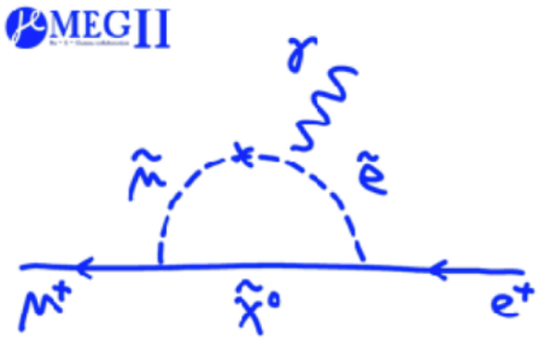
東京大学
素粒子物理国際研究センター
International Center for Elementary Particle Physics
The University of Tokyo



MEG II実験：
液体キセノン検出機の較正 および
2023年ランにむけたアニーリングについて

Sei Ban (ICEPP), for the MEG II collaboration
23rd Mar . 2022, JPS 2023年春季大会 @online,

Outline

Introduction

Calibration for 2022 data : E_γ

PDE recovery of the MPPCs in the LXe detector by annealing for 2023 run

Status and prospect of 2023 run

Summary

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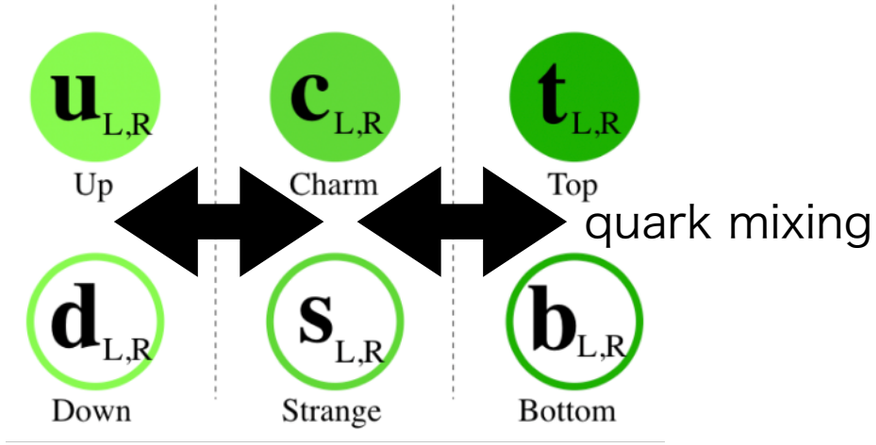
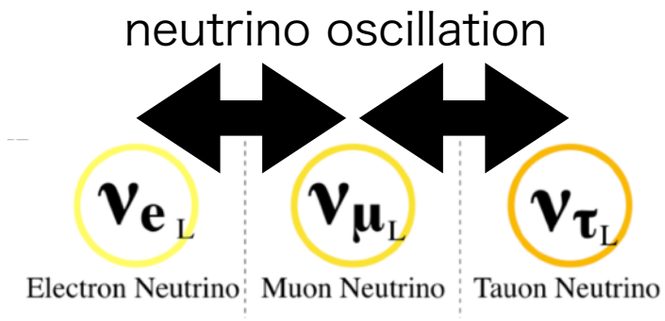
Charged Lepton Flavor Violation

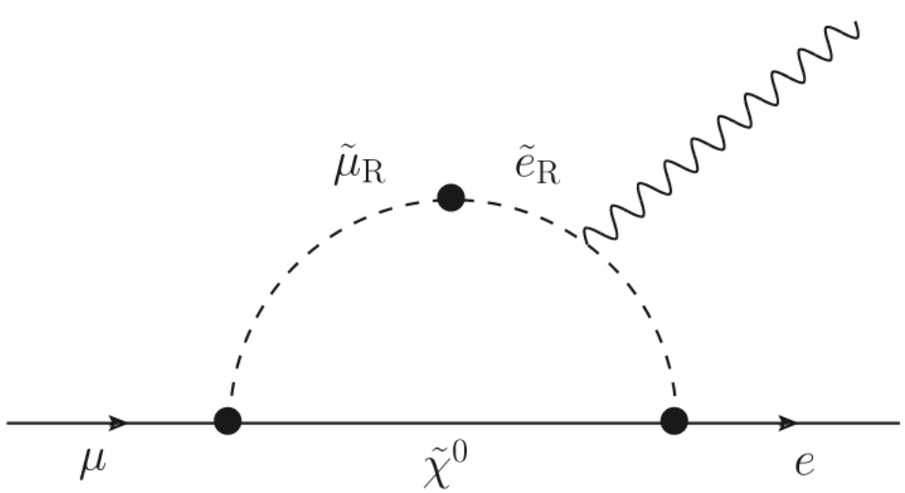
- In quark and neutrino (neutral lepton) sector, the flavor violates in SM



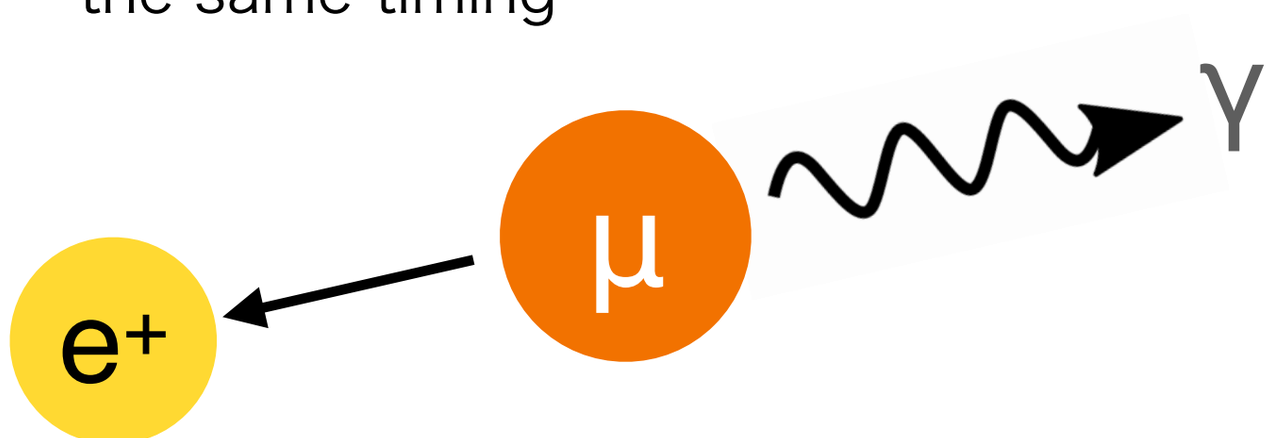


- Some theories BSM predict flavor violation in the charged lepton sector
  - In the Standard Model, it is practically prohibited : $Br(\mu \rightarrow e\gamma) = 10^{-54}$
  - In BSM, $Br(\mu \rightarrow e\gamma) \sim O(10^{-14})$ is predicted : large enough to search

- Signal : Gamma-ray and positron with 52.8 MeV ($=m_\mu/2$)
  back-to-back
  the same timing

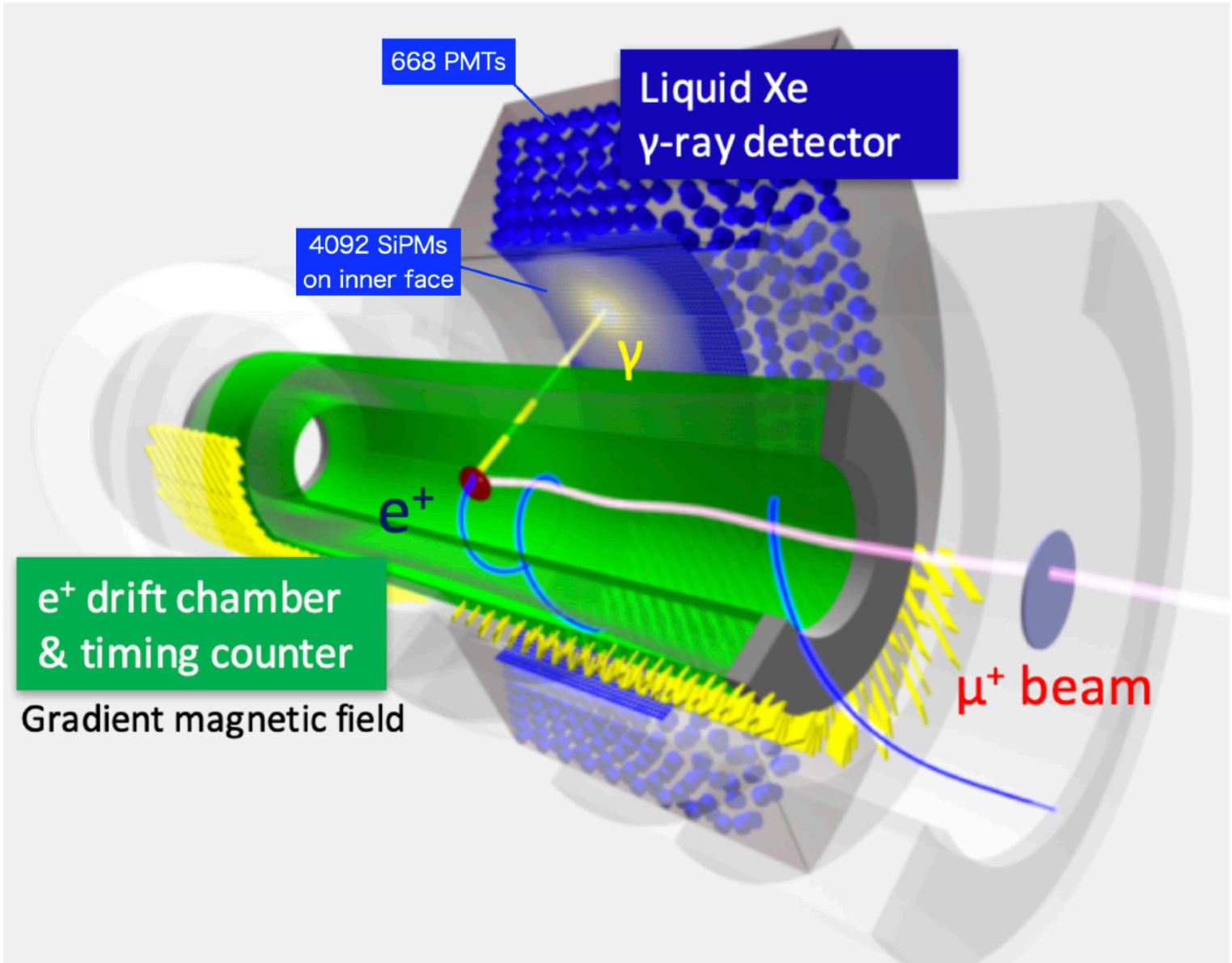


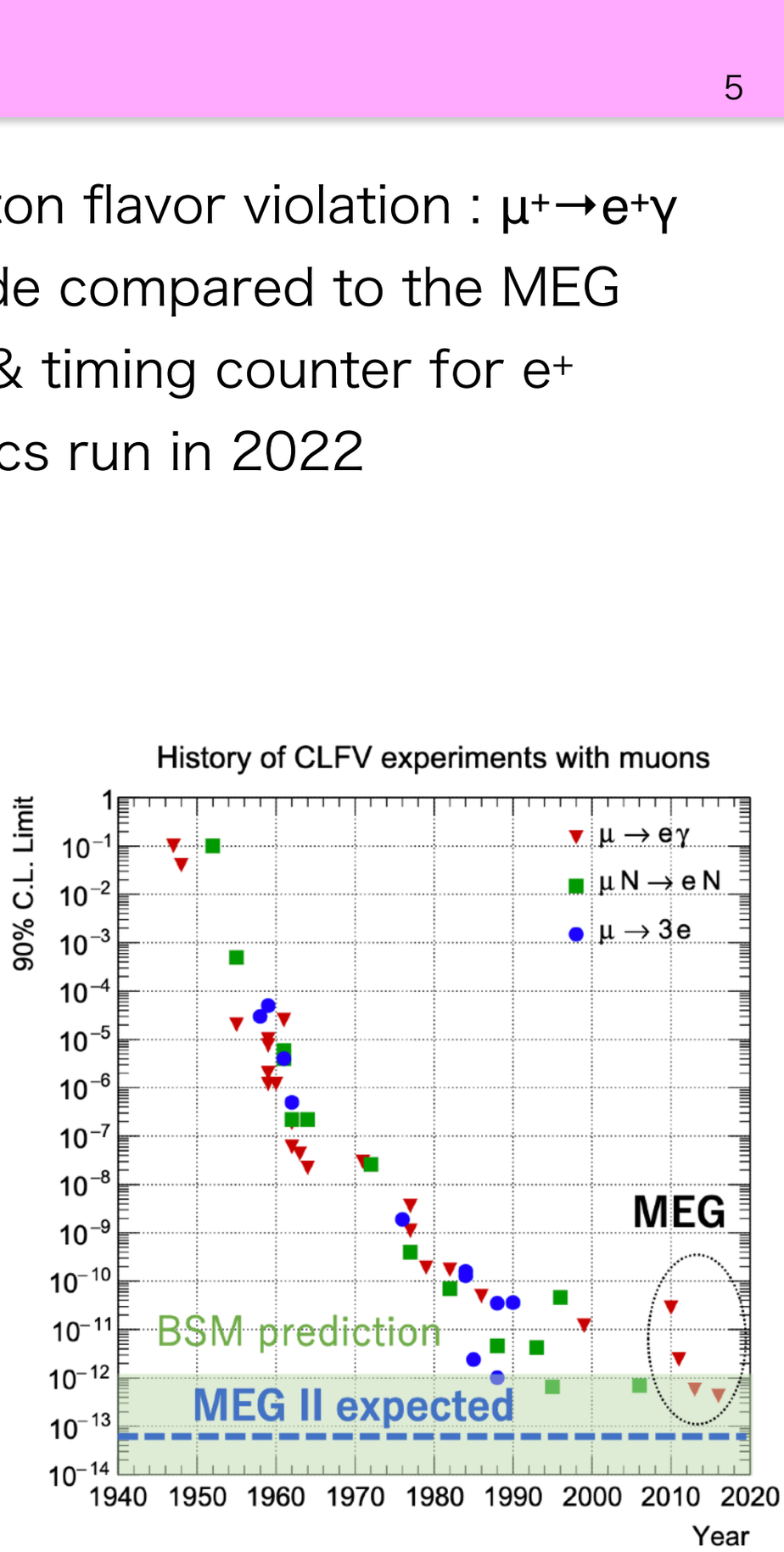
Possible diagram in SUSY-GUT senario



MEG II experiment

- MEG II experiment aims to search for charged lepton flavor violation : $\mu^+ \rightarrow e^+\gamma$
  - with higher sensitivity by one order of magnitude compared to the MEG
- Consists of LXe detector for γ-ray, drift chamber & timing counter for e^+
- Physics run started in 2021 (pilot run) -> full physics run in 2022





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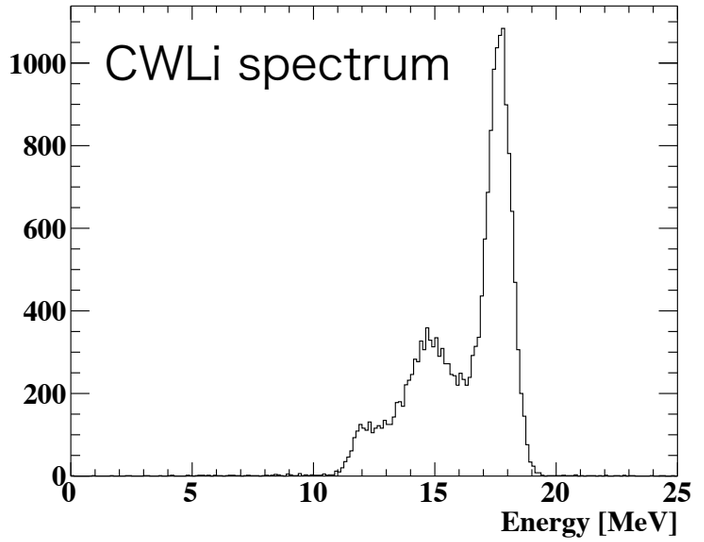
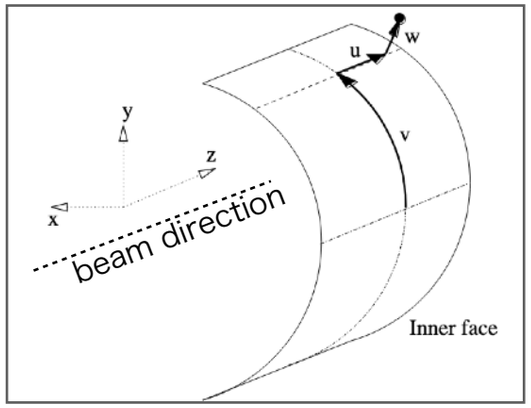
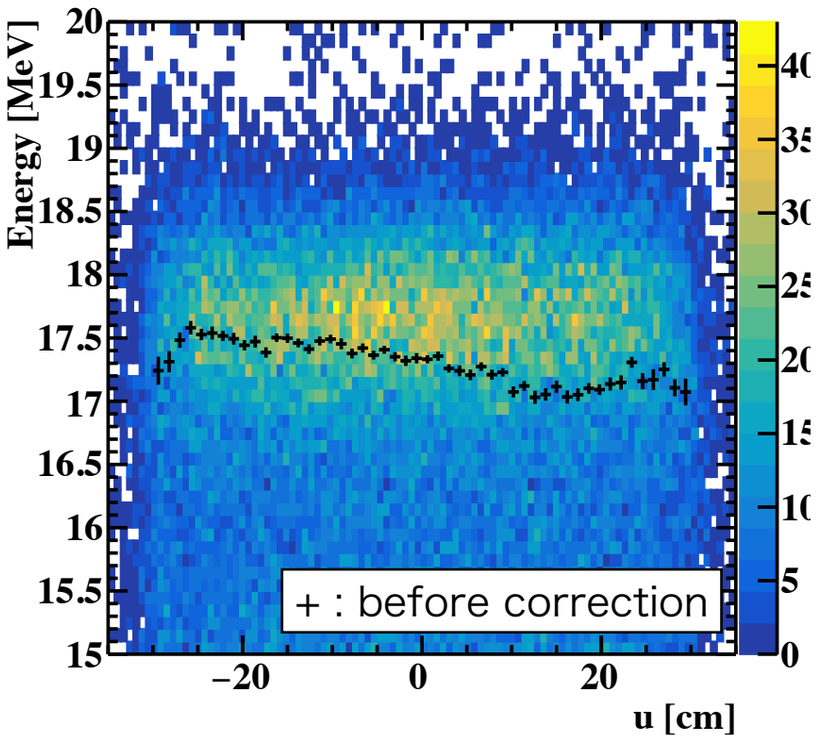
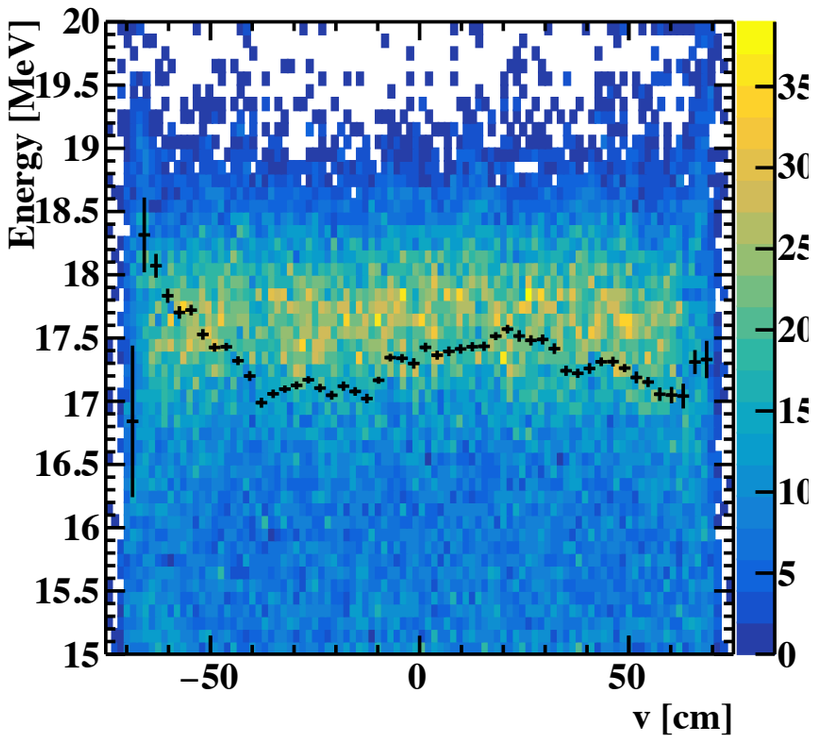
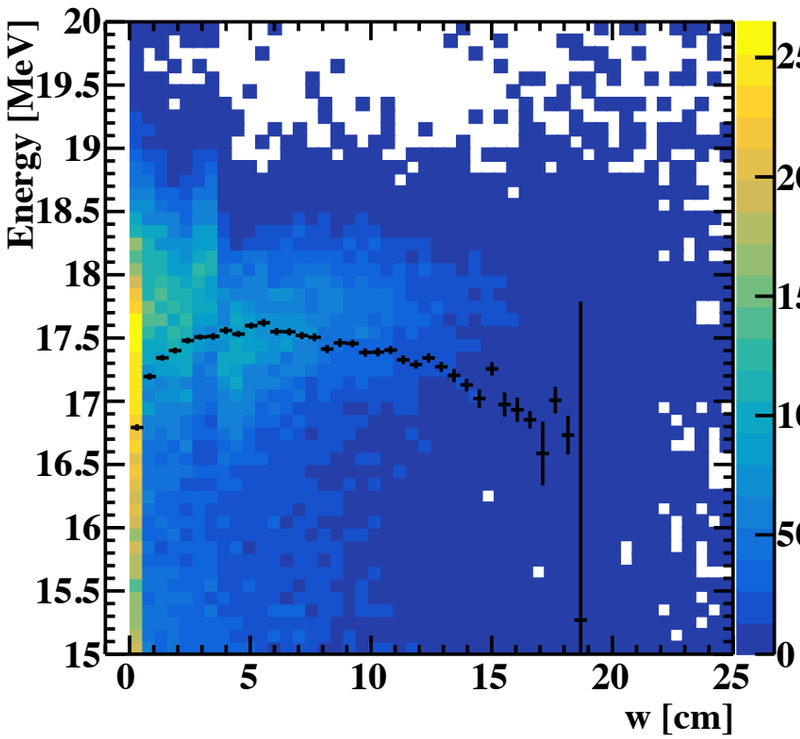
- Sensor calibrations : previous talk (23aT3-6)
- Position dependence of reconstructed energy is studied using 17.6 MeV peak by following reaction
  - p (CW acc.) + Li (target) → Li(p,γ)Be → γ (17.6 MeV)
- Non-uniformity is corrected along u, v, w direction
  - (plus additional 2D, 3D correction)
- Uniform response is obtained after the correction
- Further non-uniformity correction will be studied using 55 MeV peak from charge exchange reaction
  - $\pi^-_{\text{(pi- beam)}} \rightarrow \pi^0$ (in Hydrogen) → γ + γ





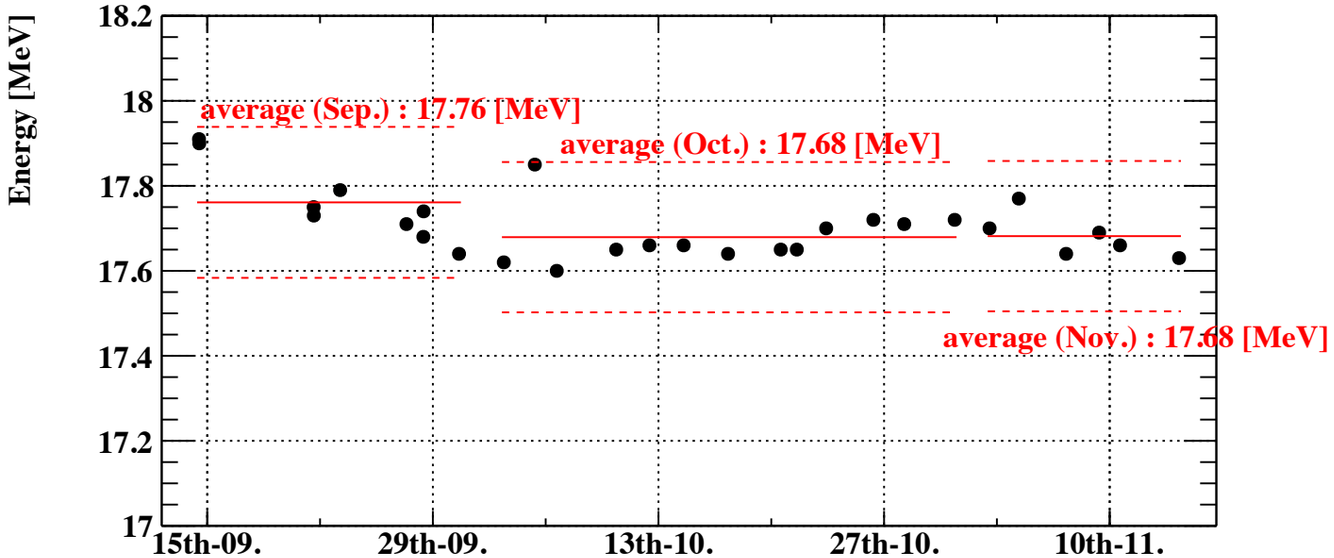


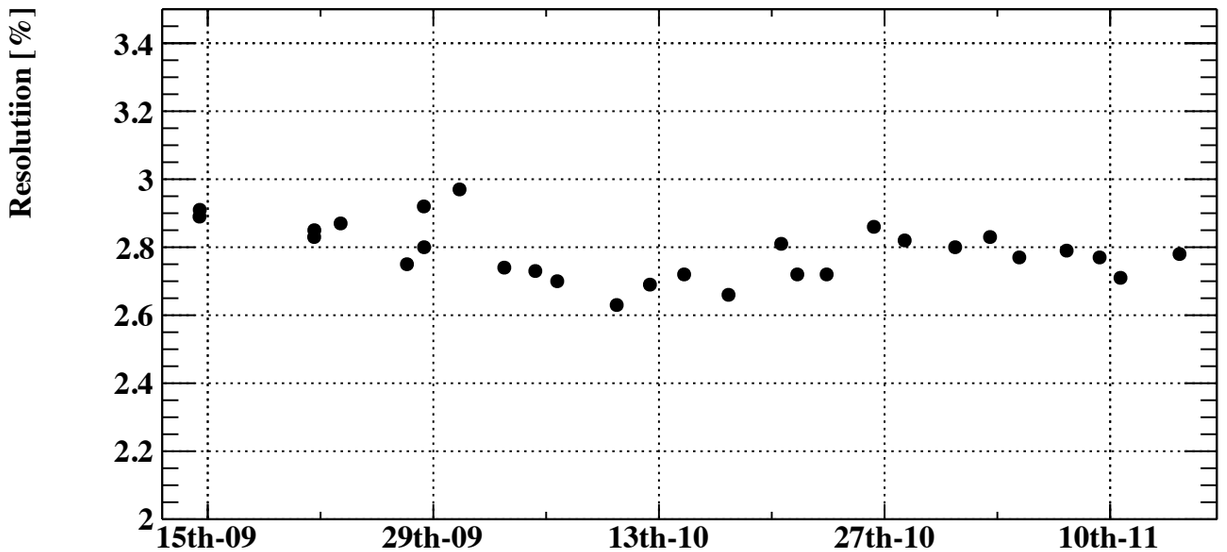




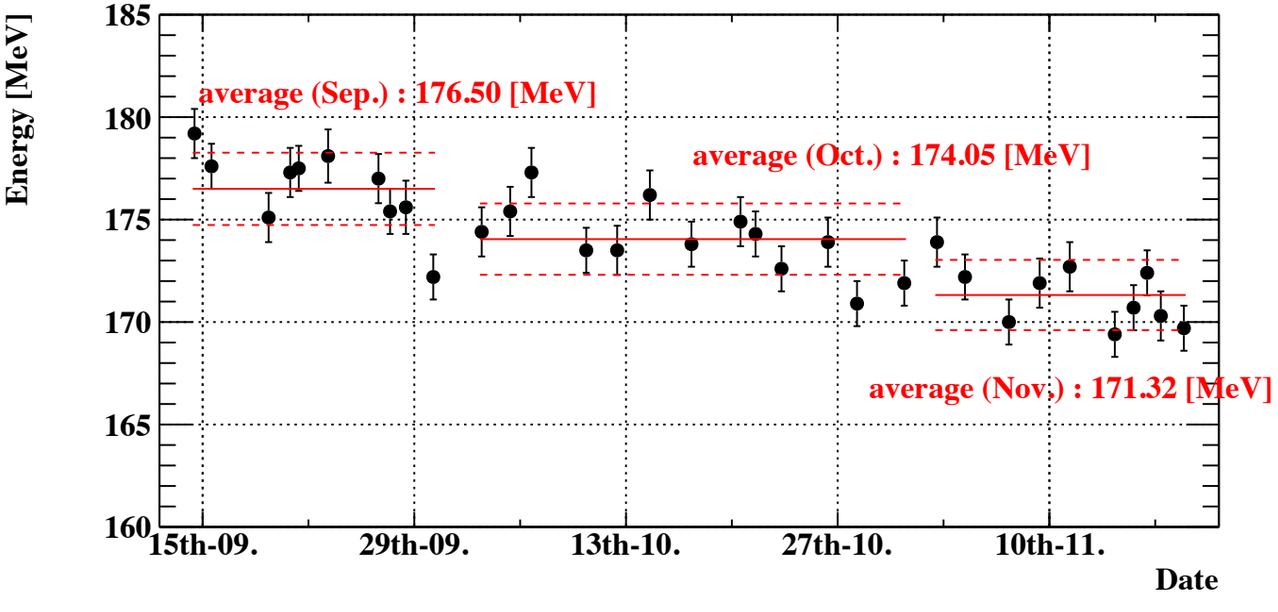
Calibration of 2022 data : E_γ

- Energy scale stability
  - Checked by off-beam calibration data : CWLi line and Cosmic ray
- CWLi line (17.6 MeV)

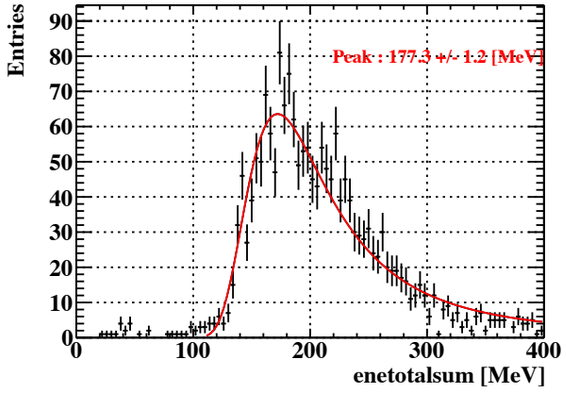


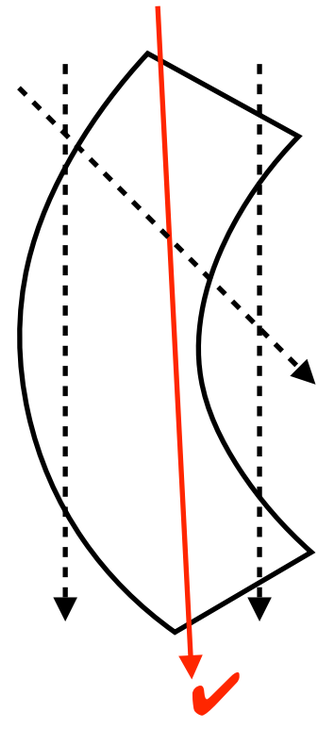


- Cosmic-ray



- Fit by Landau func.
- Inner/outer ratio cut to select cosmic event





- Calibration for rest period in 2022 is ongoing for reconstruction of E_γ

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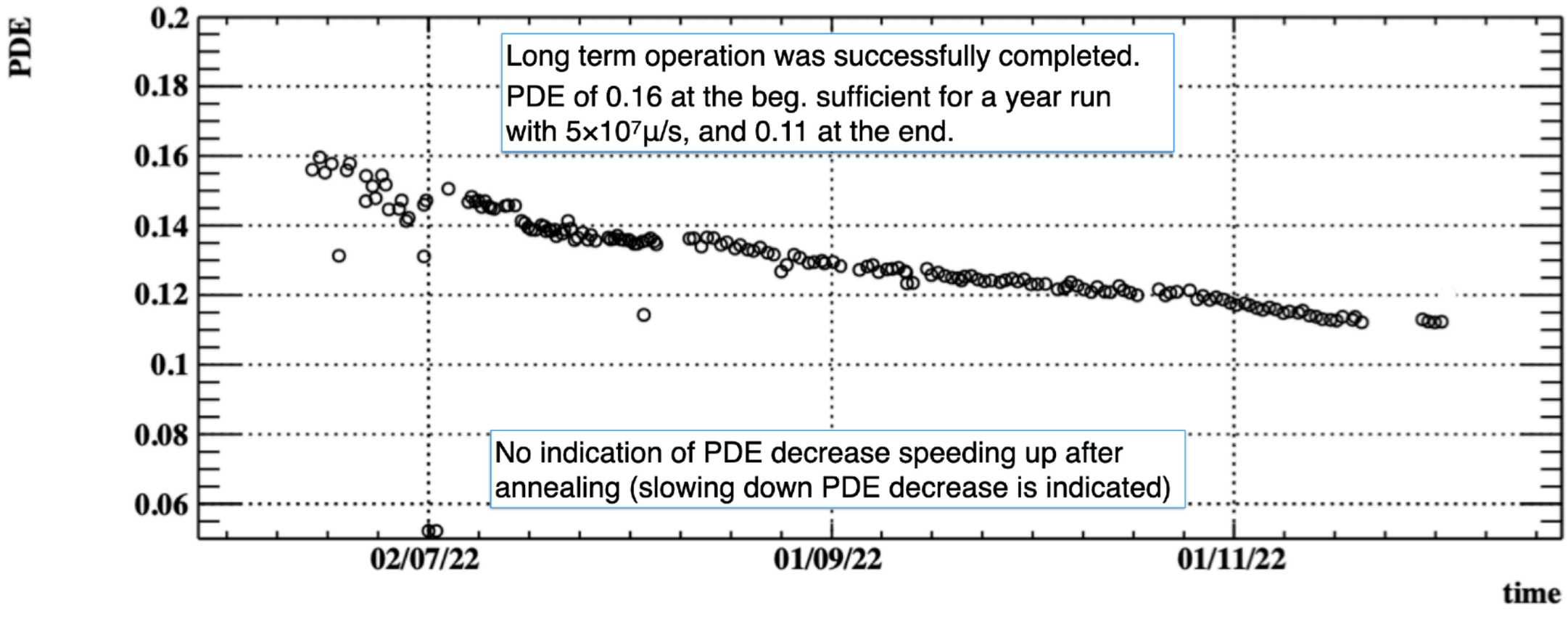
Annealing by Joule heating : PDE decrease

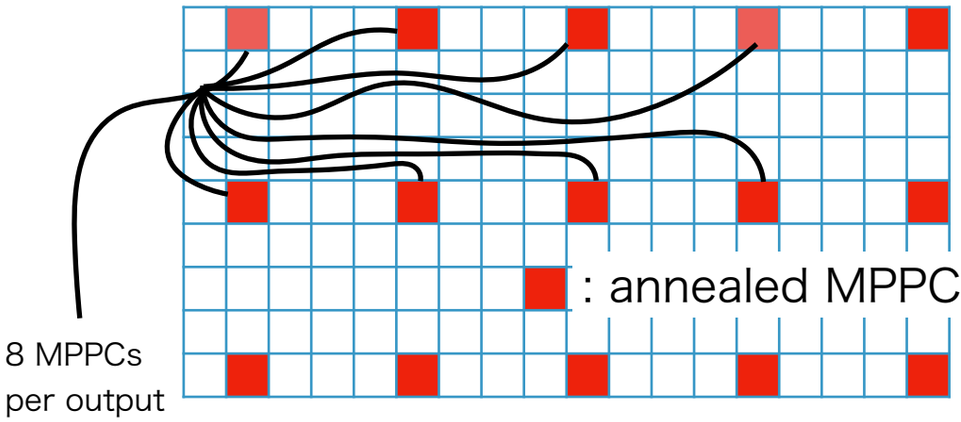
- Photon Detection Efficiency (PDE) of the MPPC decreased during beam time
  - known problem since 2017
  - (maybe) because of radiation damage by muon beam
- According to previous study, annealing (heating) procedure recovers the PDE
  - Using Joule heating of MPPC itself to heat up the MPPC

Averaged PDE history monitored during beam time using alpha-ray
- more precise calibration is ongoing for physics analysis

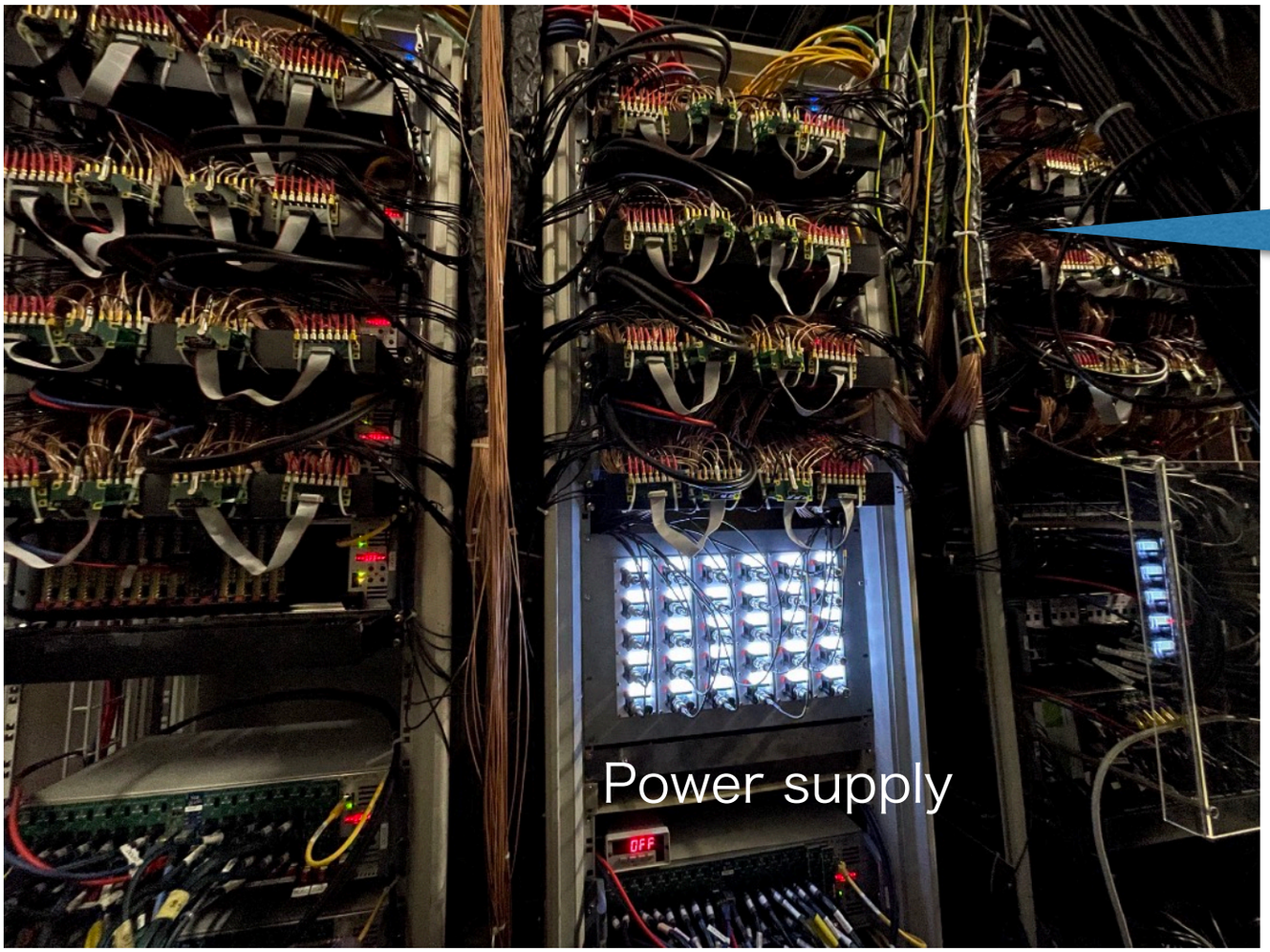


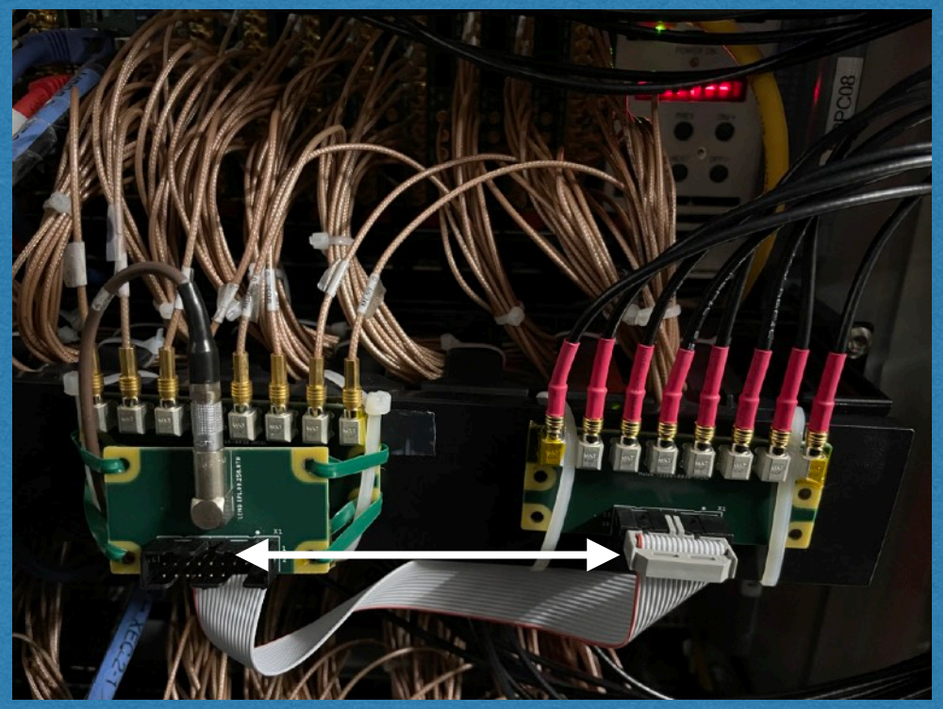
Annealing by Joule heating : Setup

- MPPC is annealed by Joule heating using a high current source and LED light
  - Heated with ~1.75W per MPPC
- MPPCs with an interval of 4 are annealed at once to avoid over heating
  - 256 MPPCs are annealed at once
    → 16 sets of annealing is required (~30h/set)



Power supply with large current : 250 mA/output, 60~80 V



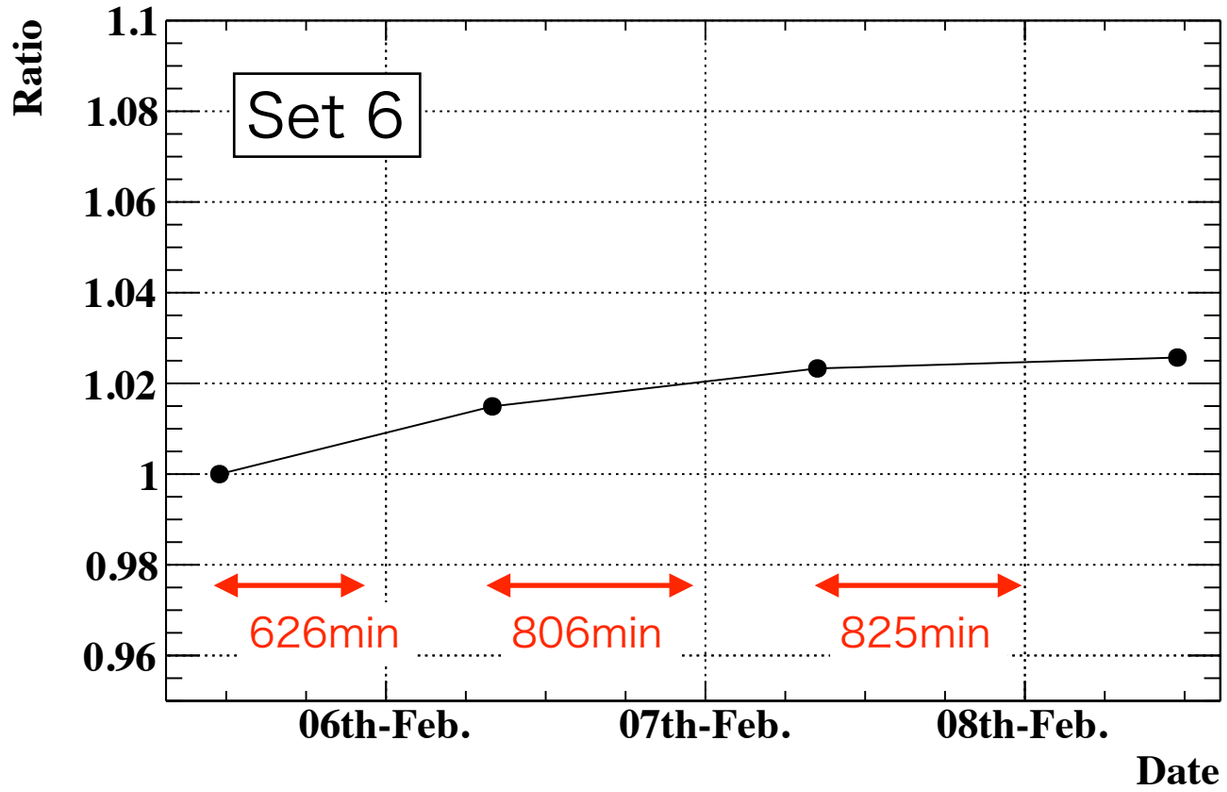


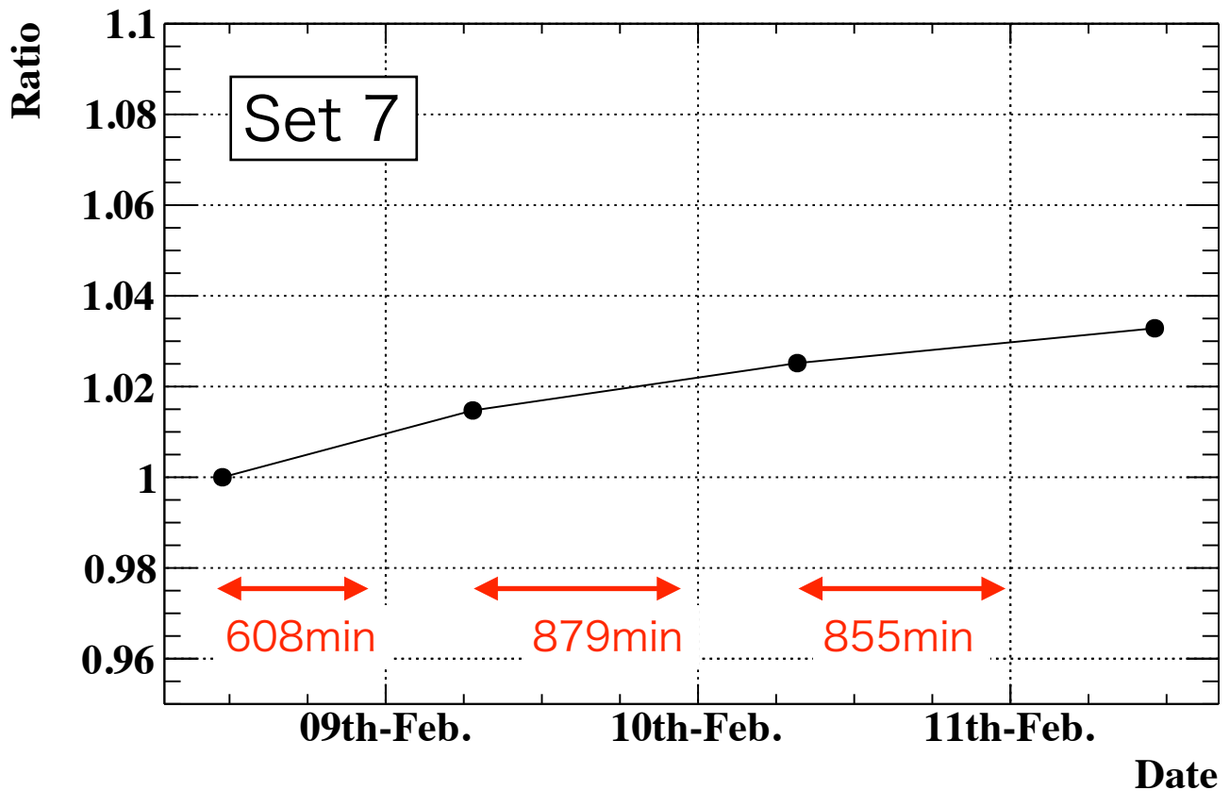
easily switch :
annealing mode ⇄ measurement mode

Blue LED

Annealing by Joule heating : Speed of PDE recovery

- Charge can be monitored to know a halfway progress of annealing
  - using visible LED installed in the LXe detector
  - Strong correlation exists between PDE recovery ratio for visible LED and VUV
    - [Recovery ratio for VUV] = 10 * [Recovery ratio for visible LED]
- (Two) Example of charge ratio : [after annealing]/[before annealing]
  - Averaged charge
- Saturation curve is seen in both
  - Three days annealing looks reasonable for one set of annealing

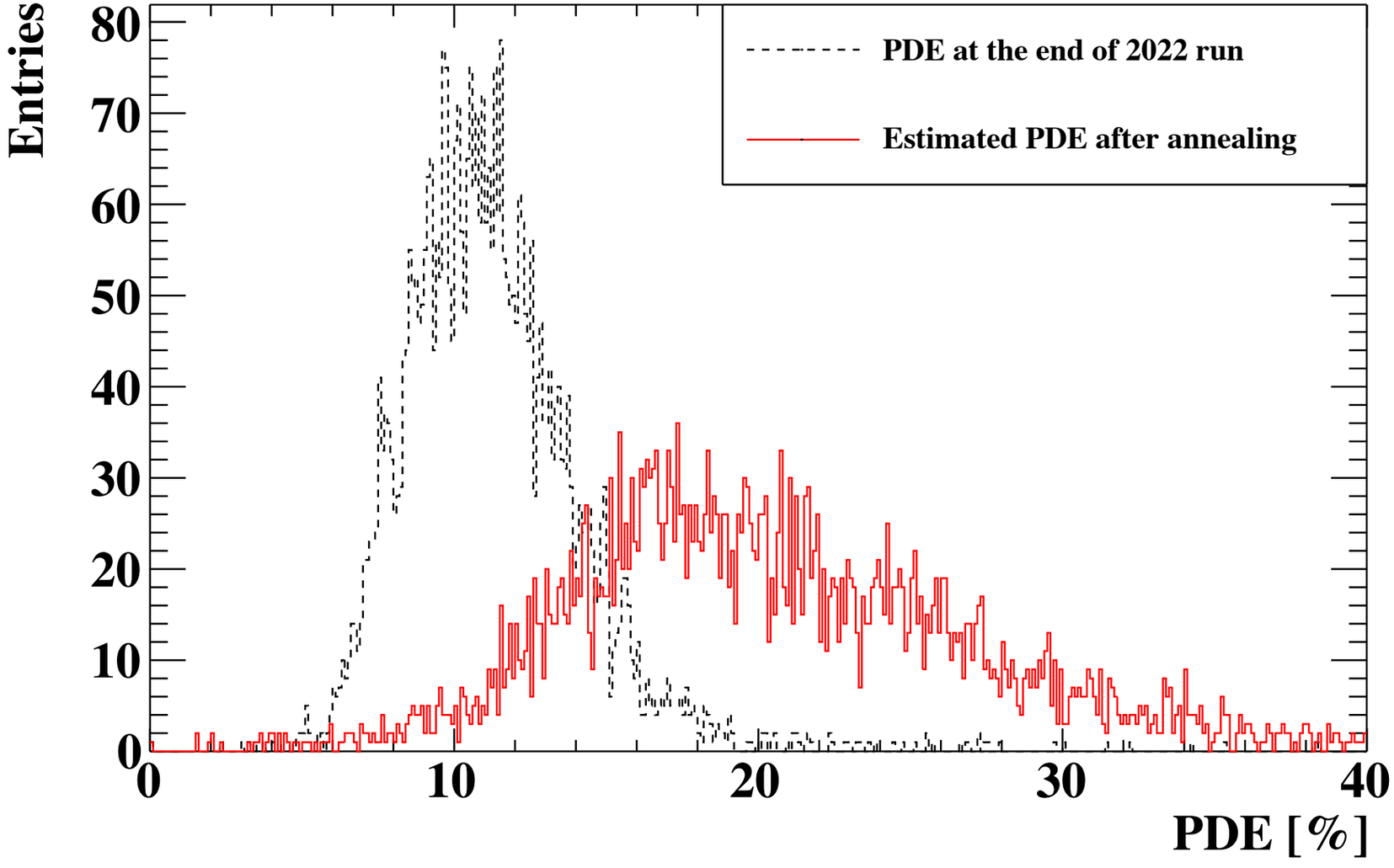




charge normalized by PMT charge and another set of MPPCs

Estimation of PDE recovery

- Strong correlation exists between PDE recovery ratio for visible LED and VUV
  - [Recovery ratio for VUV] = 10 * [Recovery ratio for visible LED]
  - -> can estimate the PDE value after the annealing without installing LXe
- In average, **Estimated PDE value : 21.01%** after the annealing in 2023
  - cf.) in average, PDE : 15.35% after the annealing in 2022
  - Estimated PDE may contain large error due to noisy data condition
- Enough PDE value to run through this year's beam time



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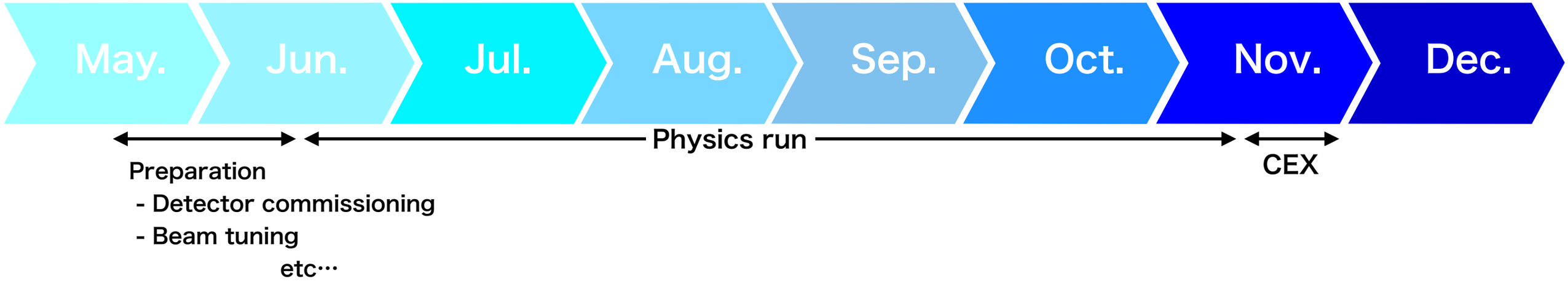
Prospect for 2023 run

- Beam time assignment for MEG II : **16th May. — 30th Nov.**
  - Detector commissioning and Beam tuning for first 1 month
  - Physics run for ~20 weeks
    - Beam intensity will be adjusted depending on the situation : PDE, etc…
  - Charge EXchange (CEX) run is planned on late Nov.
    - Energy, Timing calibration for the liquid xenon detector

- Aiming to correct further data (better statistics, better quality) than 2022

MEG II beam time in 2023

Assigned beam time : 16th May. - 30th Nov.



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- MEG II experiment searches for charged lepton flavor violation : $\mu^+ \to e^+ \gamma$

- Full period physics data was taken in 2022
- Currently calibration is ongoing
  - (for LXe detector) energy scale, uniformity, timing…
  - Calibration of data from Sep. to Nov. : done
  - Rest of calibration (Aug. and Jul.) is worked in progress

- PDE recovery of the MPPCs in the liquid xenon detector was conducted
  - By annealing with Joule heating
  - Annealing of all MPPCs : done
  - PDE value after the annealing is estimated using visible LED
    - in average, ~21%
    - Enough PDE value for 2023 run

- MEG II beam time is assigned in 2023 : 16th May. - 30th Nov.

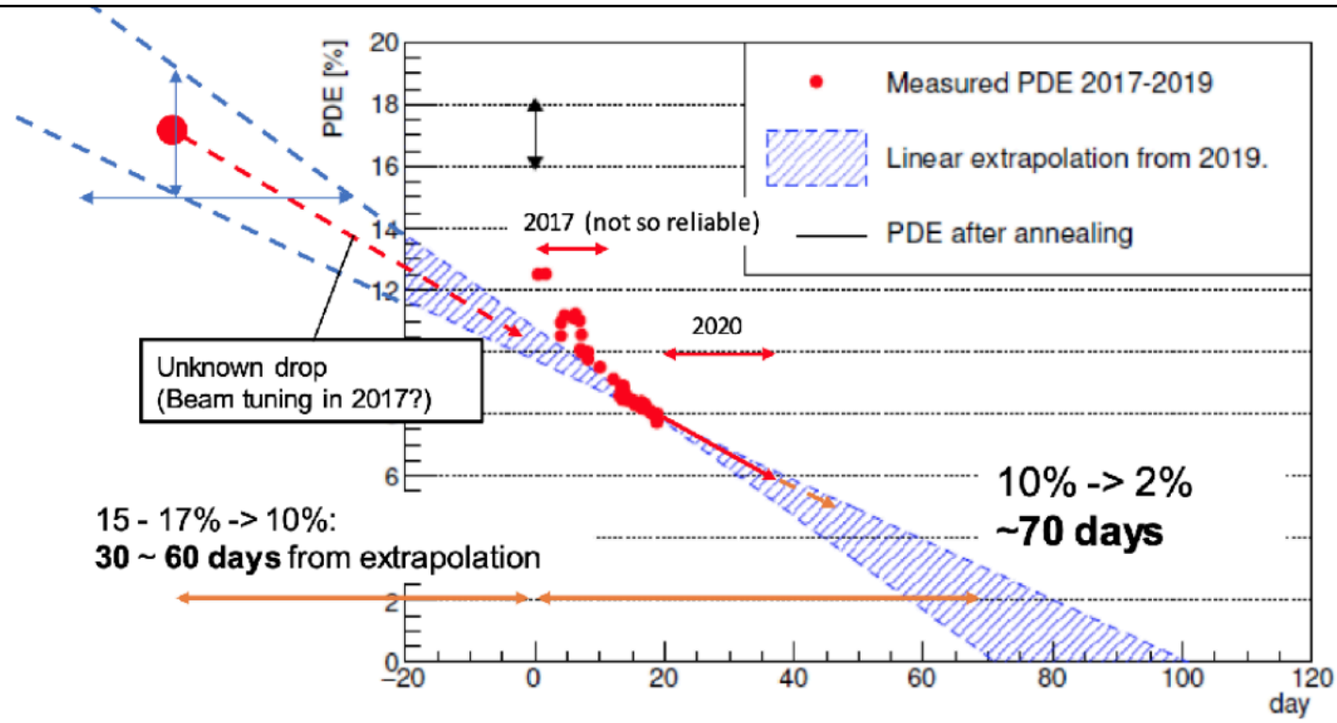
Back up

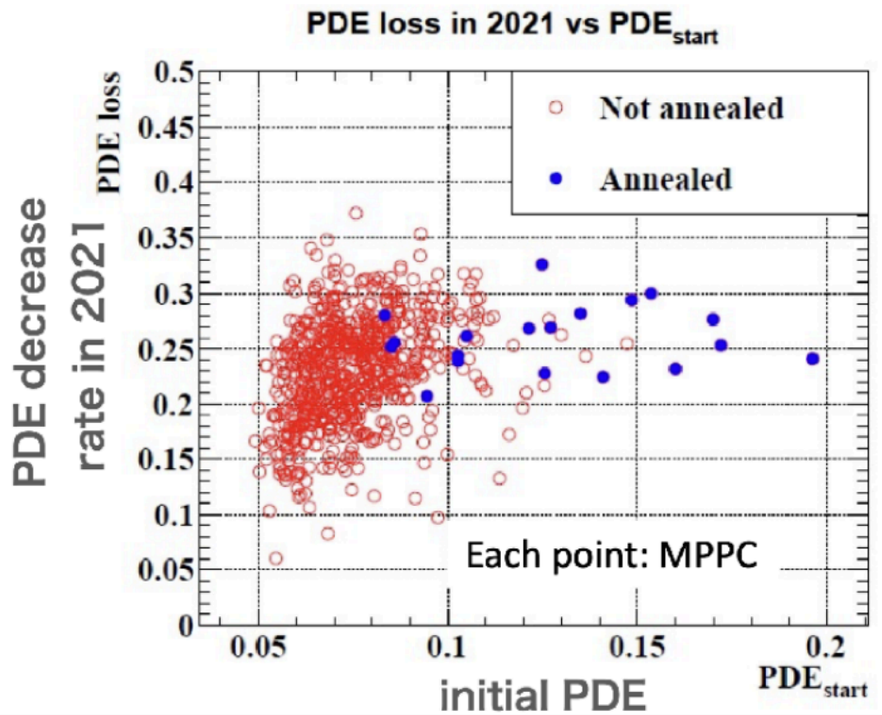
PDE decrease

Slide from T. Iwamoto (15aA562-4)

γ detector (LXe) Issue

- MPPC PDE decrease
  - observed in 2017 under muon beam
  - The cause to be investigated
  - Based on 2021 operation, PDE will change from 16% to 2% in ~100 days MEG II intensity
  - Annealing recovers PDE fully
- Strategy for run 2022
  - LXe MPPC can sustain ~ 120 days with 5×10^7 μ/s
    - Beam intensity optimization necessary
  - Annealing for all MPPCs during accelerator winter shutdown period

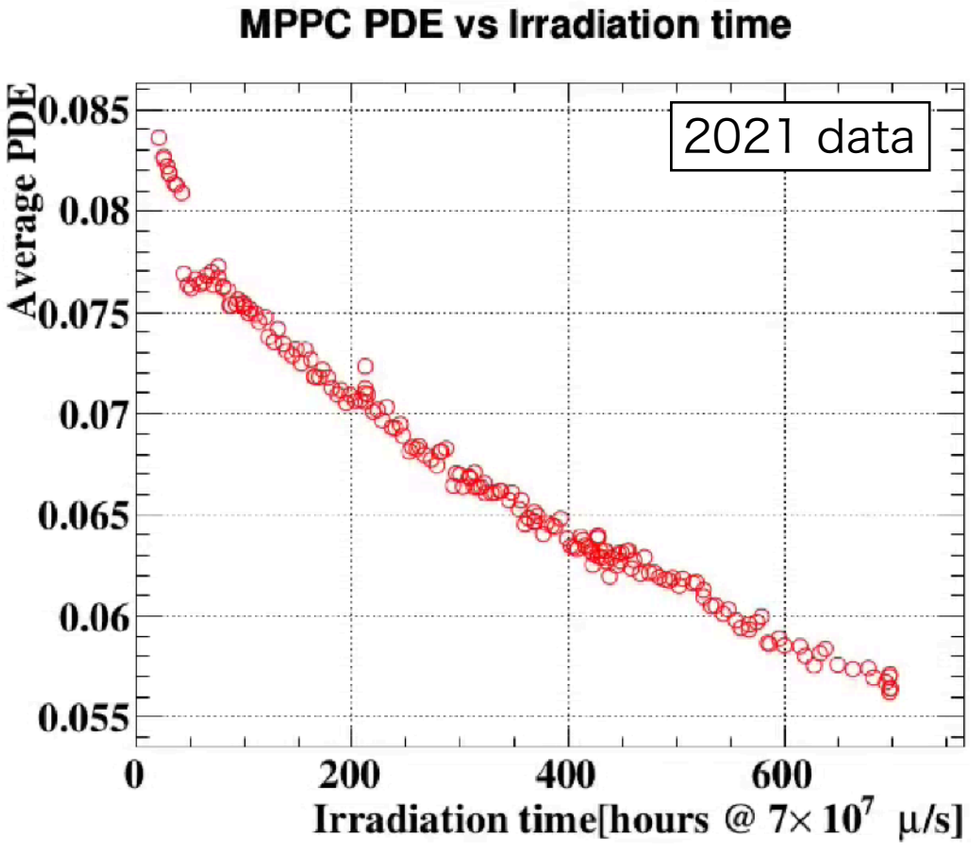


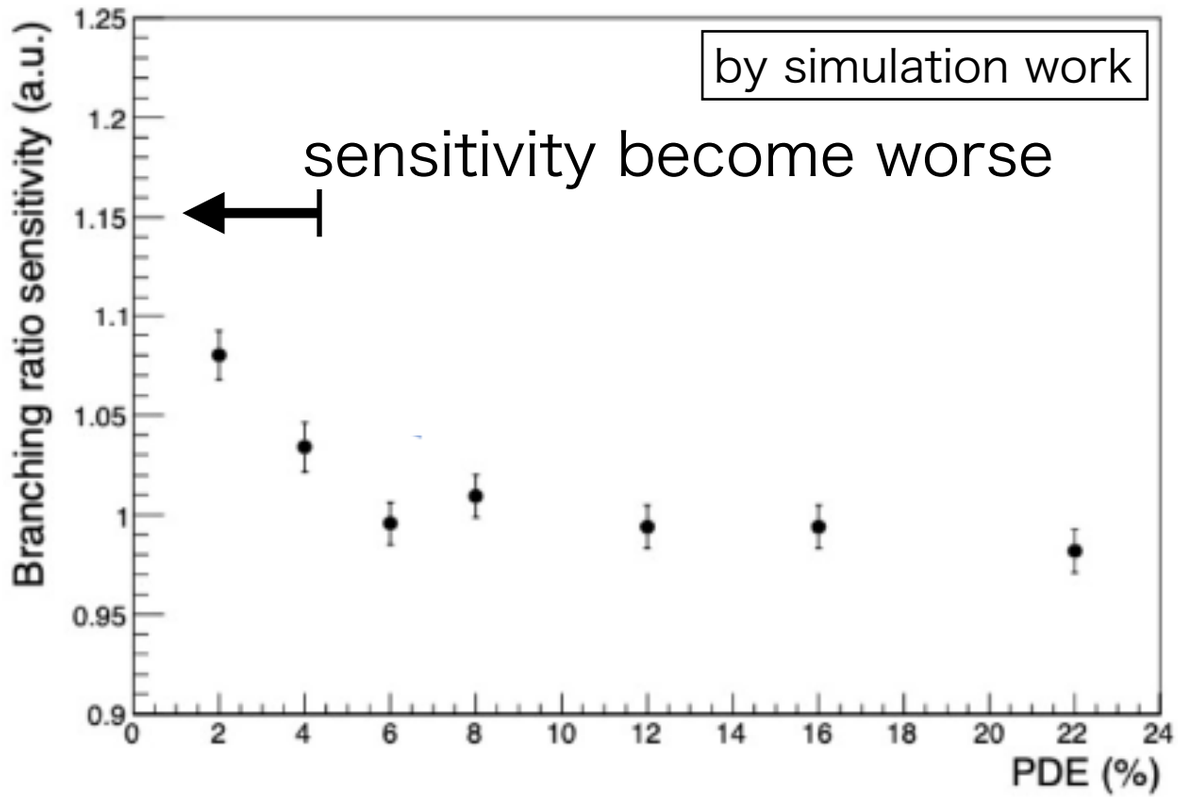


Liquid xenon detector : PDE decrease & Annealing

- Photon Detection Efficiency (PDE) decrease was observed in 2021 run (known problem since 2017)
  - Averaged PDE : 8.4% → 5.6%
- It worse the sensitivity if PDE becomes lower than ~4%

- PDE recovery by annealing was conducted before the beam time 2022
  - There are two method
    - Hot water annealing : easy but low temperature (45℃)
    - Joule annealing : established by previous work (but small number)

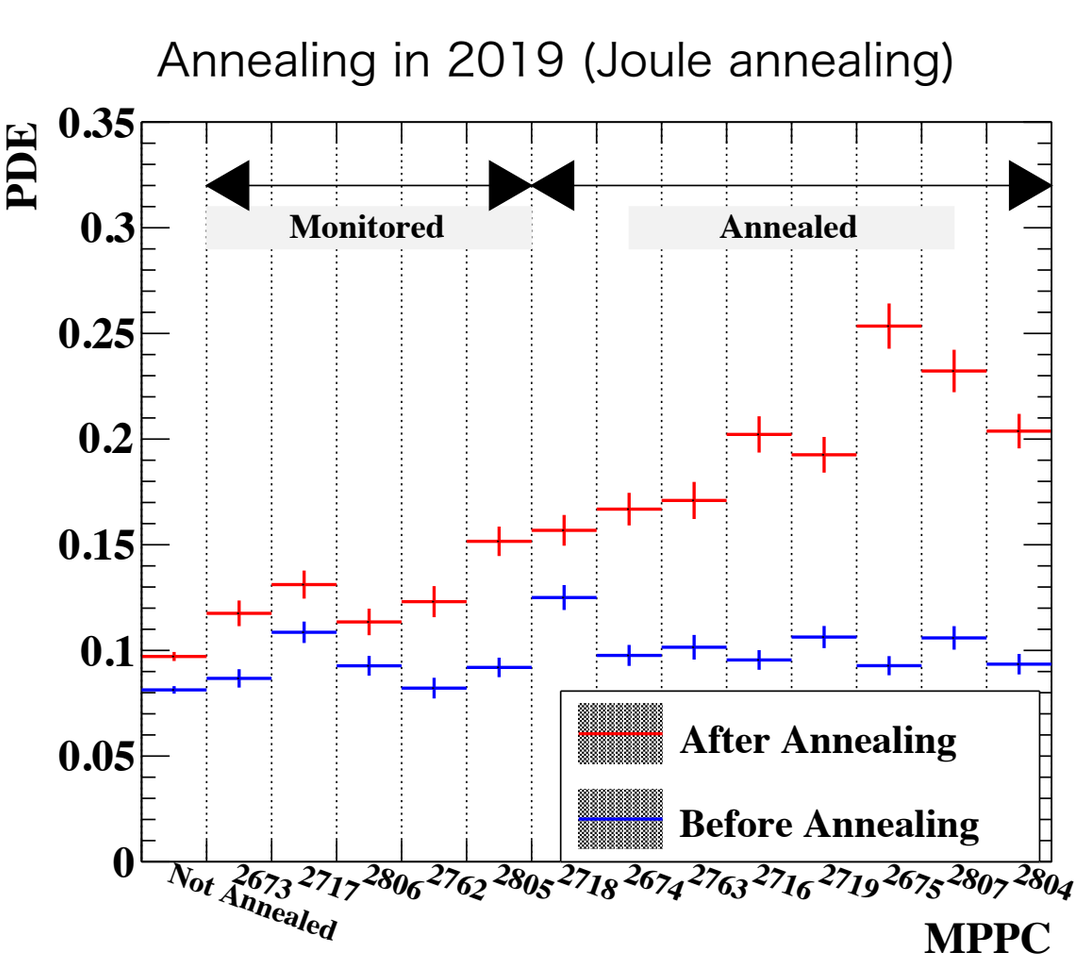


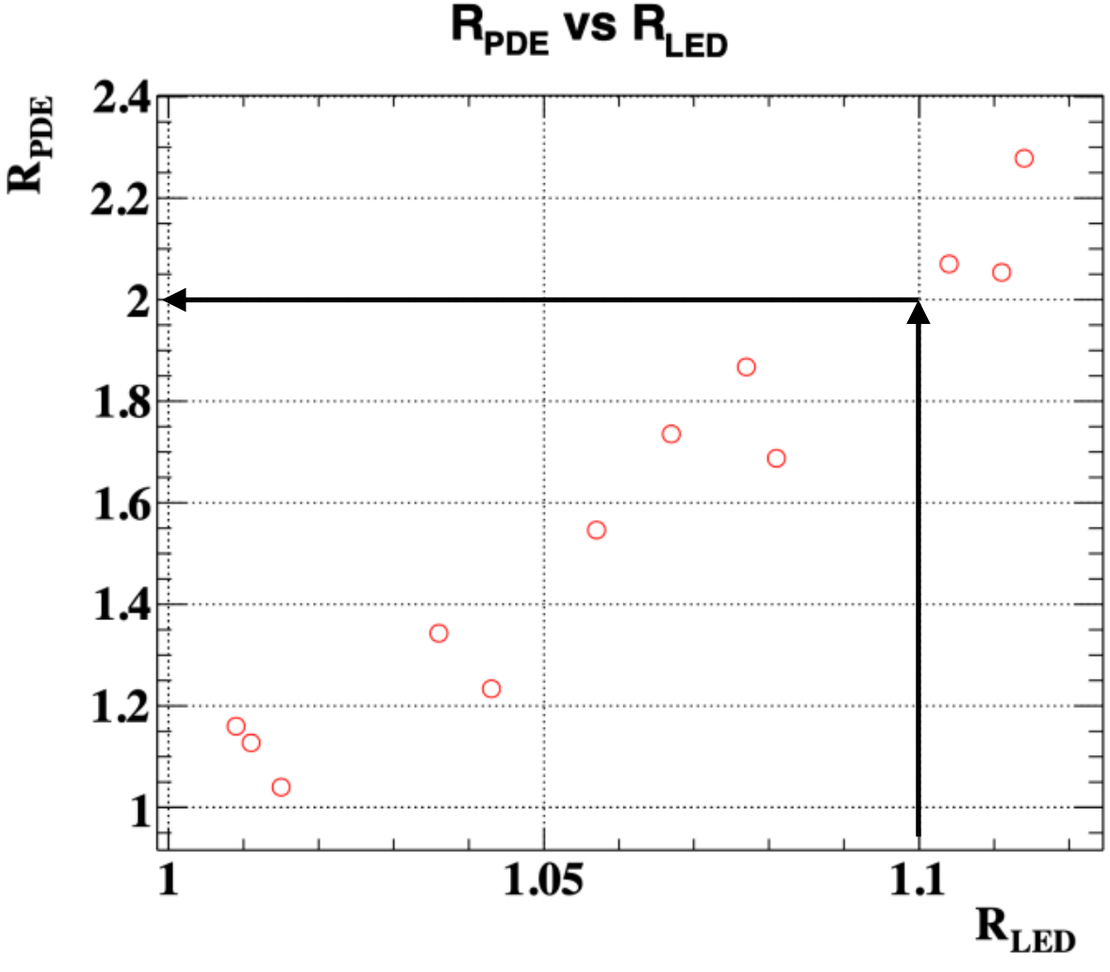


PDE estimation with visible LED

- By previous work,
  - Recovered amount of charge (PDE) for LED can be translated into that for VUV
    - $\Delta R_{PDEforVUV} = 10 \times \Delta R_{PDEforLED}$
      - relatively 10% recovery for LED light corresponds to relatively 100% recovery for VUV-light
- The PDE value is estimated by visible LED during the annealing period

- In principle, absolute PDE value will recover to 20% (initial value at manufactured)

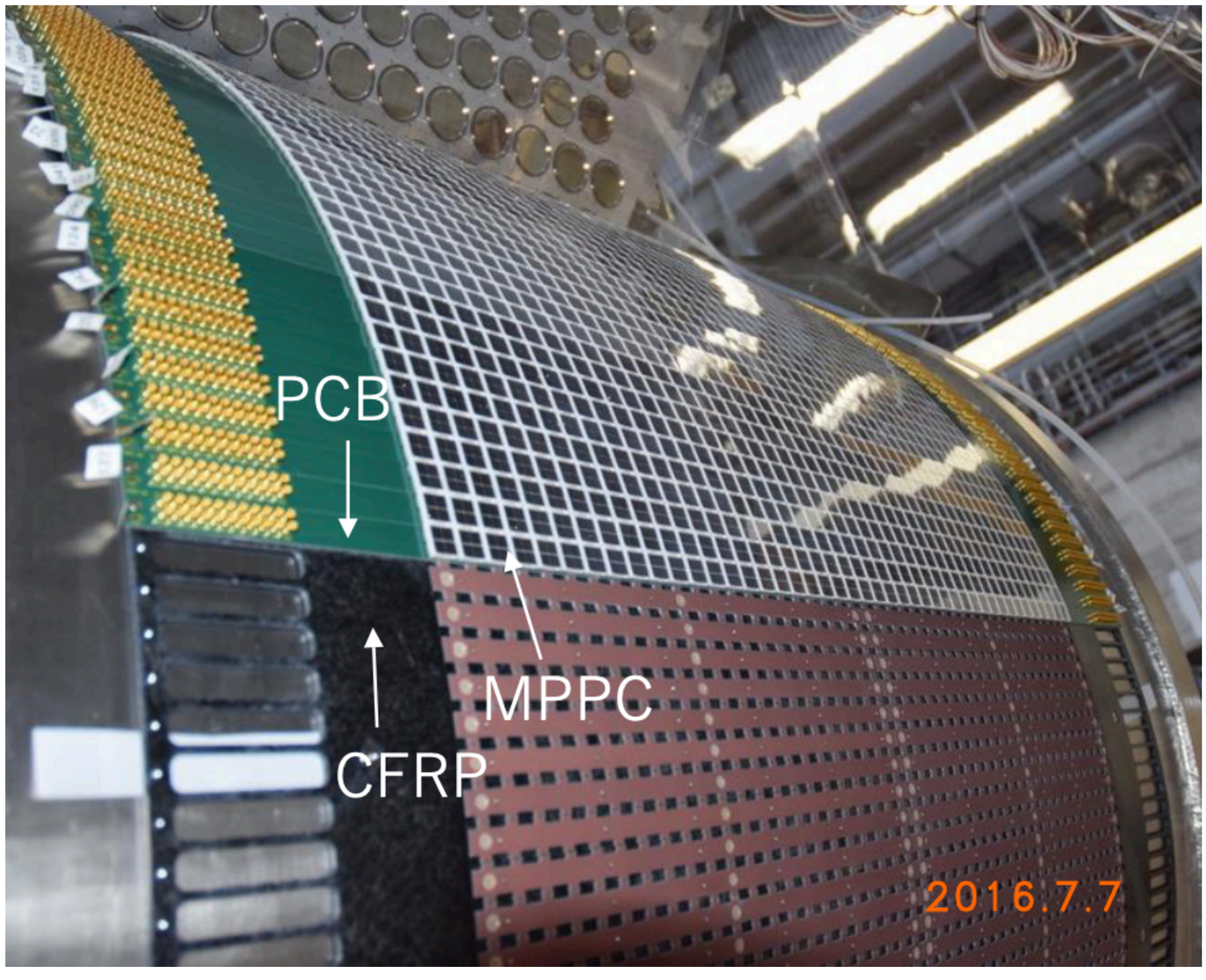




Temperature limitation

CFRP should not exceed 45℃

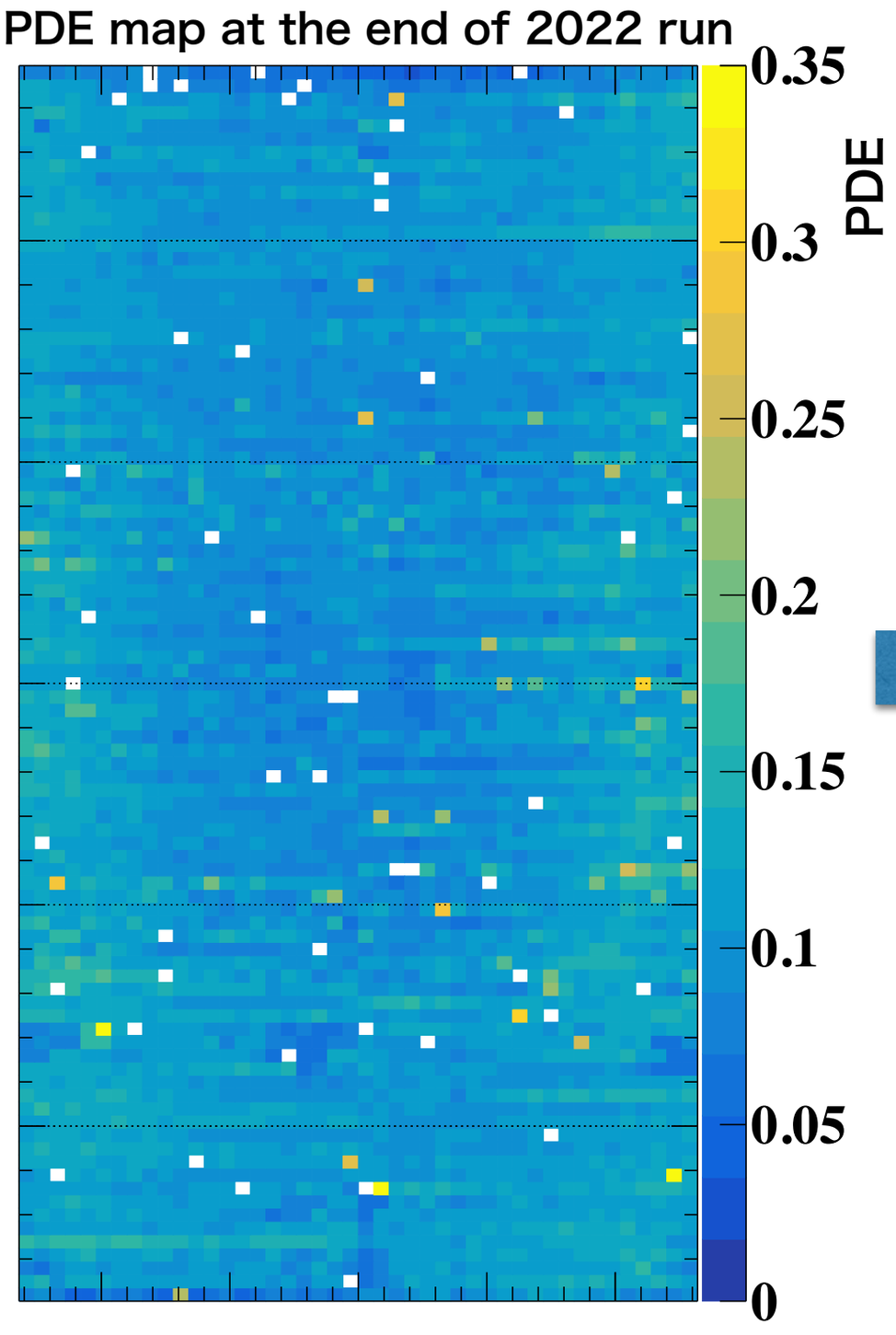
→ the maximum temperature setting in hot water annealing must be 45℃

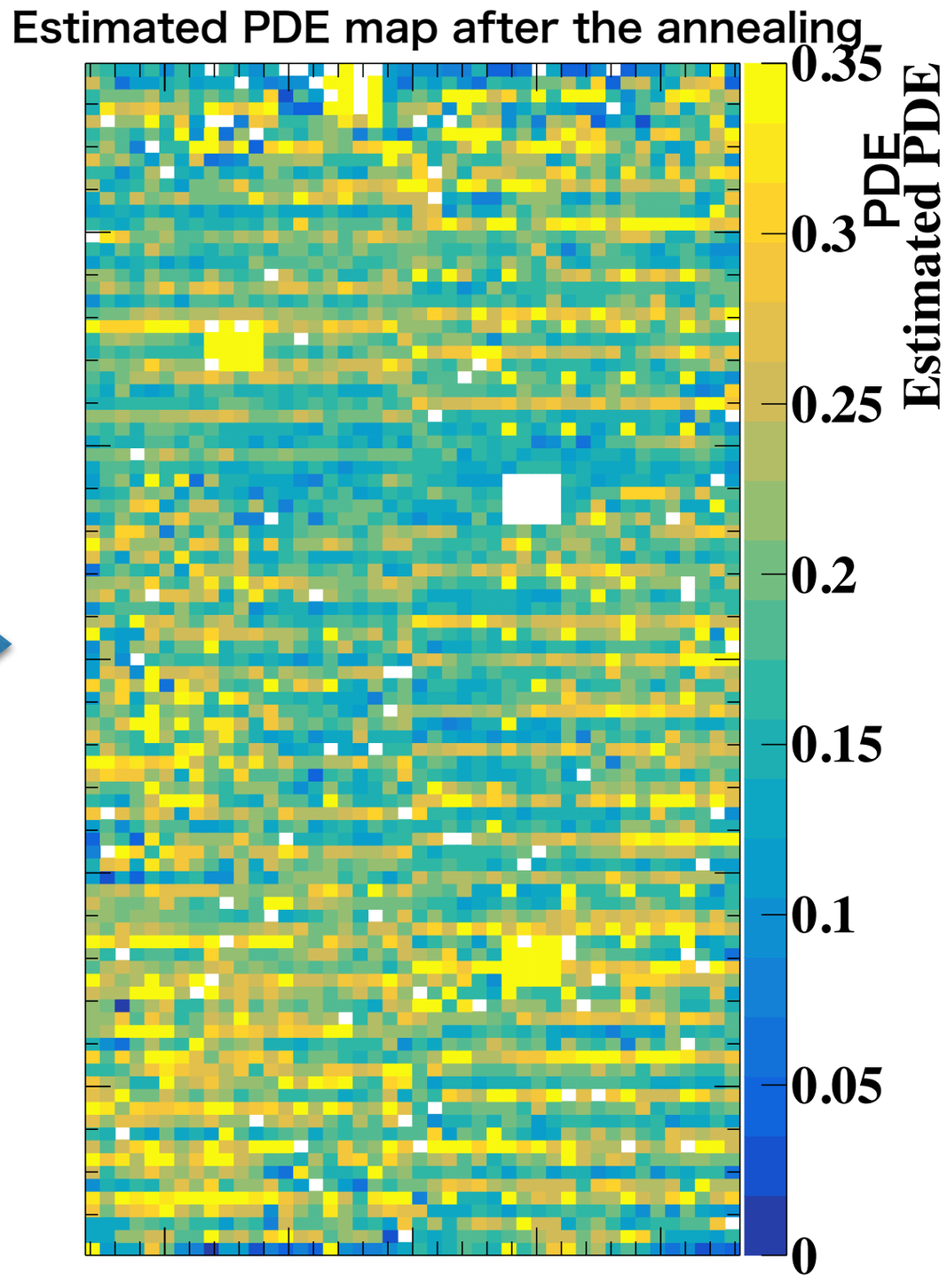


- Temperature limit
  - MPPC: 100°C
  - PCB: 120°C
  - **CFRP: 45°C**
  - Glue: 65°C

Estimation of PDE recovery

- Estimated PDE value

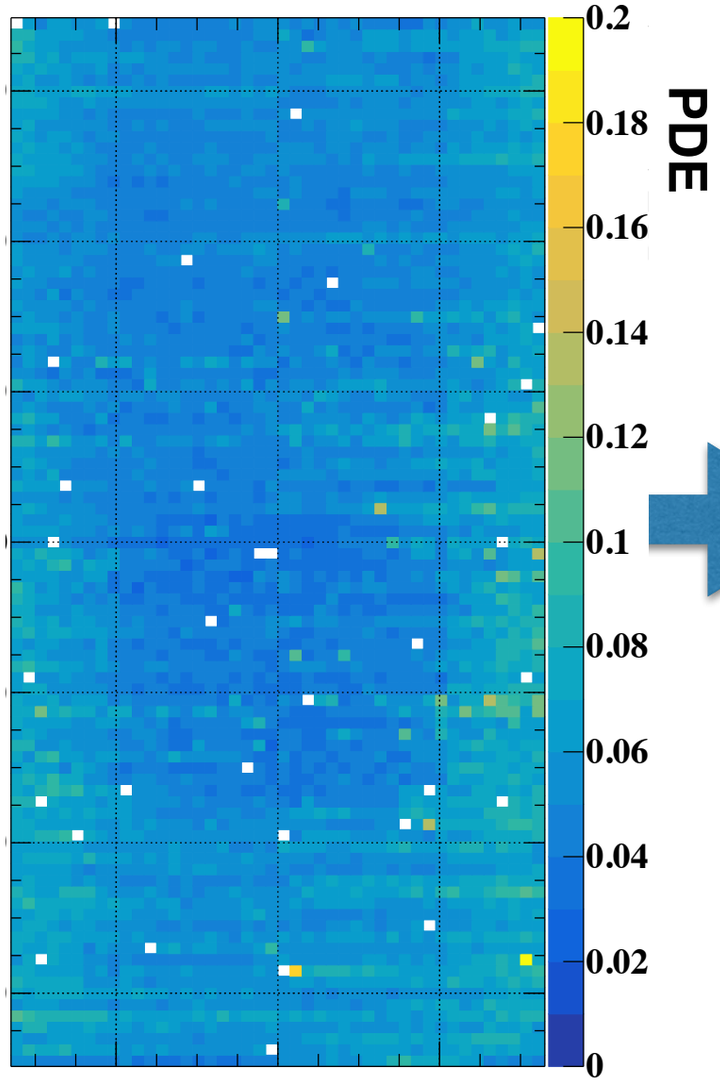




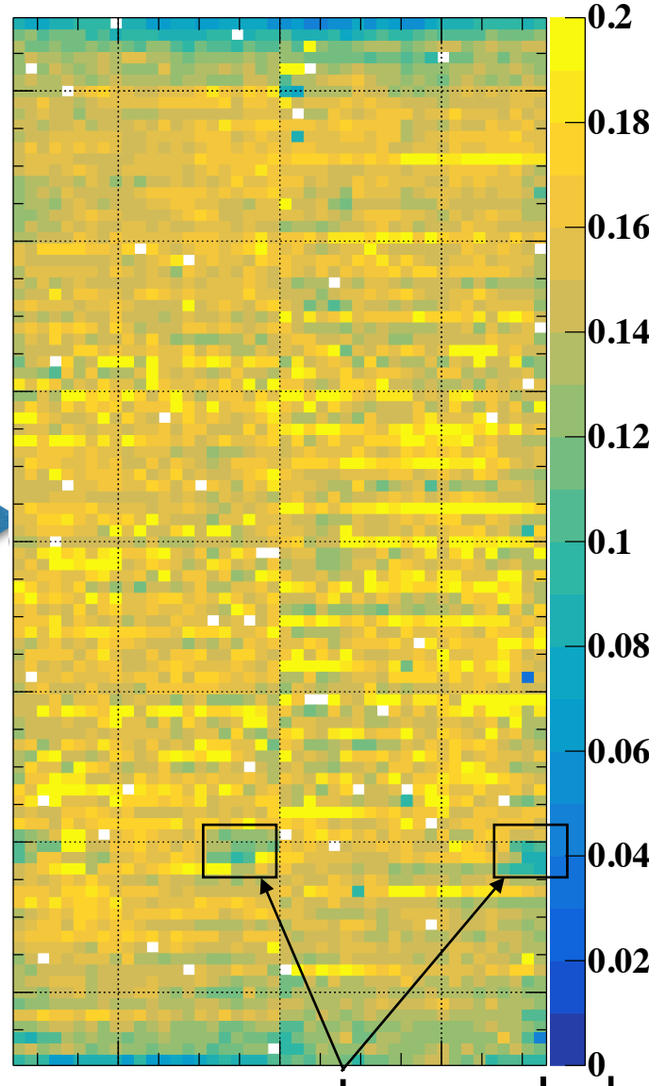
PDE after the annealing 2021 with LY correction

- MPPC PDE before/after the mass Joule annealing in 2021
- Light yield is corrected using calculated PMT QE value : Ayaka's slide in the collaboration meeting 9/29, 2022

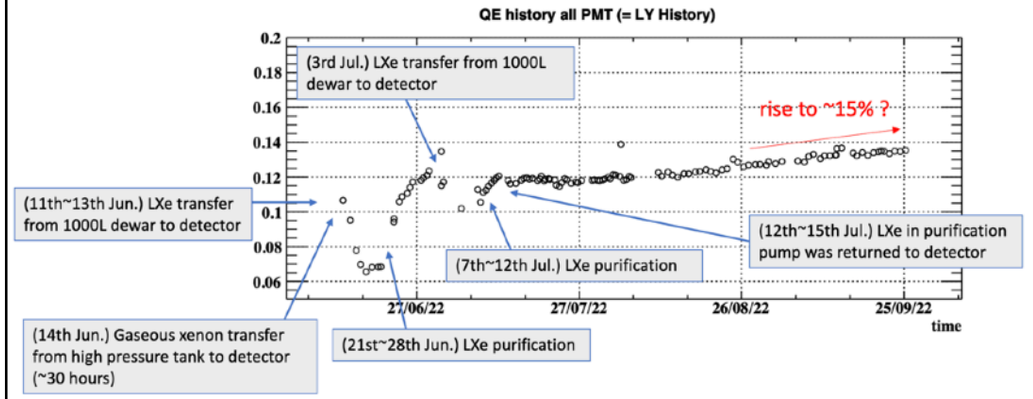
- The PDE value after annealing is updated with LY correction
- The averaged PDE after annealing : ~15%



PDE after annealing
with LY correction



LY History



Assume PMT QE does not change. → Measured apparent QE variation is due to LY.
It was concluded that LY had recovered fully on 12th Jul. and LXe purification was finished.
LY has been rising since the end of Jul.
LY at the end of the last year's beamtime was 14.8%.
LY may continue to rise.
Impact of absorption need to be investigated.

PDE before/after the annealing
with LY correction (after annealing)