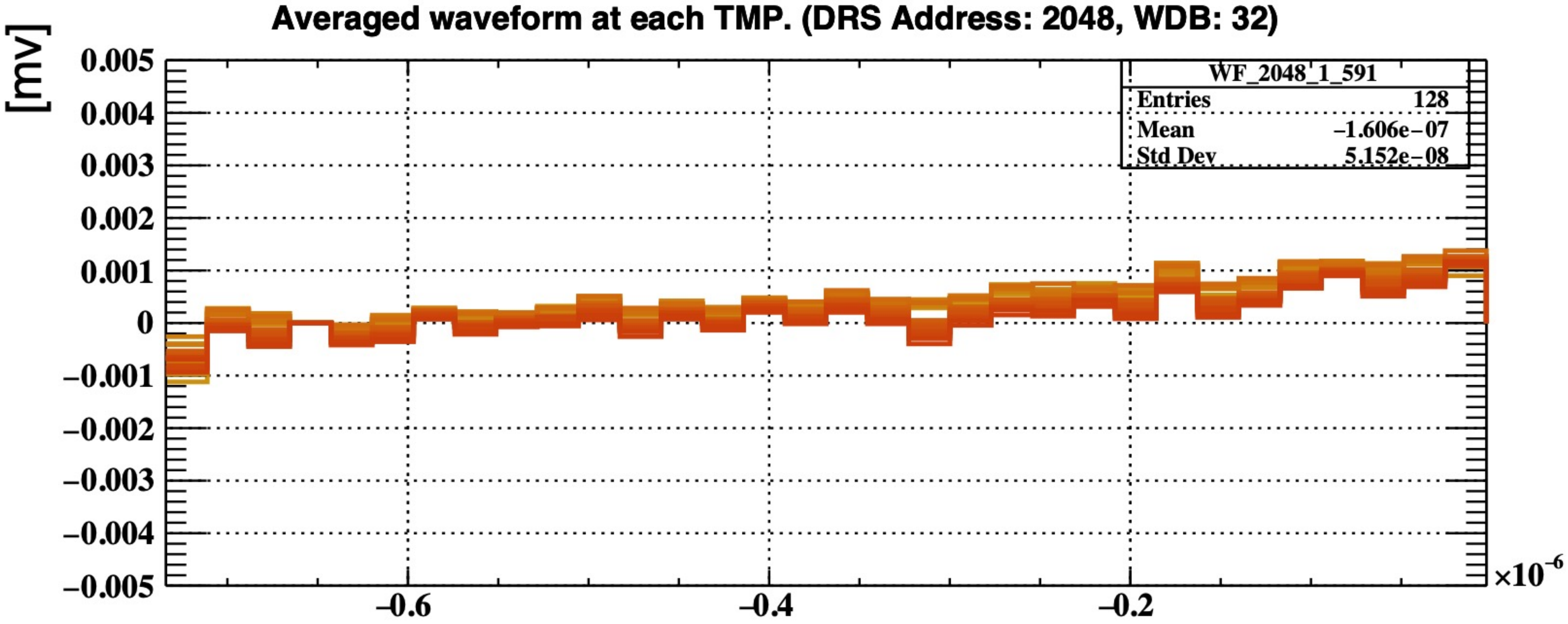
3rd process

More detailed analysis
- Beam-on calibration data
- Calibration with dedicated run

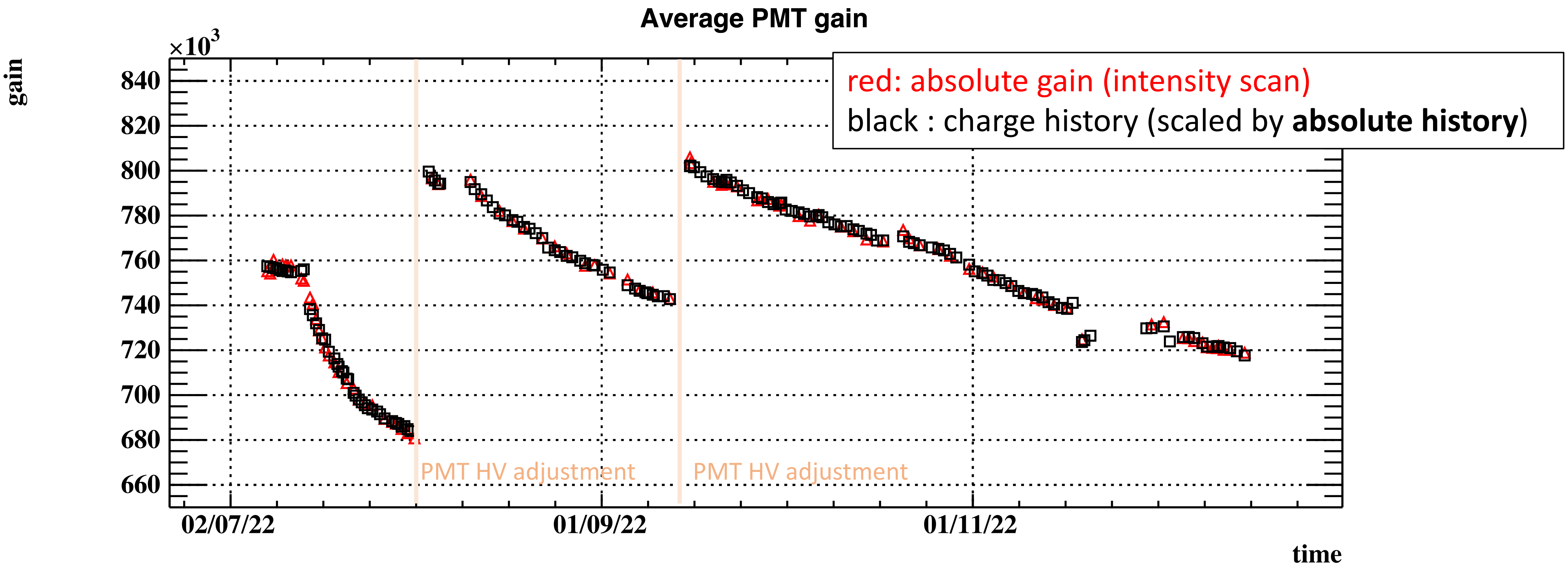
some updates

The 2nd process is ongoing.

Temperature dependent template



PMT gain history



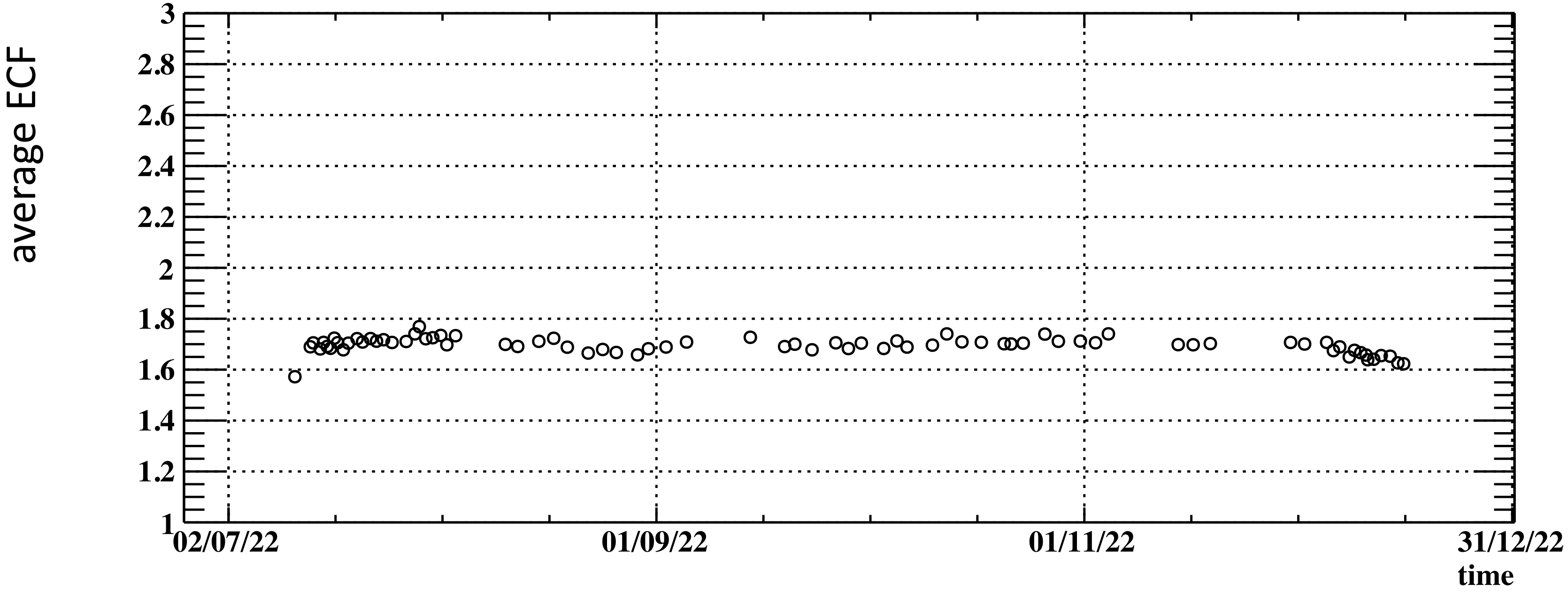
Correlation between LXe purity and the discrepancy between absolute gain history and charge history scaled by one plot.
Charge history is scaled by a linear function to compensate for the effect of LXe purity.
Discrepancy between absolute gain history and scaled charge history is less than 0.5%.

(scaled charge gain) = a * (original charge gain) + b

$$\Delta g = \sum (\text{absolute gain} - \text{scaled charge gain})^2$$

Minimize Δg and estimate a and b sensor by sensor in each period.

ECF history

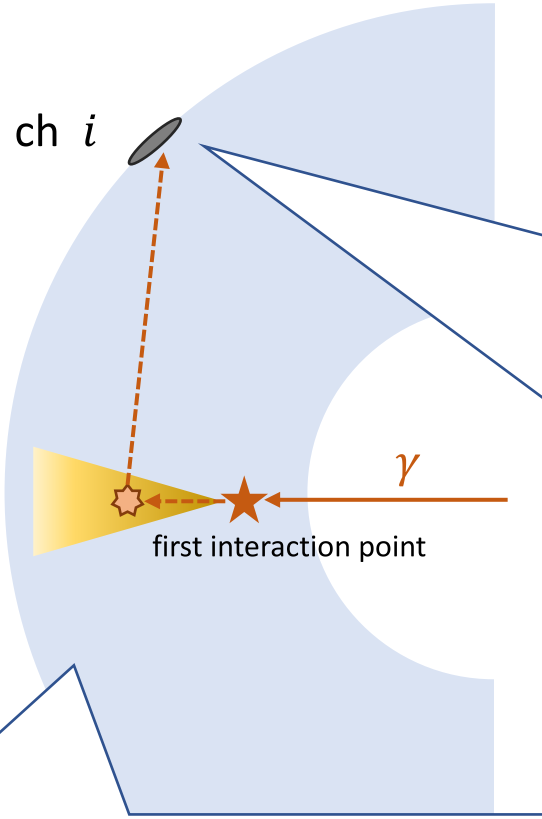


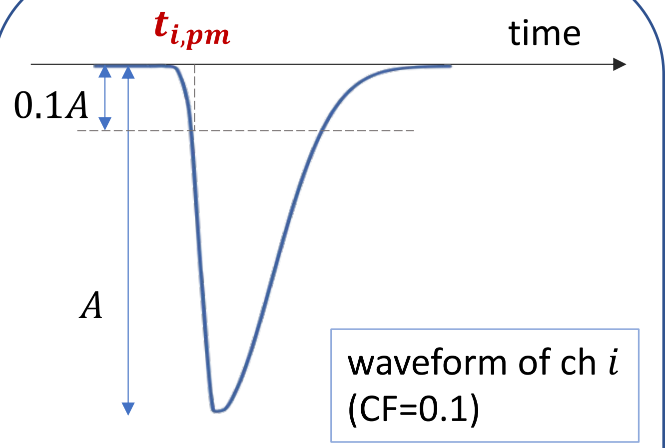
ECF is stable during the physics run. (1.5%)
ECF of each sensor during the physics run is treated as a constant.

Timing reconstruction in LXe detector

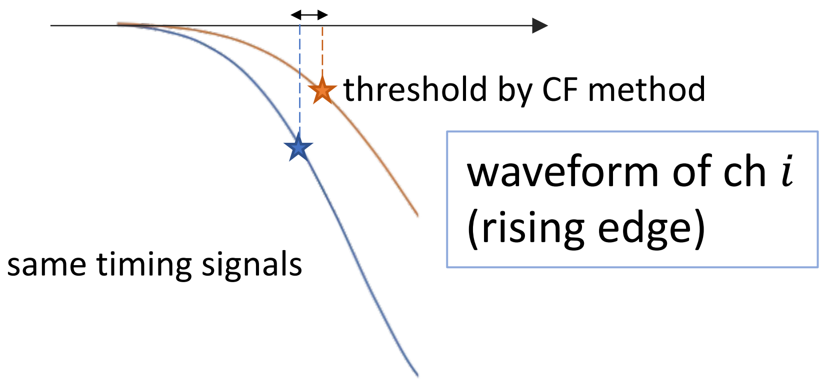
Gamma-ray timing t_γ is reconstructed with χ^2 minimization fit.

$$\chi^2 = \sum_{i \subset \mathrm{MPPC,PMT}} \left(\frac{t_{i,\mathrm{pm}} - t_{i,\mathrm{prop}} - t_{i,\mathrm{walk}} - t_{i,\mathrm{offset}} - t_\gamma}{\sigma_{i,\mathrm{pm}}} \right)^2$$





$t_{i,\mathrm{pm}}$: the signal detection timing of each sensor



$t_{i,\mathrm{walk}}$: the time walk effect of each sensor
Calibrate the effect of time walk as a function of N_{phe}

$t_{i,prop}$: Propagation time of scintillation light from the first interaction point to each sensor

$t_{i,\mathrm{offset}}$: the time offset of each sensor
Calibrated using pion beam run data based on the dedicated timing calibration counter

Timing resolution evaluation of LXe detector

Charge EXchange reaction (CEX)

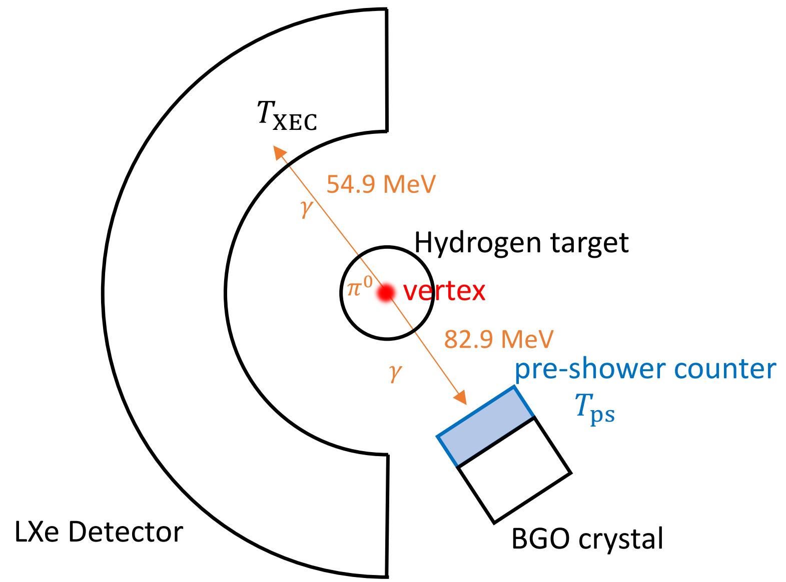
$$\pi^- p \to \pi^0 n$$

$$\pi^0 \to \gamma\gamma$$

π^- is injected into a liquid hydrogen target.

Back-to-back γ-rays : <u>54.9 MeV</u> and 82.9 MeV

Close to the energy of the signal event (52.8 MeV).

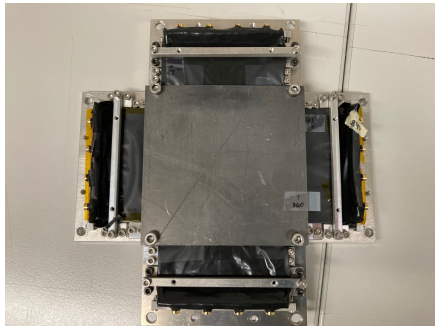


Gamma-ray hit timing on pre-shower counter is used as a reference.
Inner face is divided into 24 patches and scanned.

absolute timing resolution $\sigma_{\mathrm{abs}} = \sigma(T_{\mathrm{xec}} - T_{\mathrm{ps}}) \ominus \sigma_{\mathrm{ps}} \ominus \sigma_{\mathrm{vertex}}$

even odd timing resolution $\sigma_{\mathrm{evenodd}} = \sigma(T_{\mathrm{even}} - T_{\mathrm{odd}})/2$

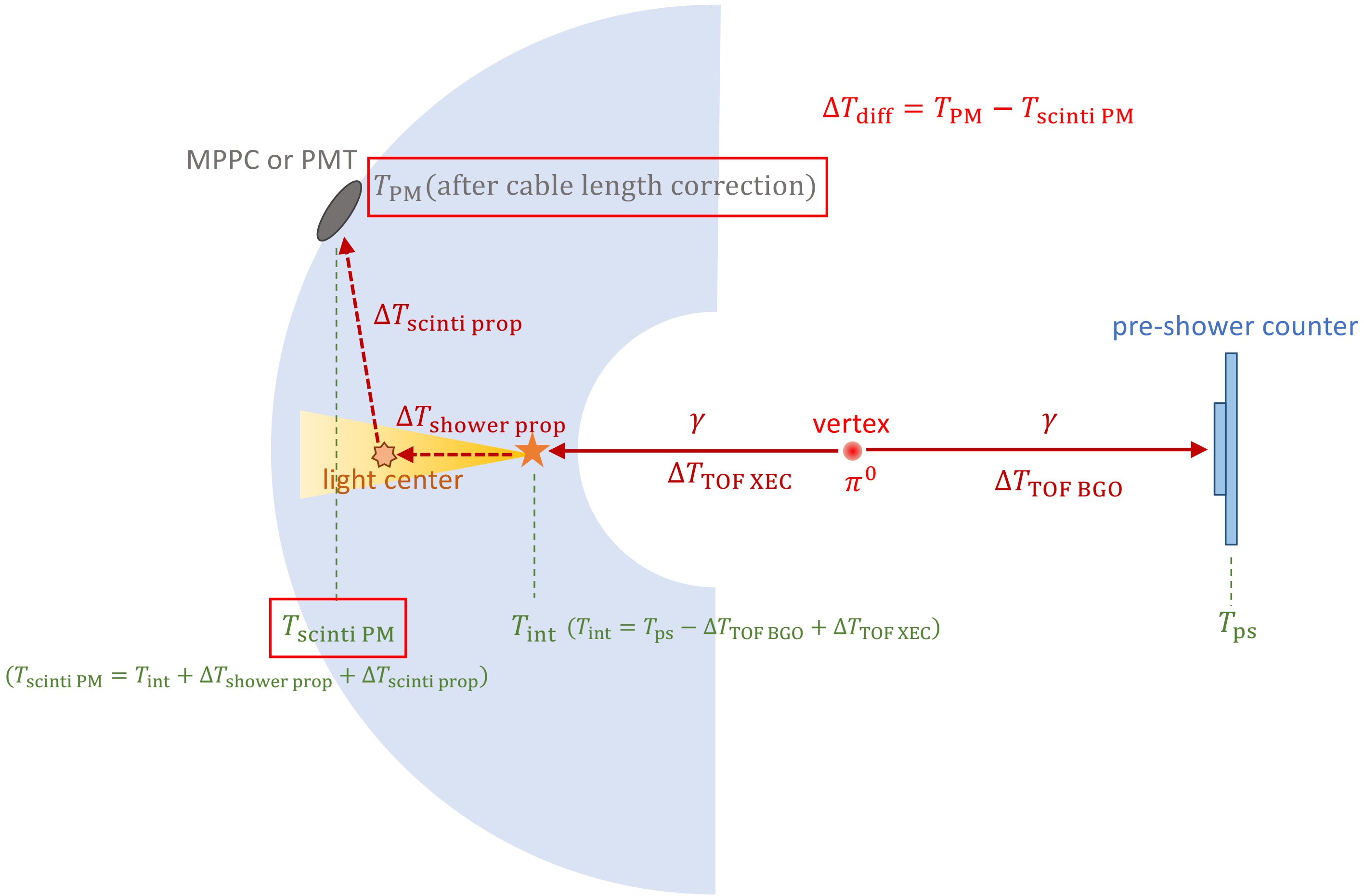
It is necessary to measure σ_{vertex} to evaluate σ_{abs}.



pre-shower counter

Pb converter + two plastic scintillator plates
Signal waveforms are read out by MPPCs
from both ends of the plates

Sensor timing calibration



Time offset and time walk are calibrated in pion beam run.

$$\Delta T_{\mathrm{diff}} = T_{\mathrm{PM}} - T_{\mathrm{scinti\ PM}}$$

T_{PM} : Signal detection time in each sensor obtained from waveform analysis

$T_{\mathrm{scinti\ PM}}$: Time when scintillation light reaches the sensor calculated using T_{ps} as a reference

<u>Time offset calibration</u>

Average of ΔT_{diff} at each sensor is extracted.

<u>Time walk calibration</u>

Sensors are divided 6 groups.

Dependence of ΔT_{diff} on N_{phe} is extracted.

These parameters are calibrated iteratively.