# MEG II実験液体キセノンガンマ線検出器におけるMPPCの大強度ミューオンビーム環境下での光子検出効率低下率測定

Measurement on the degradation rate of Photon Detection Efficiency of MPPC in the Liquid Xenon Gamma-ray Detector of the MEG II Experiment

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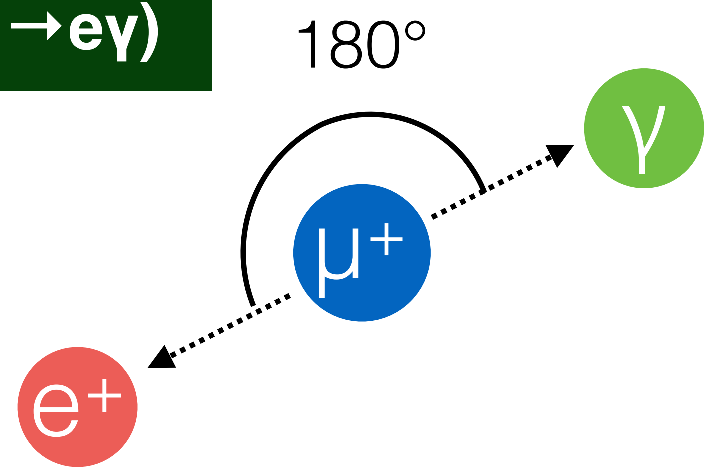
# Related talks

- We MEG II Liquid xenon group have several talks focused on the **radiation damage of photodetectors(VUV-MPPC, PMT)**.
- Four presentations on photodetectors of MEG II LXe gamma-ray detector.
  - K. Toyoda(16pG22-10):
    - PMT gain degradation & solution
  - **S. Kobayashi(16pG22-11):**
    - **MPPC PDE degradation measurement in 2019**
  - K. Ieki(16pG22-12):
    - Annealing effect on MPPC PDE
  - S. Ogawa(16pG22-13):
    - Detecter performance with reduced MPPC PDE
- Two presentations about lab tests of VUV-MPPC.
  - R. Onda(17aG22-7):
    - PDE degradation test at room temperature
  - K. Shimada(17aG22-8):
    - PDE degradation test at low temperature

# μ→eγ search

**Signal (μ→eγ)**

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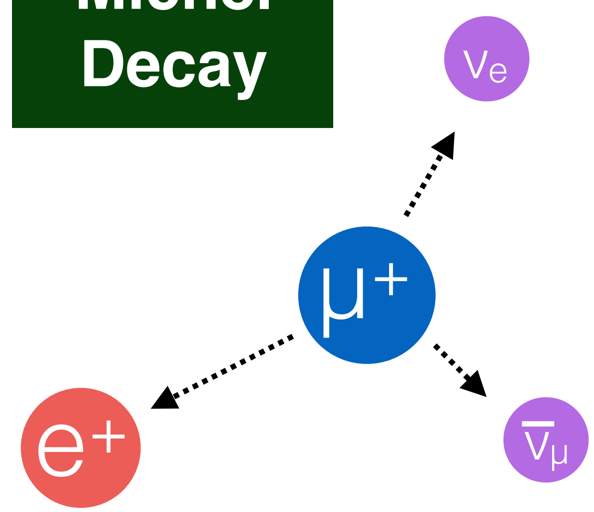
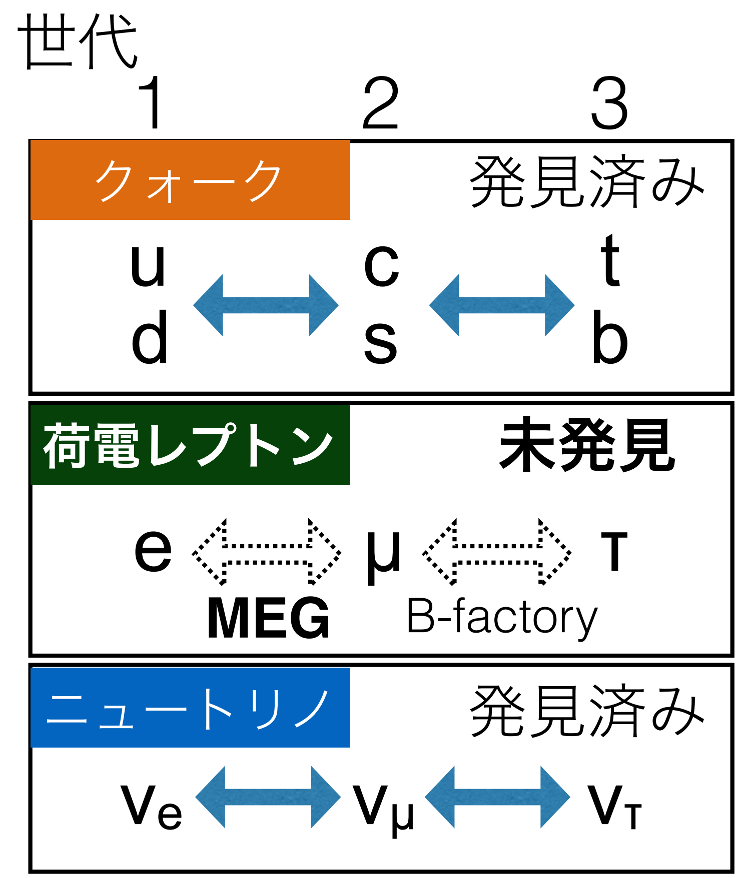
**Michel Decay**

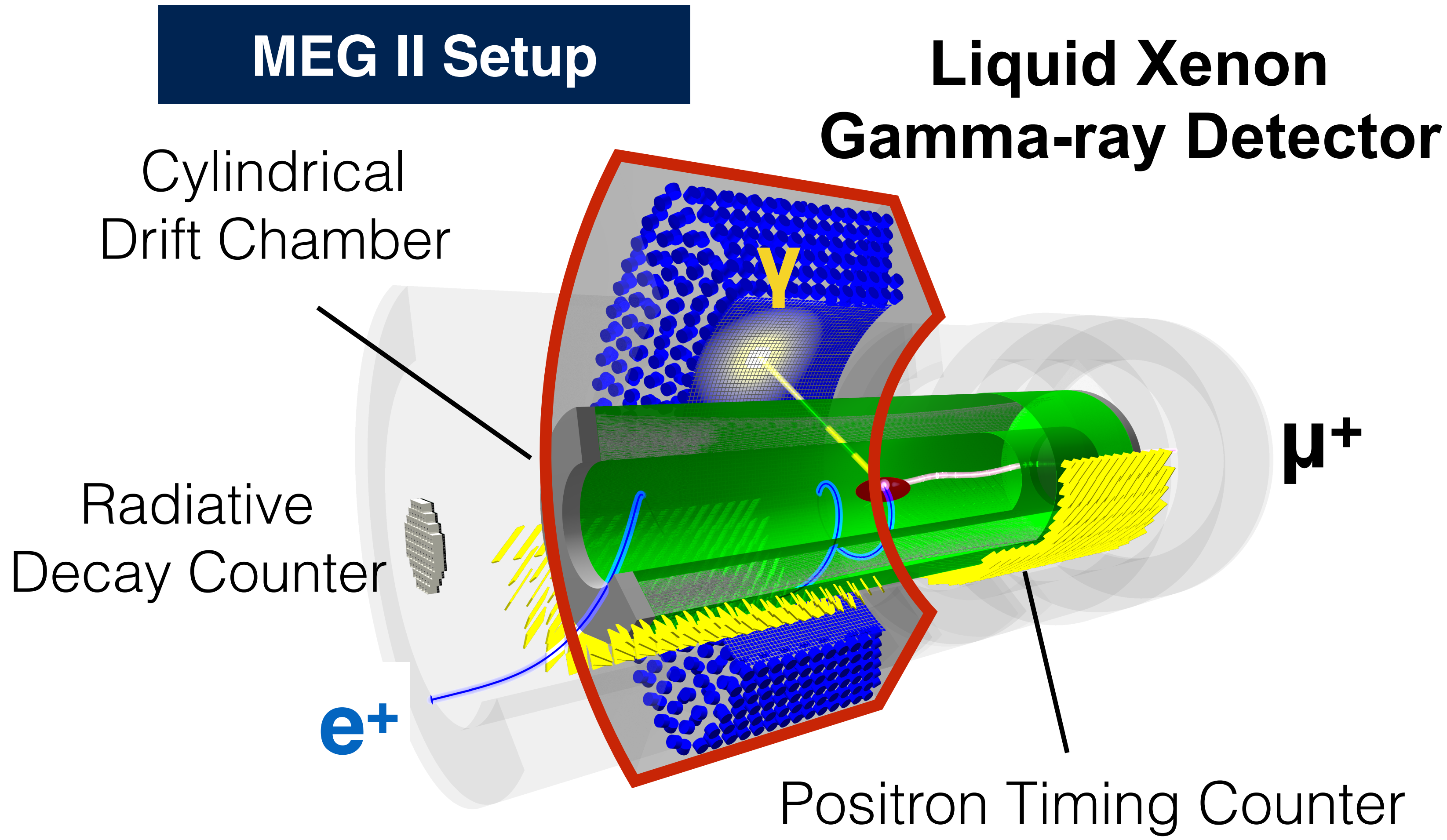



- Simultaneously emitted
- Back-to-back
- Same energy(52.8MeV)

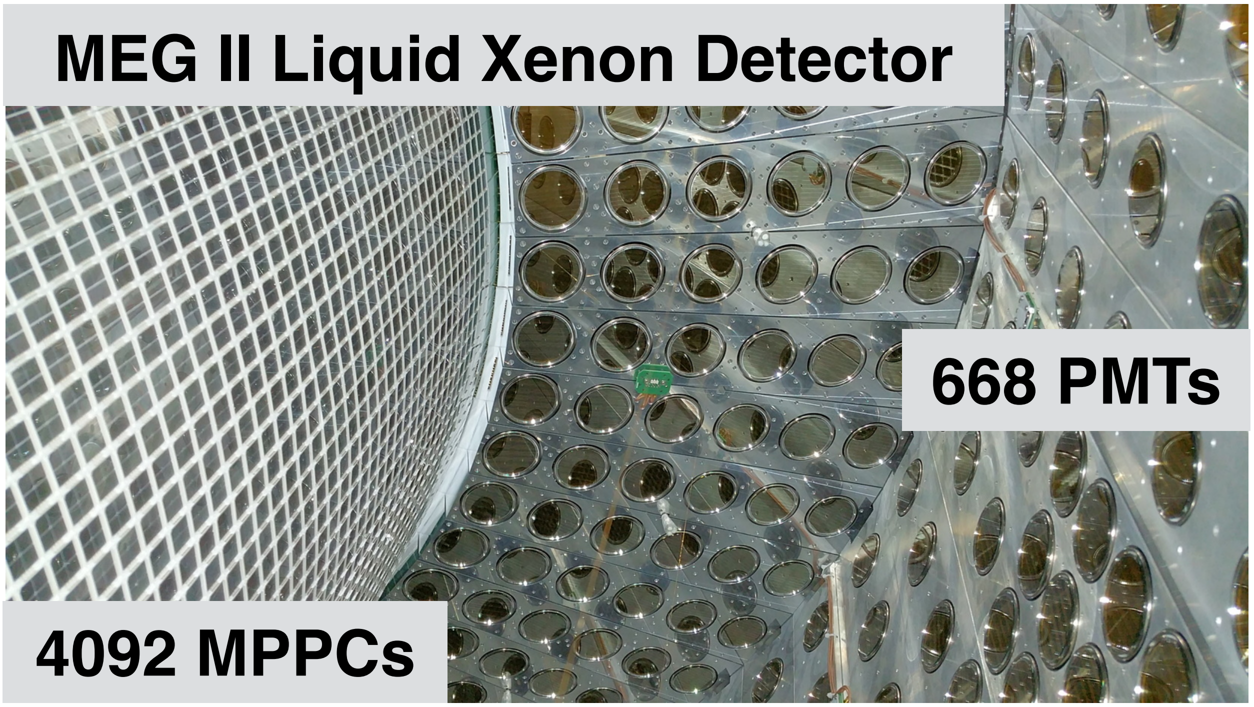
- μ→eγ decay is a lepton flavor violating decay.
  - **Almost forbidden** in SM+ν. oscillation(Br(μ→eγ)~$10^{-54}$)
  - **Predicted** in some theories(Br(μ→eγ):$10^{-11}$~$10^{-14}$)
- Current upper limit of Br(μ→eγ) is given by the MEG experiment.
  - **$4.2\times10^{-13}$** (90% C.L.)

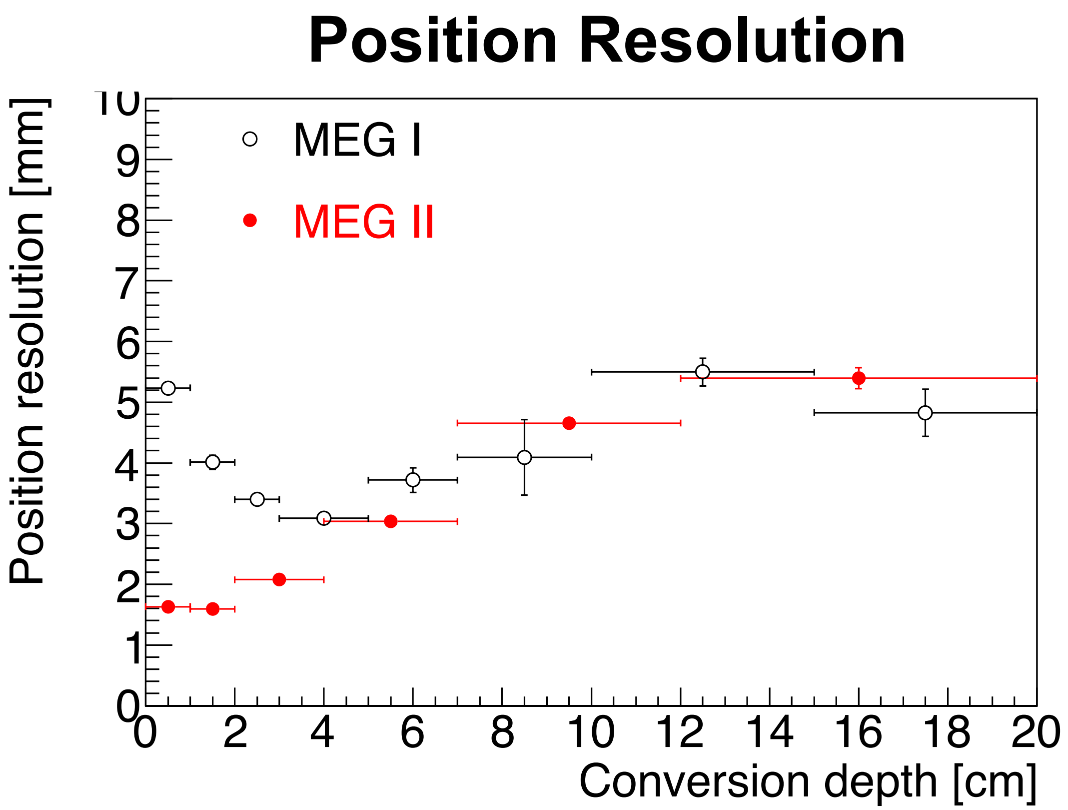
# MEG II Experiment




- MEG II will search for the μ→eγ decay with unprecedented sensitivity.
  - Goal: Br(μ→eγ)~$6\times10^{-14}$ in 3 years
  - Even **higher intensity muon beam**$(3 \times 10^7 \mu/s \rightarrow 7 \times 10^7 \mu/s)$
  - **Detector upgrade**( $\times\, 2$ improvement for each detector)
- Liquid Xenon gamma-ray detector measures position, energy and timing of the incident gamma-ray.

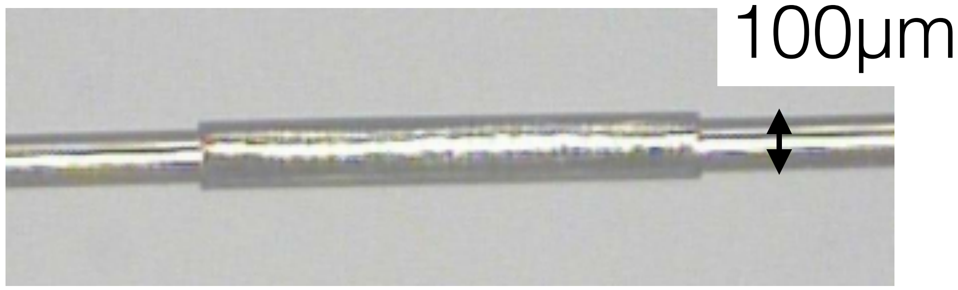
# Liquid Xenon Detector Upgrade



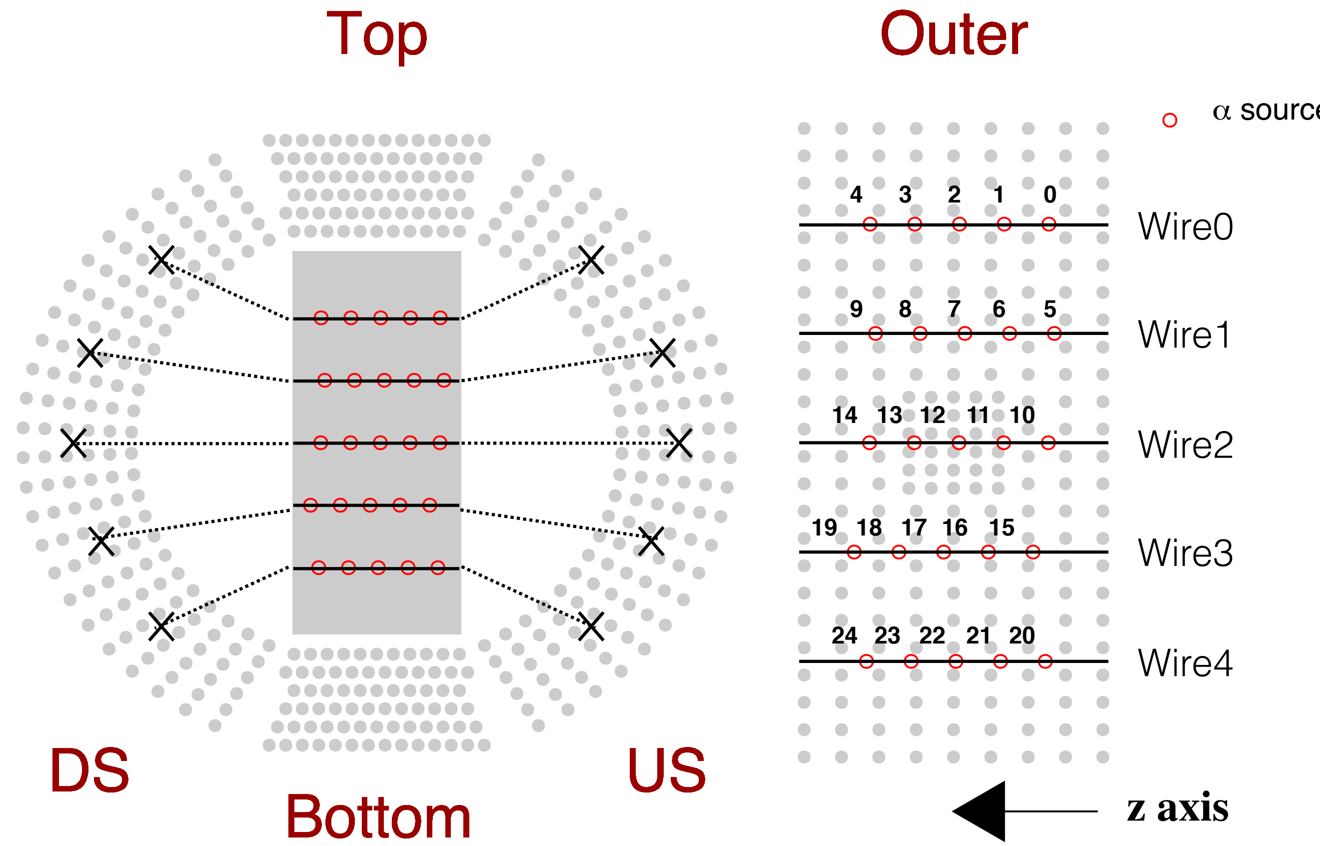




- 216 2-inch PMTs ⇨ **4092 12×12 mm² VUV-MPPCs**.
  - High granularity, uniform readout at the entrance face.
    - Position resolution: 5 mm → **2.5 mm**
    - Energy resolution: 2% → **1%**
- **Detector commissioning is in progress from 2017.**
  - The number of readout electronics is limited to 1/4.

# Calibration instruments


$^{241}$Am source mounted to wire




$$PDE_{data} = PDE_{MC} \times \frac{\overline{N_{pe,data}}}{\overline{N_{pe,MC}}} \times C_{LXe}$$

Detector Condition
- Light yield of LXe
- Absorption in LXe
- Reflection at walls

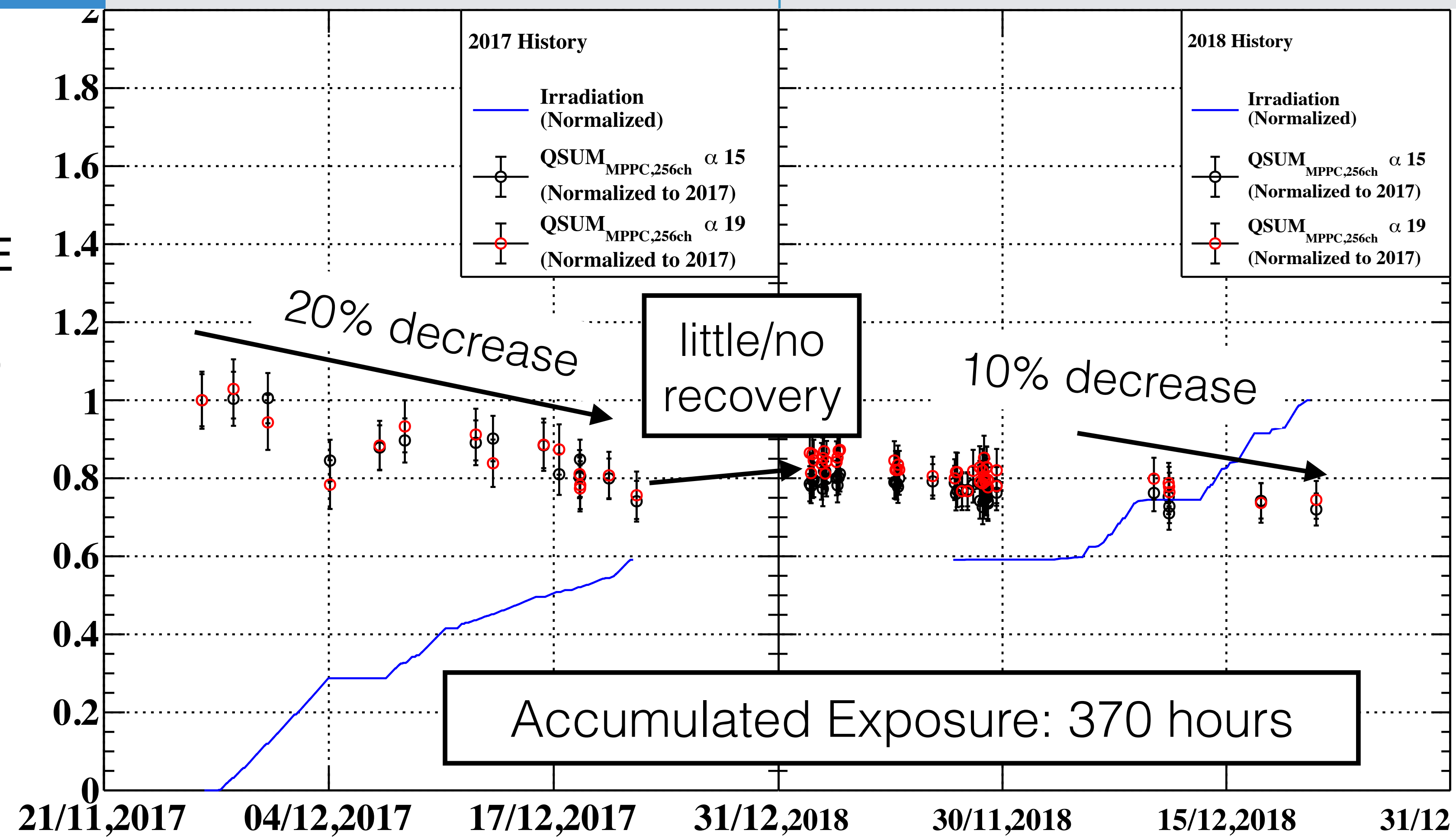
- LEDs($\lambda = 460$ nm) for calibration of gain and excess charge factor(ECF).
- 25 $^{241}$Am sources (5 wires × 5 points, 5.5 MeV α-ray) for PDE calibration.
- PDE for VUV light is estimated using MC simulation.
  - Detector conditions have to be taken into account.

# MPPC PDE history in 2017 and 2018

**Reminder**

| | 2017 | 2018 |
|---|---|---|
| **Exposure @MEG II Intensity ( $7 \times 10^7 \mu/s$ )** | 220 hours | 150 hours |
| **Total Decrease** | ~20% | ~10% |

Normalized MPPC PDE (Normalized at the beginning of 2017 run)

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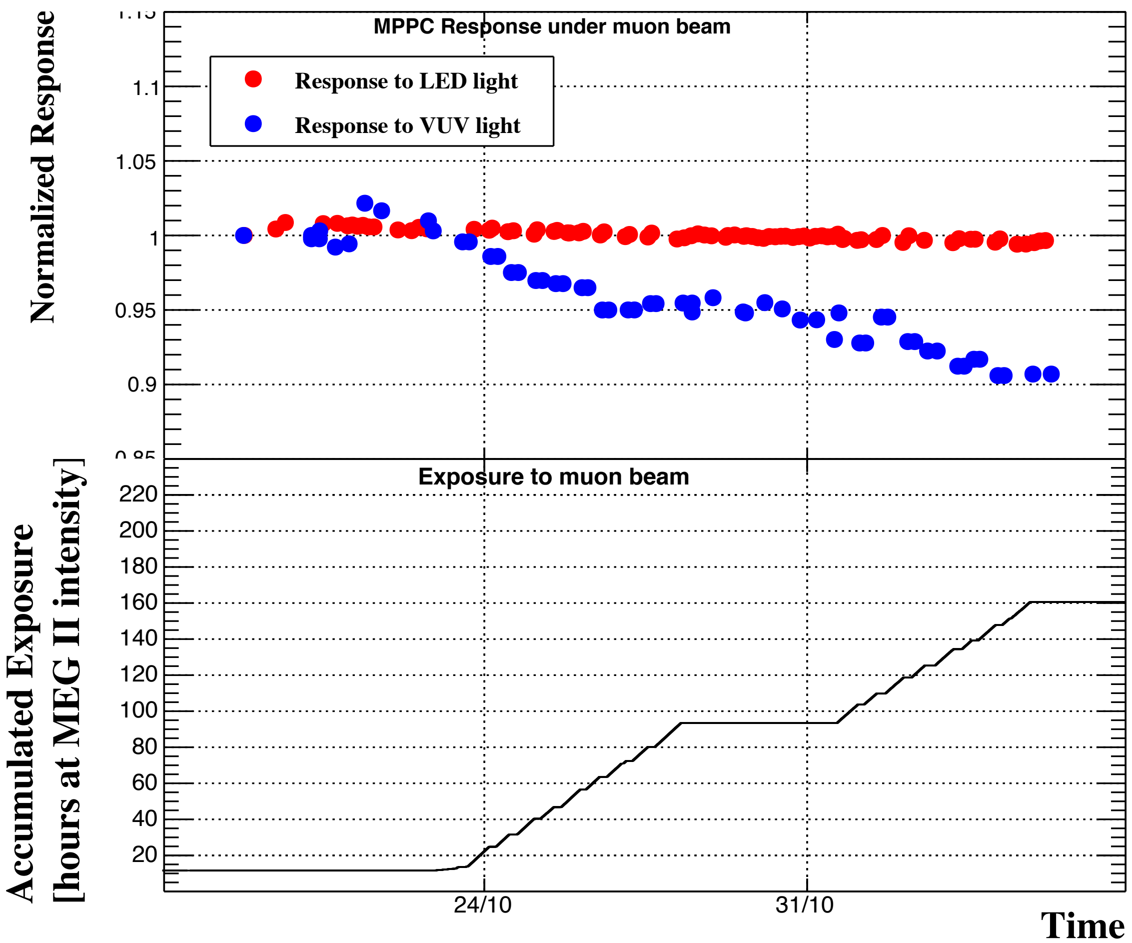
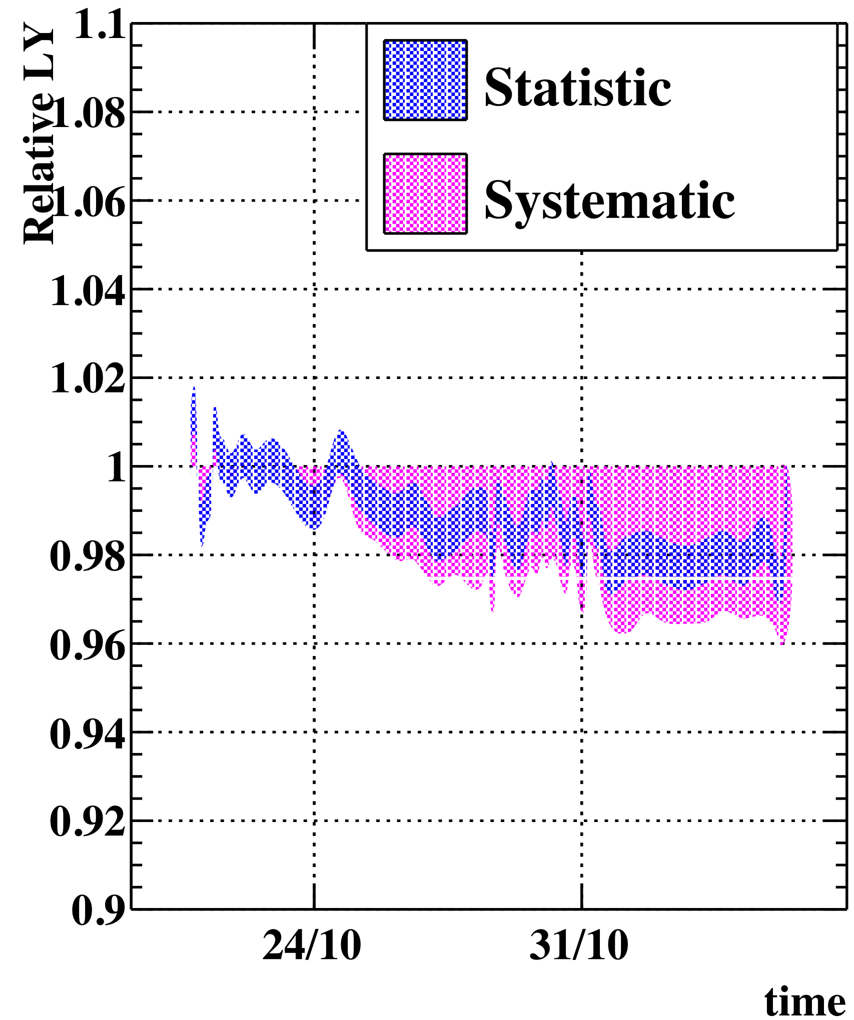
- Fast MPPC PDE decrease under high intensity muon beam was implied.

➡ Precise measurement on the deterioration rate was necessary.

# PDE History in 2019

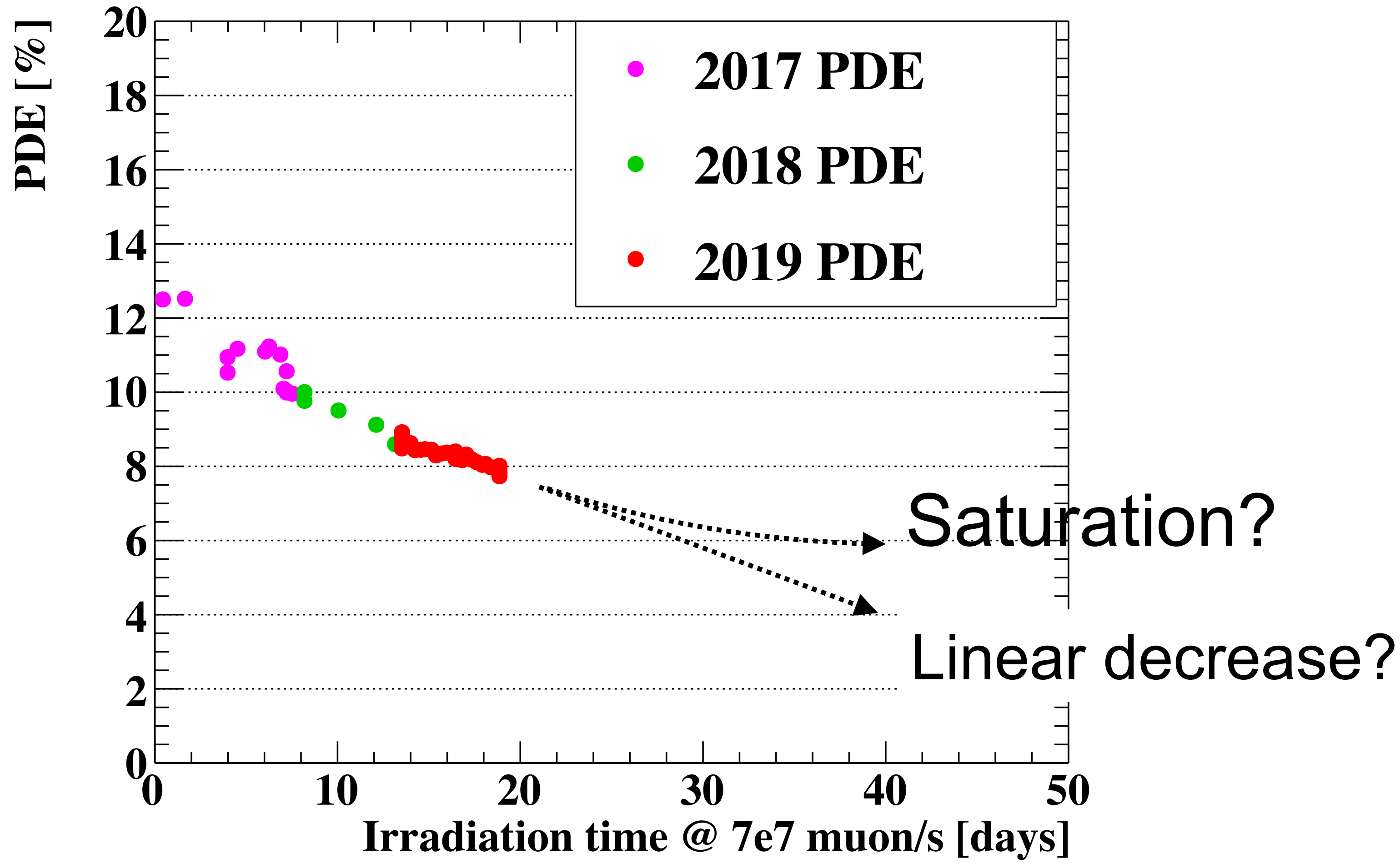



Relative Light yield of liquid xenon



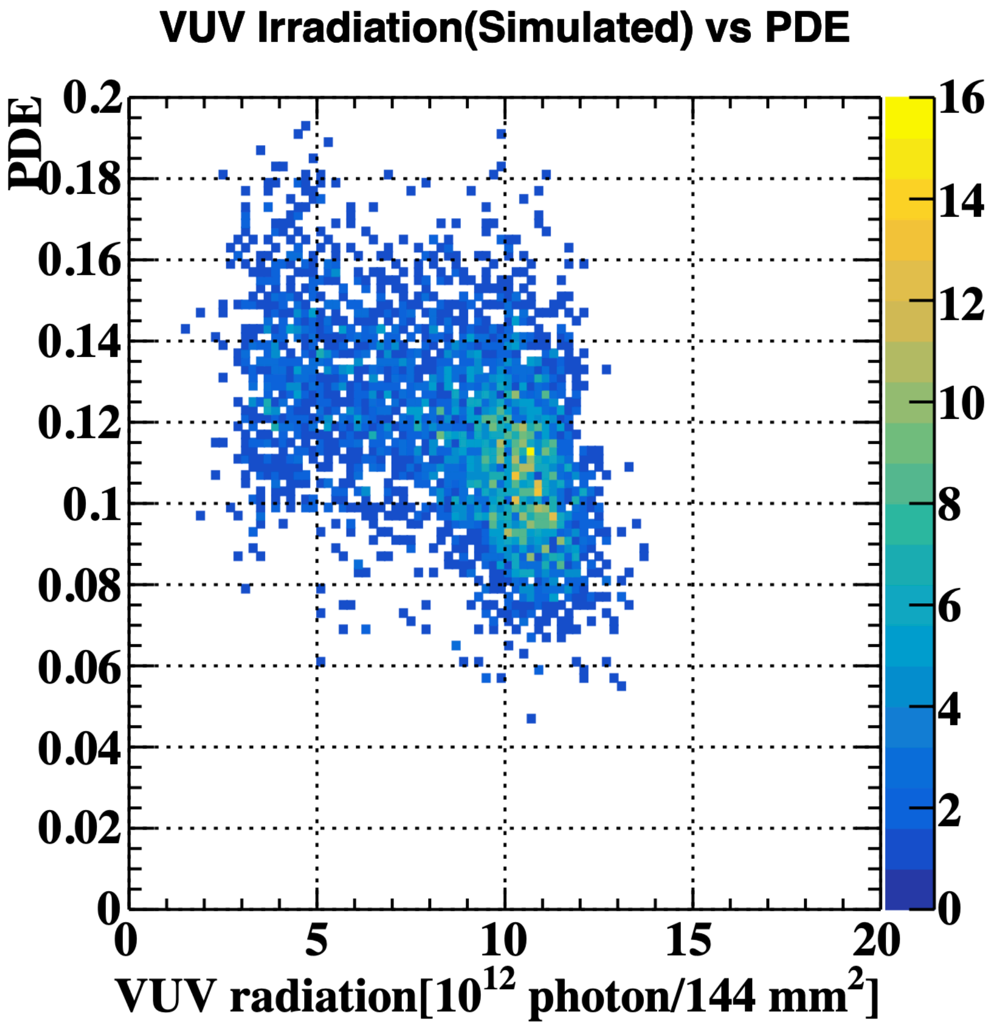

- **PDE for VUV light significantly decreased over time.**
  - 9(2)%/160 hours = 0.06(1)%/hour(@ MEG II intensity $7 \times 10^7 \mu/s$)
- Response for visible light from LEDs also decreased but only by 1%.
  - The product of gain, excess charge factor and PDE for visible light.
- Instability of light yield of liquid xenon does not account this decrease.
  - $2 \pm 2~\%$ decrease in 2019 run

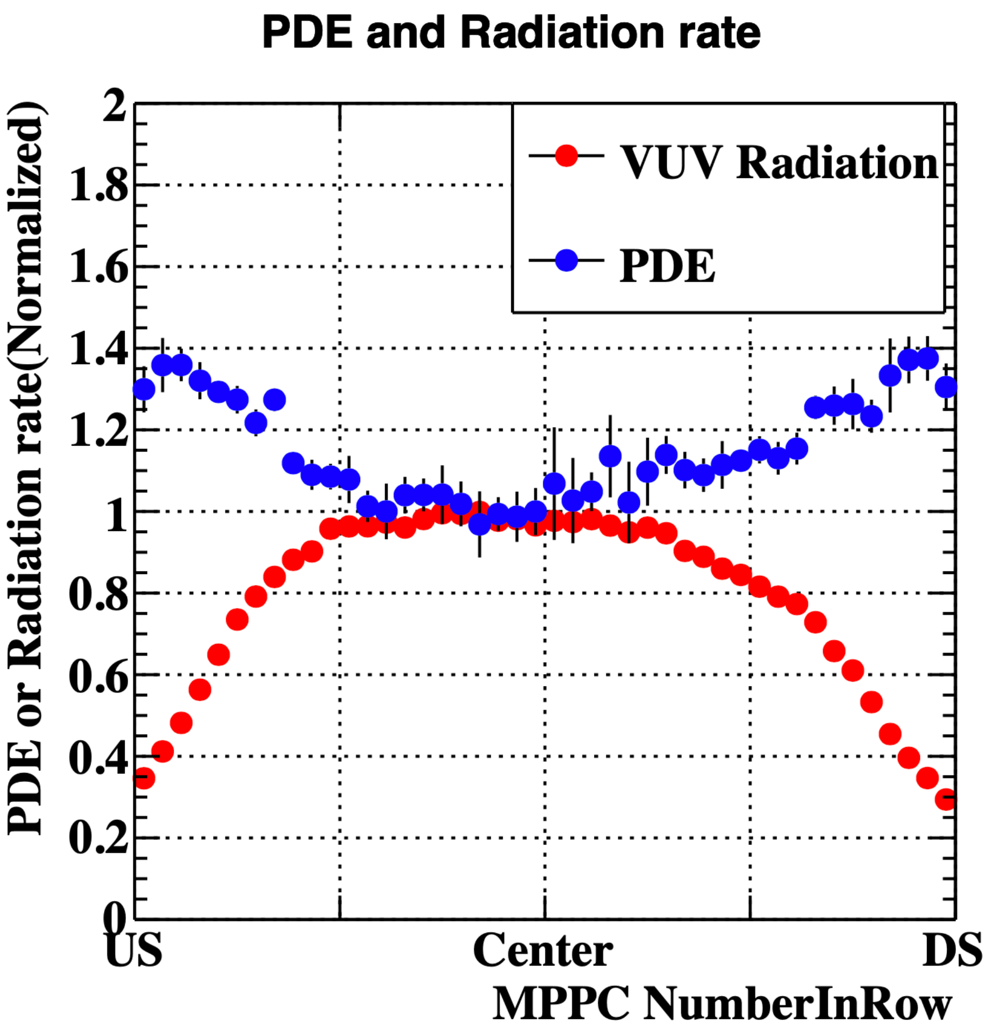
# PDE from 2017 to 2019




- VUV sensitivity decreased by relatively ~40% after 530 hours of beam usage.
  - **Very fast**: We were going to use $\mu$ beam for 140 days per one year.
  - MPPC PDE reaches zero in **70 days** when we assume linear decrease.
  - Lab test at room temperature indicates that PDE decrease saturates at 30%
    - (17aG22-7(R. Onda))
- A good news is that we found the annealing were able to recover PDE by 80%
  - (16pG22-13(K. Ieki)).
  - We are going to do the annealing when the PDE becomes too low to achieve a good resolution.

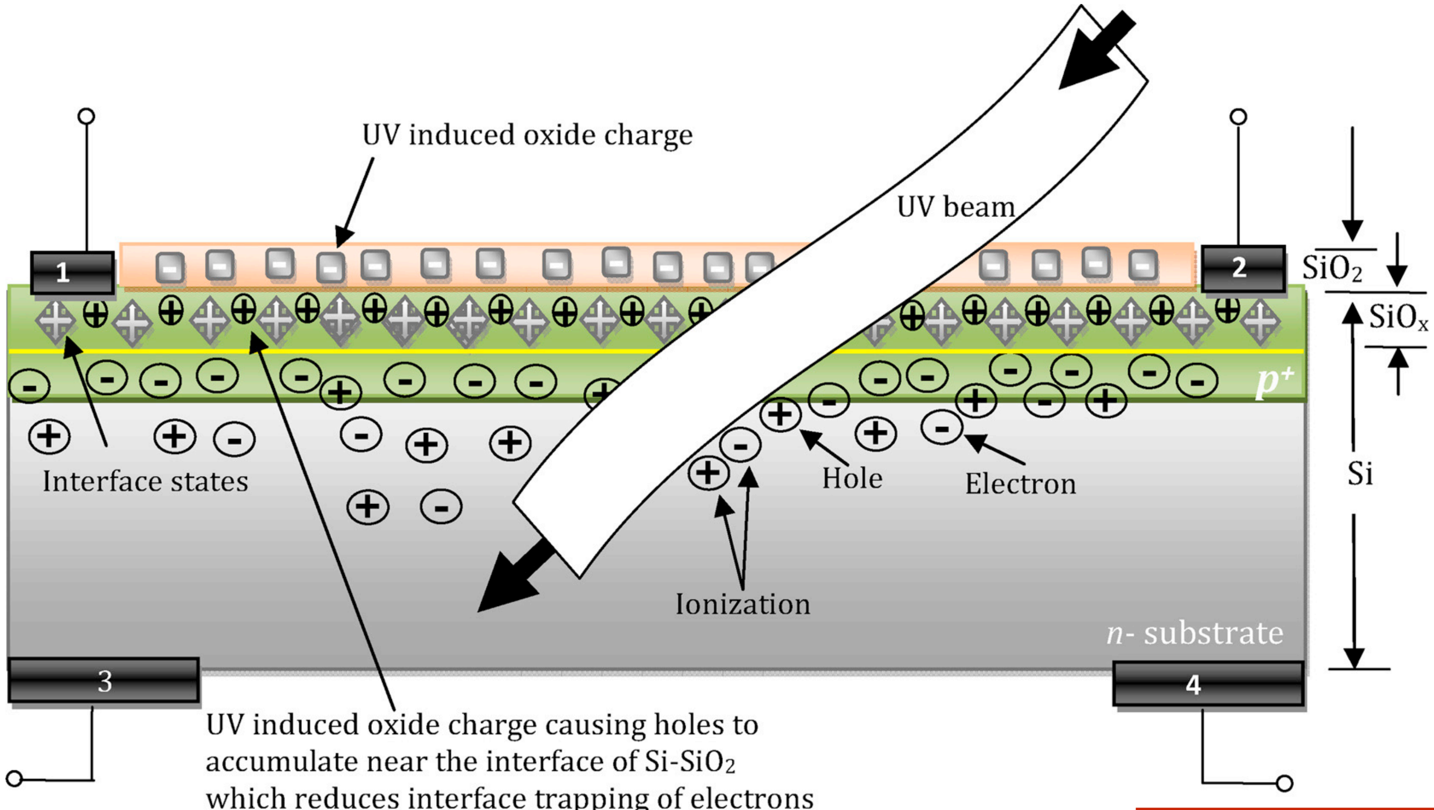
# Mass MPPC Test before 2019 run




- Right after 2018 run, we examined all MPPCs in order to confirm that almost all MPPCs are usable after two years of pre-engineering runs.
- **PDE was well correlated with the simulated VUV photon radiation dose**.
  - VUV photon irradiation seems to be a strong candidate of PDE decrease.
  - Other candidates: Gamma-ray or electron/positron

# Possible Reason of PDE Degradation




Brief flow of surface damage
1. Continuous VUV radiation.
2. Holes in SiO2 are trapped in interface states.
3. Enhanced recombination in the vicinity of the interface.
4. Decrease of quantum efficiency for VUV light.

Esebamen O, "Effect of UV radiation surface damage on silicon position sensitive photodetector"

- **Surface damage at the interface of Si-SiO2 is the most suspicious.**
  - Recombination in the vicinity of the interface is enhanced.
  - PDE for VUV light can be reduced.
  - Annealing should recover PDE by de-trapping of holes.
- VUV photon radiation in 2019: 5-6e12 photons(MC simulation).

# Summary

- MEG II liquid xenon gamma-ray detector has 4092 VUV-MPPCs.
- 2017 and 2018 commissioning data implied an **unexpected decrease of VUV sensitivity** of MPPC.
  - Not conclusive due to sparse monitoring.
- **Decrease of MPPC VUV sensitivity under high intensity muon beam was confirmed** in 2019 run.
  - 9(2)% /160 hours = 0.06(1)%/hour @ $7 \times 10^7 \mu/s$
  - Decrease of sensitivity for visible light was far smaller.
- VUV photon irradiation might be degrading MPPC PDE.
  - Correlation between PDE and radiation dose.
  - In 2019, $5 \sim 6 \times 10^{12}$ VUV photons after 160 hours.

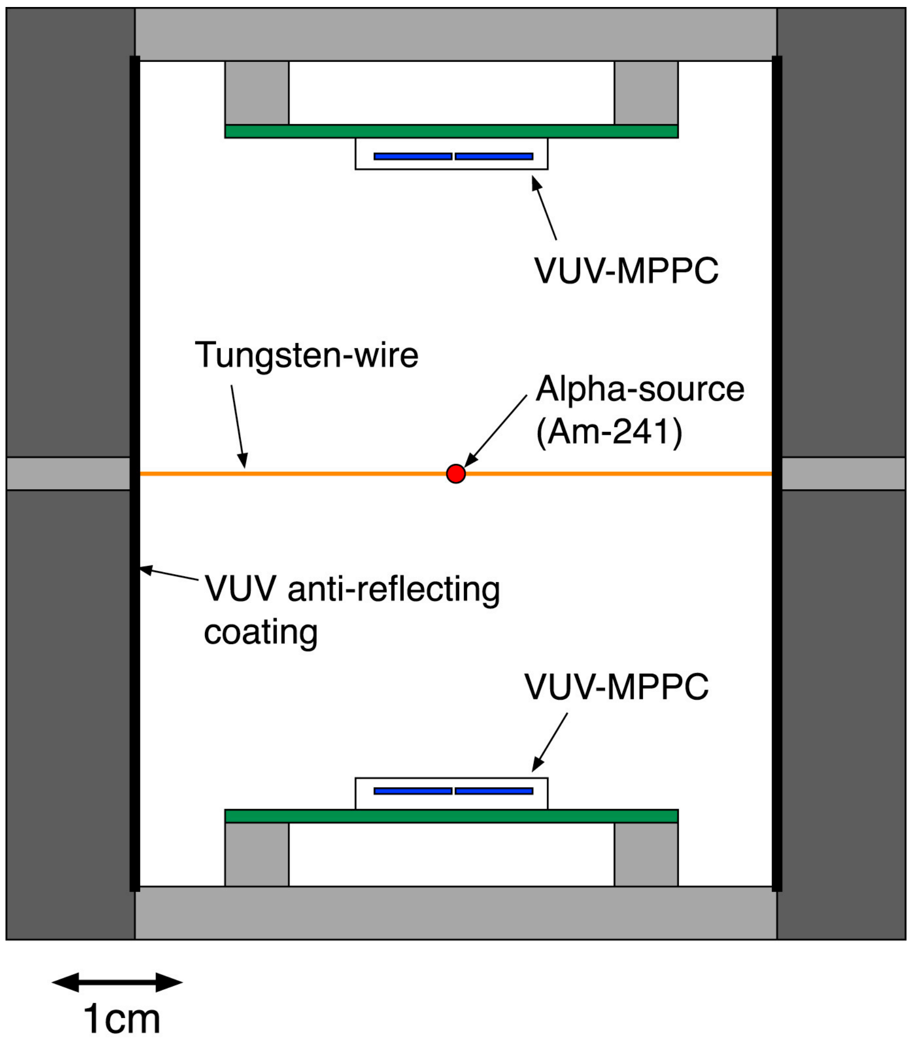
# Prospects

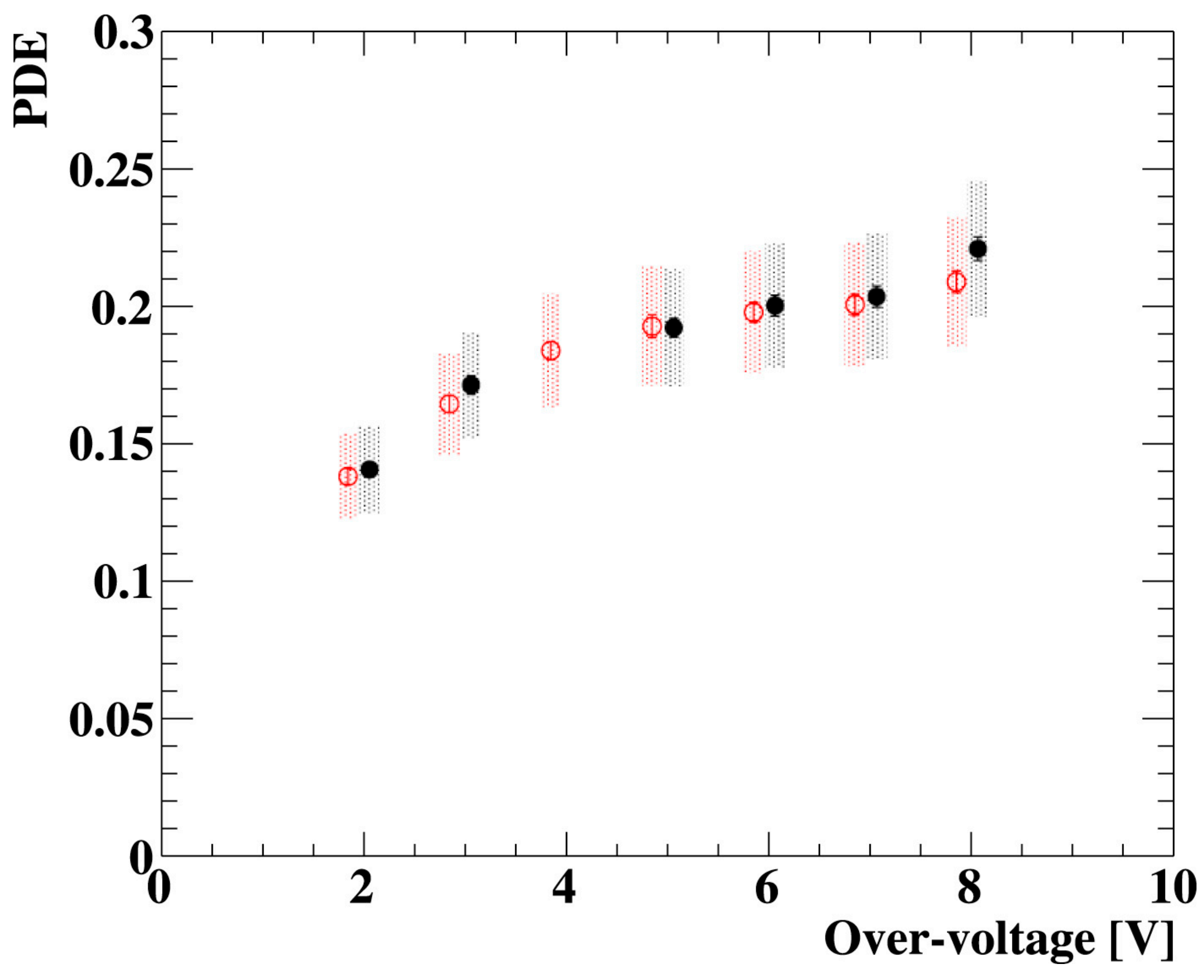
- Lab tests to reproduce and investigate PDE decrease.
  - Will the PDE decrease be saturated at some point?
  - Is VUV photon really the reason of PDE decrease?
  - 17aG22-7(R. Onda), 17aG22-8(K. Shimada)
- Optimization of annealing configuration.
  - HV, temperature, duration, etc…
  - 16pG22-13(K. Ieki)
- Simulation of detector performance with reduced sensitivity.
  - This determines how many times we should perform annealing in one year.
  - 16pG22-14(S. Ogawa)

# Back Up

**Thank you for your attention!!**

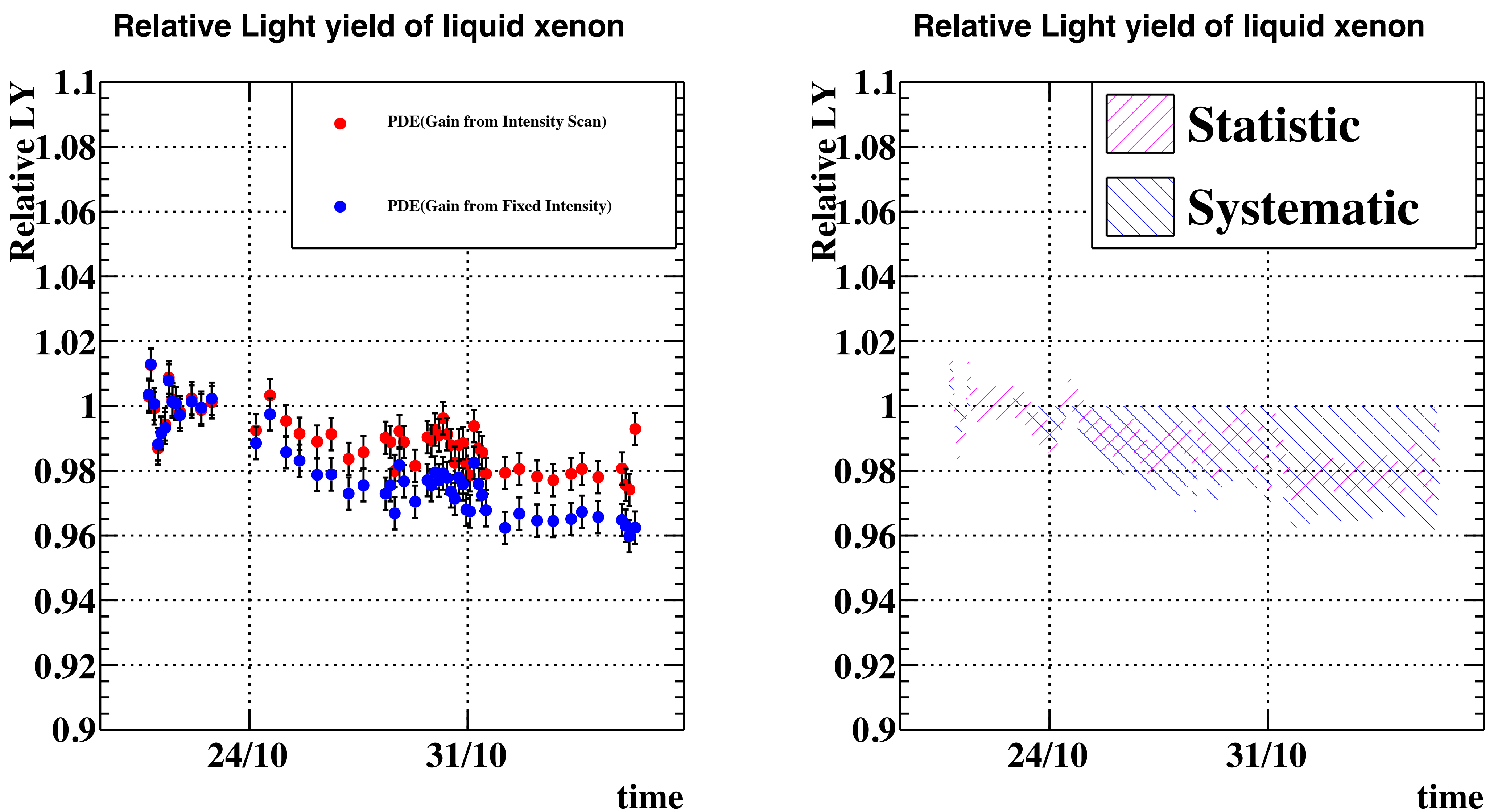
# VUV-MPPC for MEG II Liquid Xenon Gamma-ray Detector




- PDE of VUV-MPPC was measured to be ~20%.
  - ["Large-area MPPC with enhanced VUV sensitivity for liquid xenon scintillation detector "]

# Light yield monitoring in 2019




- Light yield of liquid xenon was measured using PMT.
  - From MEG's experience, we know that PMT QE is relatively stable.
- PMT Gain was monitored in two ways by LED.
- Alpha data indicated that the PMT response to VUV scintillation decreased by 2-4%.
- There are three scenarios depending on gain monitoring method and interpretation.
  - 0% or 2% or 4% decrease.
  - We use the intermediate scenario as the best estimate and use others for error estimation.