MEG II 実験液体キセノン検出器の 2024年ランの運転状況

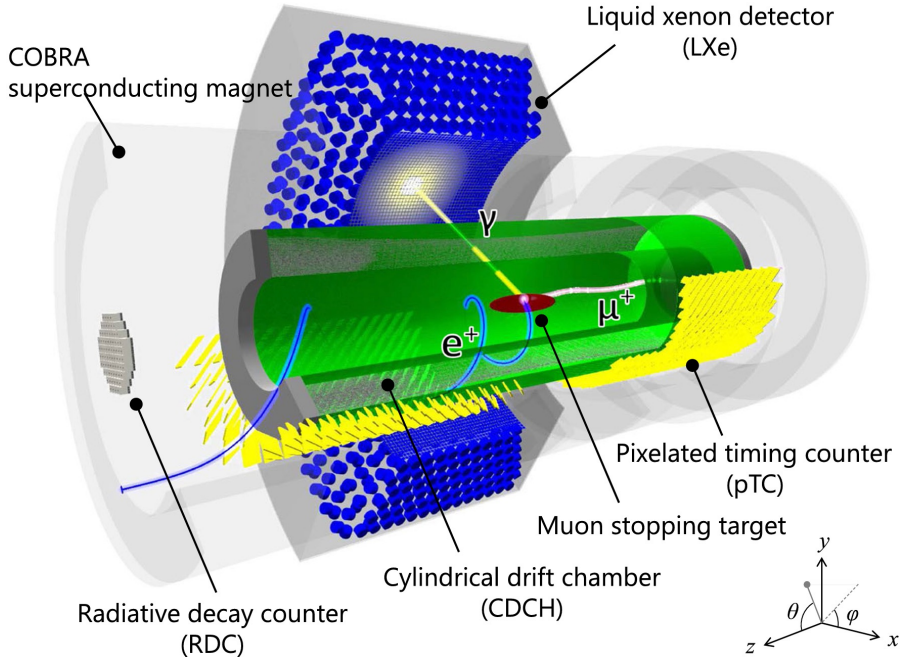
(The status of MEG II liquid xenon detector in 2024 run)

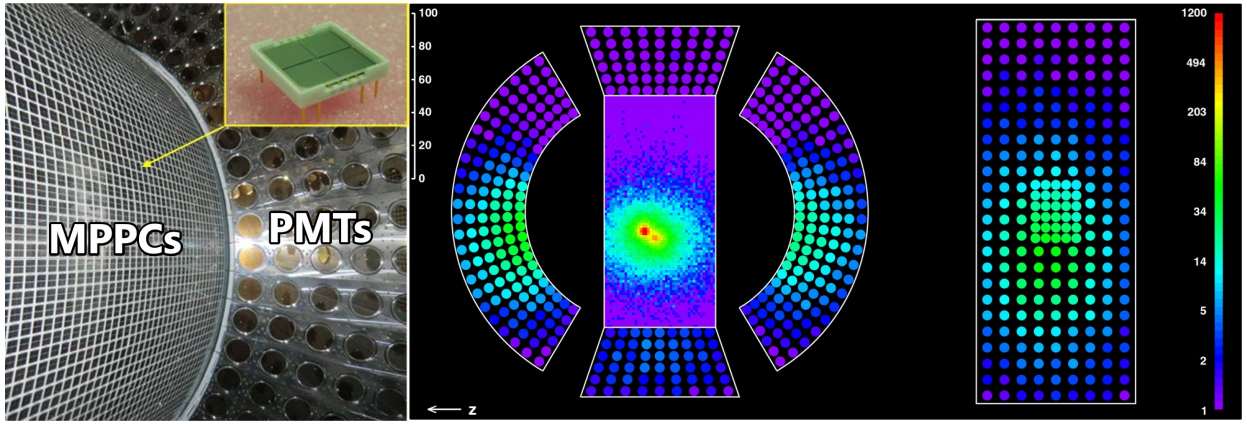
Ryusei Umakoshi,
On behalf of the MEG II collaboration,
The University of Tokyo

Introduction

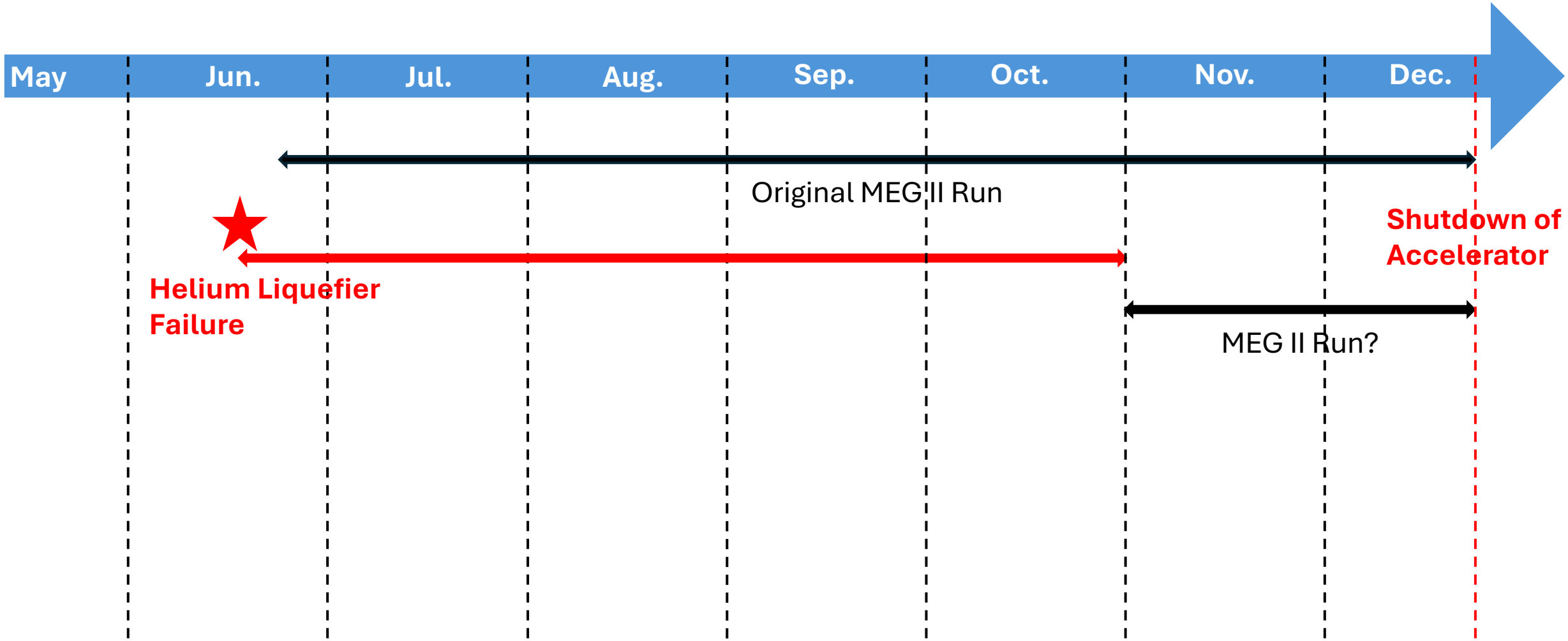
- MEG II experiment
  - Search for $\mu^+ \rightarrow e^+\gamma$ as a probe of new physics
    - Muon intensity: (3-5×10^7 μ/s)
      - One of the highest intensities in the world

- Liquid xenon (LXe) detector
  - Measure position, time, energy of photon by detecting scintillation light of xenon
    - 2.7 t LXe inside
  - PMT and MPPC are used as photo-sensors
    - PMT
      - Number: 668
      - Diameter: 2-inch
    - MPPC
      - Number: 4092
      - Size: 15 × 15 mm^2
  - The PMT and MPPC are sensitive to VUV (Vacuum UltraViolet) light

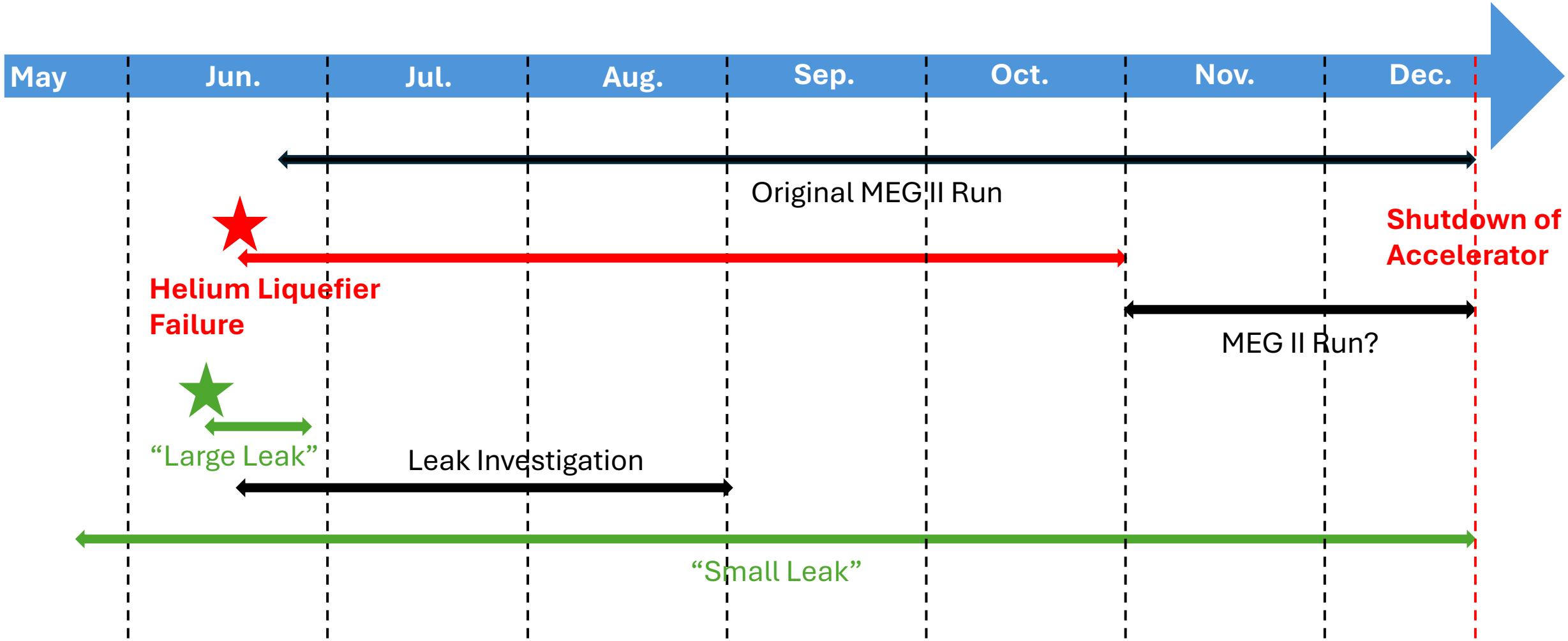




Timeline towards 2024 MEG II Run

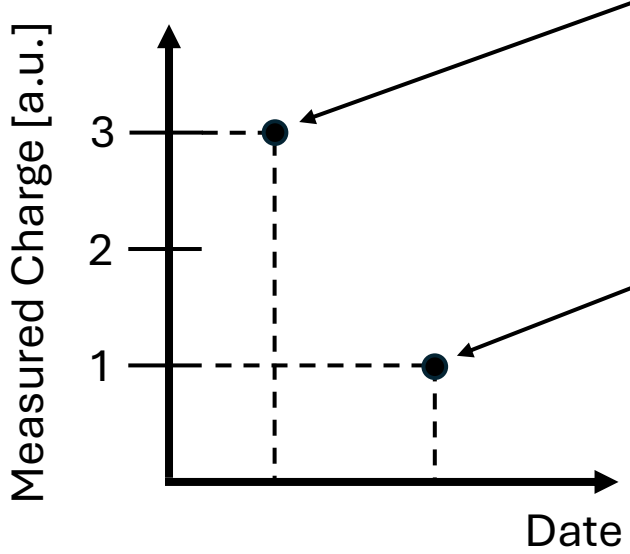


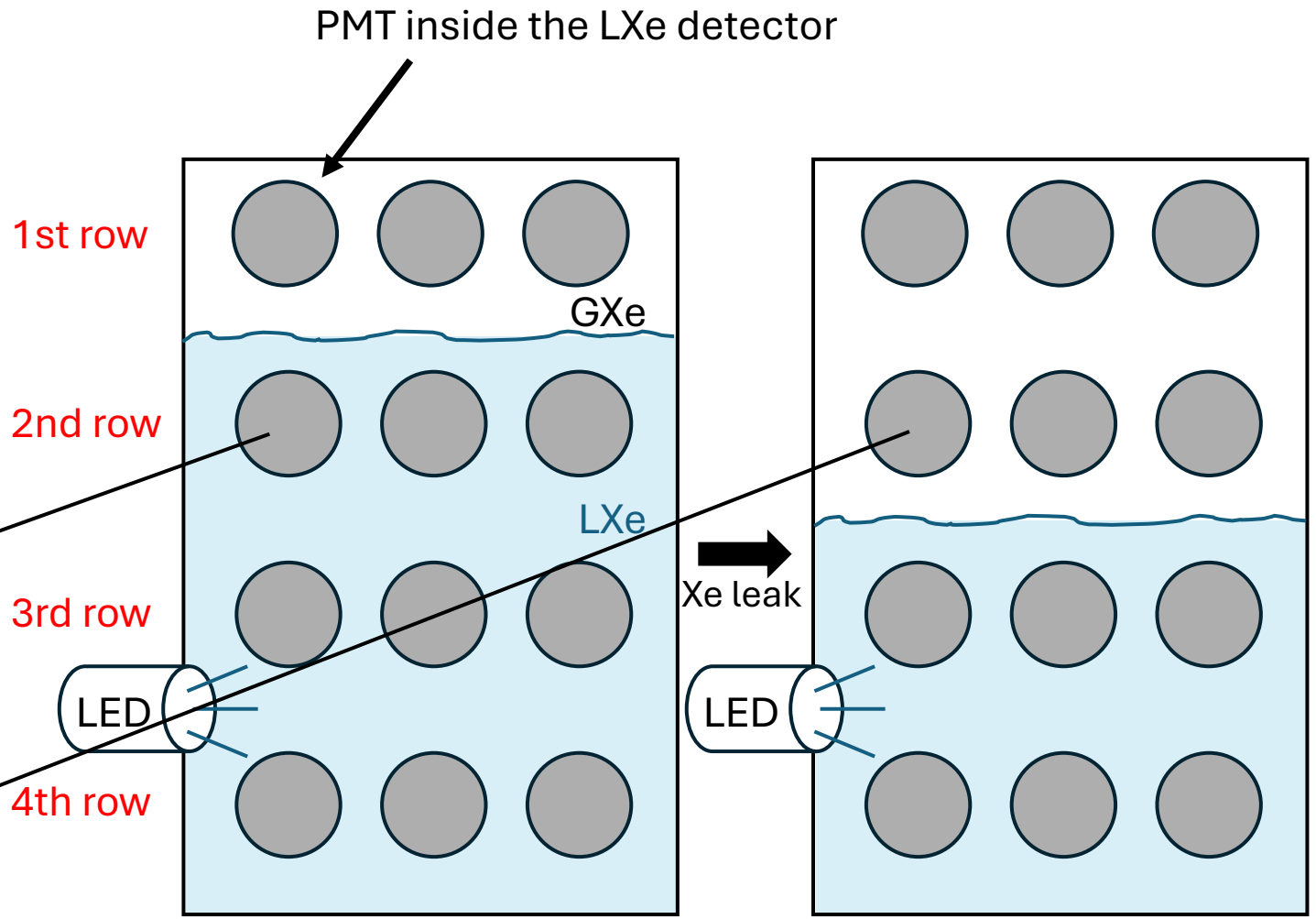
Timeline towards 2024 MEG II Run



Method to Estimate Liquid Level and Detect Leak

- 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
- Leak can be detected by this method



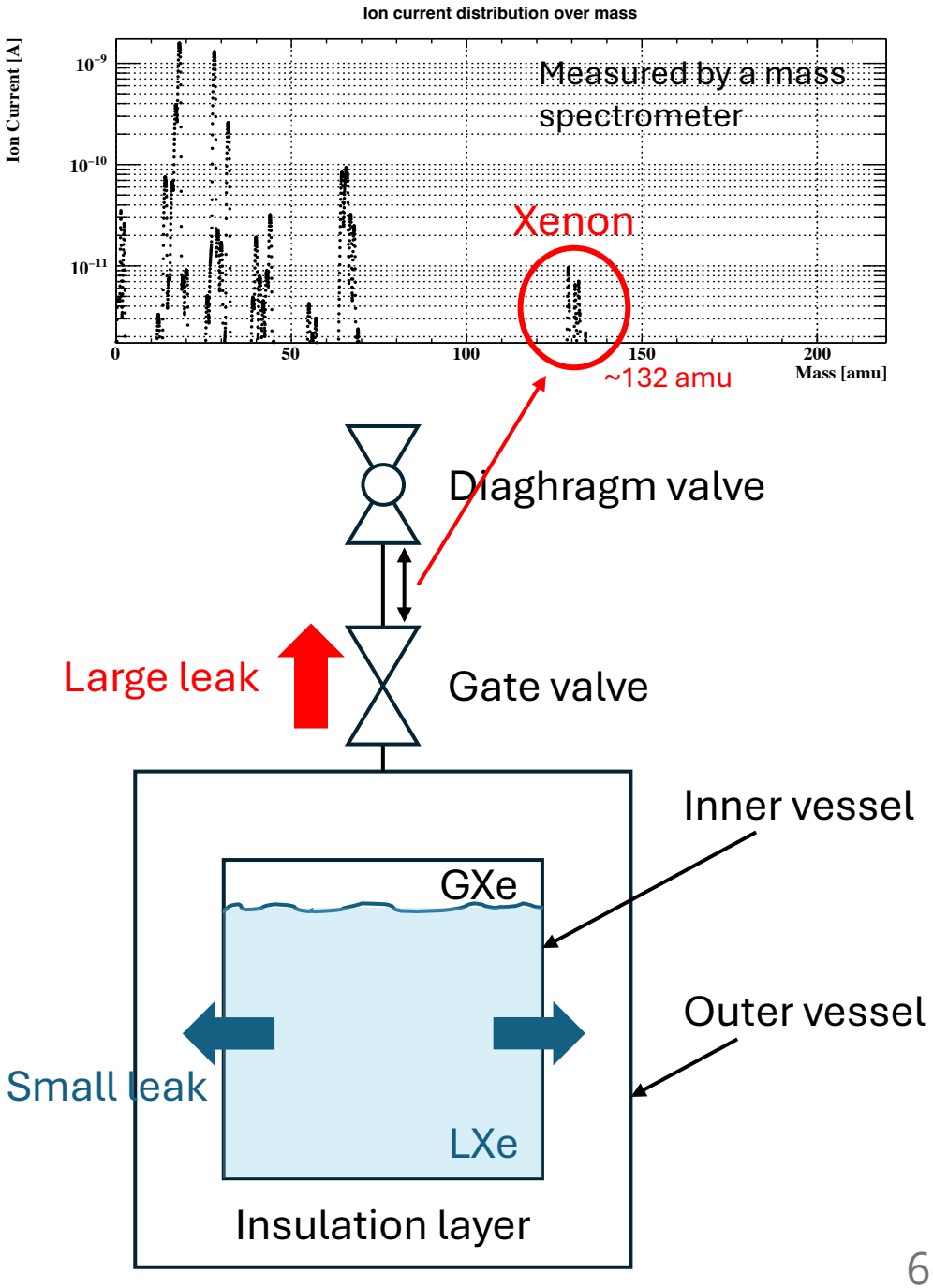


Two Kinds of Leak: "Large" and "Small Leaks"

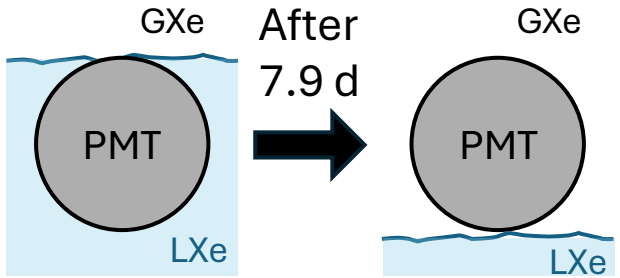
- Parts of the LXe detector related to leak
  - Inner vessel: LXe and GXe inside
  - Outer vessel: Evacuated continuously
  - Gate valve: Separate atmosphere and GXe

- **"Large leak"**
  - From inner vessel to atmosphere via gate valve
    - Happened only in 2024
    - Lost 40-80 kg xenon until the middle of September 2024
  - Cause: lack of leak tightness of the gate valve
  - No leak anymore
    - Dealed with temporarily
    - Need exchange of the gate valve

- **"Small leak"**
  - From inner vessel to insulation layer
    - Happened from 2021 MEG II run
    - Lost 10-20 kg xenon until the middle of September 2024
  - Cause: Lack of leak tightness of inner vessel gasket

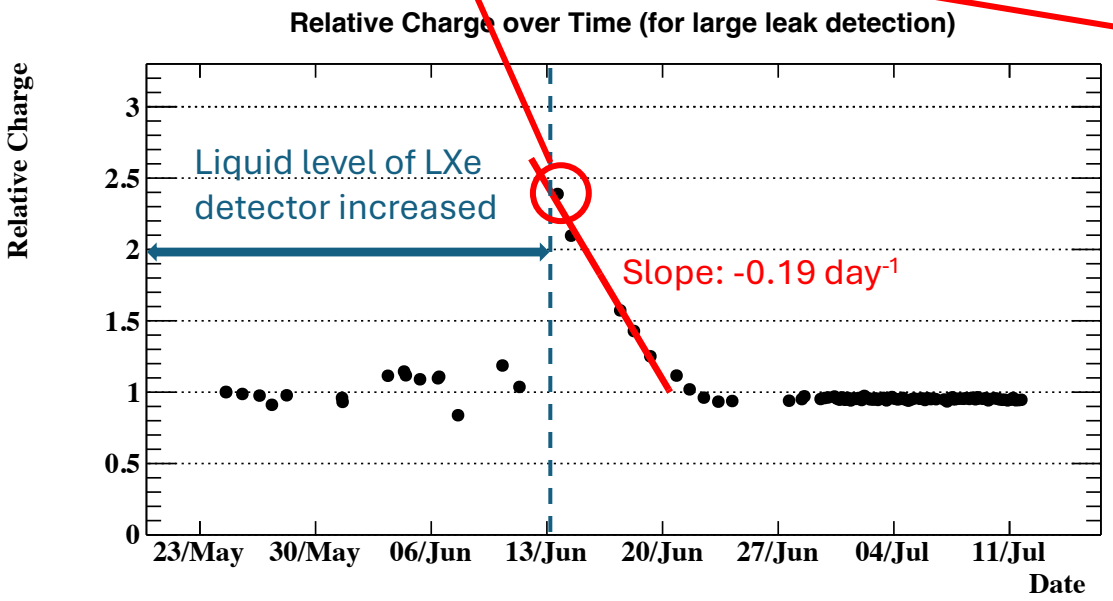


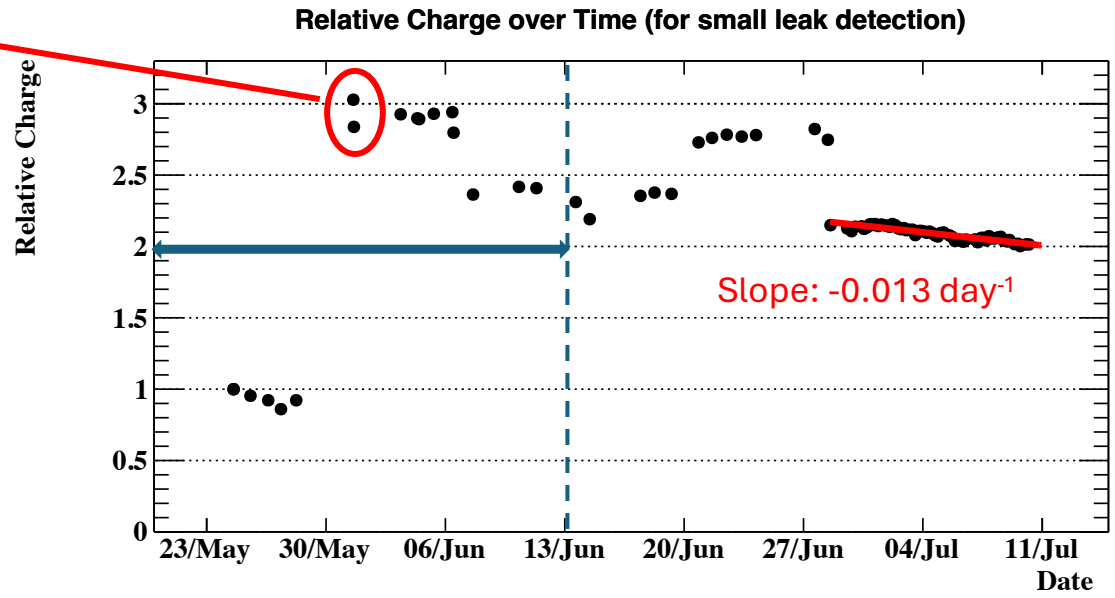
Leak Rates of "Large" and "Small Leaks"



$$-0.19t + 2.5 = 1$$
$$\Longrightarrow t = 7.9 \text{ day}$$

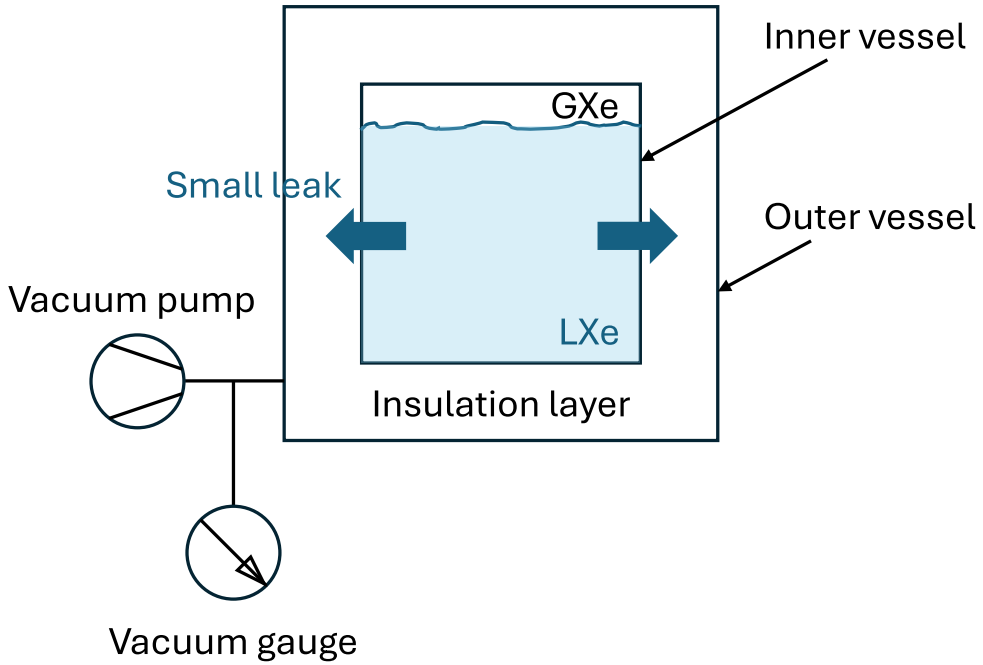
	Averaged heighest relative charge (assumption)	Slope [day^{-1}]	Number of days until PMT faces to GXe [day]	Lost xenon considering fiducial volume [kg]	Leak rate [kg/day] (uncertainty: 50%)
Large leak	~2.5	-0.19	7.9	44	5.6
Small leak	~2.8	-0.013	138	44	0.32

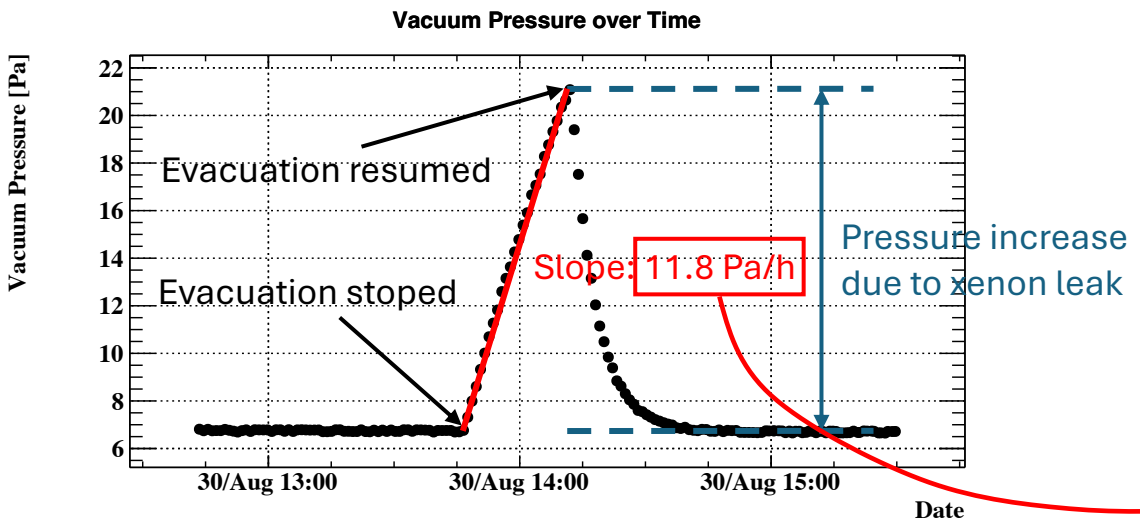


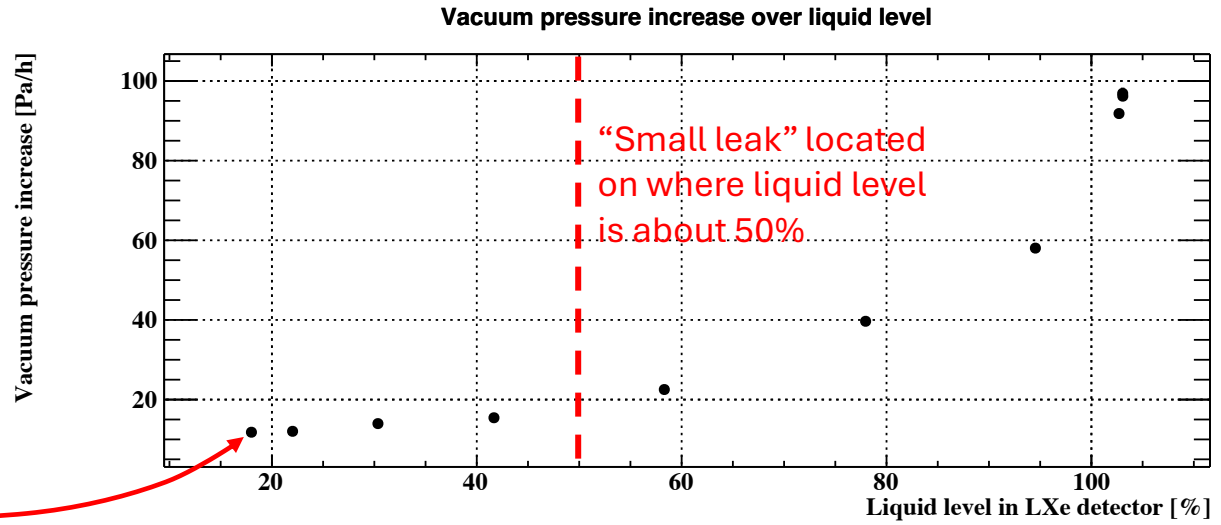


Method to Calculate "Small Leak" Rate (by Pressure Increase of Insulation Layer)

- Pressure of insulation layer increased when evacuation of insulation layer stopped
  - Due to xenon leak from inner vessel
- Calculate the slopes of pressure increase, then track them by liquid level
- "Small leak" rate strongly depends on liquid level

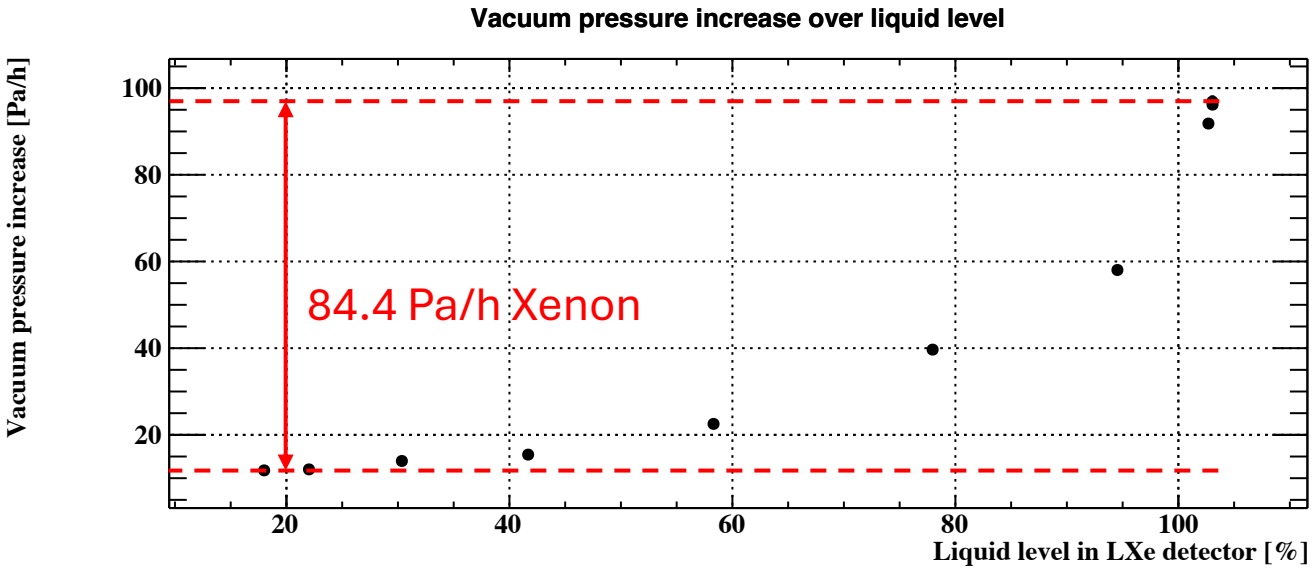






Leak Rates of "Small Leak" (by Pressure Increase of Insulation Layer)

- 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)



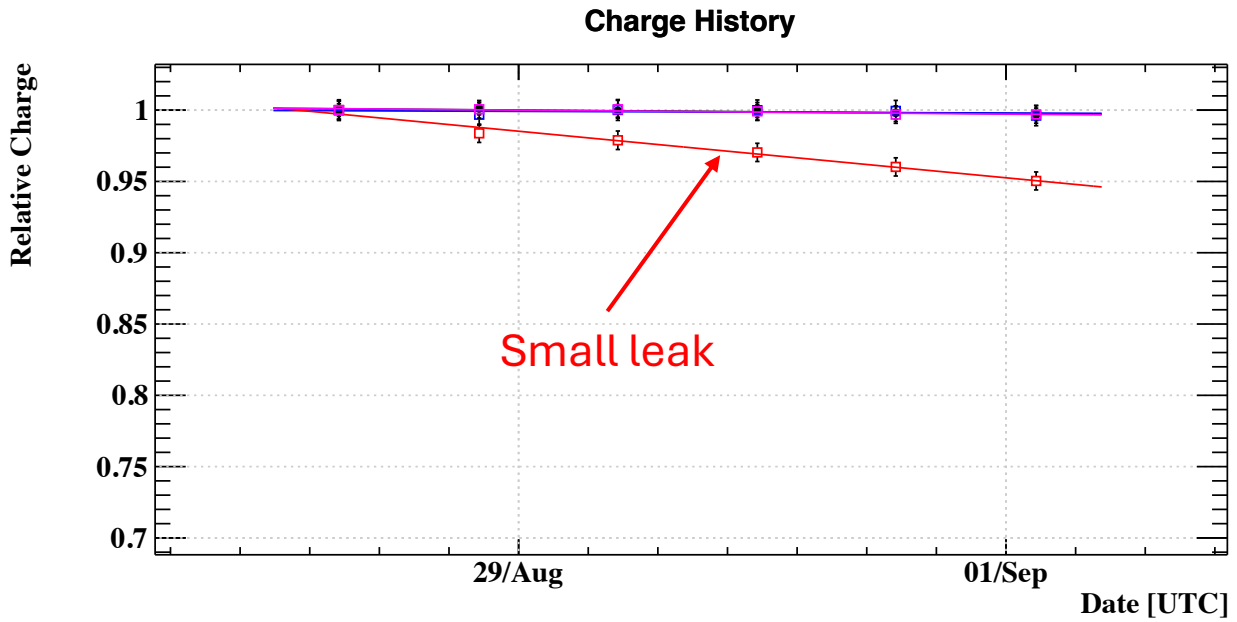
$$\dot{M} = 84.4\ \mathrm{Pa/h} \cdot \frac{M_{\mathrm{Xe}}V}{RT} = 0.16\ \mathrm{kg/day}$$

	From PMT charge by LED light	From vacuum pressure increase
Small leak rate [kg/day]	0.32 (uncertainty: 50%)	0.16 (uncertainty: 50%)
Cause of uncertainties	Fiducial volume of inner vessel, Averaged heighest relative charge	Volume of insulation layer, Temperature of insulation layer

- The small leaks from PMT charge and vacuum pressure increase are consistent within a factor of 2 times

Plan of 2024 MEG II Run

- Introduced regularly monitor to detect “large” and “small leaks”
  - Take data which were PMT response when LED light blinking (called “LED data”)
    - Once per day
  - Regularly monitor “large” and “small leaks” after taking LED data
- Continue run with “small leak”
  - About 5% of LXe detector are not covered in xenon
  - Lose 10-20 kg xenon for 2 months’ run
  - The effects to data will be studied
- Xenon collection and purification
  - Collect leaked xenon by evacuation of outer vessel
  - Purify collected xenon by asking a company
    - Discussion with the company ongoing



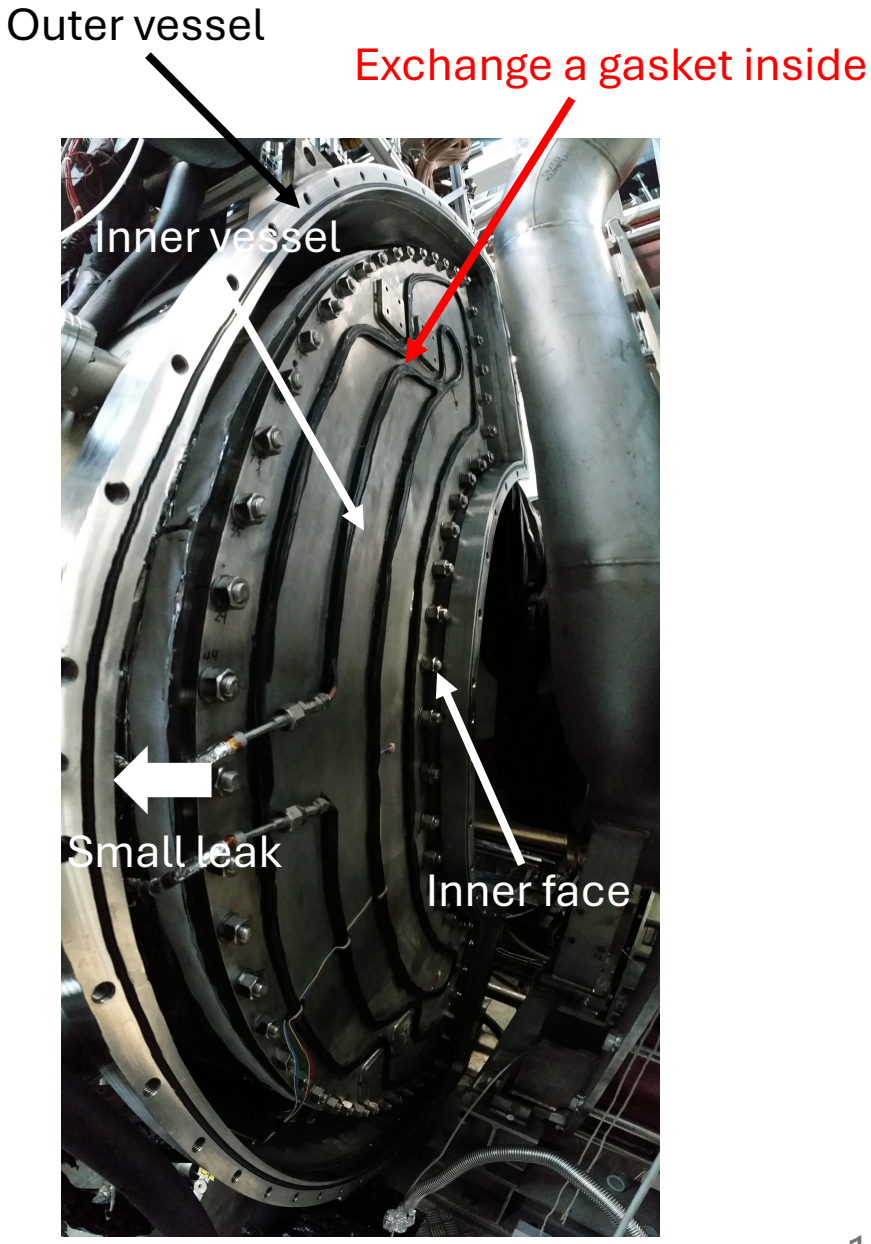
Plan during Shutdown Period

- Lose 60-120 kg xenon until shutdown of acceralator in 2024
  - 40-80 kg xenon from "large leak" + 20-40 kg xenon from "small leak"

- Xenon return & addition
  - Return collected xenon to the LXe detector
    - at most 10-20 kg xenon
  - Add new xenon from KEK to the LXe detector
    - 39 kg xenon
  - Need more xenon to compromise lost xenon

- Repair of "large leak"
  - Exchange a gate valve to new one

- Repair of "small leak"
  - Exchange a gasket of inner vessel
  - It takes over 2 months
    - Tough work
  - If "small leak" located on the inner face, this leak can not be fixed easily
    - Inner face does not have stiffness to a force from outside
    - This face was welded
    - Repair takes 1 year or more?
    - In this case, give up the repair of this leak



Summary

- Two kinds of leak were found in the LXe detector
  - Regularly monitor both leaks

- Leak at gate valve (called “large leak” in these slides)
  - Happened only in 2024
  - Leak rate: 5.7 ± 2.9 kg/day
  - Lost 40-80 kg xenon
  - Cause: Lack of leak tightness of a gate valve
  - Repair: This leak stopped temporarily.
    Exchange the gate valve to new one during shutdown period

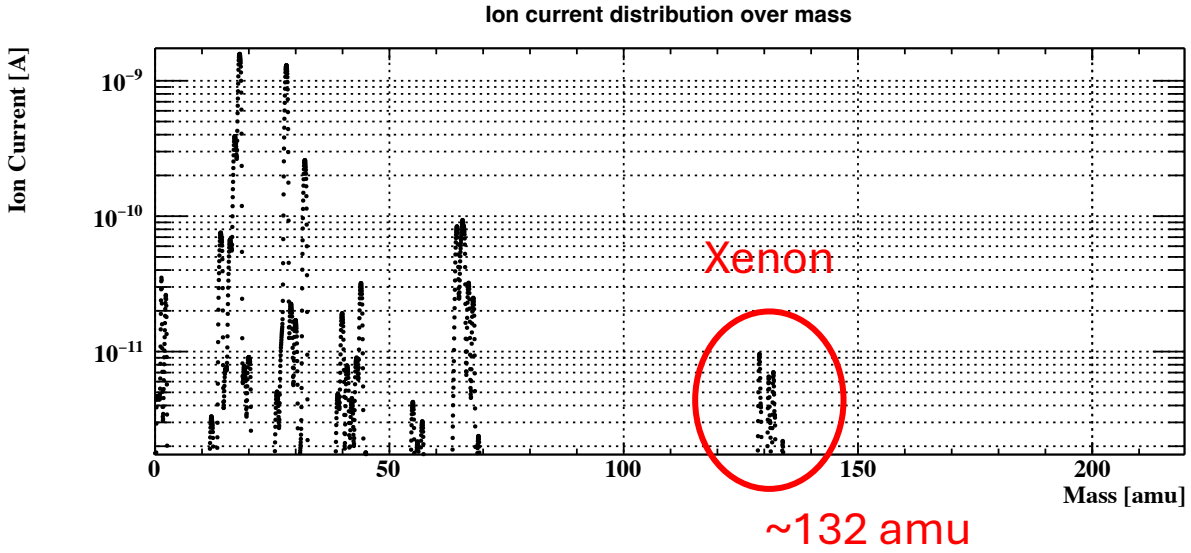
- Leak at inner vessel gasket (called “small leak” in these slides)
  - Continues from 2021 MEG II run
  - Leak rate: 0.32 ± 0.16 kg/day
  - Lost 10-20 kg xenon and will lose 10-20 kg xenon in 2024
  - Cause: Lack of leak tightness of inner vessel gasket
  - Repair: Exchange inner vessel gasket to new one during shutdown period

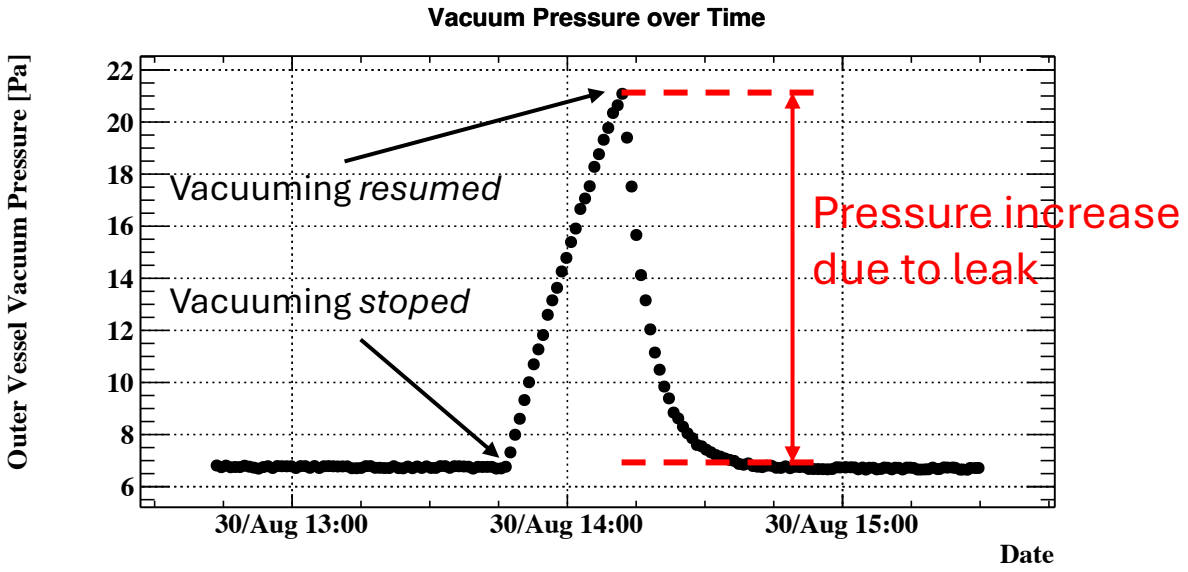
- Xenon collection and return
  - Collect and purify leaked xenon
  - Return these xenon to the LXe detector during shutdown period

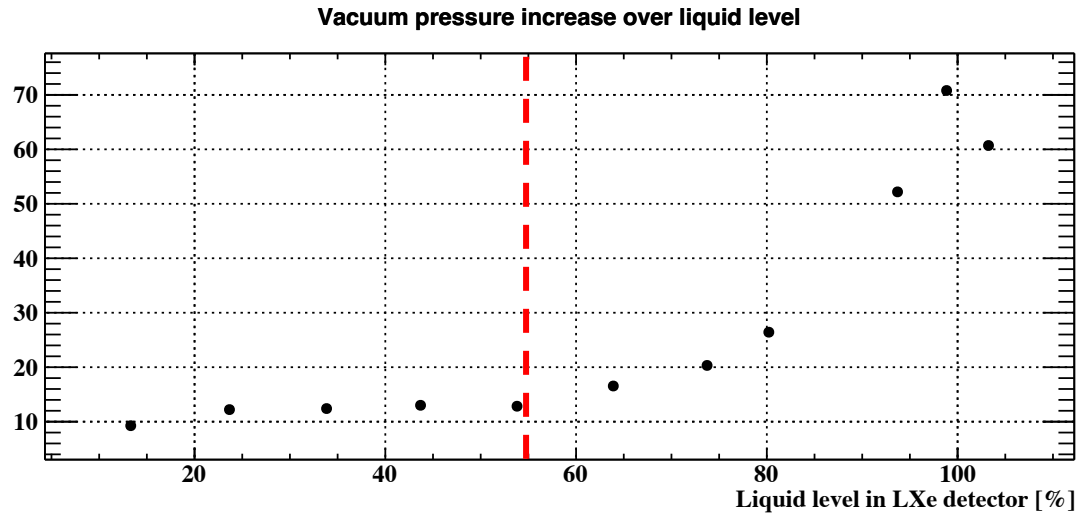
Backup

Pressure Increase of Insulation Layer

- Xenon was found in insulation layer
- Vacuum pressure increase rate [Pa/h] increase after 50% liquid level in LXe detector
  - Leak might be located higher than the height of 50% liquid level





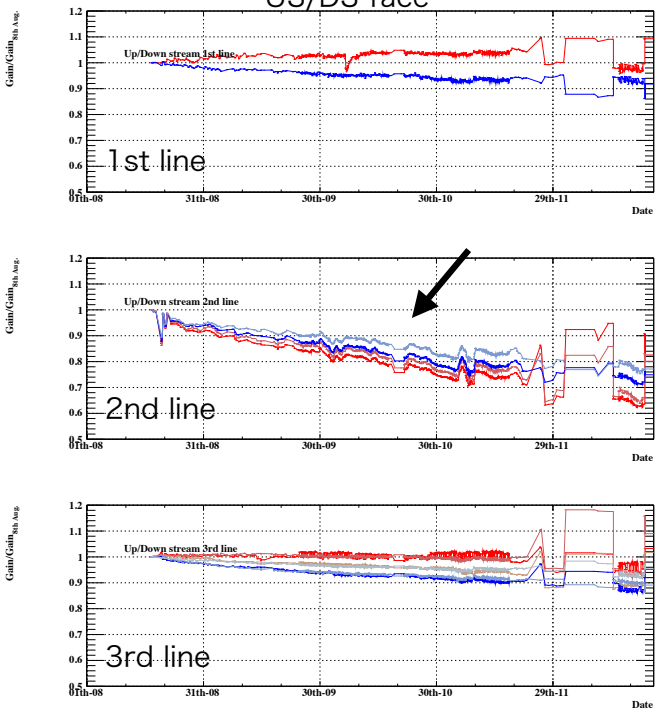


Small Leak in 2021 MEG II Run

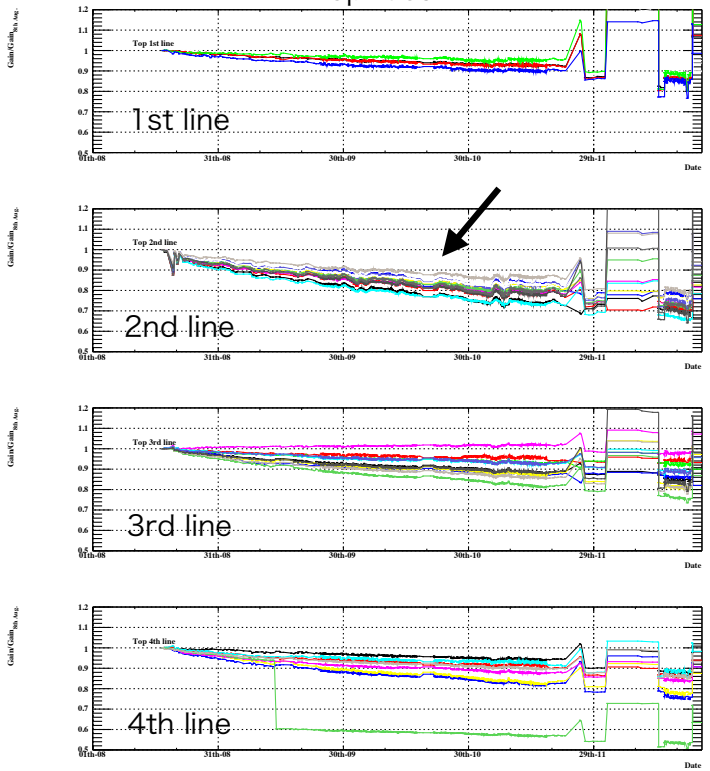
Liquid level : 2021

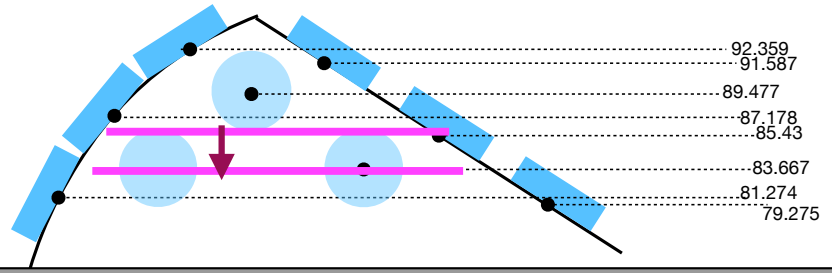
LED charge
(normalized to 1 at the 1st point)

US/DS face



Top face



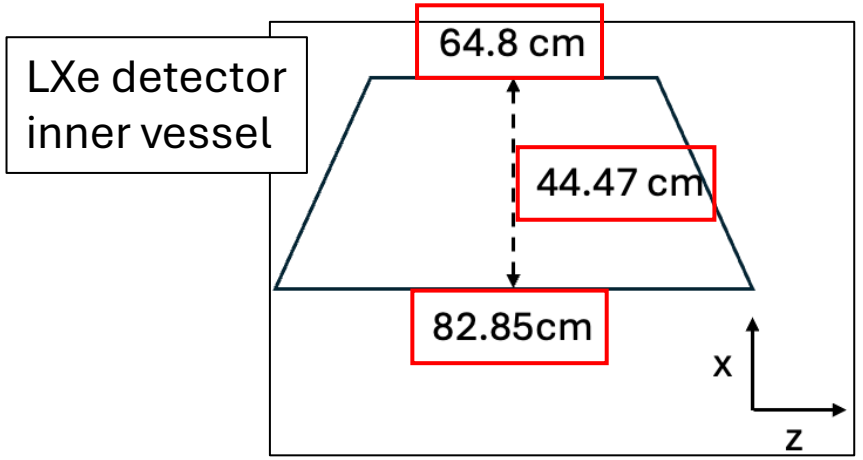


14

Fiducial Volume of Inner Vessel of LXe detector

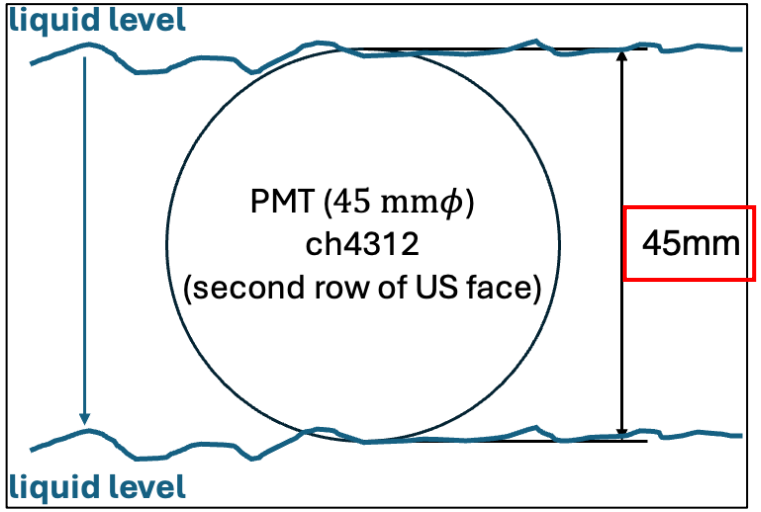
- Fiducial volume (*trapezoid*);

$$\frac{64.8 + 82.85}{2}\ \text{cm} \times 44.47\ \text{cm} \times 45\ \text{mm} \approx 14.8 \times 10^3\ \text{cm}^3 = \mathbf{14.8\ L}$$

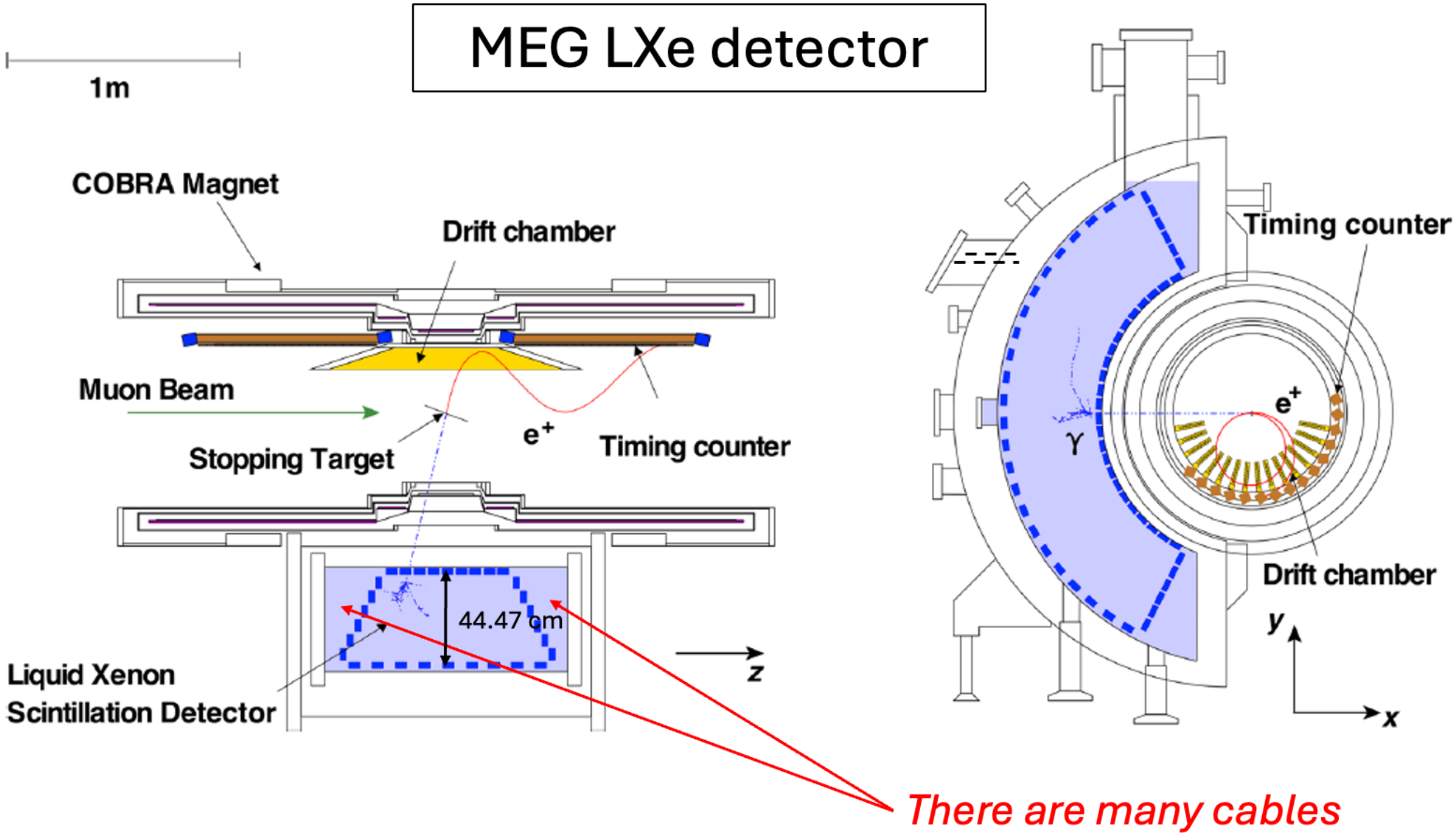


- Assume liquid density is approximately 3 kg/L. If the small leak continue for 139 days, the lost Xe is

44.4 kg



Geometry of LXe detector



Xenon leak during preparing for run

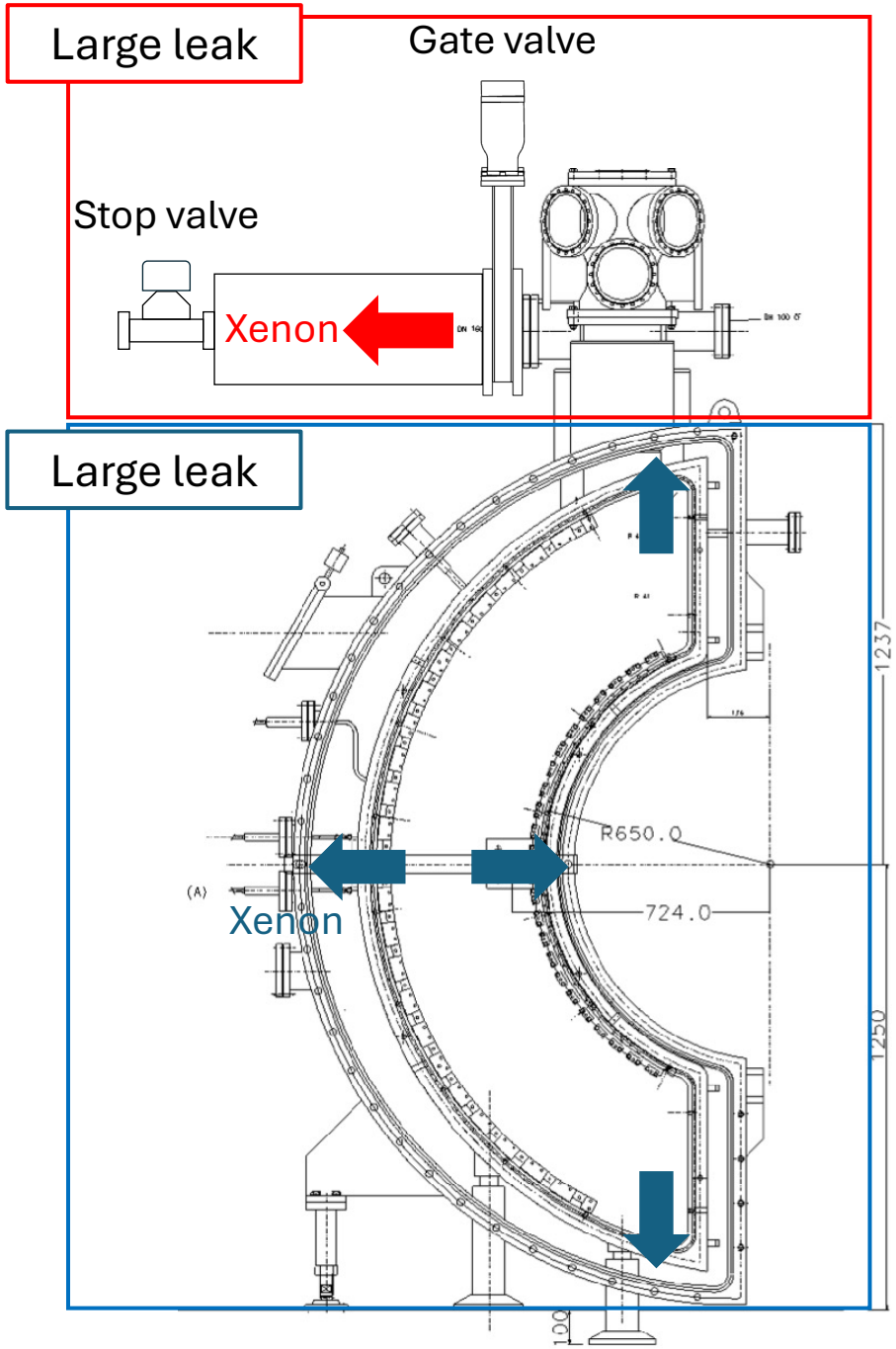
- There are two leak regarding to LXe detector;
  - Large leak
  - Small leak

- Found xenon in insulation layer
  - By mass spectrometer and outer vacuum pressure increase

- Cause of leak
  - There is a leak in inner vessel
  - This leak happened when the detecter is cooling (~165 K)

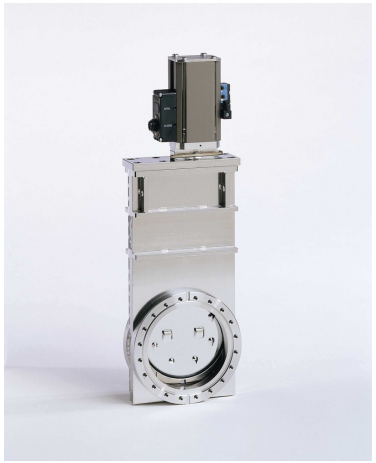
- Countermeasure
  - Online monitor of small leak detection was implemented
    - Unfortunately, there is no way to stop small leak at least in 2024 run

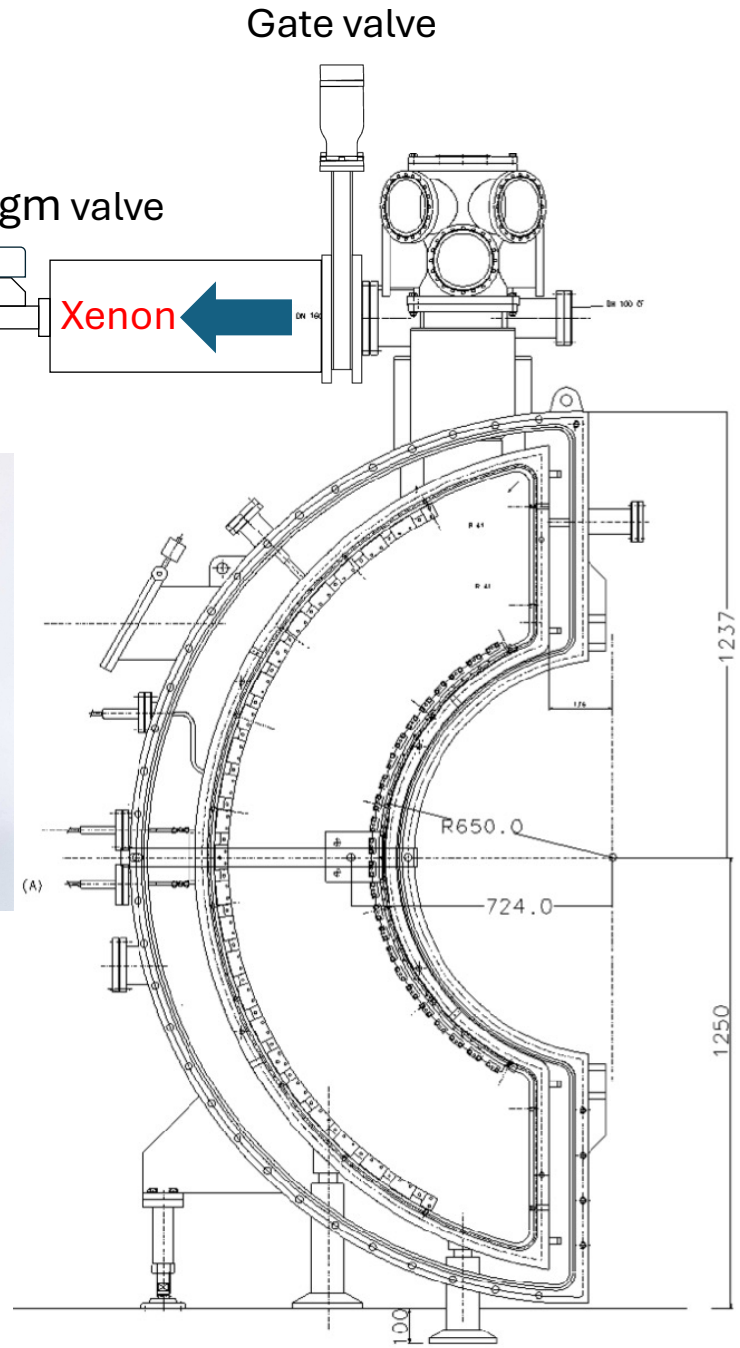
  - Exchange gasket in inner vessel during shutdown period



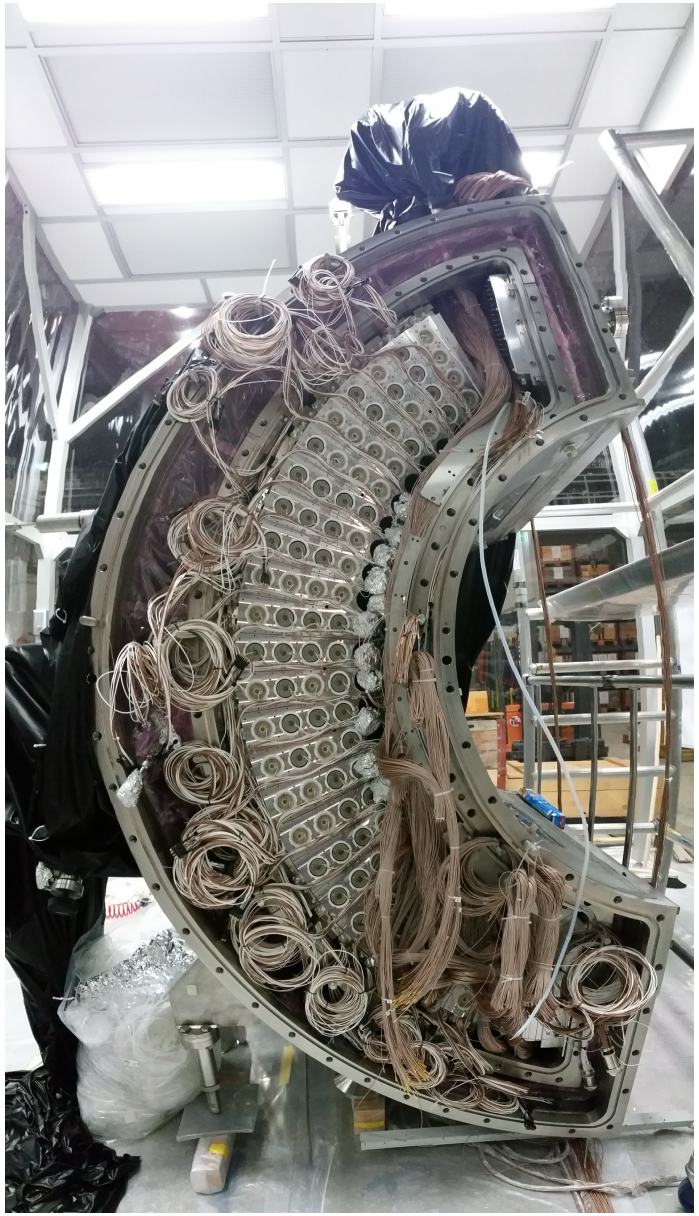
Large leak

- Found xenon between gate valve and stop valve
  - By mass spectrometer
- Gate valve: 10840-CE14 (CF203), VAT
- Leak rate: 5.7 ± 2.9 kg/day
- Cause of leak
  - Gate valve was not leak tight
    - To open or close gate valve, compressed air should be supplied to pneumatics cylinder
  - Stop valve is not enough leak tight
- Countermeasure
  - For a while, supply compressed air to gate valve continuously
  - Replace diaghragm valve to new
  - Currently, no large leak anymore
  - Online monitor of large leak detection was implemented

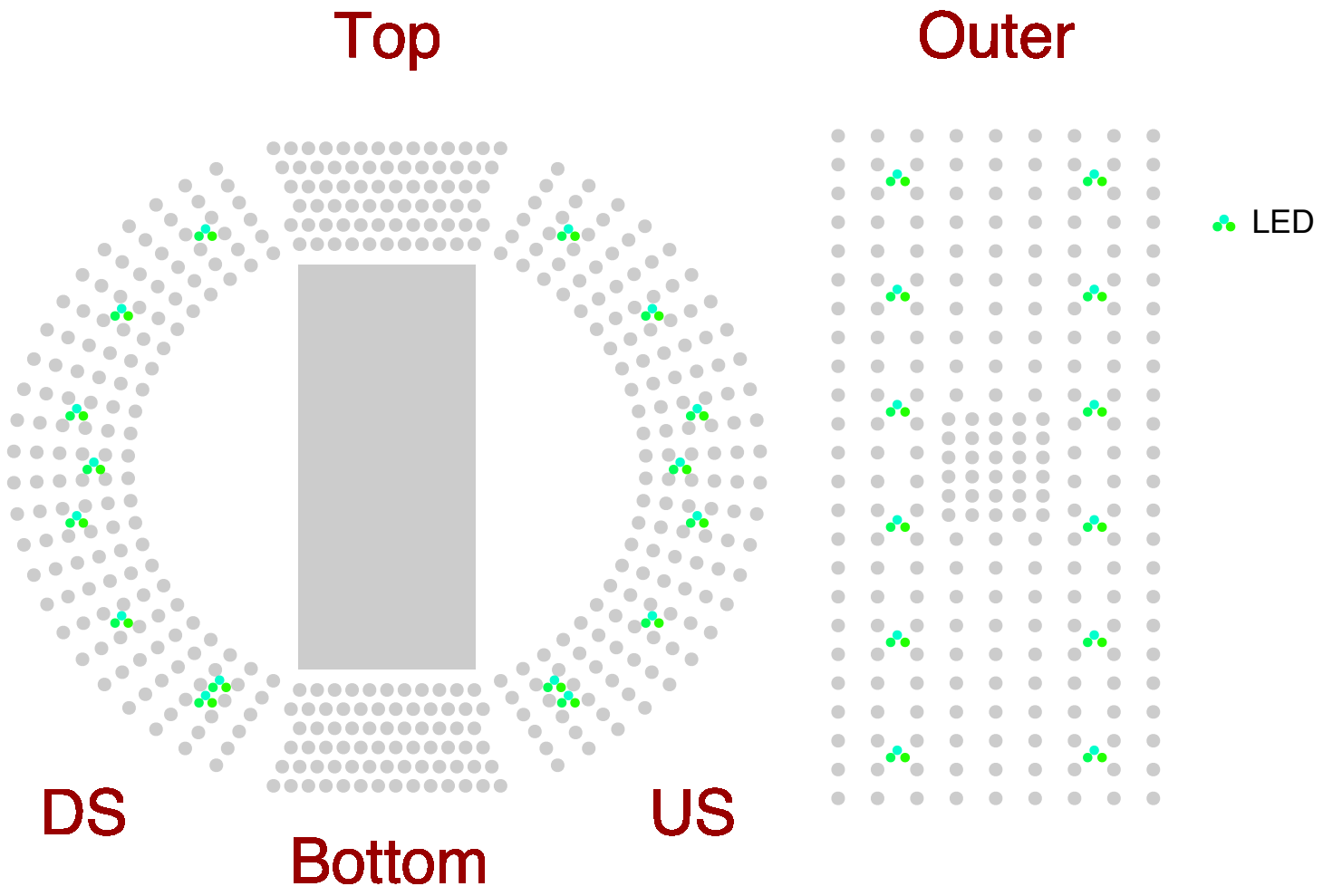




LXe detector inner vessel

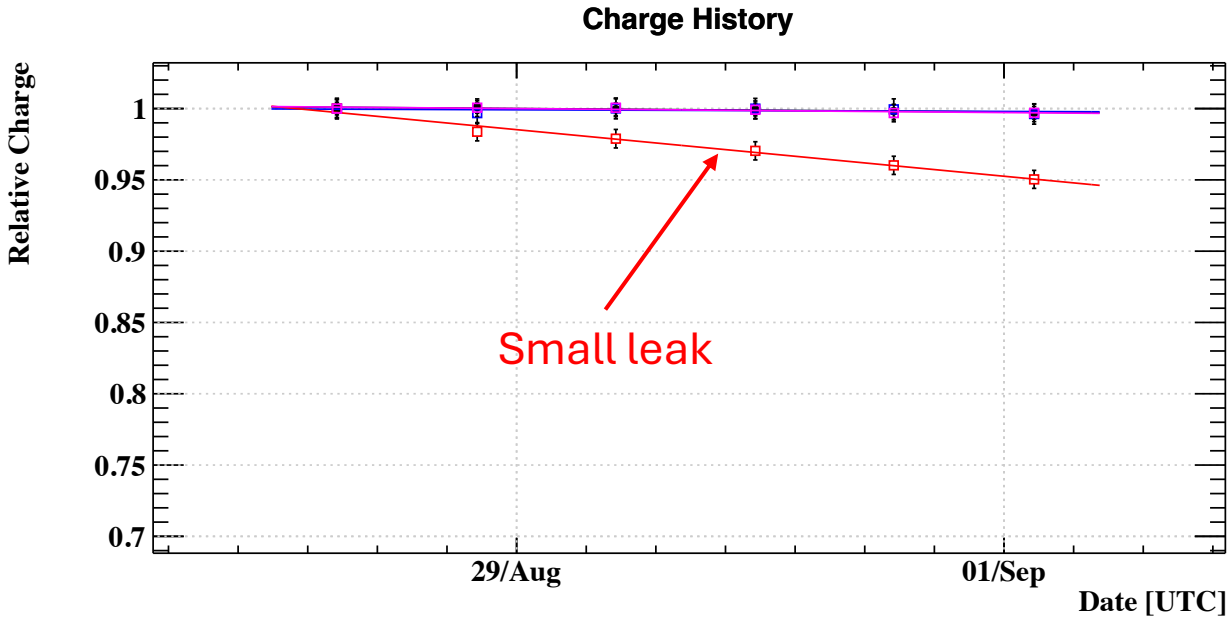


LED inside LXe detector



Regularly Monitor to Detect “Large” and “Small Leaks”

- Introduced regularly monitor to detect large and small leaks
  - Take data which were PMT response when LED light blinking (called “LED data”)
    - Once per day
  - Regularly monitor of large and small leaks after taking LED data



- Algorithm of large leak detection
  - Subtract charges of PMT which taken once per day
  - If the difference is larger than a given threshold (which was determined referring previous large leak), the alarm rings

- Algorithm of small leak detection
  - Calculate the slope of PMT charges, which taken once per day, for the past 7 days
  - If the slope is larger than a given threshold (which was determined referring previous small leak), the alarm rings