Core-to-Core Program

MEG II実験液体キセノン検出器用VUV-MPPCにおけるPDE減少の真空紫外光を用いた調査

Research on PDE decrease of MPPC for MEG II liquid xenon detector by using vacuum-ultraviolet

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Mar. 12th, 2021

Introduction

- The motivation of searching for $\mu \to e\gamma$
- Overview of MEG II

MPPC

- MPPC PDE decrease
- Surface damage by VUV light

Measurement of PDE decrease at low-temp

- Irradiation by xenon flash lamp
- Irradiation by liquid xenon scintillation light

Summary and Prospect

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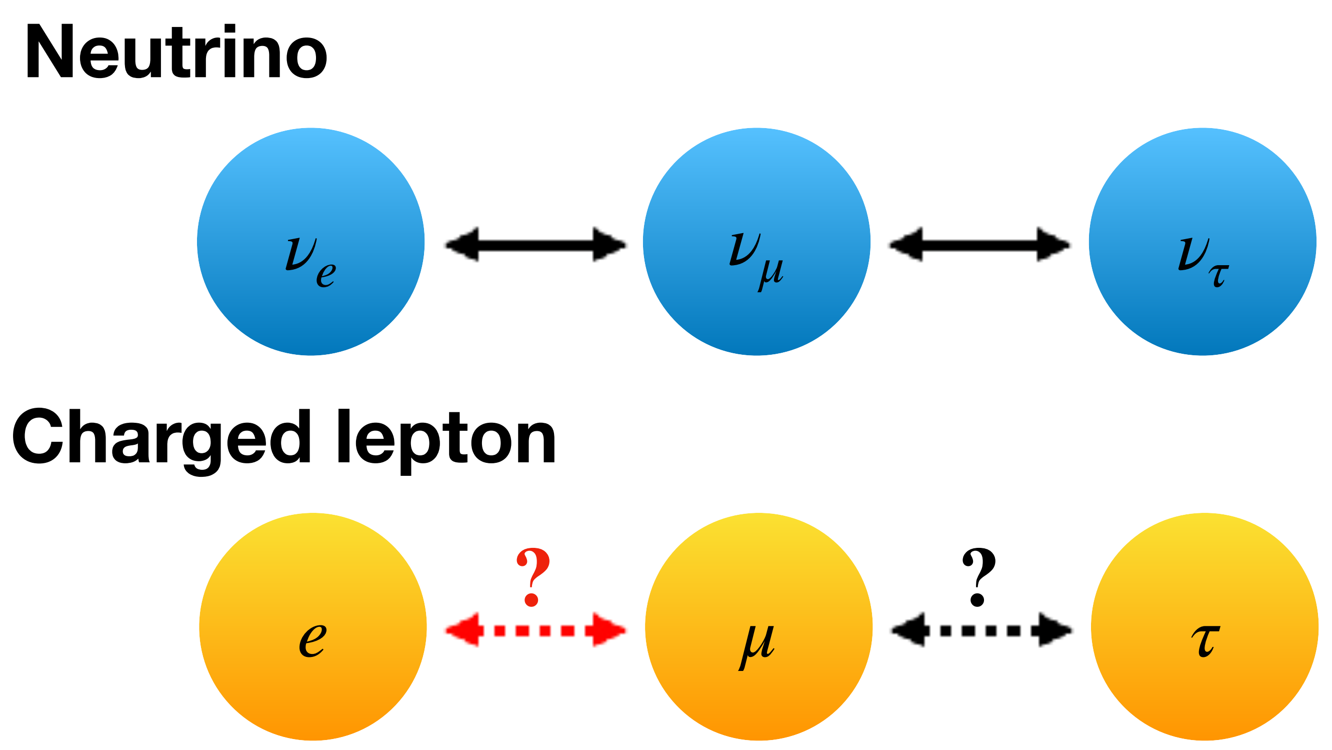
Summary and Prospect

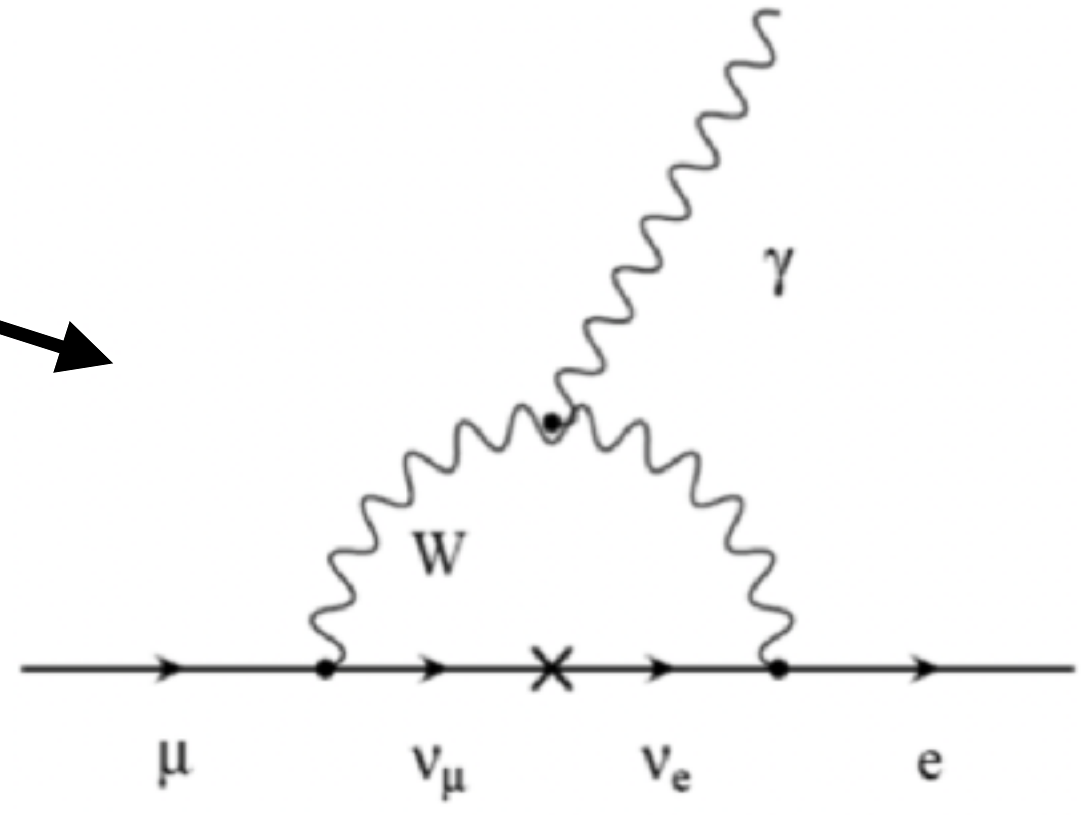
The motivation of searching for $\mu \to e\gamma$



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

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

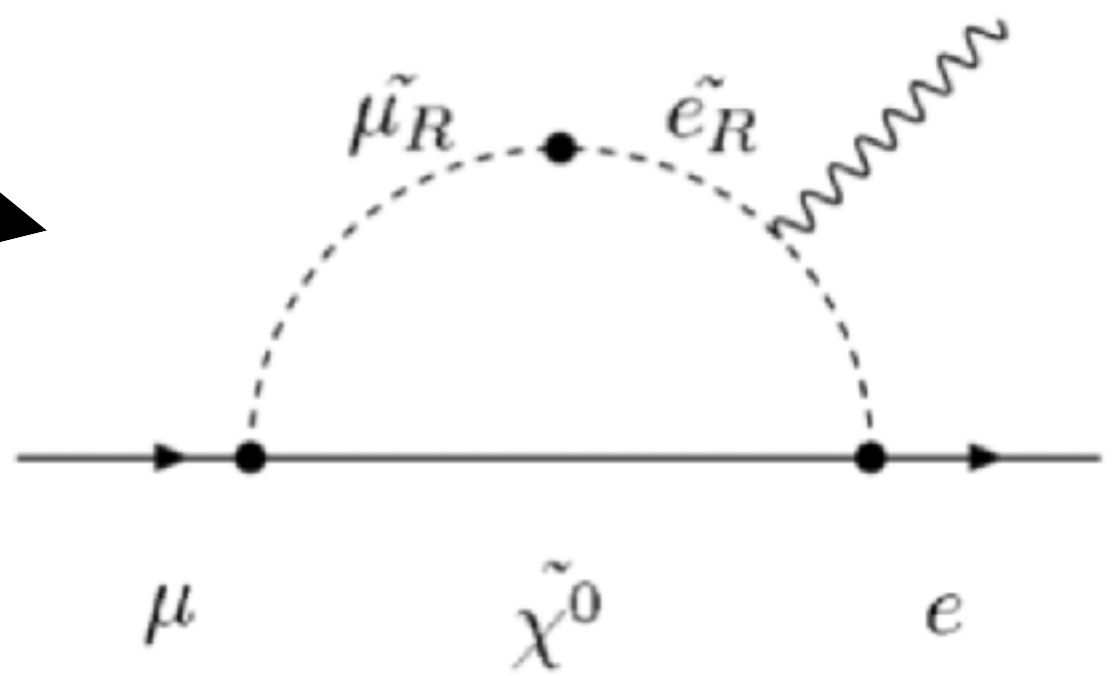
  - **Cannot be observed**



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

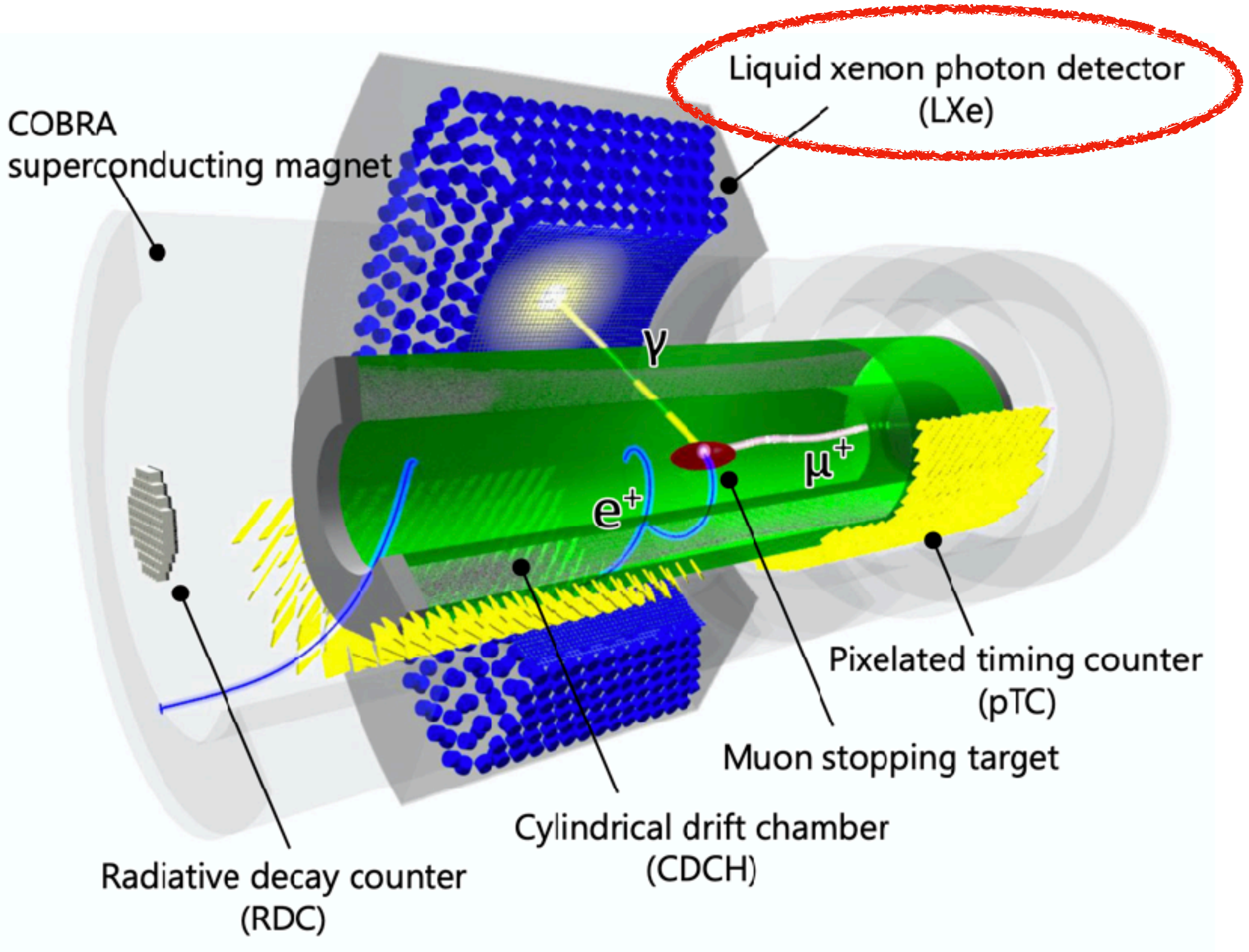
$$Br(\mu \to e\gamma) = \mathcal{O}(10^{-12}) - \mathcal{O}(10^{-14})$$

  - **Can be observed**

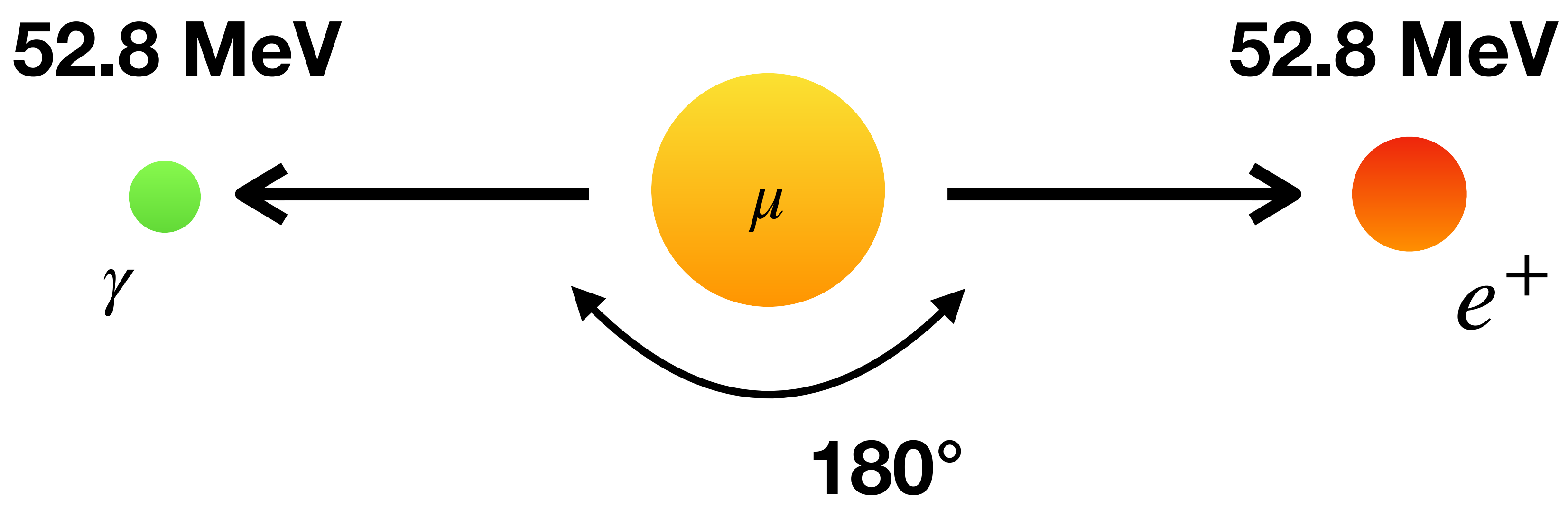


Overview of the MEG II experiment at Paul Scherrer Institut

- 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 and time are measured by LXe



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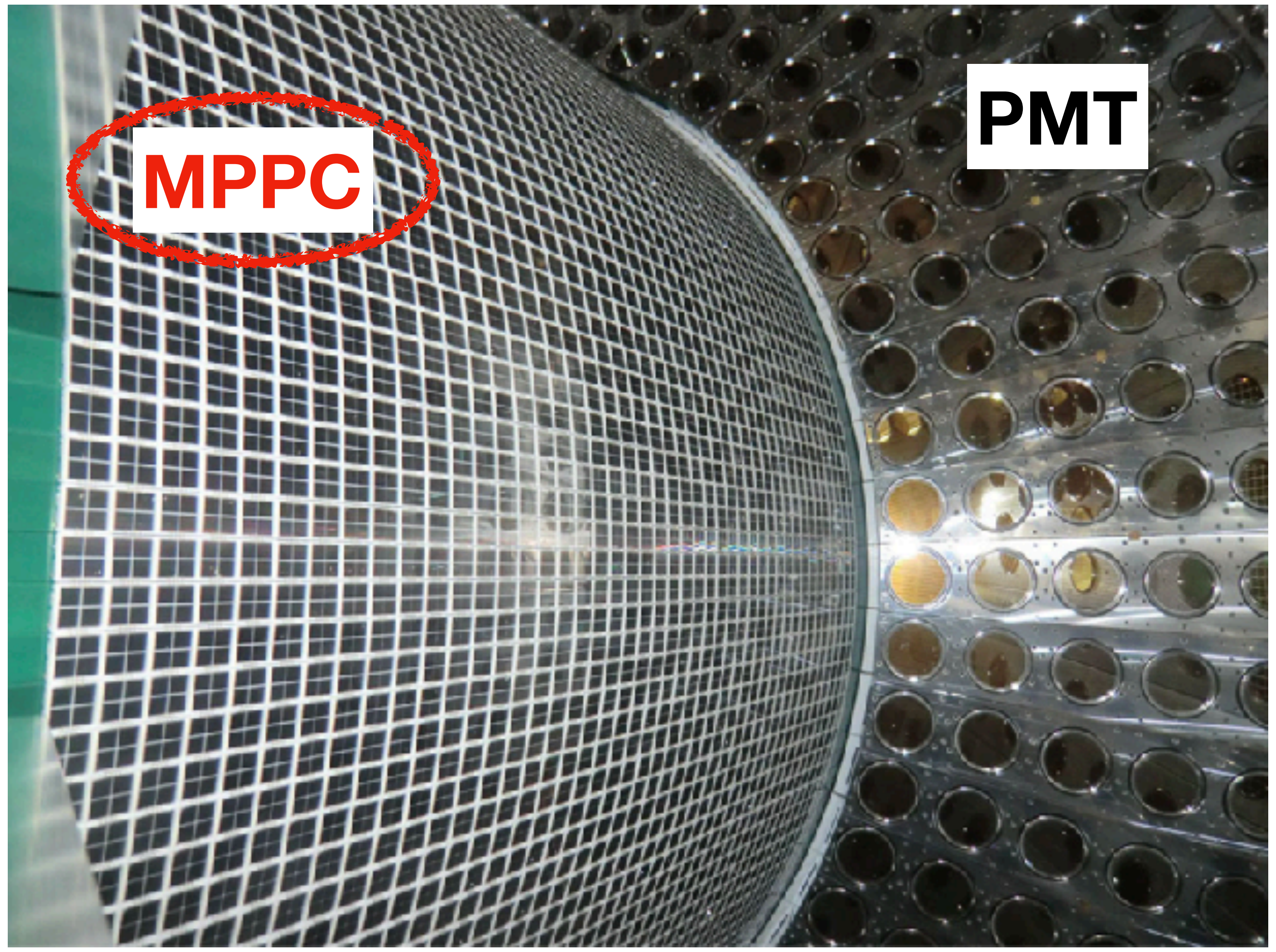

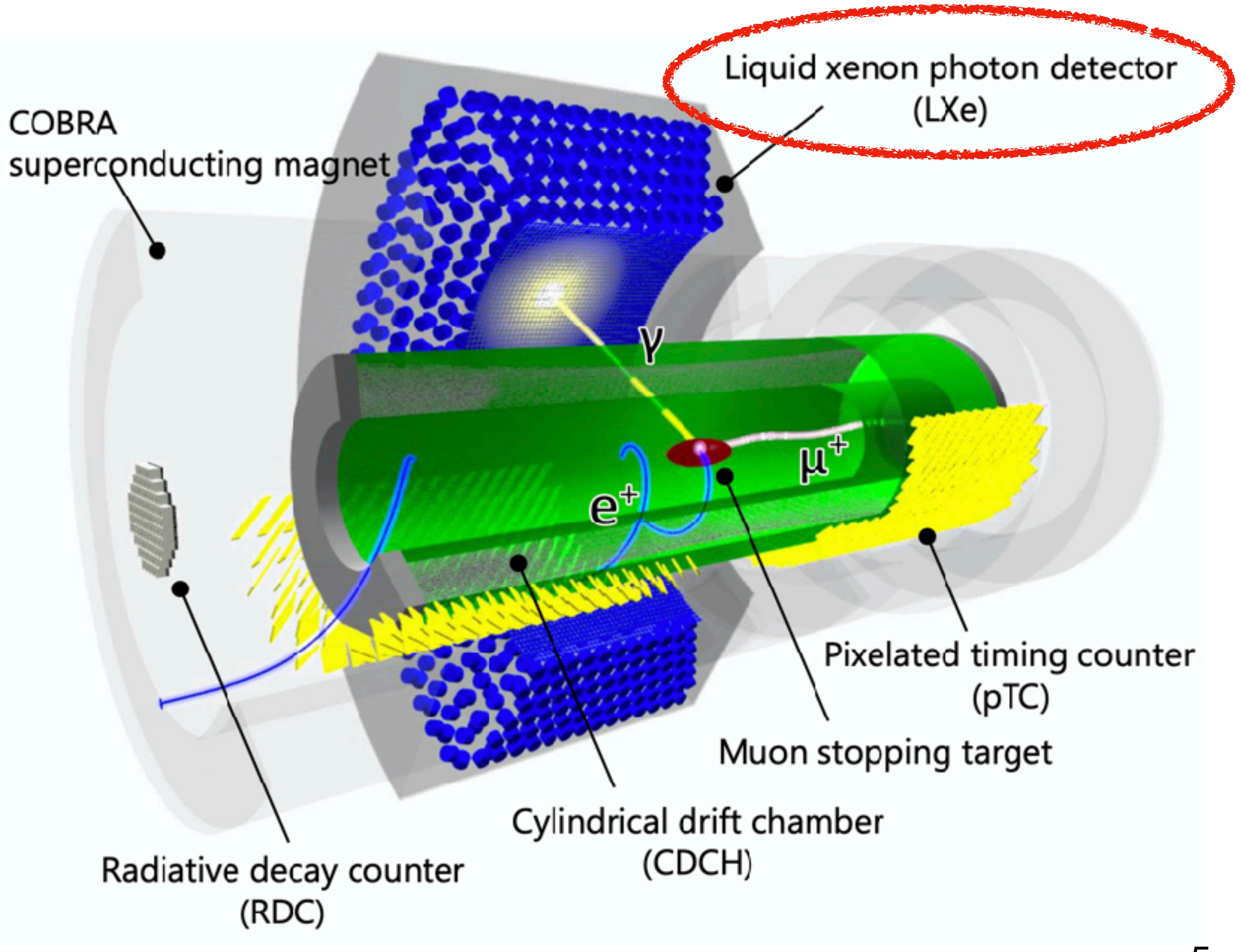

- **Detect the scintillation ($\lambda = 175$ nm)**
- **4092 MPPCs, 668 PMTs at ~165 K**
- **Energy and position resolutions will be improved as compared with MEG by a factor of two**
- **Under commissioning since 2017**

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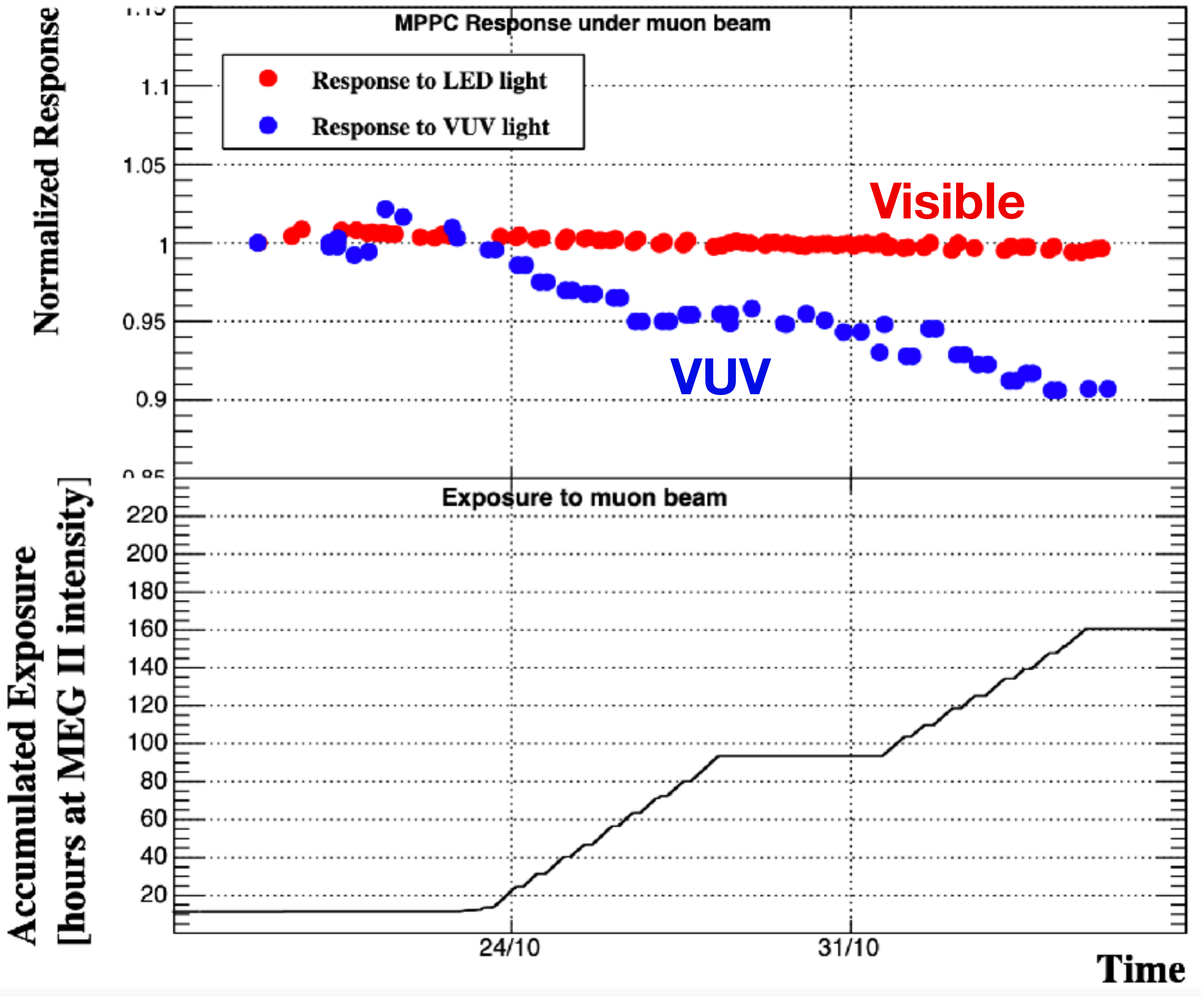
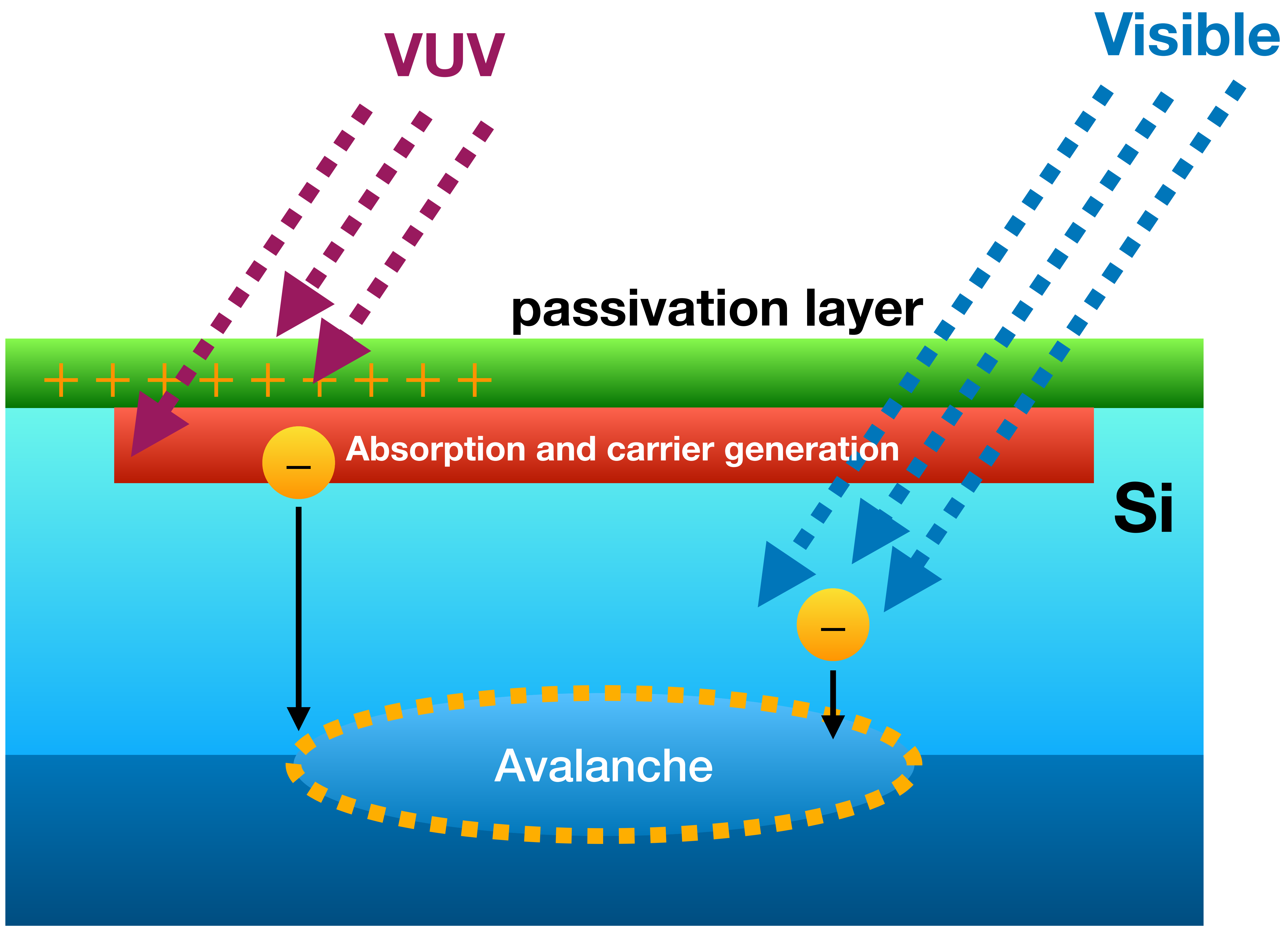
VUV-sensitive MPPC PDE decrease



- Photon detection efficiency (PDE)
- Visible sensitivity was almost unchanged
- Degradation of VUV sensitivity
  →Total decrease in 2019 : 9%
  (in 1 week under MEG II beam intensity $7 \times 10^7\ \mu/\mathrm{sec}$)
- Design MEG II DAQ time : 360days (3 years)
  →This degradation is a serious problem

Possible cause : surface damage by VUV light



- Surface damage was observed in other experiments
- Most VUV light pass through the passivation layer (e.g. SiO_2), but some of them stopped in it
  - Electron-holes are generated in passivation layer
- Holes are trapped at interface b/w passivation layer and Si
- The electric field near the boundary of the two surfaces will be reduced by the holes
  - Collection efficiency will be reduced
- Degradation may be accelerated **at low temperature** because holes hardly move
- Holes will be removed by heat
  - Annealing effect was observed

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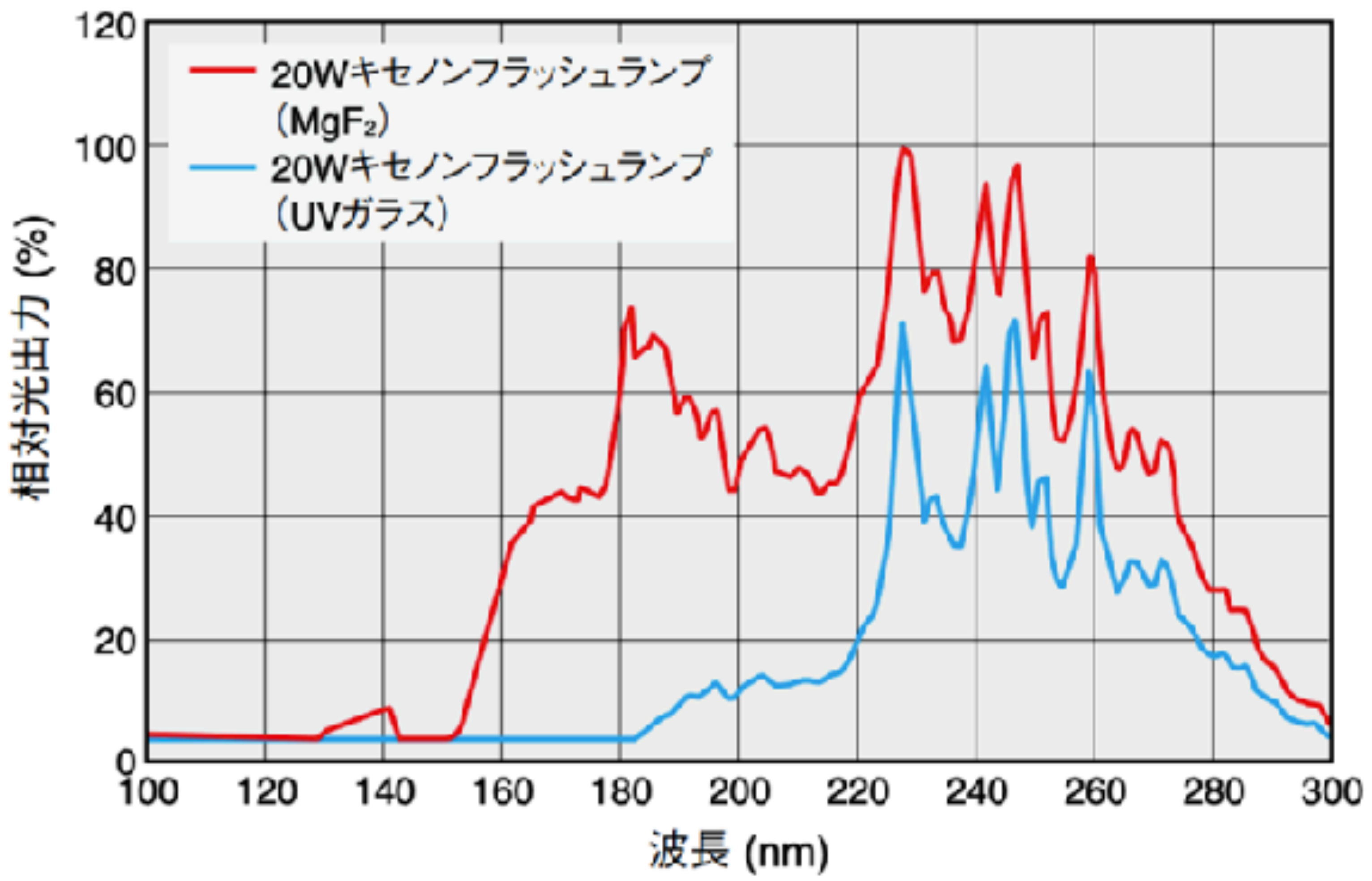
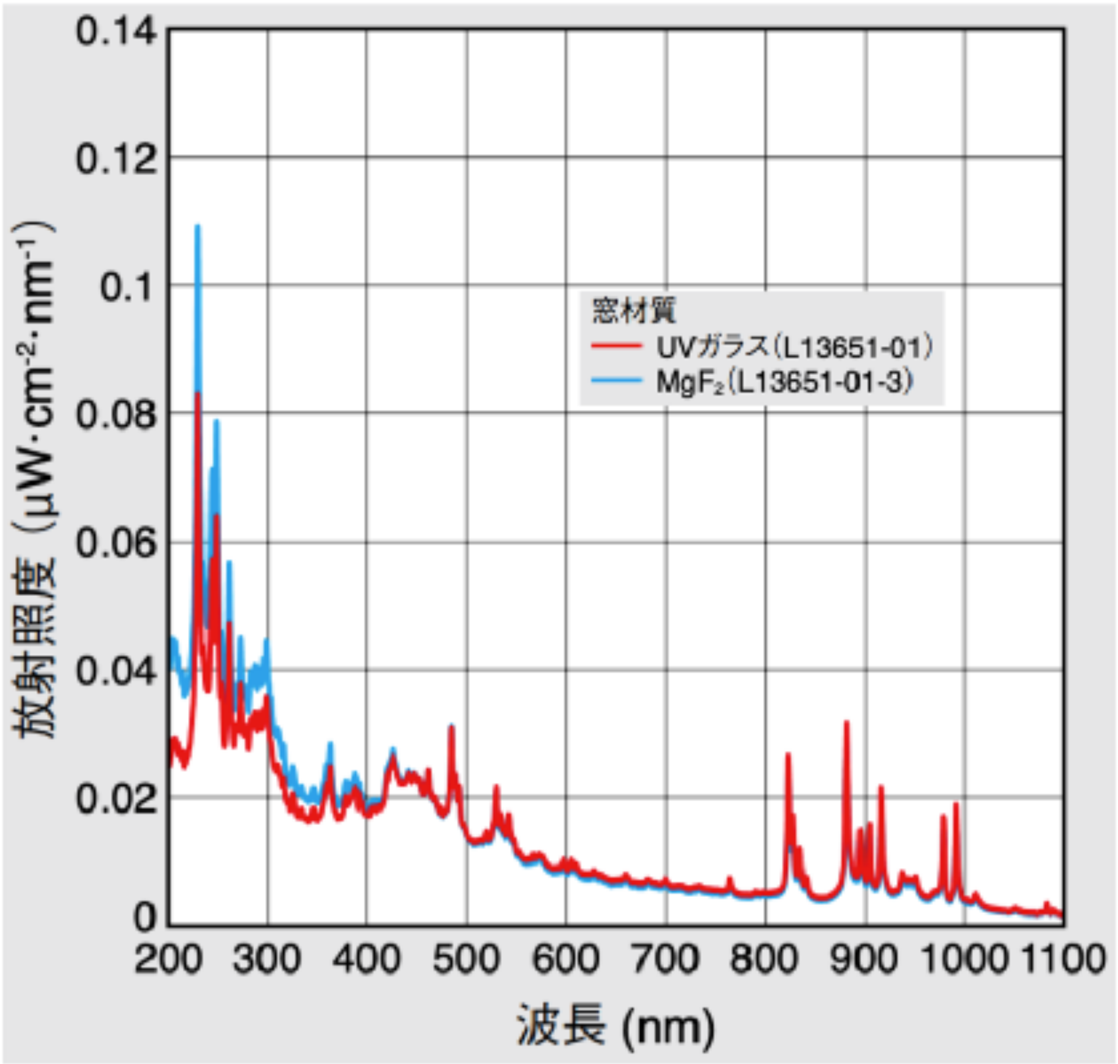
Overview of the measurements

- We want to know how PDE decreases in MEG II DAQ time
- PDE decrease by UV and low-temp effect were observed in previous measurement (15pSF-5)
  - Much slower than MEG II LXe detector
  - There may be wave length effect
- This time, MPPCs were irradiated by VUV at ~165 K
- Irradiation source
  - Xe flash lamp
  - Xe scintillation light

Xe-lamp 2 W module (L13651-01-3)

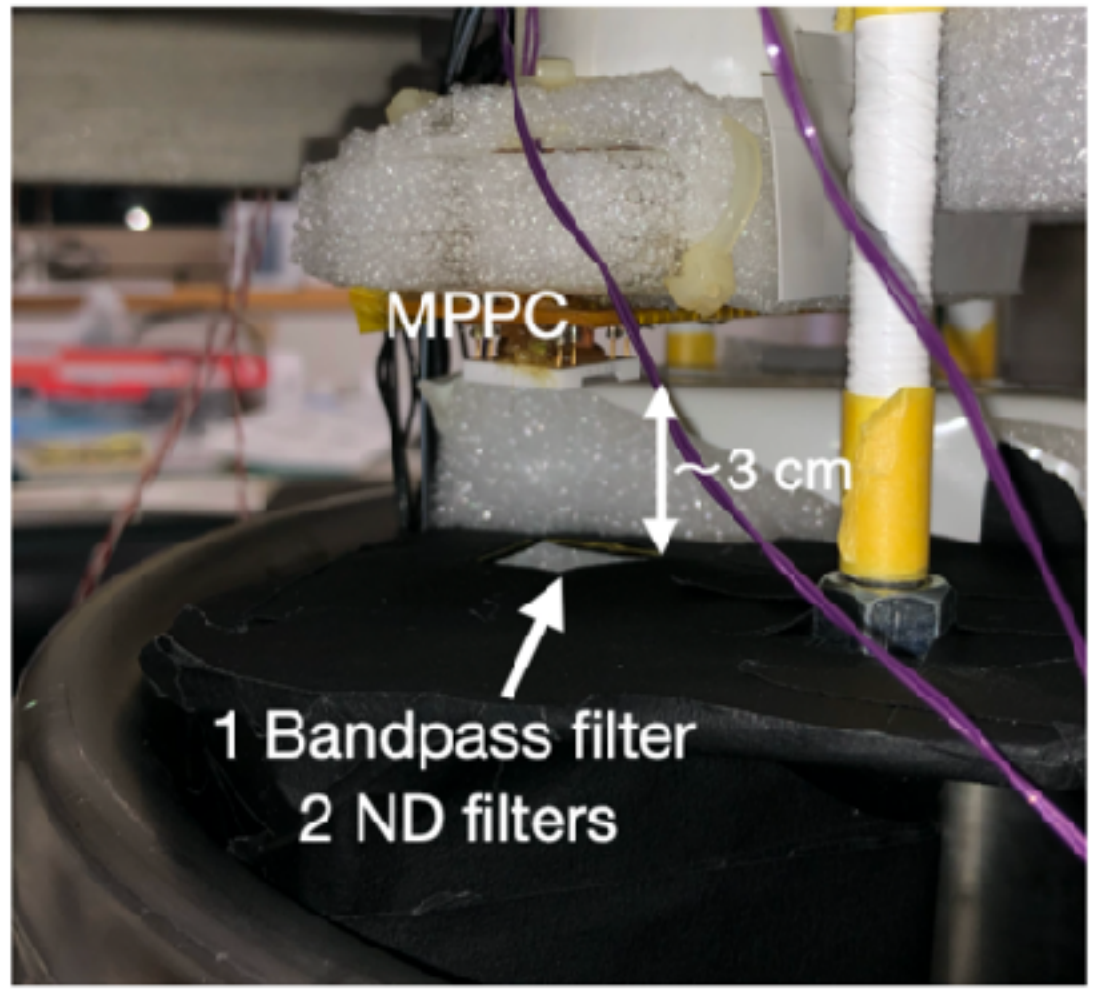




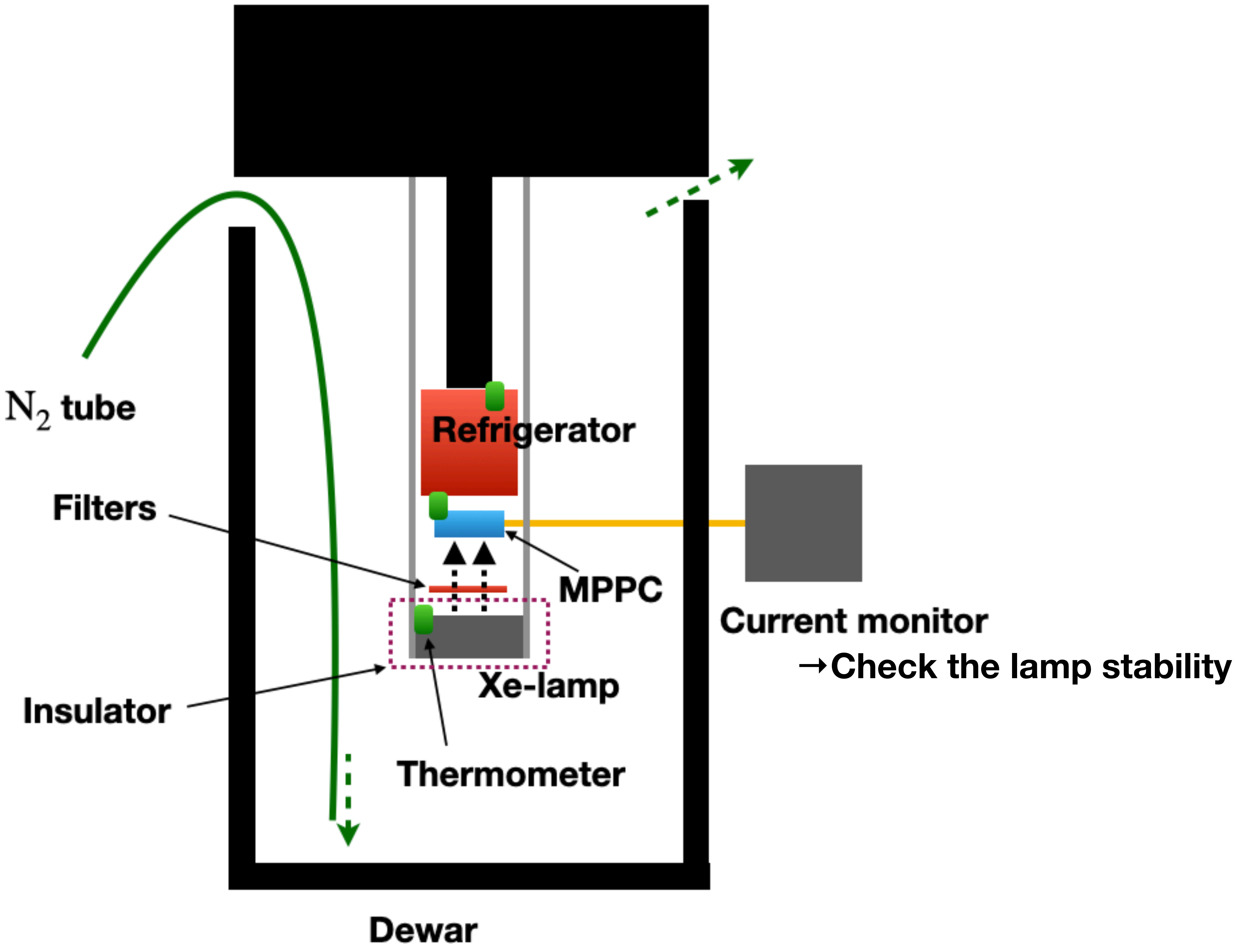
https://www.hamamatsu.com/jp/ja/product/light-and-radiation-sources/lamp-module_unit/xenon-flash-lamp-module/index.html

Irradiation by Xe-lamp

- Irradiation source : Xe-lamp (MgF_2 glass)
- Cooled the MPPC in N_2 gas
  - Prevent dew formation
  - Allows VUV to reach MPPC
    - Absorption length of N_2 is smaller by ~2 orders of magnitude than that of O_2
- MPPC was mounted on refrigerator
  - MPPC temp ~ 165 K

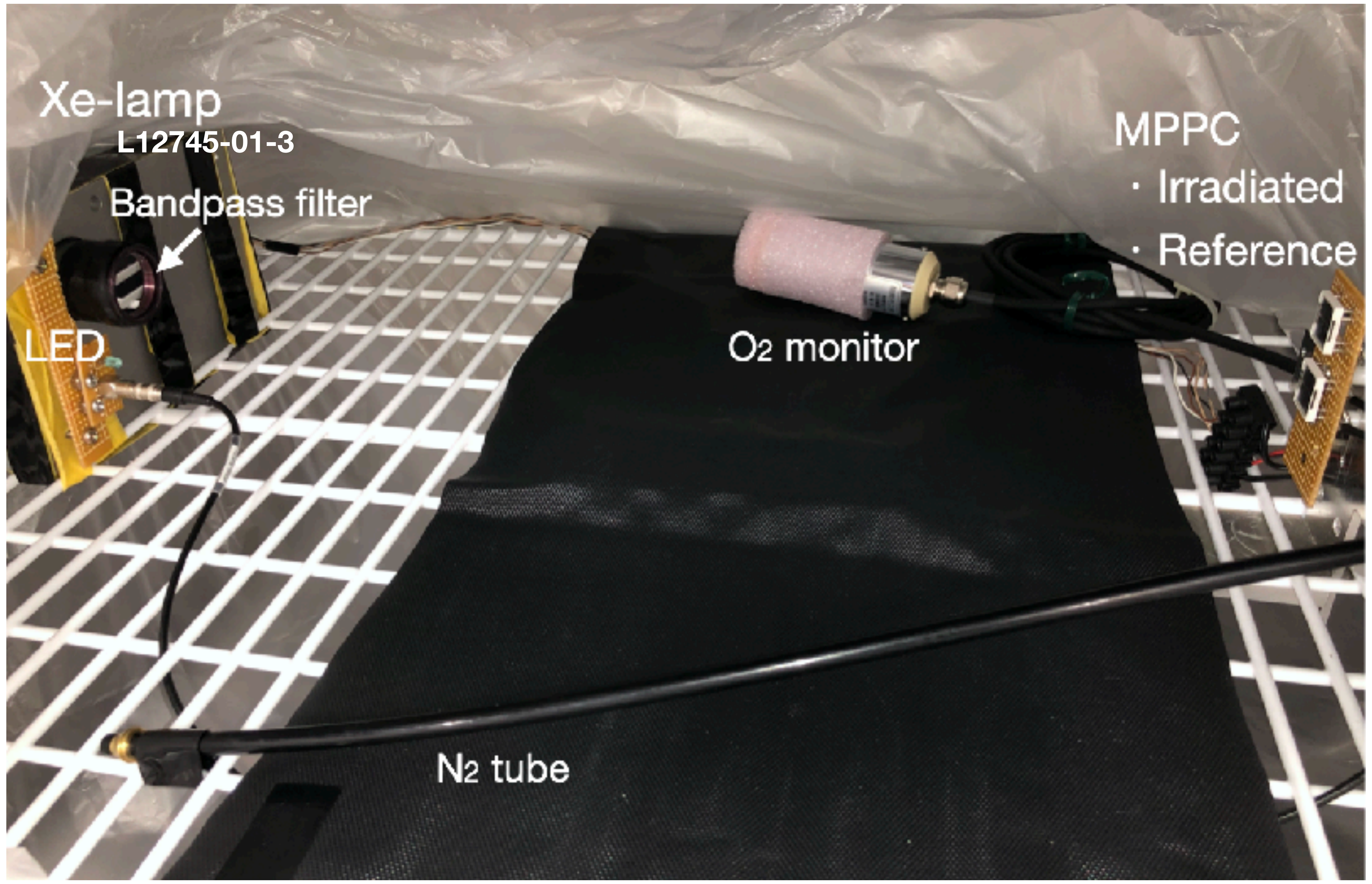


Overview of setup : Irradiation

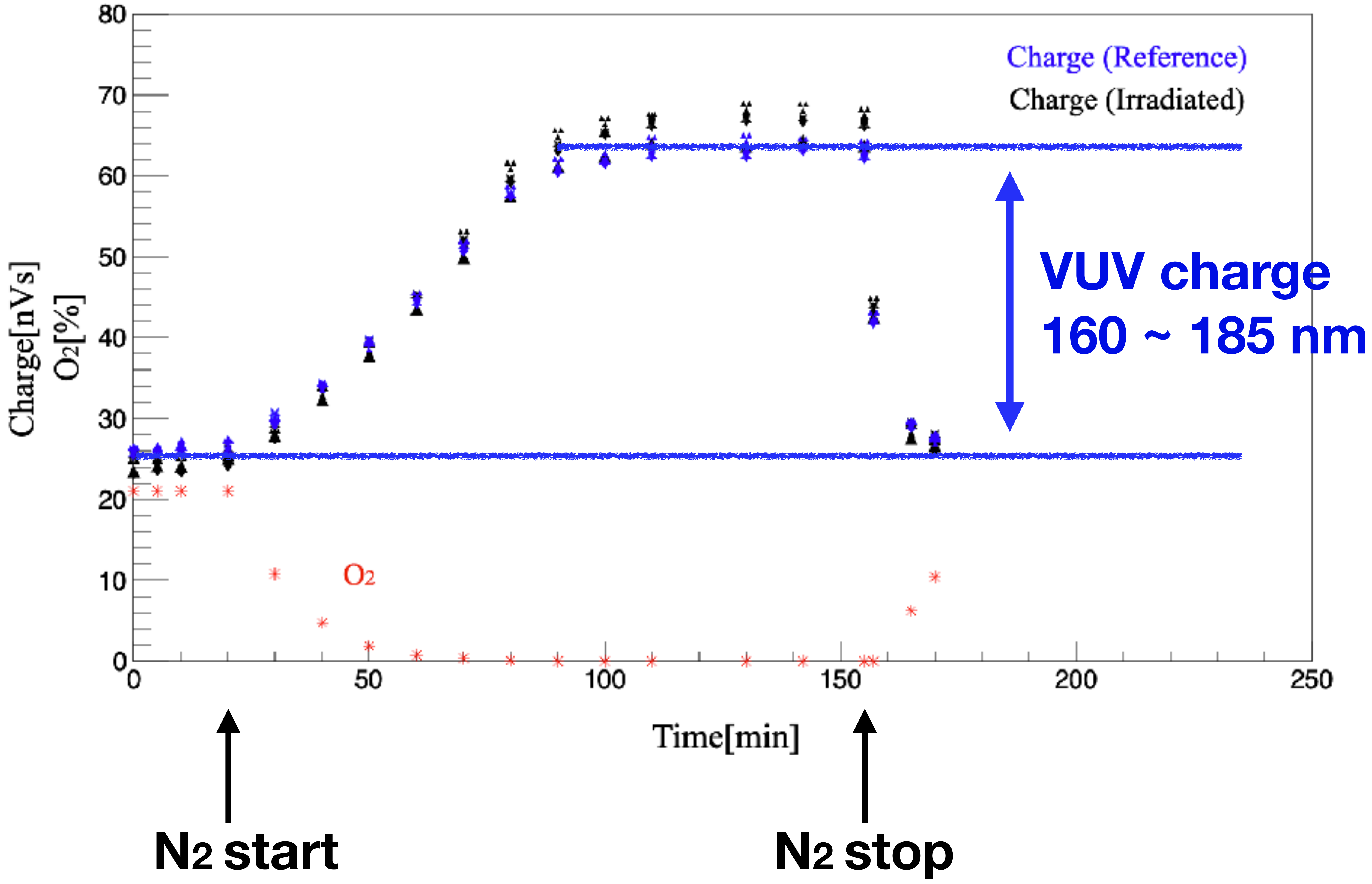


Irradiation by Xe-lamp

- Signal charge was measured before and after the irradiation
- Non irradiated MPPCs were also used as reference



- Observed VUV charge by using N_2 gas
  - Absorption cross section of 175 nm is largely different b/w O_2 and N_2



VUV irradiation at low-temp

$\mathrm{PDE}_{\mathrm{after}}/\mathrm{PDE}_{\mathrm{before}}$

	chip 1	chip 2	chip 3	chip 4
Reference	1.06	1.07	1.11	1.08
Irradiated	1.16	1.17	1.17	1.15

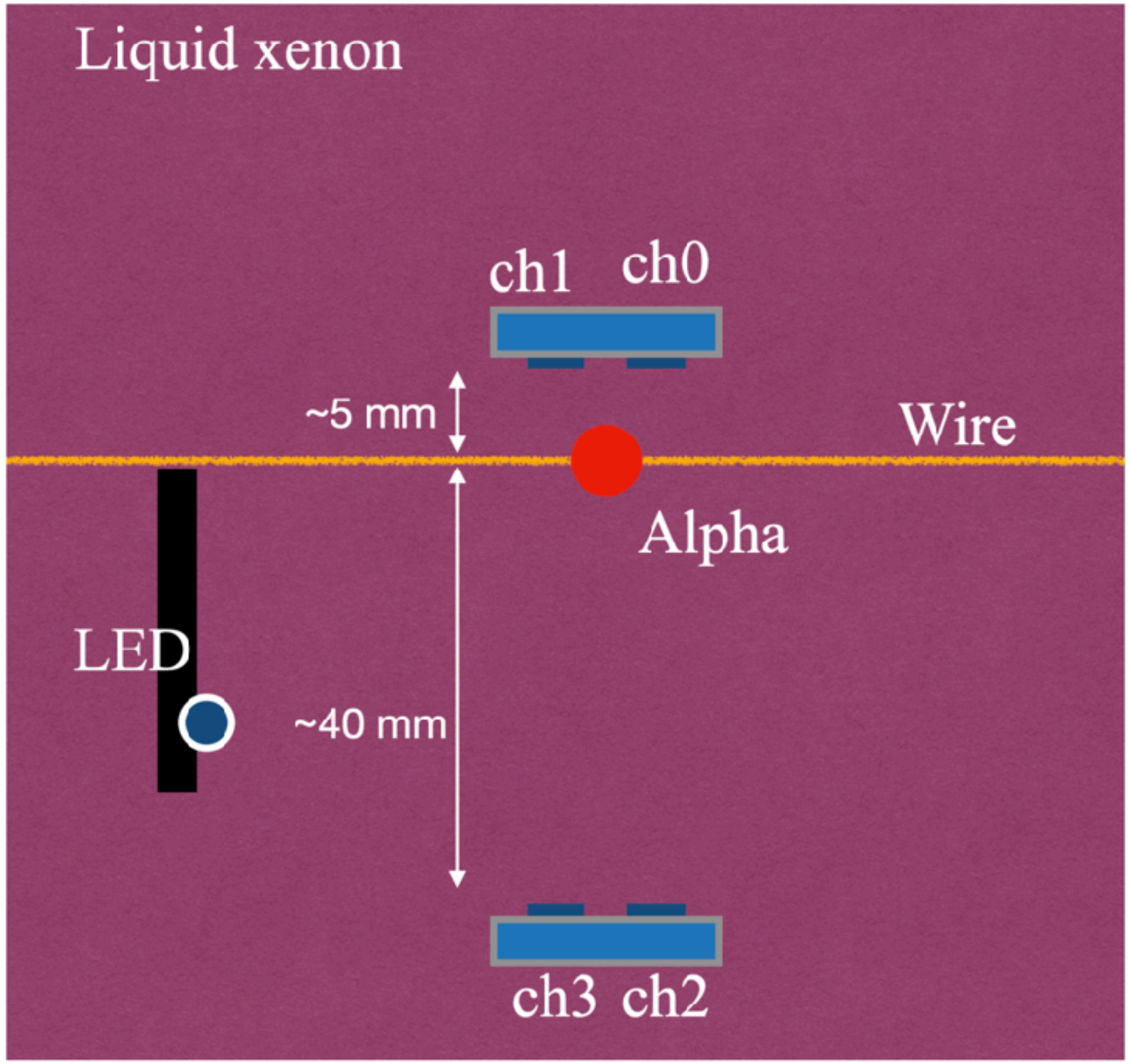
- **N_{VUV} : Dose level in this measurement**
- **$N_{2019,VUV}$: Dose level in LXe detector in 2019**

- **Dose level (in 21 h) :** $160\ \mathrm{nm} \lesssim \lambda \lesssim 185\ \mathrm{nm}$
  - $N_{VUV} = 1.7 \times 10^{11}\ \mathrm{photon/mm^2}$
    $= N_{2019,VUV} \times 3.3$

  →Corresponds to ~ 30% decrease

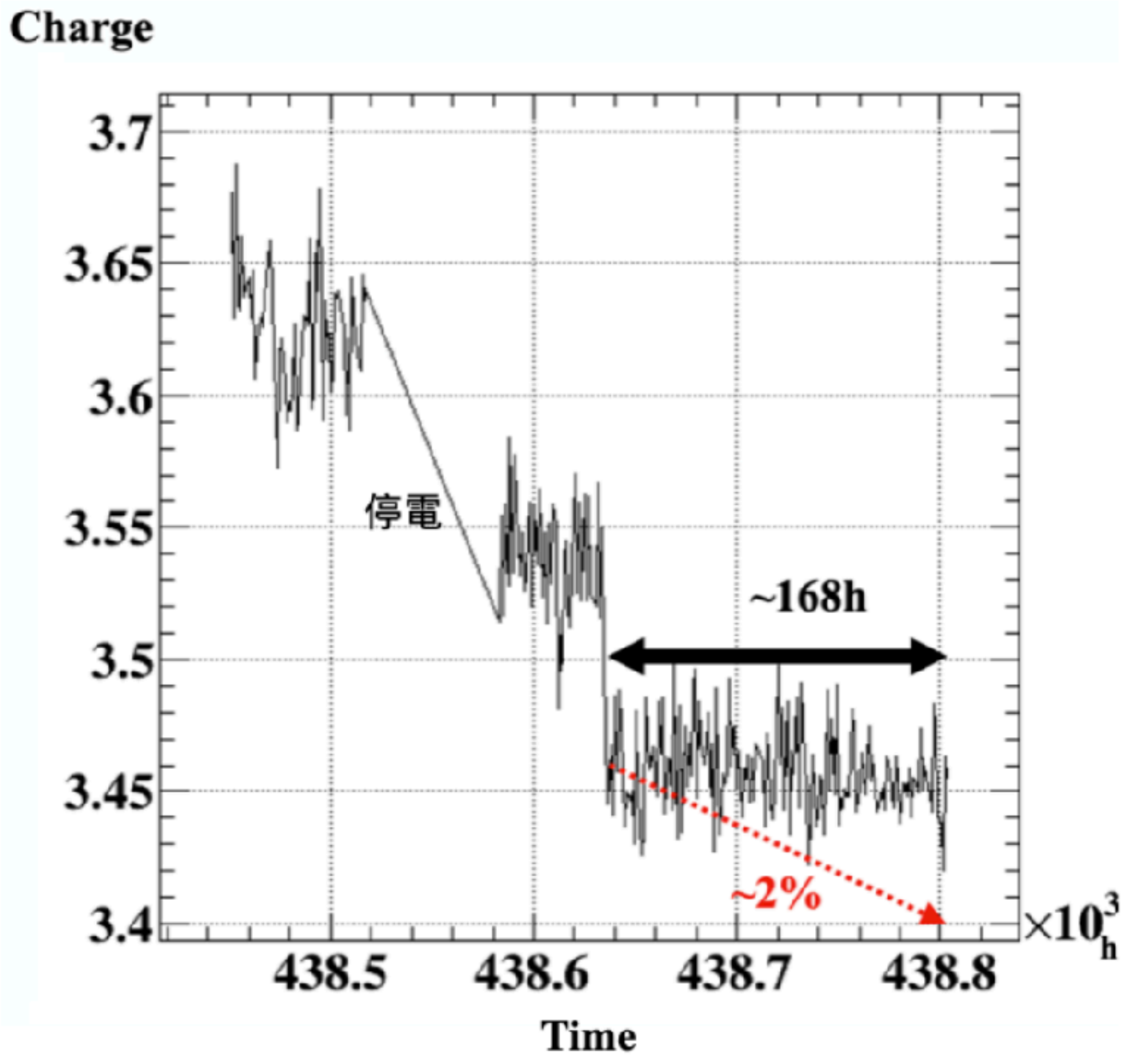
- **VUV-PDE decrease was not observed**

Irradiation by liquid xenon scintillation light using alpha sources



- Light source : liquid xenon scintillation light
  - Alpha source (^{241}Am, range : 50 μm) was set in liquid xenon
  - Dose level is smaller than Xe-lamp
  - Other conditions are the same as LXe detector
- Signal charge was monitored
- LED was set for calibration and monitoring visible sensitivity

Irradiation by liquid xenon scintillation light using alpha sources



- **The data in last 168 h was stable**
- **Signal charge for LED was not changed**
- **Dose level (in 168 h) :** $\lambda = 175$ nm
  - $N_{VUV} = 1.6 \times 10^{10}$ photon/mm^2
    $= N_{2019,VUV} \times 0.31$
- **In all chips, VUV-PDE decrease was not observed**

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Summary and Prospect

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- **In MEG II LXe detector, VUV-PDE decrease was observed**
  - **It was guessed that the degradation was caused by surface damage**

- **Irradiation measurements were performed**
  - **PDE decrease by UV was observed in previous measurement**

$$N_{UV} \gg N_{2019,VUV}$$

  - **VUV-sensitivity degradation was not observed**

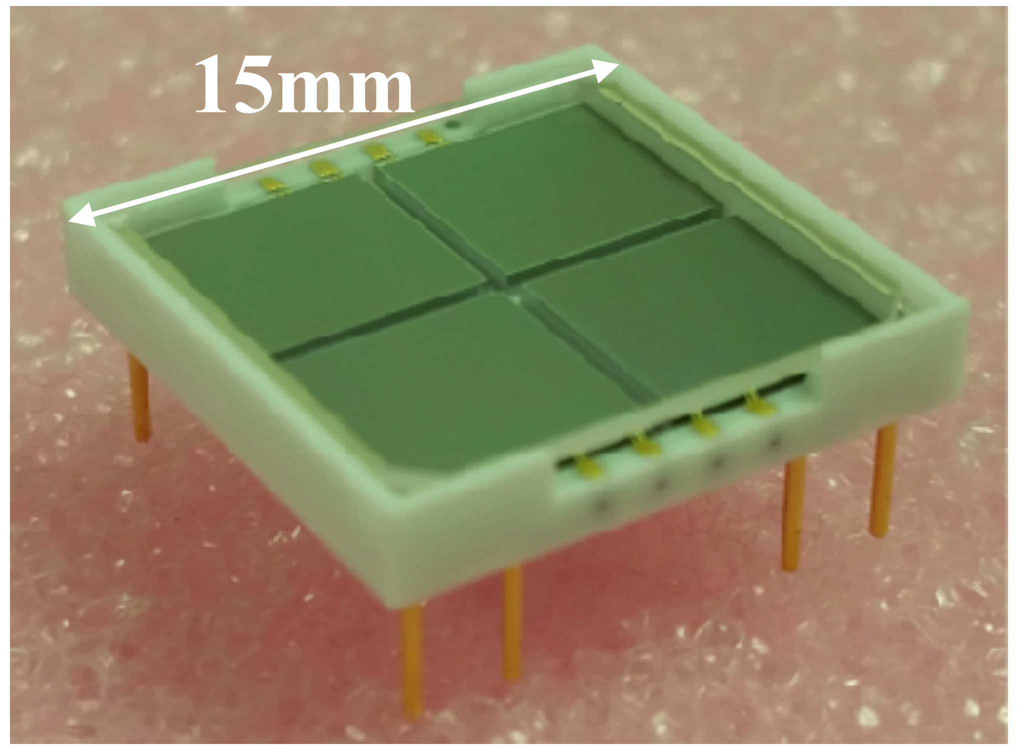
$$N_{VUV} \sim N_{2019,VUV}$$

  → VUV photon is not the main cause of the VUV-PDE decrease of the MPPCs in LXe detector
  - **Irradiation by excimer lamp is going to be performed**
    - $N_{2019,VUV} \times 10^3/\mathrm{sec}$ at 5 cm $(\lambda = 172\ \mathrm{nm})$

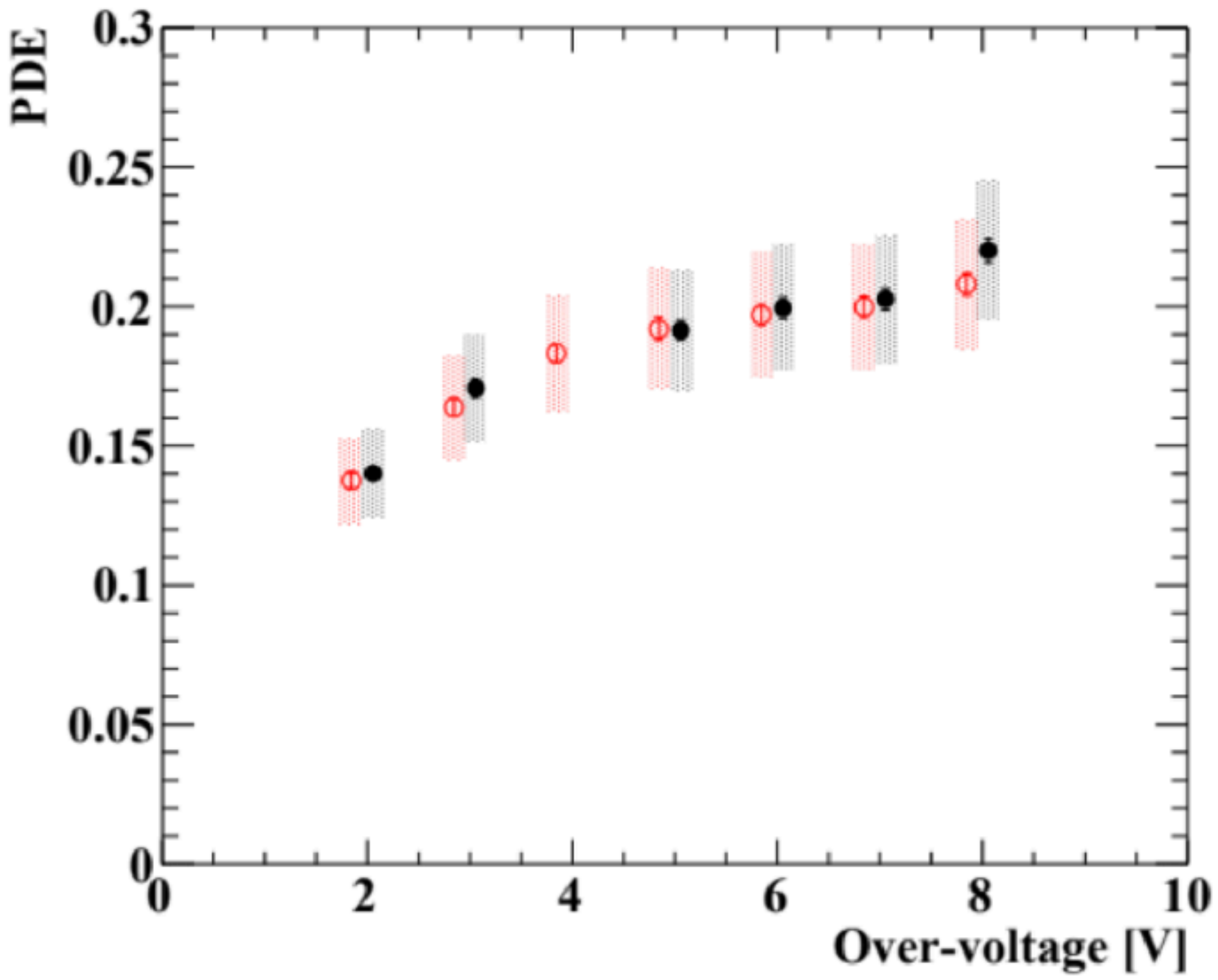
- **Other candidates**
  - **MPPCs in LXe detector were irradiated γ and neutron**
  - **We are now investigating this effect (next talk 12pT2-9)**

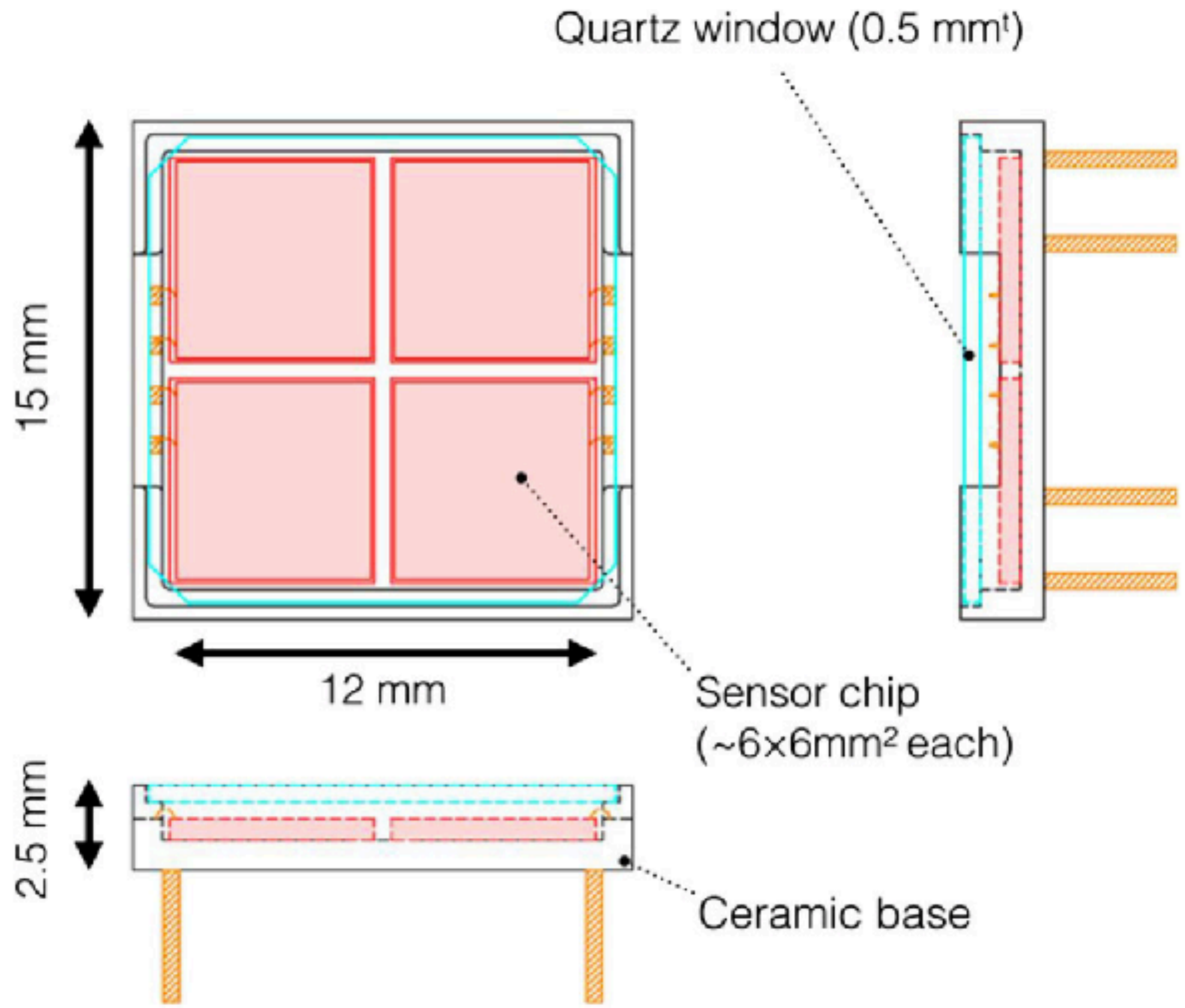
Backup slides

VUV-sensitive MPPC (SiPM)



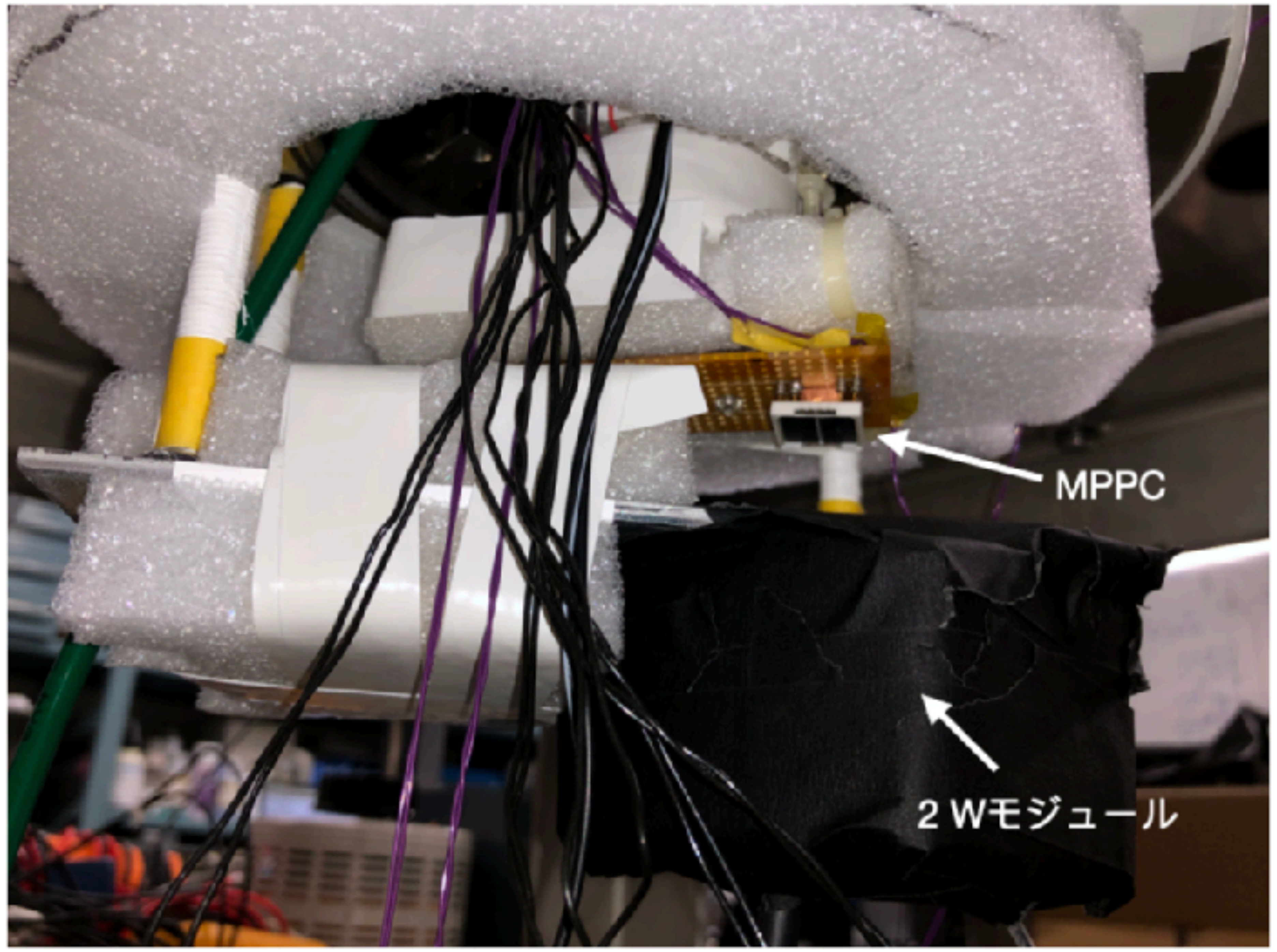
- VUV-sensitive MPPC has been newly developed for MEG II
- Operational at low temperature (~165 K)
- Photon detection efficiency (PDE) $>$15% at $\lambda = 175\text{nm}$

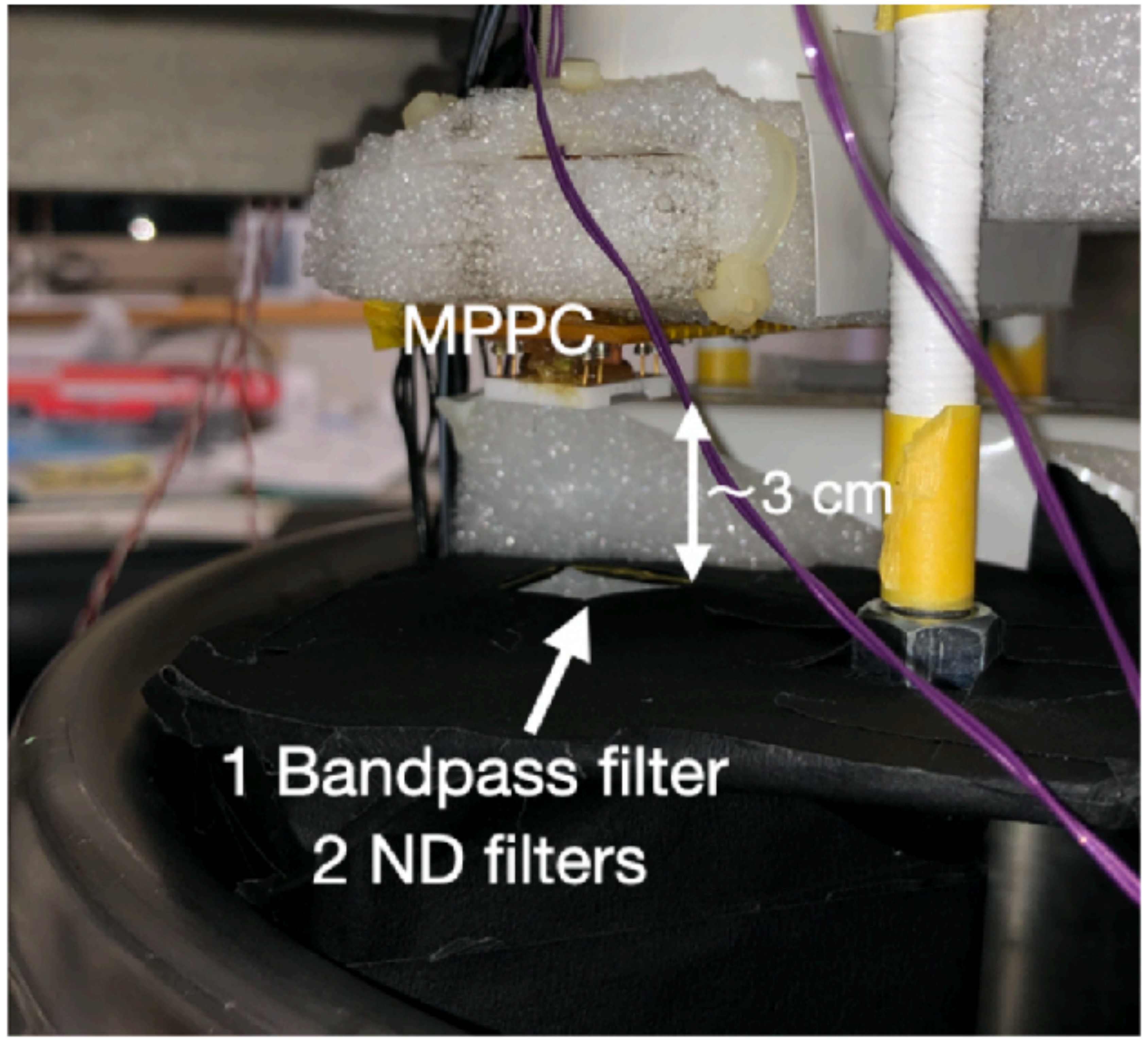




VUV irradiation at low-temp

- Light source : Xe-lamp (MgF_2 glass)
- Cooled the MPPC in N_2 gas
  - MPPC was mounted on refrigerator
- Signal charge was monitored
  - Non irradiated MPPCs were also used as reference





Irradiation by liquid xenon scintillation light using alpha sources

- Light source : liquid xenon scintillation light
  - Alpha source (^{241}Am) was set in liquid xenon
  - Range : $50\ \mu$m
- Signal charge was monitored
- LED was set for calibration and monitoring visible sensitivity