MEG II実験液体キセノン検出器における較正用アルファ線源を用いた光センサーの光子検出効率の較正

Calibration of Photon Detection Efficiency of Photo-sensors in MEG II Liquid Xenon Gamma-ray Detector with Alpha-ray Sources

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The University of Tokyo

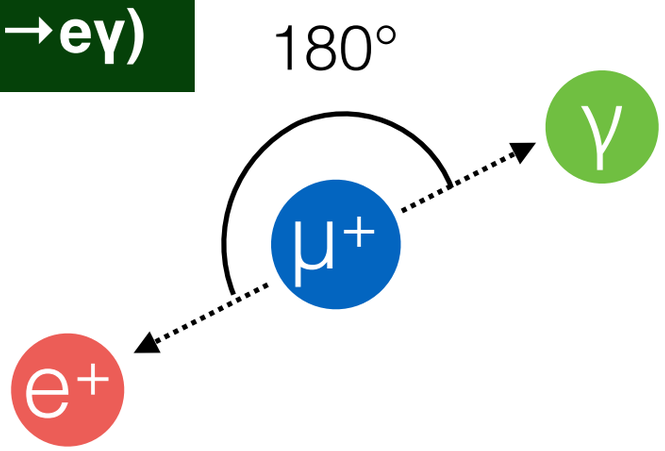
Core-to-Core Program

Outline

- Introduction
  - MEG II experiment
  - Liquid Xenon Gamma-ray Detector upgrade
- Photon Detection Efficiency(PDE) Calibration
  - Principle
  - Measured PDE
  - History in 2017 and 2018
- Summary

μ→eγ search

Signal (μ→eγ)



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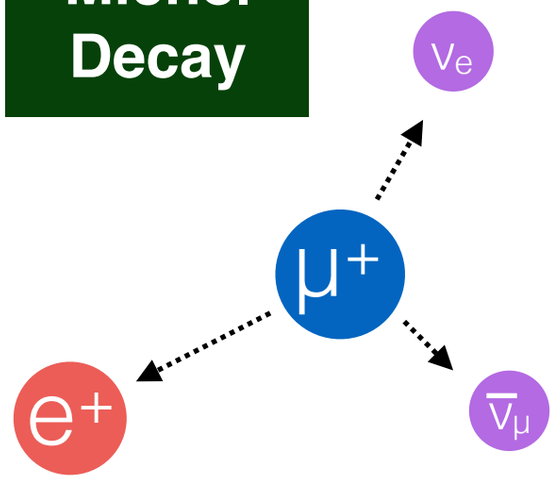
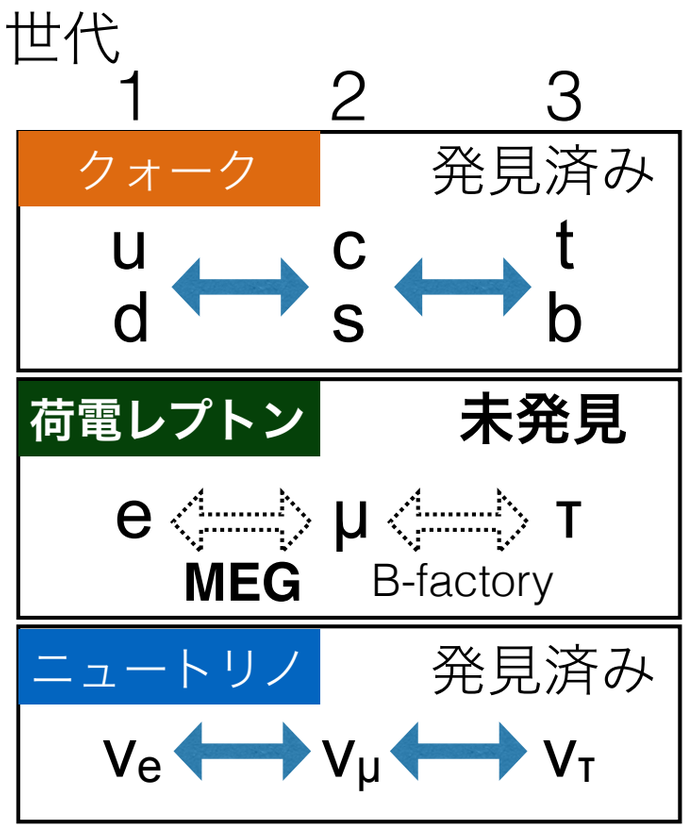
Michel Decay



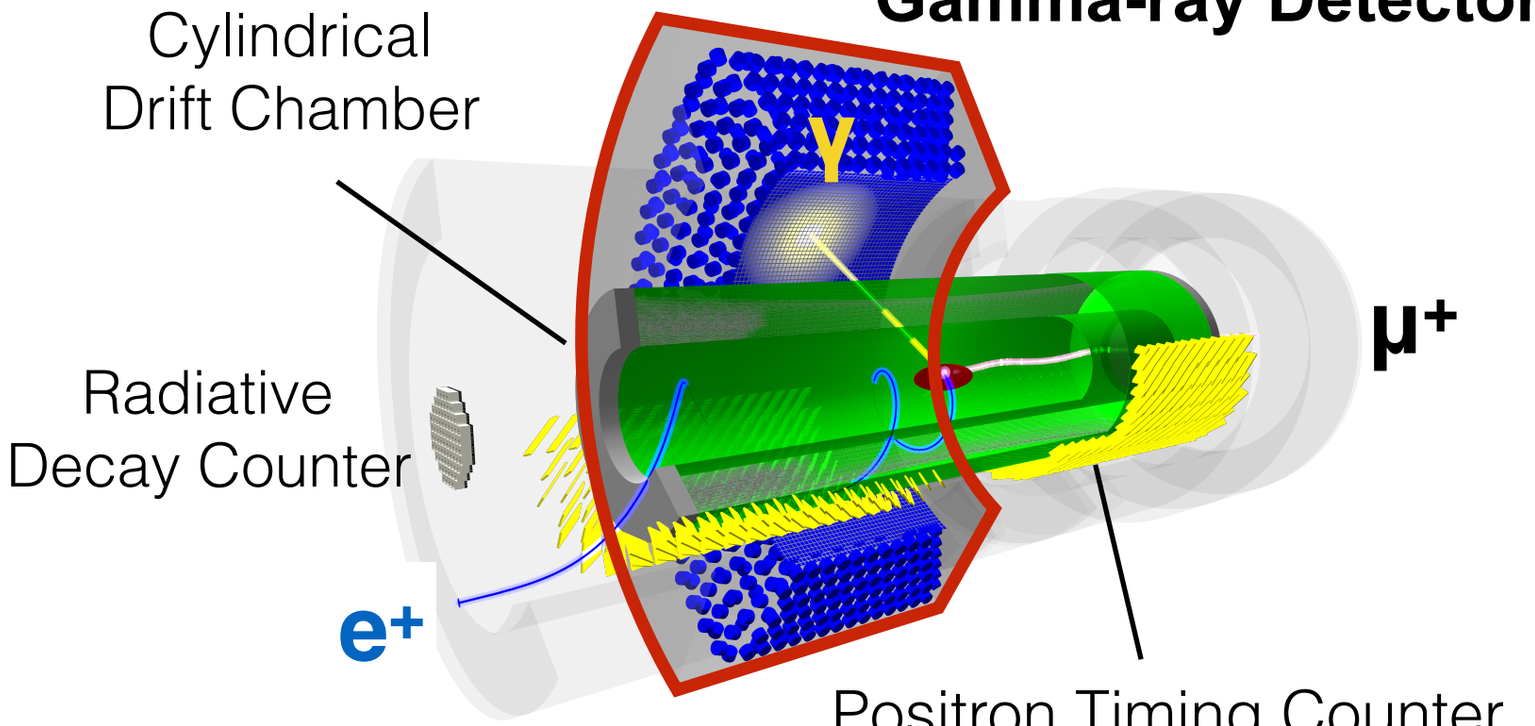
- Simultaneously emitted
- Back-to-back
- Same energy(52.8MeV)



- μ→eγ decay is a lepton flavor violating decay.
  - **Almost forbidden** in SM+ν. oscillation(Br(μ→eγ)~10^{-54})
  - **Predicted** in some theories(Br(μ→eγ):10^{-11}~10^{-14})
- Current upper limit of Br(μ→eγ) is given by the MEG experiment.
  - **4.2×10^{-13}** (90% C.L.)

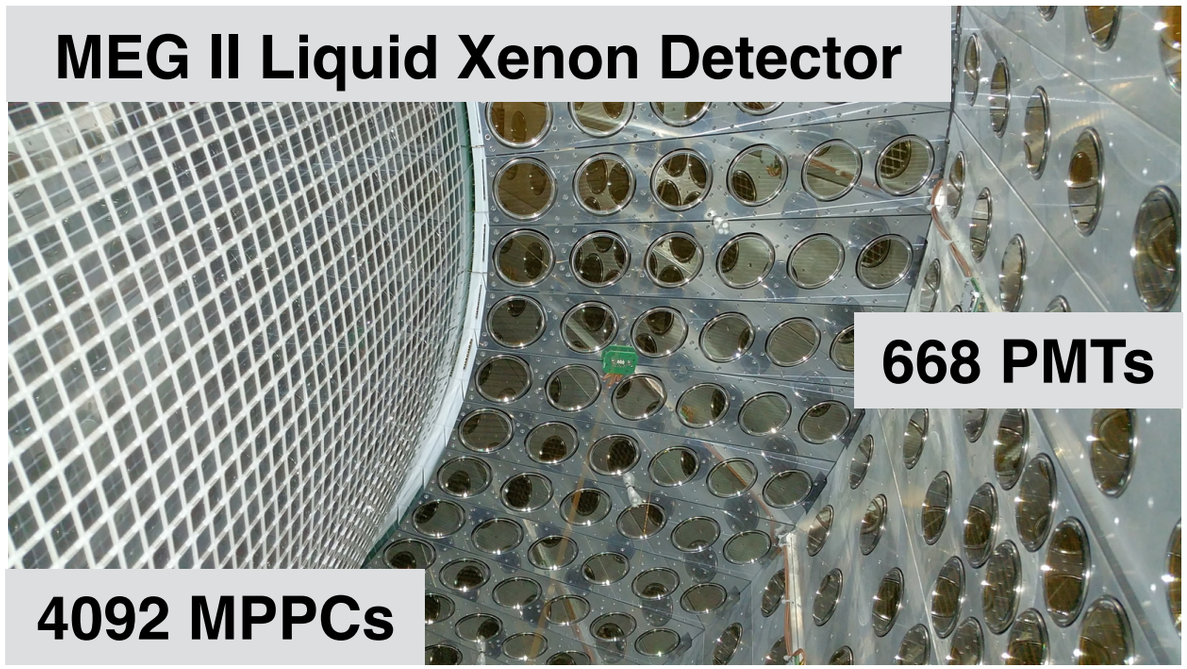
MEG II Experiment

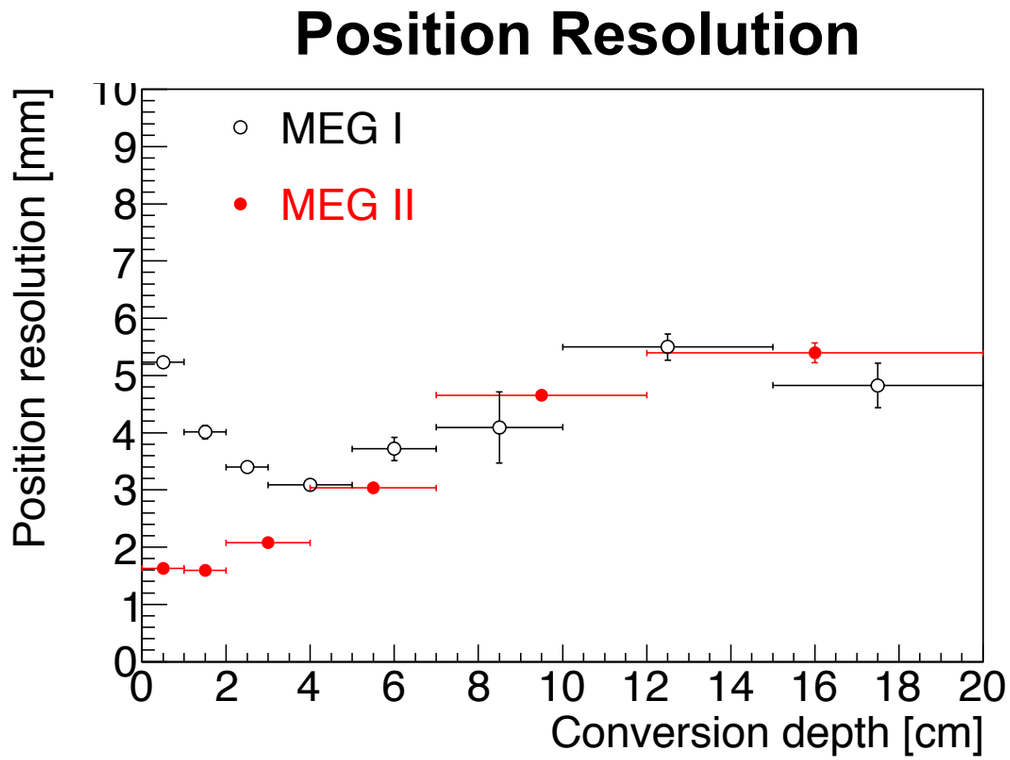
MEG II Setup



- MEG II experiment will search for the μ→eγ decay with unprecedented sensitivity.
  - Br(μ→eγ)~6×10^{-14} in 3 years
- Liquid Xenon gamma-ray detector measures position, energy and timing of the incident gamma-ray.

Liquid Xenon Detector Upgrade





- 216 2-inch PMTs ⇨ **4092 12×12 mm² VUV-MPPCs**.
  - High granularity, uniform readout at the entrance face.
    - Position resolution: 5 mm → **2.5 mm**
    - Energy resolution: 2% → **1%**
- **Two pre-engineering runs in 2017 and 2018.**
  - The number of readout electronics is limited to 1/4.

19pT14-6,7,8(豊田、小川、家城)

Photosensor Calibration

γ-energy is weighted sum of the number of incident photons at photo sensors.

Gamma-ray Energy $$E_\gamma = \sum_i C_i \times \boxed{N_{pho,i}}$$

Constant weight @ each sensor

Number of incident photons $$N_{pho} = \frac{Q}{\boxed{PDE} \times G \times ECF}$$

Charge

Today's topic → **Photon Detection Efficiency**

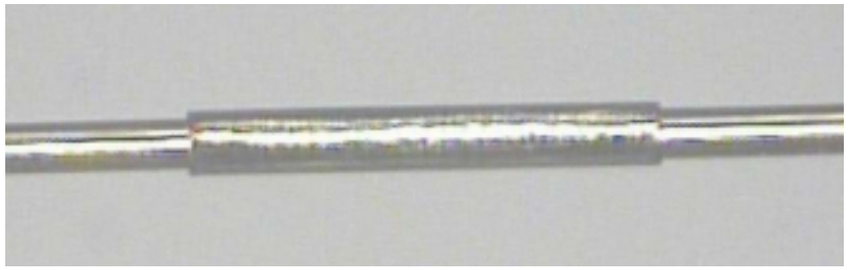
Gain

Excess Charge Factor

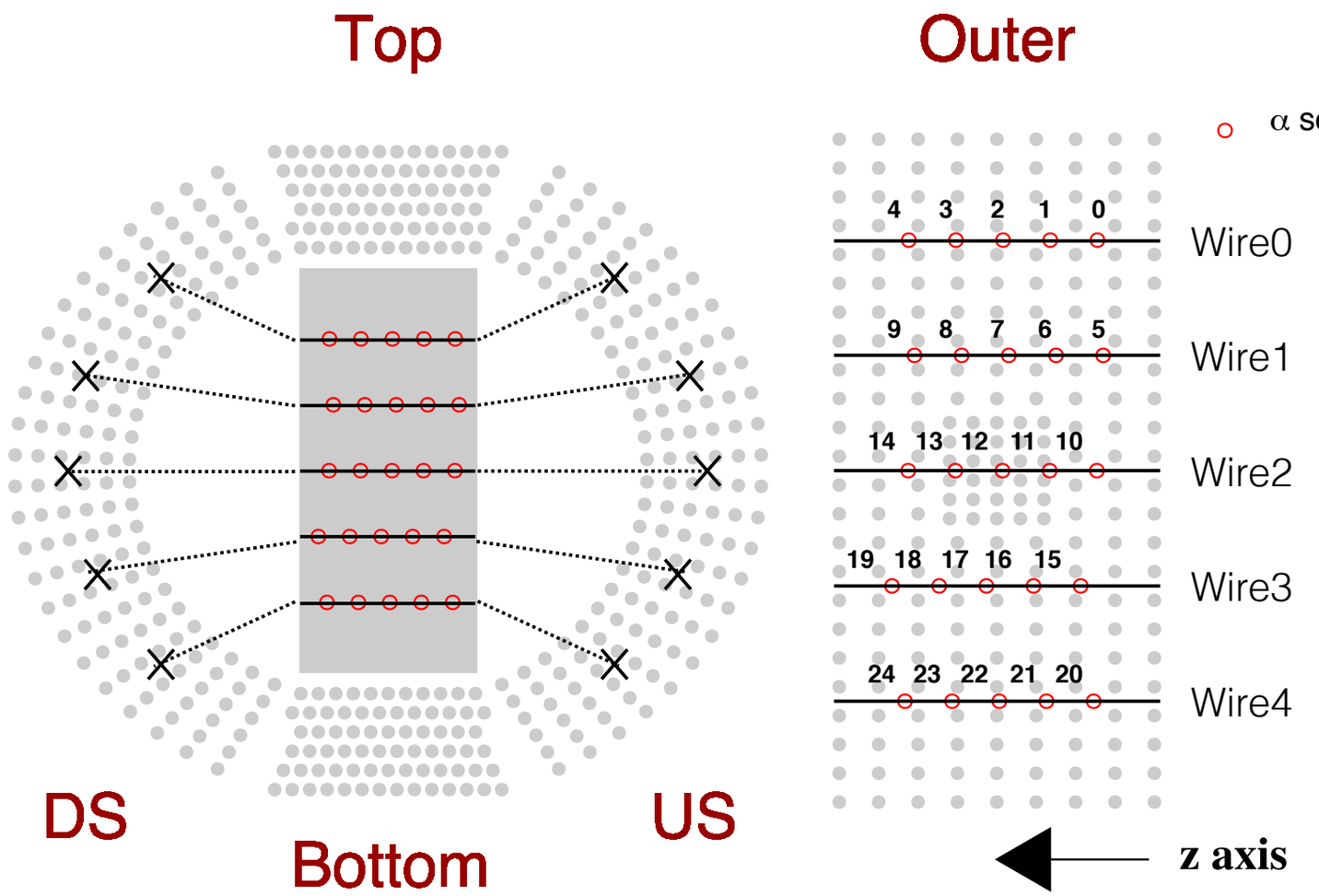
LED Measurement

- Precise photosensor calibration plays a crucial role to achieve the expected energy resolution(~1%).

PDE Calibration



^{241}Am source mounted to wire



- 25 ^{241}Am sources (5 wires × 5 points, 5.5 MeV α-ray) for PDE calibration.
- PDE is estimated using MC simulation.
  - Detector conditions have to be taken into account.

$$PDE_{data} = PDE_{MC} \times \frac{\overline{N_{pe,data}}}{\overline{N_{pe,MC}}} \times C_{LXe}$$

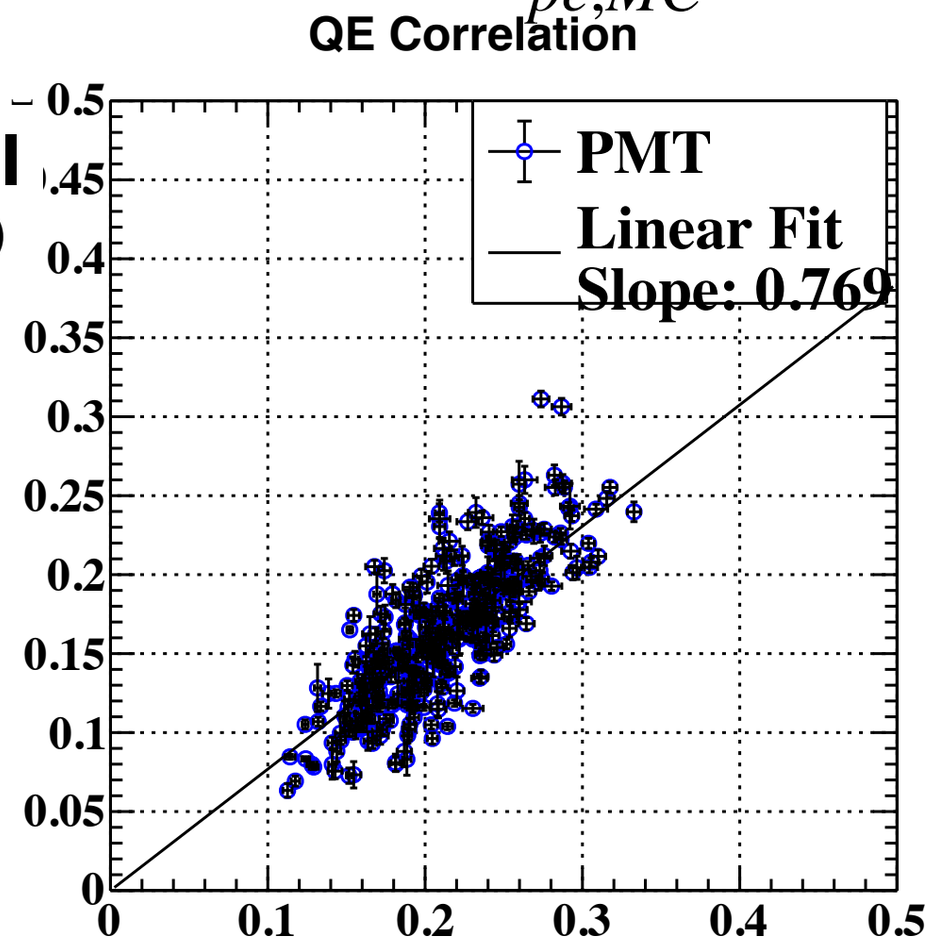
Detector Condition
- Light yield of LXe
- Absorption in LXe
- Reflection at walls

LXe Property Measured with PMTs

$$PDE_{data} = PDE_{MC} \times \frac{\overline{N_{pe,data}}}{\overline{N_{pe,MC}}} \times \boxed{C_{LXe}}$$

- Light yield
- Absorption
- Reflection

PMT PDE @**MEG II**
(Assuming LXe term = 1)



$$C_{LXe,MEGII}/C_{LXe,MEG} = 0.77$$

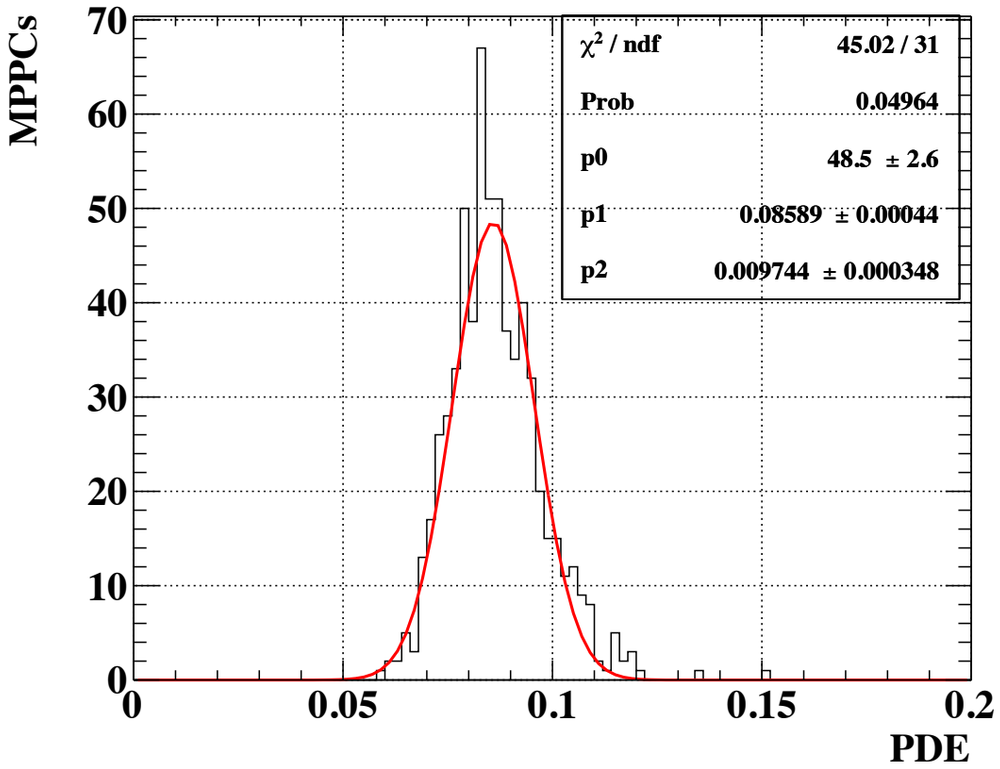
- MEG PMTs are being reused in MEG II.
- The difference between measured PDE in MEG and in MEG II reflects the difference of LXe properties.
  - Assuming the true PMT PDE has been stable from the end of MEG.
  - LXe term was **85% of MEG** in 2017 and **77% in 2018**.

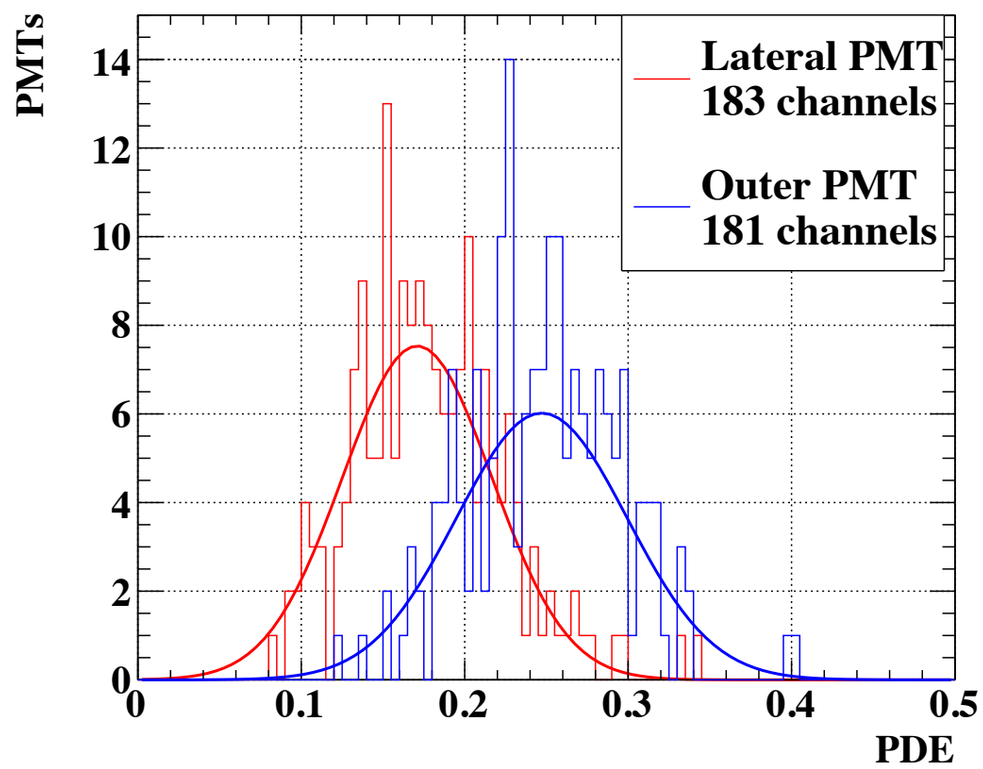
Measured PDE

MPPC

PMT

※High PDE PMTs are assigned in outer face





- Individual difference of measured PDE:
  - MPPC: 1.0%(636 channels)
  - PMT: 5.2%(364 channels)

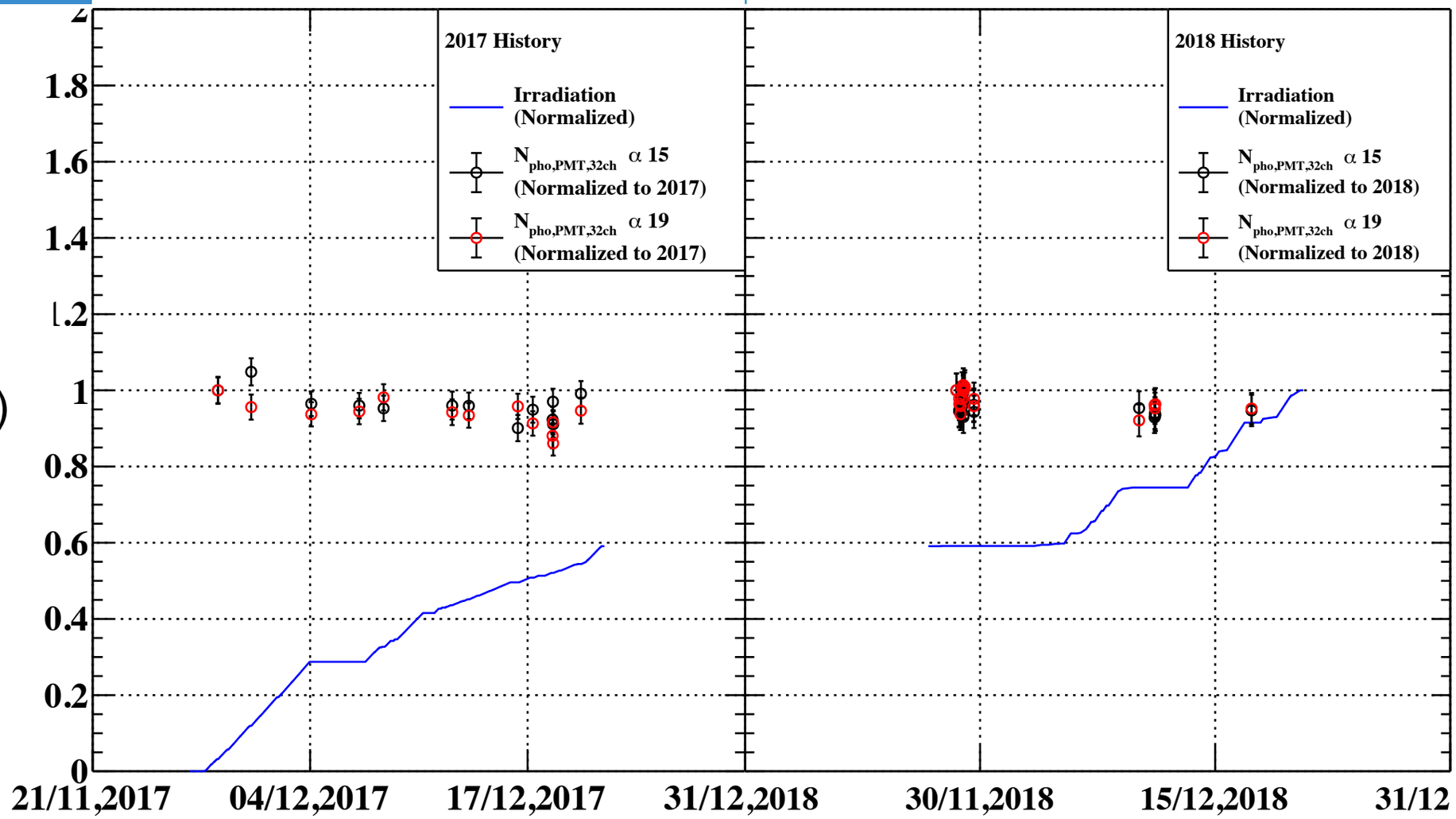
$$\sigma_{obs} \sim \sqrt{\sigma_{true}^2 + \sigma_{resolution}^2}$$

- Calibration precision is better than this individual difference.

PMT PDE history in 2017 and 2018

	2017	2018
Exposure @MEG II Intensity ($7 \times 10^7 \mu/s$)	220 hours	150 hours

Normalized PMT PDE (Normalized at the beginning of each year.)

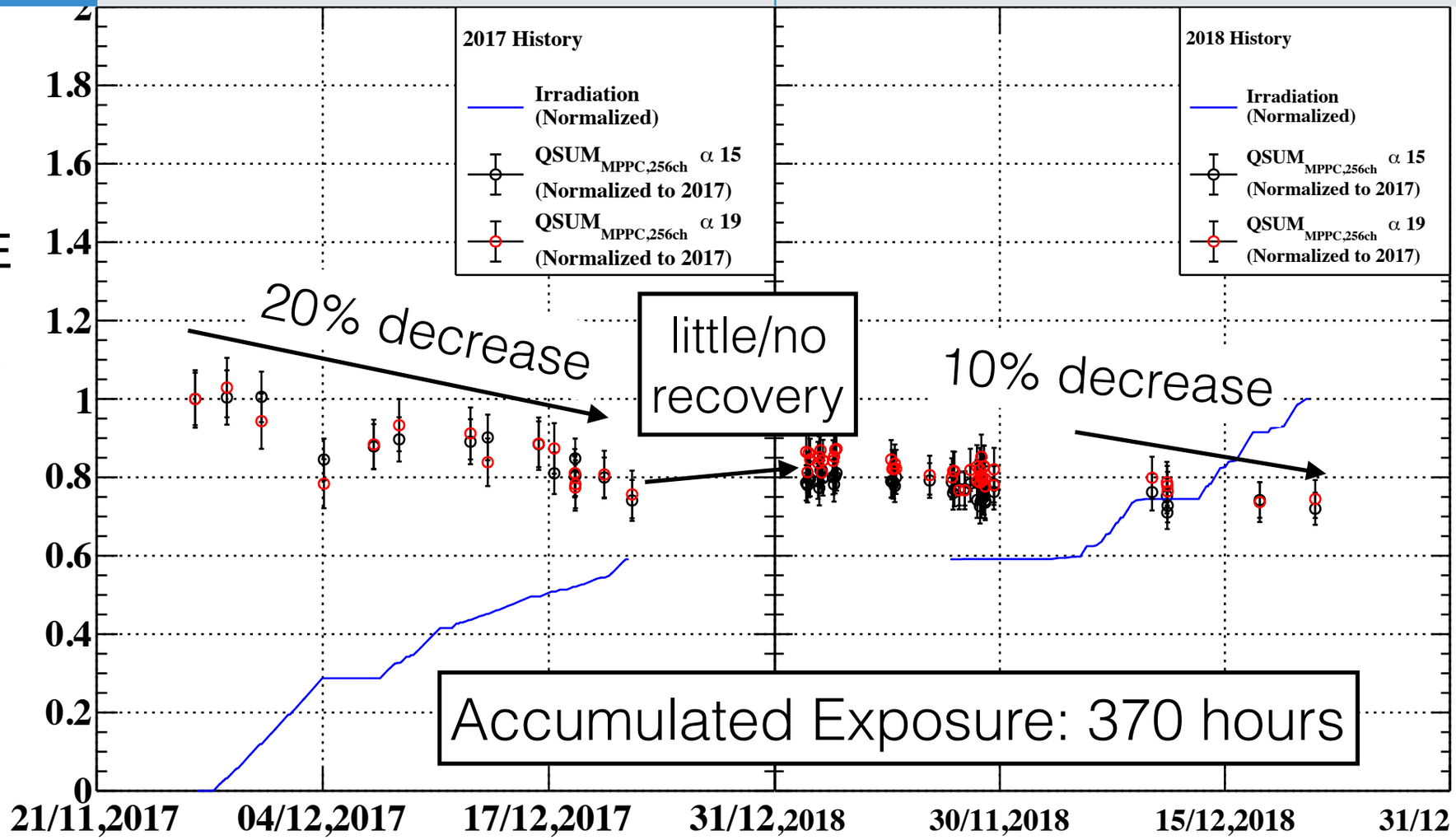


- As expected, no significant aging effect under beam was observed.

MPPC PDE history in 2017 and 2018

	2017	2018
Exposure @MEG II Intensity ($7 \times 10^7 \mu/s$)	220 hours	150 hours
Total Decrease	~20%	~10%

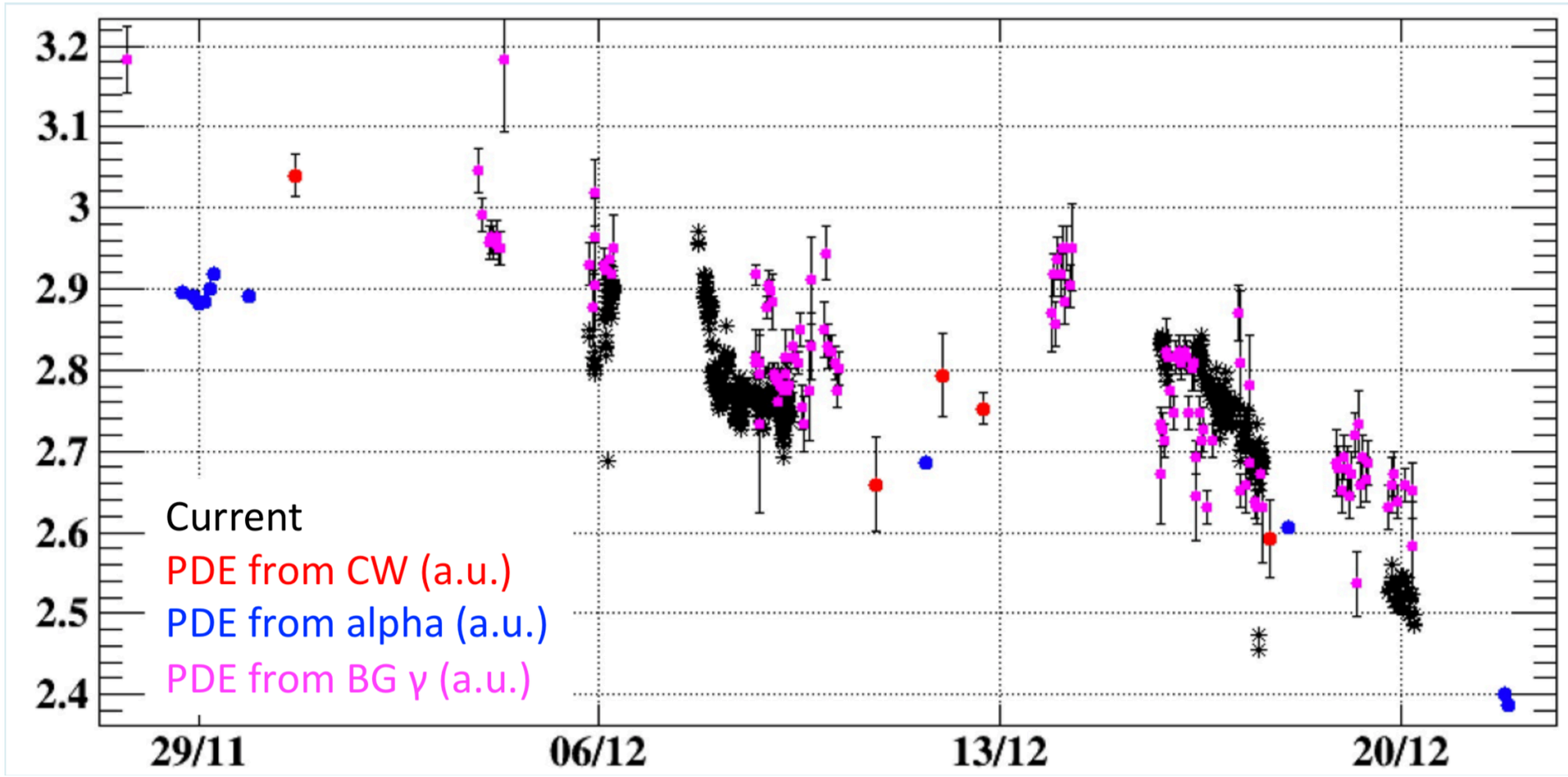
Normalized MPPC PDE (Normalized at the beginning of 2017 run)



- On the other hand, MPPC PDE decreased under high intensity muon beam.

Other Observation of MPPC PDE decrease

PDE[a.u.]



By S.Ogawa

- MPPC PDE decrease to VUV light was cross-checked by other measurements in 2018.
  - Current Readout
  - Monochromatic γ(17.6 MeV)
  - Continuous γ spectrum(40~60 MeV from muon decay)

Summary & Prospects

Summary

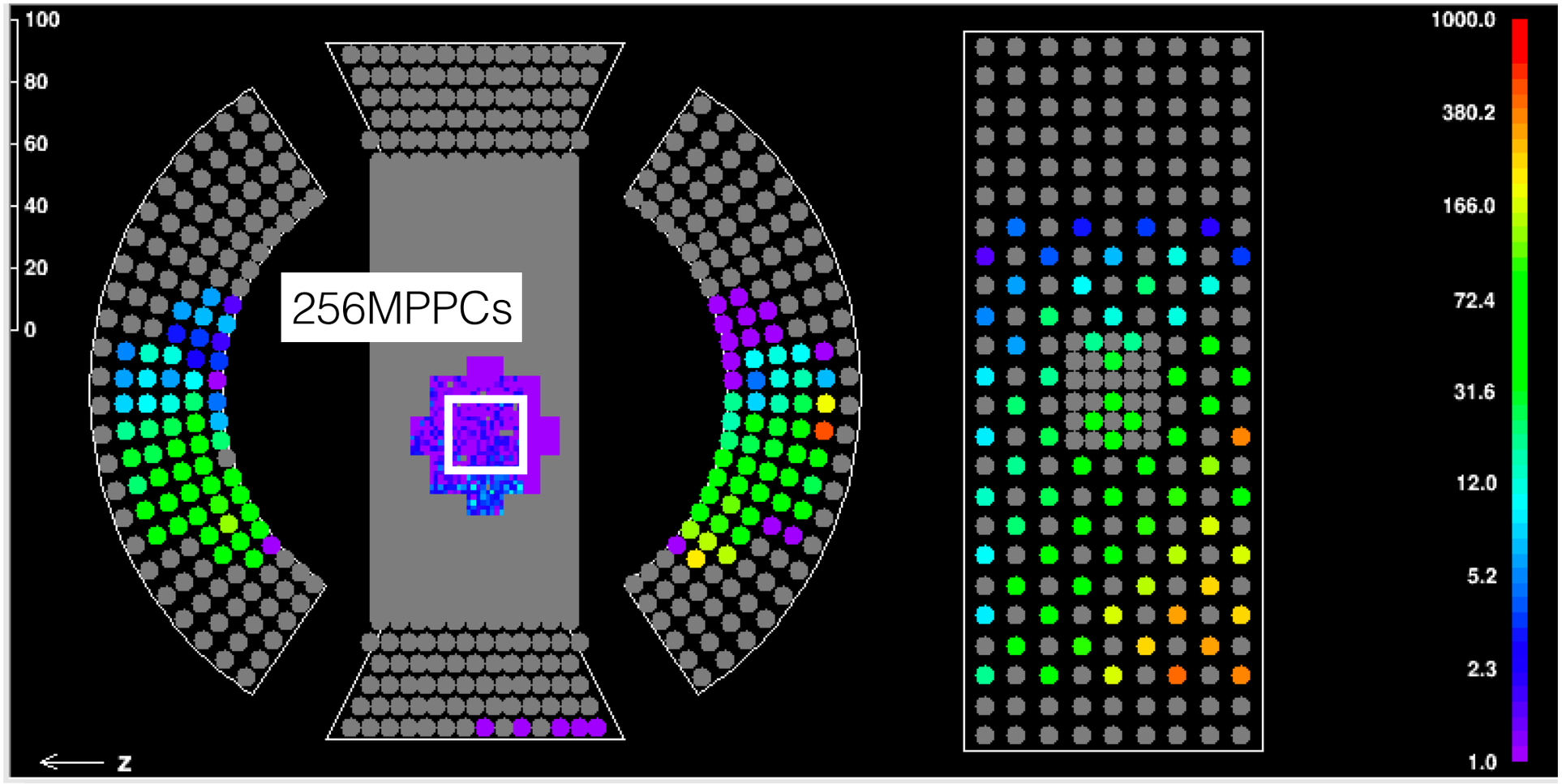
- PDE calibration for PMTs and VUV-MPPCs in MEG II LXe gamma-ray detector was presented.
- Measurement indicates that MPPC PDE has decreased by 20% in 2017 and 10% in 2018 under high intensity muon beam.
  - Deterioration rate: ~0.1%/hour @MEG II intensity($7 \times 10^7 \mu/s$)
- The reason of the deterioration of MPPC PDE is under investigation.
  - Discussed in detail later. **17aT12-5(恩田)**

Prospects

- In 2018, PDE calibration was not so frequent that we could not understand the phenomena deeply.
  - For example, dependence on the beam rate is unknown.
- We are planning to have a PDE monitoring run under beam.
  - Frequent sensor calibration with alpha sources and LEDs.

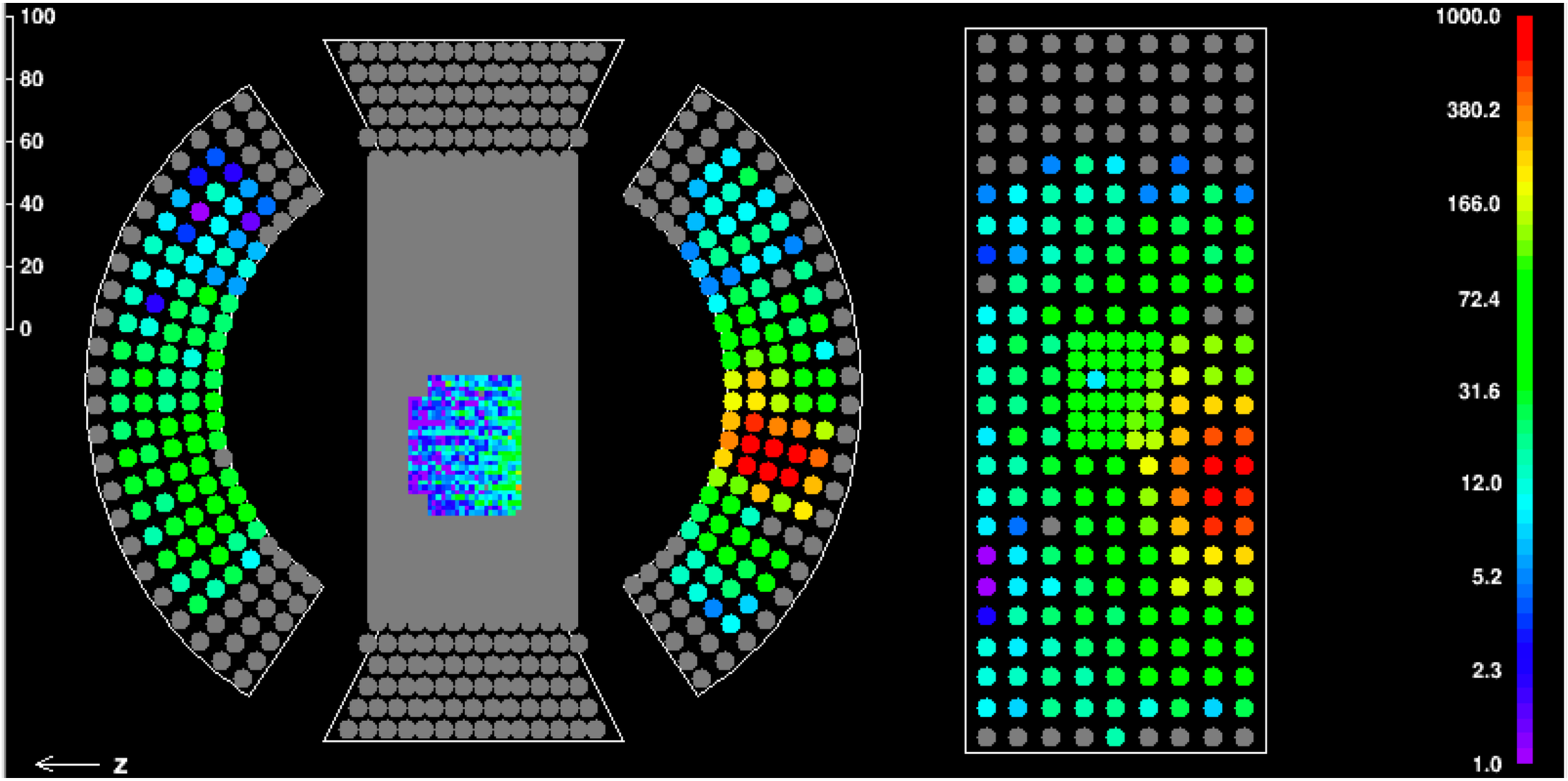
Backup

DAQ Configuration 2017



- 256 MPPCs are used during the whole beam time.
- Difficulty: Source separation is not working well except for sources near to the lateral faces.
  - Due to the limited number of PMT channels.
  - **Use source # 15 and 19 on wire 3.**

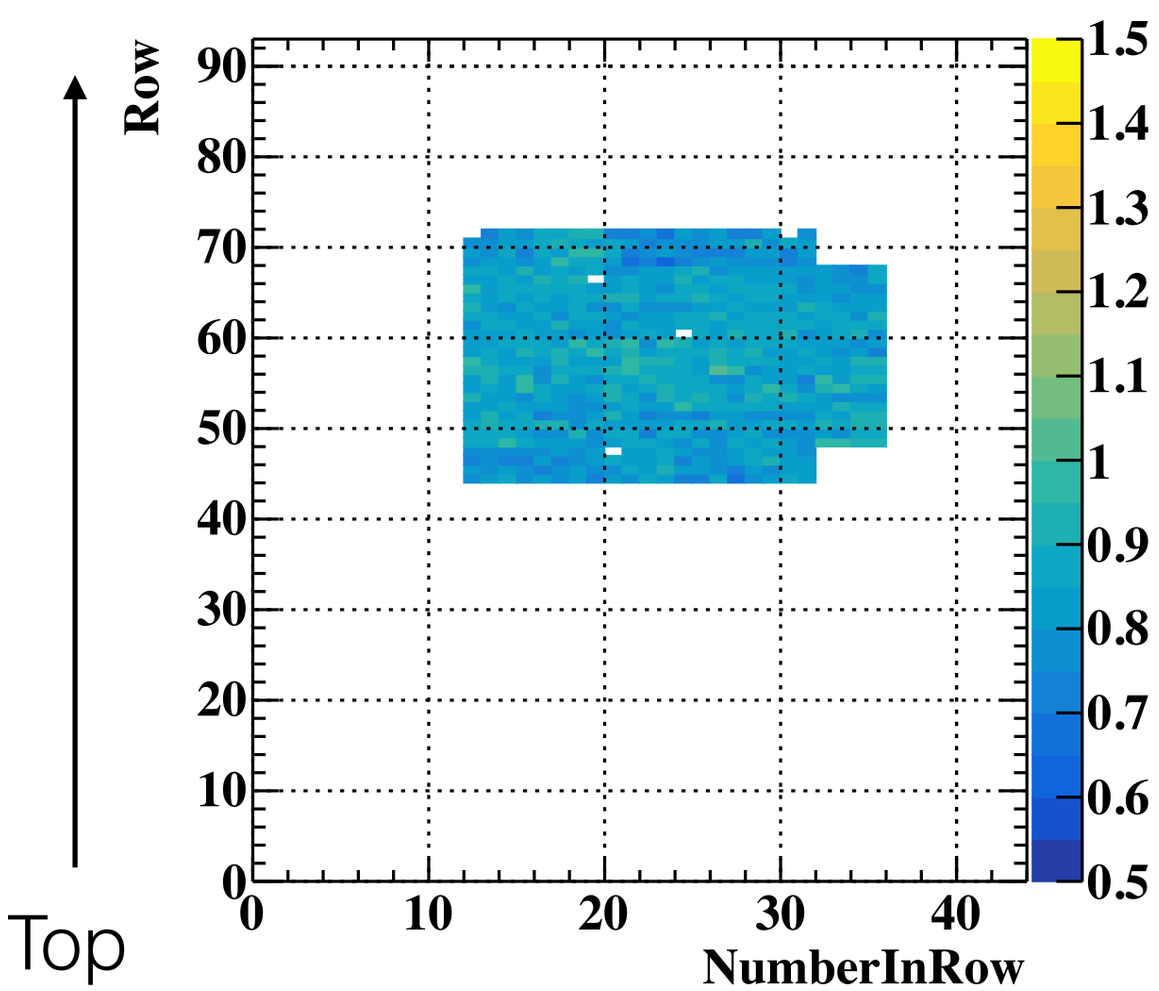
DAQ Configuration 2018



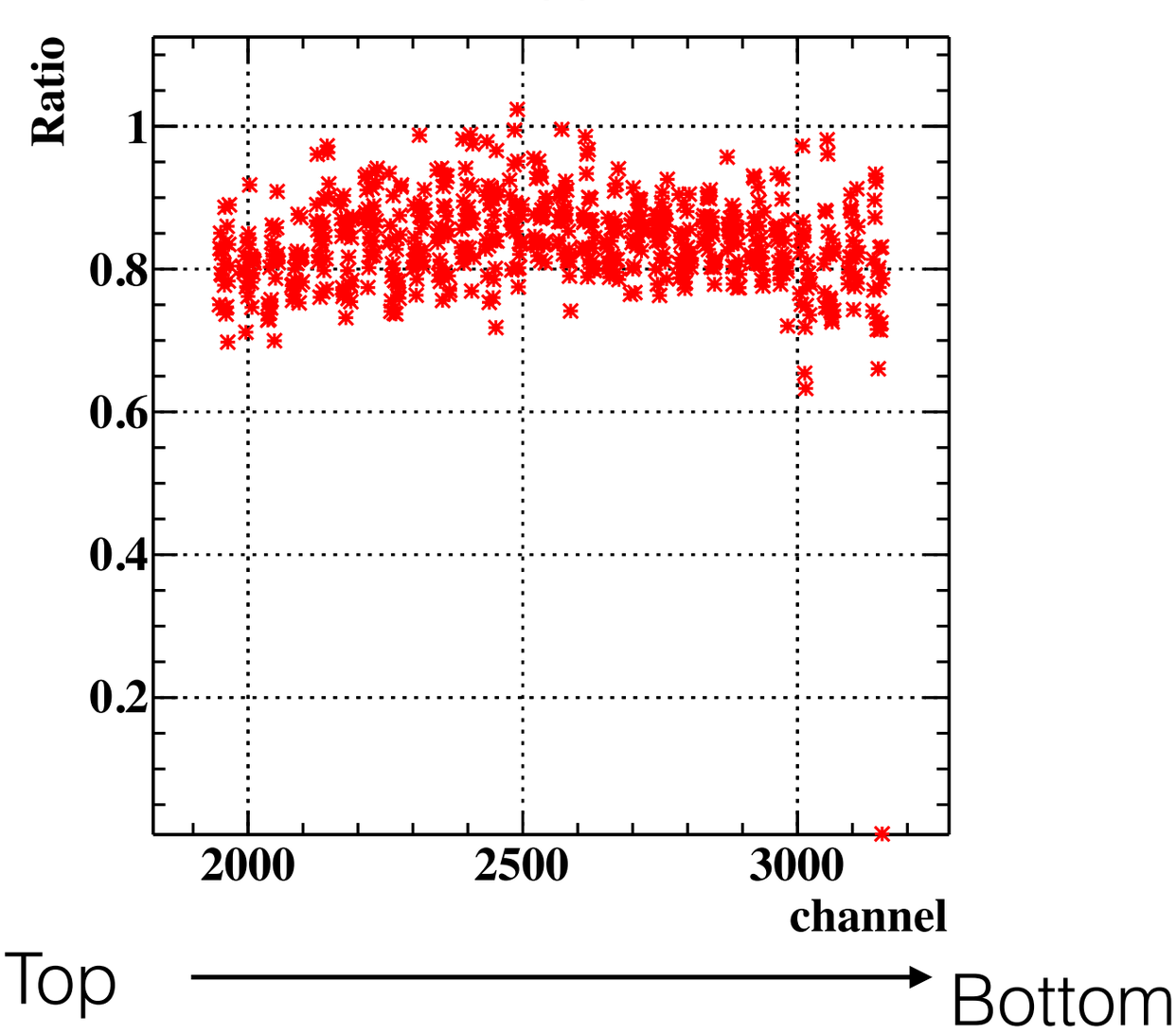
- 636 MPPCs + 364 PMTs.

Position Dependence of PDE decrease

Bottom



Top



Top → Bottom

- No apparent position dependence was observed.

MEG PMT PDE history

光子検出効率の較正 - 手法

粒子の識別

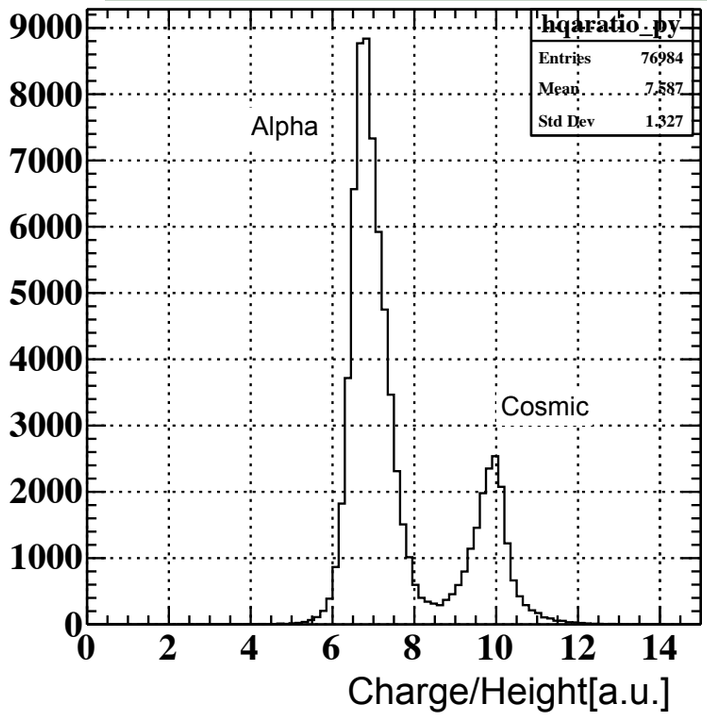
α線の位置再構成

線源の識別

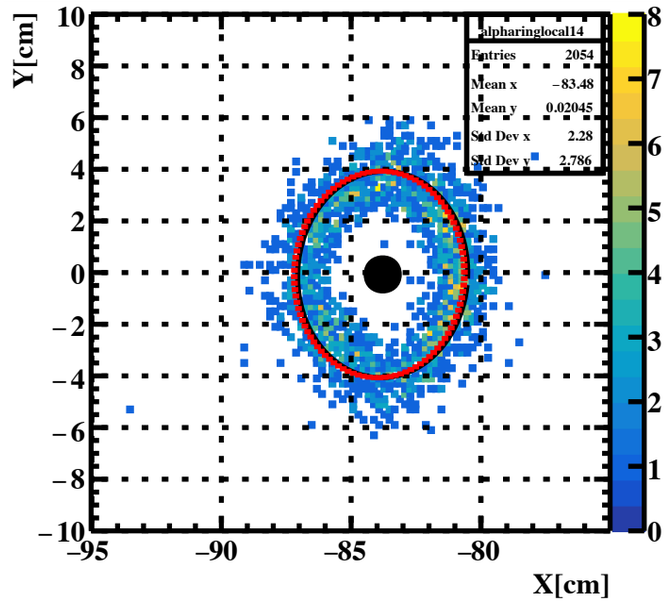
α線放出角度の計算

検出光電子数の計算

PMT波形の電荷と振幅の比

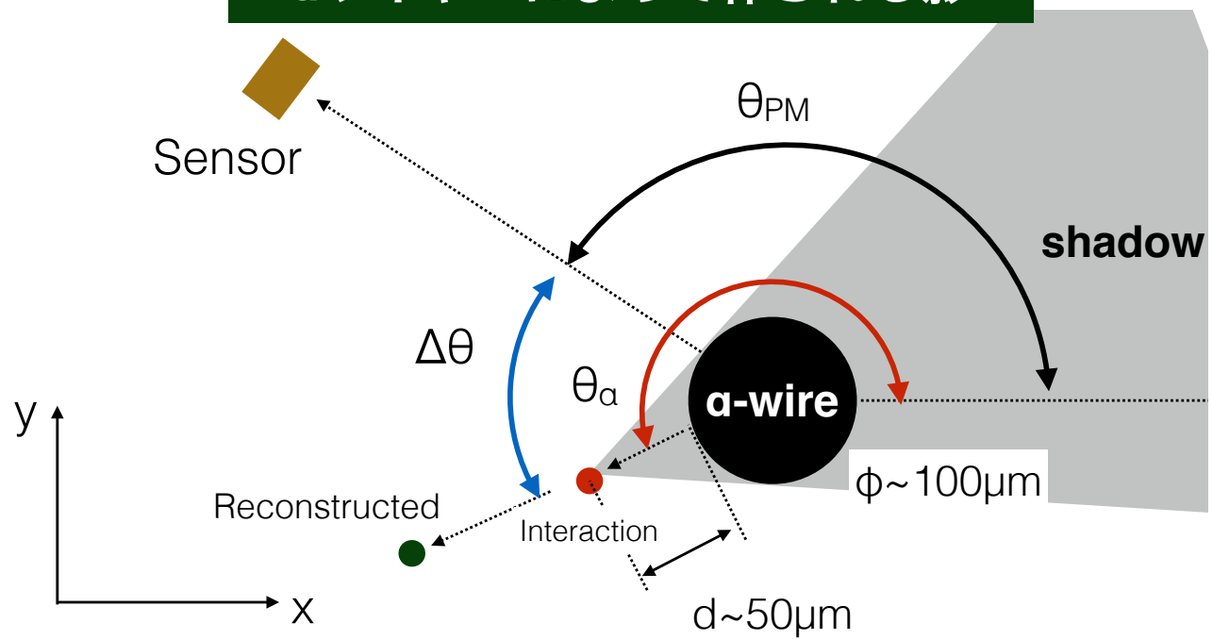


α線の再構成位置分布



- 宇宙線イベントはシンチレーションの時定数がα線と比較して長いことを利用して排除
- α線の位置はワイヤーの影によってバイアスを受けリング状に再構成される
  - 再構成された位置をもとに線源を識別する

αワイヤーによって作られる影



光子検出効率の較正 - 手法

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α線の位置再構成

線源の識別

α線放出角度の計算

検出光電子数の計算

- α線の放出角度を再構成
  - それぞれの光センサーから光源の見えるイベントを選択
- 検出光電子数分布をフィットし、その平均を算出

相対的放出角度と検出光電子数の相関

光センサーから光源の見えるイベント

光センサーから見て光源がワイヤーの影に隠れているイベント