Study on radiation-induced degradation of VUV sensitivity in multi-pixel photon counters tested in liquid xenon

K. Yamamoto[1], S. Ban[1], D. Gallacher[2], T. Iwamoto[1], H. Ogawa[1], W. Ootani[1], H. Suzuki[1,3]

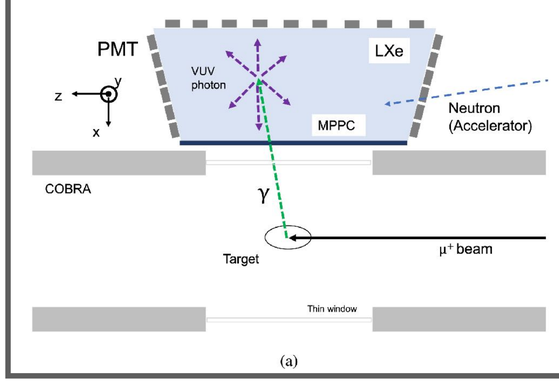
[1]The University of Tokyo, [2]TRIUMF, [3]Kobe University | Contact: kensukey@icepp.s.u-tokyo.ac.jp

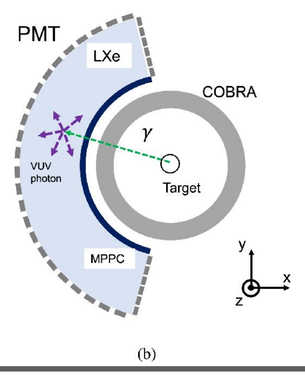
Abstract

The VUV sensitivity of MPPCs deployed in the MEG II liquid xenon γ-ray detector has been observed to degrade under high-rate irradiation [1]. We conducted a VUV irradiation test of the MPPCs in LXe using α particles emitted from ^{241}Am, to identify the mechanism underlying VUV-sensitivity degradation. The two MPPC chips exposed to 10^{11} VUV photons show different trends in the number of photoelectrons, providing no conclusive evidence of VUV-sensitivity degradation. This poster also discusses ongoing and planned studies towards more conclusive testing.

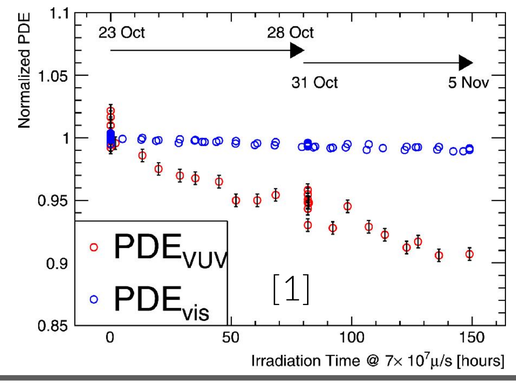
Motivation: To identify the mechanism of the VUV-sensitivity decrease observed in the MEG II experiment

- A liquid xenon γ detector using 900 L of LXe & 4760 VUV-sensitive photosensors has been developed in the MEG II experiment, in search of $\mu^+ \to e^+\gamma$ [2, 3]
- 4092 newly developed MPPCs [4] are installed on the photon-incident surface
- **Photon detection efficiency for VUV light has decreased as beam is irradiated**



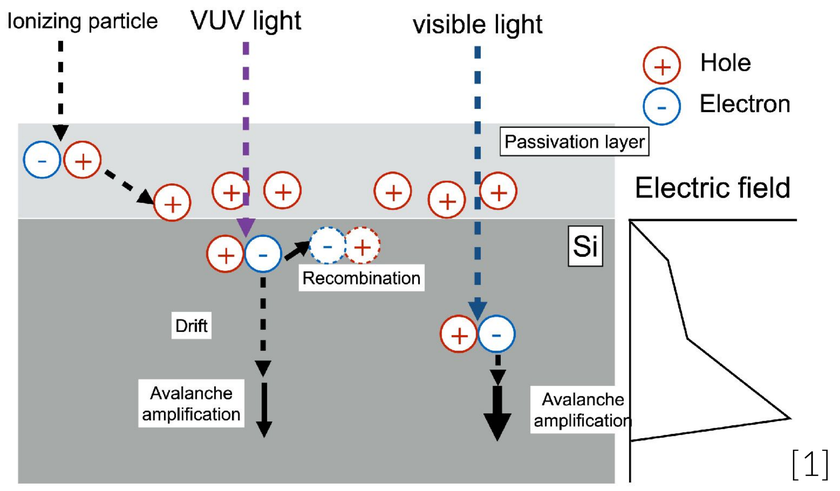


[1]



[1]

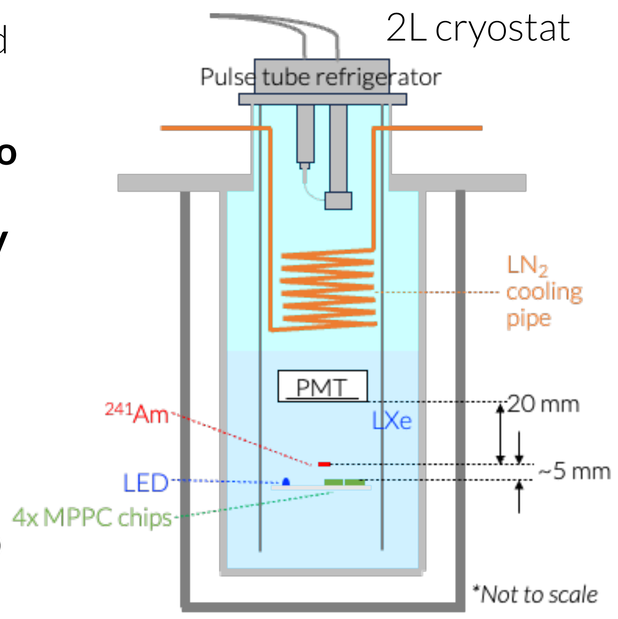
Mechanism hypothesis: Surface damage

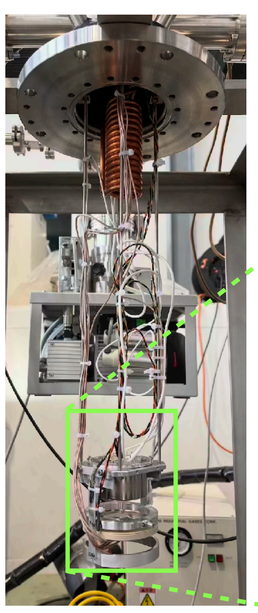


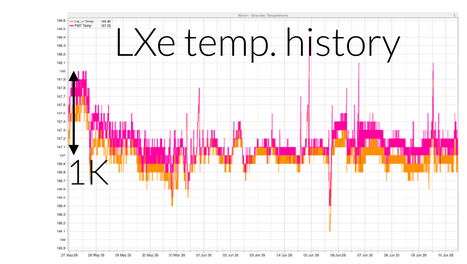
[1]

VUV irradiation test setup in LXe

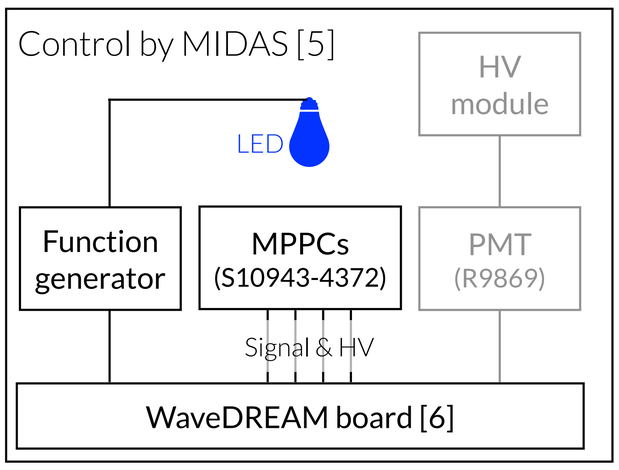
- VUV photons suspected of "ionizing particle"
- **MPPC chips exposed to LXe scintillation light (175 nm) from 5.5 MeV α particles from ^{241}Am**
- Exposure for 10 days
- With biasing
- Self-triggered α data and weakly flashed LED data acquired hourly



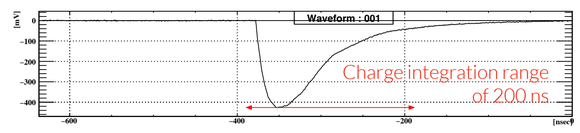




Control by MIDAS [5]



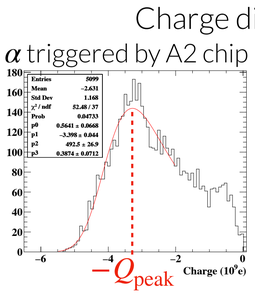
MPPC waveform in an α event



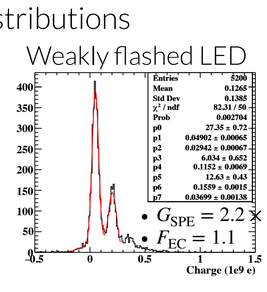
Results: Different behaviours between two MPPC chips

Charge distributions

α triggered by A2 chip



Weakly flashed LED

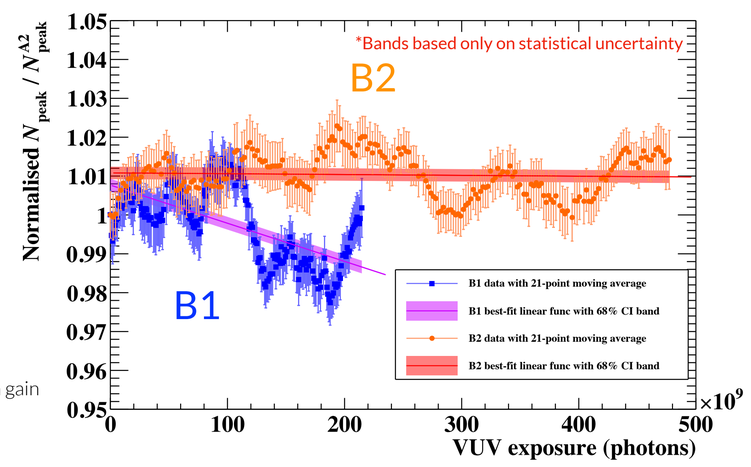


- $G_{SPE} = 2.2 \times 10^6$
- $F_{EC} = 1.1$

Peak of # of p.e. calculated as

$$N_{peak} = \frac{Q_{peak}}{G_{SPE} \cdot F_{EC}}$$

- G_{SPE}: Single-photoelectron gain
- F_{EC}: Excess charge factor



VUV flux estimated as $\Phi_{VUV} = (5 \pm 1) \times 10^5\ s^{-1}$

Consistent with two estimation methods:

Trigger channel basis

$$\Phi_{VUV} = \frac{\bar{N}}{PDE} \cdot R_{TRG}$$

Current basis

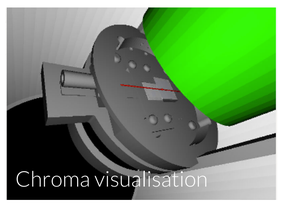
$$I \propto \Phi_{VUV} \cdot G_{SPE} \cdot F_{EC} \cdot PDE$$

Not conclusive due to different behaviours

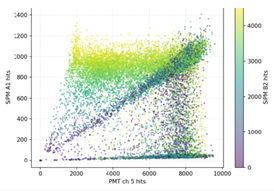
Dominant uncertainty on flux is PDE (25%)

Towards more conclusive testing

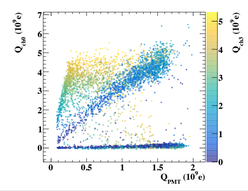
- **Higher exposure** to see a more significant trend
  - ➡ Planning positron beam test at PiM1 beamline at Paul Scherrer Institut (Switzerland) this autumn
    - Positron beam rate is 10^6 e/s, and expected VUV flux is 10^8 photons/s
- **Precise PDE calculation** required to precisely calculate VUV photon flux
  - ➡ Chroma [7] -based optical simulation in progress
    - To compare measured # of p.e. and simulated # of VUV photons



Simulated photons impinging on 3 photosensors



Charges measured by 3 photosensors



References

[1] K. Ieki, et al., NIM-A 1053 (2023), 167365
[2] A. M. Baldini, et al., EPJC 78 (2018), 380
[3] K. Afanaciev, et al., EPJC 84 (2024), 190
[4] K. Ieki, et al., NIM-A 925 (2019), 148-155
[5] MIDAS, https://daq00.triumf.ca/MidasWiki/
[6] L. Galli, et al., NIM-A 936 (2019), 399-400
[7] Chroma, https://github.com/pennneutrinos/chroma

Acknowledgement

We are grateful for the technical and engineering support from PSI. We also thank W. Li, T. Mori, and Y. Uchiyama for their cooperation in monitoring the slow-control system and the DAQ during the tests. This work is supported by JSPS KAKENHI Grant Numbers 21H04991, 22K21350, and 24H00019 (25K24622).

Summary

- Conducted a VUV irradiation test in LXe on VUV-sensitive MPPCs to investigate the mechanism of VUV-sensitivity degradation observed in the MEG II LXe γ-ray detector
- Two MPPC chips exposed to 10^{11} photons show different trends in the number of p.e., giving no conclusive results on PDE degradation
- Plan a higher-irradiation test with a high-intensity positron beam at PSI