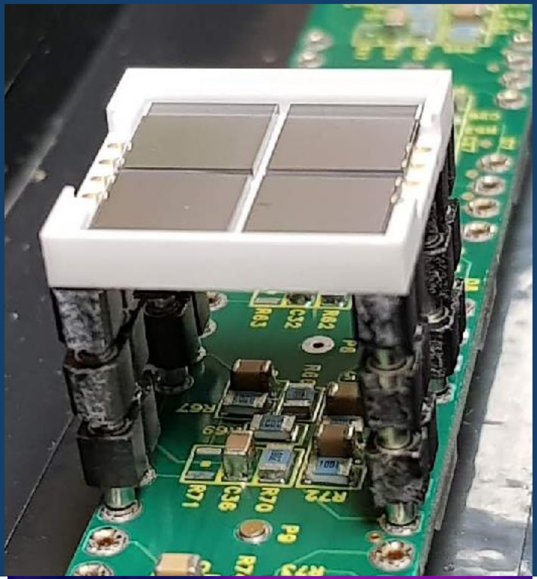
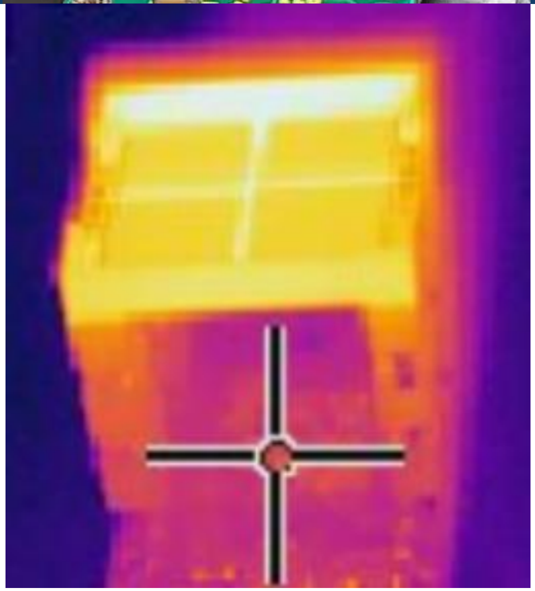
Annealing of MPPCs for MEG II liquid xenon detector





Kei Ieki
on behalf of MEG II collaboration

ICEPP
The University of Tokyo

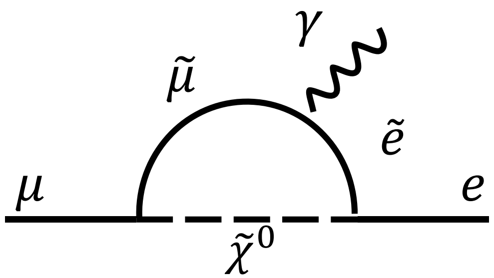
MEG II

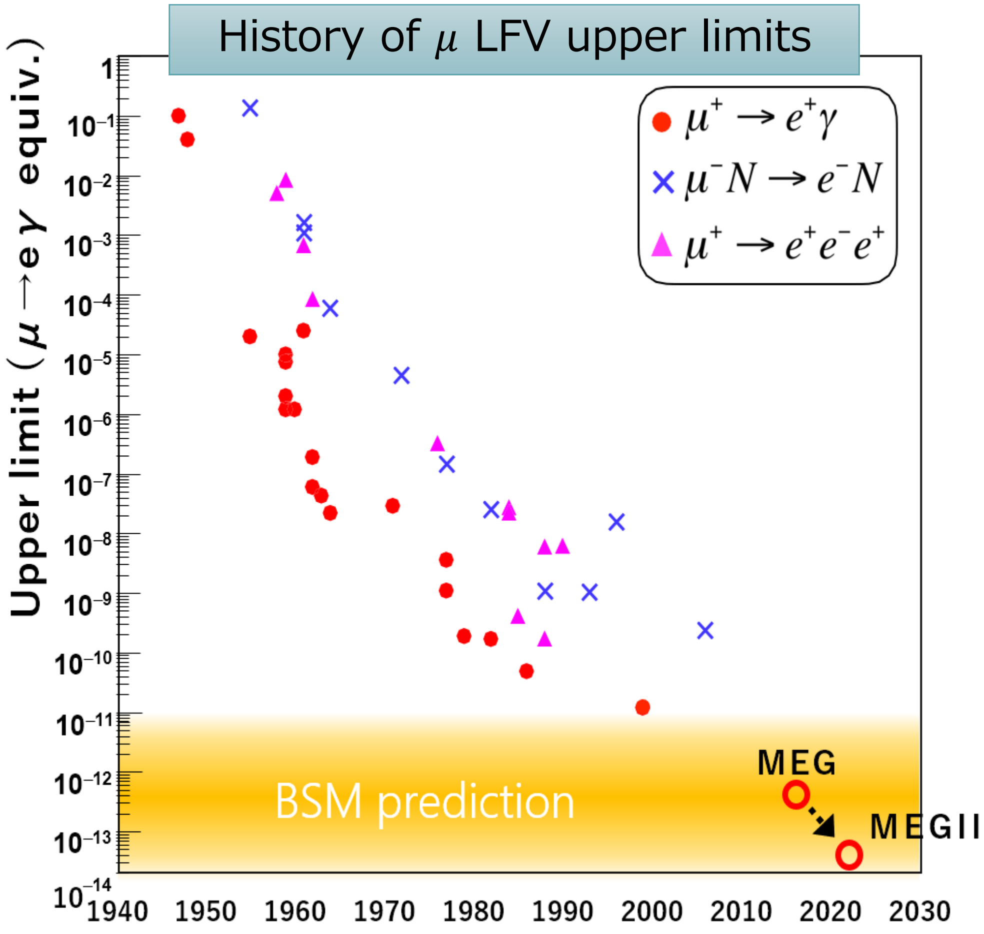
JSPS
Core-to-Core
Program

$\mu \to e\gamma$ search

MEG II experiment searches for cLFV decay, $\mu \to e\gamma$.

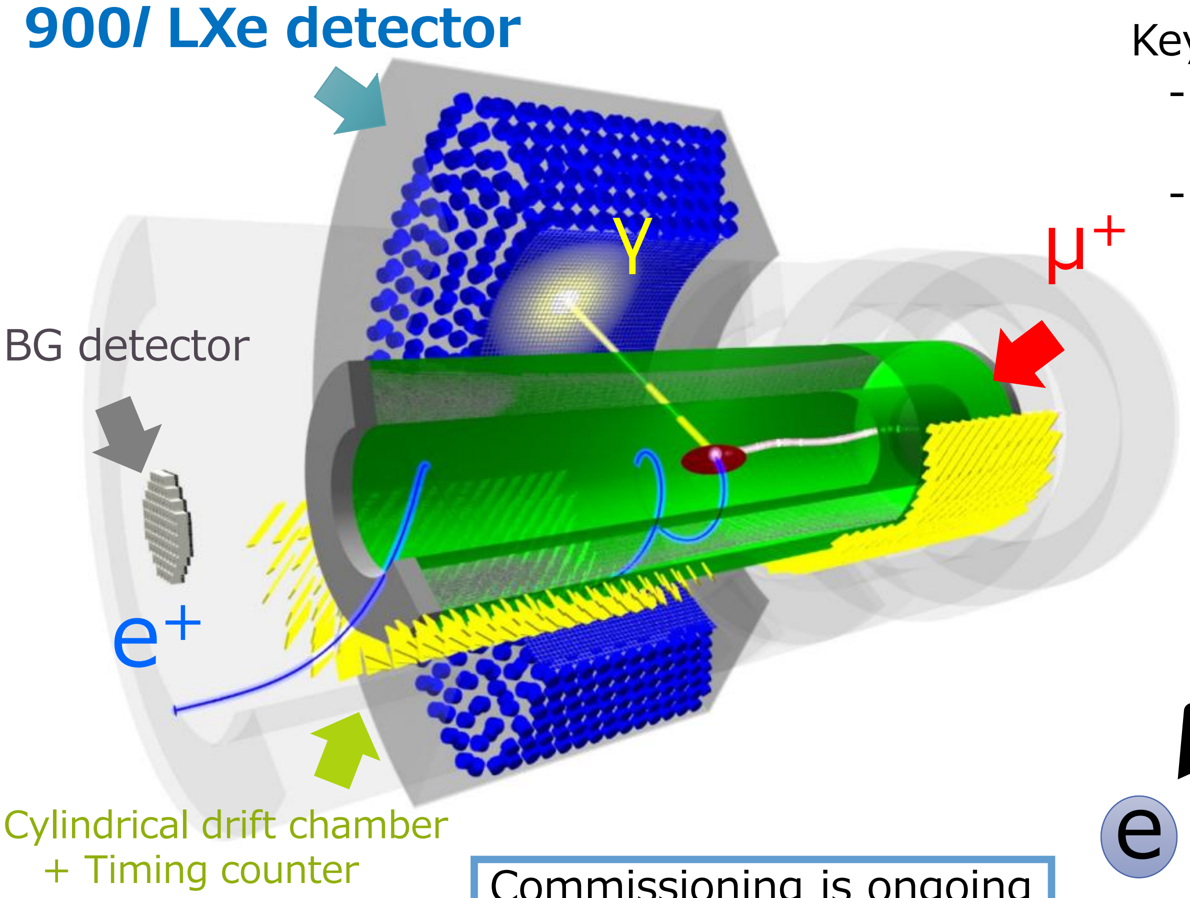
- Sensitivity goal: 6×10^{-14}
  (10 times better than MEG)
- BSM prediction : $O(10^{-14})$
  (e.g. SUSY-seesaw)





If $\mu \to e\gamma$ is found → Discovery new physics!

MEG II experiment

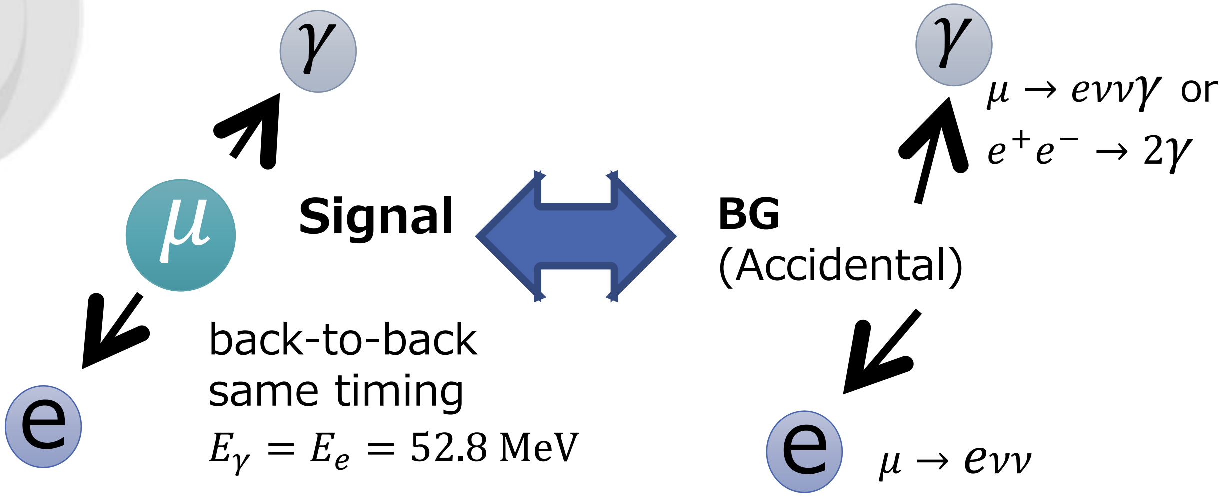


Commissioning is ongoing with all detectors

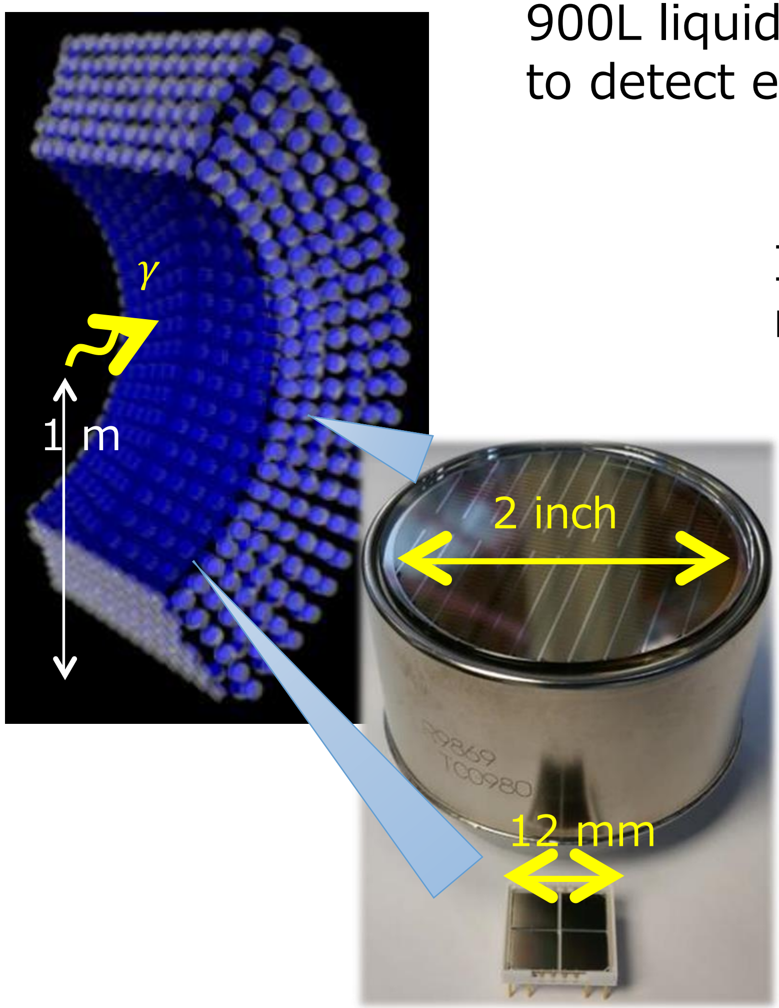
(w/ partial readout electronics)

Key concepts:
- **High rate** continuous μ^+ beam at PSI $(7 \times 10^7 \mu/\mathrm{sec})$
- **High resolution** detectors to distinguish $\mu \to e\gamma$ from accidental BG

both **x2** improve from MEG



Liquid Xe detector

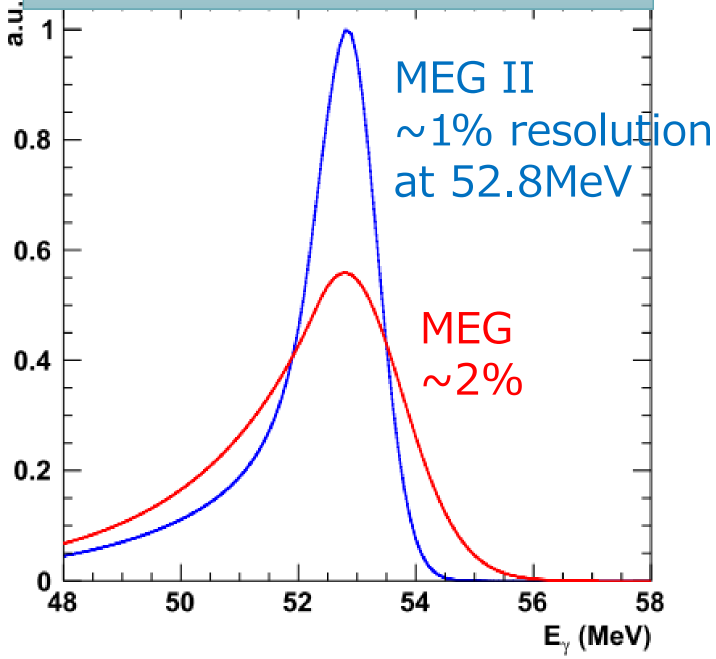


900L liquid Xe (LXe) scintillator
to detect energy, position and timing of γ

In MEG II, γ entrance face is replaced from
216 PMTs (2 inches)
to 4092 MPPCs (12x12 mm^2)

Light collection uniformity and granularity improved!
→ x2 energy and position resolution improvement expected

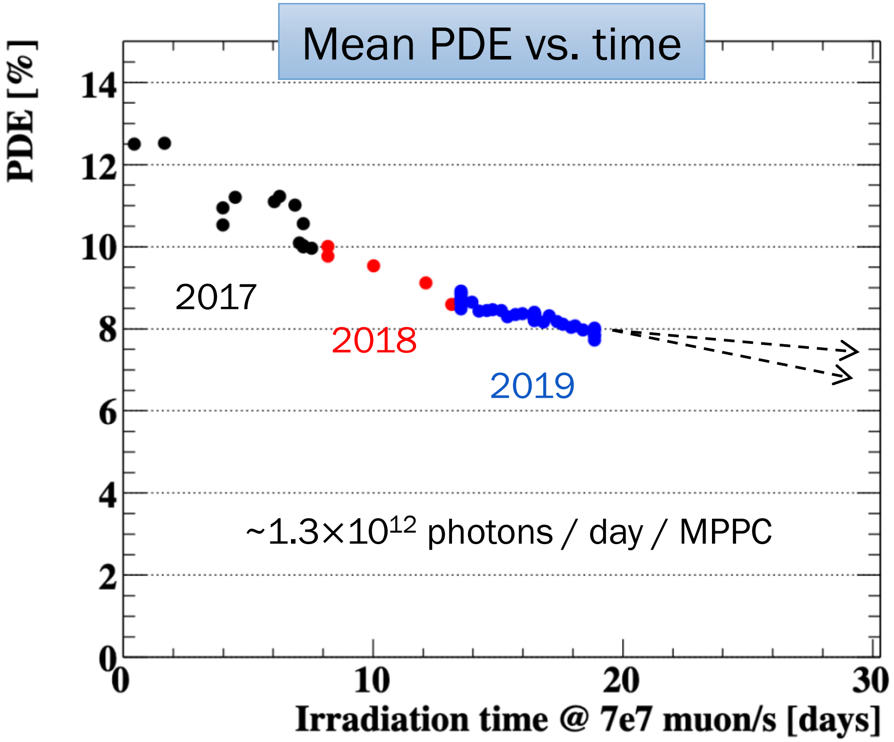
γ energy distribution (MC)

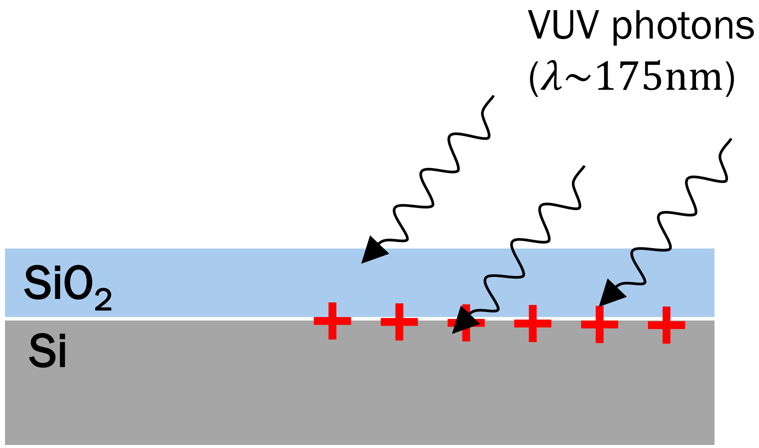


PDE degradation problem

Decrease of MPPC PDE was observed while commissioning with γ from $\mu \to e\nu\nu\gamma$.

→ surface damage by VUV light from LXe scintillation?





Accumulation of holes near SiO_2-Si interface

→ reduction of carrier collection efficiency

Similar phenomena is known for UV photo diode.

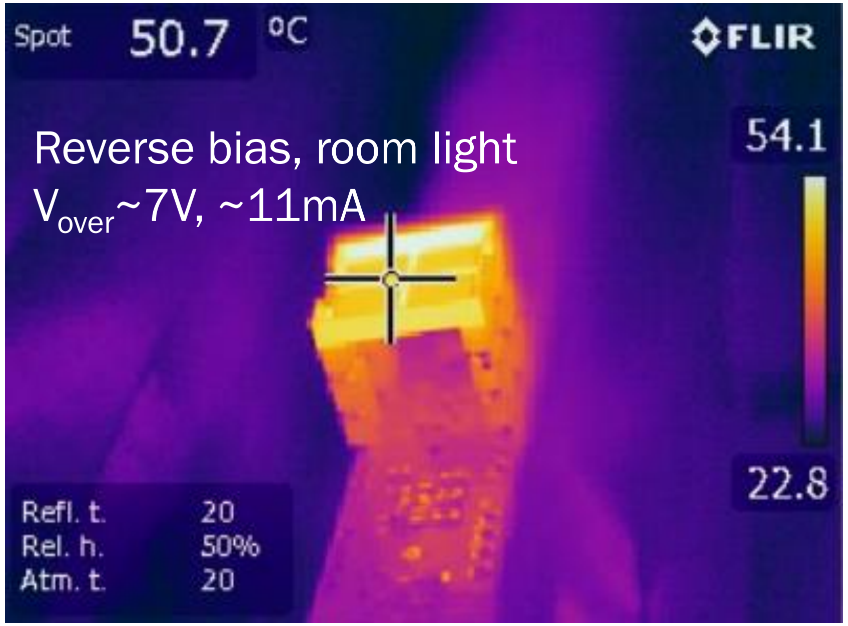
Possible solution: annealing

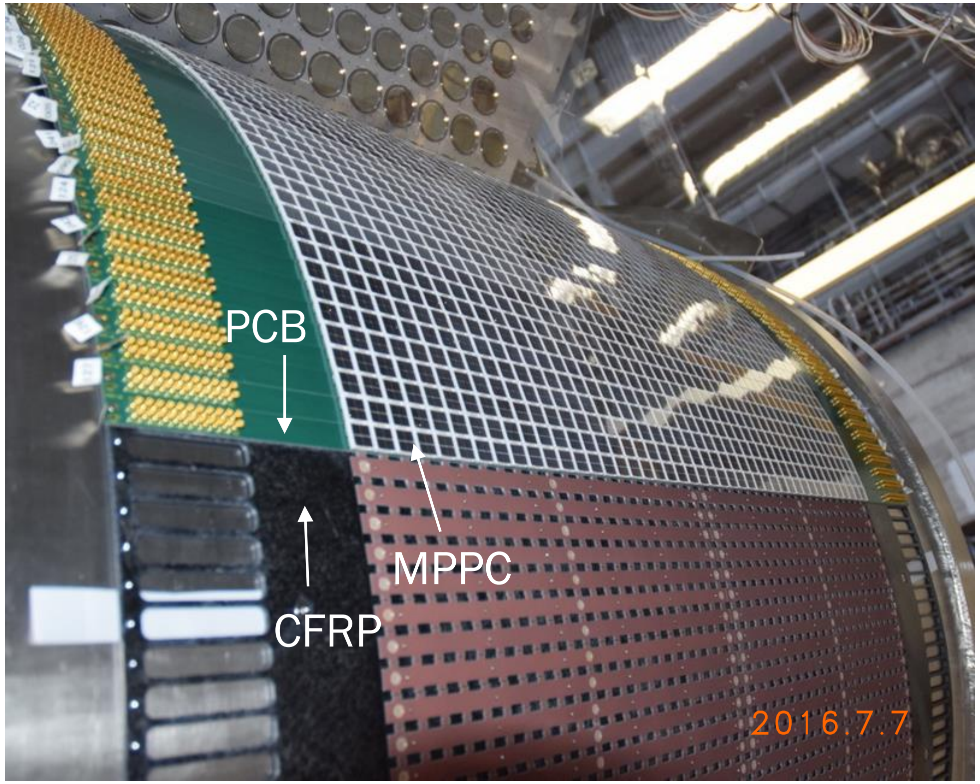
Accumulated charges can be removed by **annealing (heating).**

→ Generate Joule heat by applying reverse bias on MPPC under light
(We need special HV source to apply high current.)

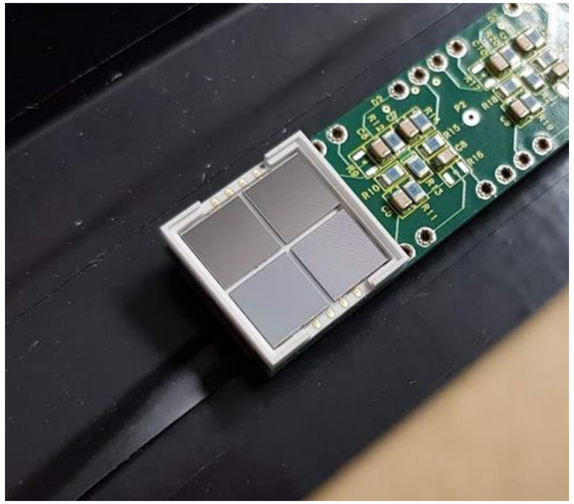
We should not exceed temperature limits:

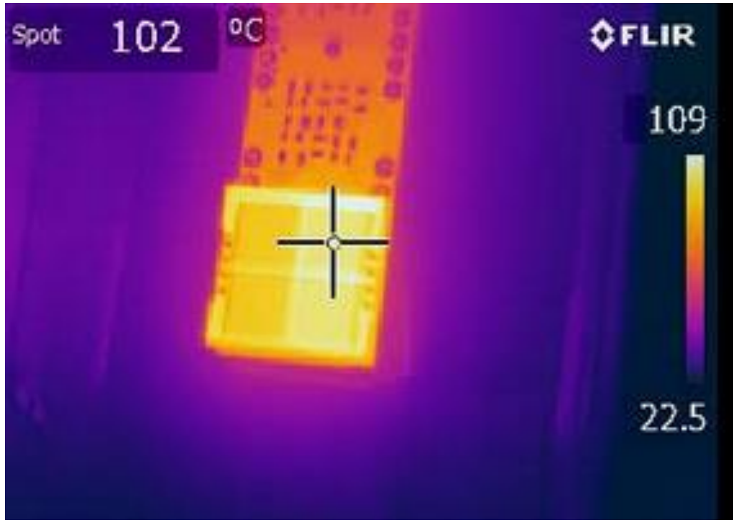
- MPPC 100 deg.
- PCB 120 deg.
- **CFRP 45 deg.**
- Glue 65 deg.





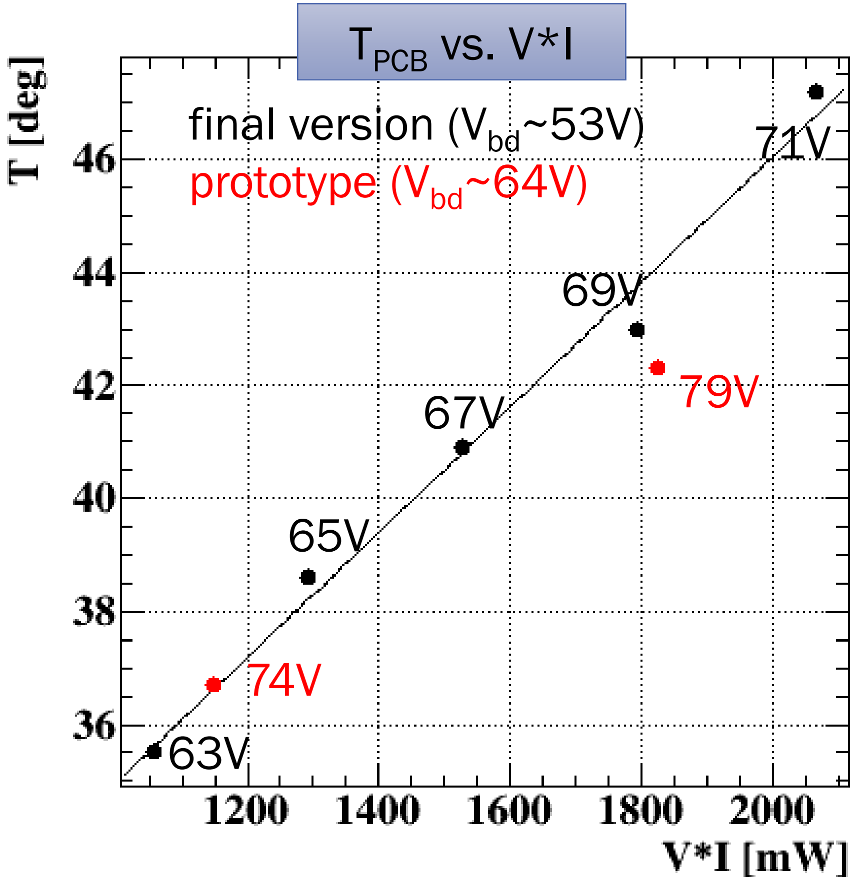
Lab. tests

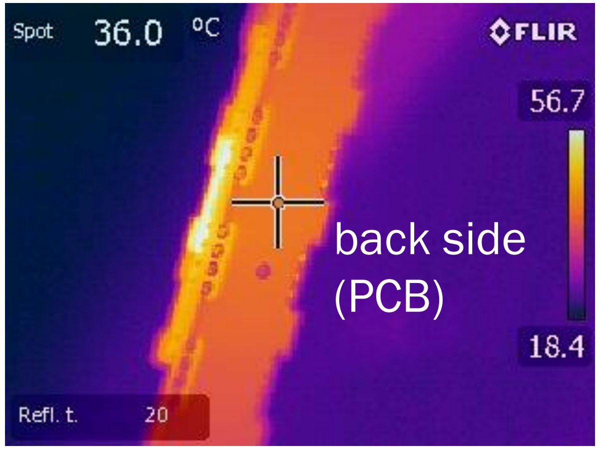


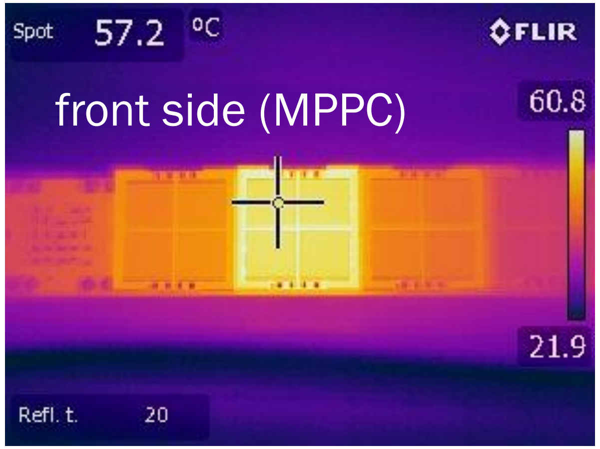


How much voltage can we apply?

PCB temperature should not exceed 45 deg. → How much V,I can we apply?





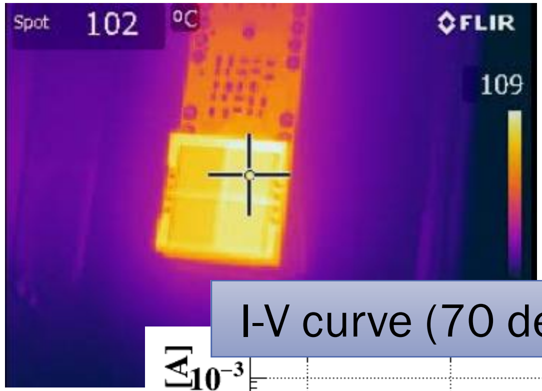


- Temperature and V*I have roughly linear relationship.
  → **V should be below ~70V** to keep backside of PCB below 45 deg. T_{MPPC} is around 70 deg.
- **Adjacent channels are also heated** to T_{MPPC}~45 deg.

Does heating cause any damage?

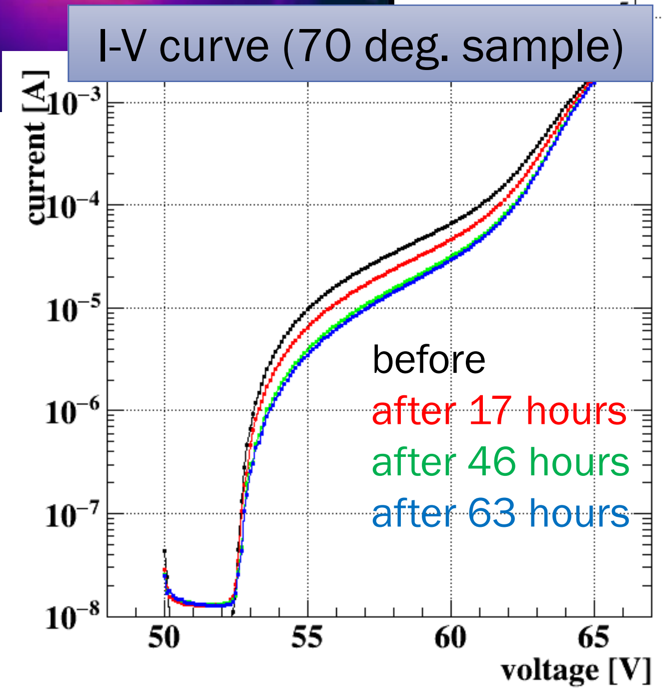
We applied reverse voltage V_{over}=12-22V under room light with three spare MPPCs

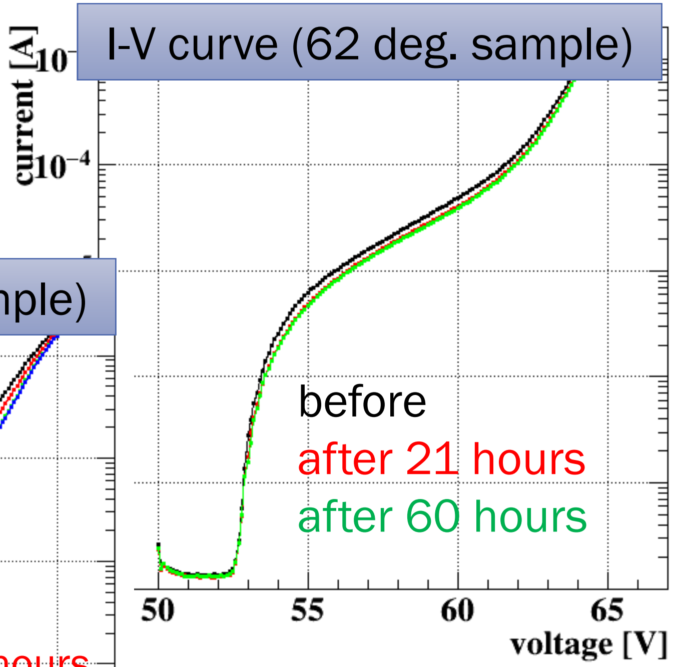
- 20-100deg (several hours)
- 70deg, 63 hours
- 62deg, 60 hours



Then we tested the performance:

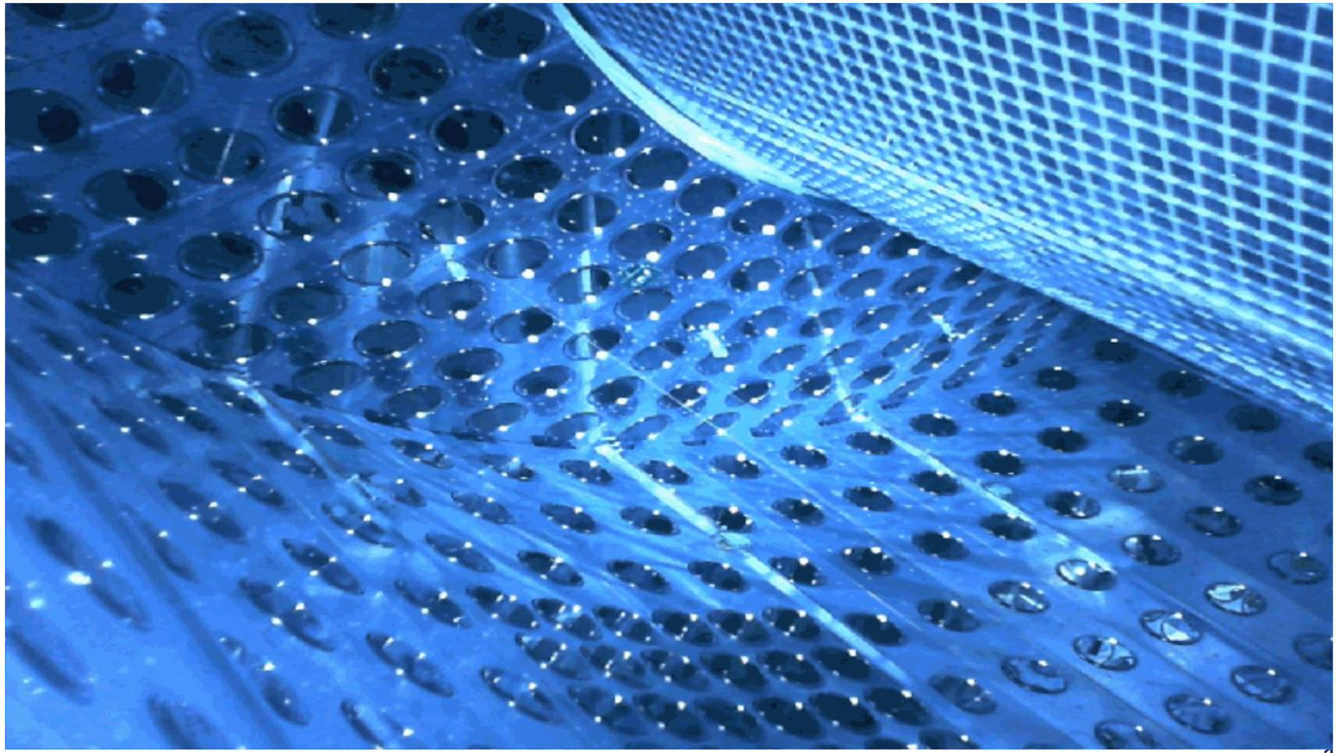
- I-V curve measurement (all samples)
  → **Current reduced for 62 and 70 deg., samples, while it increased for 100 deg.**
- Gain, crosstalk + afterpulsing, dark rate measurement (62 deg. sample)
  → **Gain, crosstalk + afterpulsing did not change. Dark rate reduced by 15%.**





No performance degradation
except for 100 deg. sample

Annealing of installed MPPCs

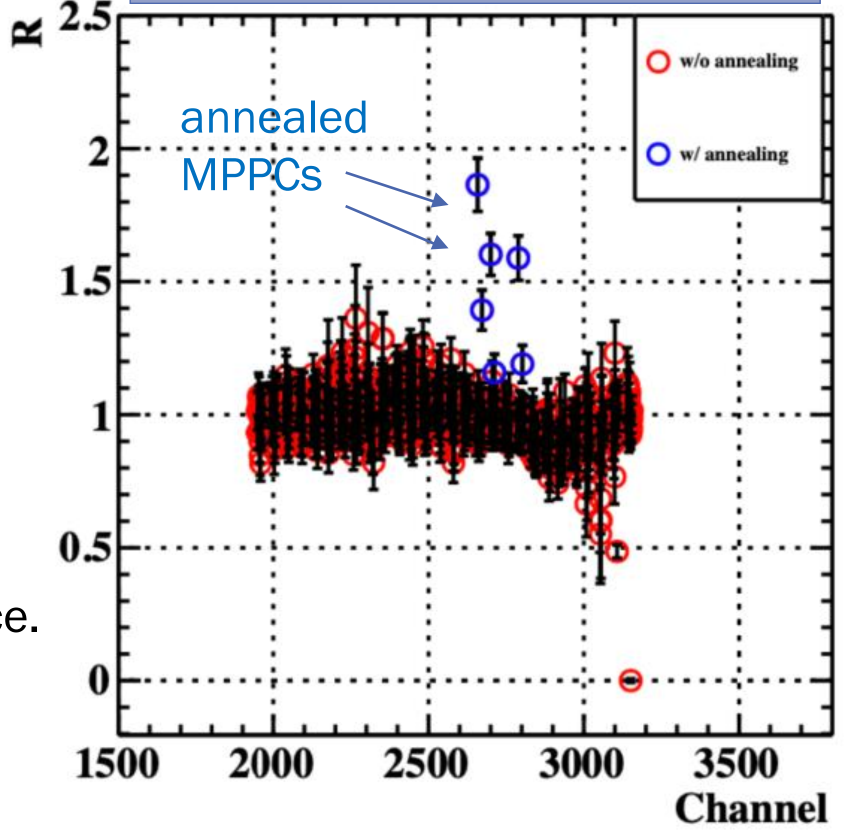


Annealing test for installed MPPCs

In 2019, we **annealed 7 MPPCs in cryostat** before filling LXe.
LEDs inside the cryostat were used as light source.

MPPC	Current [mA]	Time [hr]	PDE [%] 2018	PDE [%] 2019	Recovery
2763*	20	22	-	-	-
2672	19-20	23	9.12	12.7	1.39
2802	17-19	23	8.03	9.56	1.19
2712	19	23	8.44	9.78	1.16
2789	19-24	38	8.37	13.3	1.59
2700	20-24	38	9.18	14.7	1.60
2658	21-24	38	7.21	13.4	1.86

PDE_{2019}/PDE_{2018} vs. channel ID



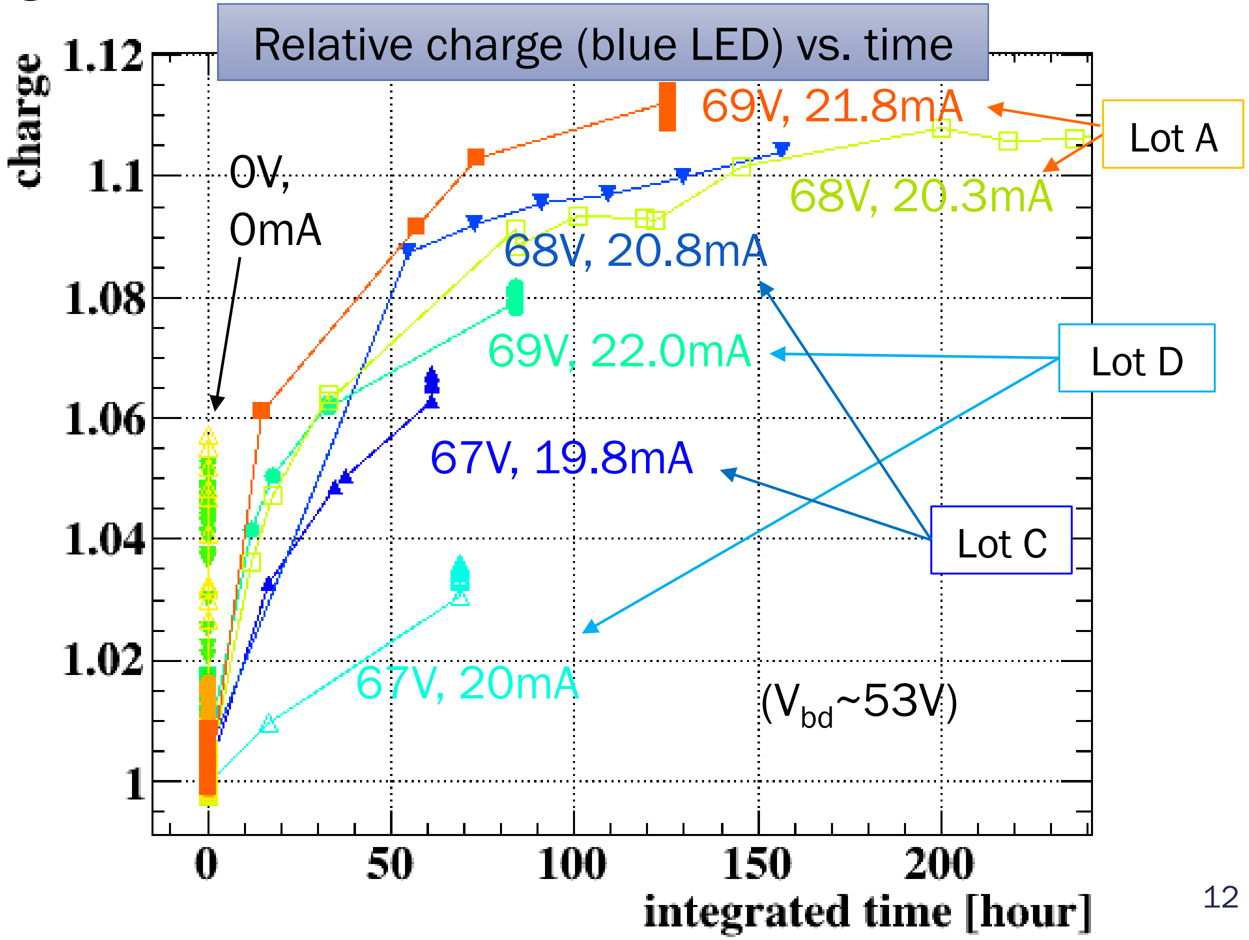
- In LXe, PDE was measured with VUV light from α source.
- **Increase of PDE was observed (up to 80%)!**
  Large current applied → large PDE increase
- **Response to blue LED also increased (up to 13%).**
  → VUV PDE can be monitored with LED w/o filling LXe

Annealing speed measurement

In 2020, we measured annealing speed at different voltages.
→ Investigate optimal condition for annealing.

- Response to blue LED was monitored instead of measuring VUV PDE.
- **Annealing speed is found to depend on voltage and production lot.**
- **MPPC at 0V, heated to ~40 deg. by neighbor channel, was also annealed.**

➡ It might be safer and efficient to do annealing with warm (<45 deg.) gas.



Summary

- MPPC PDE decrease was observed in MEG LXe detector.
  We suspect surface damage by VUV light.

- PDE can be recovered by annealing (heating). We can heat the MPPC by applying reverse bias under LED light.

- In lab. test, no damage on the MPPC performance was observed up to ~70 deg. Reduction of dark current was observed.

- Some of installed MPPCs are annealed, and we observed increase of VUV PDE up to ~80%. Speed of increase seems to depend on voltage and production lot.
  It might be safer and more efficient to heat by warm gas.

Related talks

- 16pG22-11 (S. Kobayashi)
  More detail of measurement of PDE decrease under muon beam
- 16pG22-13 (S. Ogawa)
  Effect of PDE decrease on detector performance
- 17aG22-7 (R. Onda), 17aG22-8 (K. Shimada)
  Reproduce PDE decrease with Xe flash lamp, with room and low temperature

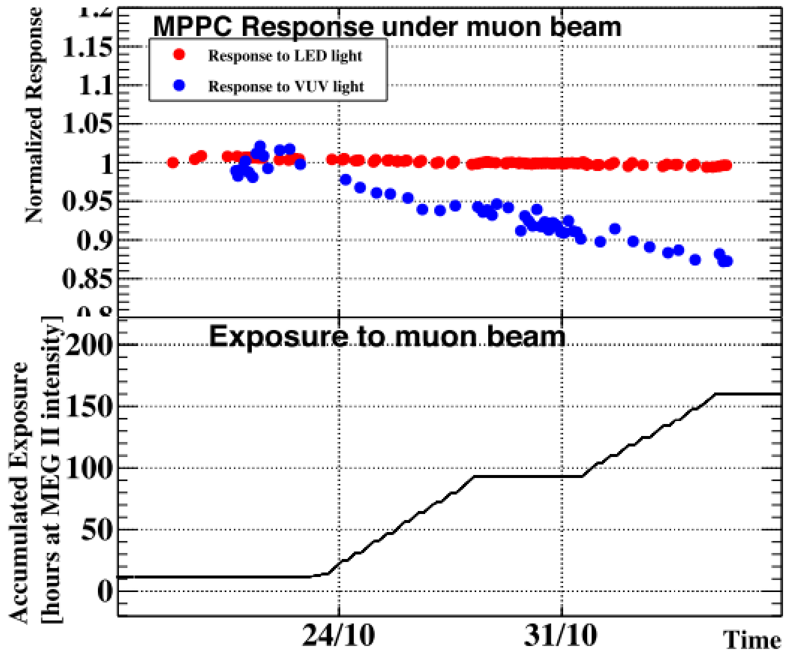
Backup slides

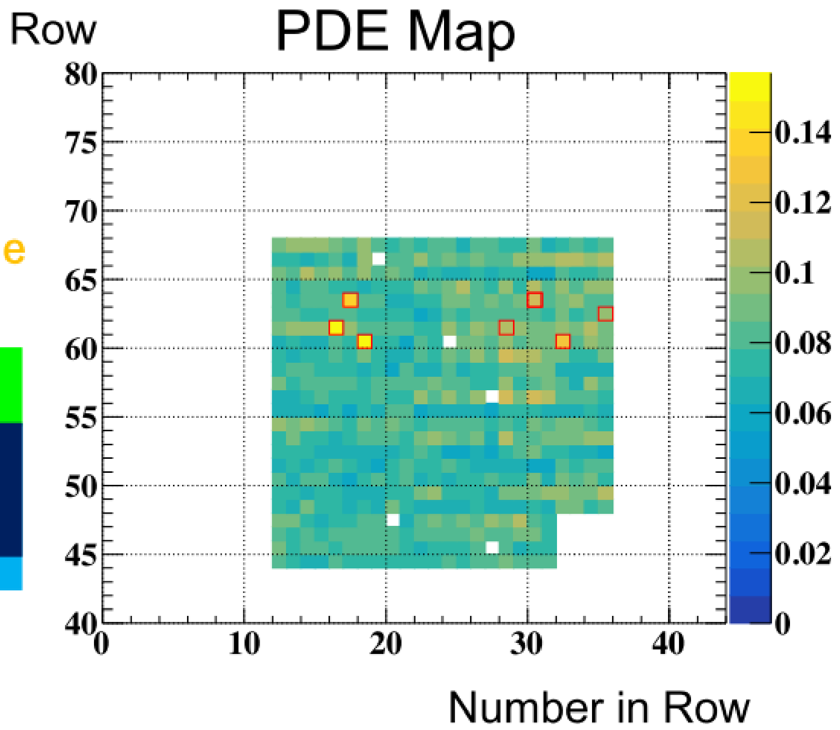
So far

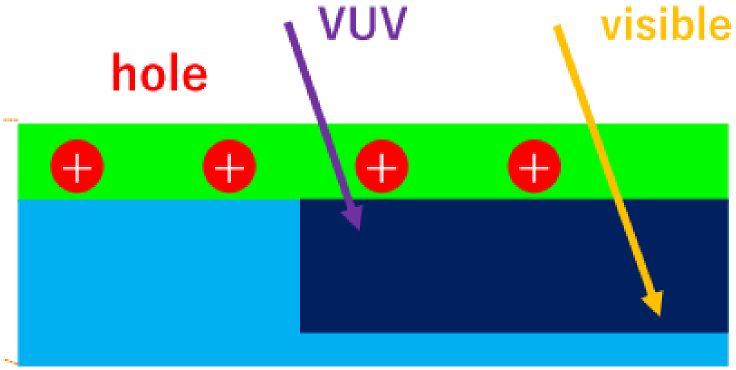
- PDE degradation is confirmed in 2019 beam data.
  → 0.08%/hour with MEG II intensity

- It might be explained by accumulation of holes near Si interface due to VUV irradiation.

- Annealing was tested for few channels, and we observed increase of PDE.



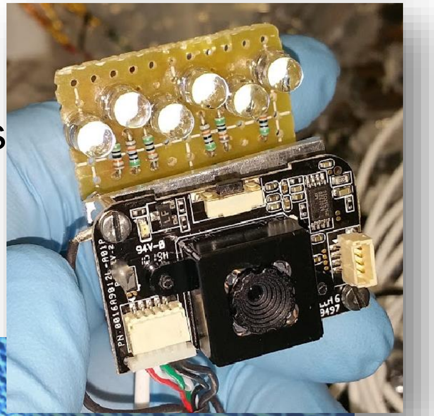


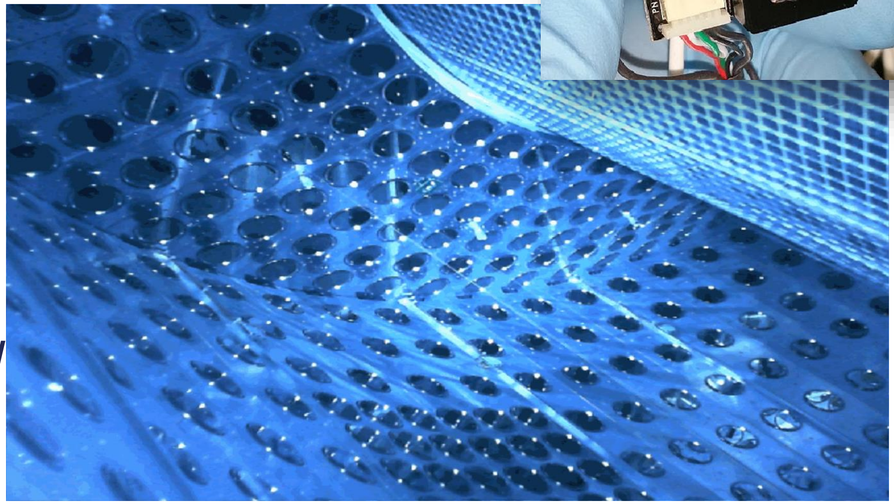


Further annealing test

- Goal: Find optimal condition of annealing
  - *How much current?*
  - *How much time do we need?*

- Method is same as before.
  - *Use MPPCs installed in XEC or spare MPPCs in lab.*
  - *Operate MPPCs under strong LED light and high voltage to heat them up*

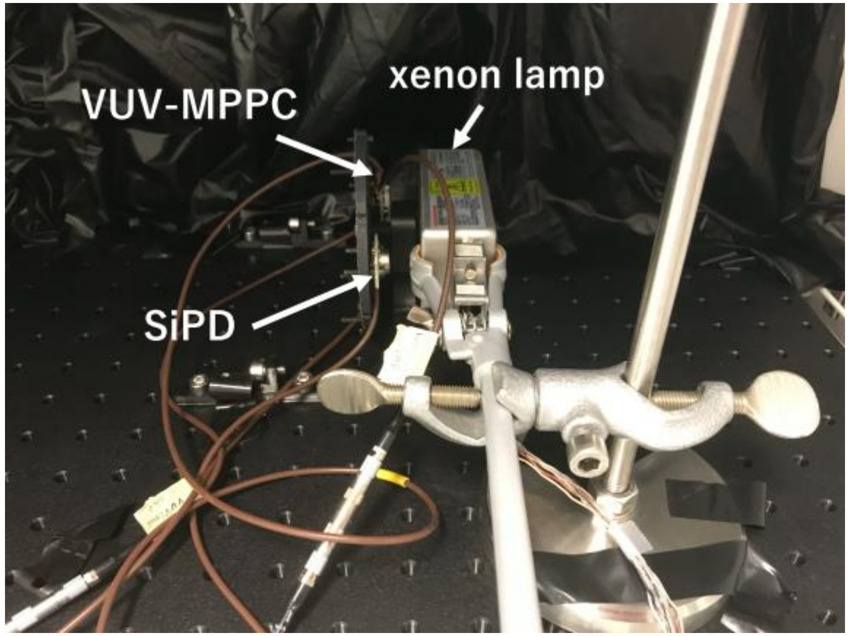


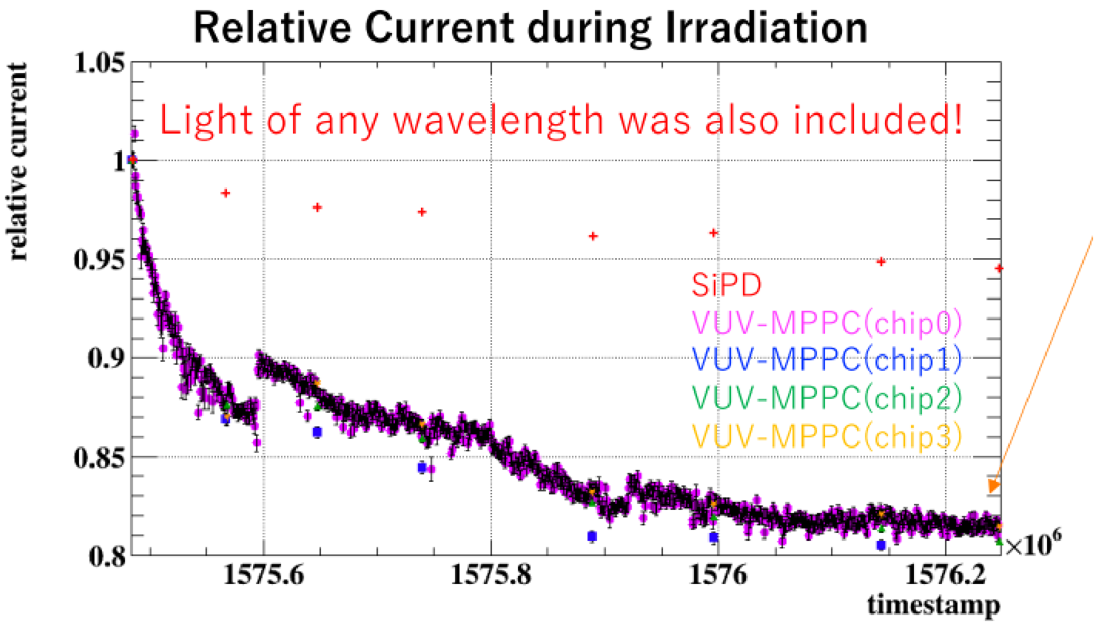


- Effect of annealing will be seen in increase of charge in LED run because there was a correlation between VUV PDE and visible PDE.

PDE degradation tests i

- Room temperature (Rina)
  - PDE degradation is already observed with Xe flash lamp irradiation
  - Degradation seems to stop at some level
  - VUV signal size after irradiation was 30% of non-irradiated MPPC
    → More precise measurement to be done soor

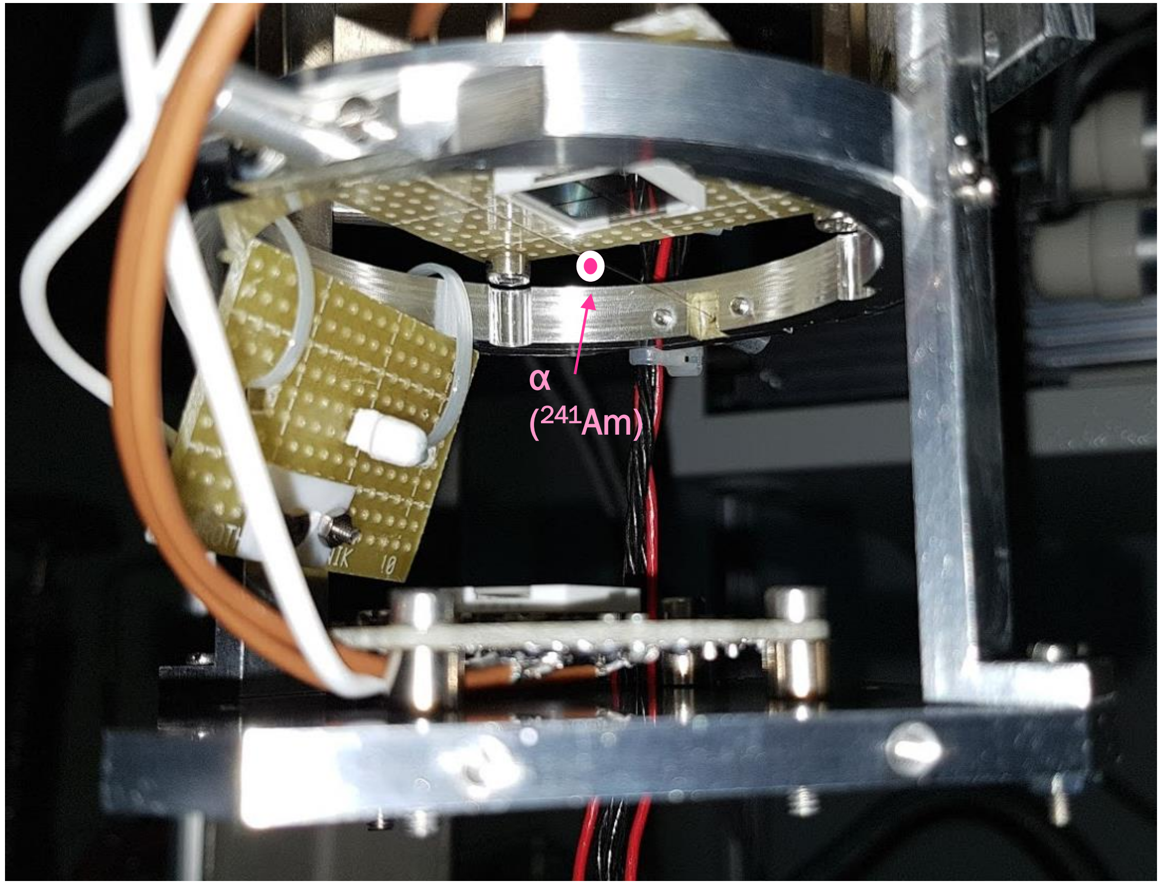




PDE degradation tests in lab

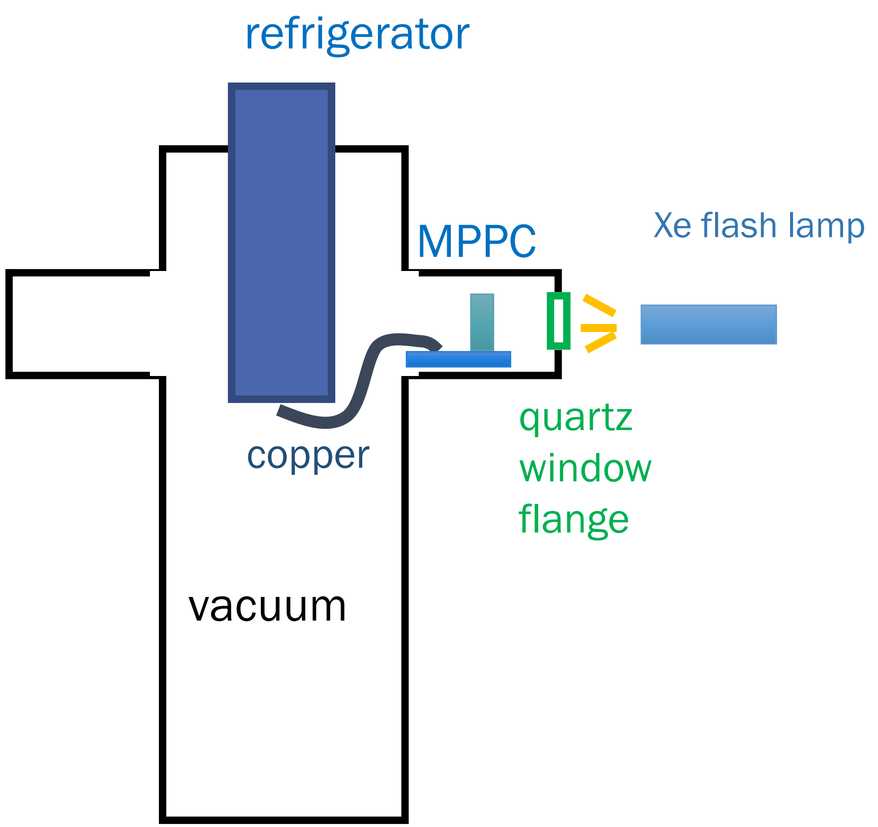
- Low temperature (Kohei)

  - Irradiation in LXe with light from α source close to MPPC to reproduce the problem in low temperature
  - Expected PDE degradation: ~5% in ~2 weeks measurement.
  - Measurement is just started.



PDE degradation tests in lab

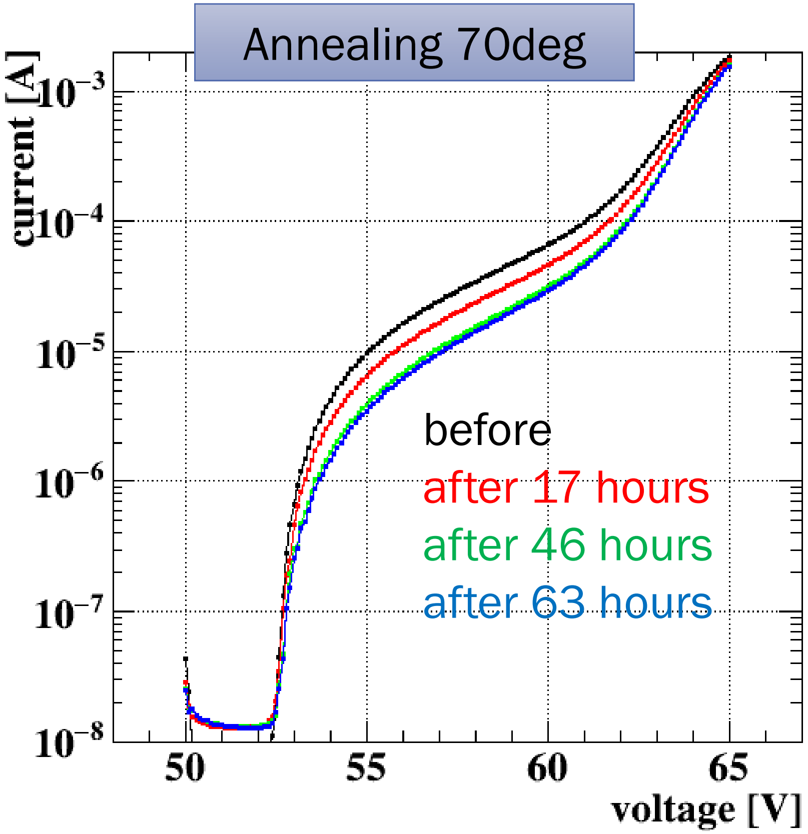
- Low temperature 2 (Kohei)
  - Faster irradiation with Xe flash lamp
  - Expect more (faster?) PDE degradation than in room temperature
  - Maybe we can make irradiated samples quickly and use it for annealing tests.
  - Setup is under preparation



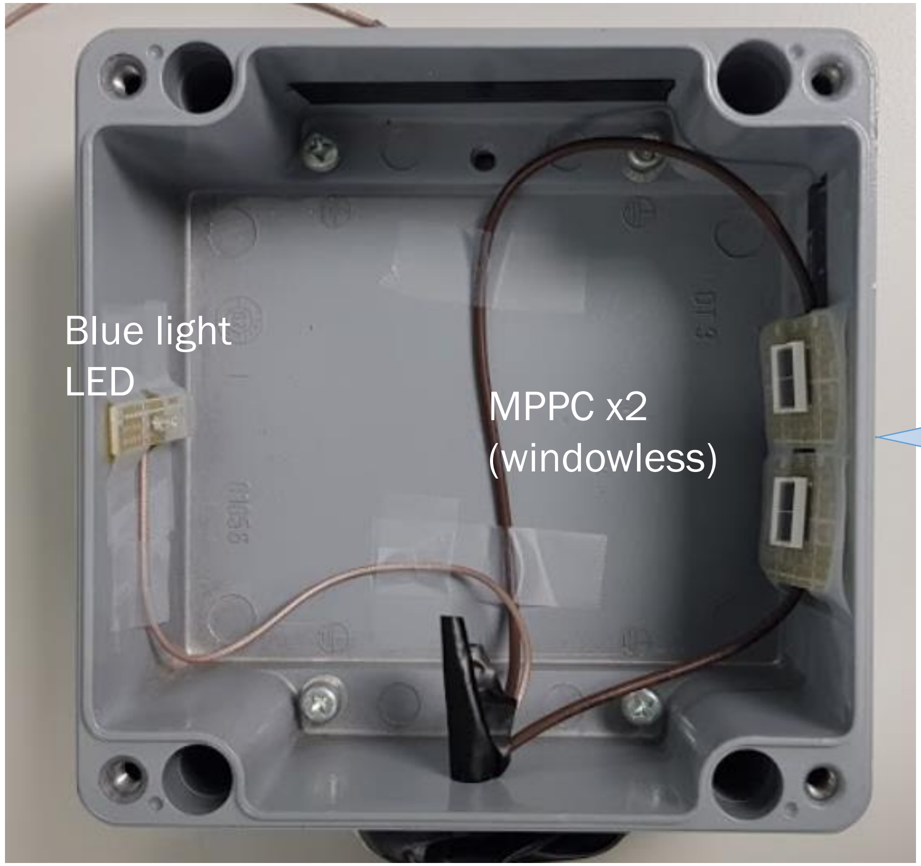
Annealing test

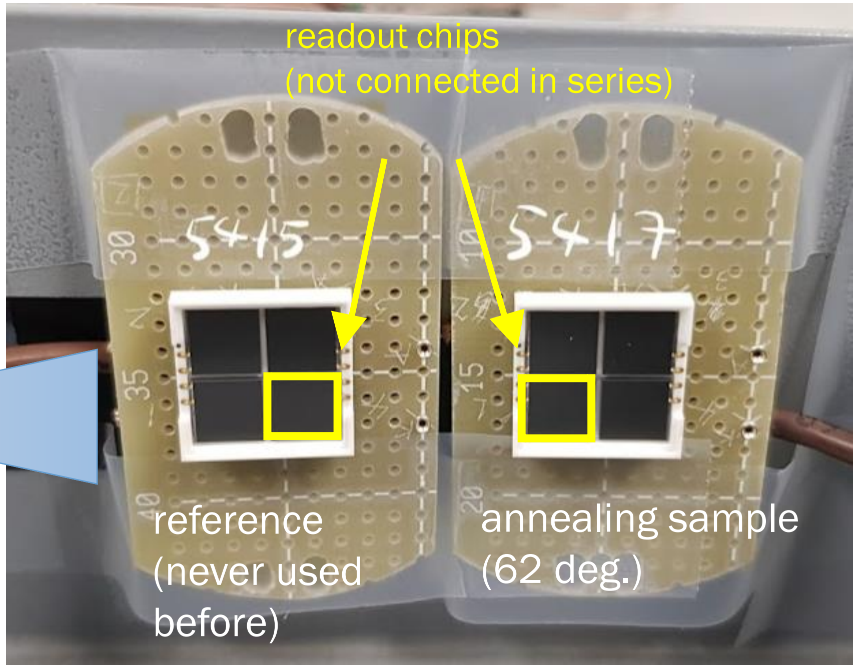
- Previous results
  - 100 deg, 85V, several hours
    → dark current increased
  - 70 deg, 70V, 61 hours
    → dark current decreased
    Back side of PCB was 53 deg.

- Updates
  - 62 deg, 65V, 60 hours
  - Measurement of gain, CTAP, dark noise, relative PDE (visible light)



Measurements with LED



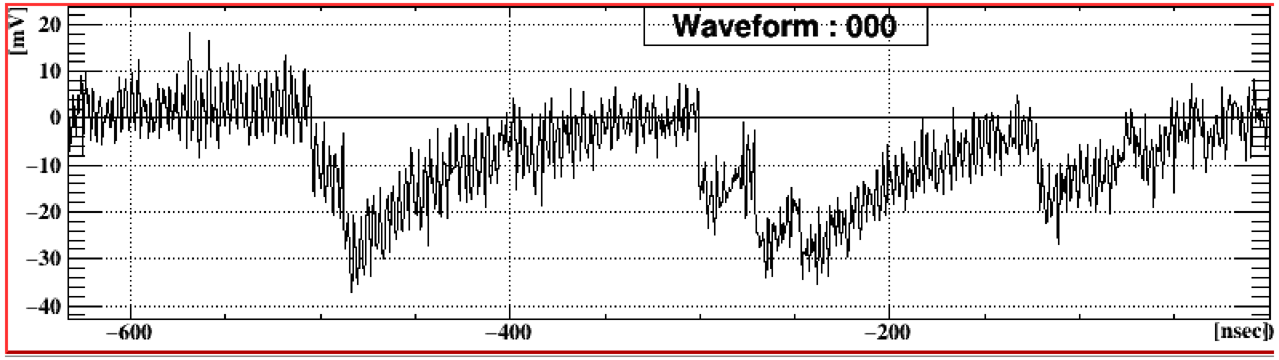


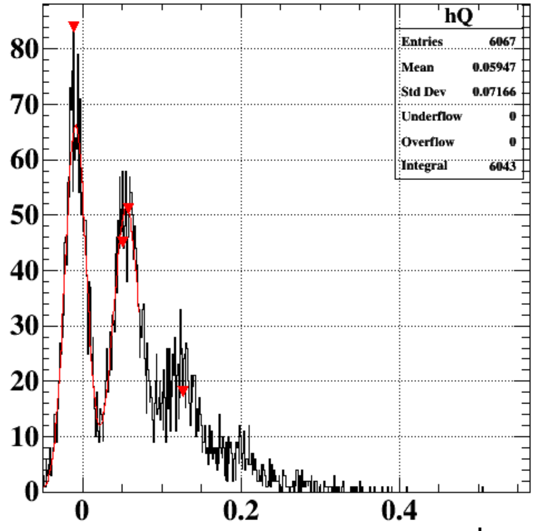
Measurements were done before/after annealing.
In light tight box (not in thermal chamber), clean room.

- Weak light → gain, CTAP
- Strong light → relative PDE
- No light → Dark noise

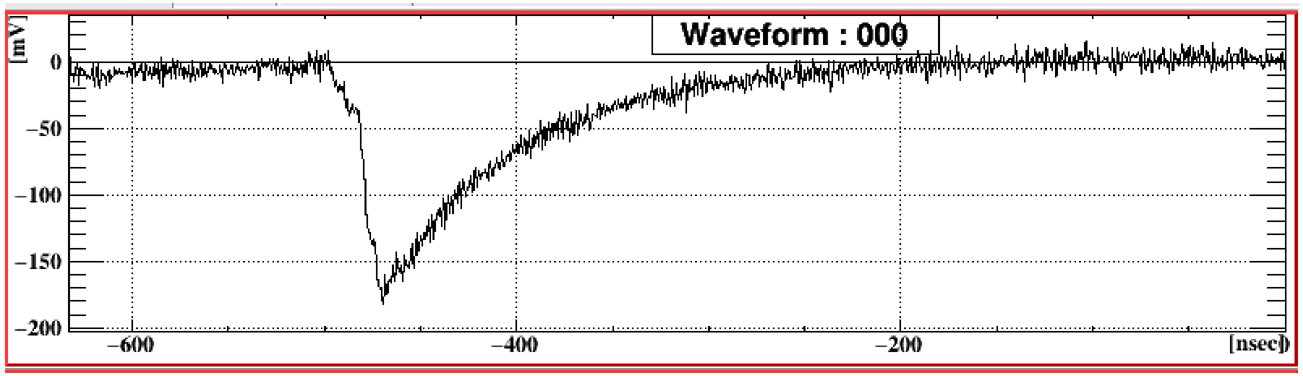
Example of raw data

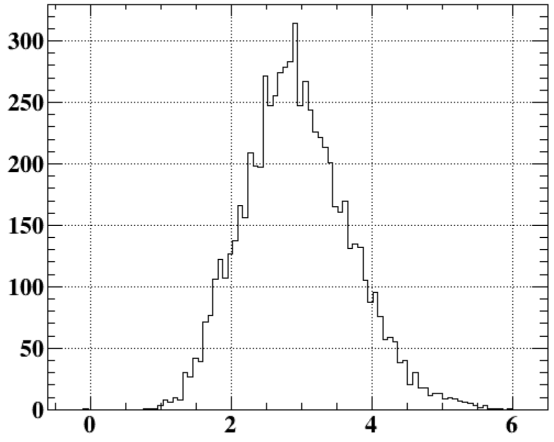
Weak light



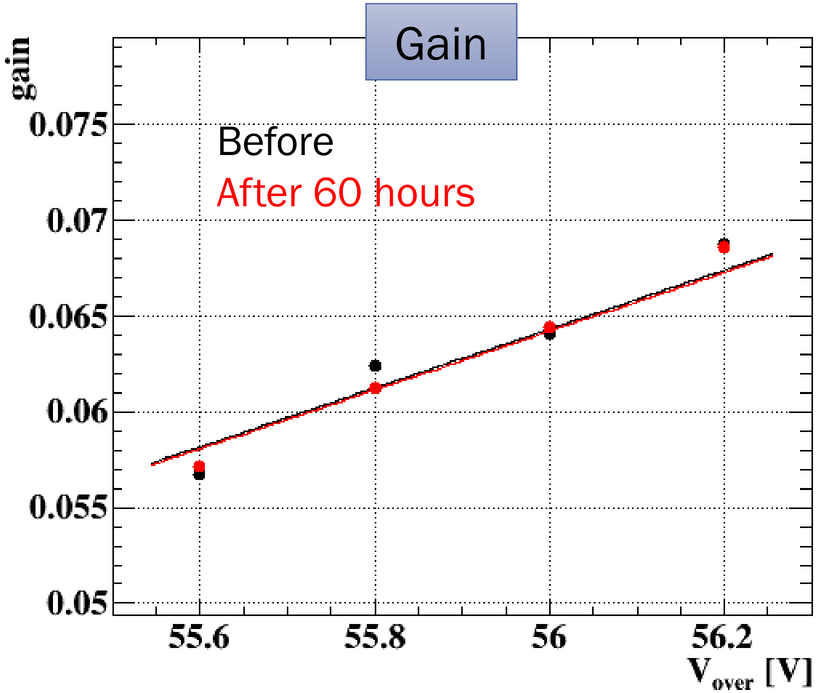


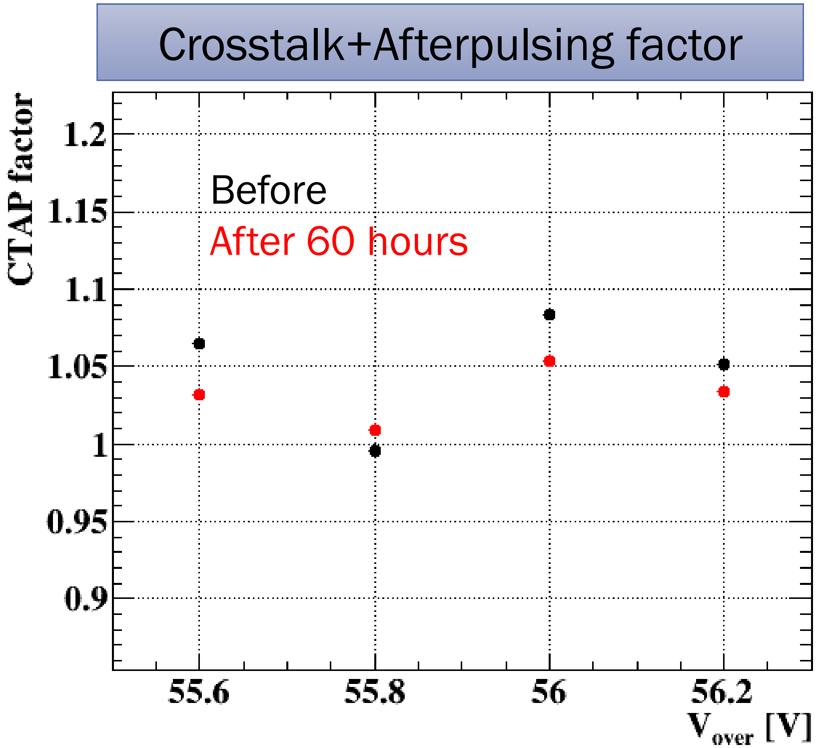
Strong light





Weak light results





No difference observed.

Strong light result

I compared gaussian fitted mean of charge distributions.

V = 56 V (V_{over}~3.5V)

	Charge (annealed)	Charge (reference)	Ratio
Before annealing	2.869	2.674	1.073
After 60 hours	2.724	2.622	1.039

3.4% decrease by annealing
(Maybe within systematic fluctuation)