MEG II 実験液体キセノン検出器用MPPCに対して低温環境が与える影響の評価

Kohei Shimada
On behalf of MEG II collaboration
The University of Tokyo

Feb. 17th, 2020

Introduction

- **The motivation of searching $\mu \to e\gamma$**
- **Overview of MEG II**
- **Liquid xenon photon detector**

MPPC

- **VUV-sensitive MPPC**
- **The mechanism of VUV detection**
- **MPPC PDE decrease**
- **Surface damage by VUV light**

Measurement of PDE decrease

- **Outline**
- **Setup**
- **Result**
- **Summary**

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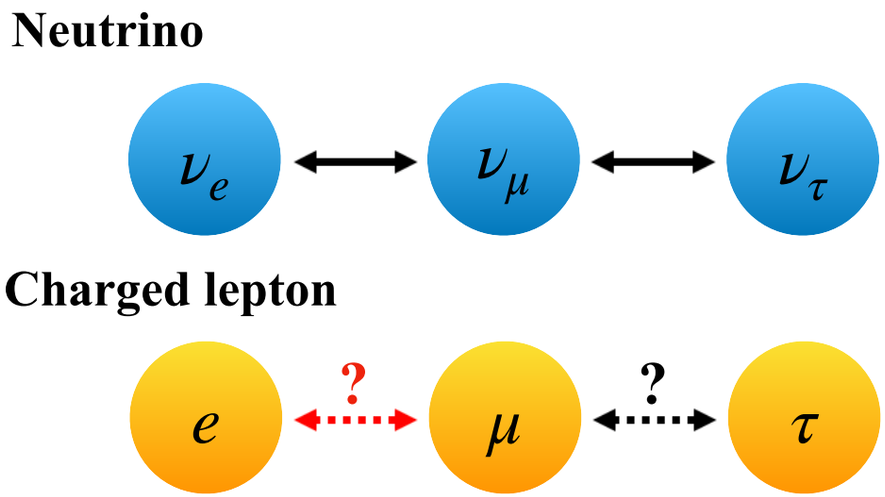
The motivation of searching $\mu \to e\gamma$



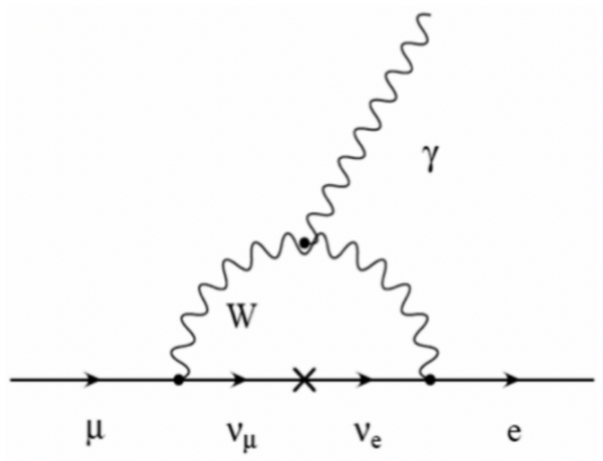
- **Neutrino oscillation was discovered (1998)**

  →Shows that neutrinos have mass and mixing

- $\mu \to e\gamma$ **in the standard model**

$$Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{i1}}{M^2_W}\right|^2 \simeq 10^{-54}$$

→Cannot be observed

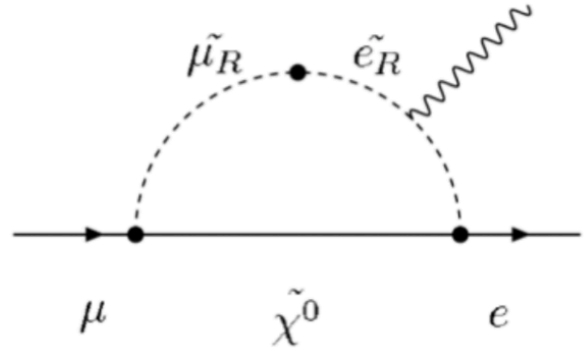


- $\mu \to e\gamma$ **in a new physics e.g. SUSY GUT**

  →Assume unknown heavy paticle

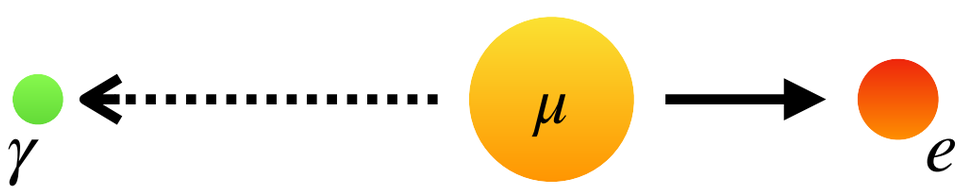
$$Br(\mu \to e\gamma) = \mathcal{O}(10^{-12}) - \mathcal{O}(10^{-14})$$

→Can be observed

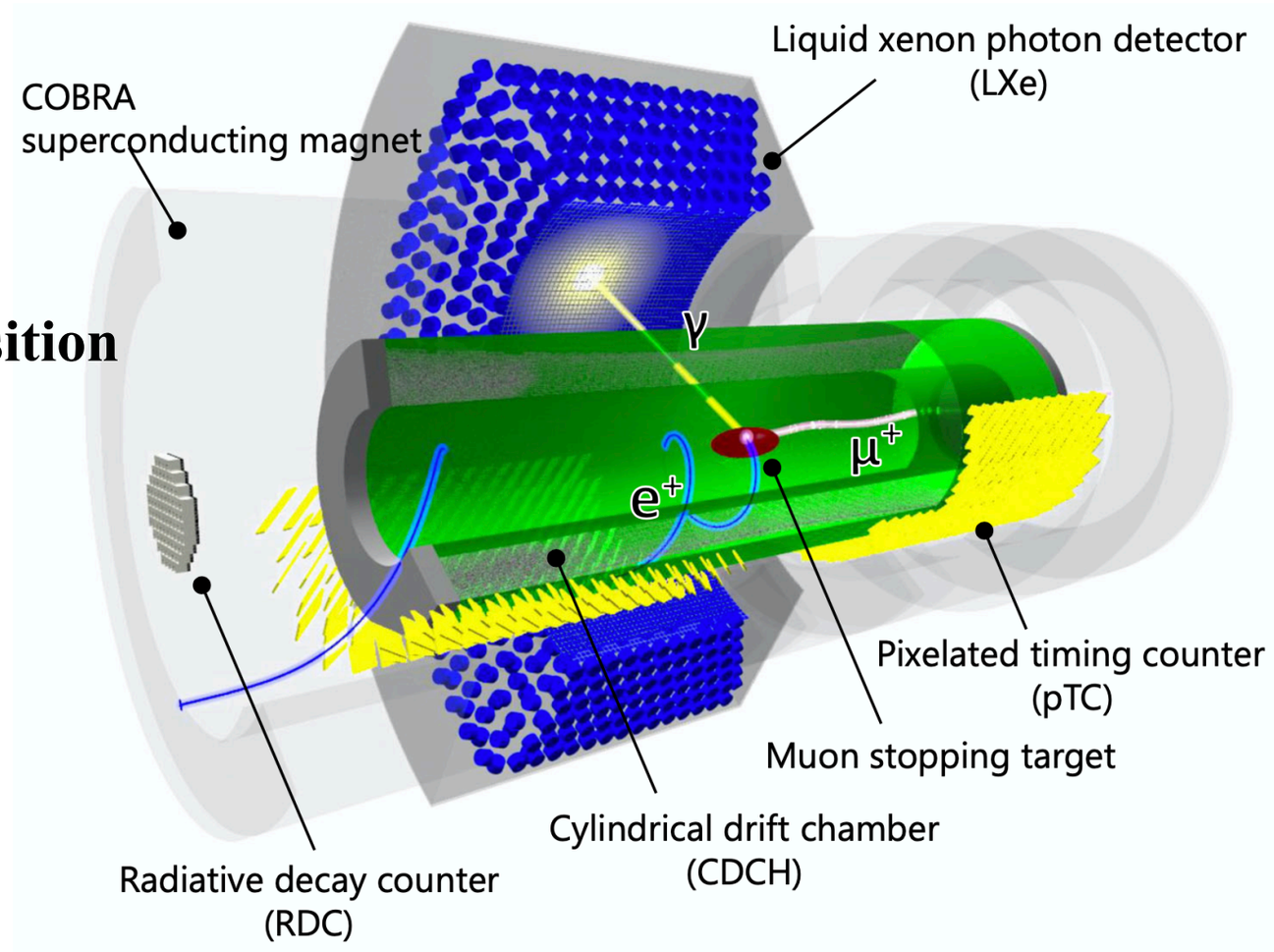


Overview of the MEG II experiment at Paul Scherrer Institut

- **The world's most intense μ beam** $7 \times 10^7 \mu/\mathrm{sec}$
- **Muons are stopped at the target**
- **Two-body decay**



- **The photon energy, interaction point position and time are measured by LXe**



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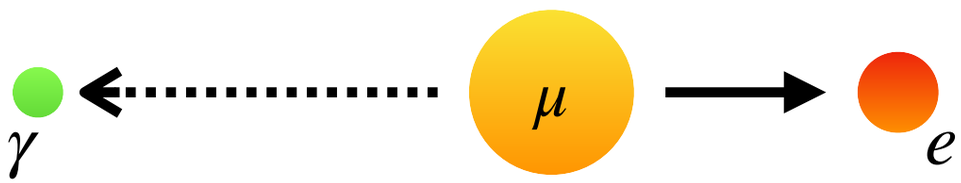

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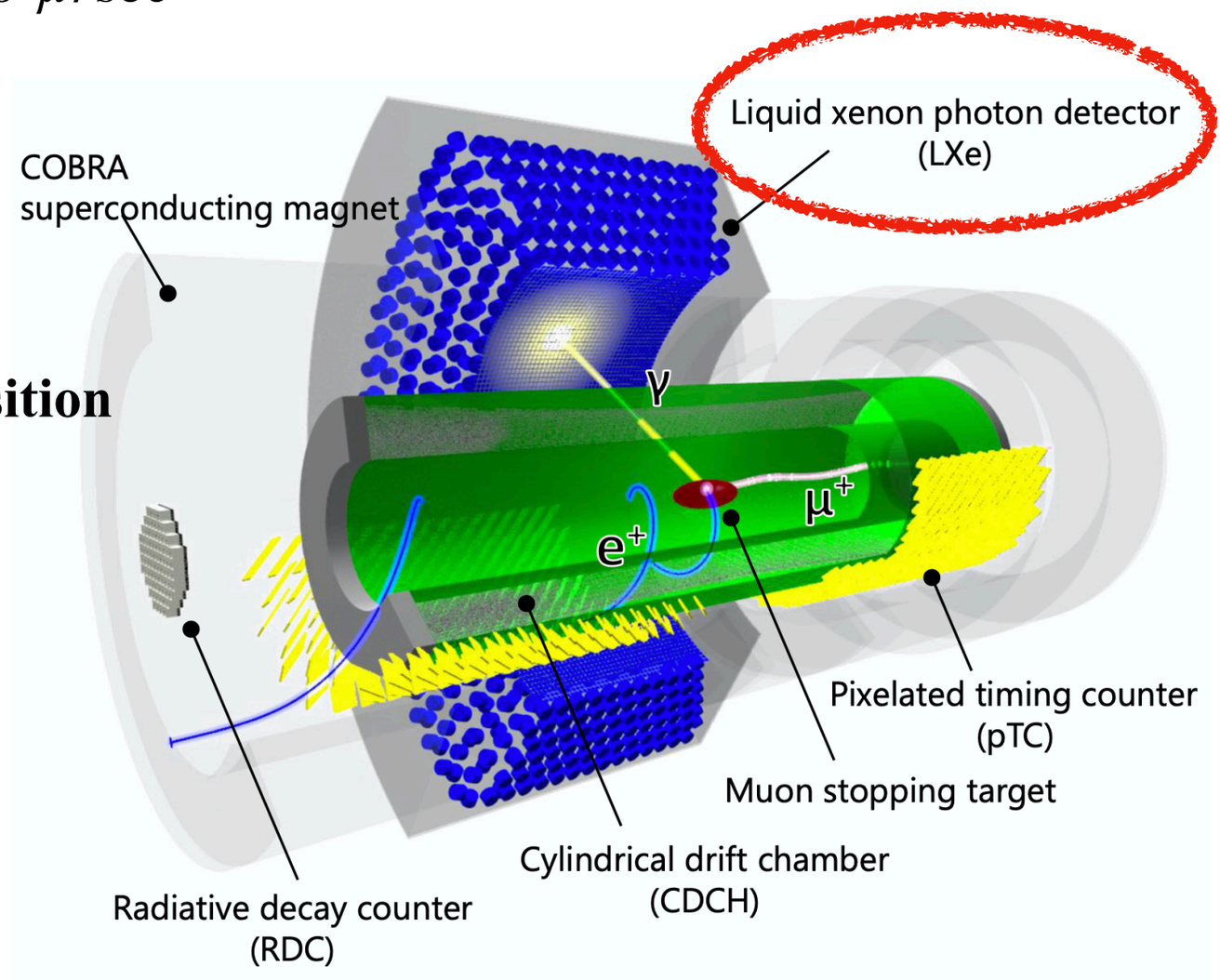
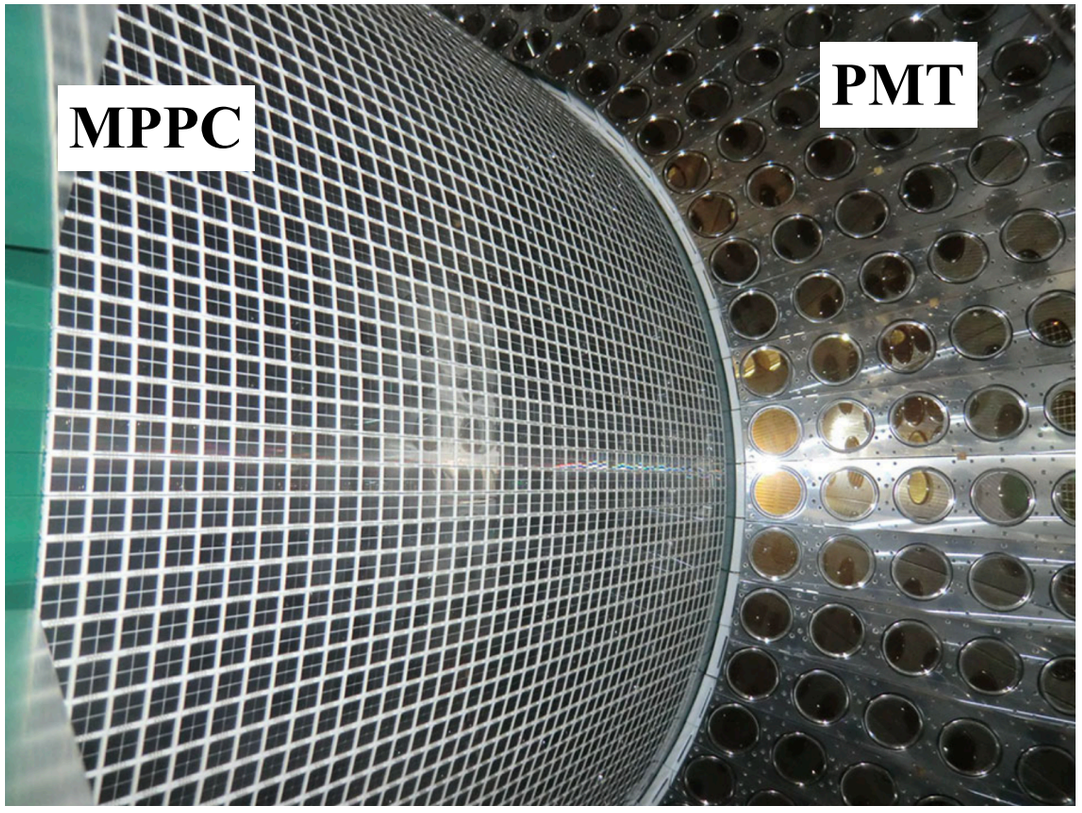
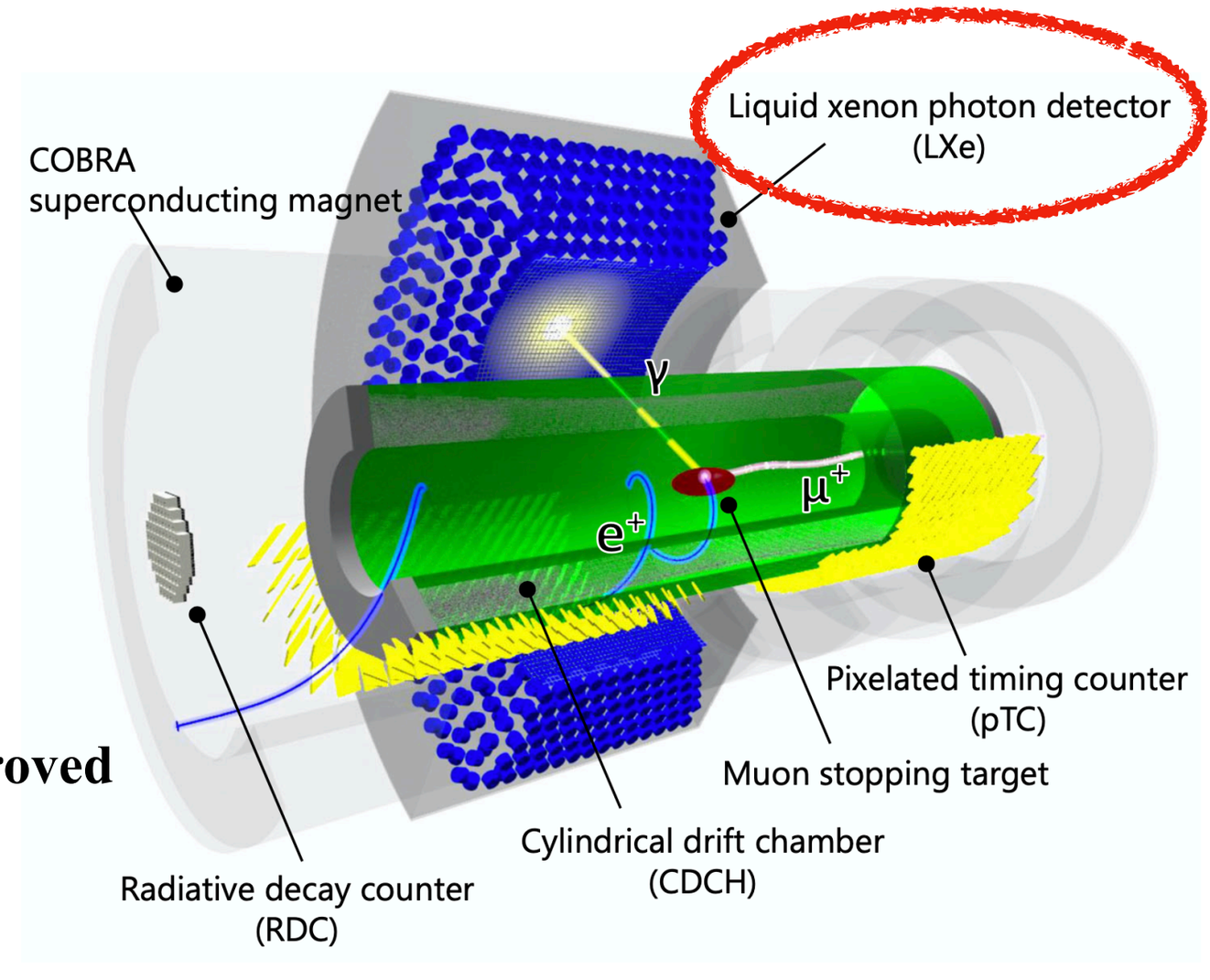


Liquid xenon photon detector (LXe)



- **Liquid xenon to measure 52.8MeV photon**
- **Detect the scintillation ($\lambda = 175$nm)**
- **4092 MPPCs, 668PMTs at 165K**
- **Energy and position resolutions will be improved as compared with MEG by a factor of two**
- **Under commissioning since 2017**



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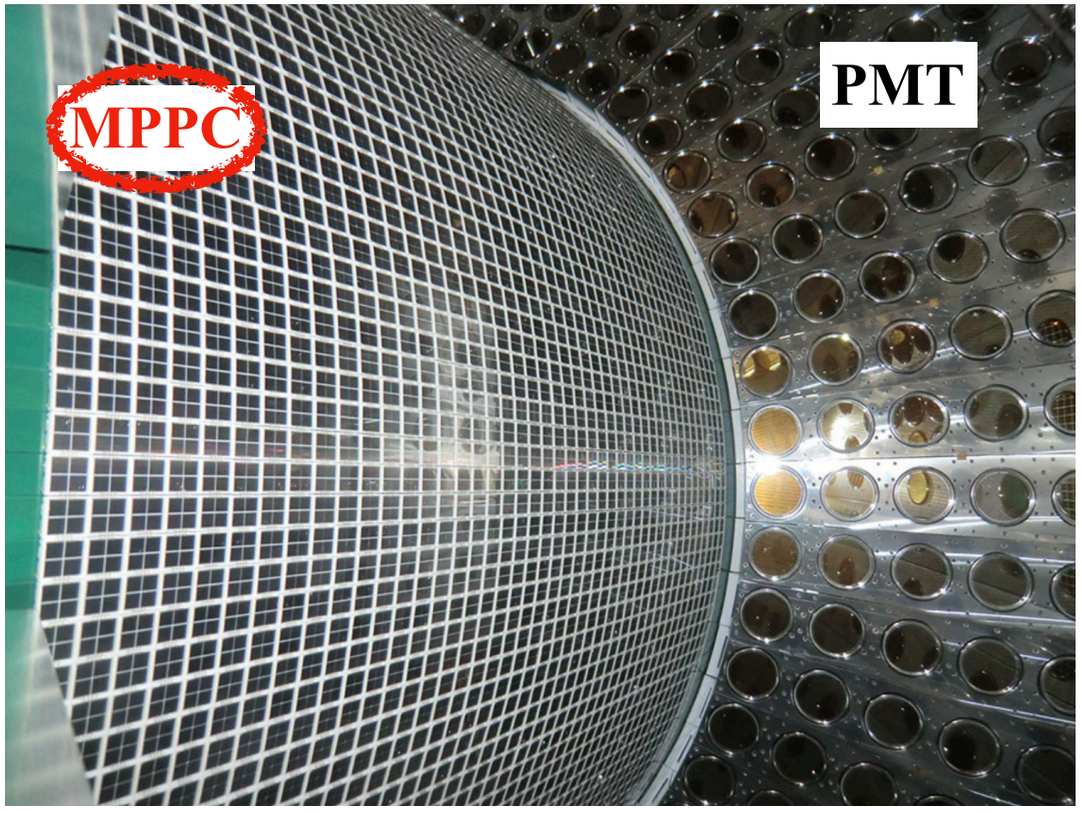

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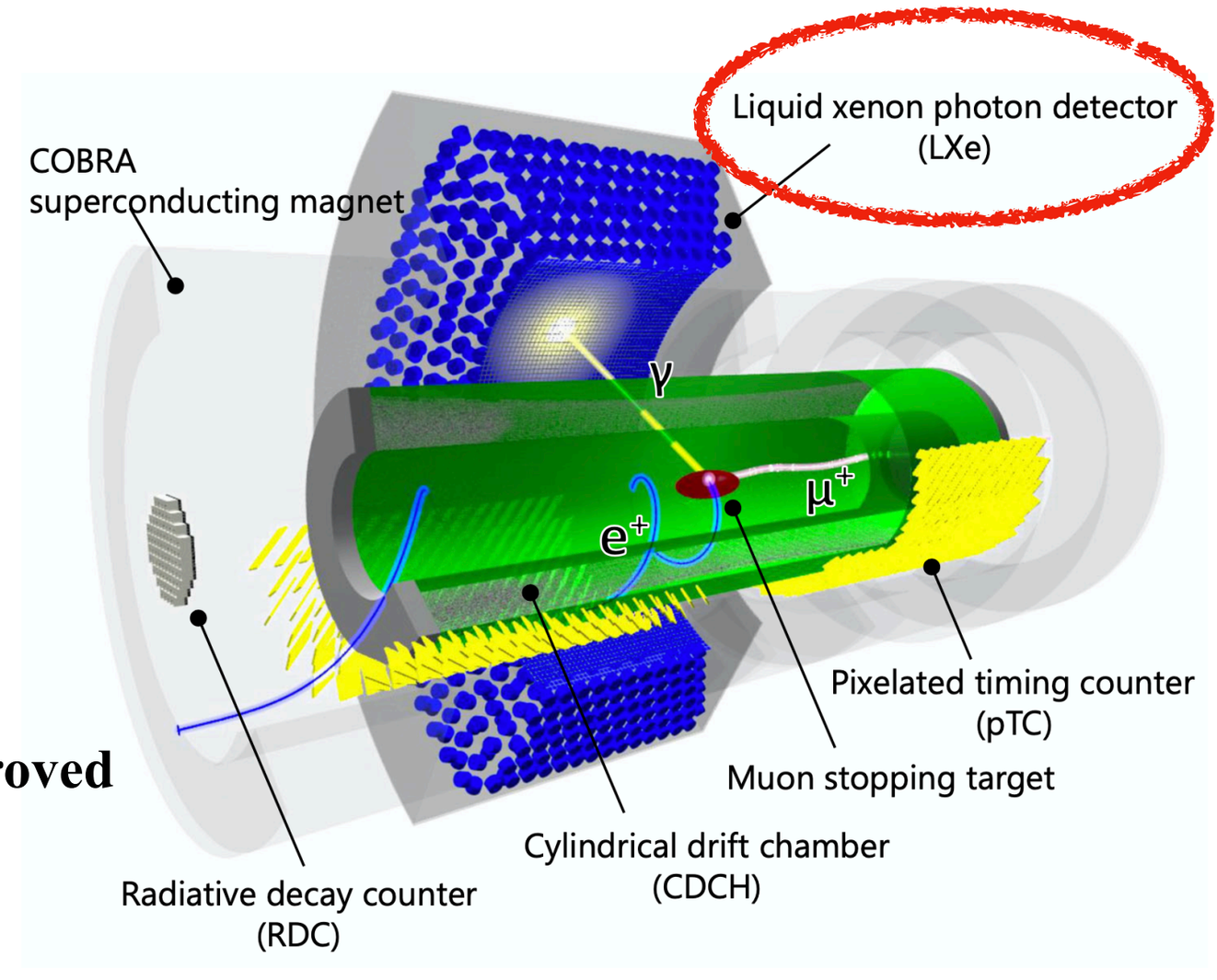

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Measurement of PDE decrease

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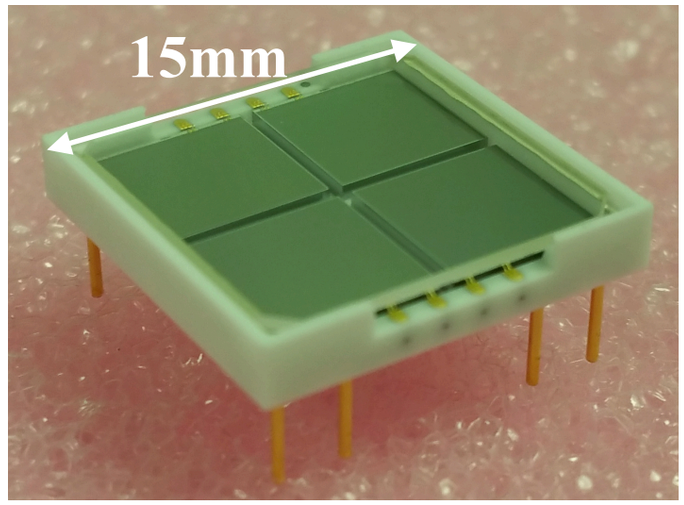
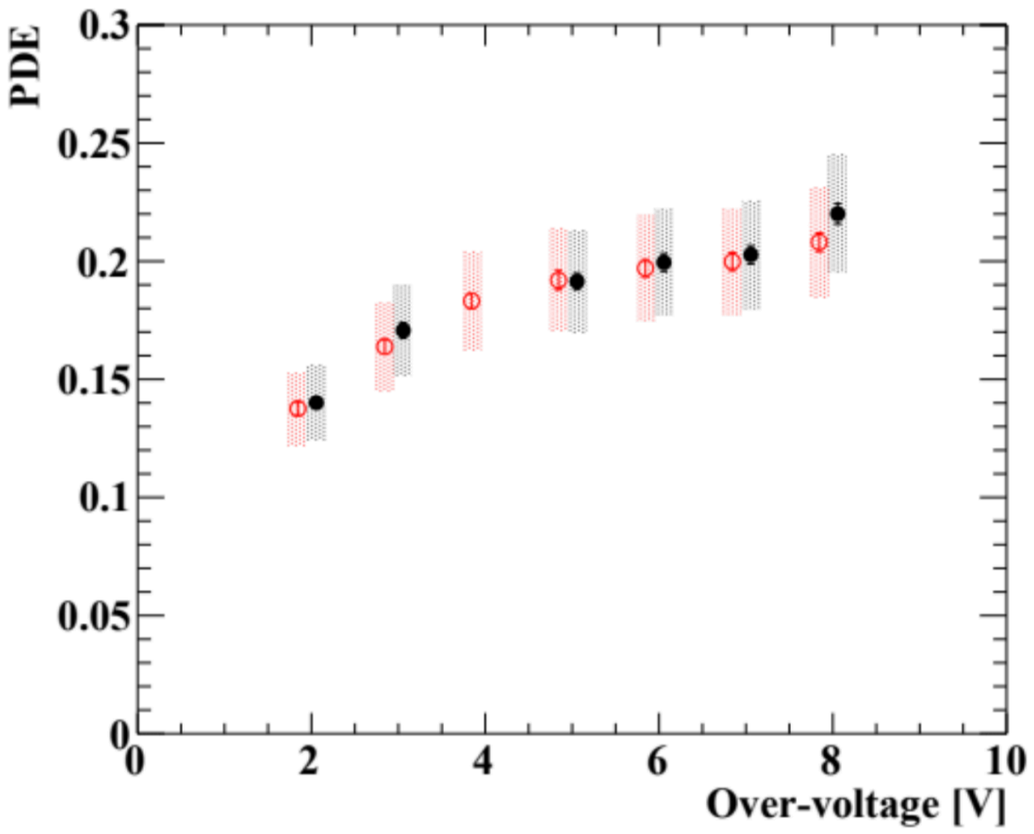
VUV-sensitive MPPC (SiPM)

- **SiPM is a high-performance photon detector**
- **VUV-sensitive MPPC has been newly developed for MEG II**
- **Operational at low temperature (165K)**
- **Photon detection efficiency (PDE) >15% at** $\lambda = 175\text{nm}$
- **Large sensitive area** $(12 \times 12\ \text{mm}^2)$

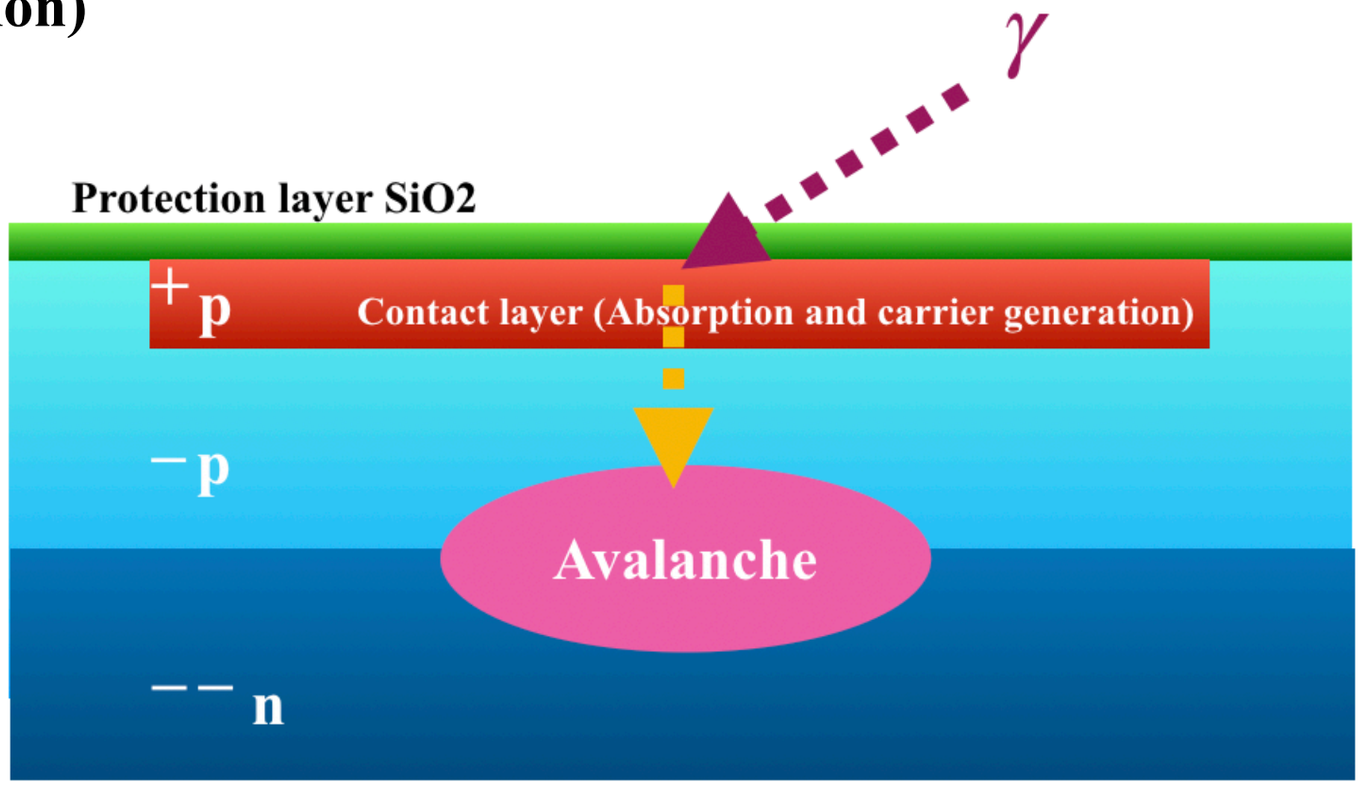




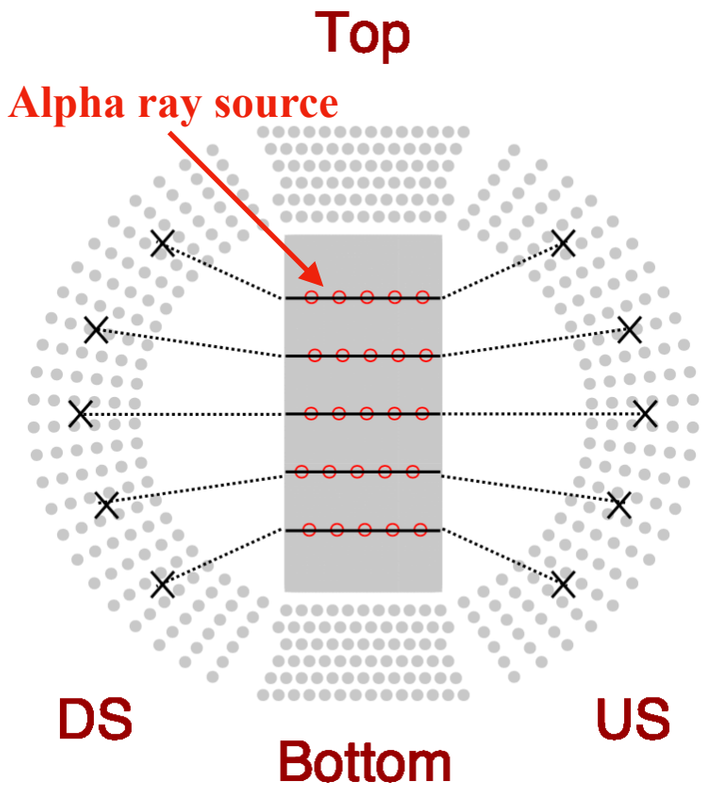
The mechanism of photon detection

- **General SiPM**
  - **Depletion layer : p-n junction**
  - **Incoming photons generate electron-hole pairs**
  - **Reverse voltage is larger than a threshold**
    →“Geiger mode”
  - **In geiger mode, carriers make other carriers**
    →Number of electron-hole pairs increase exponentially (avalanche multiplication) to make a signal
- **Insensitive to VUV**
  →VUV stops near the surface
  →Visible light reach the deep part

- **VUV-sensitive MPPC**
  - **Remove the protection coating (epoxy)**
  - **Thin down the contact layer**



VUV-sensitive MPPC PDE decrease

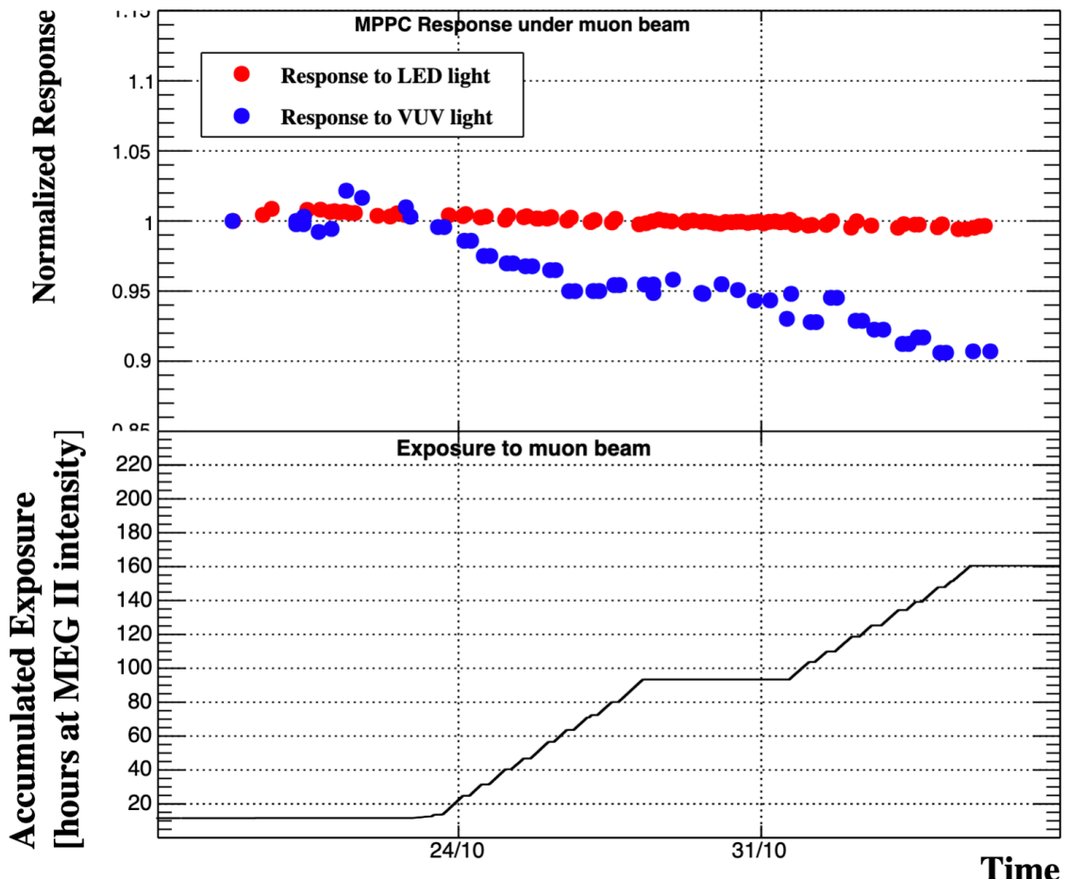


- **Alpha ray sources are in the detector**

  →Produce VUV scintillation light

- $\mathrm{PDE} = \dfrac{\mathrm{N(photon)_{observed}}}{\mathrm{N(photon)_{expected}}} \sim 8\,\%$

  →much lower than that measured in Lab(＞15%)



- **Degradation of MPPC VUV-sensitivity**

  →quite fast ~0.05%/hour

  (under MEG II beam intensity $7 \times 10^7 \mu/\mathrm{sec}$)

- **MEG II DAQ time (design) : 140 days/year, 3 years**

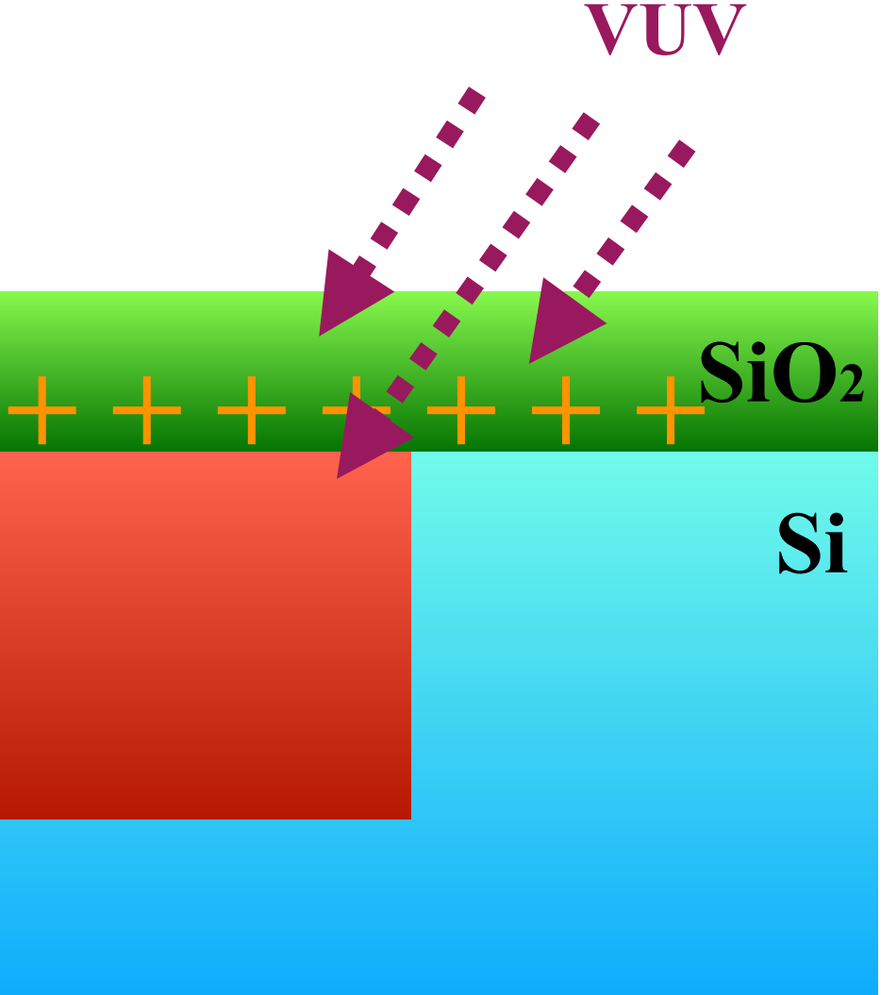
  →This degradation is not negligible

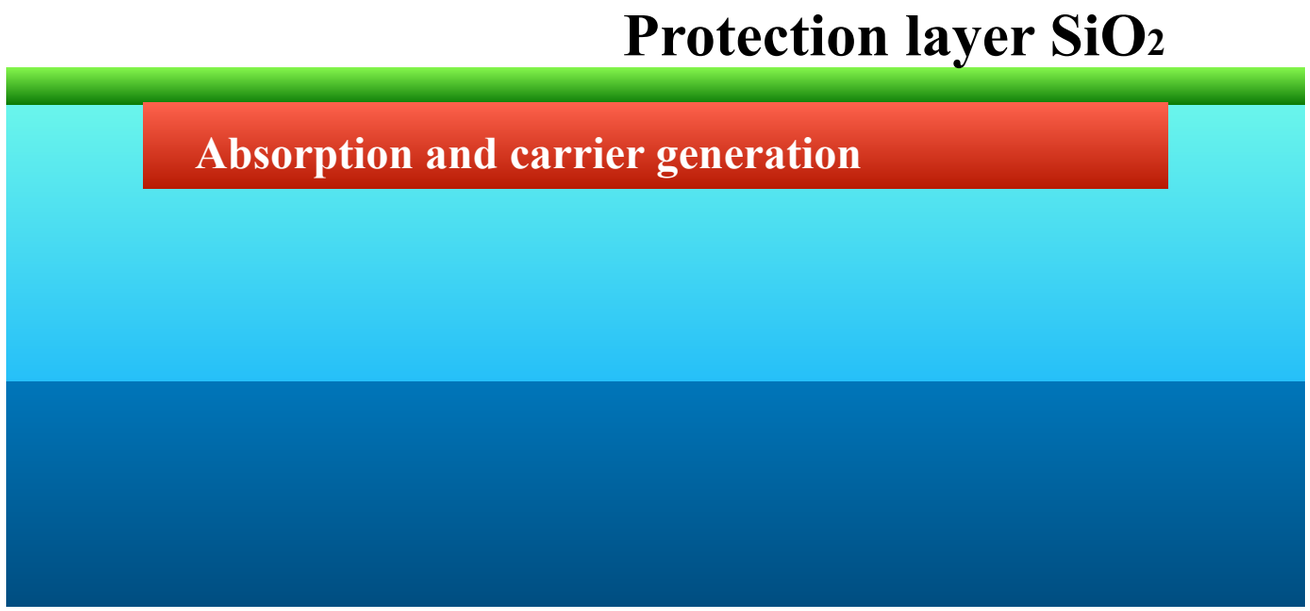
- **A possible cause: Gamma, Neutron irradiation**

  →In lab test, no effect on PDE was observed (at room-temp)

Surface damage by VUV light

- **Electron-holes are generated in SiO_2 by VUV light**
- **Holes are trapped at interface SiO_2-Si**
- **The electric field near the boundary of the two surfaces will be reduced by the holes**
  →Collection efficiency will be reduced
- **Degradation seems accelerated at low temperature**
  →Holes hardly move





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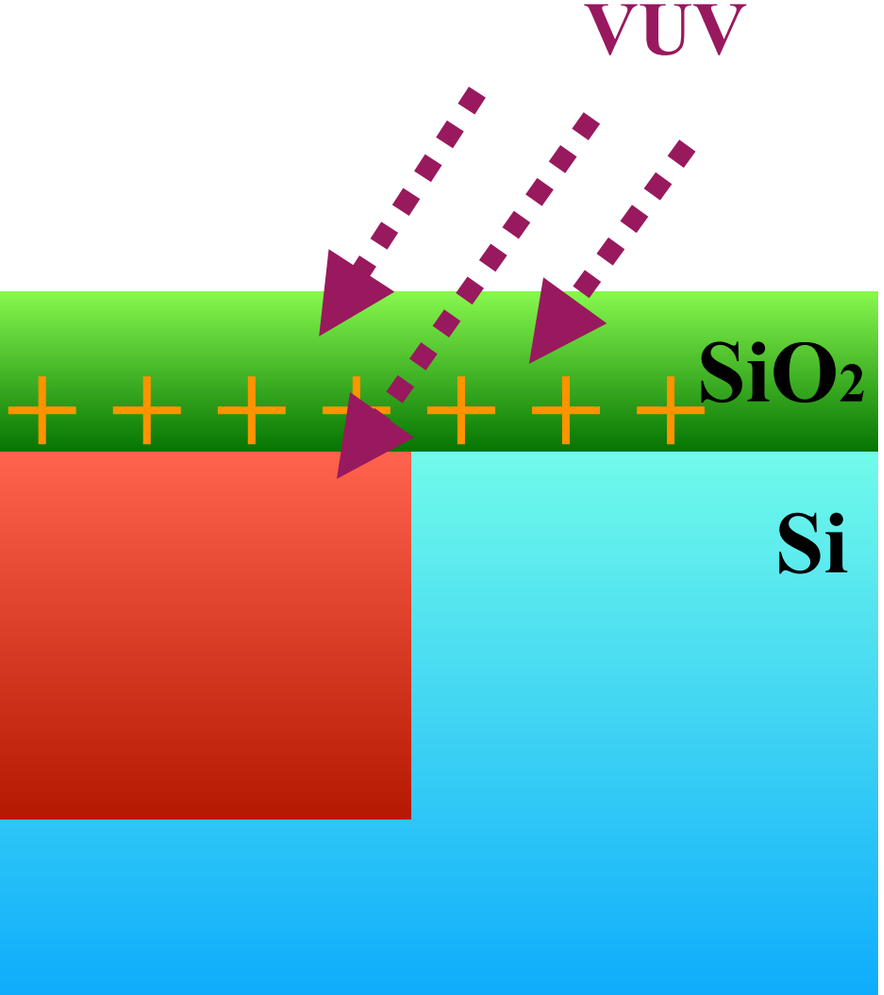

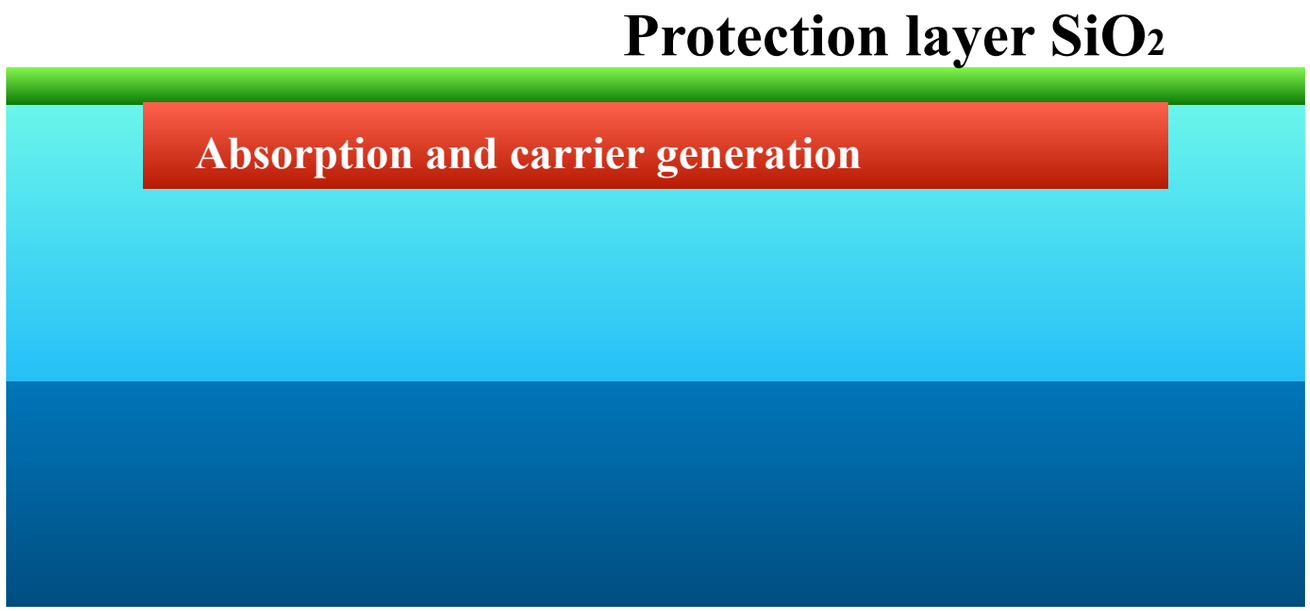

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Outline

- **To survey the effect of low temperature on the PDE decrease**

  →Compare the PDE decrease at room temperature and low temperature

- **To induce and monitor the PDE decrease**

  →Irradiate a MPPC

  →Read current with no bias voltage

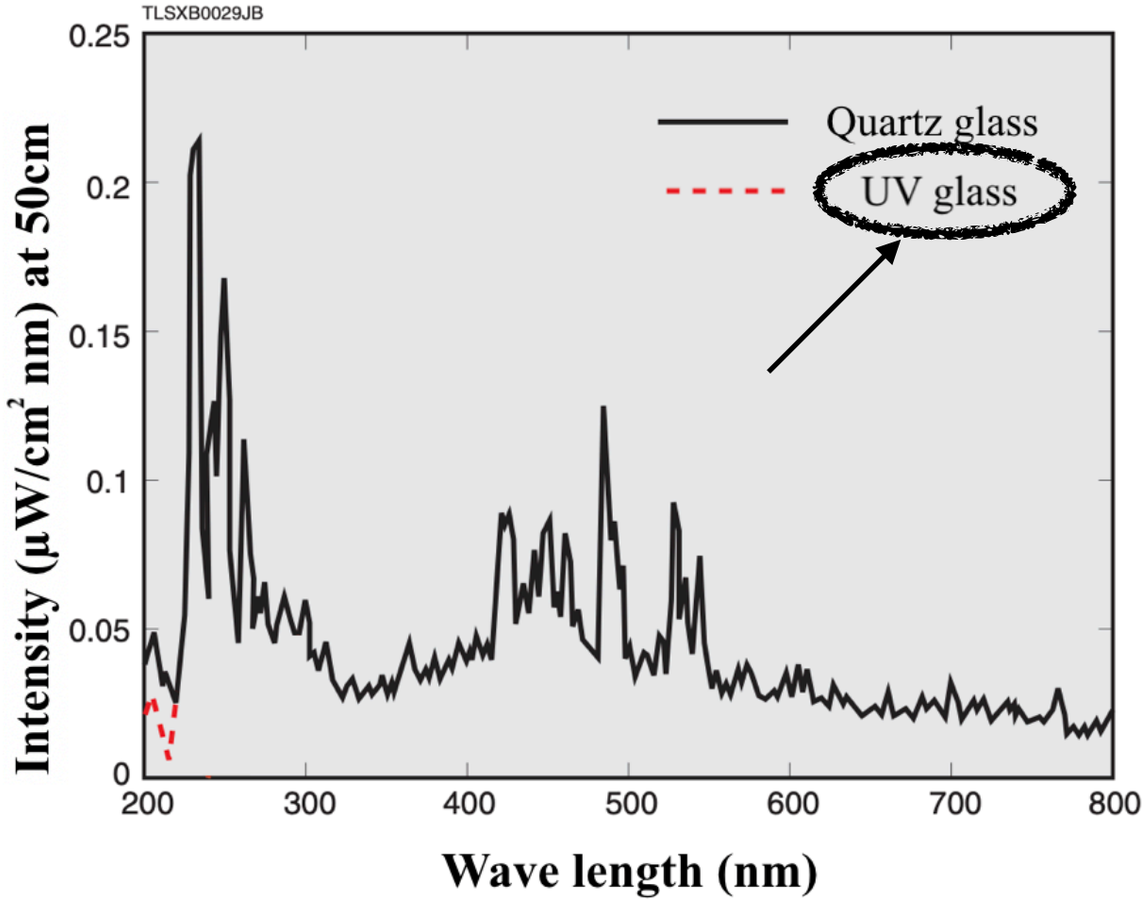
  (in previous research, correlation between current and PDE was observed)

- **Xe flash lamp as a irradiation source**

  →To irradiate with short-wavelength light (~175nm)

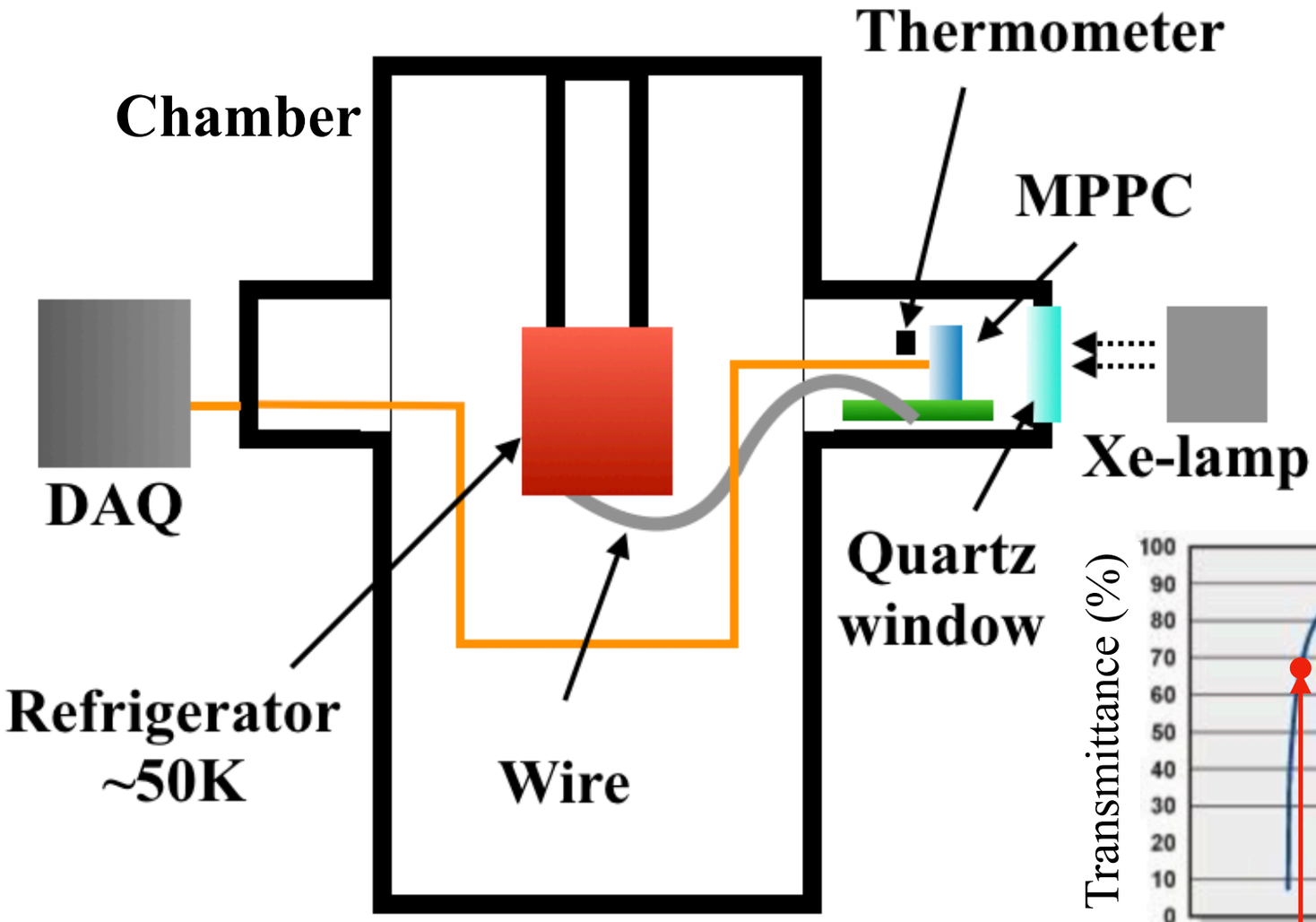
Xe flash lamp

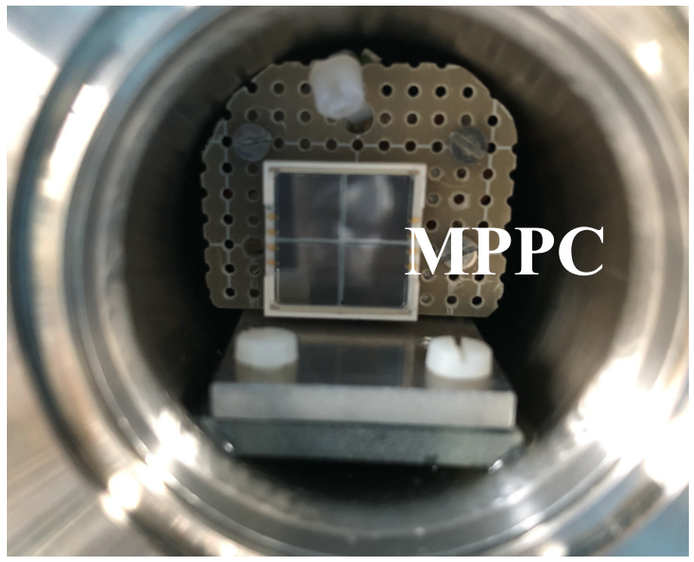
HAMAMATSU - L9455 series

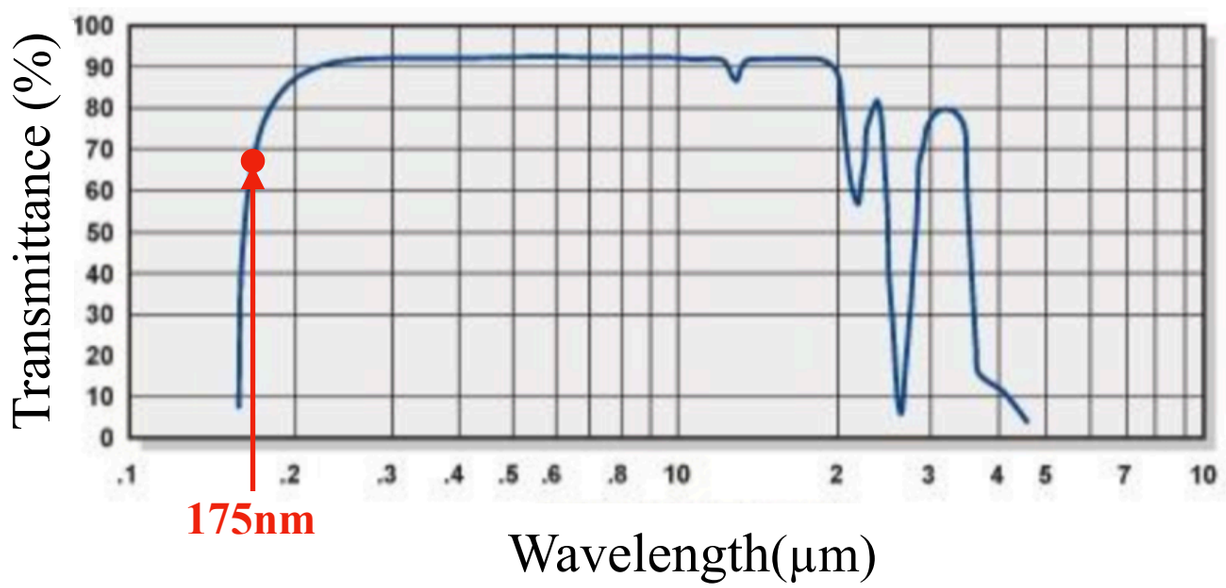


Setup

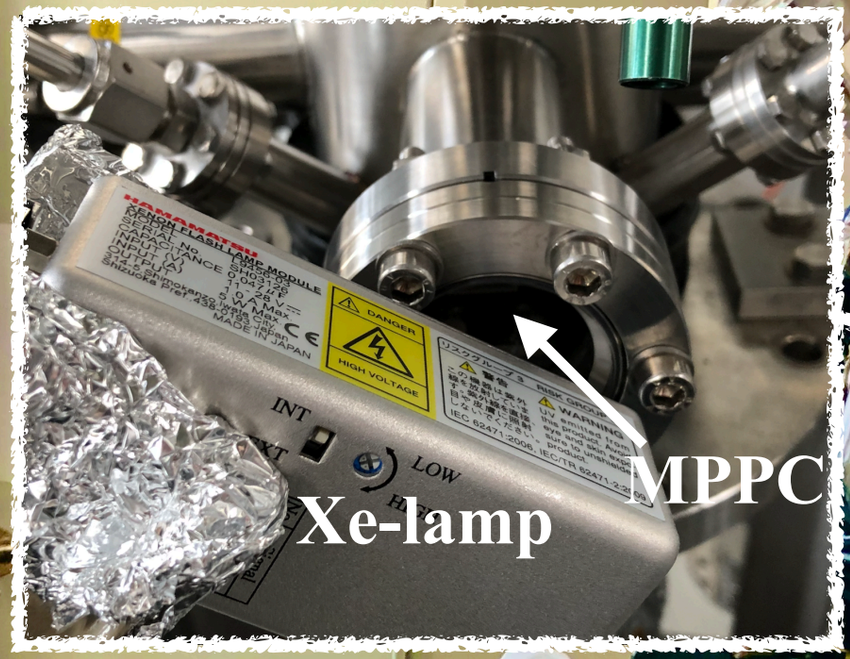
- Make vacuum in the chamber, for insulation
- Wire carries low temperature from refrigerator
- ~240K, around the MPPC
  →Could not reach the LXe temp(165K)
- MPPC is irradiated through quartz window
  →Distance : 5cm
- Read 1chip current (MPPC has 4chip)
  →HV=0V







Setup



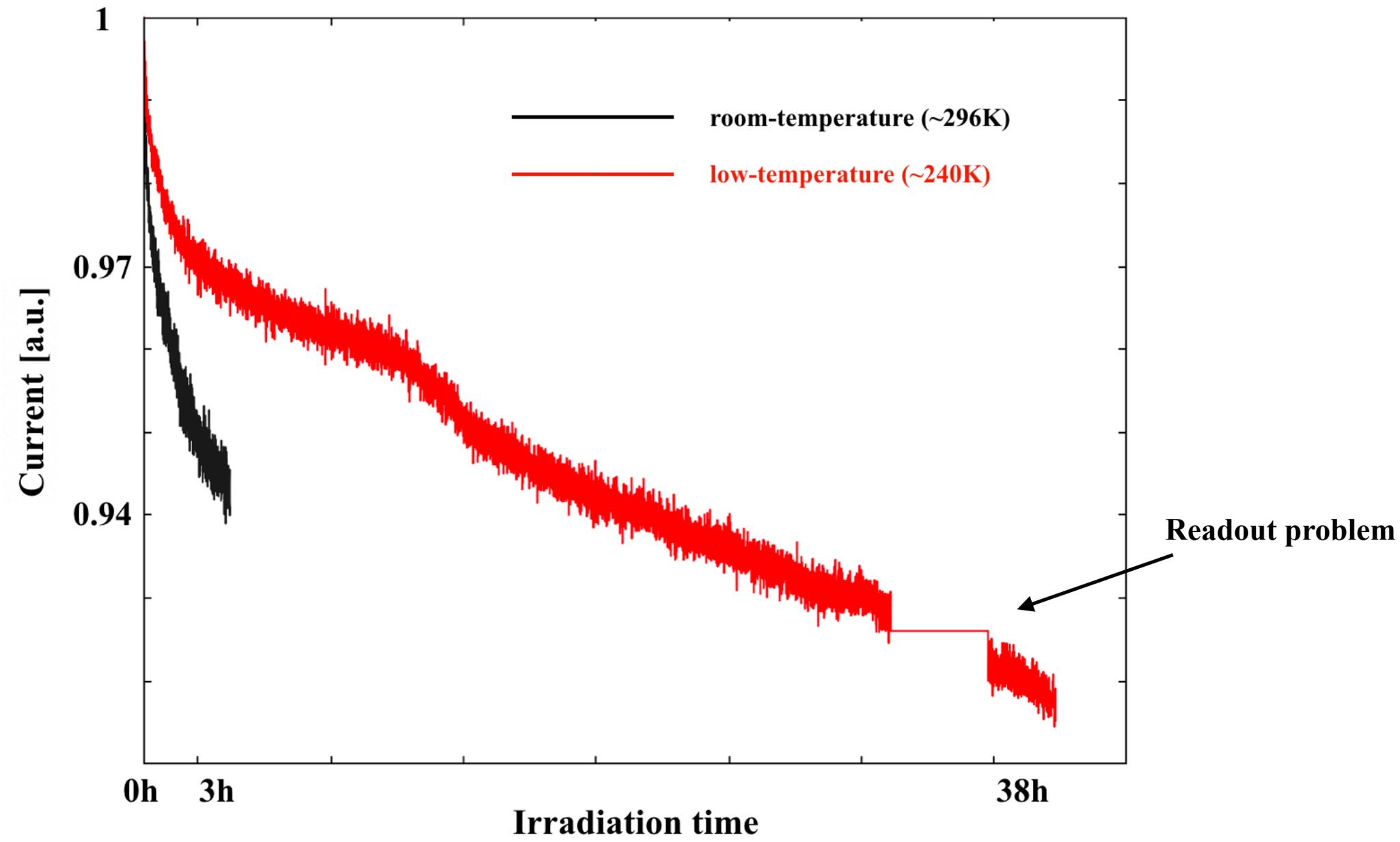
Black sheet for safety

Trigger for Xe-lamp

1ch current readout
HV=0V

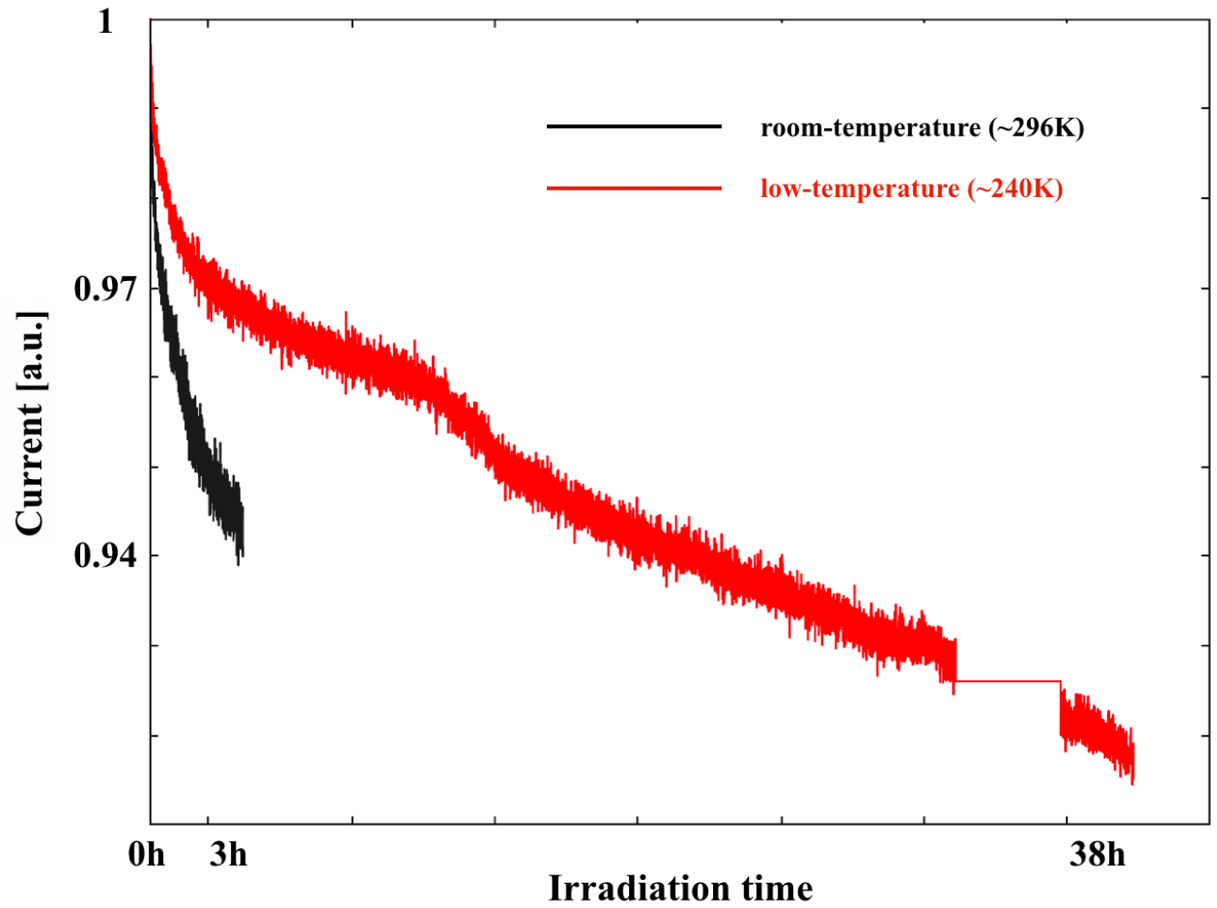
Chamber

Result (HV=0V)



- Irradiated one MPPC (low-temp → room-temp)

Result (HV=0V)



- **Decrease of current was observed both at low-temp and room-temp**
  →This might means PDE decrease
- **The decrease level of low-temperature is smaller than room-temperature**
  →Contrary to expectation
- **The result includes the entire wavelength region**
  →Different from VUV irradiation
- **The temp (~240K) is much higher than LXe temp (165K)**

Summary

Motivation

PDE degradation of the MPPC was observed in LXe photon detector

- **PDE decrease by VUV irradiation at room-temp was slower than in LXe photon detector**

  → We measured at low-temp

- **Gamma, Neutron irradiation has no effect on PDE in previous research at room-temp**

  →Cannot exclude the possibility that the irradiation damage(Gamma, Neutron) at low-temp is different from room-temp

Measurement

Room temp(~296K) vs Low temp(~240K)

- **Could not reach the LXe temp(165K)**

  →Improve the setup

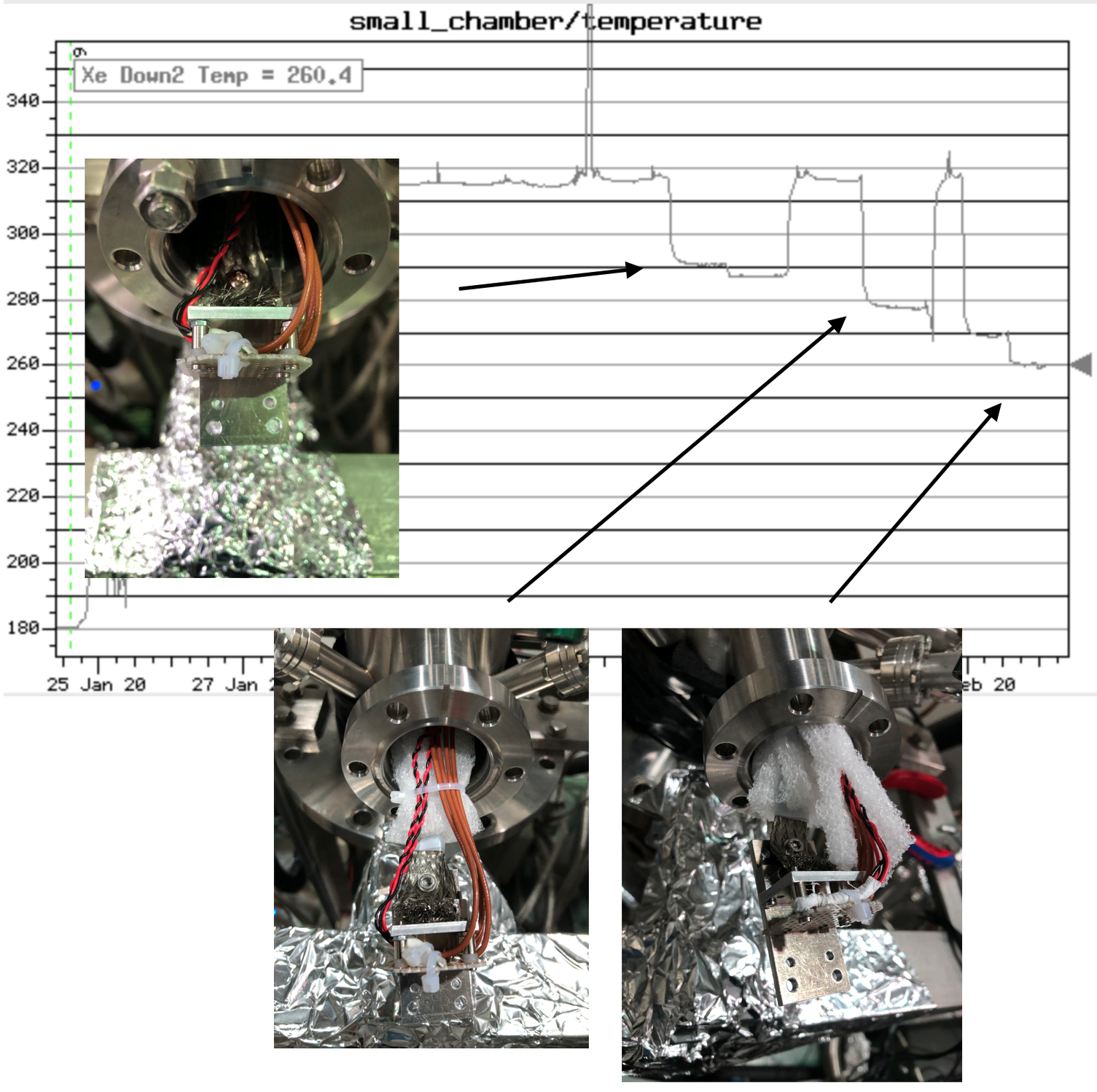
- **Contrary to expectations, current decrease at low temp was smaller**

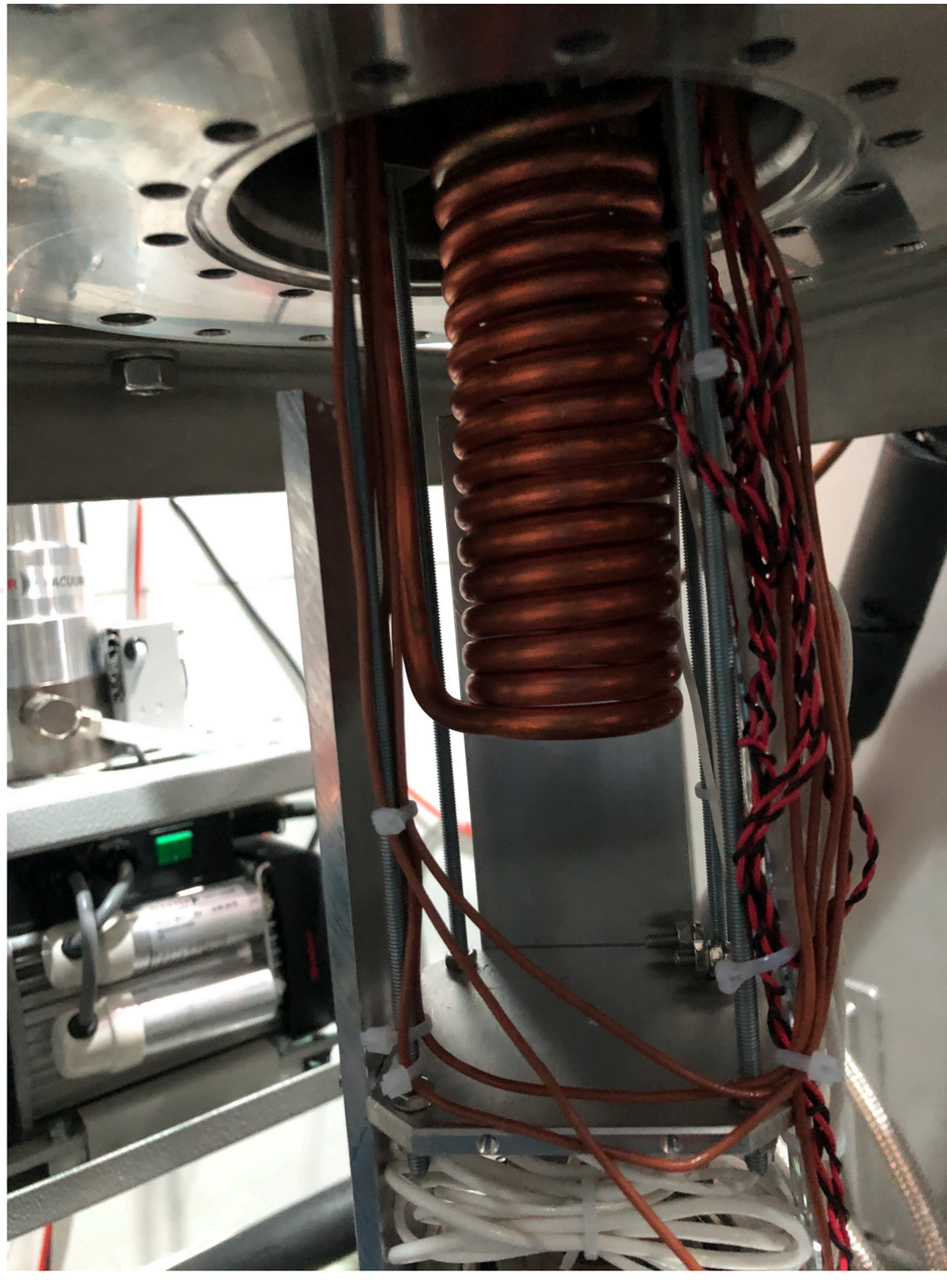
  →We do not know the reason

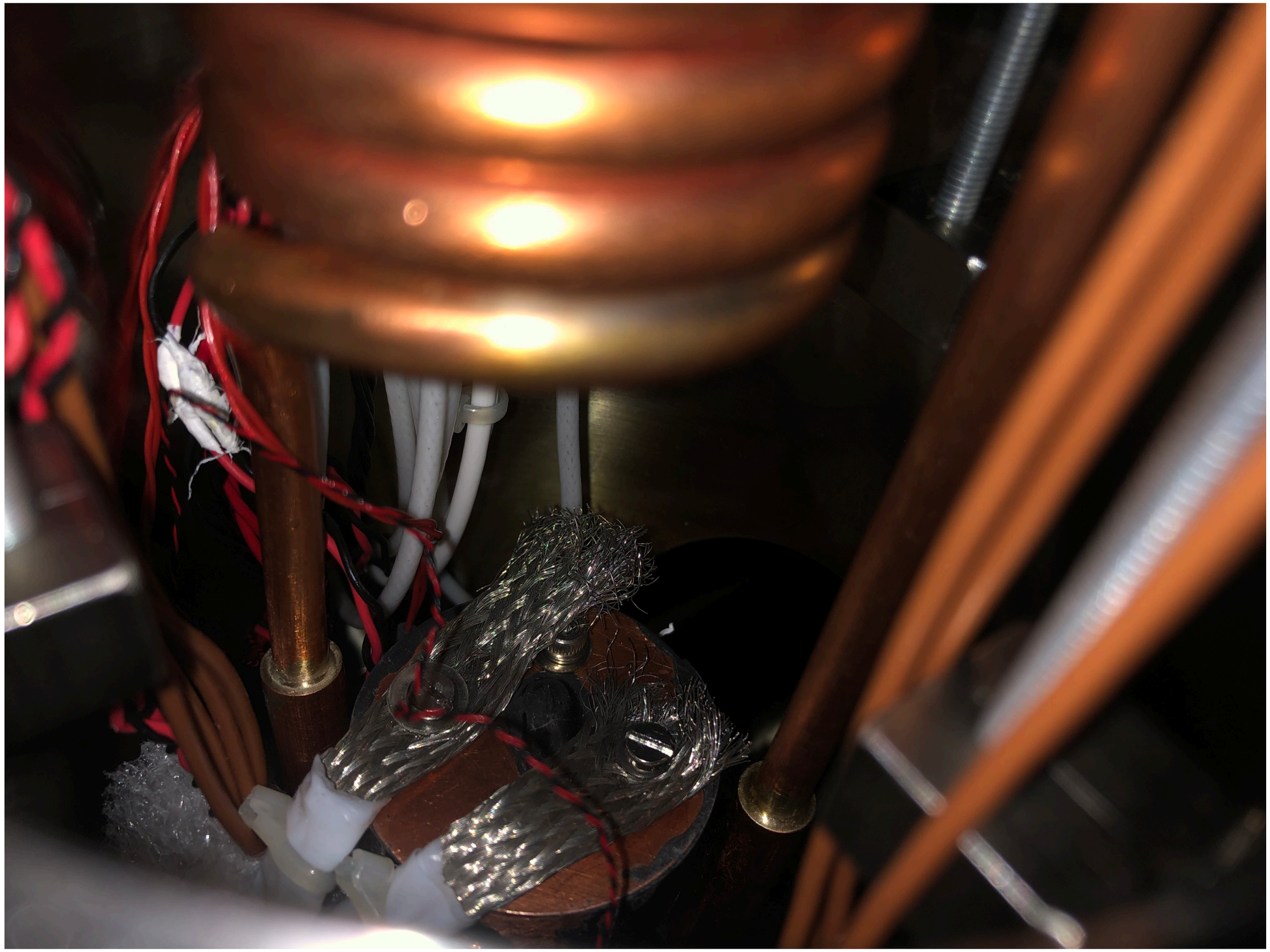
  →The possibility that we did not measure the PDE decrease for VUV light (Xe-lamp has other wave length)

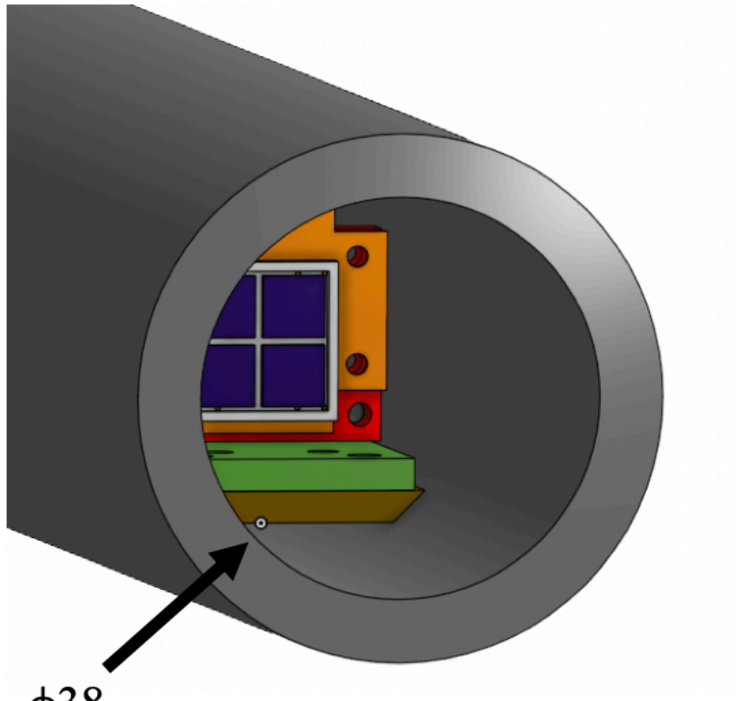
  →We should measure the charge for VUV light using filters

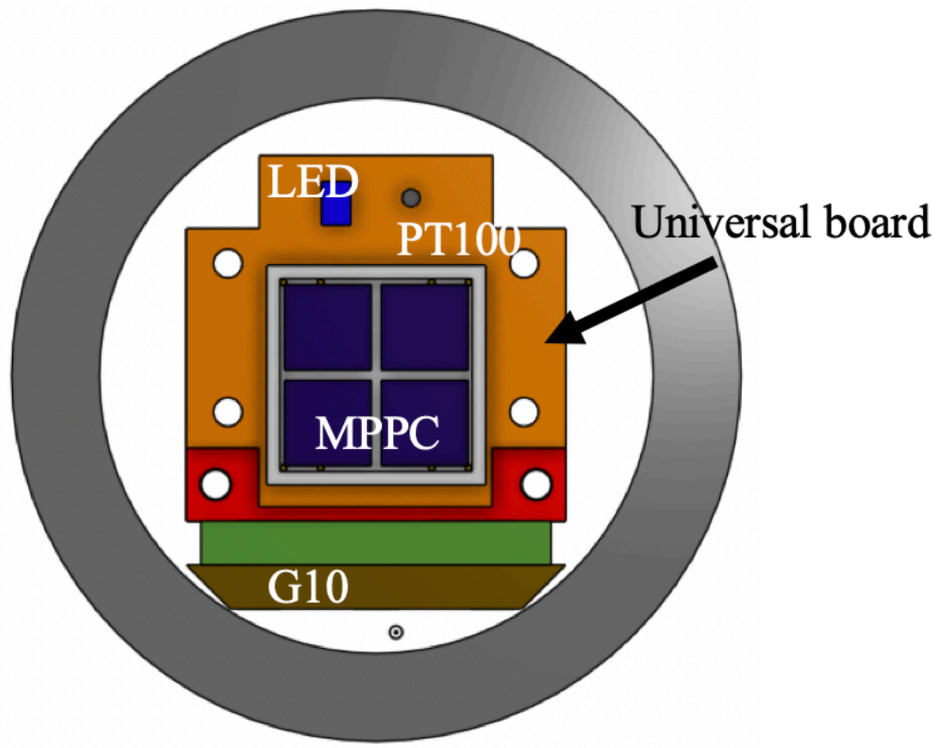
Backup slides

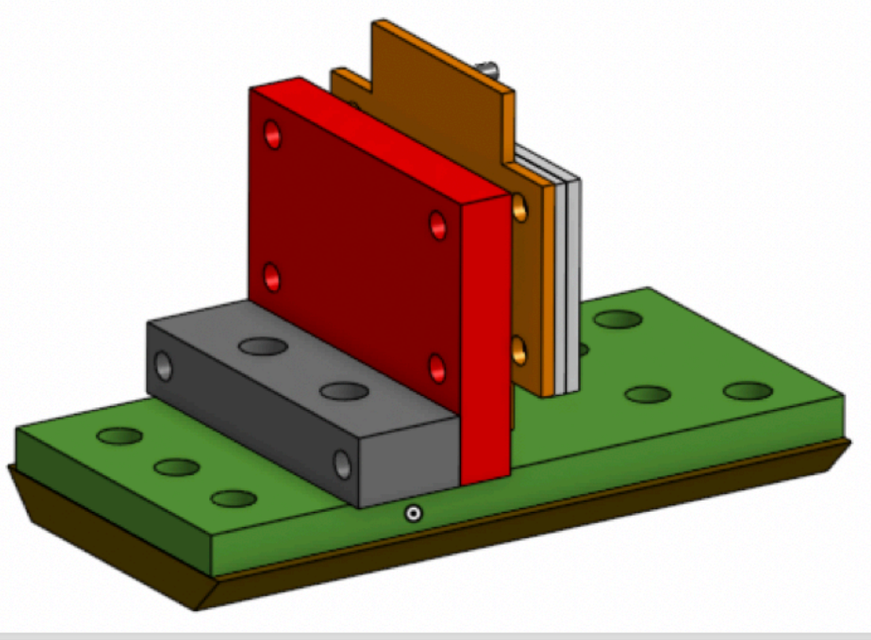

small_chamber/temperature
Xe Down2 Temp = 260.4
340
320
300
280
260
240
220
200
180
25 Jan 20
27 Jan 2
eb 20

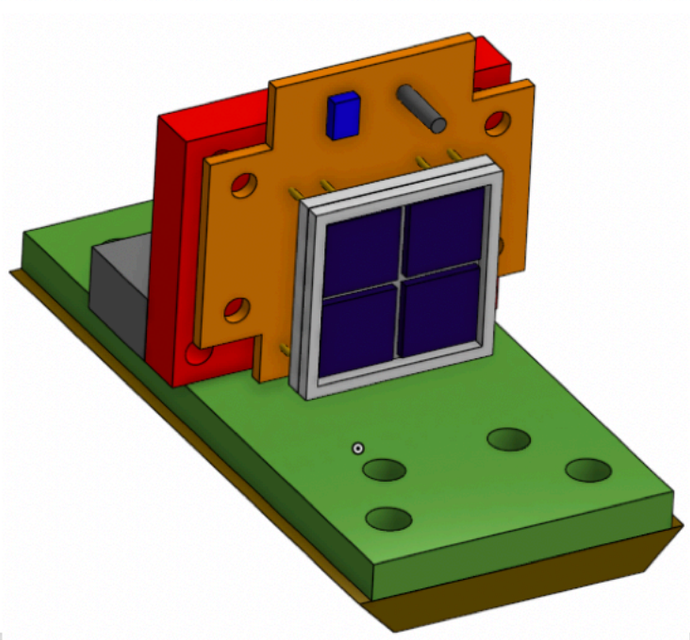


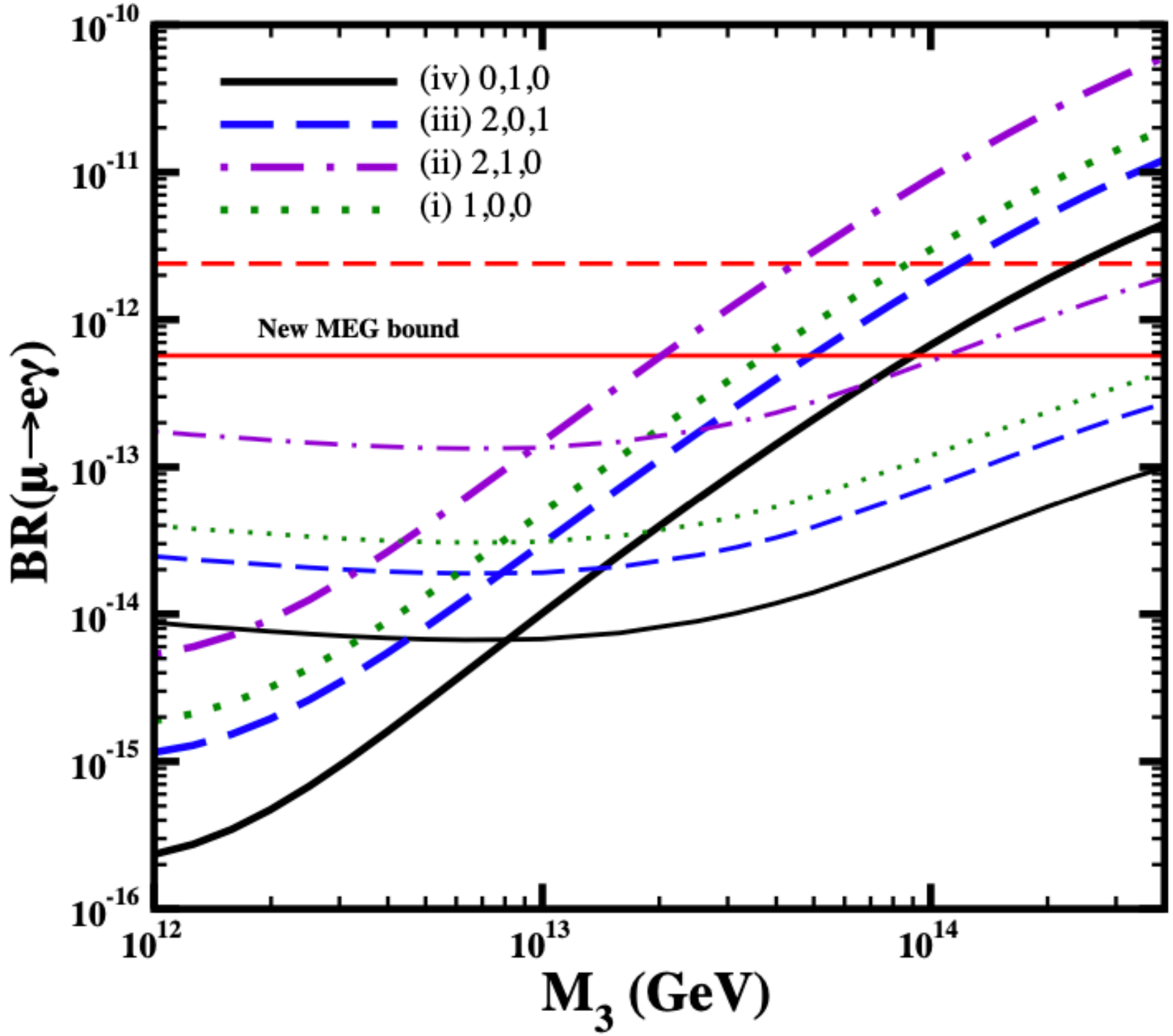



ϕ38

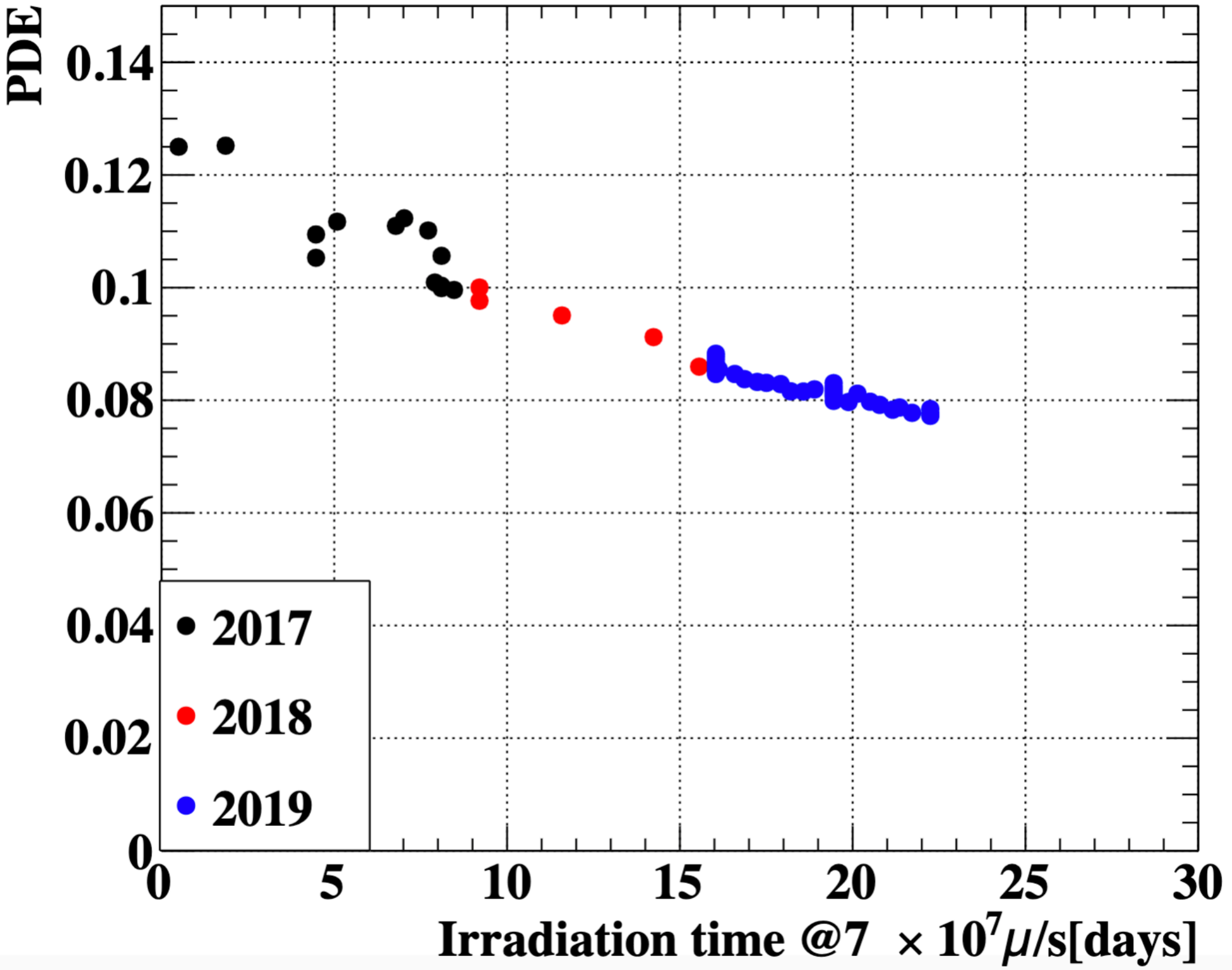

LED
PT100
Universal board
MPPC
G10





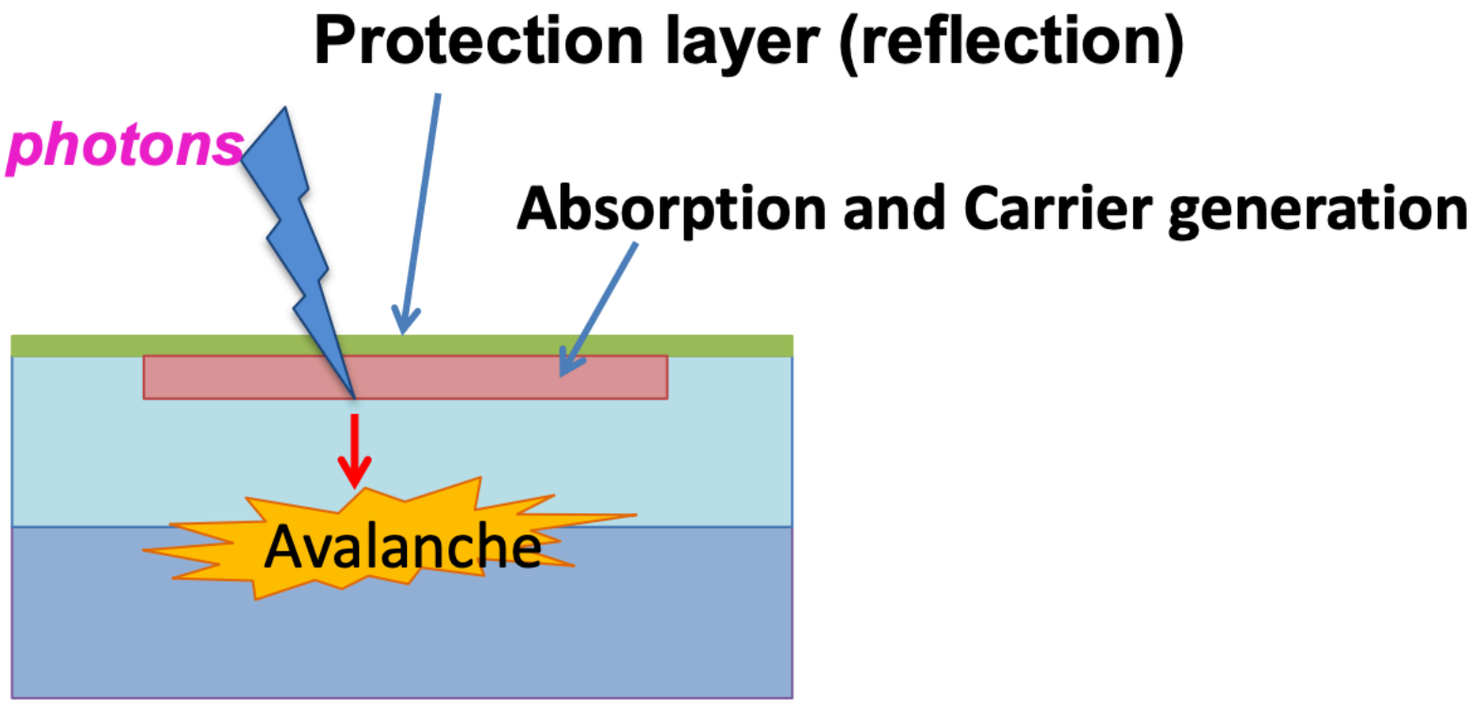

(iv) 0,1,0
(iii) 2,0,1
(ii) 2,1,0
(i) 1,0,0
New MEG bound
BR(μ→eγ)
M3 (GeV)
10-10
10-11
10-12
10-13
10-14
10-15
10-16
1012
1013
1014

MPPC PDE Decrease



VUV Detection MPPC

Cross section of the MPPC cell

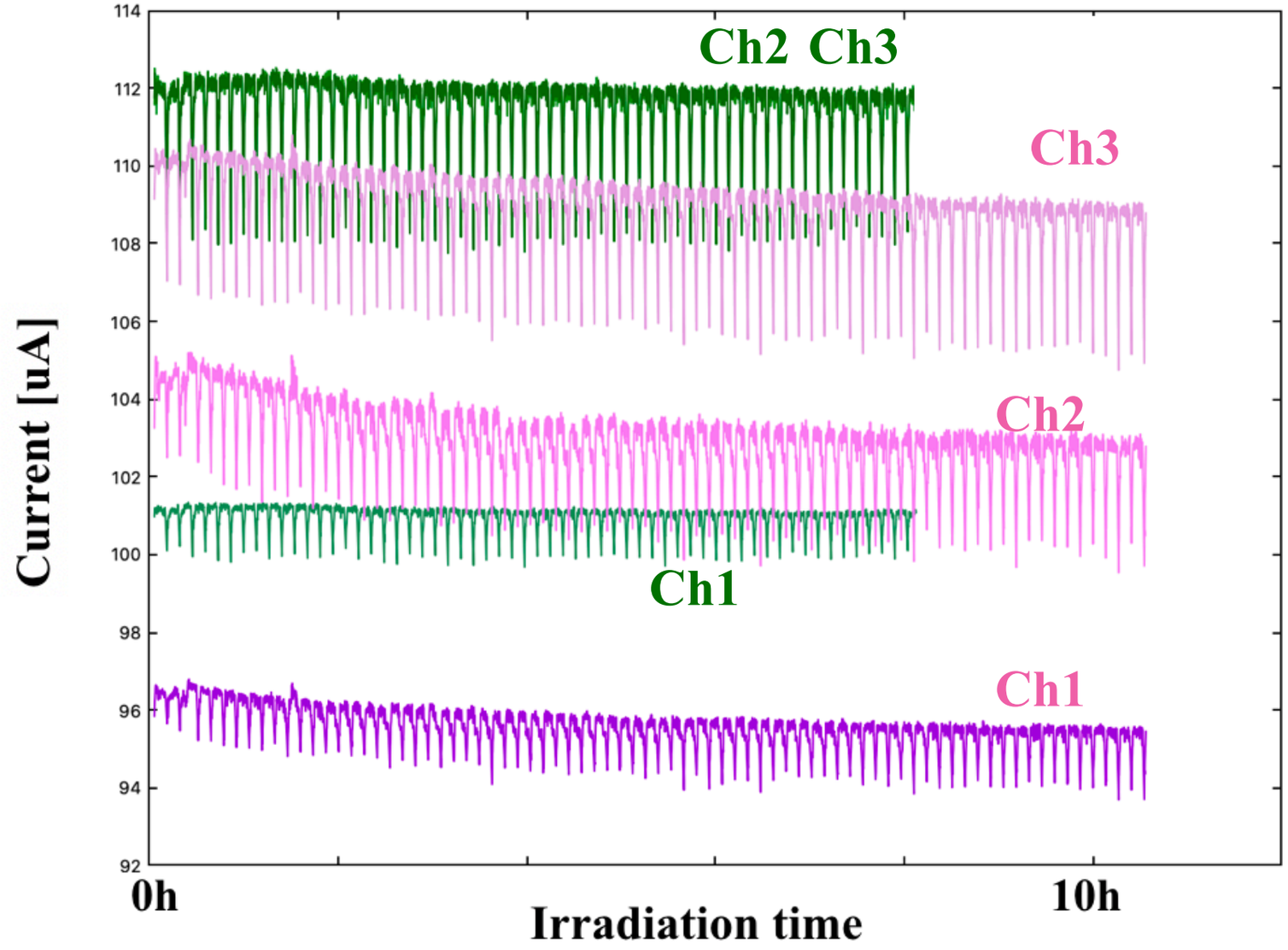


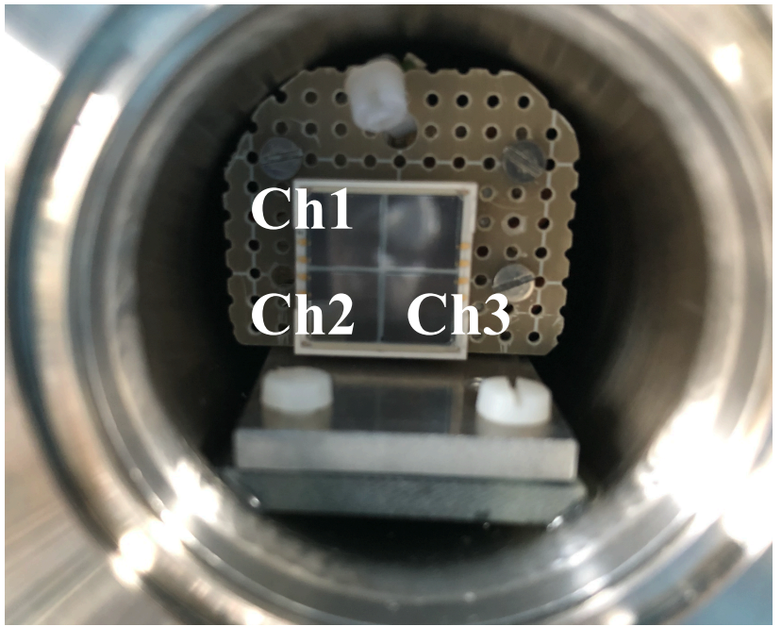
- For VUV light detection, precise control of MPPC's protection layer and absorption region is required.
- Generated photo-electrons excited by VUV light are transported to avalanche region by electric field. To obtain higher carrier collect efficiency, defect-less device is required.

Result (HV=4V)

room-temperature (296K)

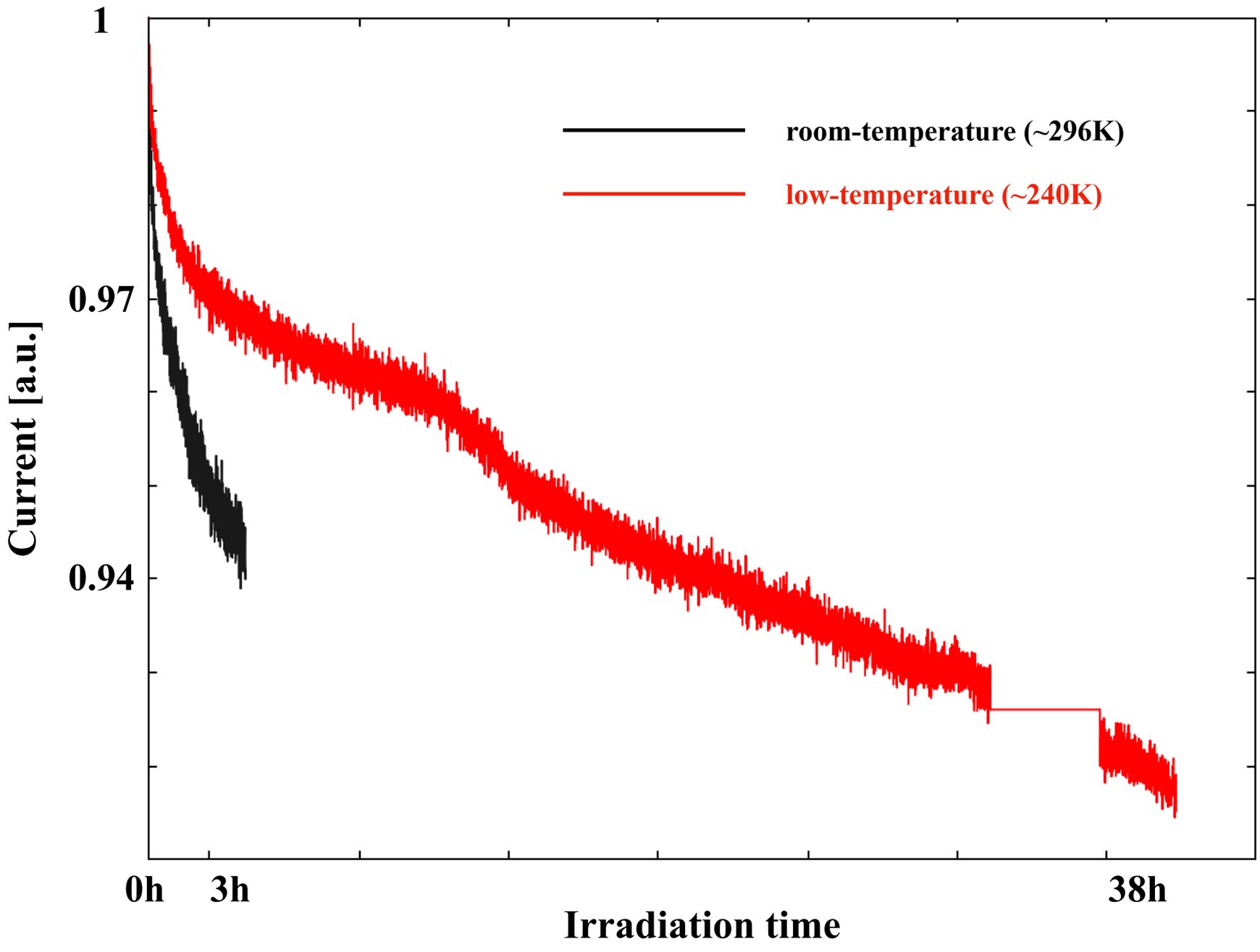
low-temperature (240K)

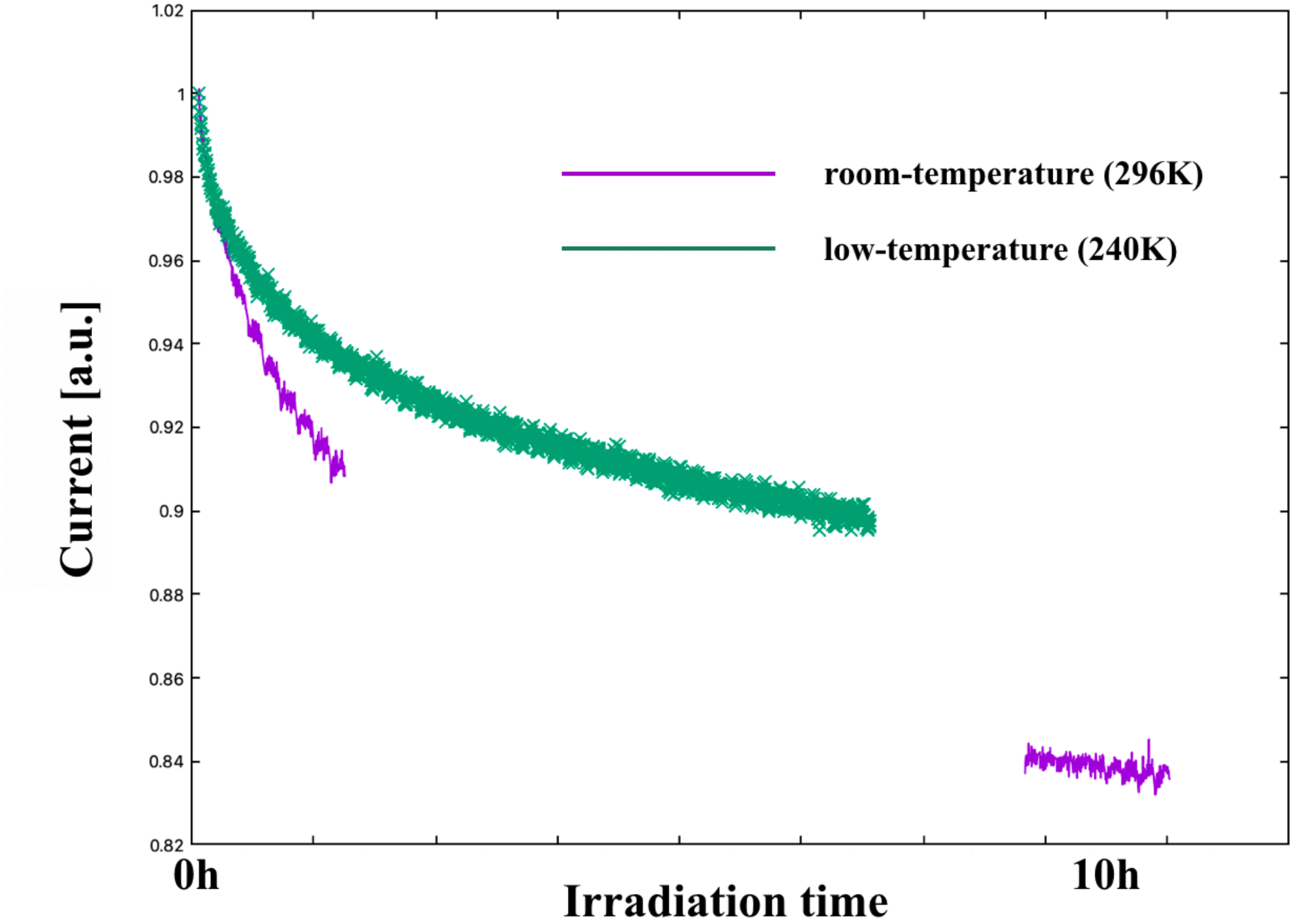




- 240K, around the MPPC
- Total irradiation time : ~10h
- When bias voltage are supplied, low-temperature current seems to decrease

Result (HV=0V)


1
0.97
0.94
Current [a.u.]
room-temperature (~296K)
low-temperature (~240K)
0h
3h
38h
Irradiation time


1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
Current [a.u.]
room-temperature (296K)
low-temperature (240K)
0h
10h
Irradiation time

Possible Cause

- **Surface damage by VUV-light**

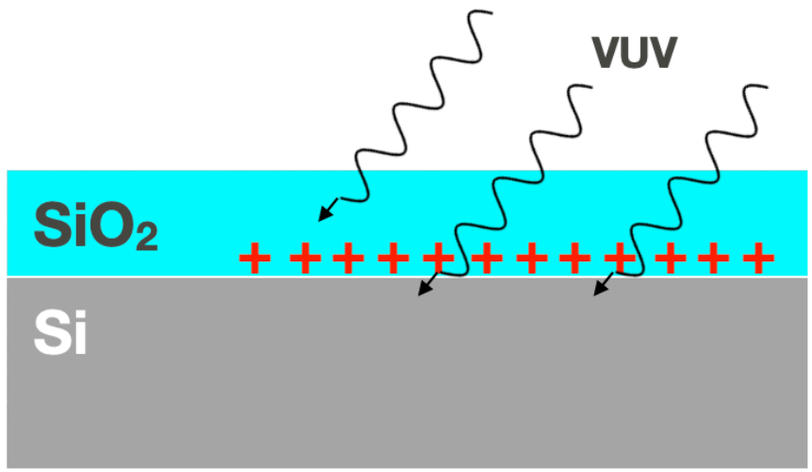
  Electron-hole pair generated in SiO_2 by VUV light

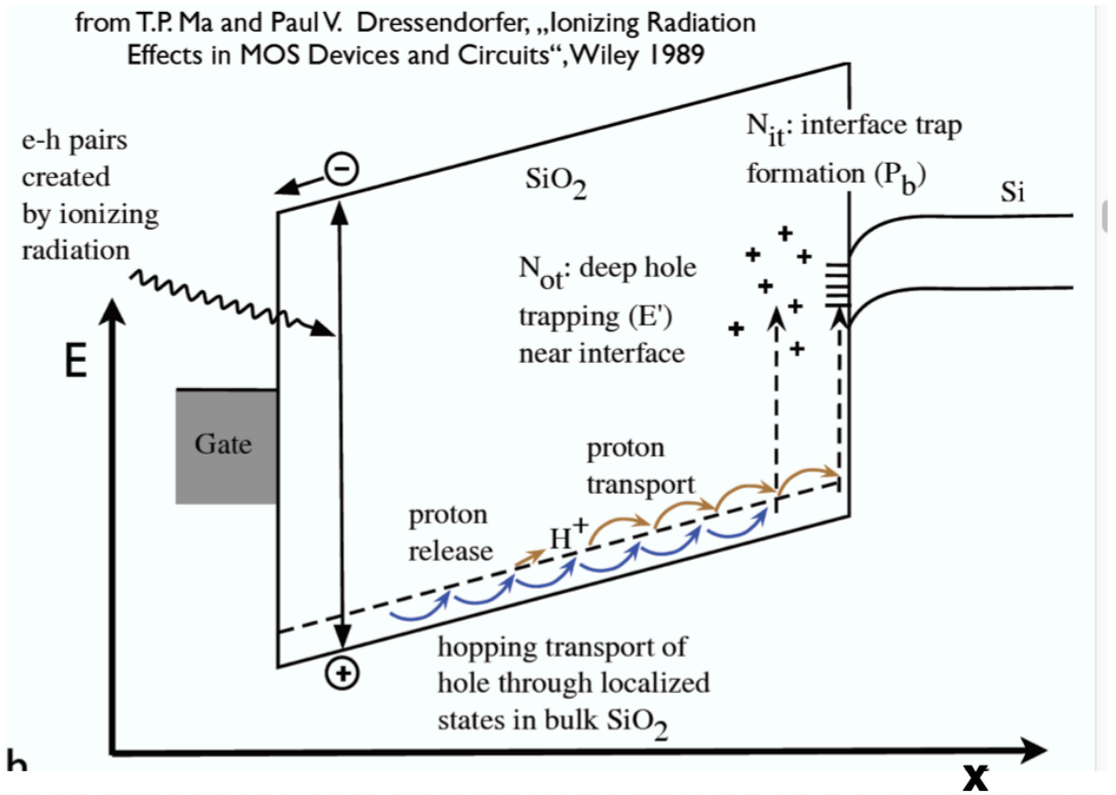
  →Holes are trapped at interface SiO_2 - Si

  →Accumulated positive charge will reduce electric field near Si surface, reducing collection efficiency of charge carrier

  - N.B. charge carrier generated within 5nm at Si surface for VUV

- **Similar phenomena are known for UV photo diode**
  - Degradation happens only with much larger amount of light at room temp.
  - **Degradation seems accelerated at low temp.**

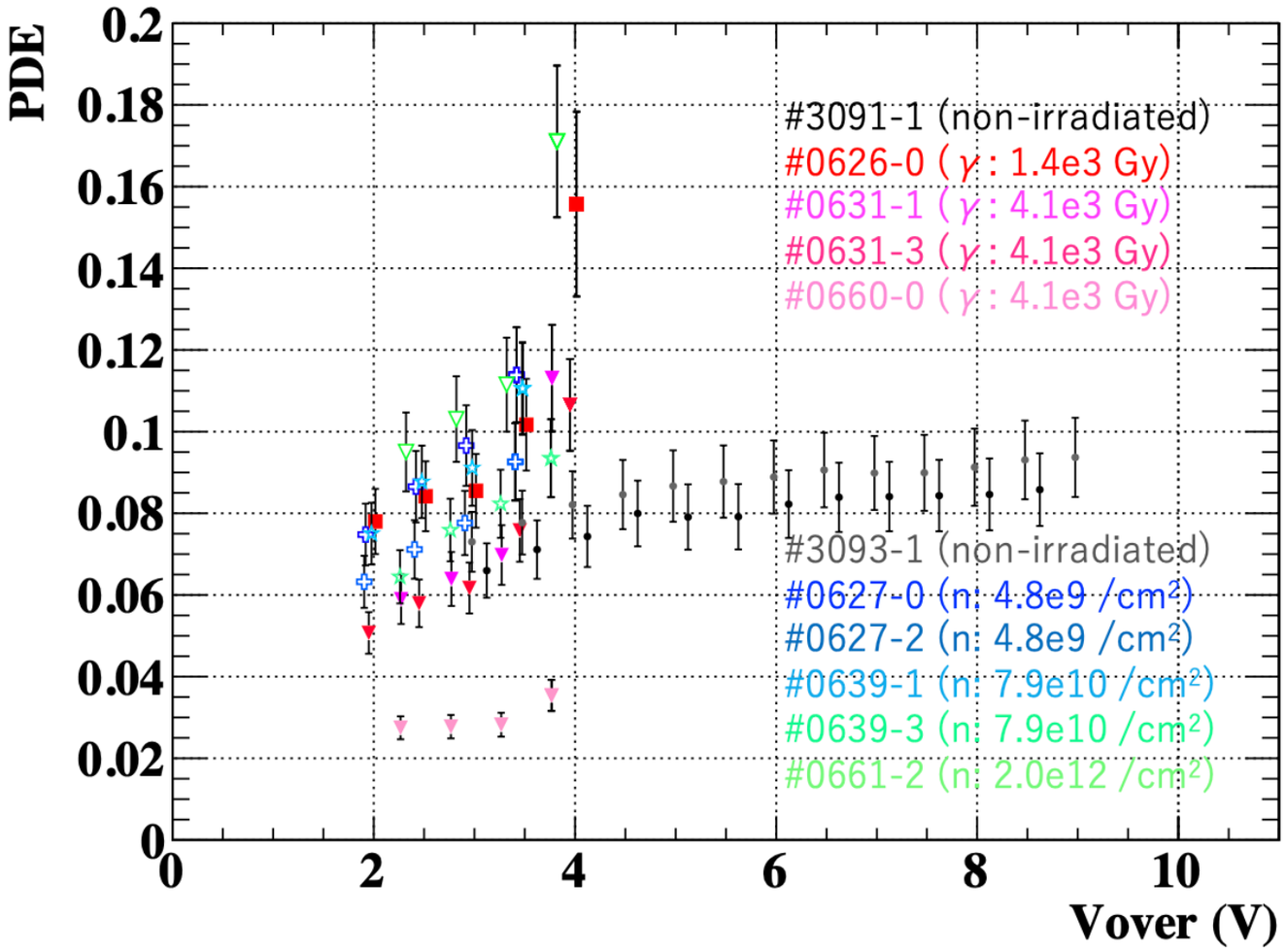




Highly Irradiated Samples

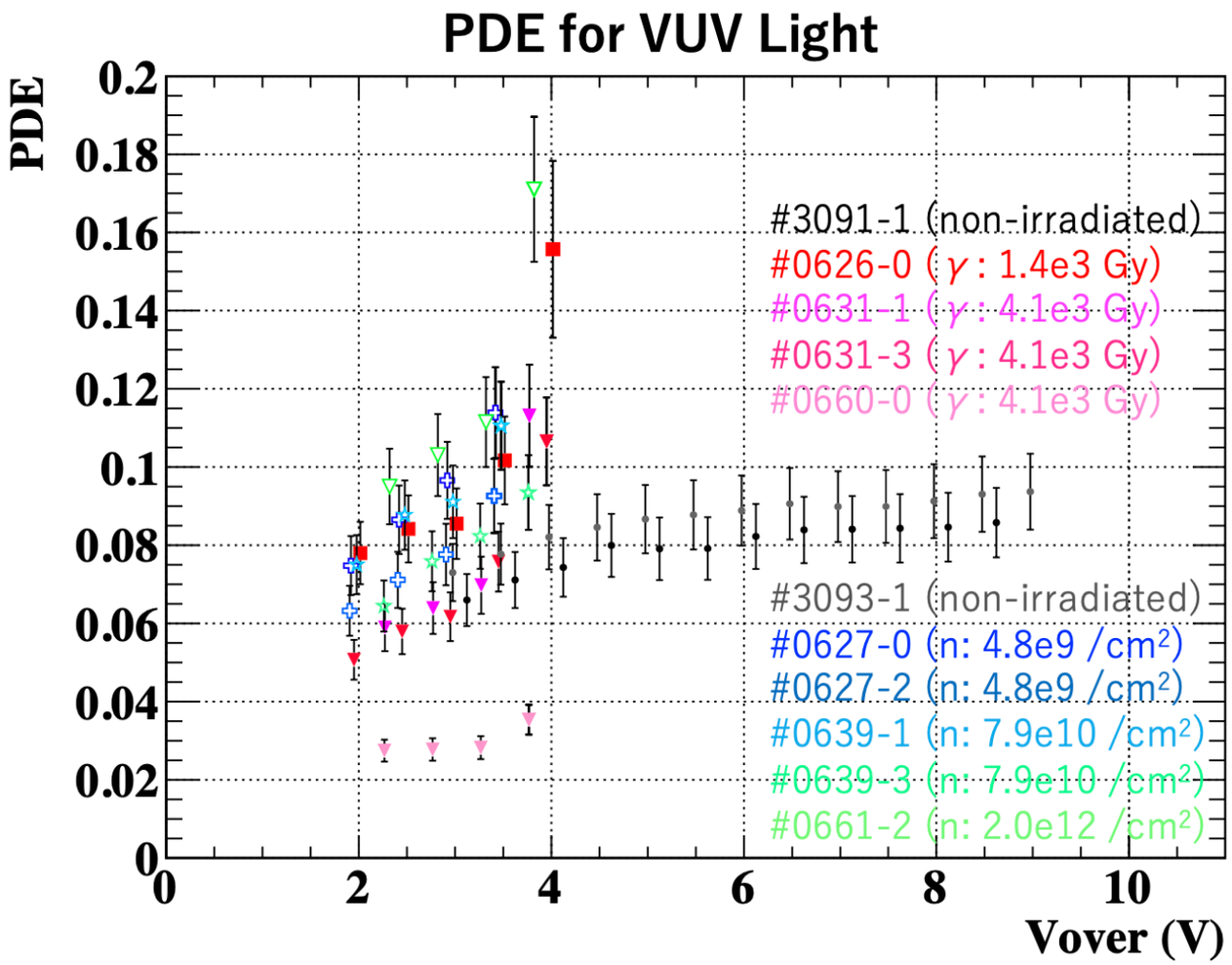
- **Highly irradiated samples produced at irradiation facilities**
- **Tested in LXe**

	Gamma [Gy]	Neutron [n_{1MeV}/cm^2]
Dose	**$(1.4\text{-}4.1)\times10^3$**	**4.8×10^9 - 2.0×10^{12}**
MEG II (3yrs)	~0.6	~10^8



→No effect on PDE!

PDE for VUV Light



※Errors include statistic errors and a systematic error of W value (10%)

- **PDE degradation was not observed for all irradiated samples.**
- Overall PDE were lower than those of the previous measurements (14-20%)
  ← purity of LXe??
- Only PDE of #0660-0 was lower though other samples with the same dose level were not the case.
  - PDE of #0660-0 for visible light was similar to others.
    ← there might be a certain damage in the surface except for radiation damage.