MEG II
Mu - E - Gamma collaboration

MEG II 実験液体キセノンγ線検出器内の真空紫外光に感度のあるMPPCにおけるPDE減少の放射線源を用いた調査

Research on PDE decrease of MPPC for MEG II liquid xenon photon detector by using radiation source.

14pT3-7

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The university of Tokyo
14th Sep. 2021

Core-to-Core Program

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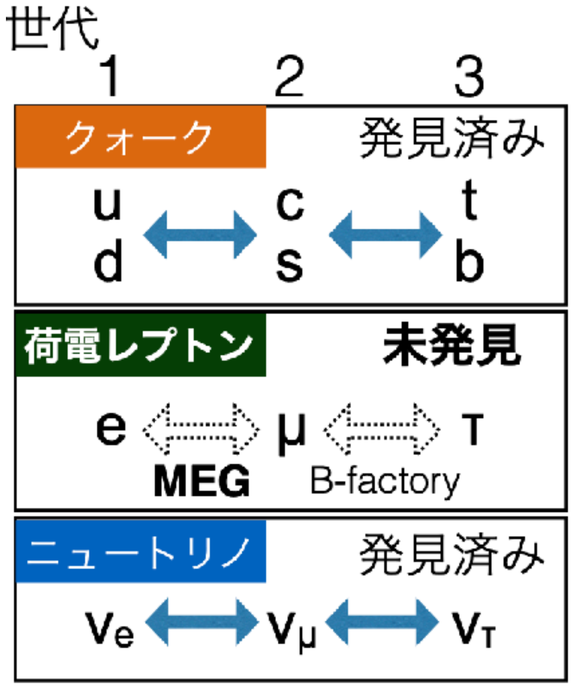
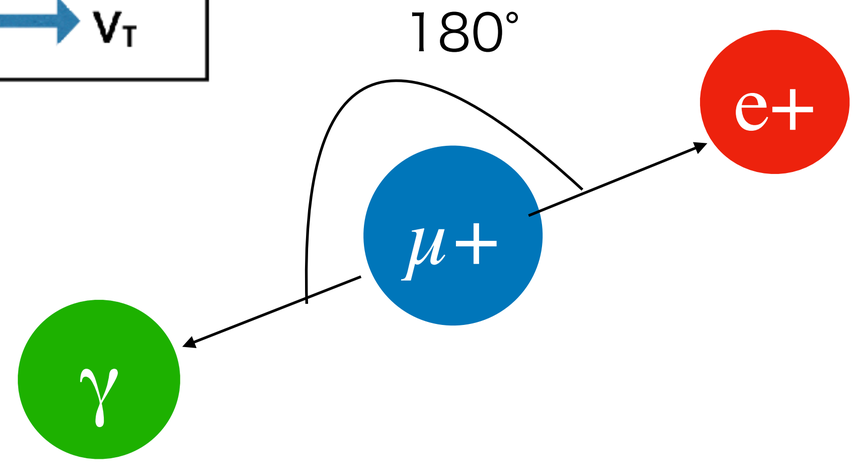
Introduction

μ→eγ search

- $\mu \rightarrow e\gamma$ decay is charged lepton flavour violation (CLFV).
- Almost forbidden in Standard Model (Br ($\mu \rightarrow e\gamma$) ~ 10^{-54}).
- However, it is predicted to occur in some theories (Br ($\mu \rightarrow e\gamma$) :10^{-11}—10^{-14}).
- MEG experiment gives the current upper limit of Br ($\mu \rightarrow e\gamma$)

Br ($\mu \rightarrow e\gamma$) < 4.2×10^{-13} (90% C.L.)



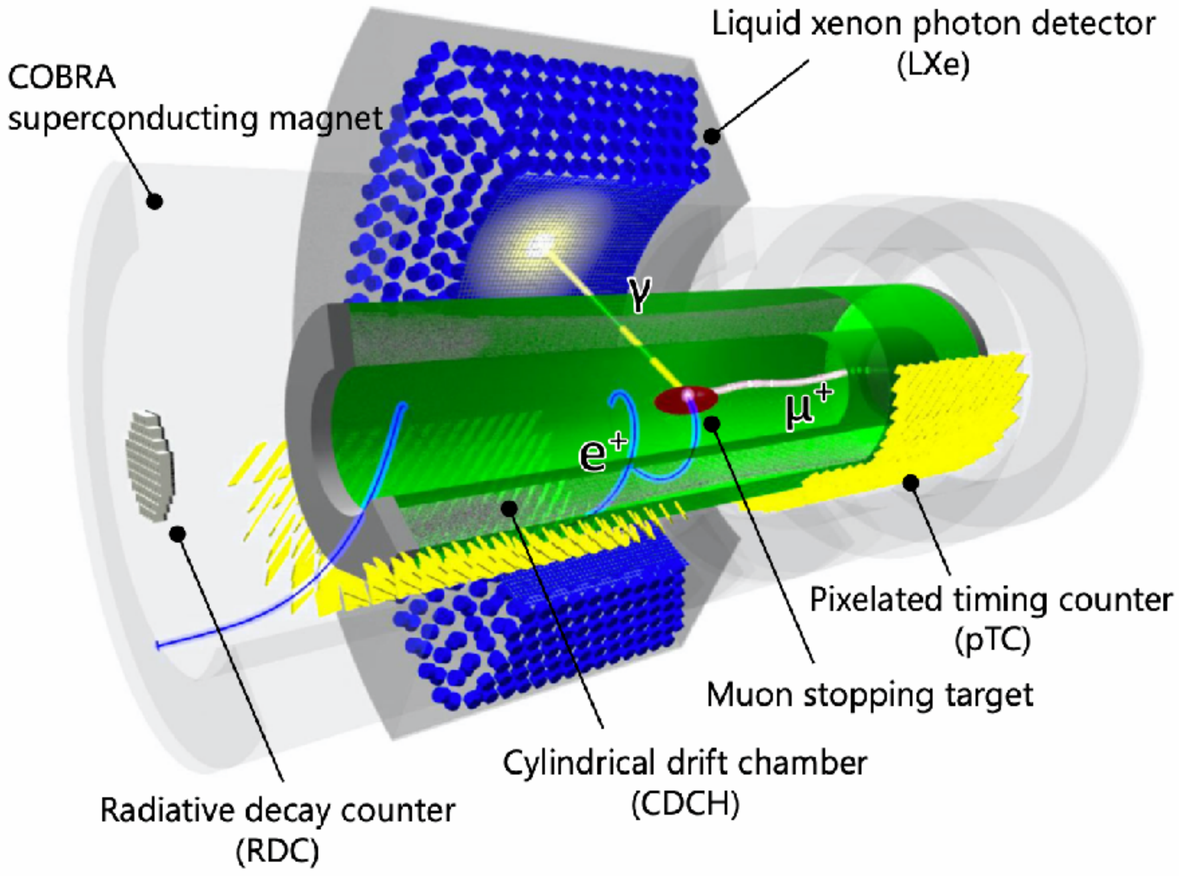


$\mu \rightarrow e\gamma$ decay is
1.Simultaneously emitted
2.Back to back (180°)
3.e+ and γ are emitted at same energy (52.8MeV)

MEG II experiment

Overview

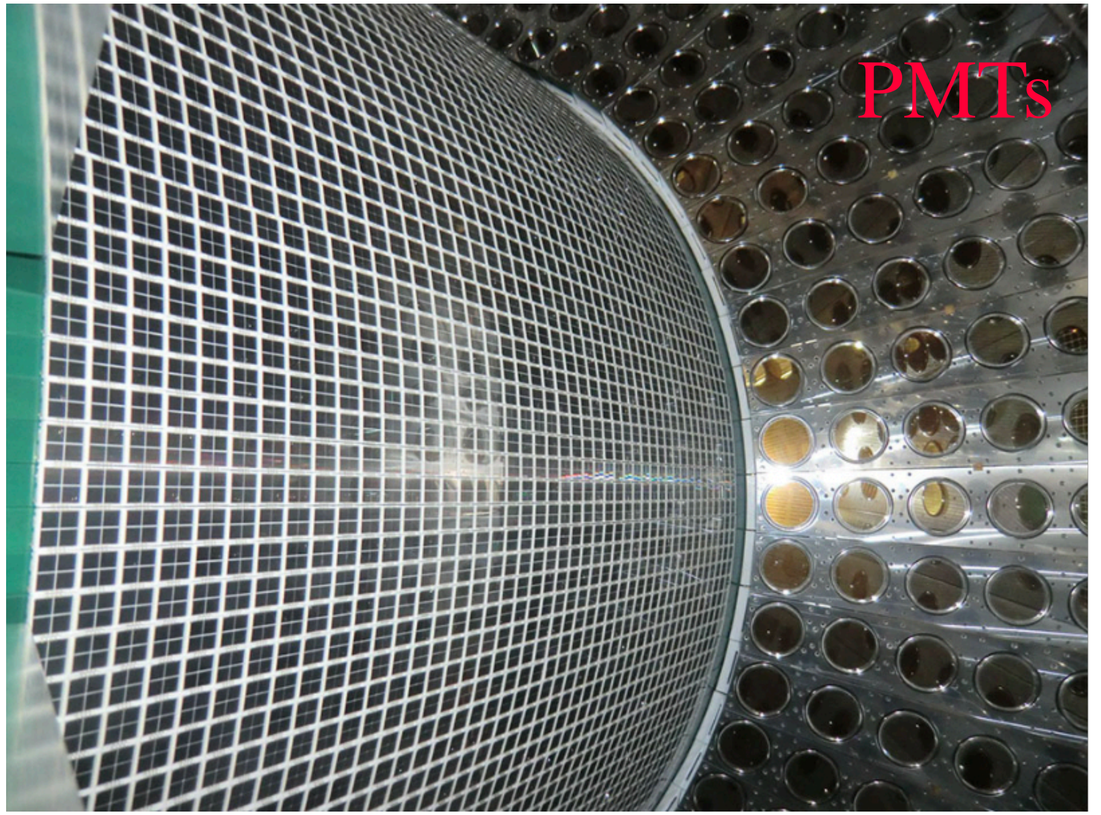
- MEG II experiment aims to detect $\mu \rightarrow e\gamma$, which is CLFV.
- Conducted at Paul Scherrer Institute (Switzerland).
- Upgraded detectors compared to that of MEG experiment.
- Using 7×10^{7}/s continuous μ beam, MEG II will reach Br ($\mu \rightarrow e\gamma$) ~ 6×10^{-14}.



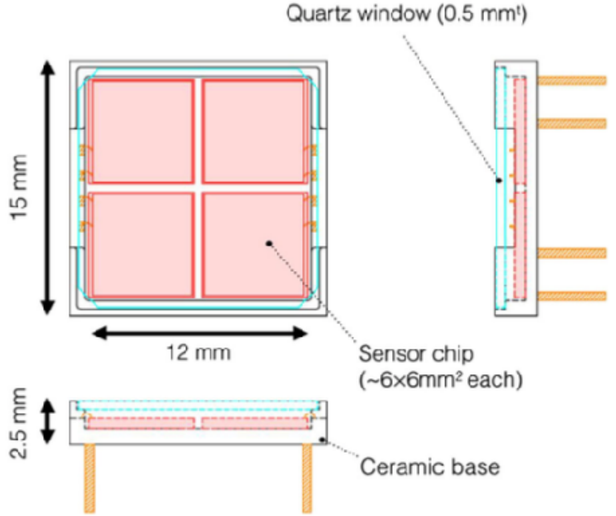
MEG II experiment

Liquid xenon photon detecter(LXe)

- In LXe, energy, position and timing of γ are measured.
- Detect the scintillation light (λ~175nm).
- Use 4092 VUV-sensitive MPPCs (newly installed) and 668 PMTs.
- Energy and position resolution will be improved compared to MEG.



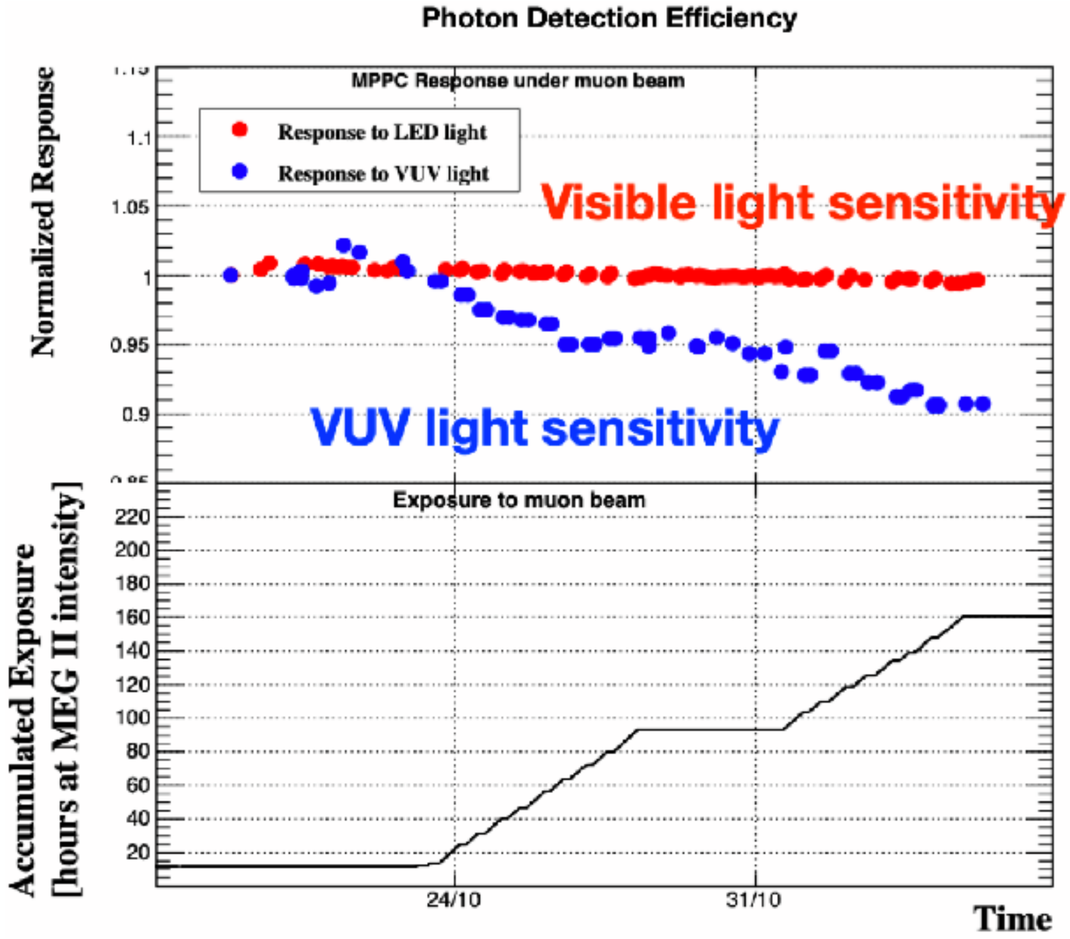
MPPCs



PDE decrease of VUV-MPPC

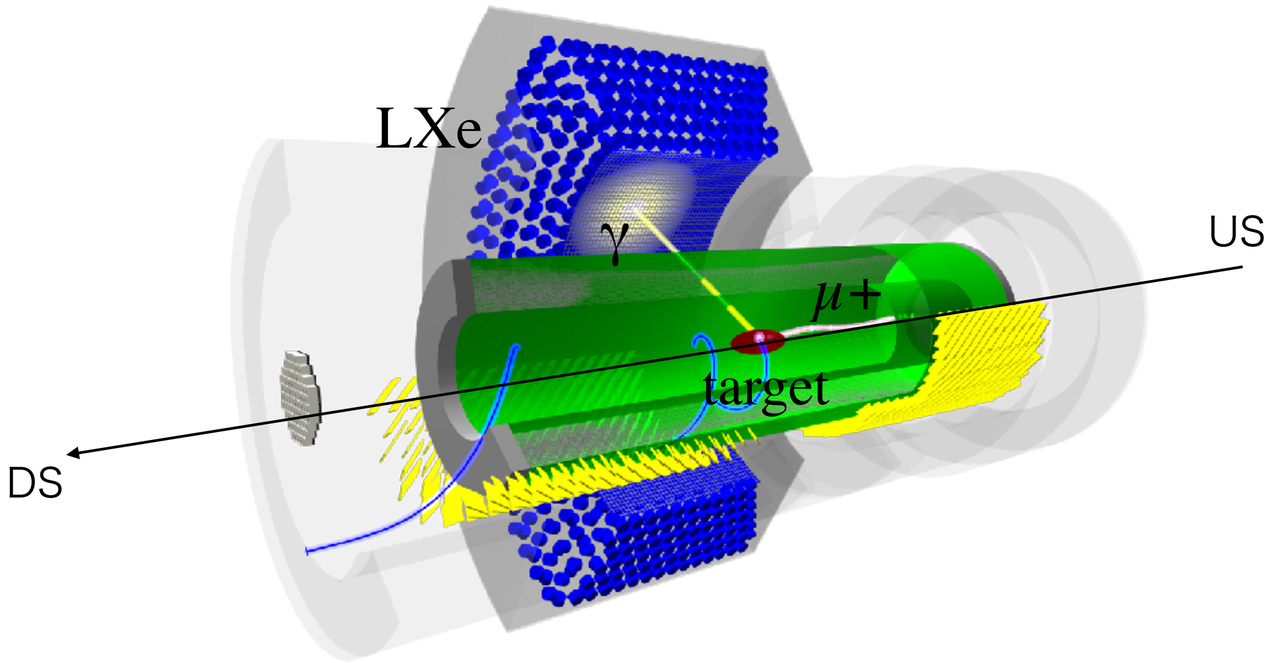
PDE decrease of VUV-sensitive MPPC

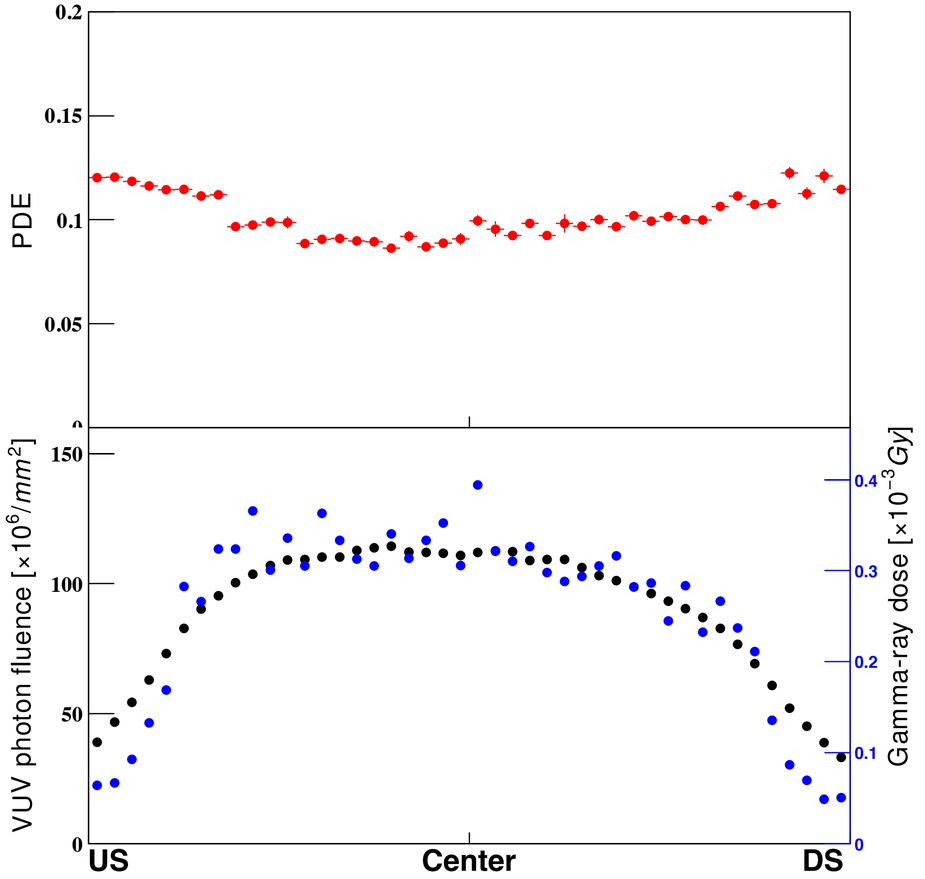
- PDE (photon detection efficiency) decrease of VUV (vacuum ultra violet)-MPPC is quite fast (~ 0.06% /h in MEG II beam intensity).
- MEG II DAQ time: 120 days/year, 3years => PDE decrease is crucial problem.
- Annealing (heating) is effective to recover the decrease.
- But cause of the decrease is unknown.



PDE history in 2019

Suspecting cause





- The speed of PDE decrease has dependence of VUV-MPPC's position.
  => Cause of the decrease may come from target.
- Possible causes : VUV, γ

horizontal: position of MPPCs(US: upstream, DS: downstream)
red: PDE of each MPPCs
black: VUV photon fluence of those
blue: γ rays dose of those

Results we have researched until now

- Researched on some causes at different temperature.
- PDE decrease was not observed in these experiment.

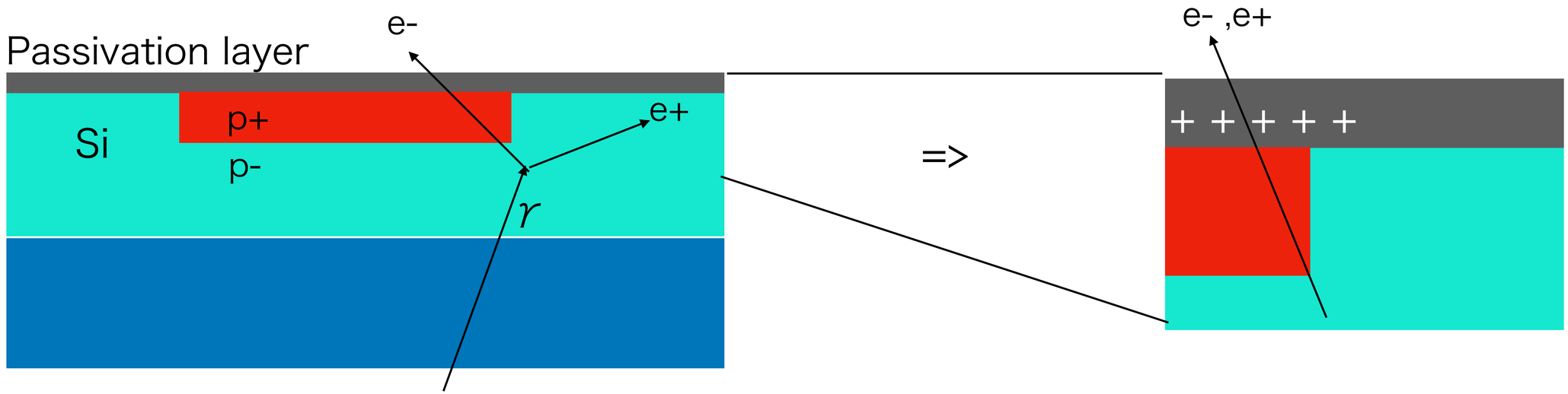
=> Researched on γ ray at low temperature (165K) this time.

Irradiated sample	Irradiated condition	Result
VUV	at room temperature	observed but too slow
	at low temperature (165K)	not observed
γ ray	at room temperature	not observed
	at low temperature (165K)	

Suspecting process of the decrease

Surface damage

- γ deposits energy in Si layer and produce e- and e+.
- e- and e+ damage Si-passivation layer interface and make holes.
- The electric field near the boundary of two surface is reduced and collection efficiency of photon reduces.
- Annealing is effective to recover PDE (may remove holes).

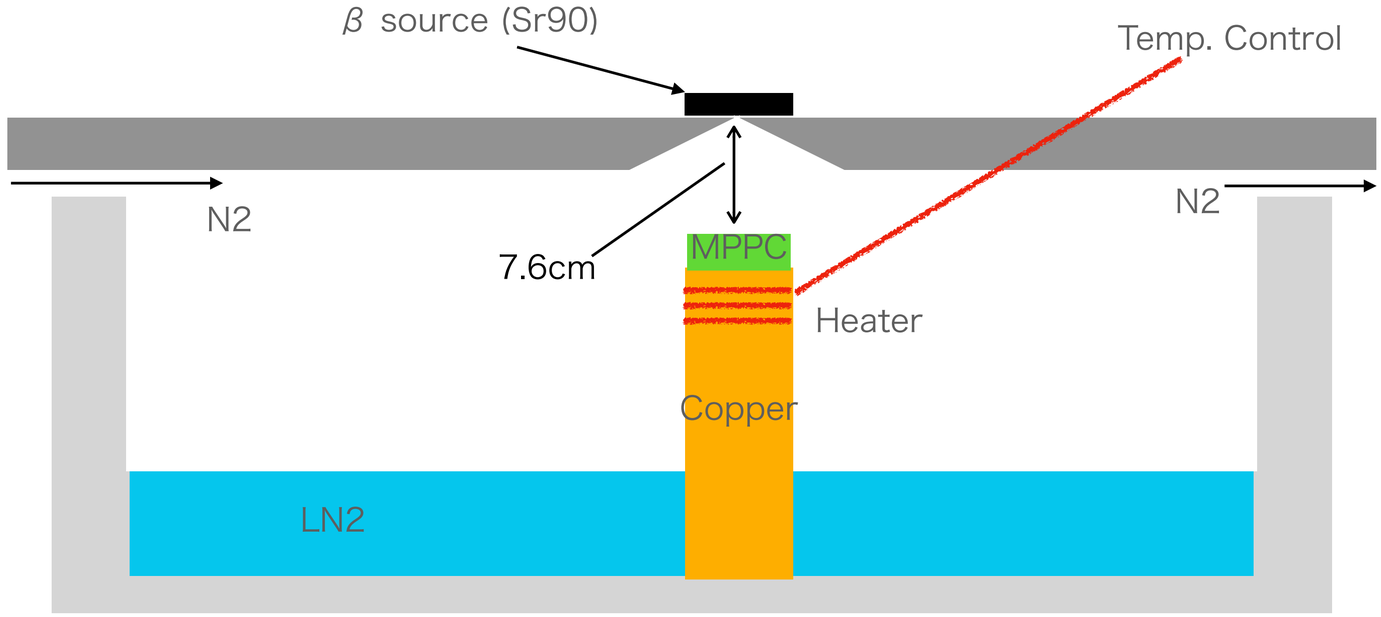


Experiment

Preparation

Setup of irradiation

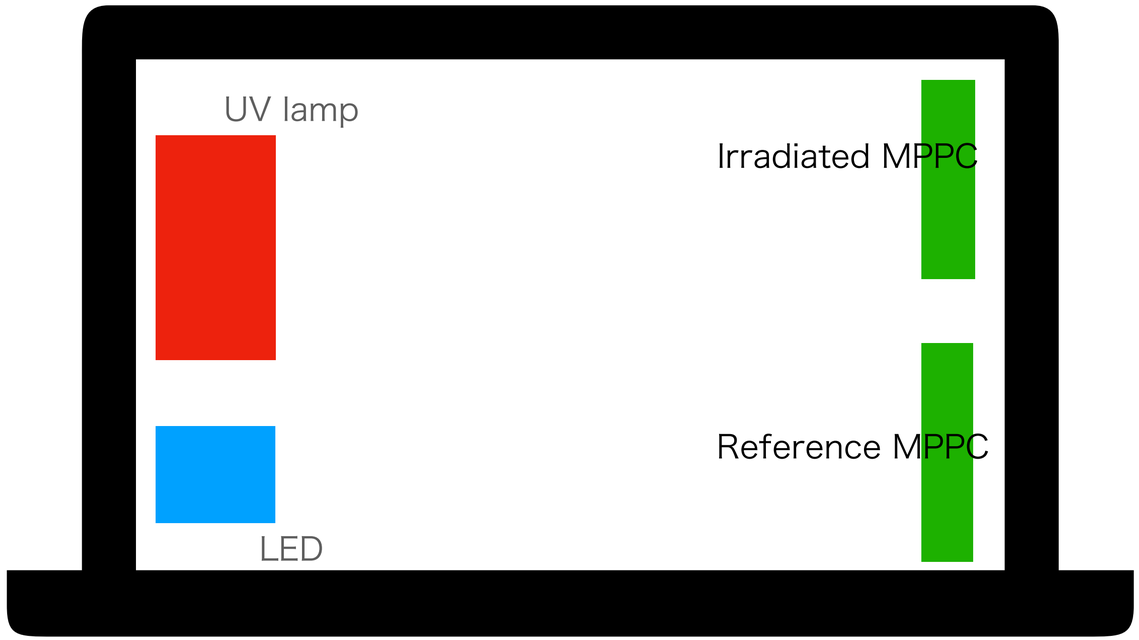
- Used β ray source to reach the γ dose in MEG II DAQ in Laboratory.
- Temperature of irradiated MPPC was kept at 165K (equals to that of LXe).
- Setup was screened from light.
- Distance between irradiated MPPC and β source was 7.6cm.
  => Dose in 5h irradiation is 6mGy
  ~ Dose of some MPPC in MEG II 3 years' DAQ.
- MPPC HV = 0V



Preparation

Setup of PDE measurement

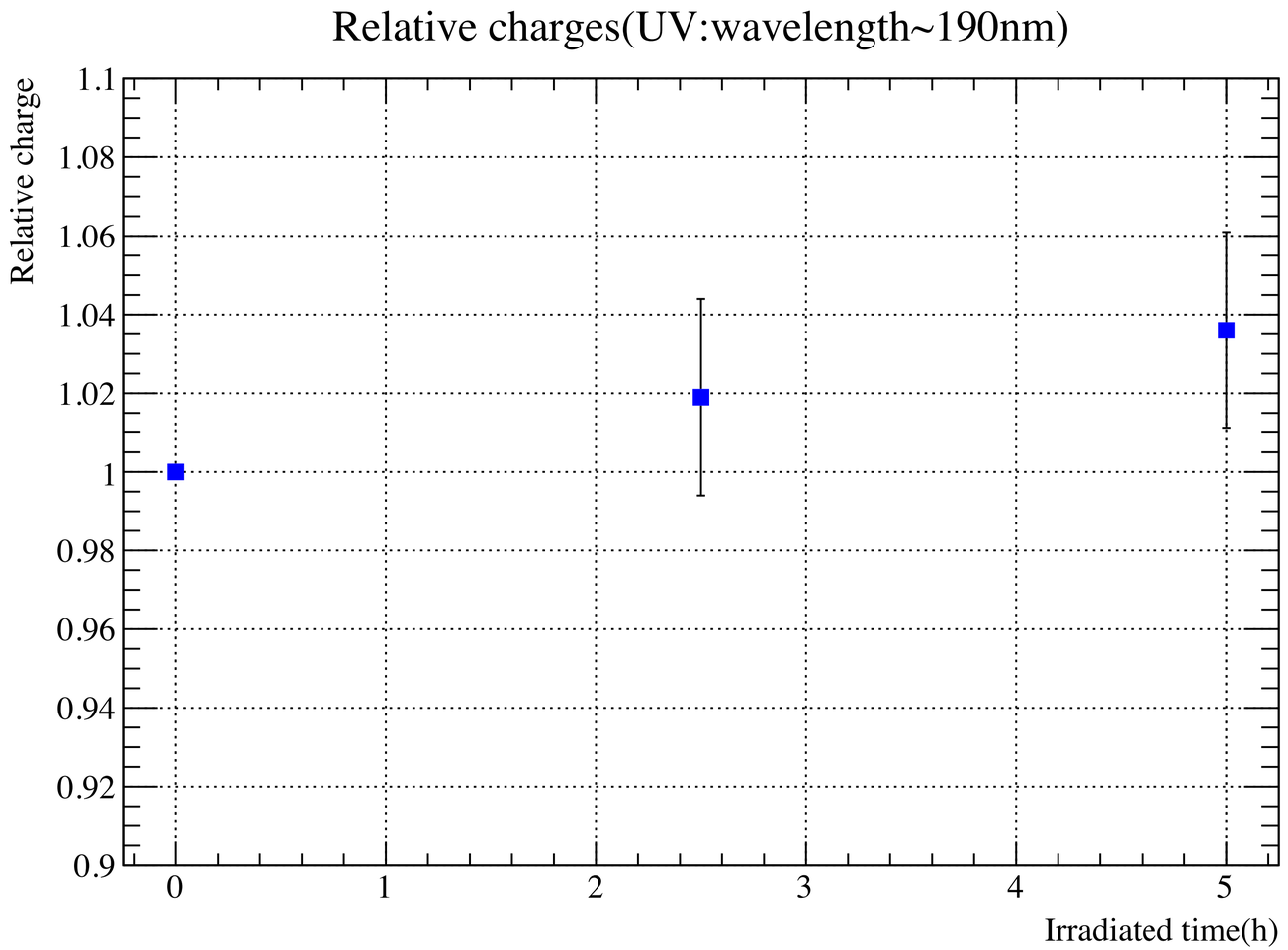
- PDE was measured by UV (~ 190nm) and LED (~ 460nm).
- Relative positions of lamps and MPPC are fixed.
- Temperature at the measurement: 22°C (constant).



Thermostatic chamber

Result

- PDE decrease was not observed in this experiment
- Dose of 5h is equivalent to MEG II 3 years' DAQ
- If PDE decrease occurs at the same speed observed in LXe, PDE will decrease 100% in 1h irradiation.

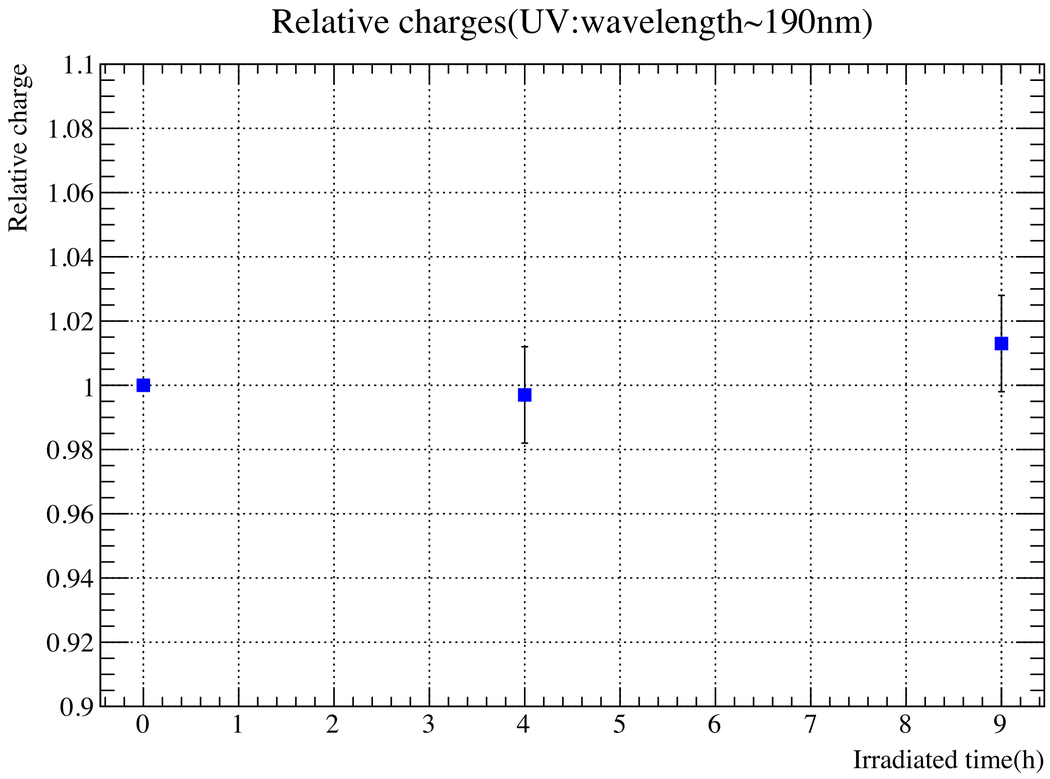


Error : considered the standard deviation

Results

Slower irradiation

- The previous irradiation was too fast compared to the situation in MEG II.
- So irradiated β rays to MPPC slower than the previous experiment (i.e. irradiation distance 7.6cm => 40cm).
- Dose of 9h irradiation is equivalent to that in 3 week MEG II DAQ.
- PDE decrease was not observed in this experiment.
- PDE will decrease 30% in 9h irradiation if it decrease at the same speed in LXe.



Error : considered instability of the UV lamp and the MPPC

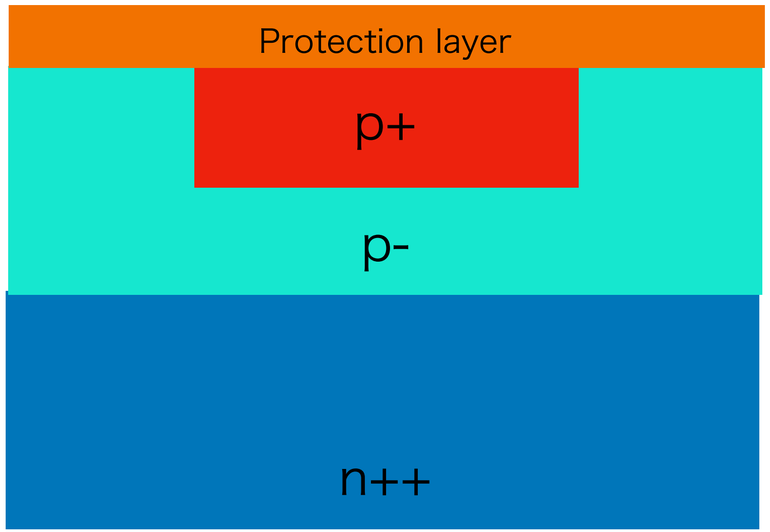
Summary

- MEG II experiment aims to detect $\mu \rightarrow e\gamma$ decay.
- PDE decrease of VUV-MPPC in LXe is crucial problem.
- We have researched many causes as the PDE decrease.
- Researched γ this time as the cause of it, and the decrease was not observed.
- We don't have other candidates for PDE decrease now, but continue to research the cause.

Backups

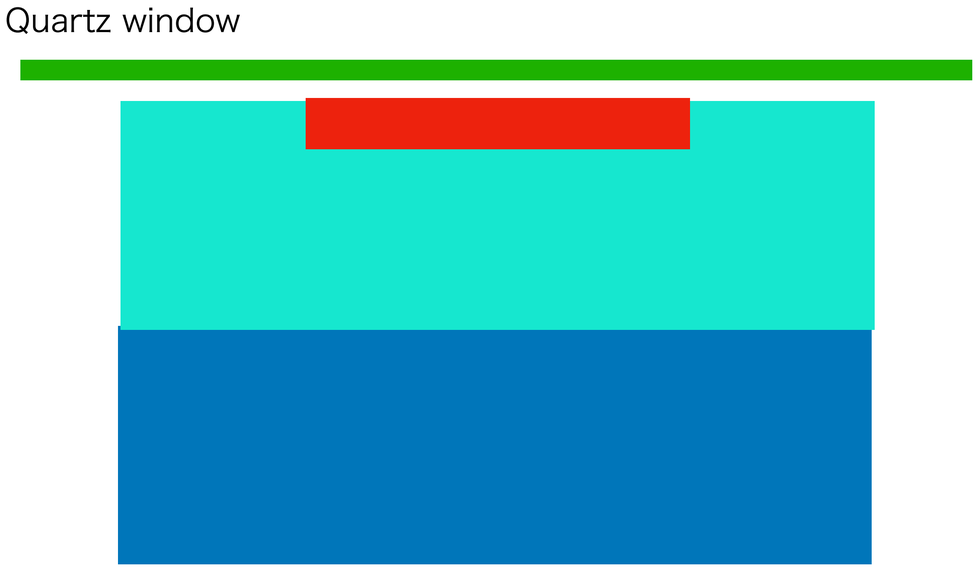
VUV-MPPC

Normal SiPM



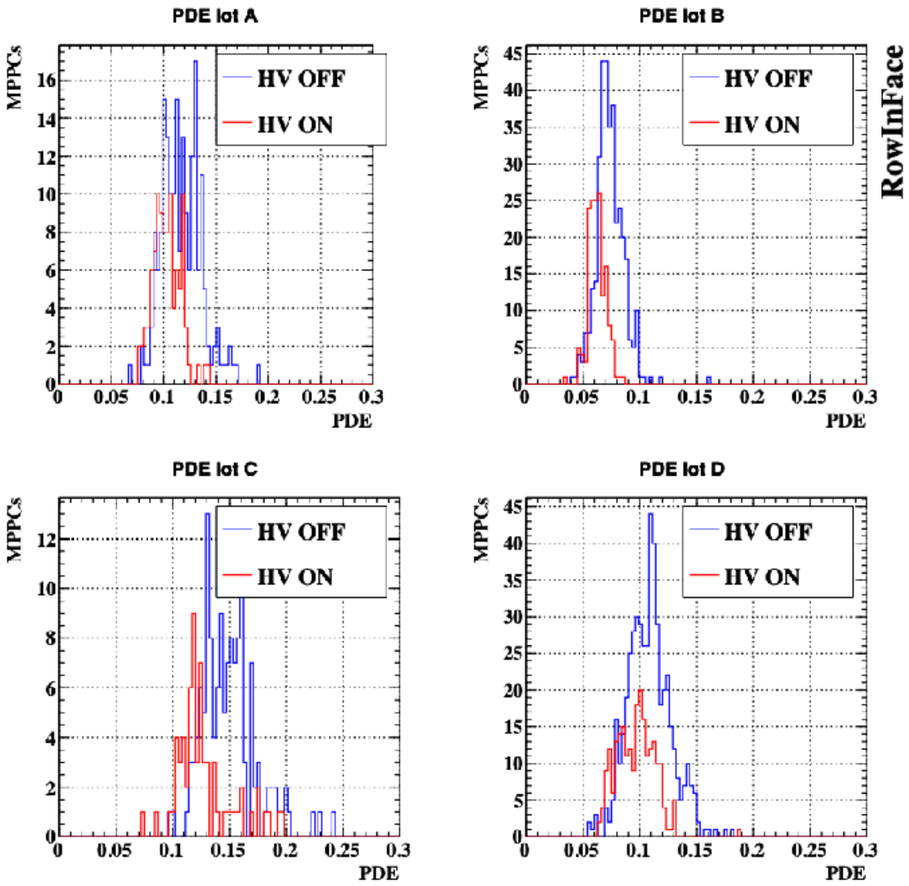
- insensitive to VUV lights because the protection layer and thick p+ layer absorb VUV lights before they reach p- layer

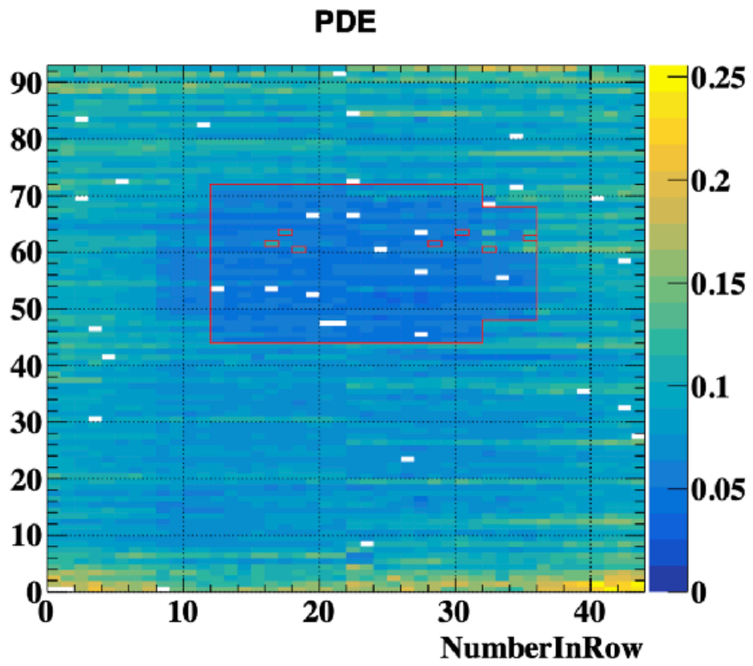
VUV-MPPC

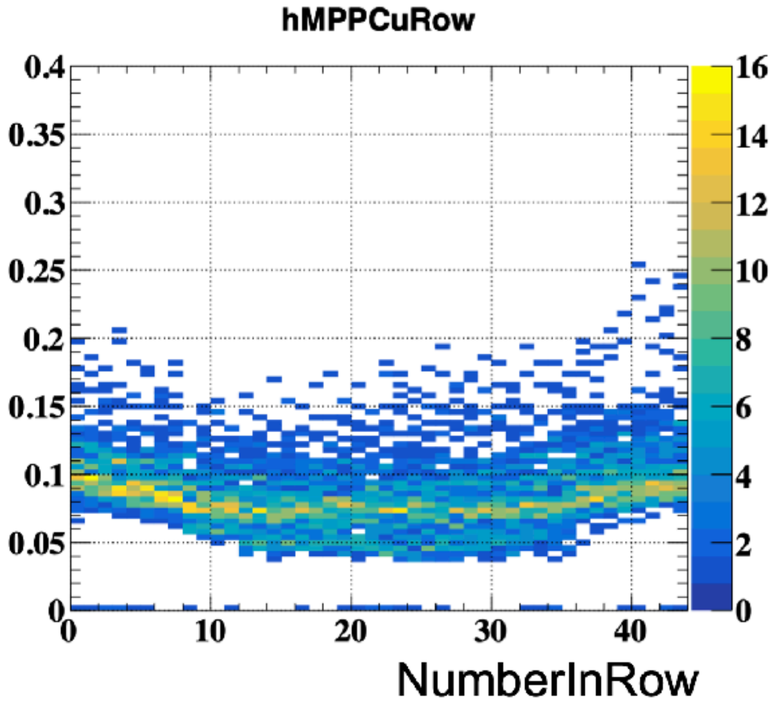


- quartz window to protect its surface instead of the protection layer
- thinner p+ layer

HV on/off and u dependence

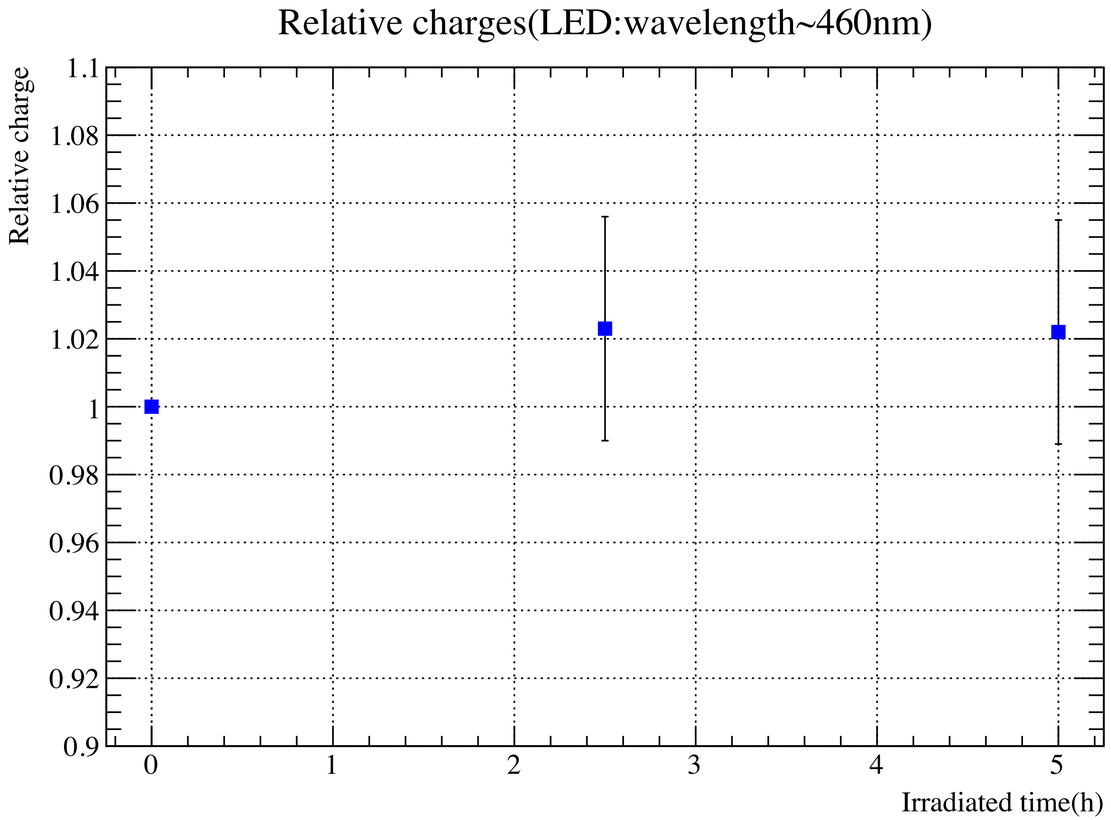


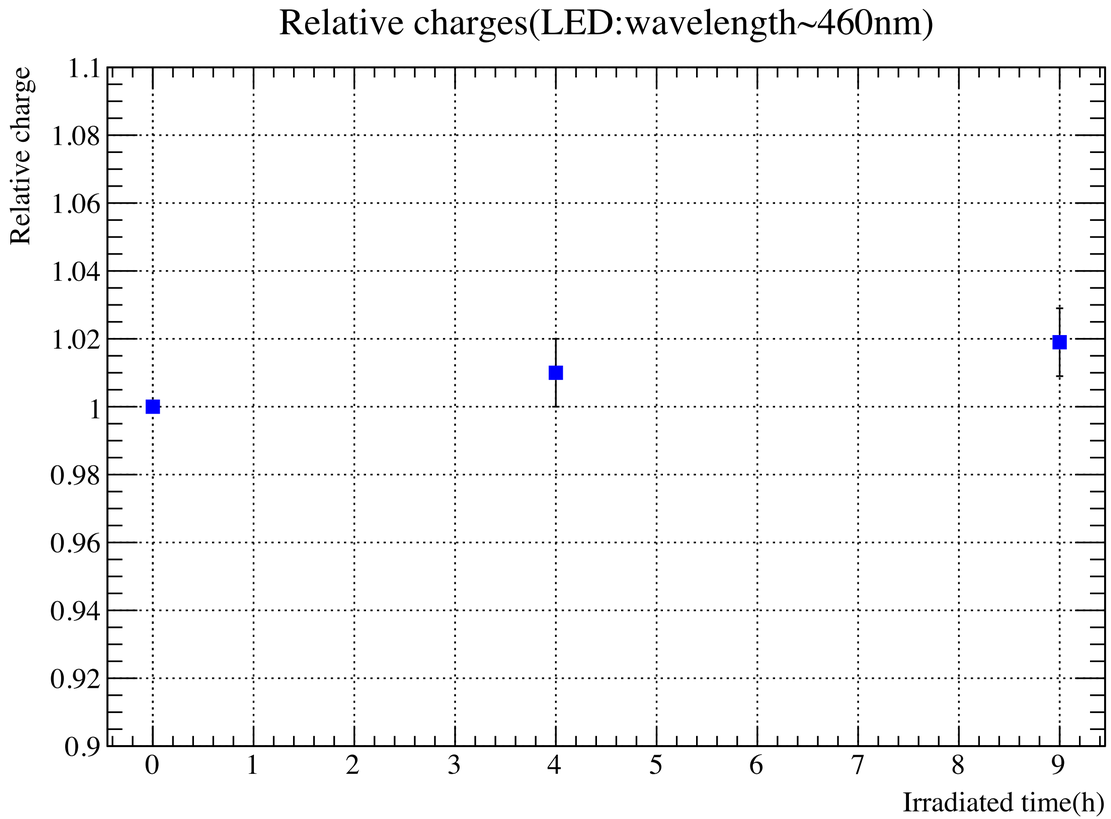




- The area surrounded by red lines is MPPC channels used before full DAQ setup this year.

Results (LED)


Relative charges(LED:wavelength~460nm)
Relative charge
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0
1
2
3
4
5
Irradiated time(h)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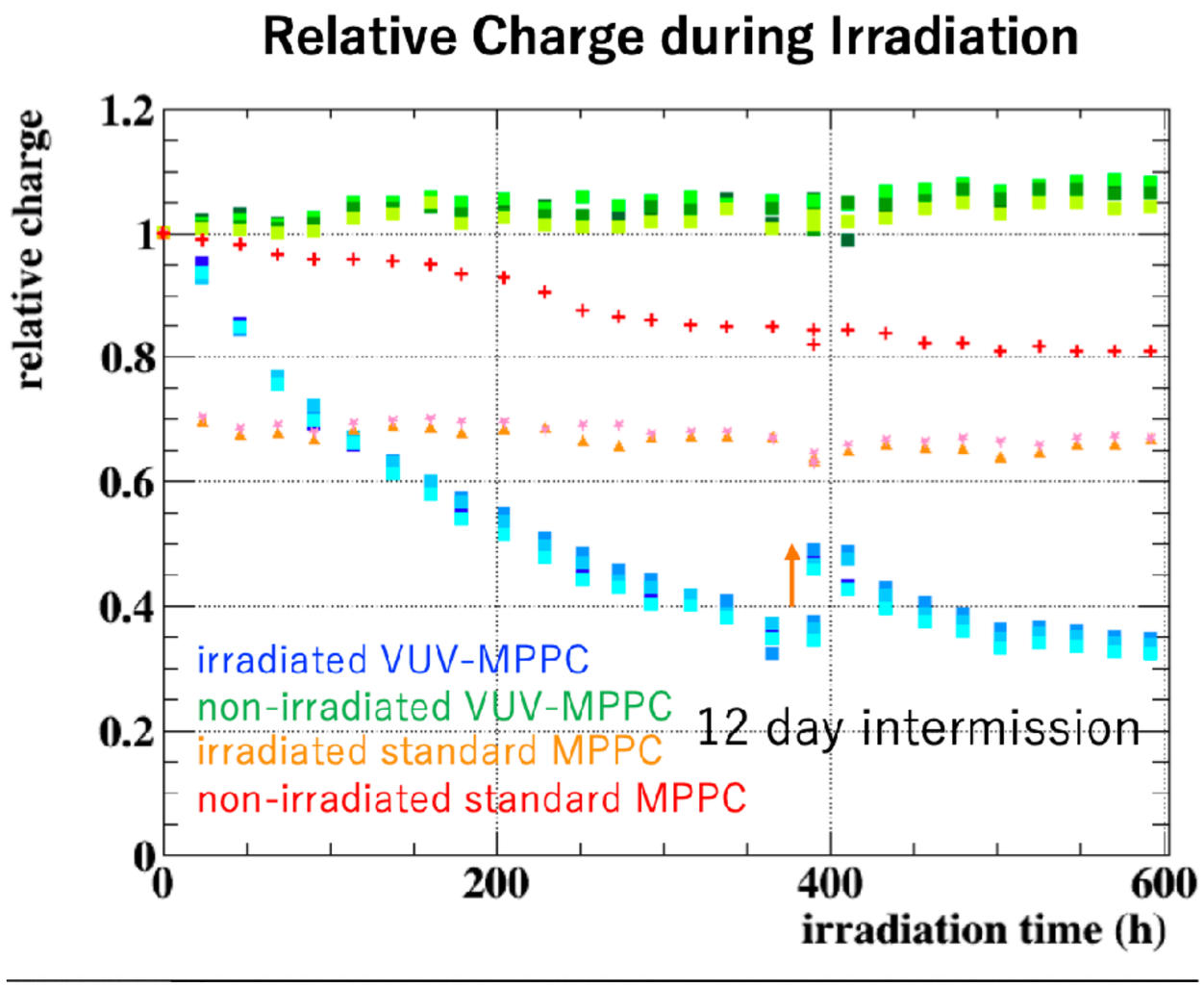
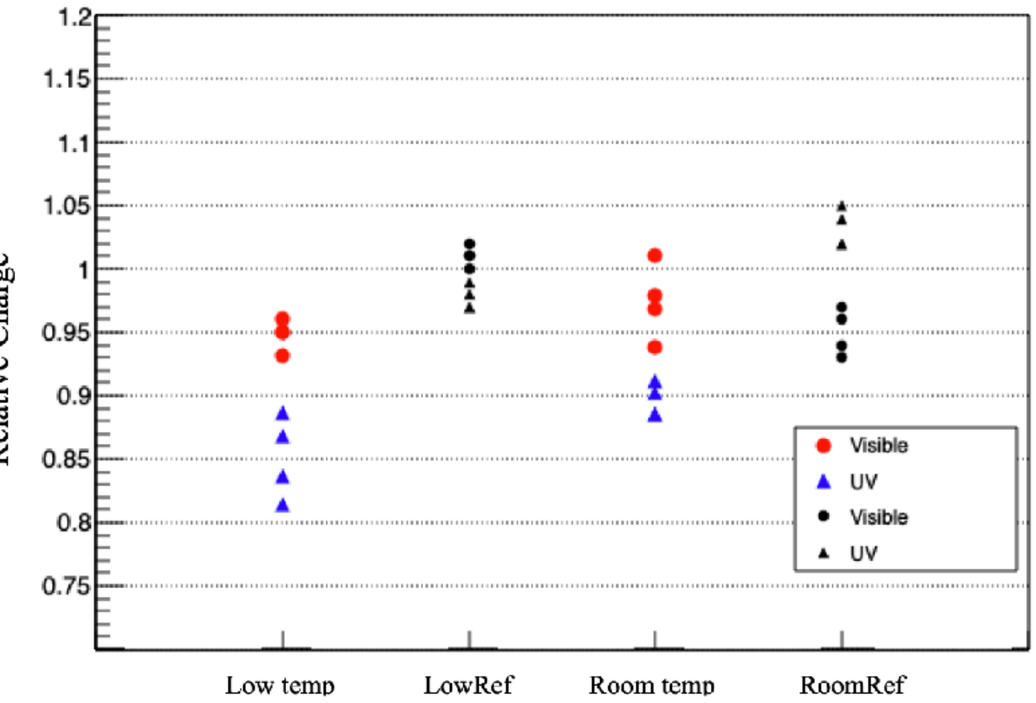
1
2
3
4
5
6
7
8
9
Irradiated time(h)

PDE decrease(2019,room temp)



- Intensity:5.2e13/mm^2/h@λ~190nm
- Total dose:3.1e16/mm^2/
- Decrease of VUV-MPPC saturated at 35%.
- Speed of decrease is 1000 times slower than that of observed in LXe.
- That of standard MPPC saturated at 70%.
- annealing in room temp.: 11% in 12days=>3.82%/100h

PDE decrease(2020,low)



- **UV PDE decrease at low temp was larger than at room temp**
  - **Low : 14.8%**
  - **Room : 10.4%**
- **At low temp, UV PDE decrease was larger than visible**
  - **UV : 14.8%**
  - **Visible : 5.2%**

	Xe-lamp	MEG II LXe
Total dose level	4.5e16 photon	4.4e12 photon
PDE decrease	14.8%(UV)	9%(VUV)

· $N_{phe,VUV} = 60\mathrm{p.e./mm^2 \cdot pulse}$

$\rightarrow N_{pho,VUV} = 400\mathrm{photon/mm^2 \cdot pulse} \quad \text{if PDE} = 15\,\%$

$$\rightarrow N_{pho,VUV} = 400 \times 144 \div (0.25)^2 \times 500\mathrm{Hz} \times \left(\frac{3\mathrm{mm}}{1\mathrm{mm}}\right)^2 \times \left(\frac{42\mathrm{cm}}{3\mathrm{cm}}\right)^2 \mathrm{photon/ch}$$

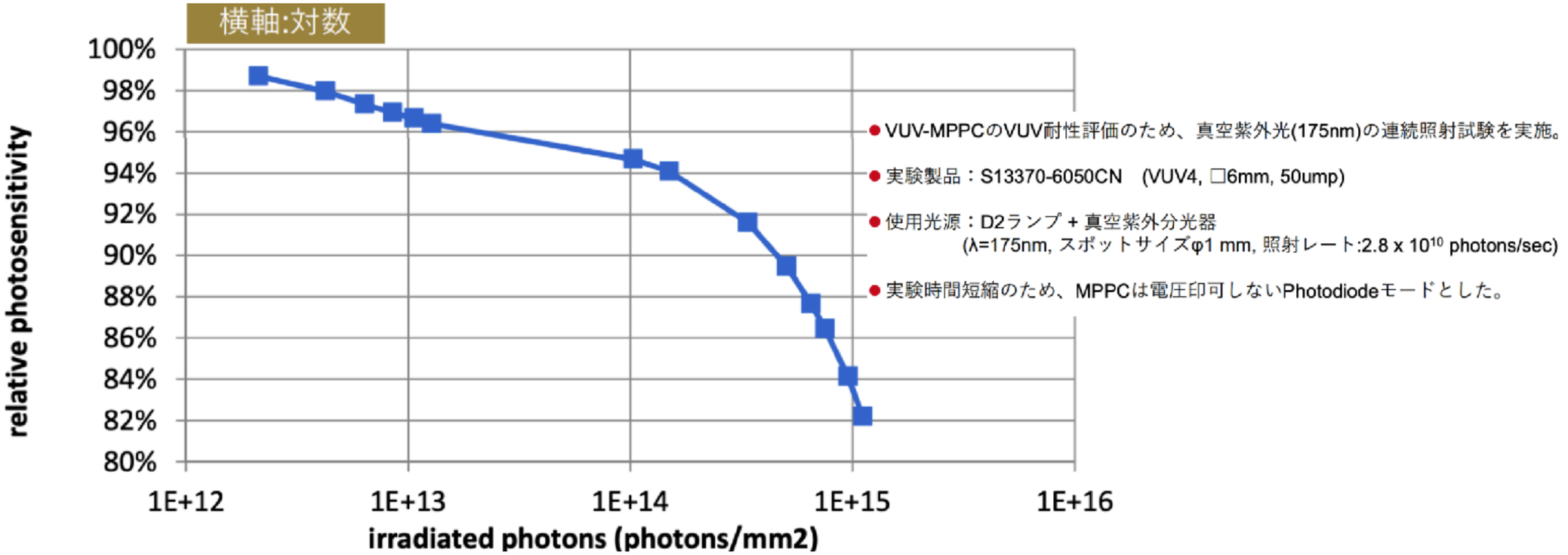
(4chip, Filters, Lamp freq, Window ratio, Distance ratio)

$$= 2.1 \times 10^{12}\mathrm{photon/ch \cdot sec}$$

· $N_{pho,2019} = 1.0 \times 10^{13} - 2.5 \times 10^{13}\mathrm{photon/ch}$

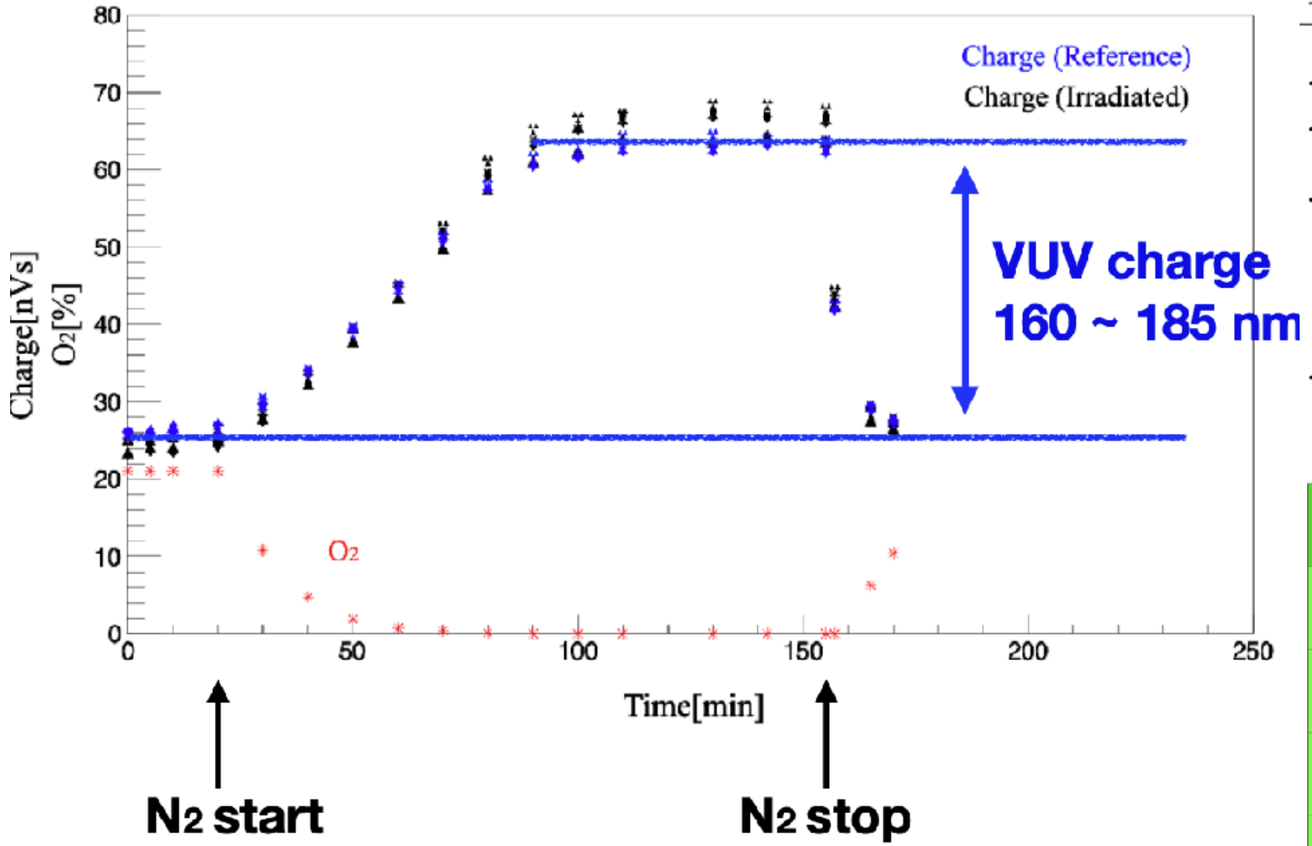
It will take ~10sec to reach 2019 run at low-temp

PDE decrease(2020,room)



PDE decrease(2020,low)

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



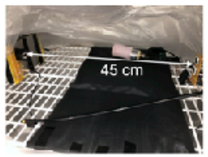
PDE_{after}/PDE_{before}

	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

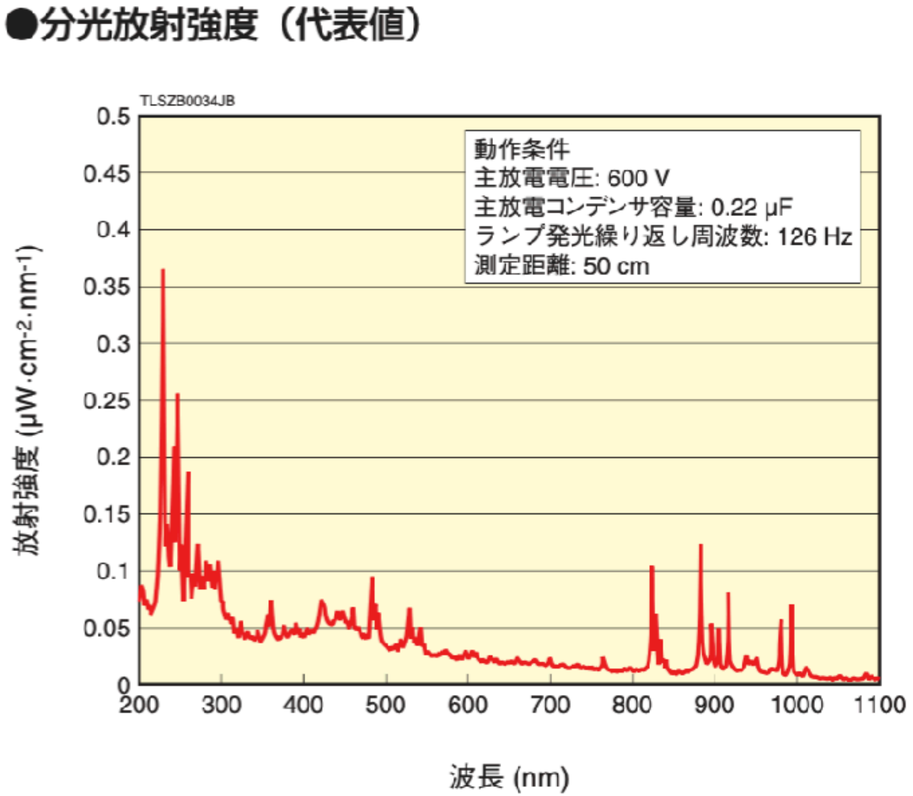
- **VUV-PDE decrease was not observed**

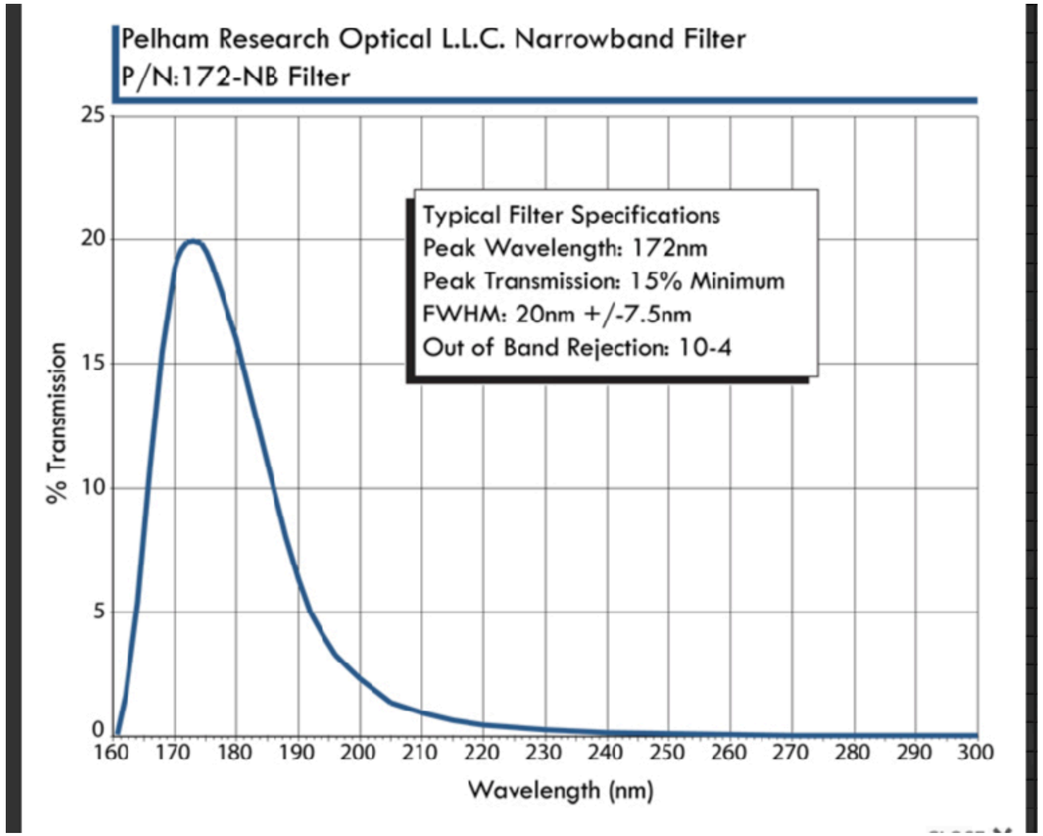


Mean free path

	160 nm	165 nm	175 nm	178 nm
$O_2 = 20.9\,\%$	0.04 cm	0.24 cm	0.64 cm	48 cm
$O_2 = 10\,\%$	0.08 cm	0.5 cm	1.34 cm	100 cm
$O_2 = 0.1\,\%$	0.8 cm	5 cm	13.4 cm	1000 cm
$O_2 = 0.04\,\%$	20 cm	12.5 cm	34 cm	2500 cm

Xe-lamp, Bandpass filter





Hamamatsu 5W Xe-lamp(L9456-01)
window material: UV glass
wave length:185nm~2500nm

eSource Optics VUV Bandpass filter(25172FNB)

Result of MPPC stability

- I estimated error of irradiation experiment by result of MPPC stability experiment because that is same situation to irradiation experiment.
- Experimet : MPPC1 was moved out when the charge was not measured, and the another(MPPC2) was not moved out.
- Evaluated error as the (deviation of relative charge MPPC1/MPPC2)/(√sample size=4).