MEG II実験液体キセノン検出器の2024年ランの運転状況および2025年ランに向けた取り組み

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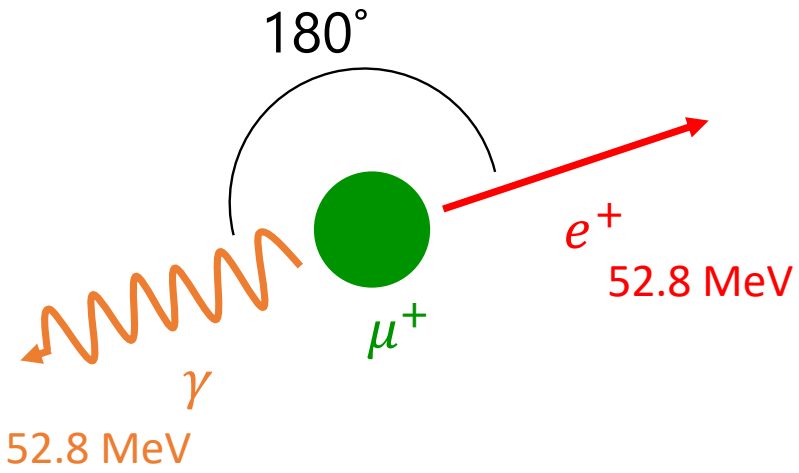
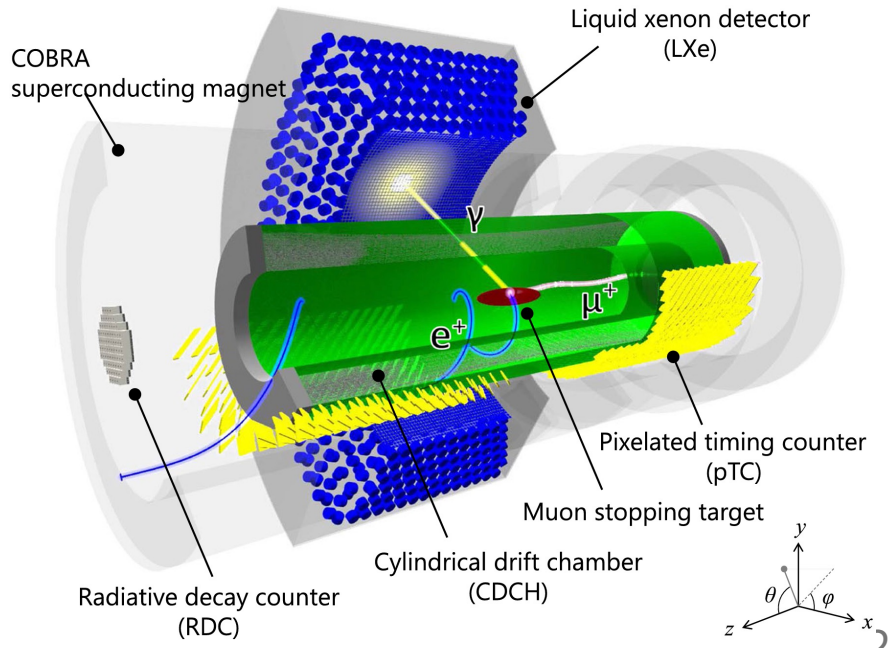
日本物理学会2025年春季大会

MEG II Experiment

- MEG II Experiment
  - Search for $\mu \rightarrow e\gamma$
    - charged Lepton Flavor Violation
    - with $2-5\times10^{7}$ μ/s beam rate at Paul Scherrer Institute (PSI)
    - Data taking from 2021 to 2026
  - Expected branching ratio of $\mu \rightarrow e\gamma$ from SUSY-GUT: $\mathcal{O}(10^{-13}-10^{-14})$
  - Prospect sensitivity: 6×10^{-14} (in 2026)
- MEG II Detector
  - Positron
    - CDCH: Tracking of positron
    - pTC: Measure time of positron
  - Gamma-ray
    - LXe detector: Measure position, time, energy of gammma-ray
      - Today's topic

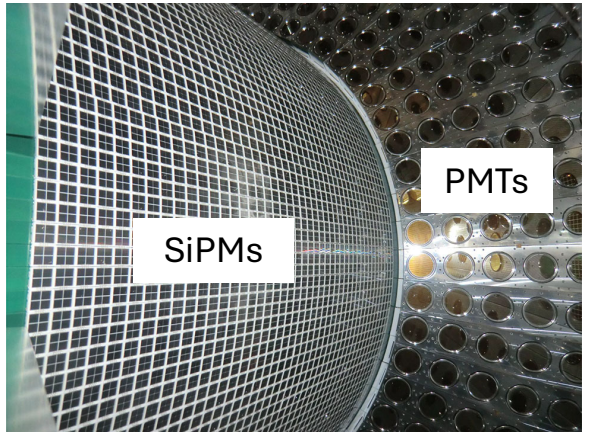




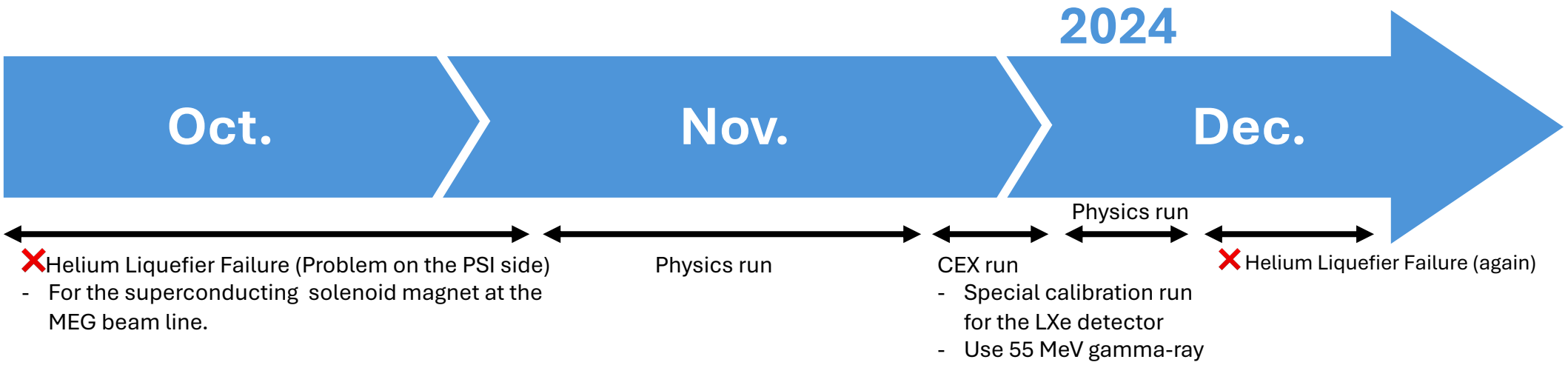
Liquid Xenon (LXe) Detector

- LXe Detector
  - Measure position and time of interaction point, energy of gamma-ray
  - Used 900 L LXe as scintillator
    - Wavelength of scintillation light of LXe: $\lambda = 175\ \mathrm{nm}$ (Vacuum Ultraviolet (VUV) region)
  - Used PMTs and SiPMs which are sensitive to VUV light
    - 668 2-inch PMTs
    - 4092 SiPMs (SiPMs size: 15 mm^2)

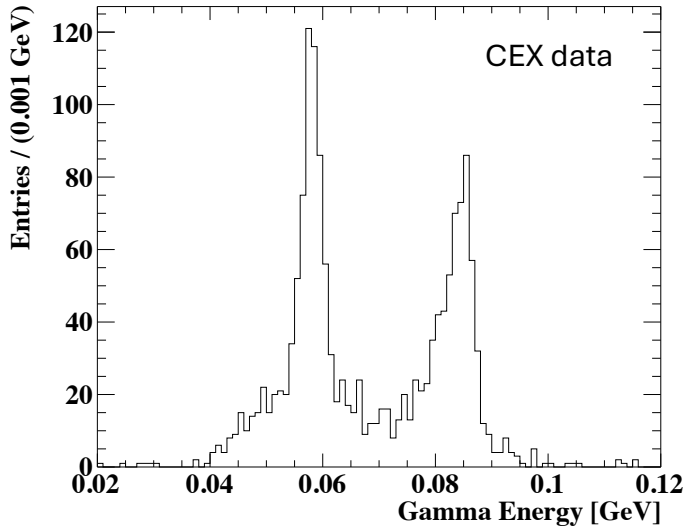
- LXe detector structure
  - LXe vessel
    - Filled with LXe
  - Theraml insulation layer
    - Vacuumed
  - Other parts
    - Gate valve on the top
    - etc...



LXe Detector Status in 2024



- Due to failure of LHe supplier, physics run couldn't start on schedule
  - Originally start from June
- Physics run started on 11th November 2024 with intensity ~4×10^7 μ/s
- Xenon leak happend but it doesn't affect data quality by appropriate calibration
- Calibration of sensor is ongoing



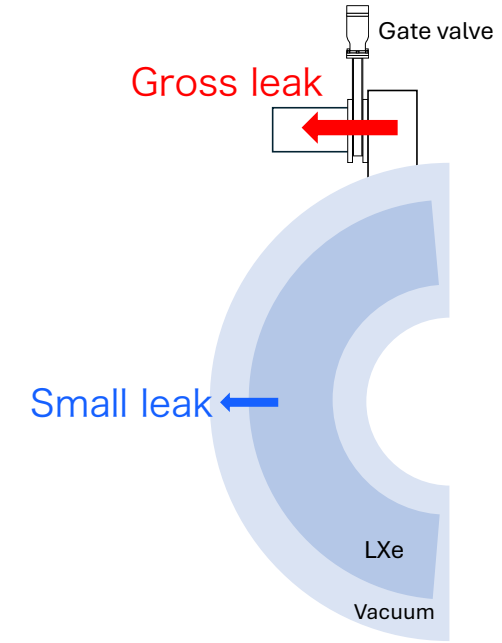
Xenon Leak

"Gross xenon leak" happened

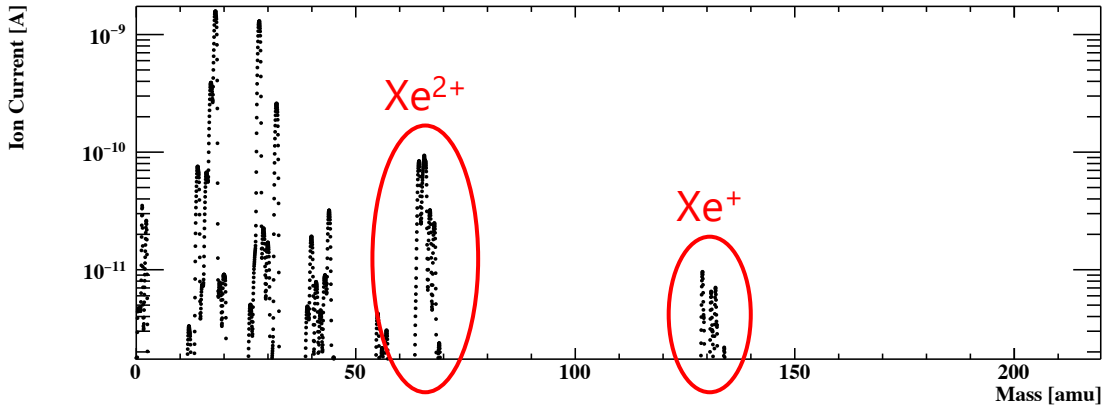
- Unexpected open of gate valve which separate the detector and atomosphere
- Fixed by blowing compressed air to the gate valve for the close operation

"Small xenon leak" happened

- leak from detector LXe vessel to insulation layer
- Monitored during MEG II run

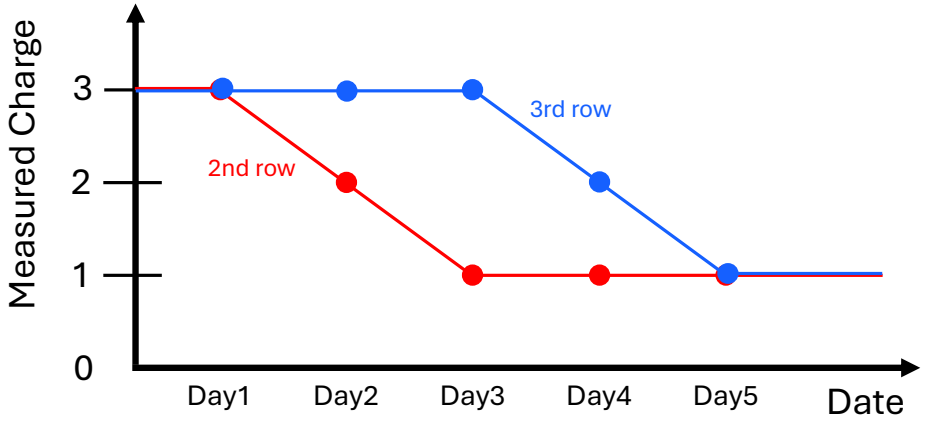


Confirm xenon peak by mass spectrum for both leaked position



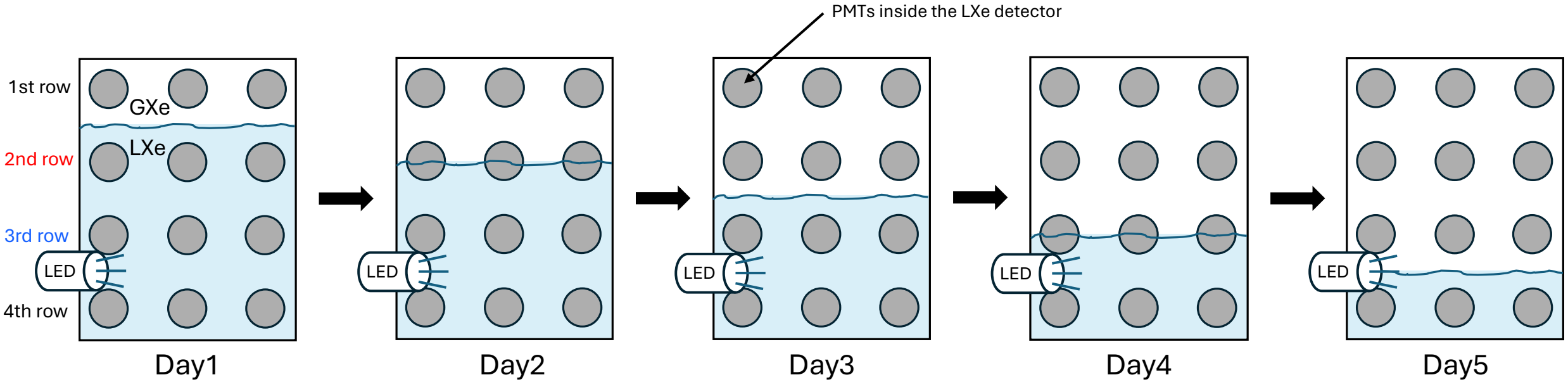
Detection of Xenon Leak Using PMTs and LEDs

- The number of detected LED photons in the liquid phase is about 2-3 times higher than in the gaseous phase
  - LED located in LXe
  - Due to reflection of LED light at the liquid/gas interface



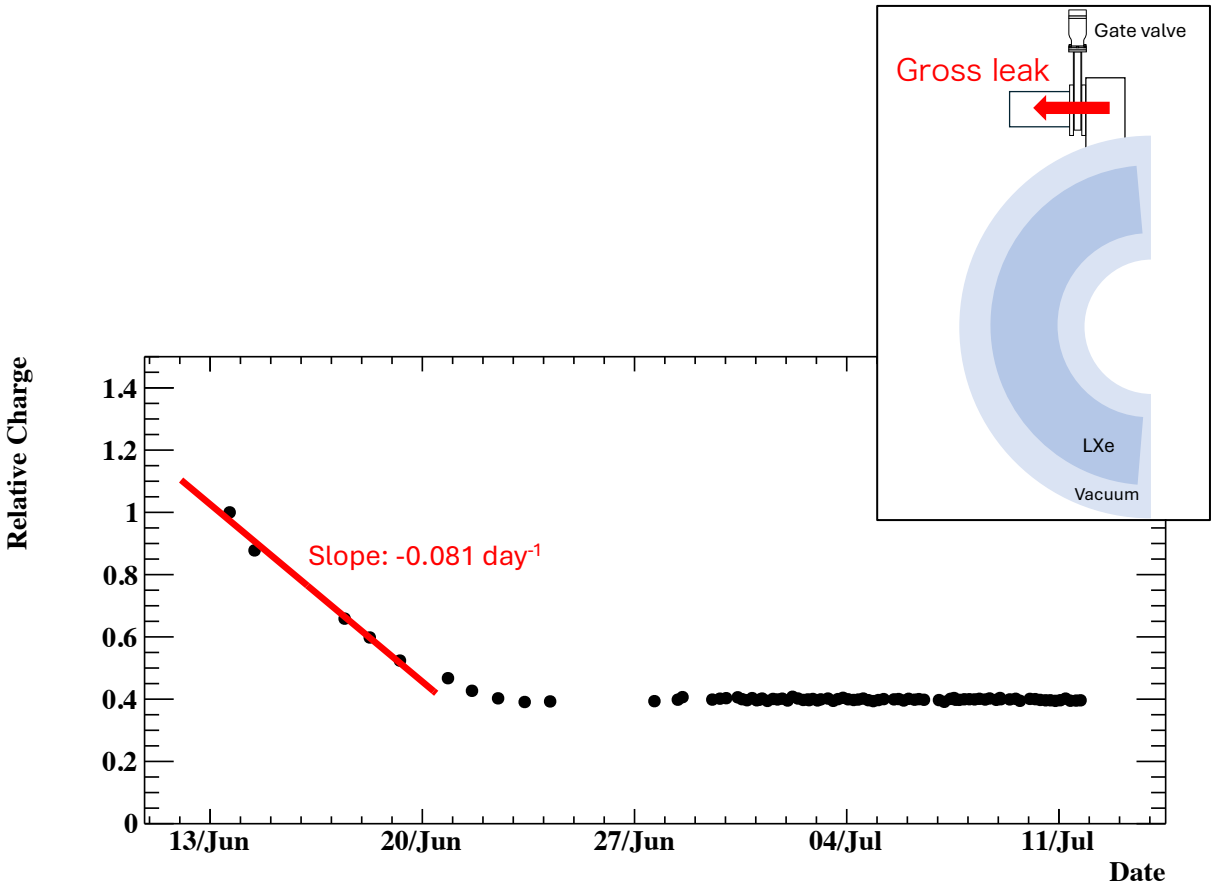
- This allows us to estimate the liquid level
  - By tracking the charge for PMT

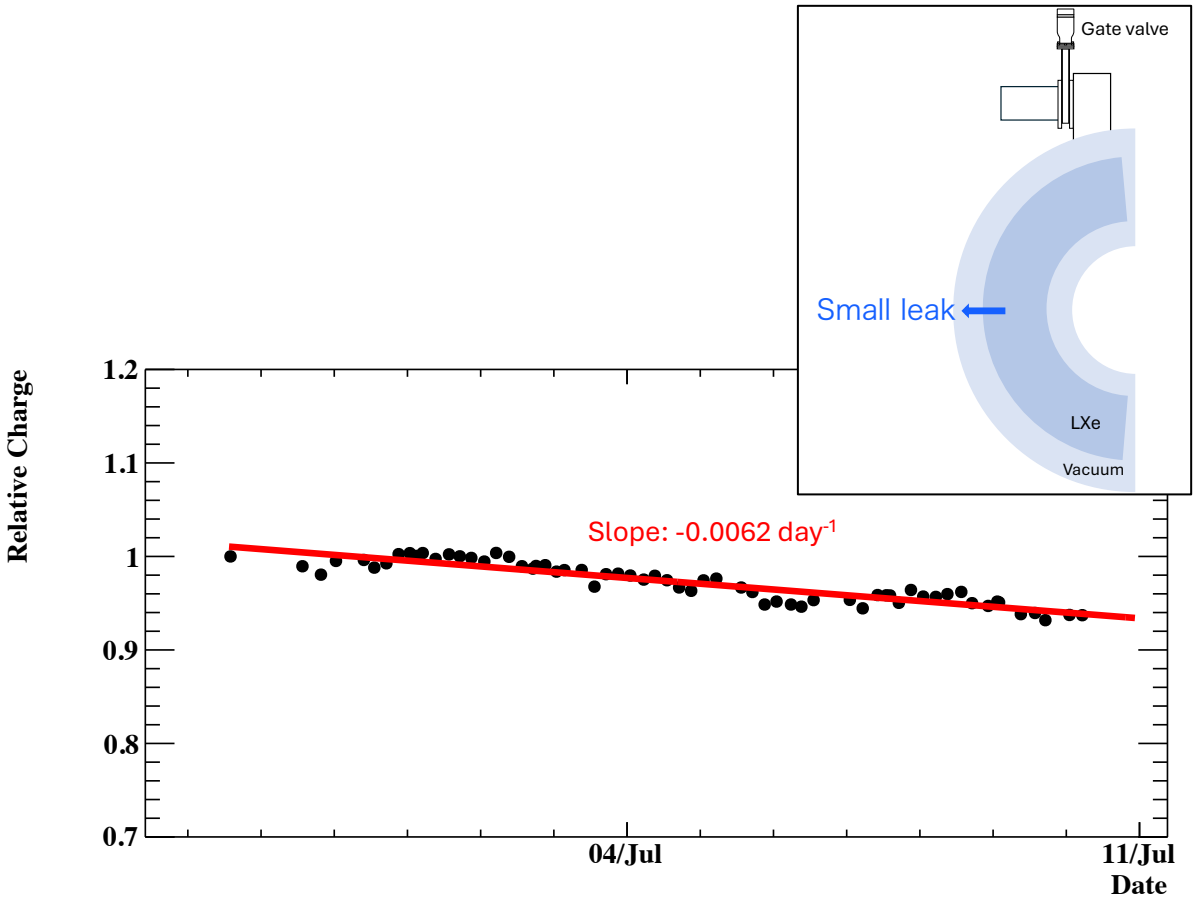
- Xenon leak can be detected by this method



Xenon Leak Rate

- Xenon leak rate
  - Gross leak: 5.9 kg/day
  - Small leak: 0.29 kg/day





Amount of Lost Xenon

	Leak Rate [kg/day]	Period of Leak [day]	Amount of Lost Xenon [kg]
Gross Leak	5.9	14	83
Small Leak	0.29 (0.78)	133 (26)	59

Leak rate increased during run due to the pressure increase of LXe vessel

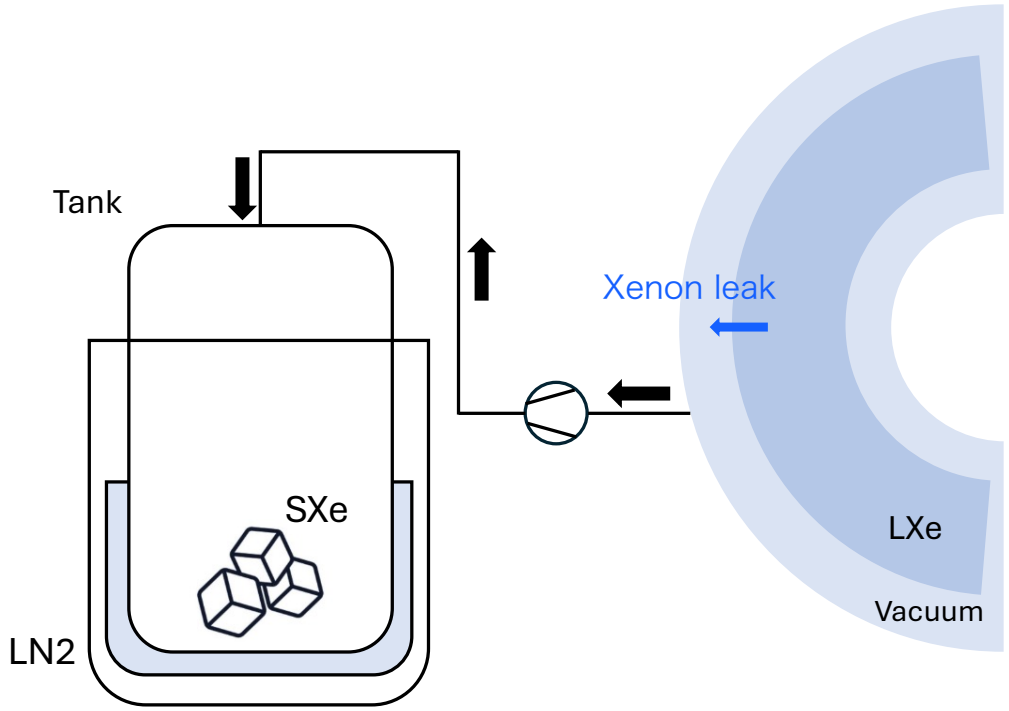
- Total amount of lost xenon in 2024: About 140 kg

- Refill xenon before 2025 run
  - To compensate lost xenon

Xenon Capture

	Leak Rate [kg/day]	Period of Leak w/ Xenon Capture System [day]	Amount of Lost Xenon [kg]
Small Leak	0.29 (0.78)	31 (26)	29

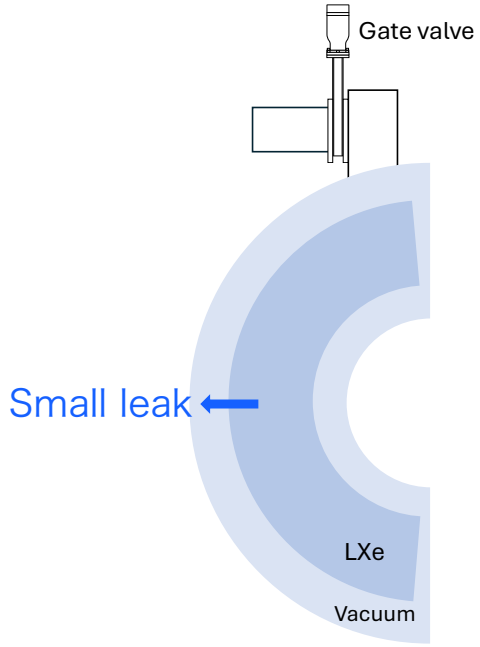
- Connected a tank to the thermal insulation layer with evacuation pump
- Stored leaked xenon in the tank
  - Used LN2 for cooling of xenon
- About 30 kg xenon was collected in 2024
- Collected xenon will be reused after purification



Fixing Works for Xenon Leak

- Nuts on the lateral faces of LXe vessel were loose
  - These nuts should be tightened with 140-200 Nm
  - Thermal cycle makes the LXe vessel looser

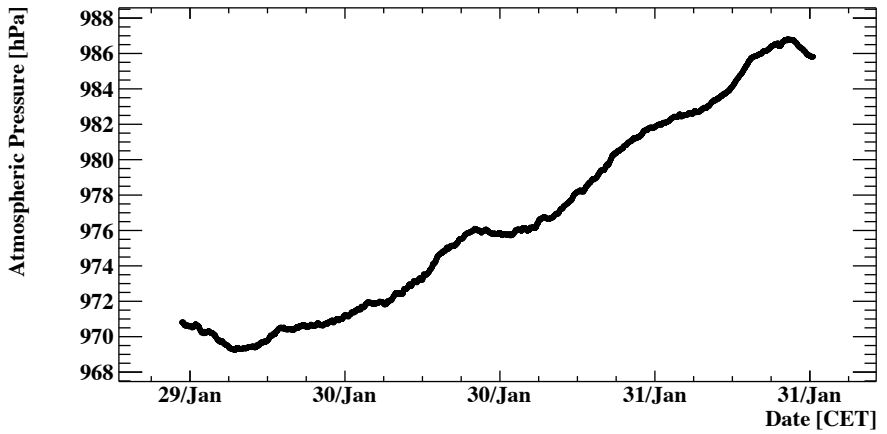
- Retightened these Nuts with 160 Nm
  - Used torque wrench



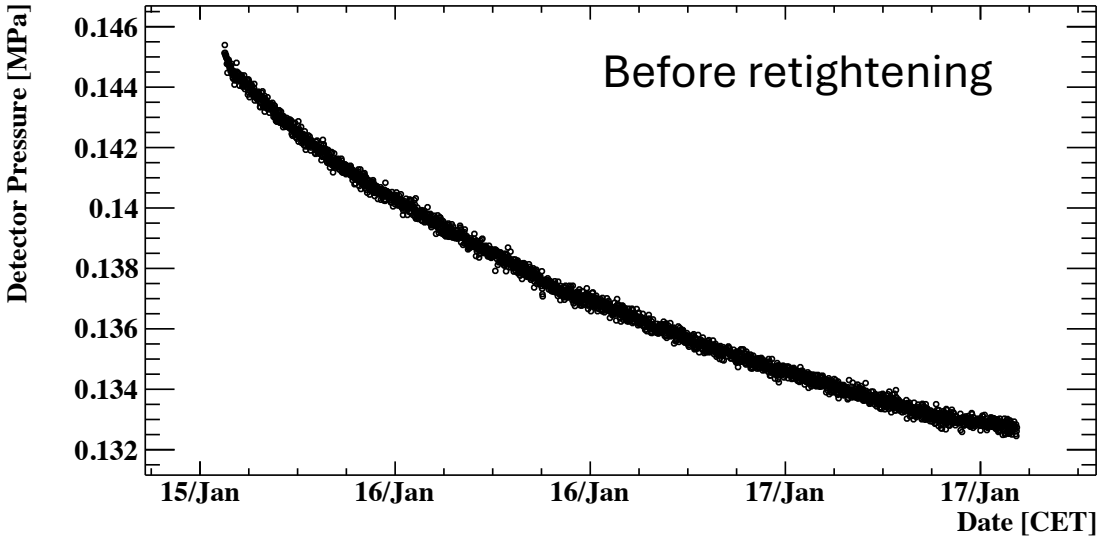
Nuts on the lateral face of LXe detecor LXe vessel

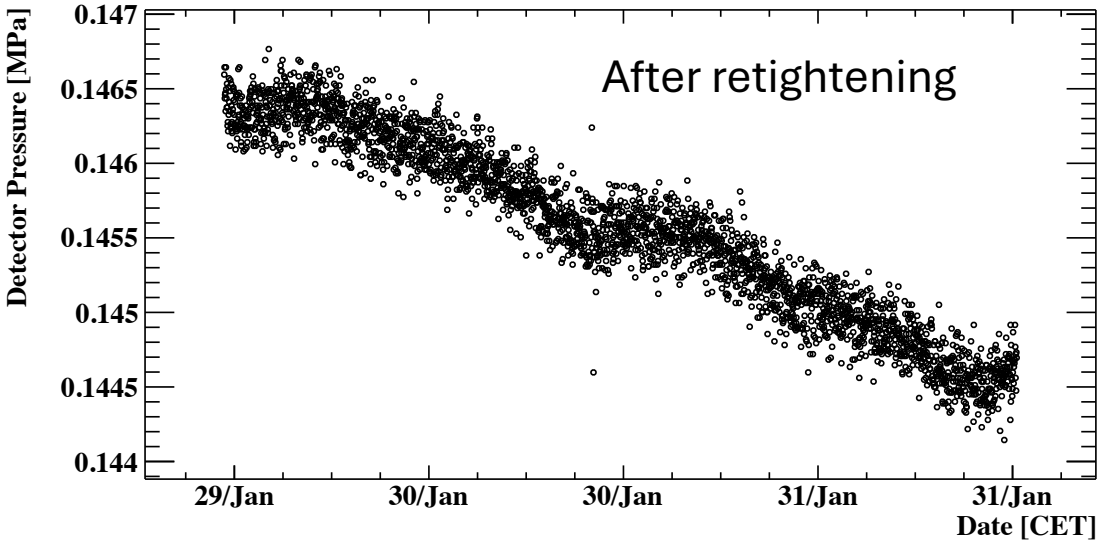
Leak Investigation

- Compare the pressure decrease for LXe detector before and after retightening
  - with ~1.5 bar N2
- After retightening, the pressure decrease became smaller
  - Or possibly saw the effect of atmospheric pressure
- One evidence that leak became small



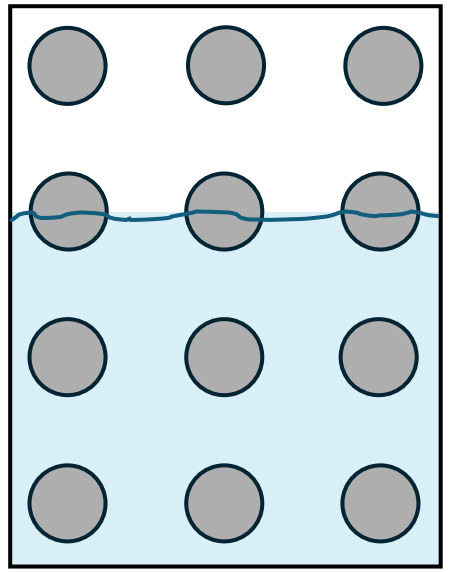
Affected by atmosperic pressure?

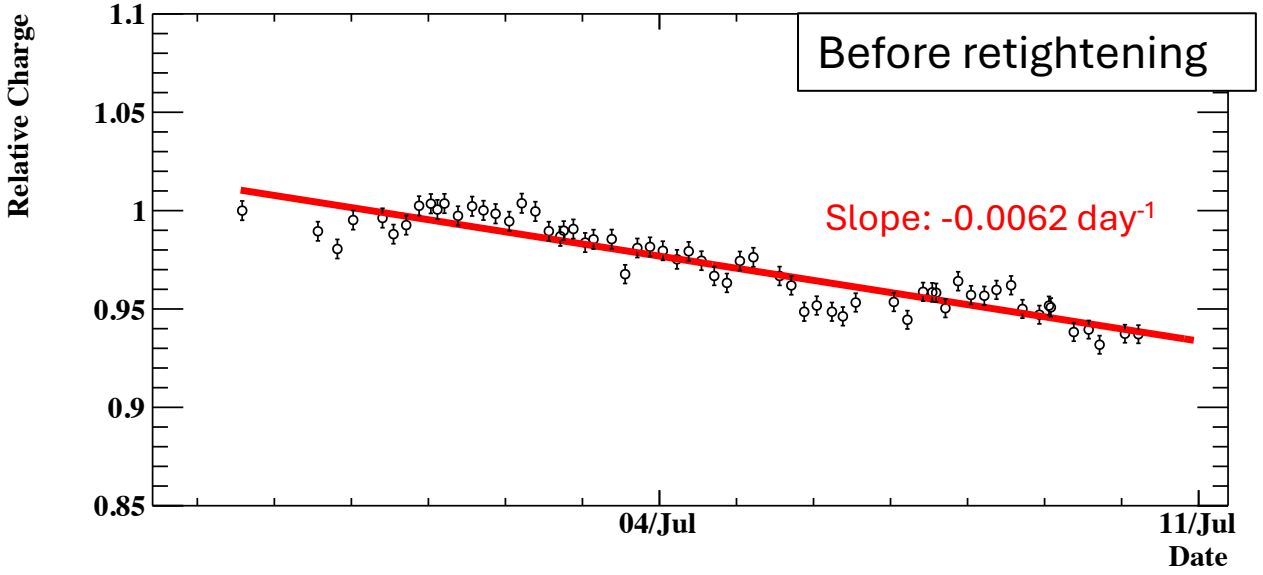


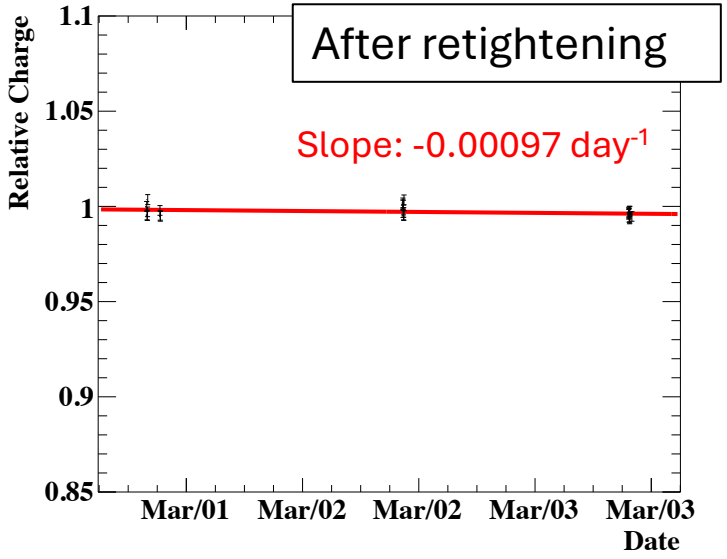


Current Xenon Leak Rate

- Xenon leak rate: 0.046 kg/day
  - with LXe in the detector
- 6 times smaller than before
- We can conduct 2025 MEG II run with negligible small xenon leak







Summary

- 2024 MEG II physics run was conducted with xenon leak
  - Xenon leak doesn’t affect data quality by appropriate calibration

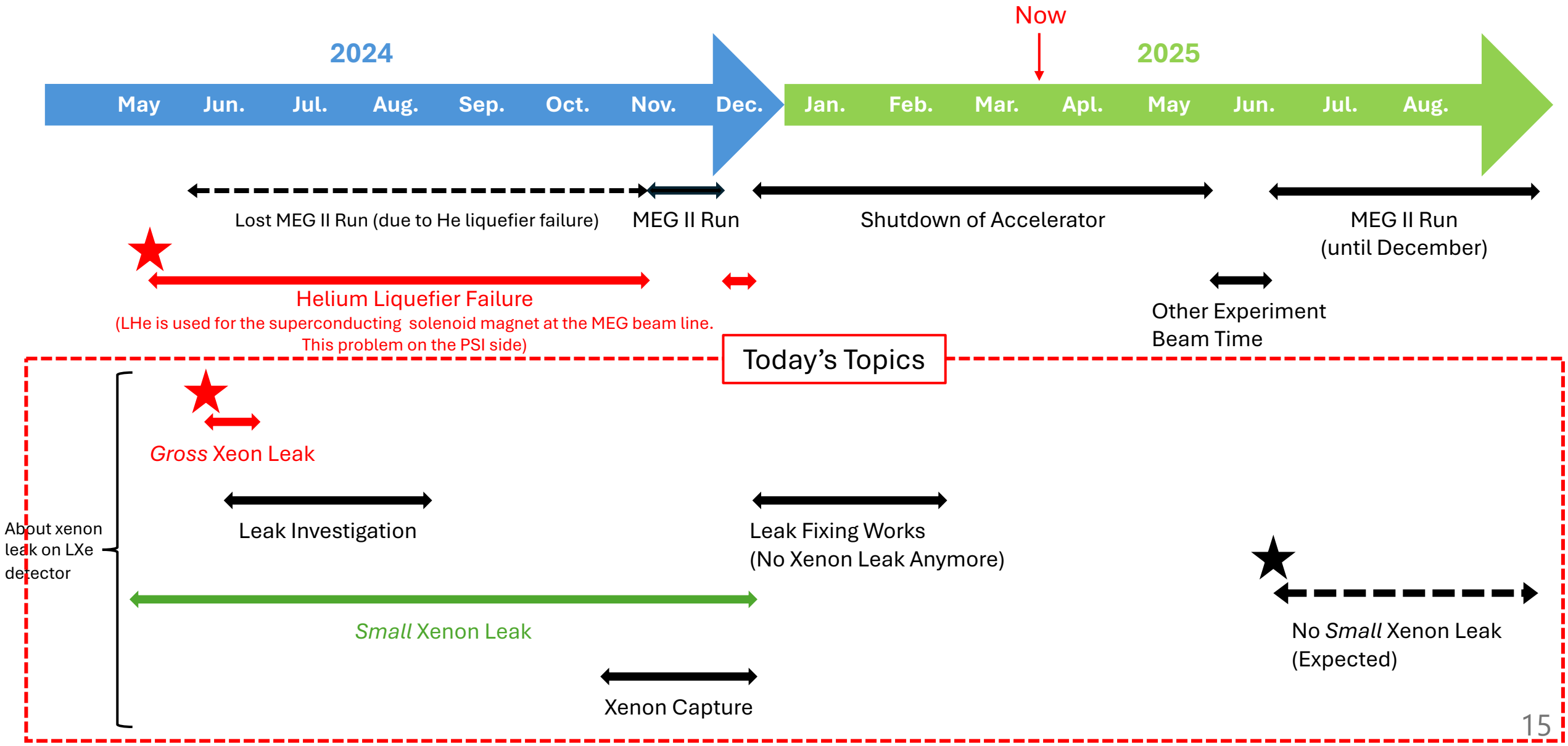
- Xenon leak was almost solved

- Refill xenon before 2025 run to compensate lost xenon

- We’re waiting coming physics run with the best detector

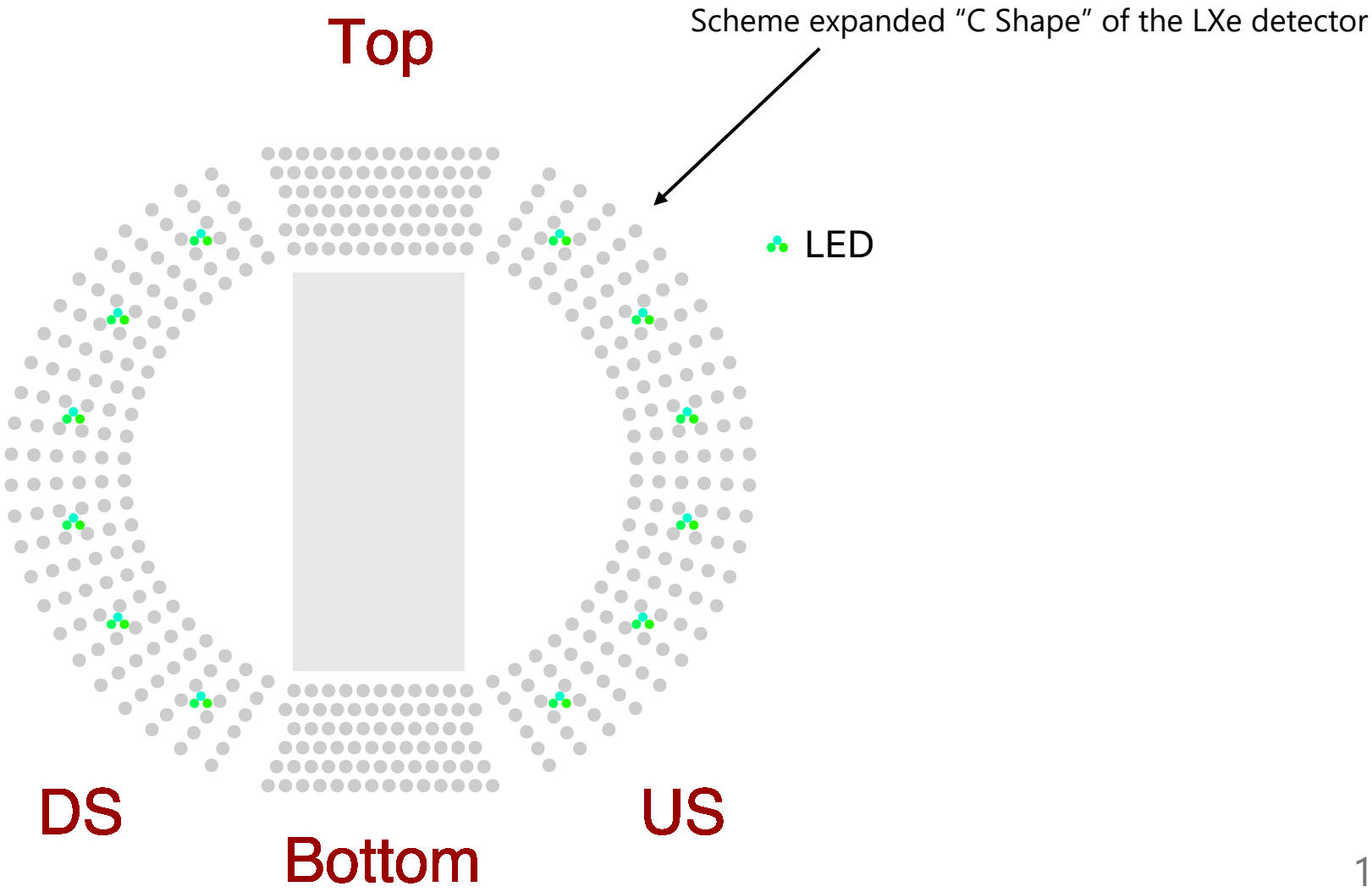
Backup

Timeline towards 2025 MEG II Run



LEDs inside LXe Detector

- To take data for PMT gain calibration, there are LEDs inside the LXe detector
  - Used these LEDs for xenon leak check (explained later)



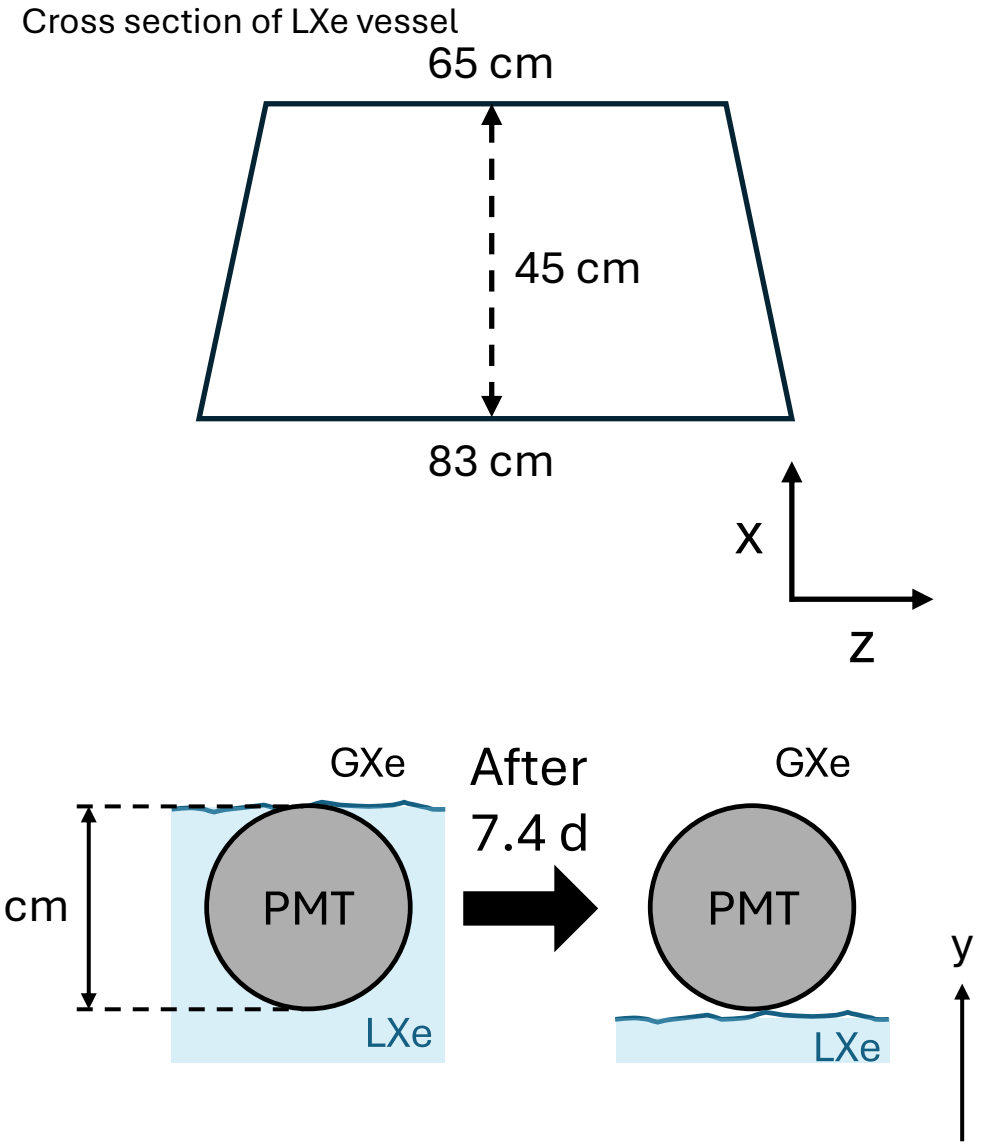
Gross Xenon Leak in 2024 MEG II Run

- Volume of lost LXe
  - Assumed the cross section of LXe vessel as trapezoid
  - Size of PMT photocathod: 4.5 cm

$$\frac{65+83}{2}\ \text{cm}\times 45\ \text{cm}\times 4.5\ \text{cm} = 15\ \text{L}$$

- Assumed the density of LXe: 2.95 kg/L

- Lost xenon during 7.4 days : 44 kg



Test of Accuracy

- Before August, the amount of lost LXe is 34 L = 100 kg (liquid density of Xe: 2.95 kg/L)
  - Calculated from liquid level meter for 1000 L LXe dewar

- From PMT charge change, the amount of lost xenon is 100 kg
  - Xenon leak rate from PMT charge is 0.29 kg/day
  - 0.29 kg/day * 57 day = 17 kg
  - Amount of lost xenon by gross leak: 83 kg

- The accuracy seems good

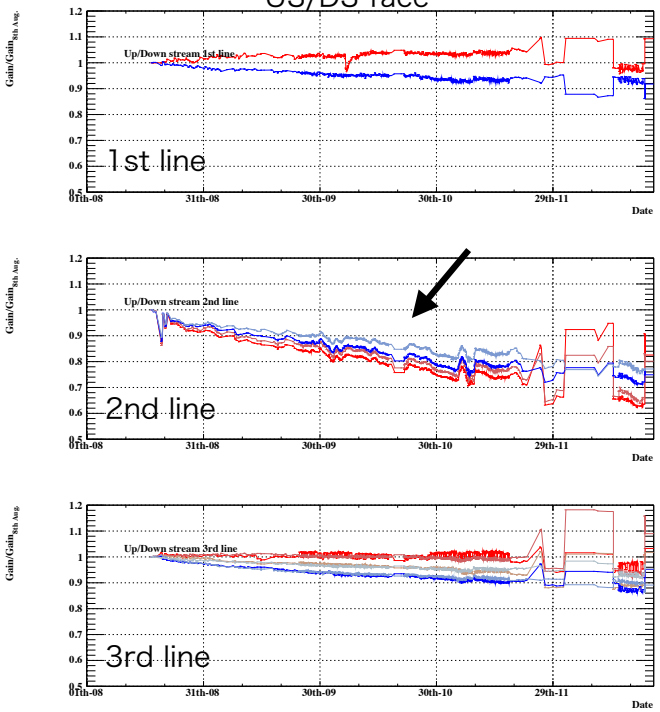
- Leak Rate Calculation from PMT is reliable

Small **Leak in 2021 MEG II Run**

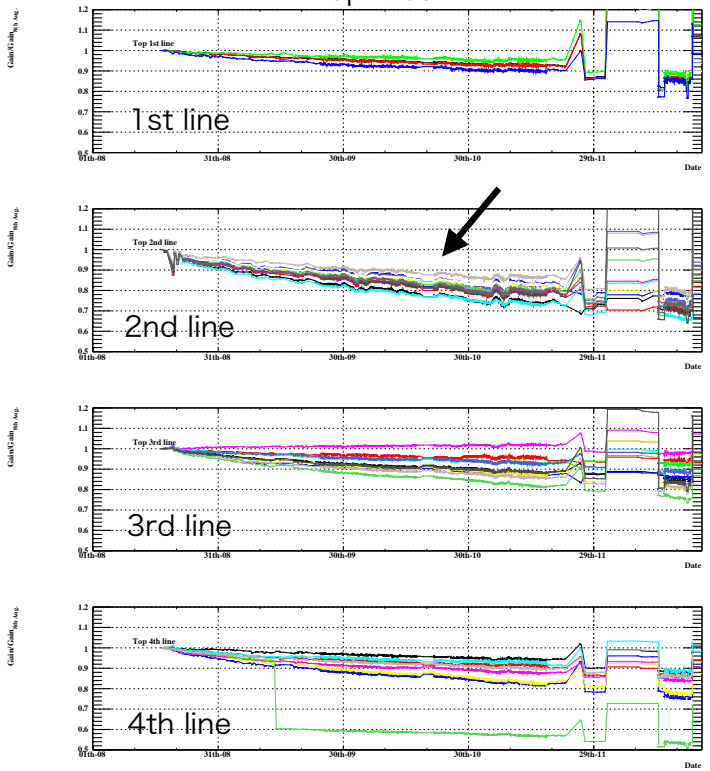
Liquid level : 2021

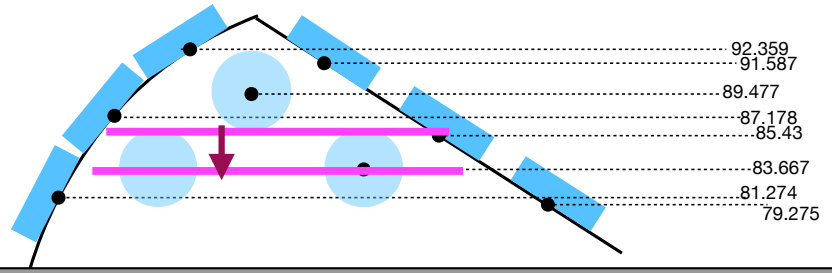
LED charge
(normalized to 1 at the 1st point)

US/DS face



Top face





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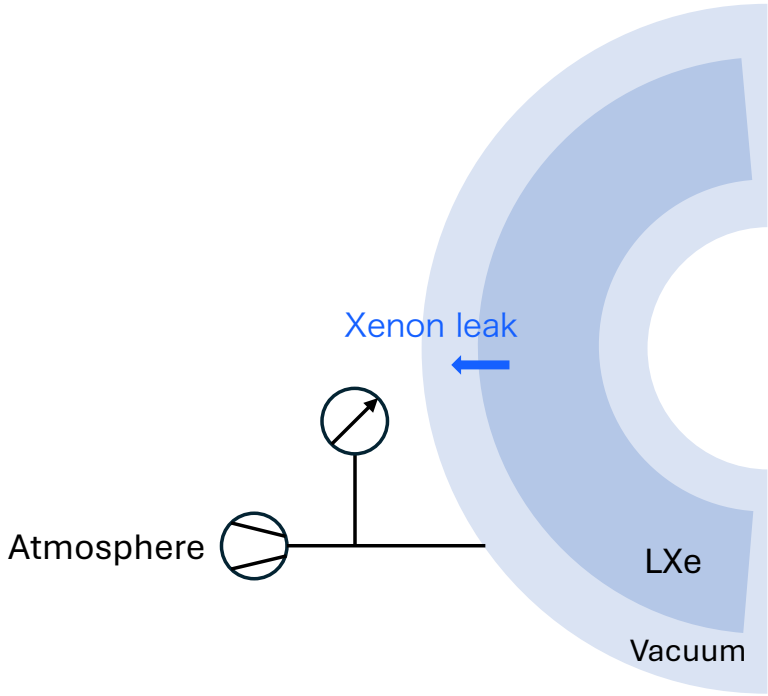
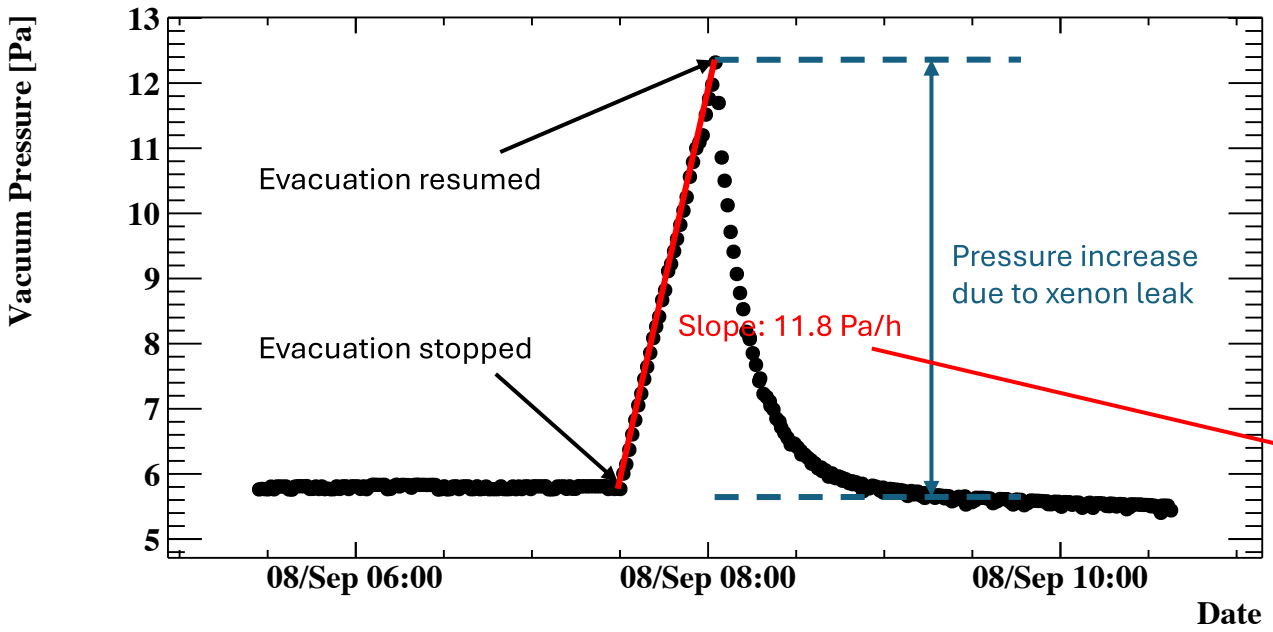
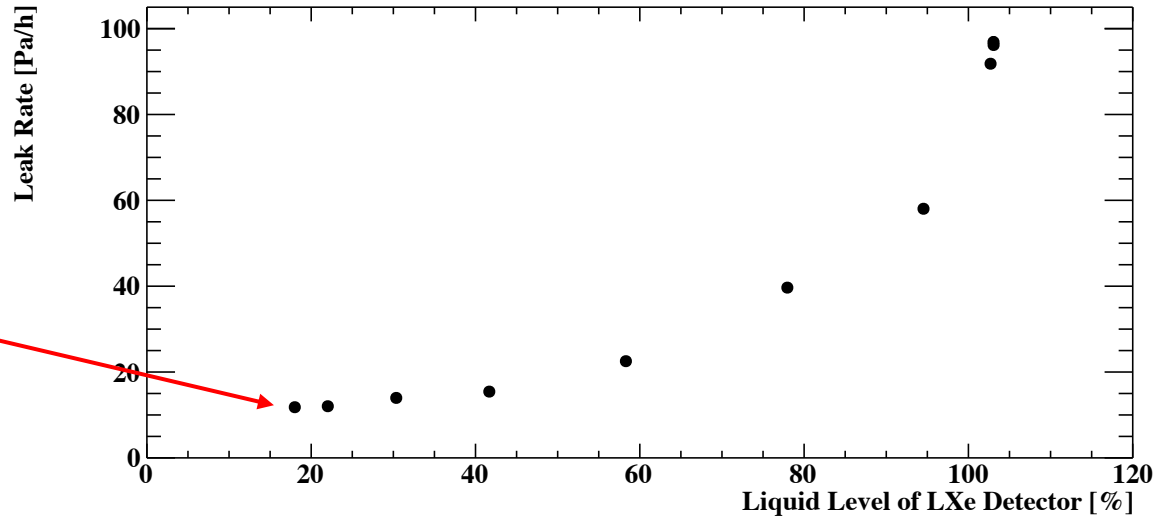
Leak Rate from Pressure of Thermal Insulation Layer

- Pressure of insulation layer increased when evacuation of insulation layer stopped
  - Due to xenon leak from the LXe vessel

- Leak rate has positive depencence of amount of LXe in the detector

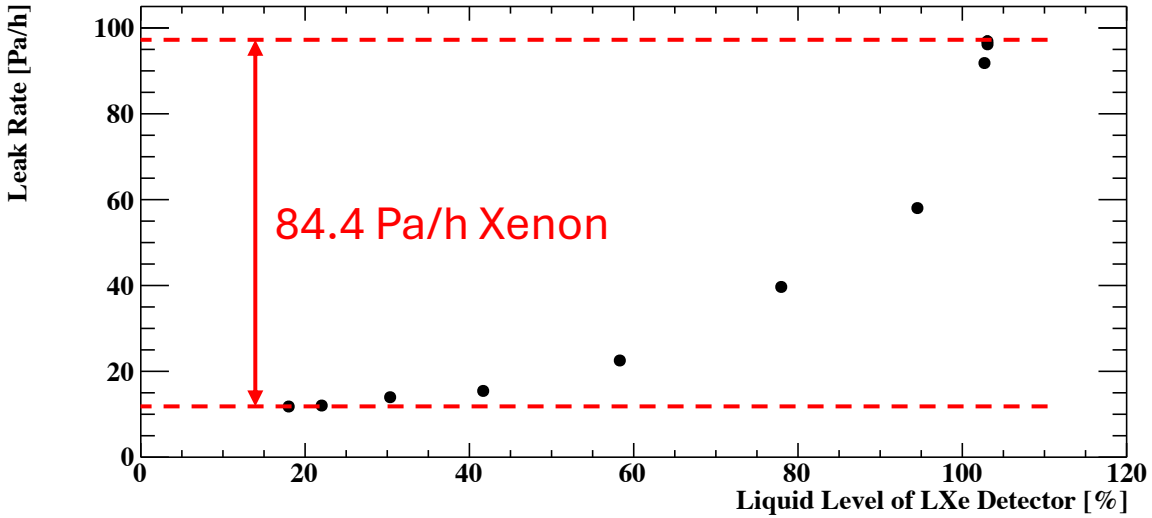






Leak Rates of "Small Leak" (by Pressure Increase of Insulation Layer)

- Mass leak rate: $\dot{M} = \dot{P}\frac{M_{\mathrm{Xe}}V}{RT}$
  - $\dot{P}$: Partial pressure increase of insulation layer
  - M_{Xe}: Molar mass of xenon (~131 g/mol)
  - V: Volume of insulation layer(~1000 L)
  - R: Molar gas constant ($8.31\ \mathrm{J \cdot K^{-1} \cdot mol^{-1}}$)
  - T: Temperature of insulation layer (~200 K)



$$\dot{M} = 84.4\ \mathrm{Pa/h} \cdot \frac{M_{\mathrm{Xe}}V}{RT} = 0.16\ \mathrm{kg/day}$$

PMT Gain Calculation

- PMT gain is calculated from LED intensity scan data

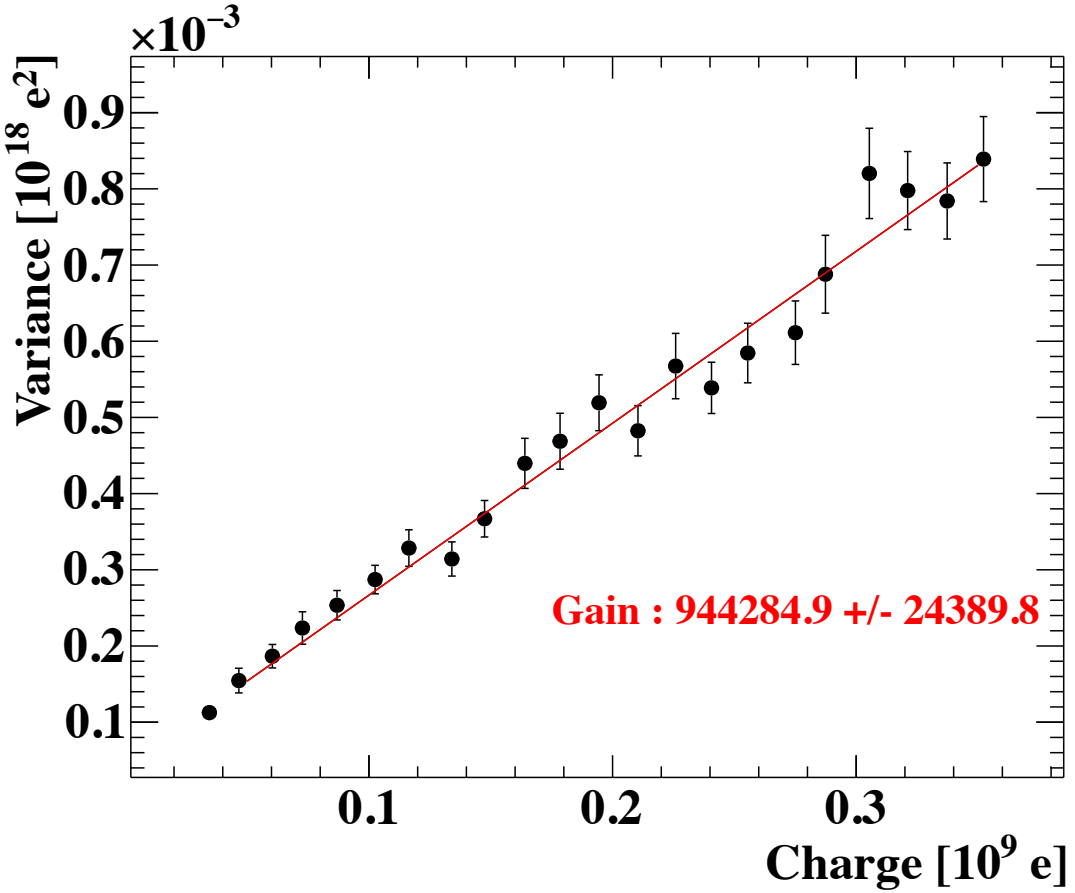
$$\sigma_Q^2 = G \cdot e \cdot \bar{Q} + \sigma_0^2$$

σ_Q: Variance of charge distribution

G: PMT Gain

e: Elementary charge

$\bar{Q}$: Mean of PMT charge



PMT Gain Calibration

- PMT gain has larger systematics than the charge
- These gain can be calibrated by the charge
- The calibration is ongoing