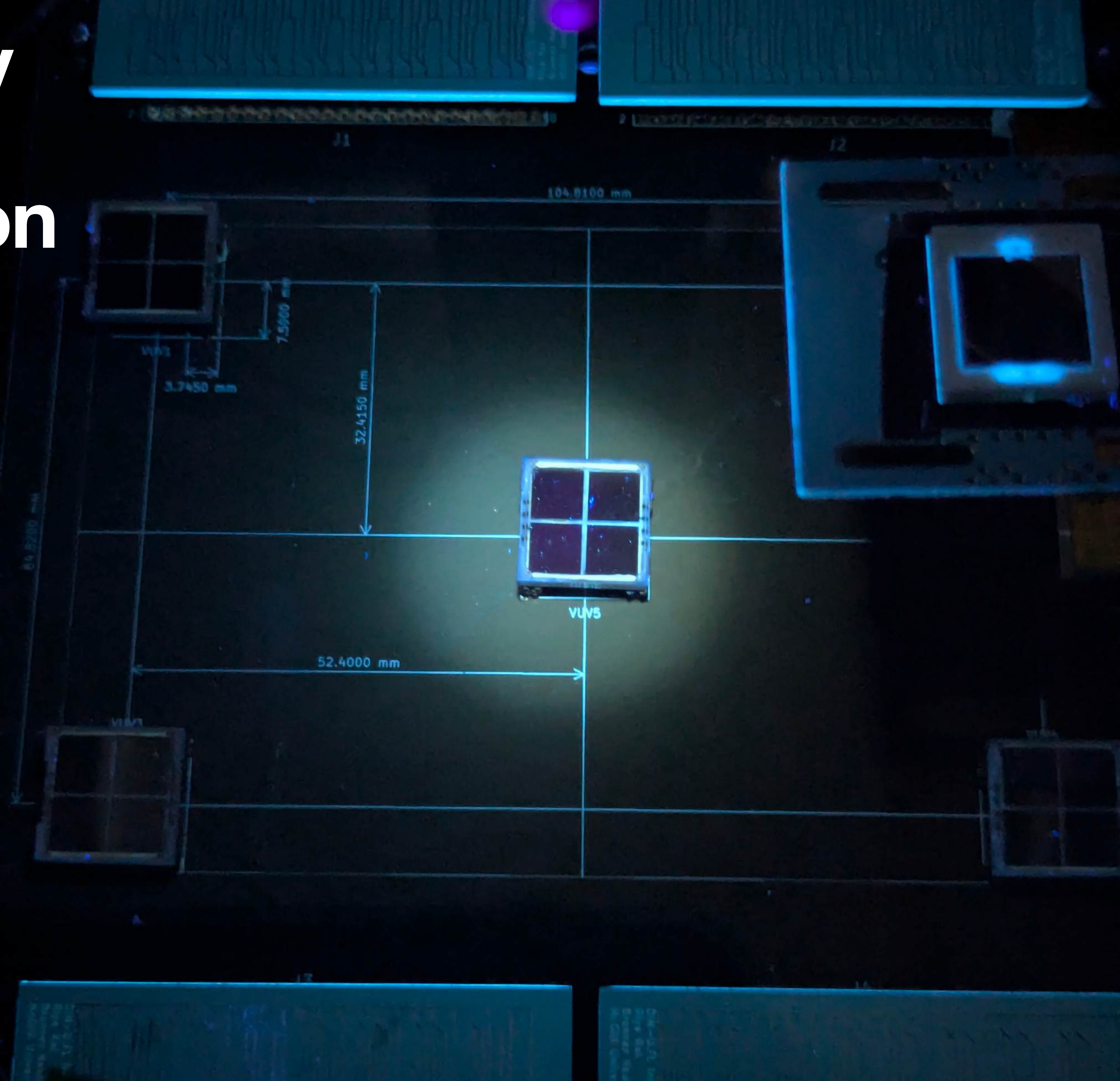
Vacuum UV Stability Measurements of SiPMs at Liquid Xenon Temperature

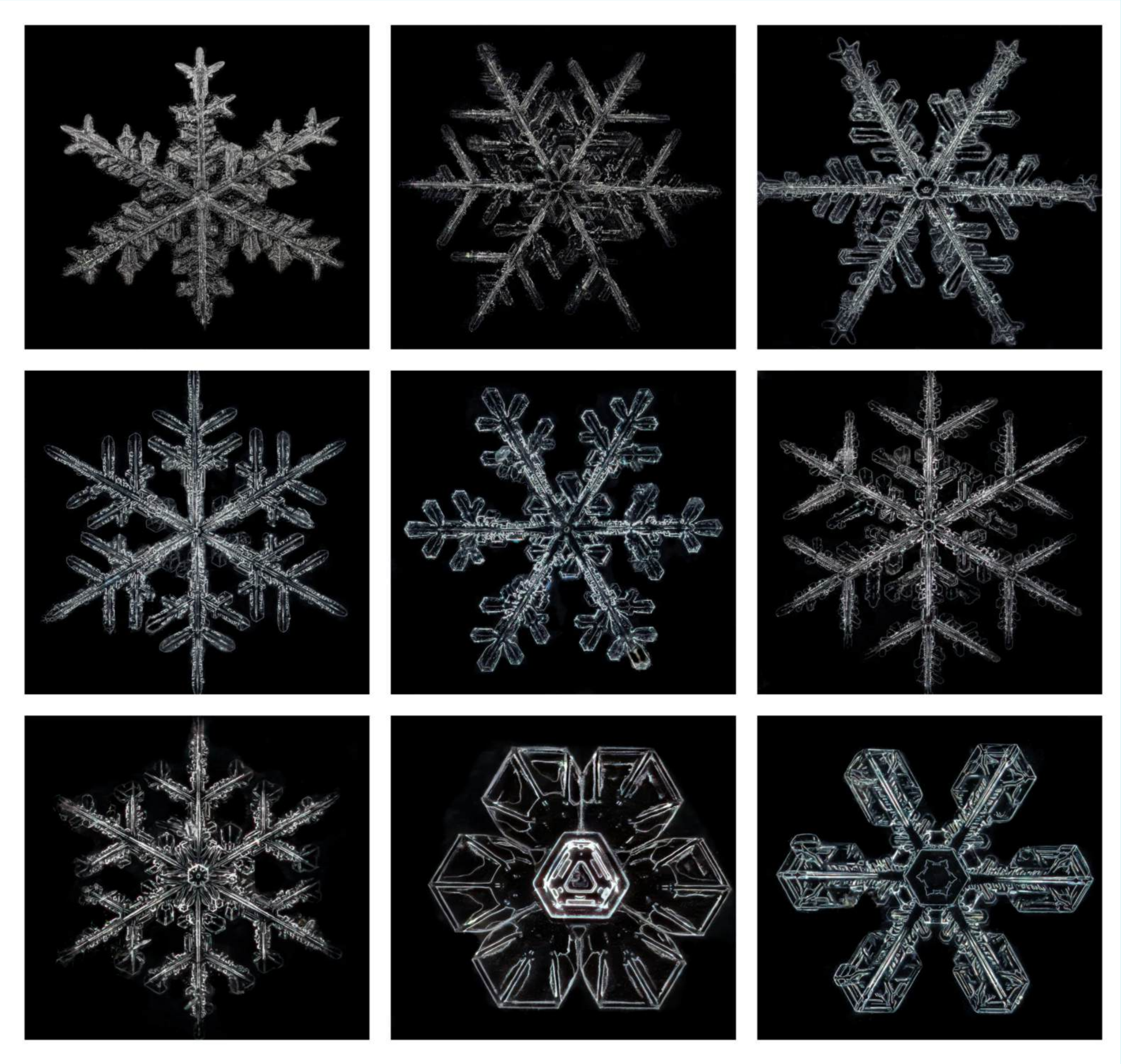
Riya Rai, Lucas Darroch, Iskender Isikbay, Naman Walia,, Eamon Egan and Thomas Brunner

Brunner Neutrino Lab
McGill University

WNPPC 2026
13th February 2026



Nature Loves Symmetry!

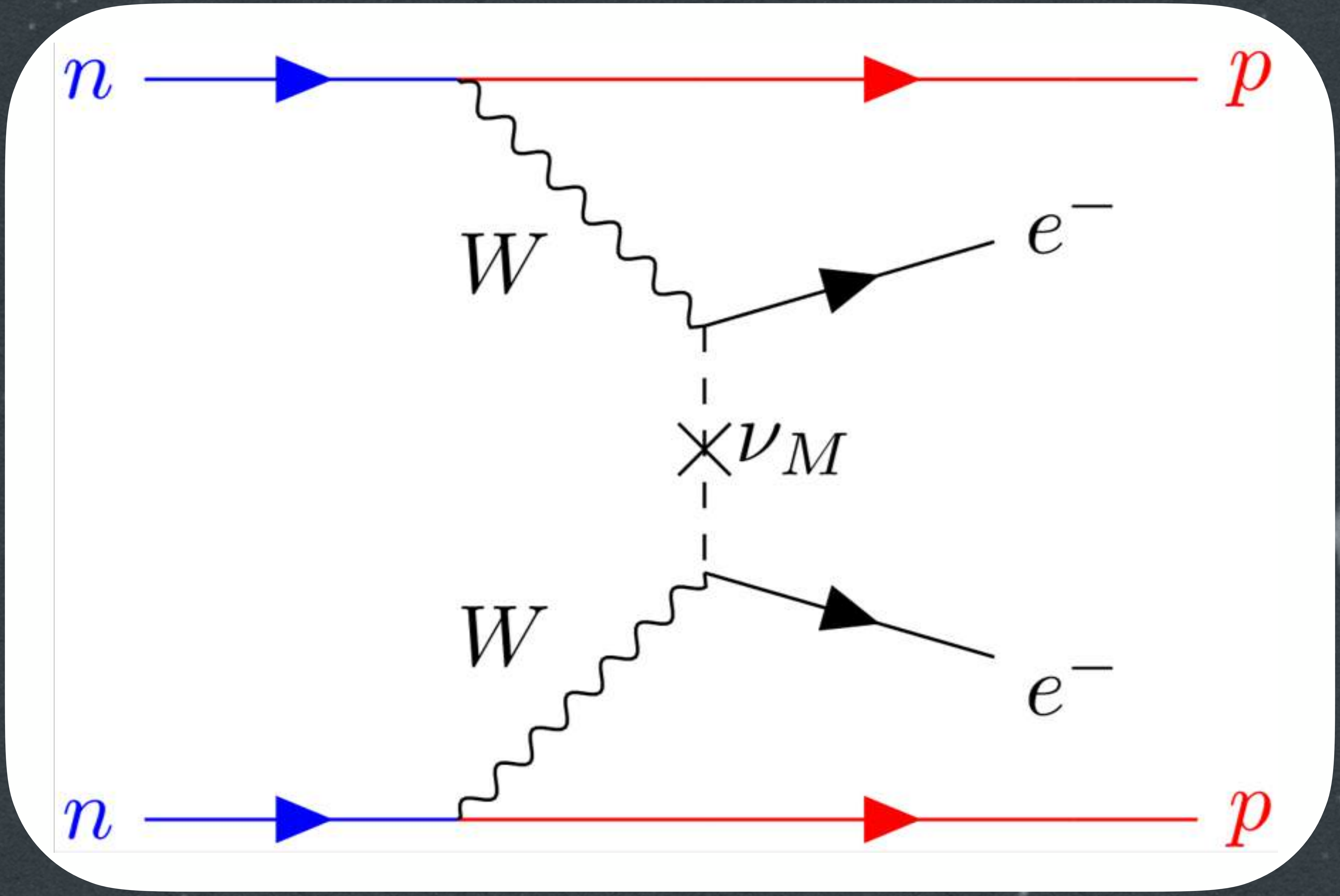


Matter - Antimatter symmetry leads to a universe with only photons

The Hubble Ultra Deep Field, Credits: NASA

Matter-Antimatter Asymmetry in the universe can be explained via:

- Baryogenesis + Leptogenesis
- Key: Lepton number violation
- Lepton number violation if neutrinos are Majorana
- Majorana neutrinos can be probed by searching for $0\nu\beta\beta$

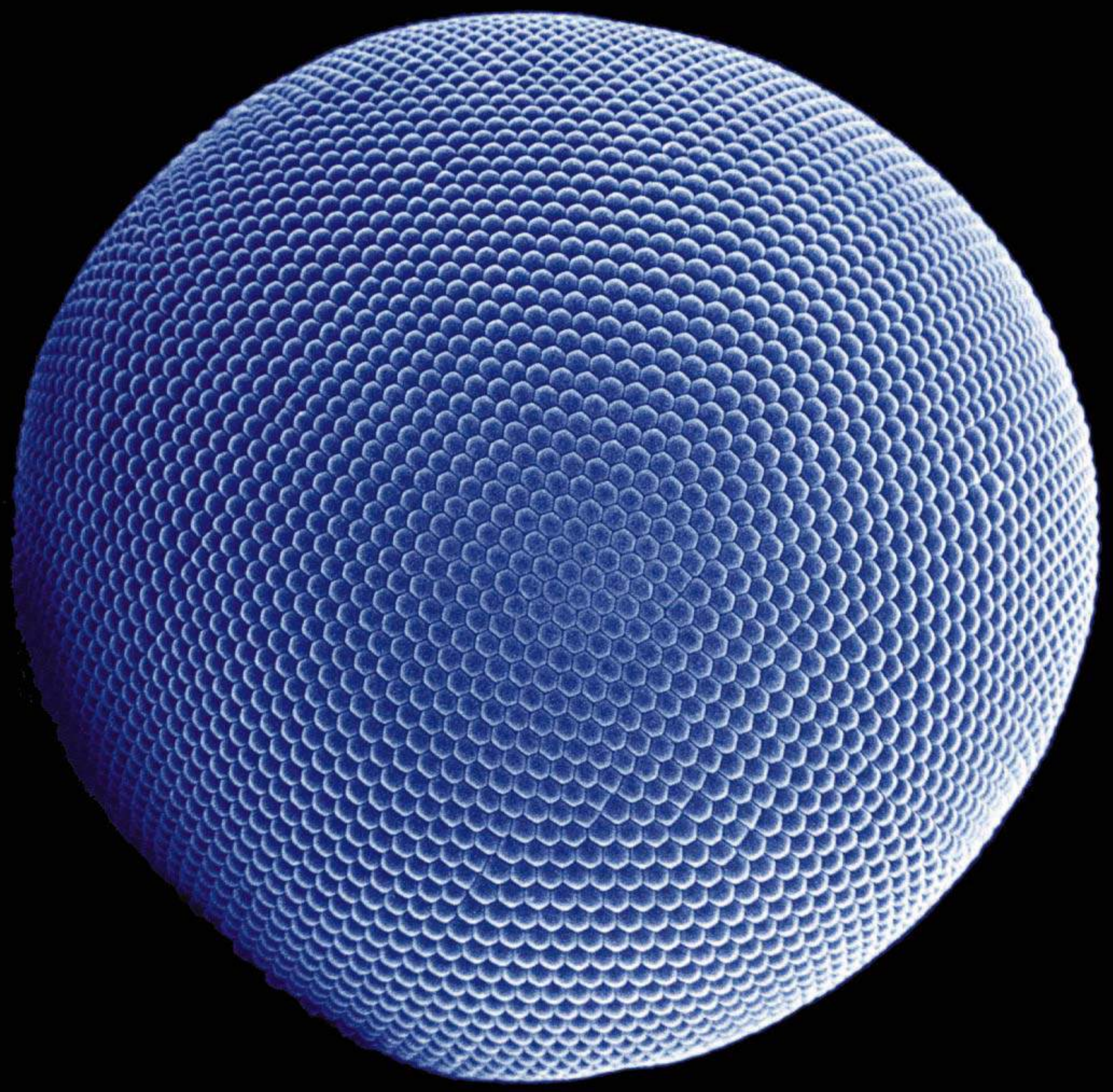


Observation of $0\nu\beta\beta$ always implies new physics!

Search for $0\nu\beta\beta$ in 5 tonnes of liquid xenon

nEXO

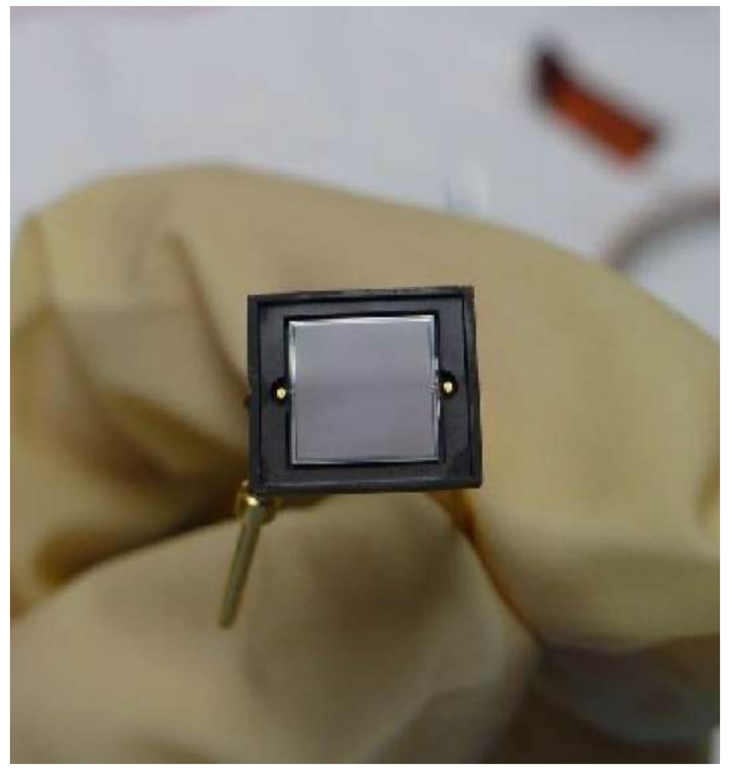
How do we *see* $0\nu\beta\beta$?



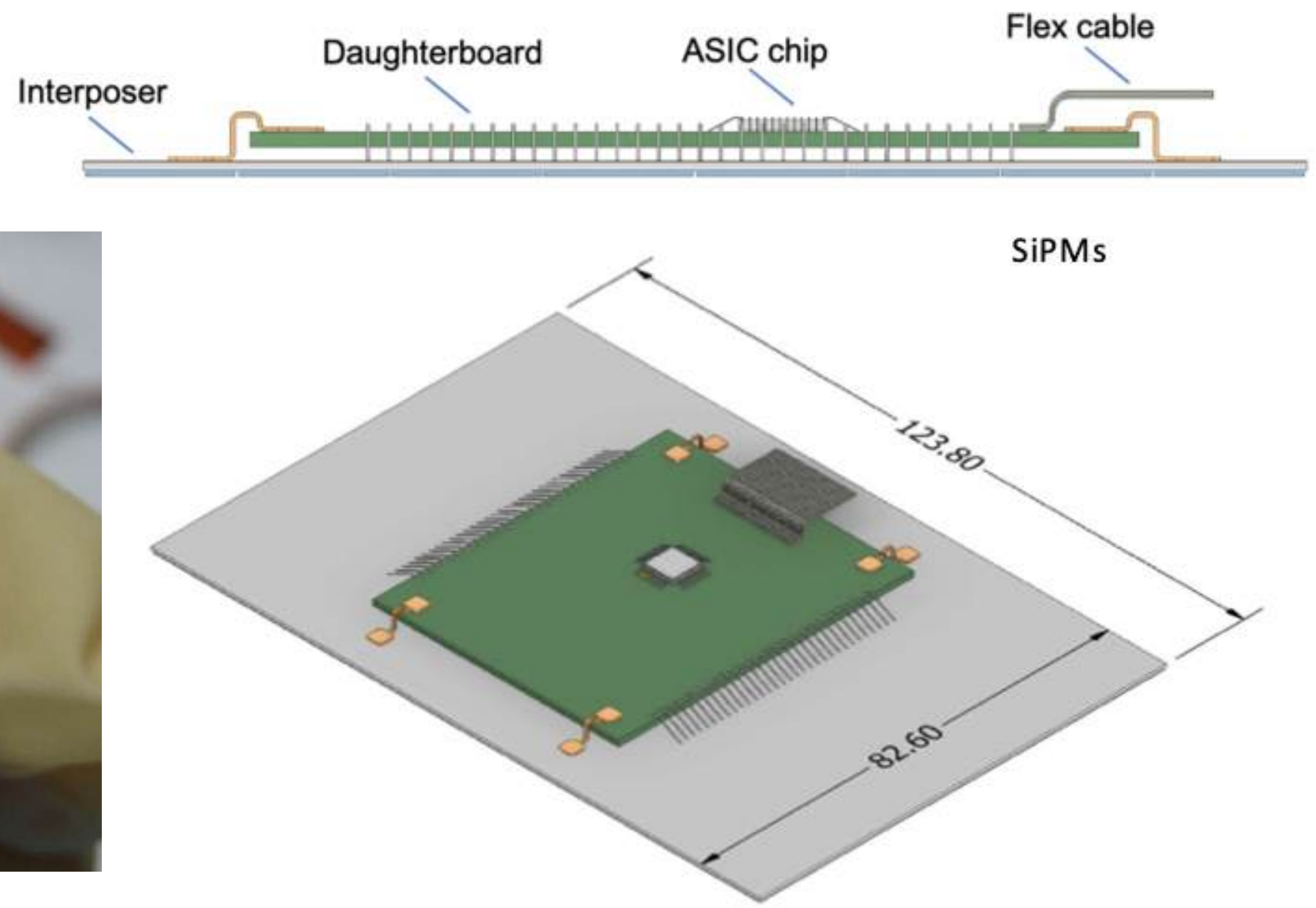
Compound eye of an antarctic krill

nEXO Photodetection System Concept

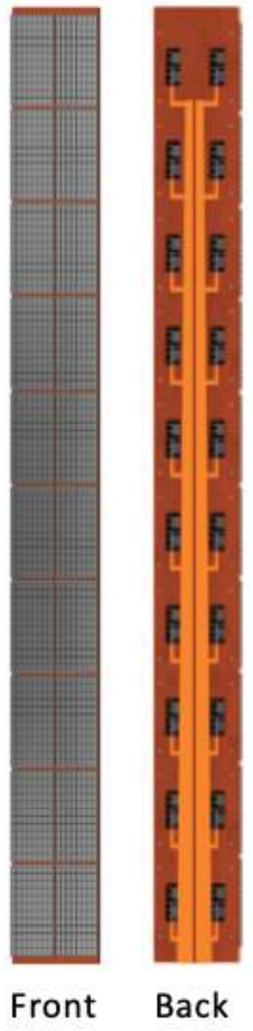
- Combined light + charge readout for 3D event reconstruction
- Silicon Photomultipliers (SiPMs) cover 4.6 m^2 of light sensitive area
- SiPM and stave characterisation at McGill



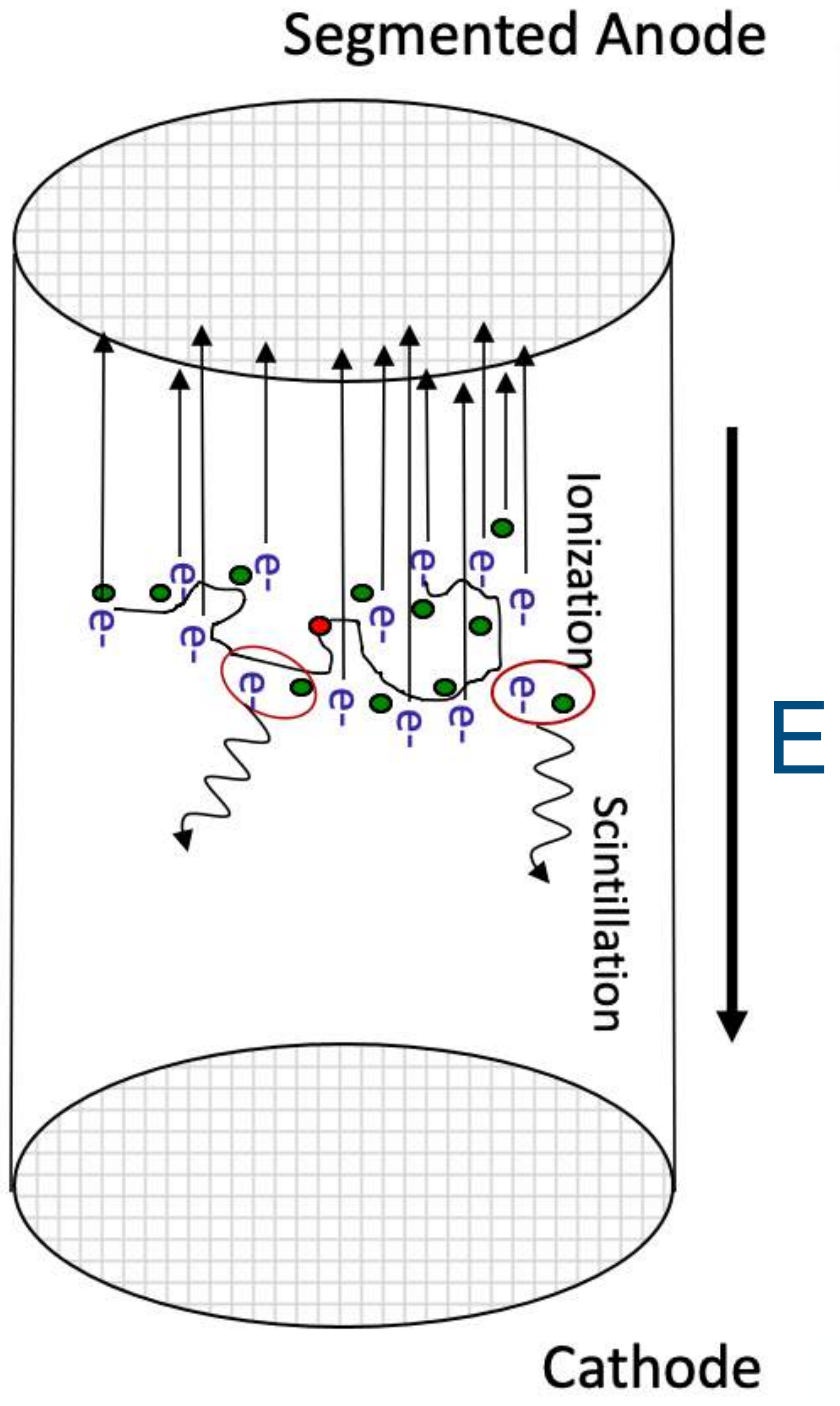
SiPM

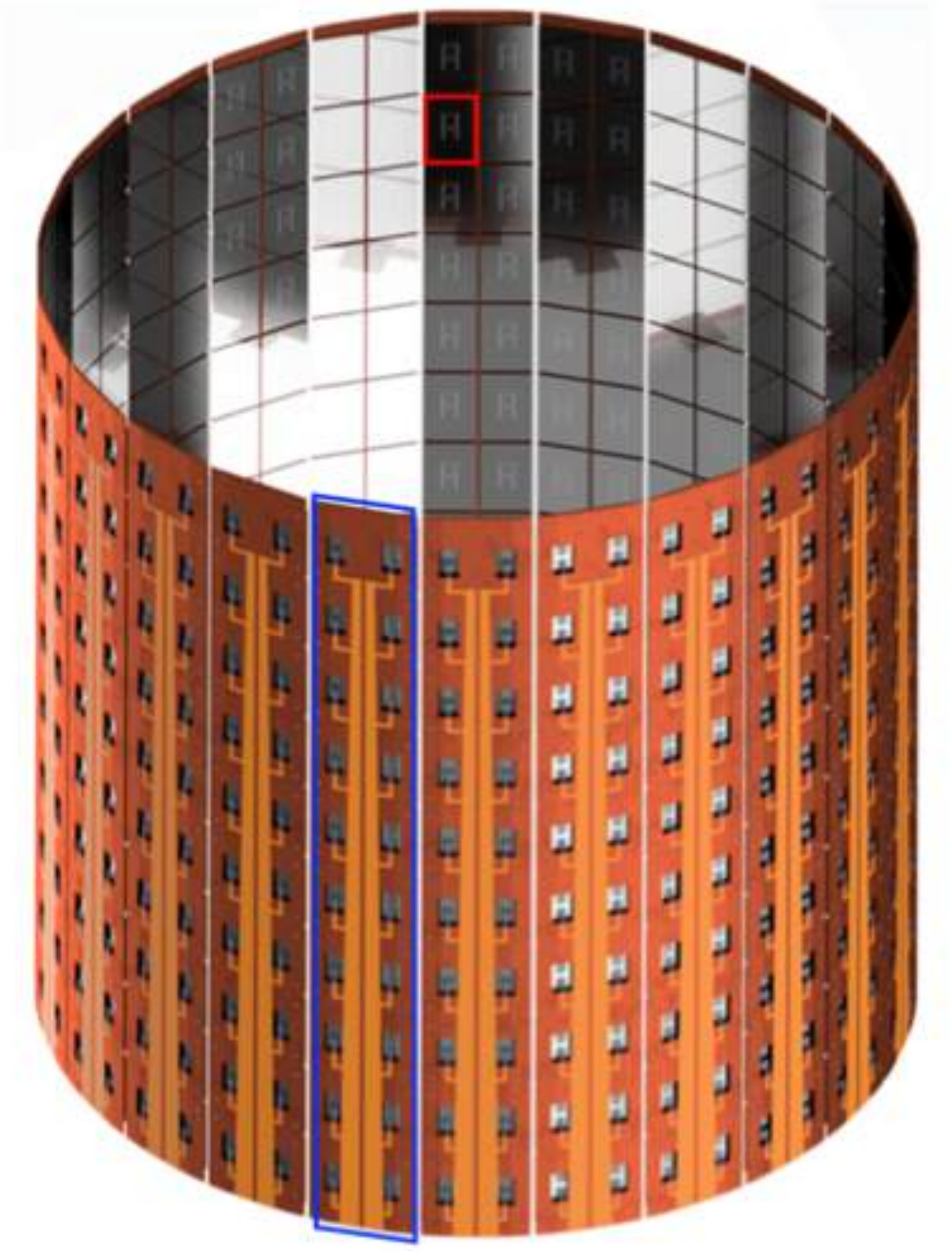


Tile with 96 (1 x 1 cm^2) SiPMs



20 Tiles per Stave





Barrel with 24 staves

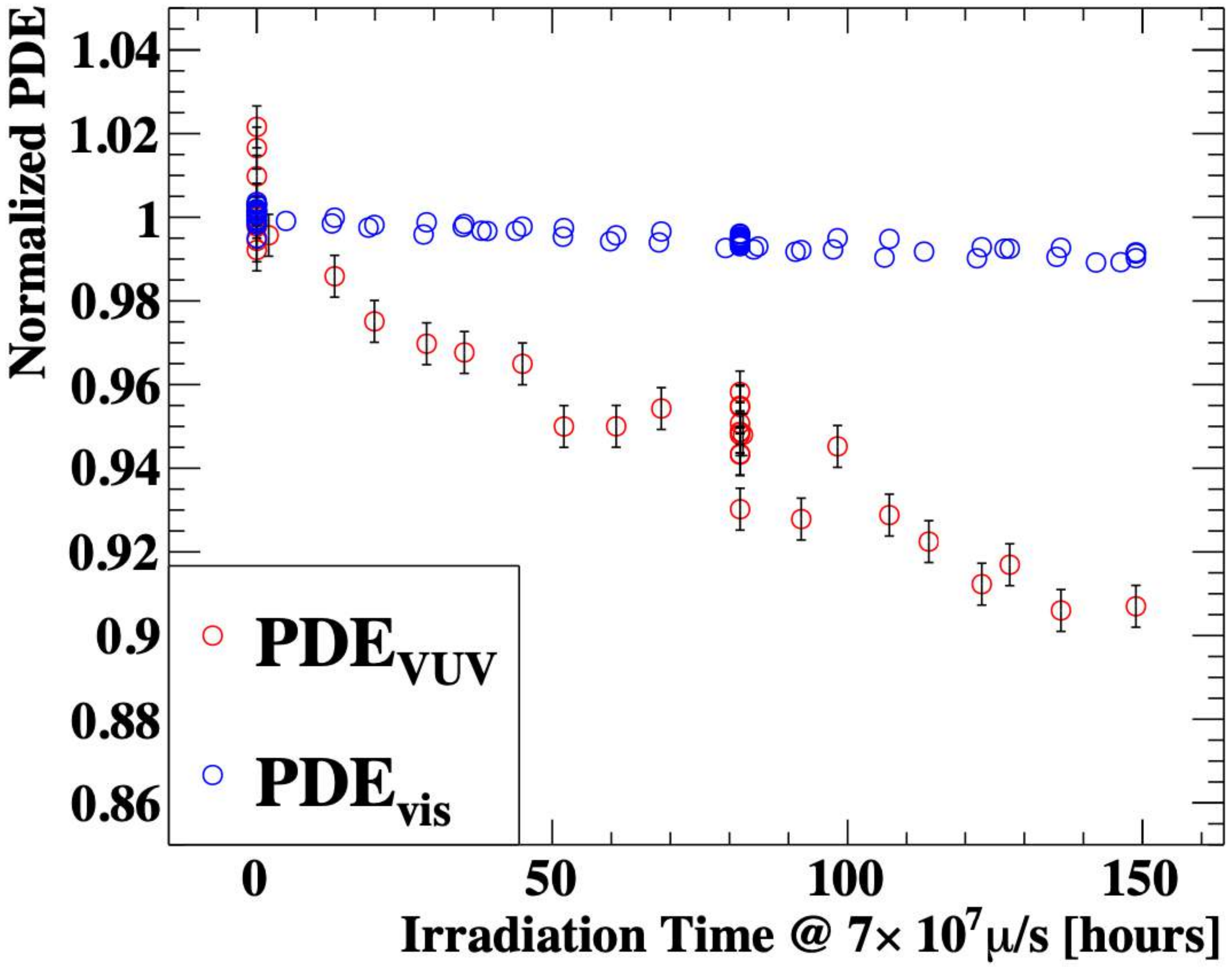
Kharusi, S. Al, et al. "nEXO pre-conceptual design report." *arXiv preprint arXiv:1805.11142* (2018).

Unexpected PDE decrease Observed in MEG II

Study on degradation of VUV-sensitivity of MPPC for liquid xenon scintillation detector by radiation damage in MEG II experiment

K. Ieki[a], T. Iwamoto[a], S. Kobayashi[a,*], Toshinori Mori[a], S. Ogawa[a], R. Onda[a], W. Ootani[a], K. Shimada[a], K. Toyoda[a]

[a] *International Center for Elementary Particle Physics (ICEPP), The University of Tokyo, Tokyo, 113-0033 Japan*



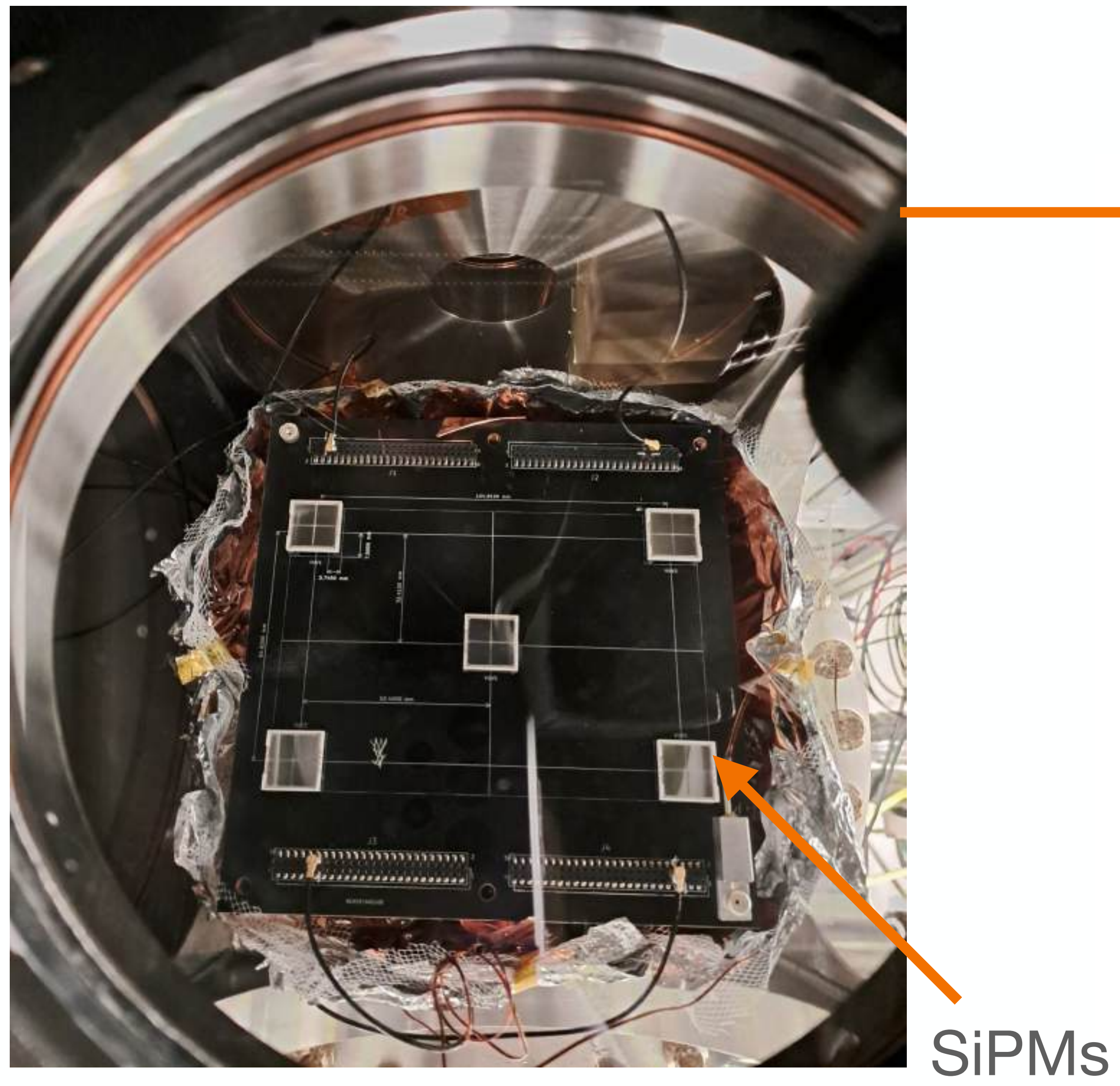
HPK SiPM (S10943-4372) at 165 K

MEG II

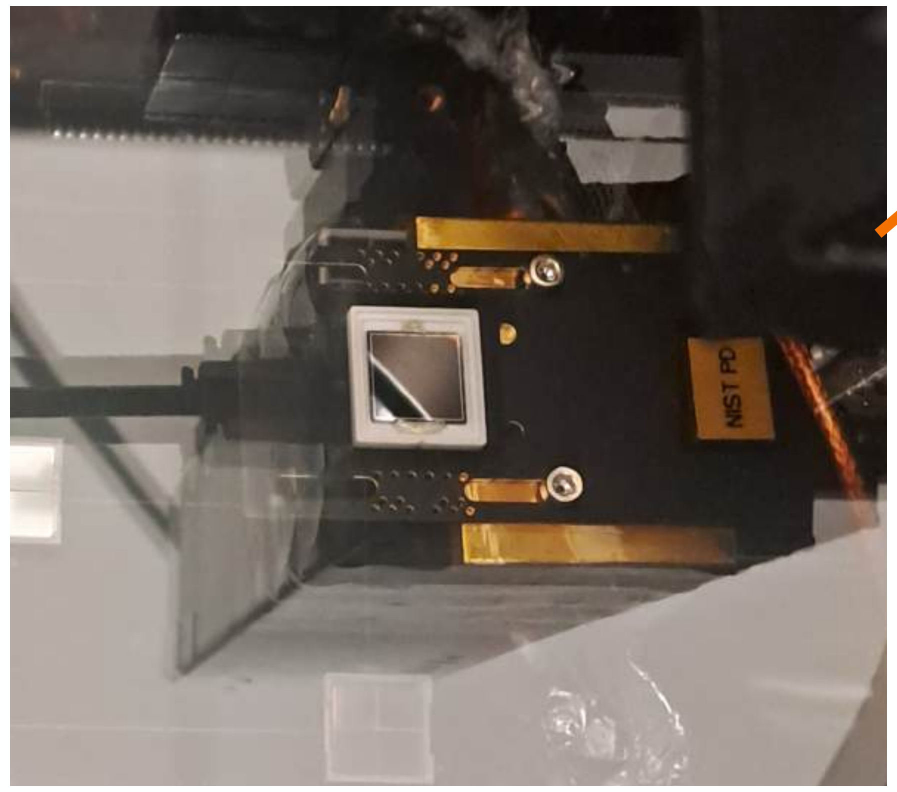
Particle	Dose/Fluence
Gamma-ray	1×10^{-4} Gy
Neutron	3×10^{6} cm^{-2} (1 MeV equivalent)
VUV photon	6×10^{10} mm^{-2} = 1.5×10^{-5} mJ/mm^2

- 10 % decrease in photodetection efficiency (PDE) for VUV light
- 1% decrease in PDE for visible light exposure

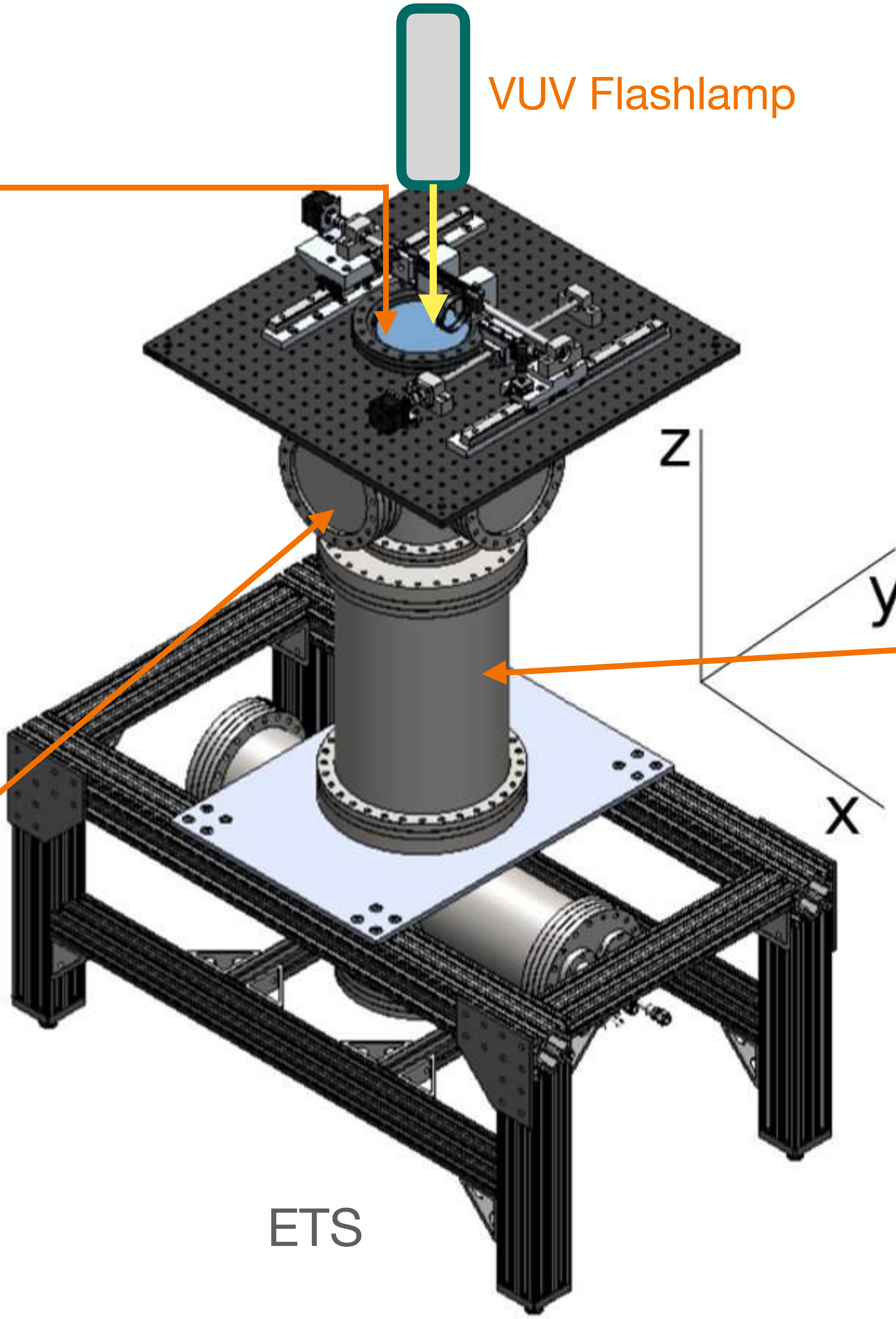
Cryogenic Setup to Characterise SiPMs at McGill

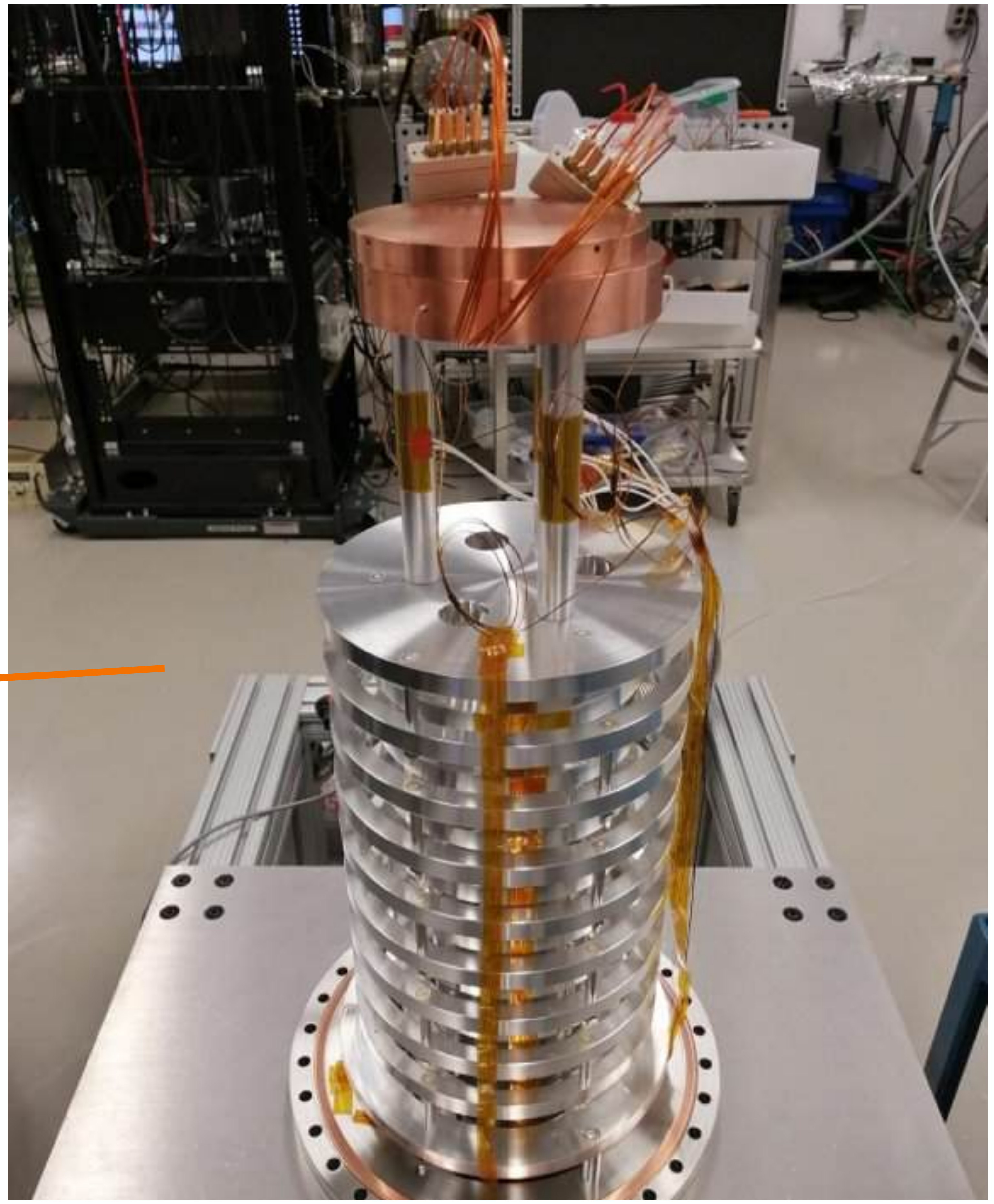


SiPM tile mounted on the cryostat cold head



Photodiode mounted on cryostat side flange





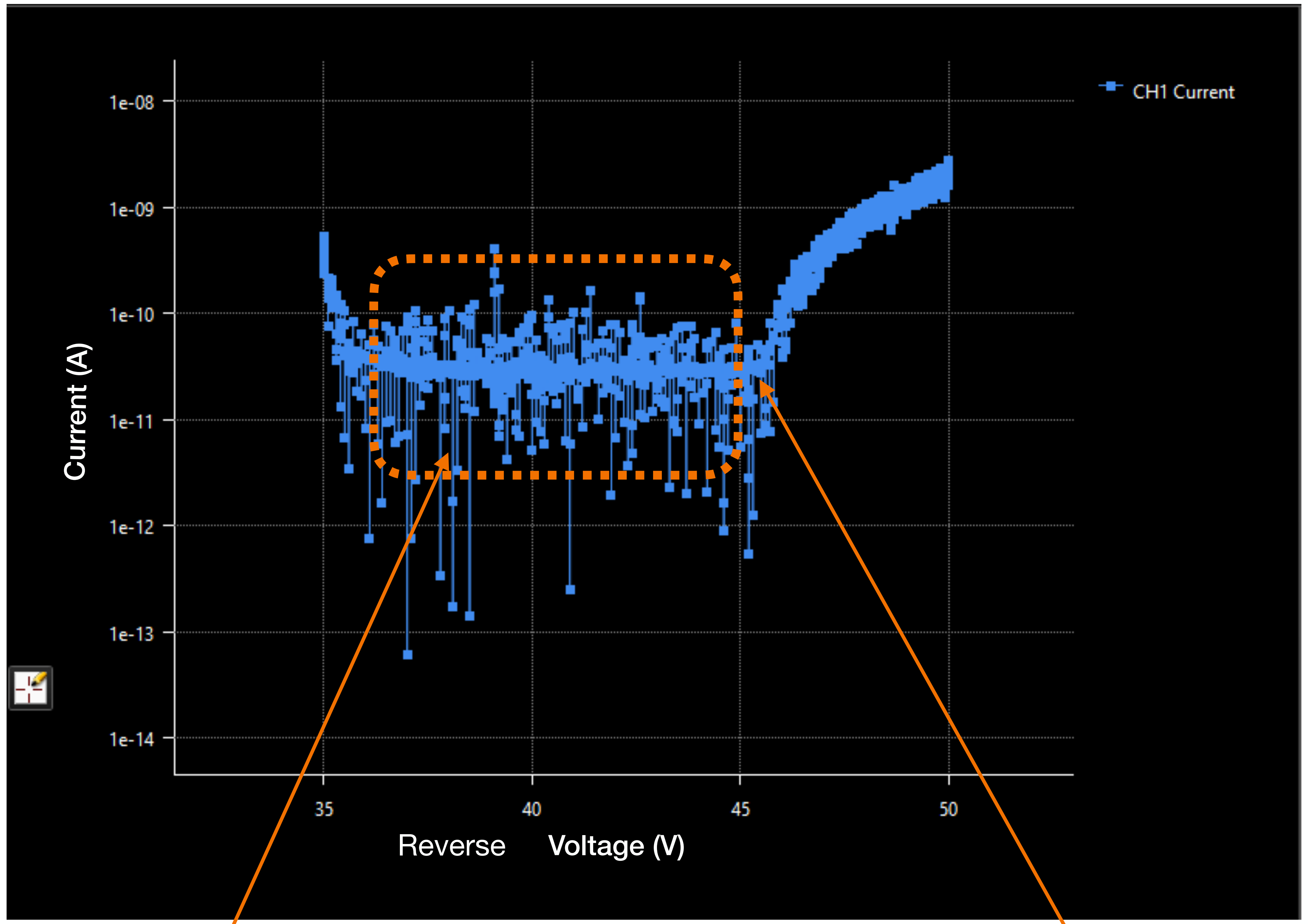
Environmental Test Stand (Cryostat)

- Previous Demonstrated Range: 120-295 K
- Stable Operation: $\sigma_T \sim 1$mK

(PhD Thesis) Darroch, Lucas. "Testing silicon photomultipliers with vacuum-ultraviolet light for nEXO." (2025).

SiPM Characteristics

IV Measurements



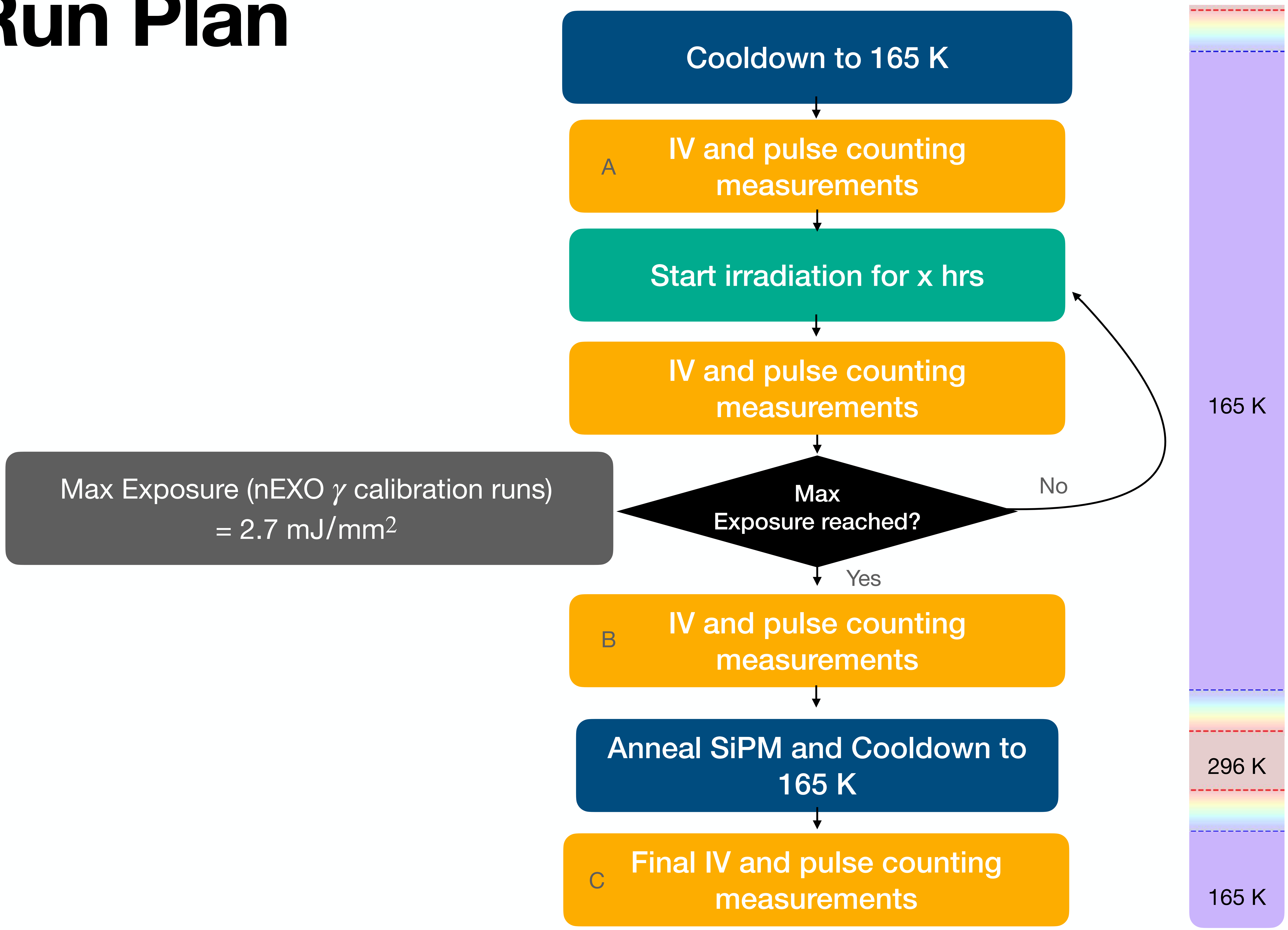
Pulse Mode Measurements

Leakage Current

Breakdown Voltage

Pulse due to a single photo electron (SPE)

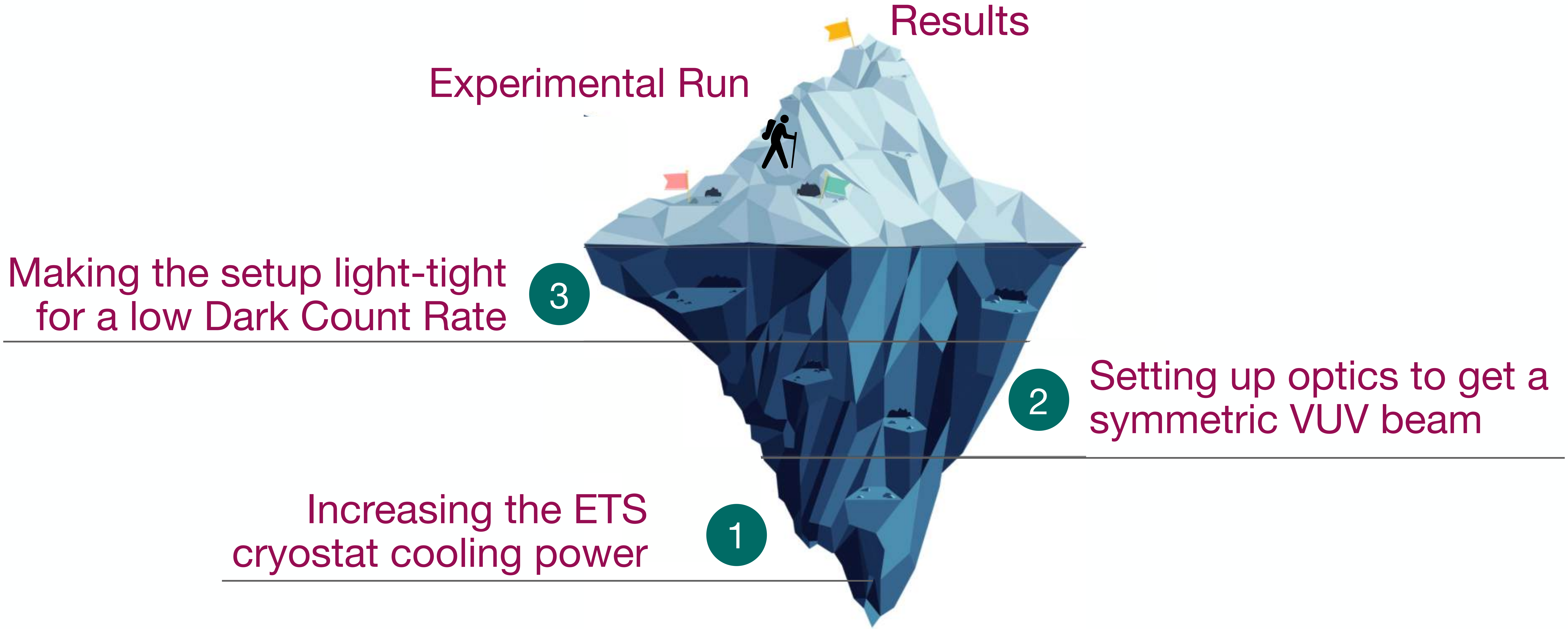
Run Plan



Cooldown to 165 K
A
IV and pulse counting measurements
Start irradiation for x hrs
IV and pulse counting measurements
Max Exposure (nEXO γ calibration runs) = 2.7 mJ/mm^2
Max Exposure reached?
No
Yes
B
IV and pulse counting measurements
Anneal SiPM and Cooldown to 165 K
C
Final IV and pulse counting measurements
165 K
296 K
165 K

But wait… it can't be that easy

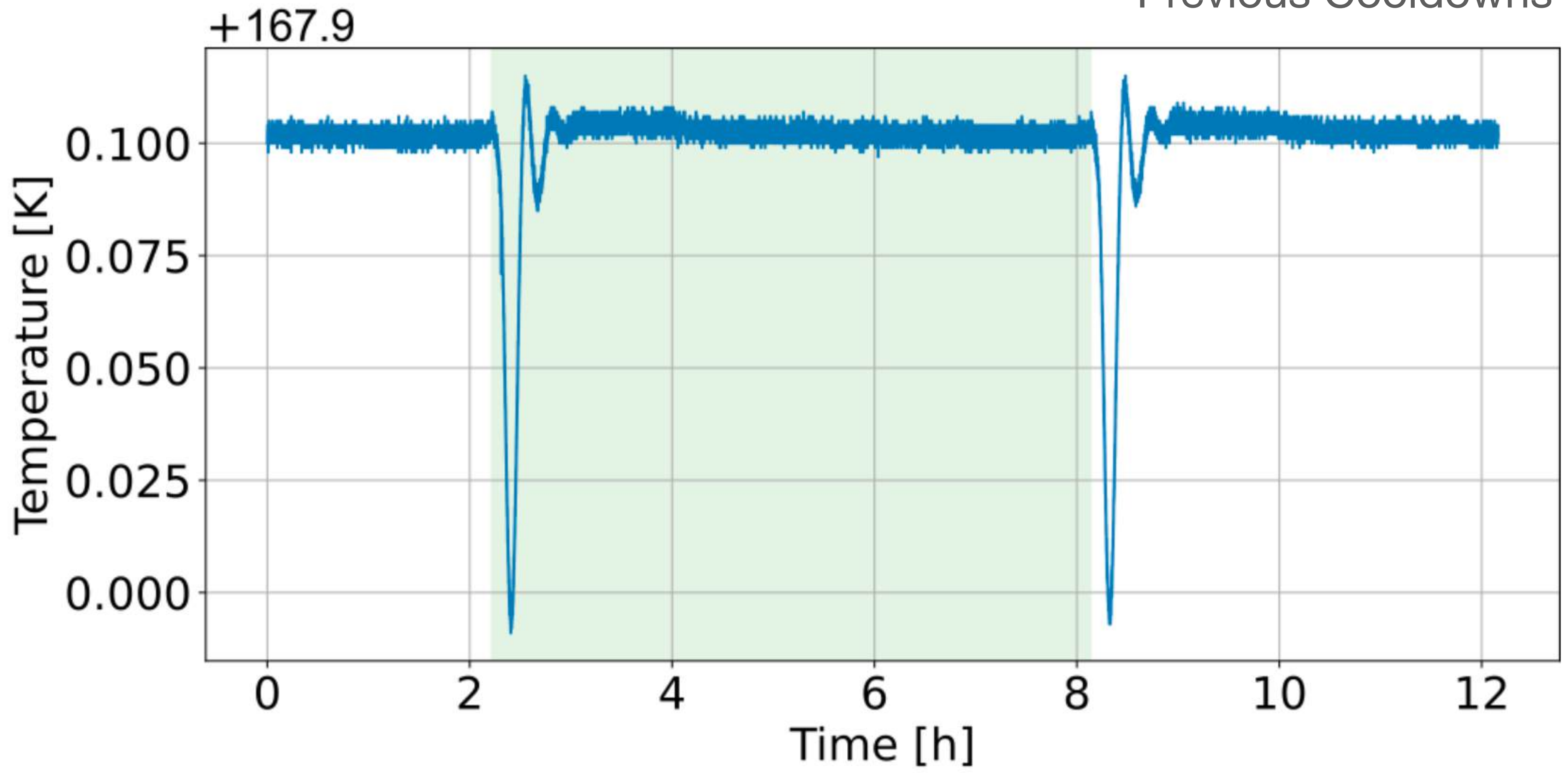
Major Challenges



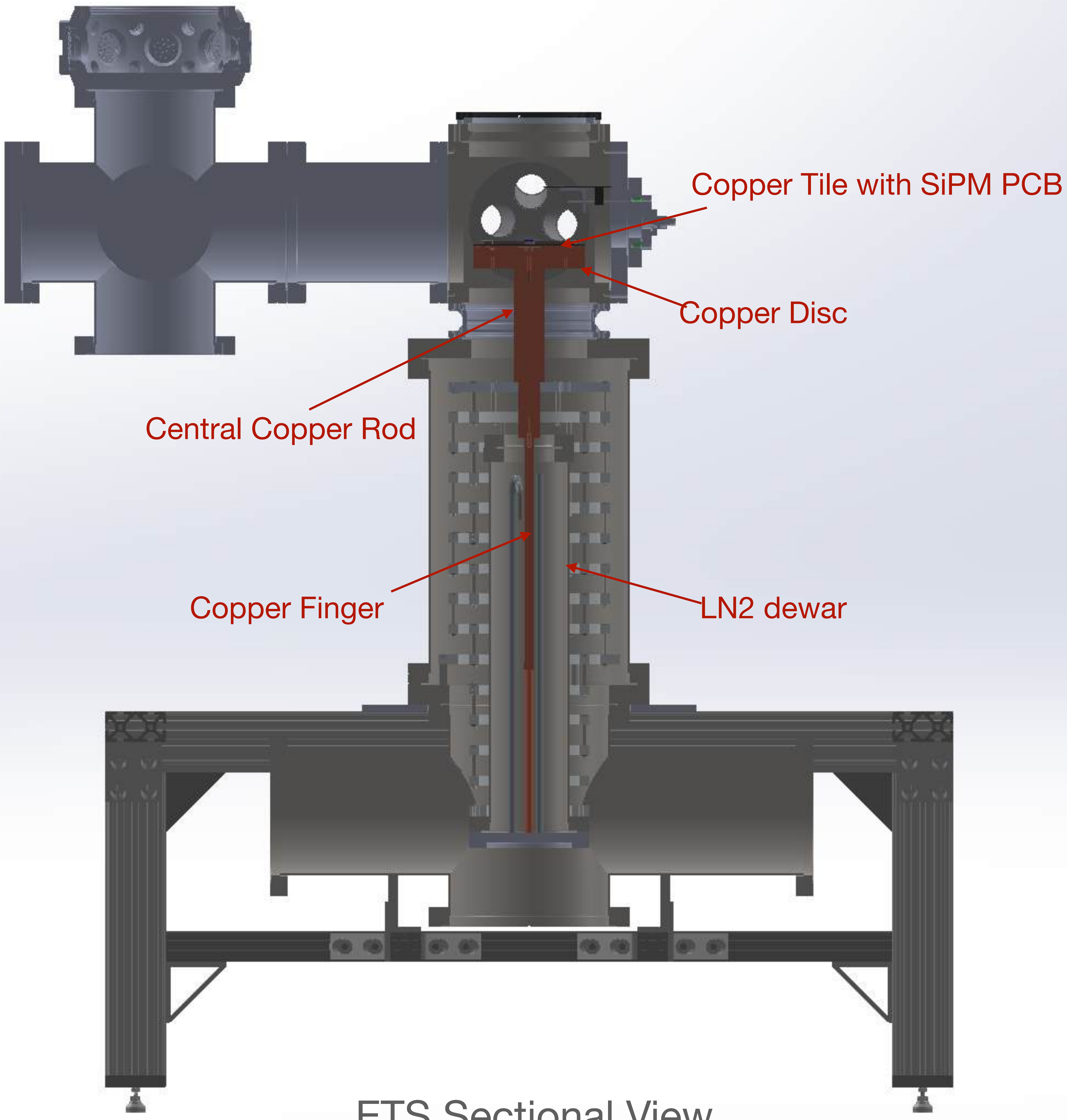
Hardware Upgrade

- We need to conduct tests at 165 K (liquid Xenon temperature)
- Previous demonstrated range of the ETS: 120K to 298 K
- Currently the ETS could not cool down to 165 K

Previous Cooldowns



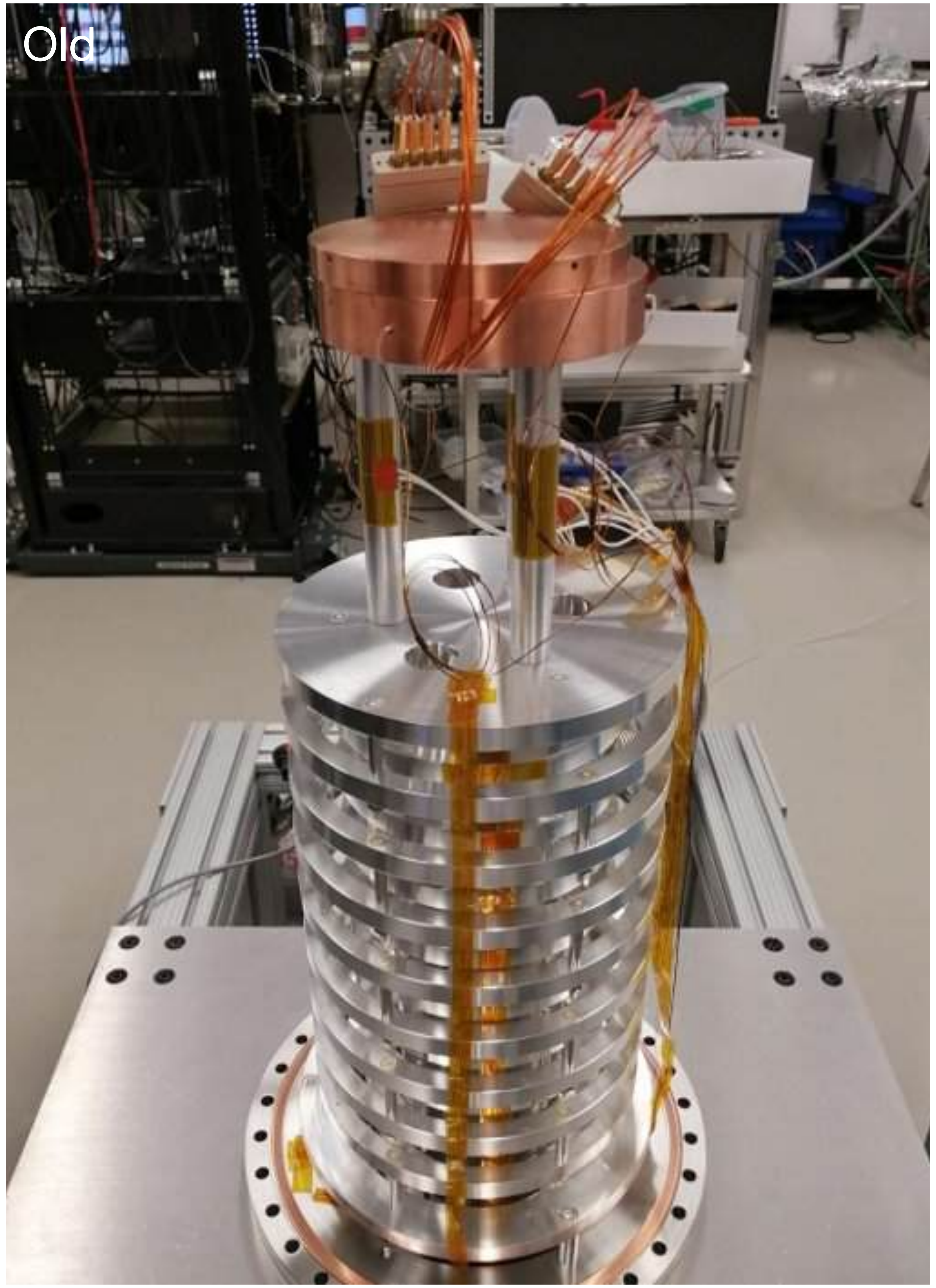
(PhD Thesis) Darroch, Lucas. "Testing silicon photomultipliers with vacuum-ultraviolet light for nEXO." (2025).

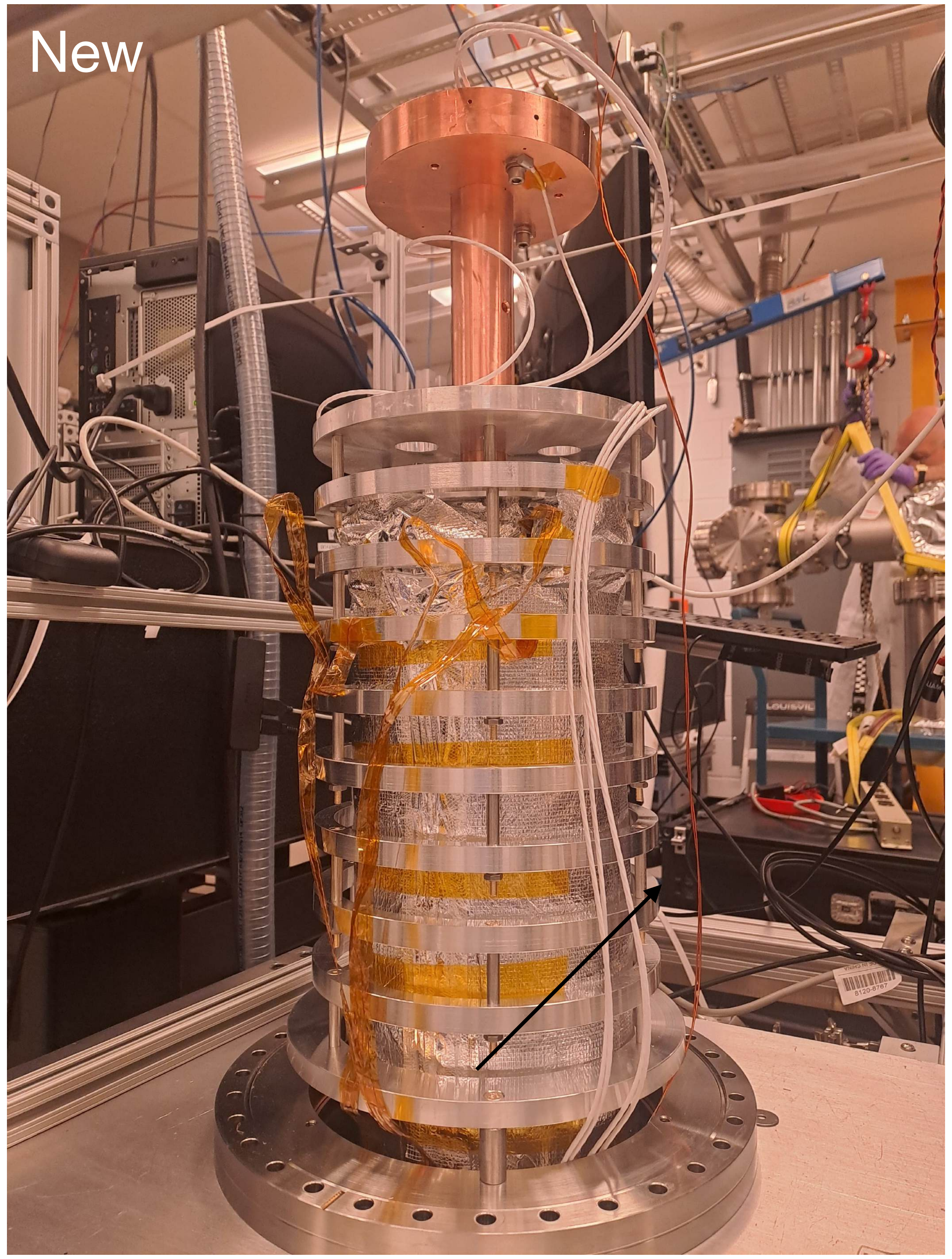


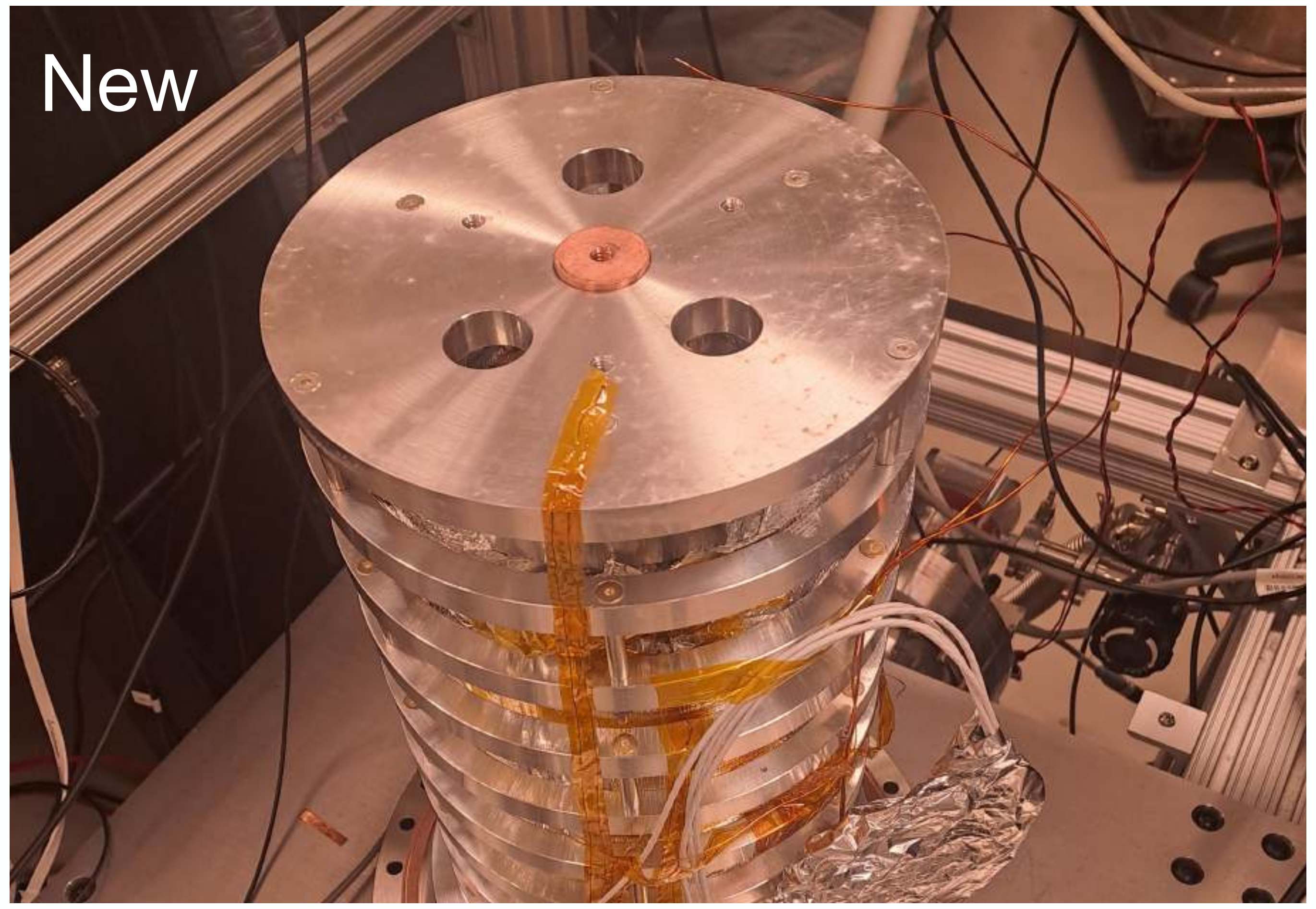
ETS Sectional View

Upgrade 1

Central Copper Rod





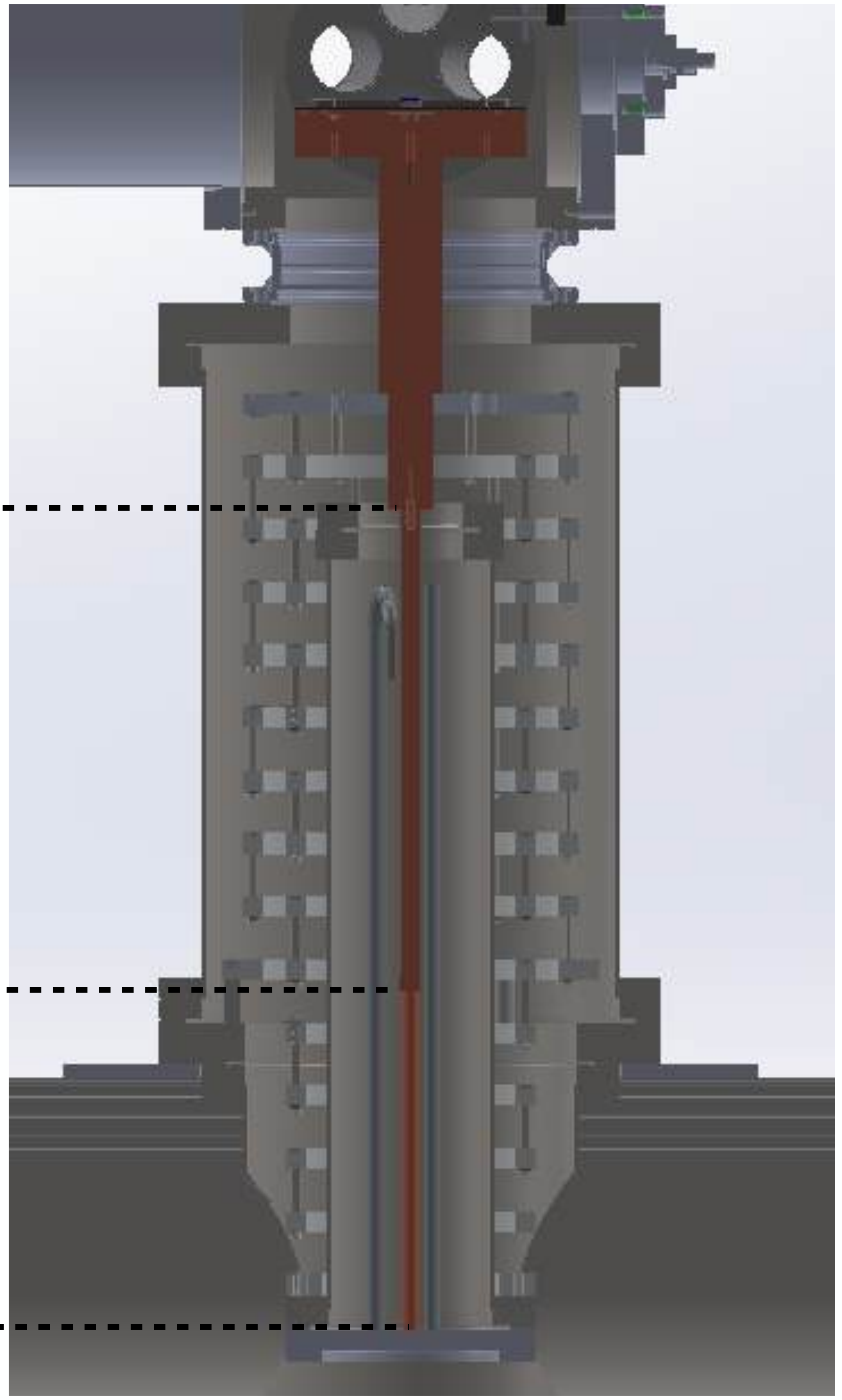


- Central rod is copper, more efficient heat conduction than aluminium
- Increased surface area for conduction
- Central copper rod bypasses the top aluminium plate

Upgrade 2

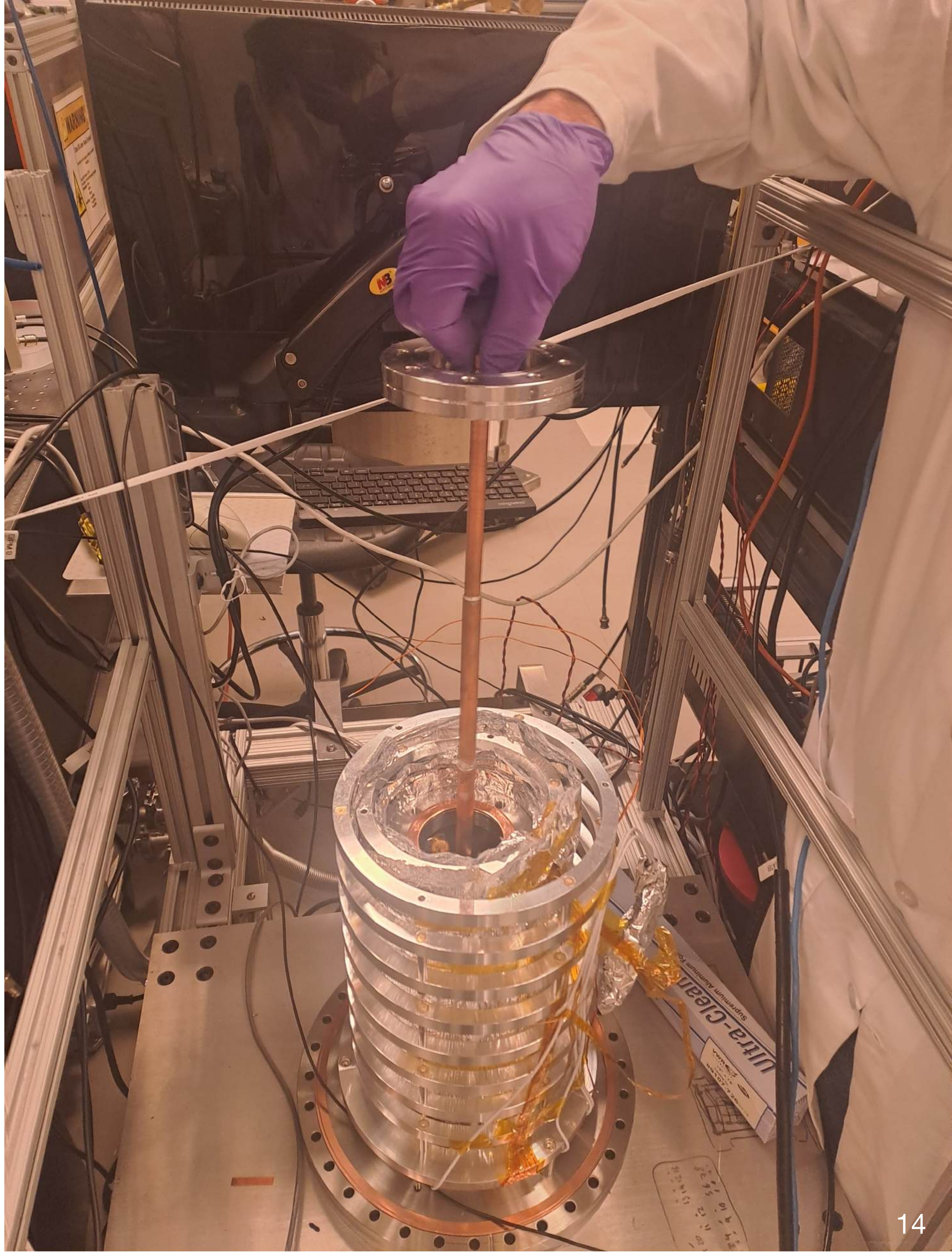
Extending the Copper Finger

- To better utilise all the LN2 in the cryostat
- Copper tubing extension to reduce sudden heat exchange, reduced turbulence

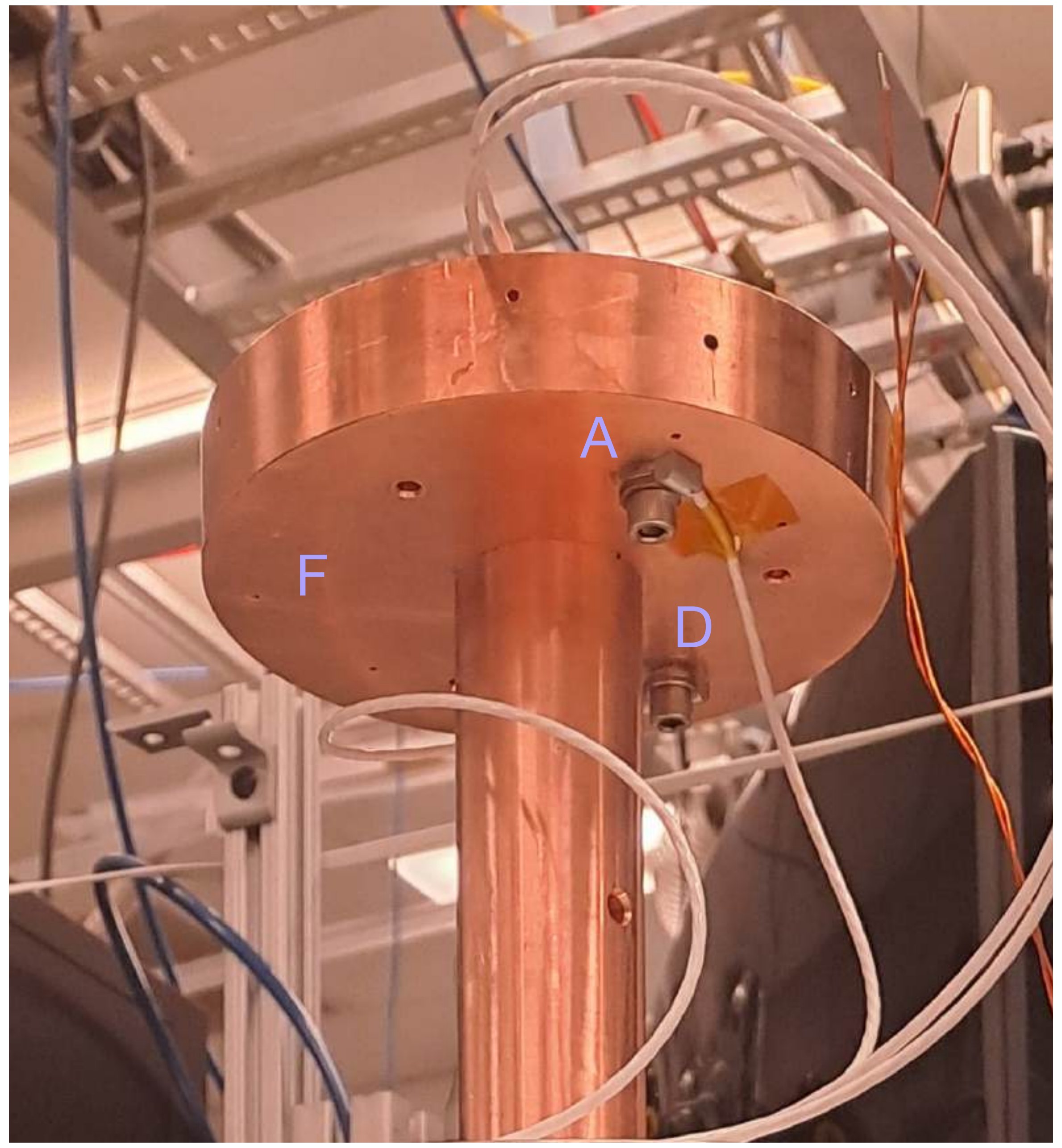


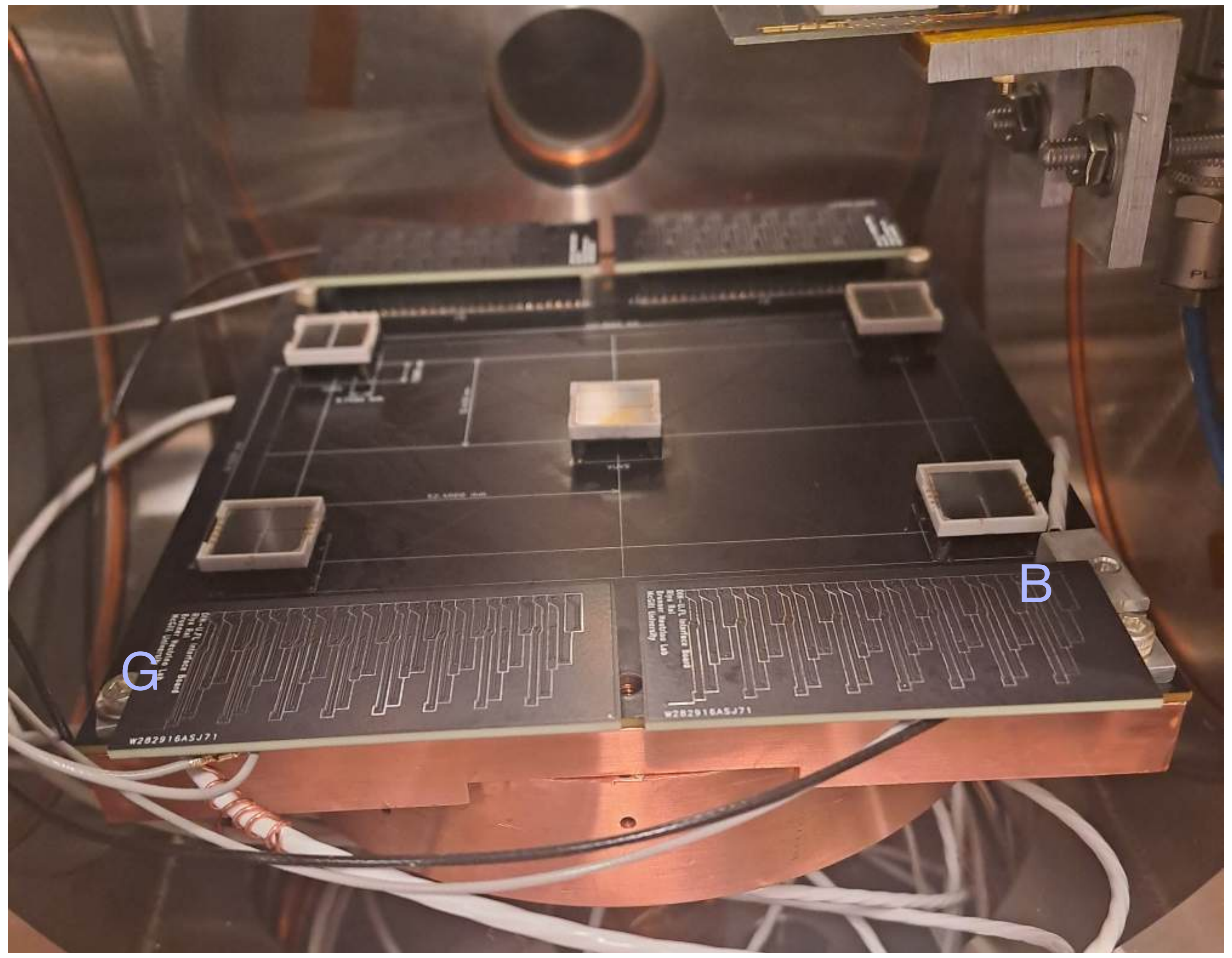
Old length = 280 mm

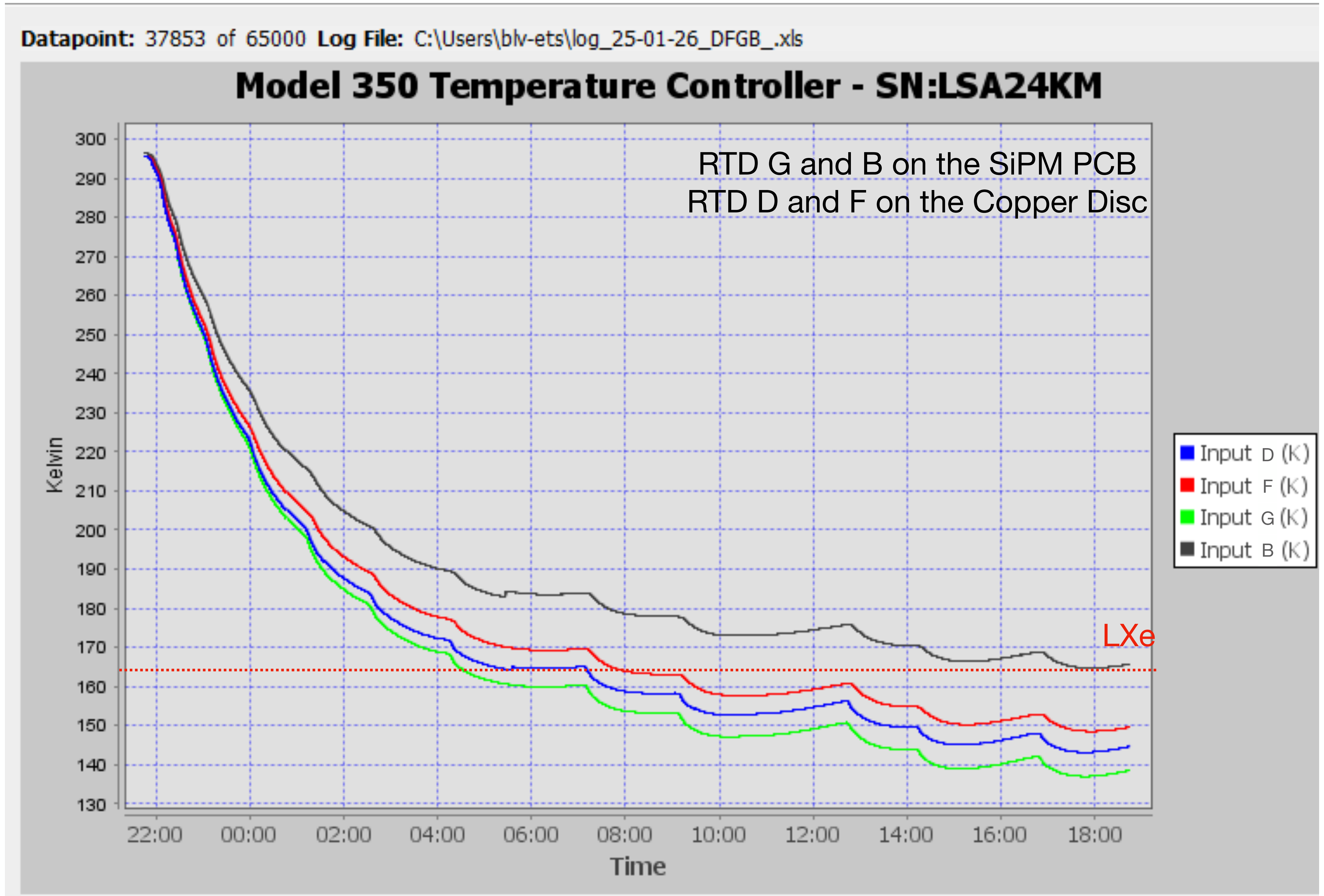
New length = 480 mm



Results

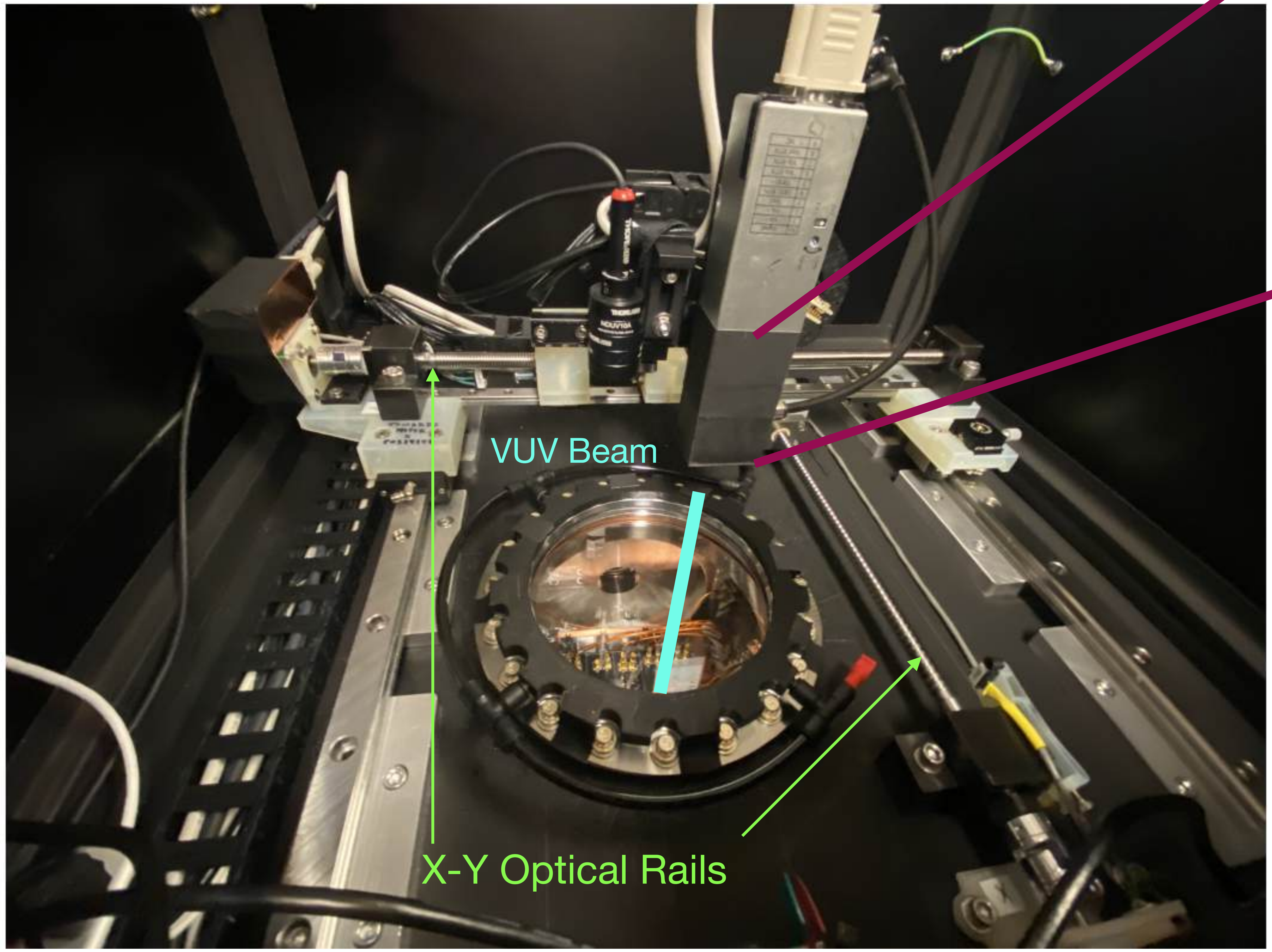


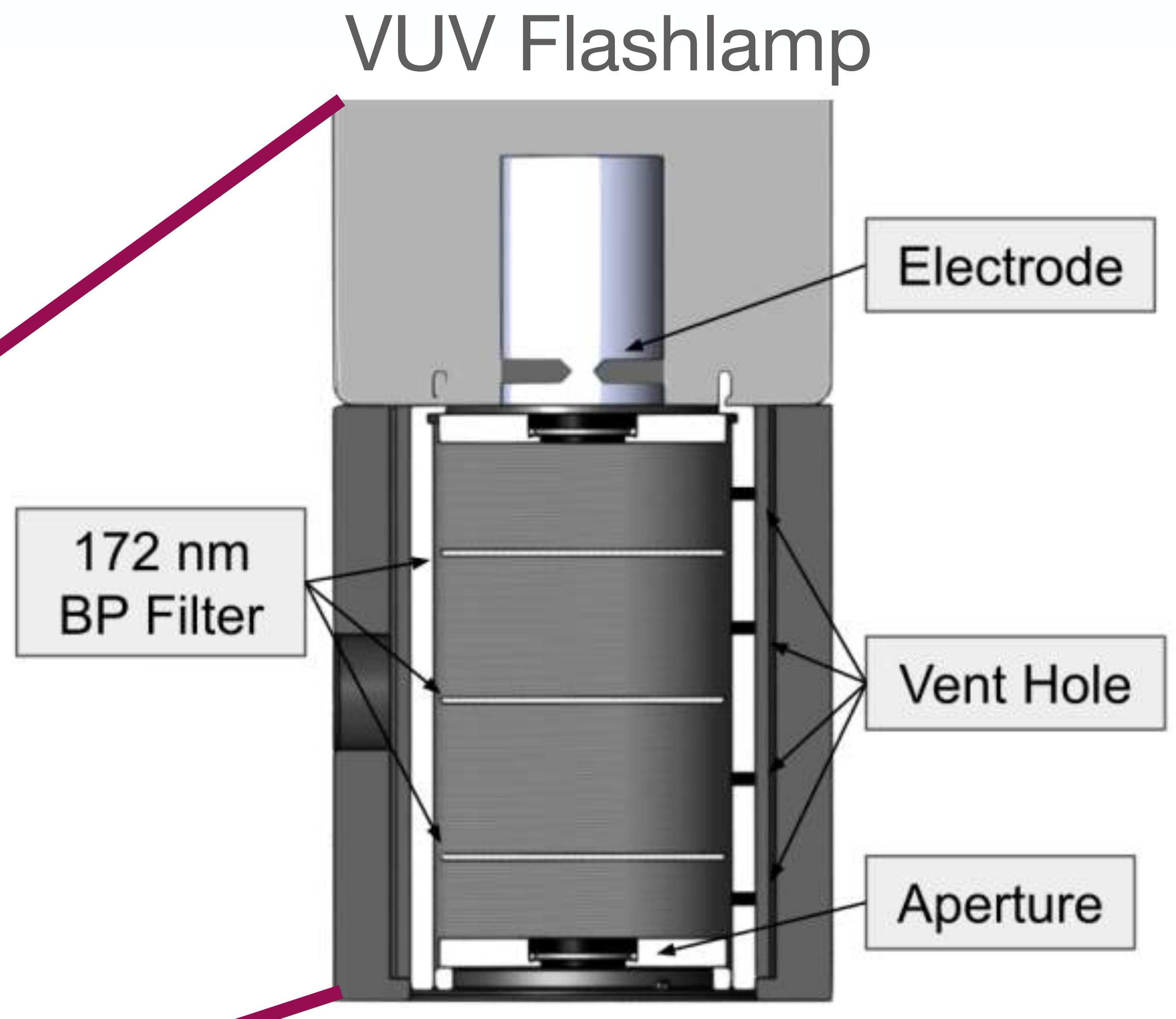


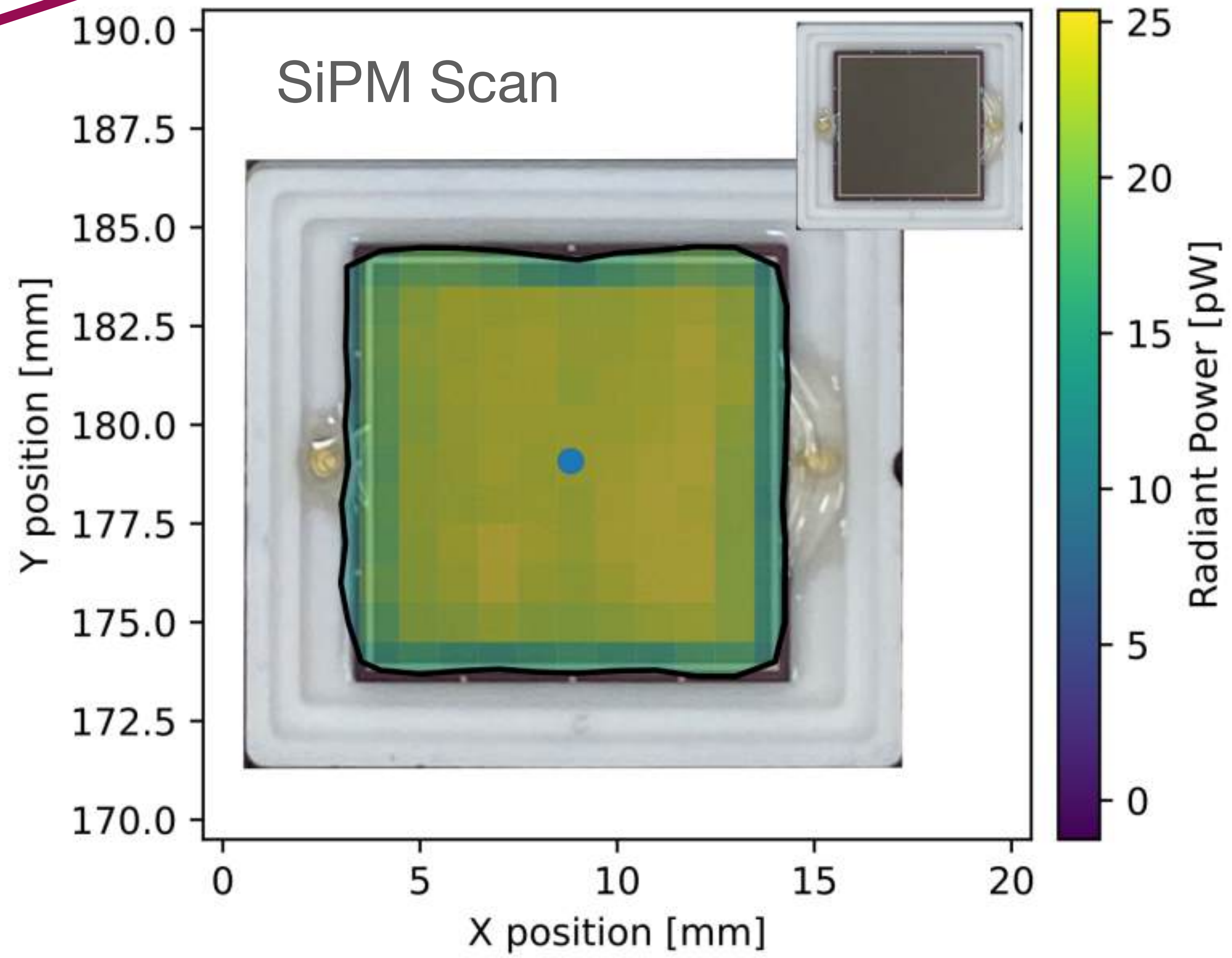


- Cryostat can now cool down well below 165 K
- RTD data from different cryostat parts obtained through multiple cooldown tests

ETS Scanning system

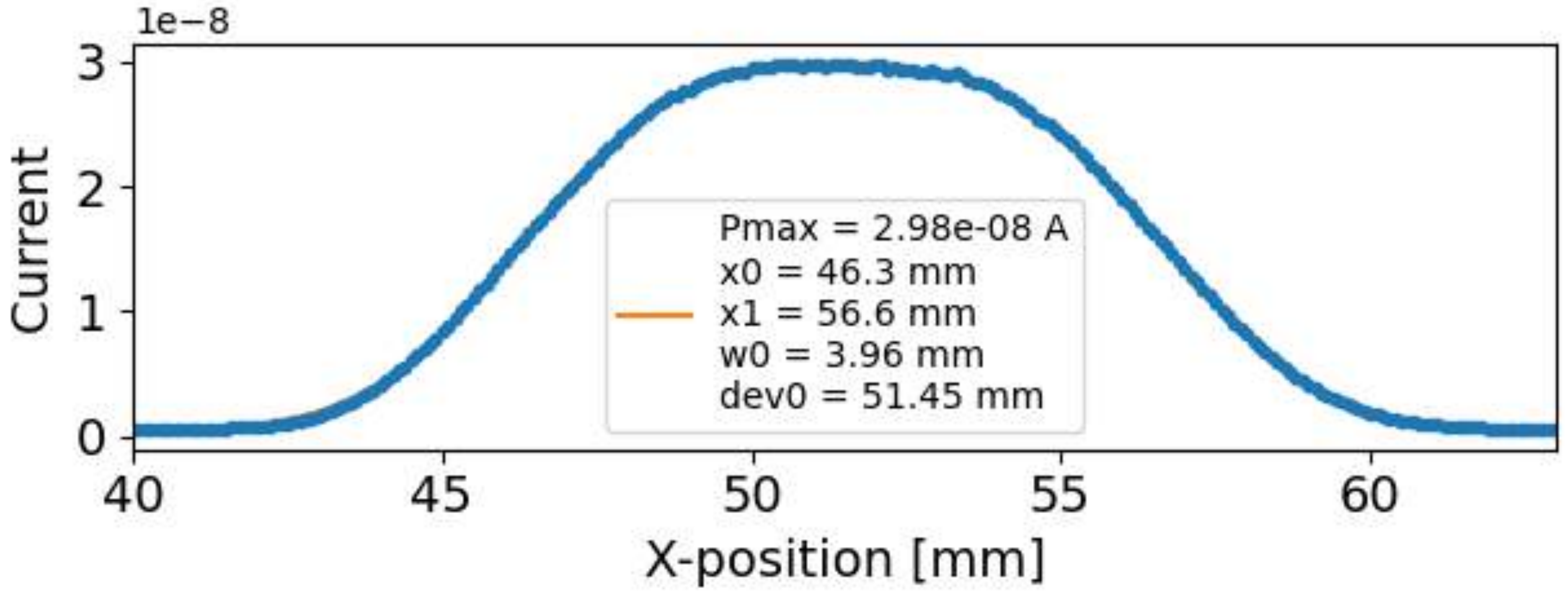






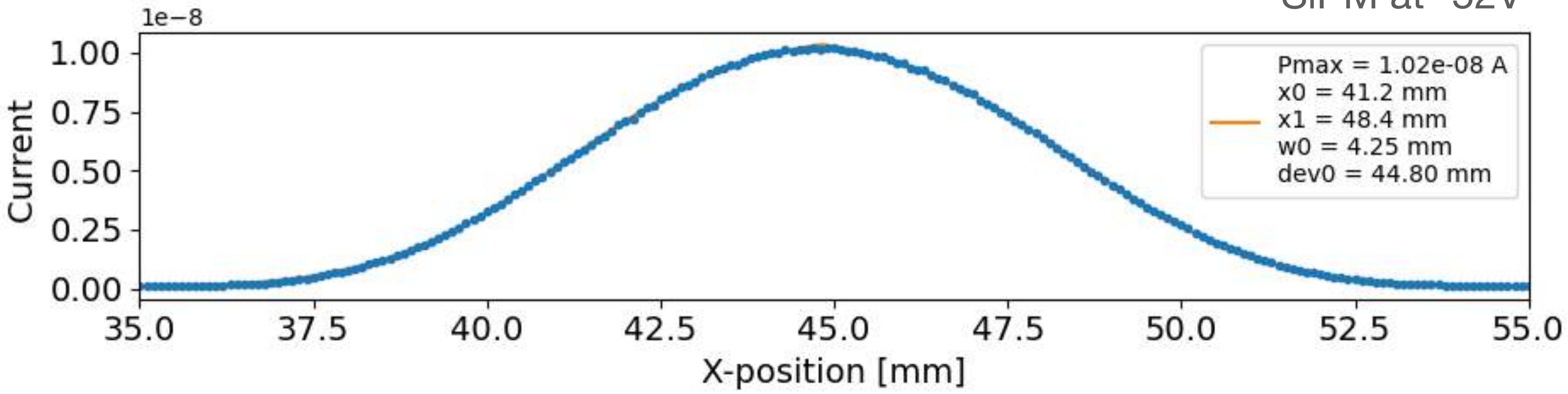
VUV Stability Calibration

Beam calibration using Photo Diode Scanning



Beam calibration using SiPM Scanning

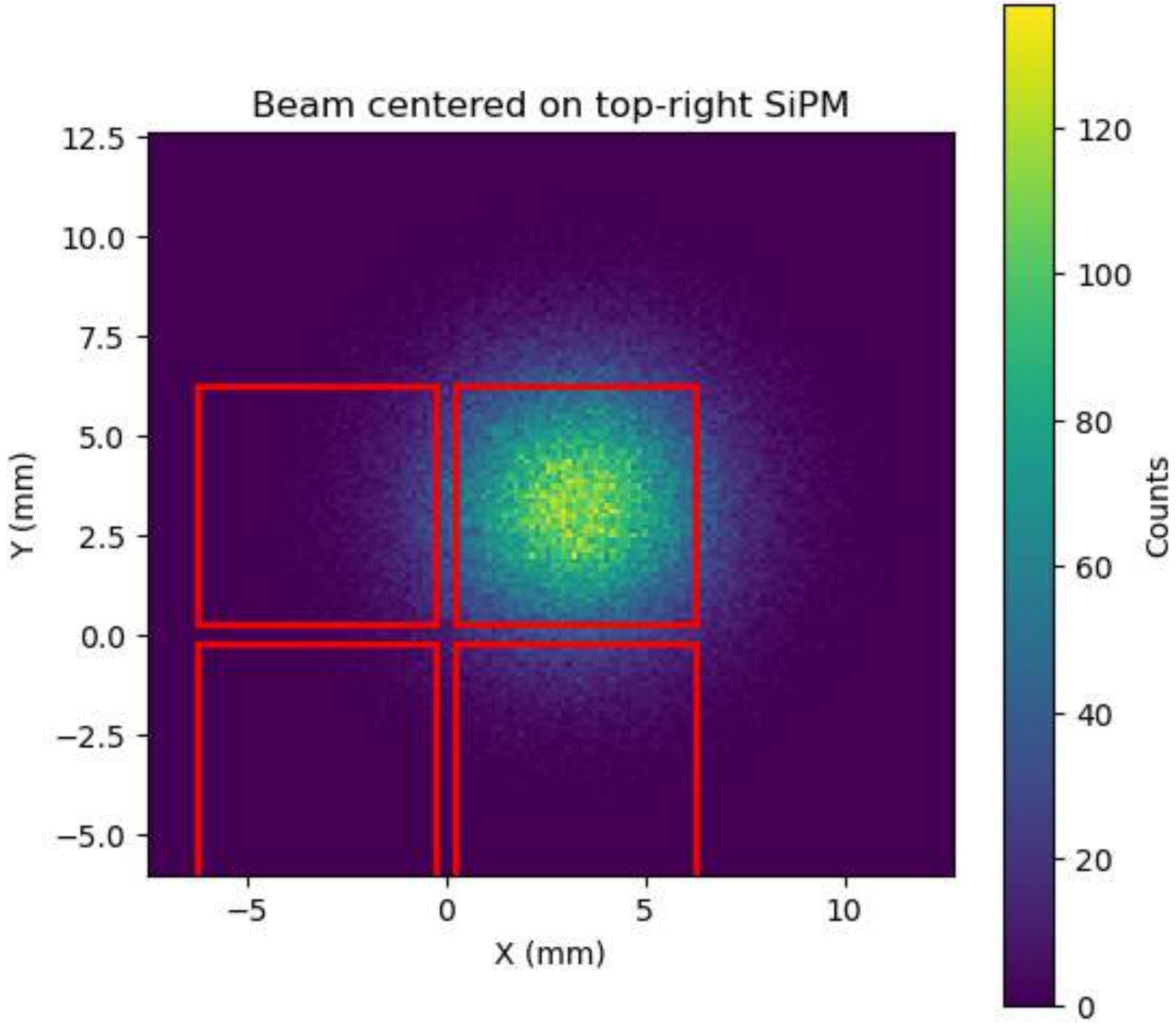
SiPM at -52V



X-Y using flashlamp to determine:

- beam dimensions and intensity of light.
- Max current on the PD to calculate the flashing period to reach the required exposure.

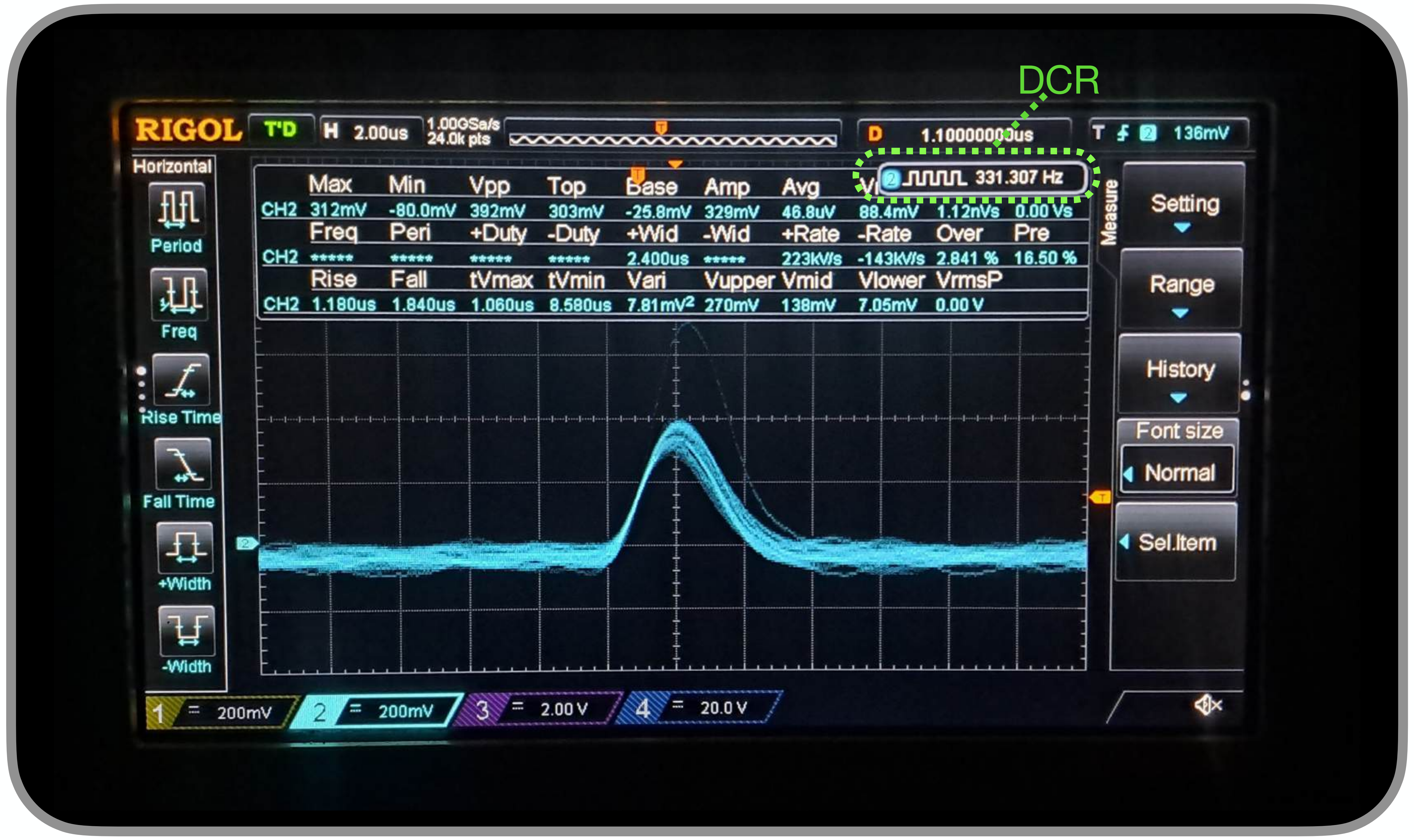
Beam Monte Carlo using SiPM Scanning



- 70% of the expected power reaches the SiPM
- Total required flashing period = 82.6 hrs

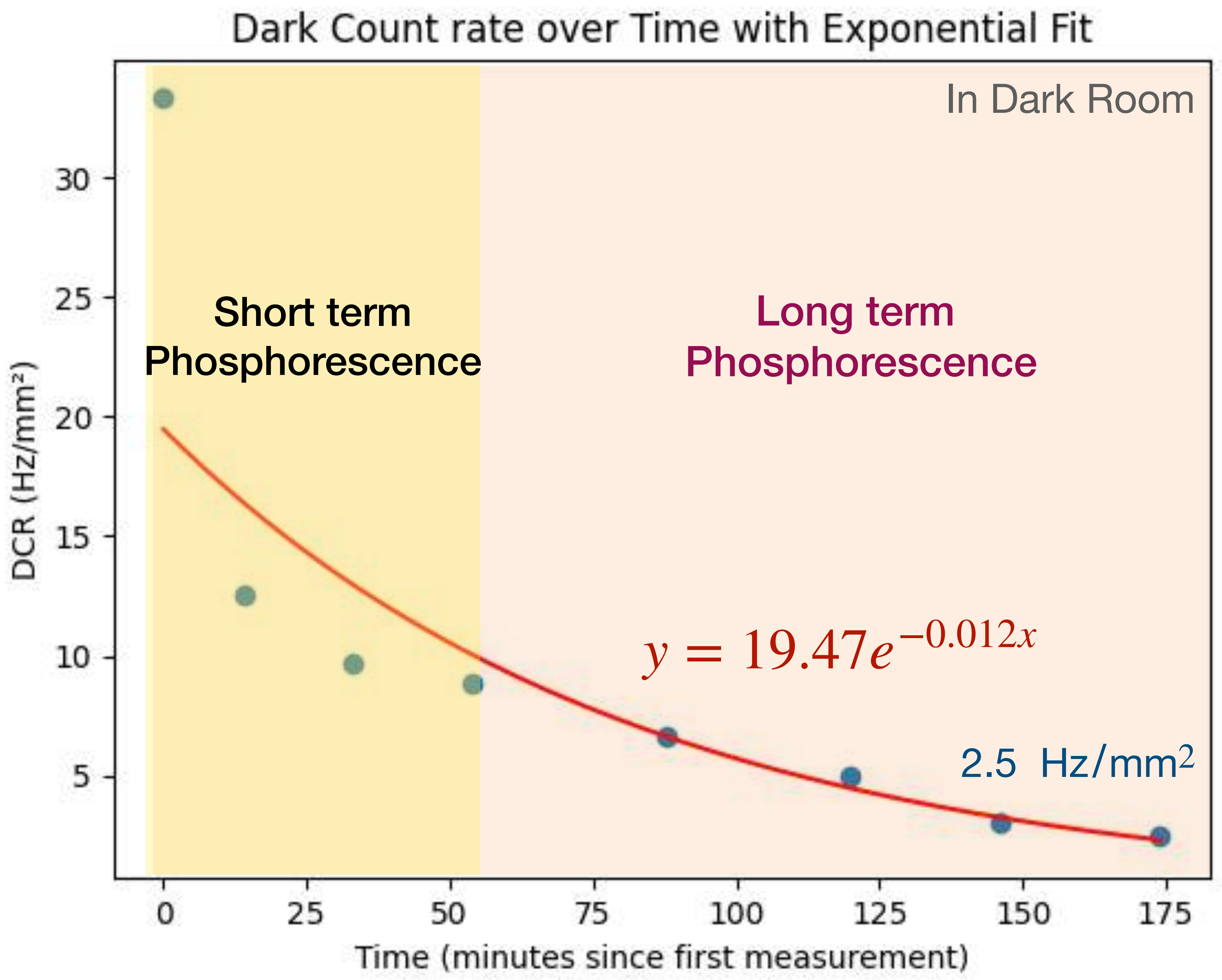
Light Leak Tests

- Unusually higher DCR than expected at 165K
- Light leaks into the ETS
- Goal to reach < 1 Hz/mm^2



Single Photon Counting through SiPM pulse mode testing

- Sealed all light leaks in the setup
- 8 days after closing the box measured a DCR of 0.6 Hz/mm^2
- Need to cover all parts which phosphoresce.

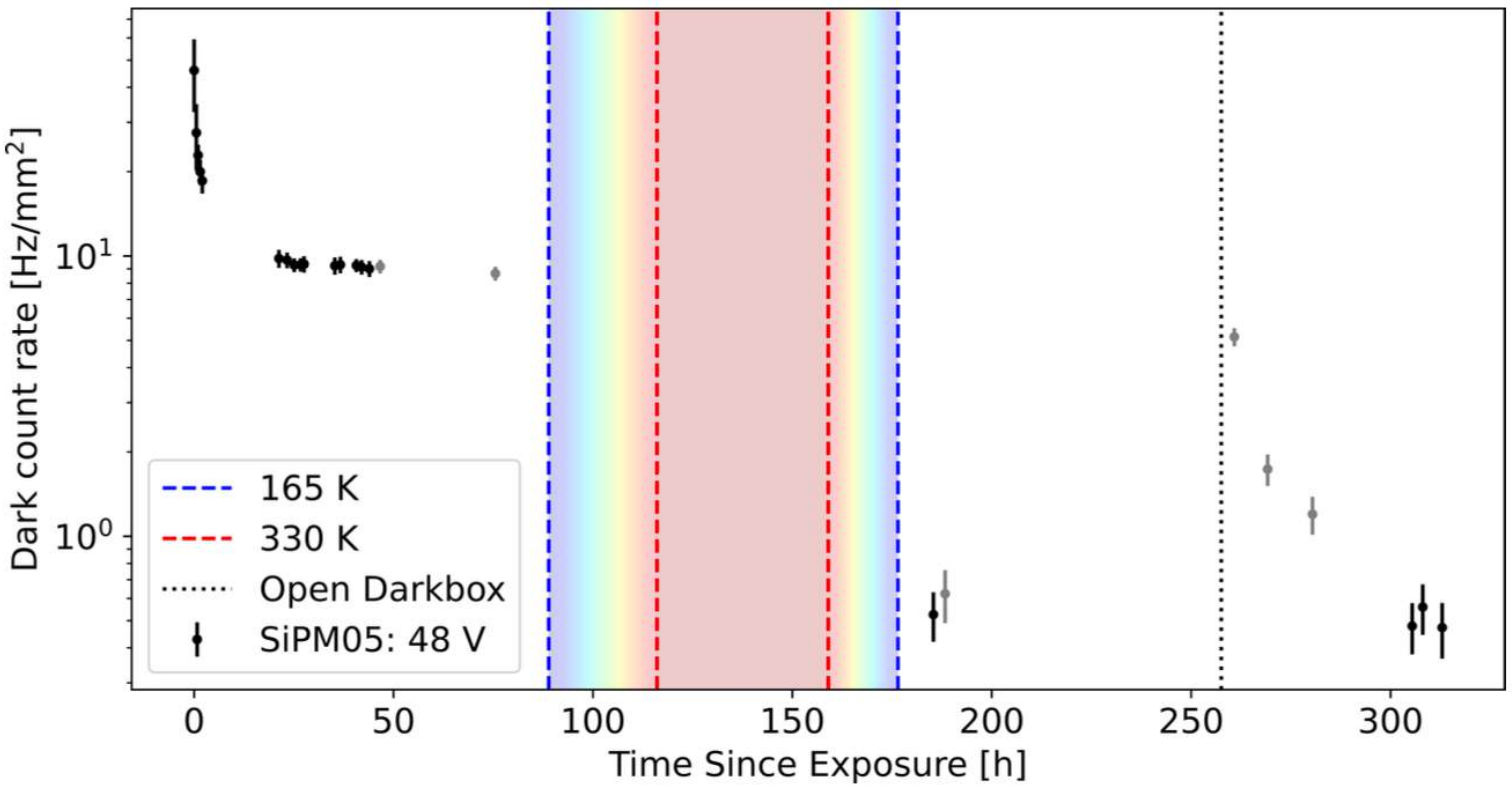


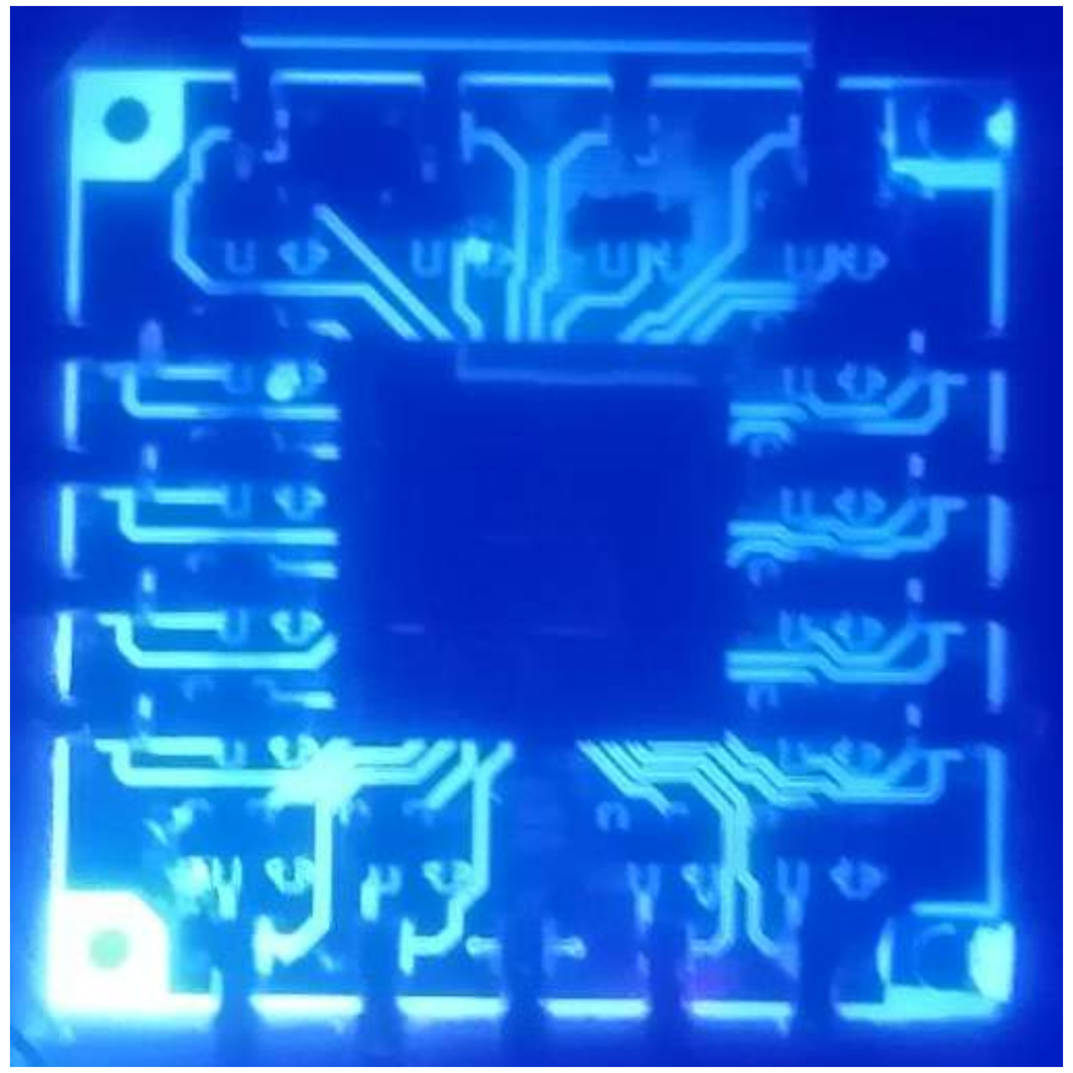
Summary

- The ETS has been upgraded for efficient and powerful cooldowns to 165 K
- Calibration measurements for the VUV tests completed
- We have measured low enough DCR, will soon complete stability measurements

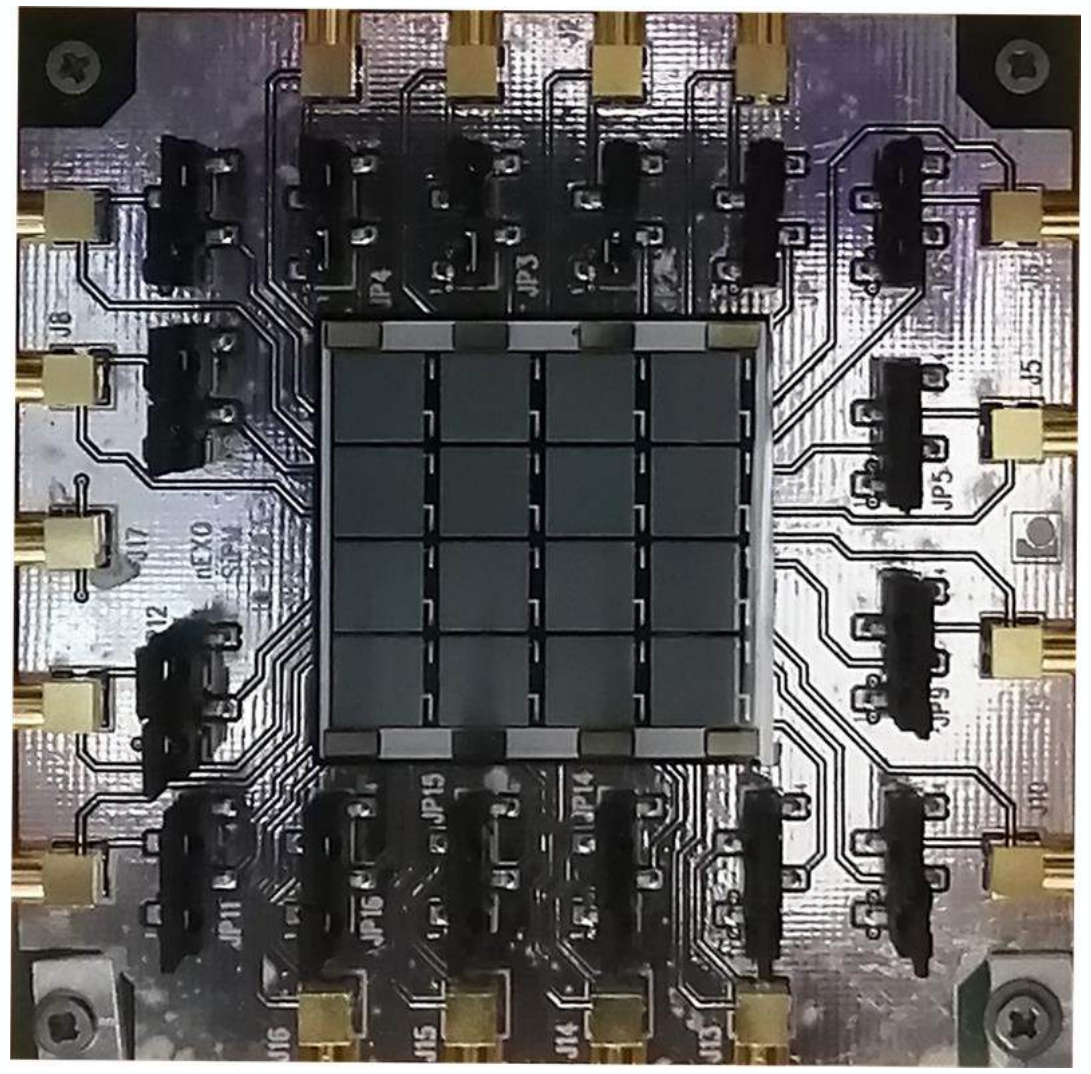
Phosphorescence and DCR measurements

Previous Tests at McGill





Phosphorescence on the PCB

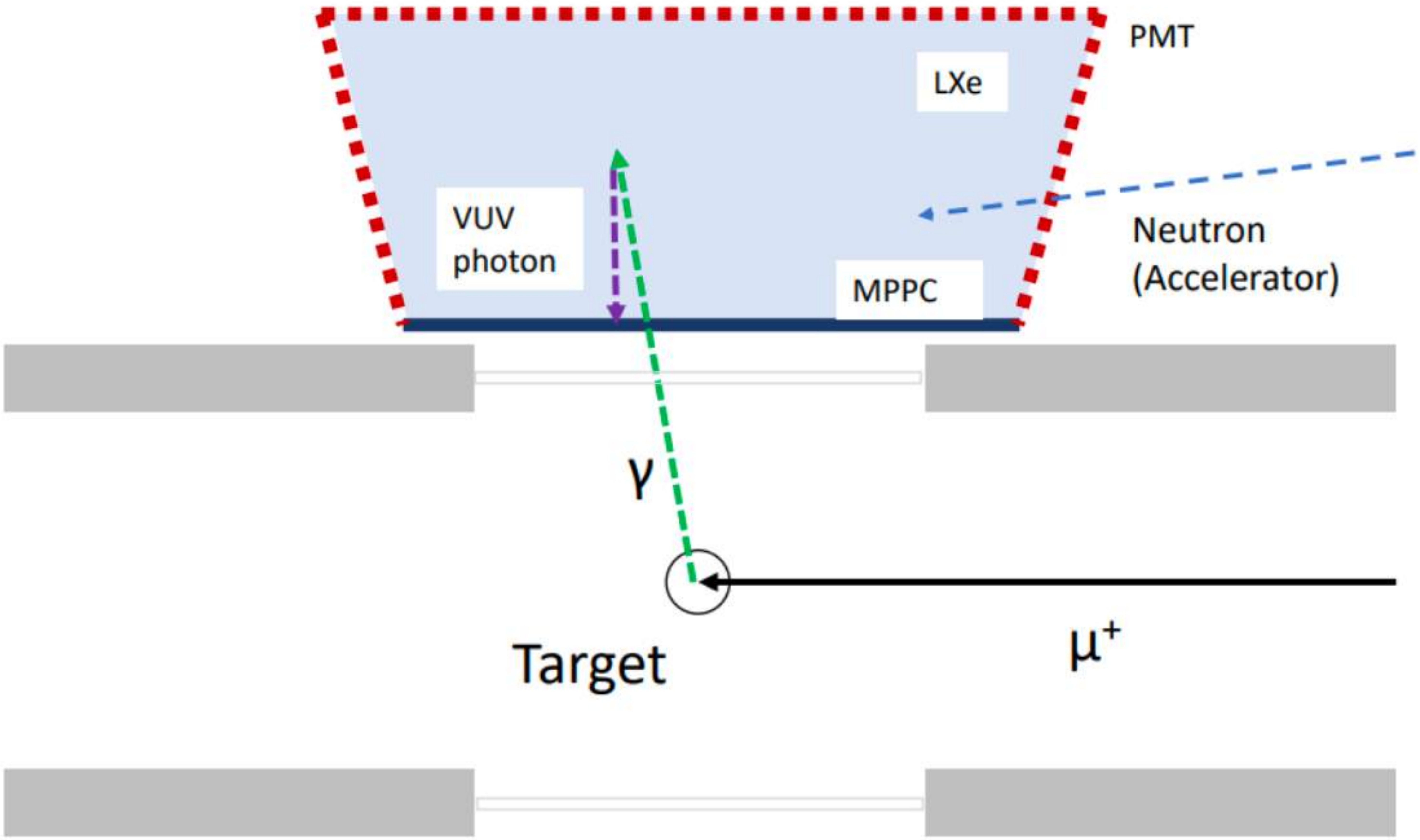


SiPMs tested previously at McGill

- Phosphorescence on the PCB substrate after VUV irradiation, measurements done after phosphorescence ended
- A more conclusive measurement needed that shows the onset of the elevated DCR from VUV irradiation.

Darroch, Lucas. "Testing silicon photomultipliers with vacuum-ultraviolet light for nEXO." (2025).

MEG II Experimental Area



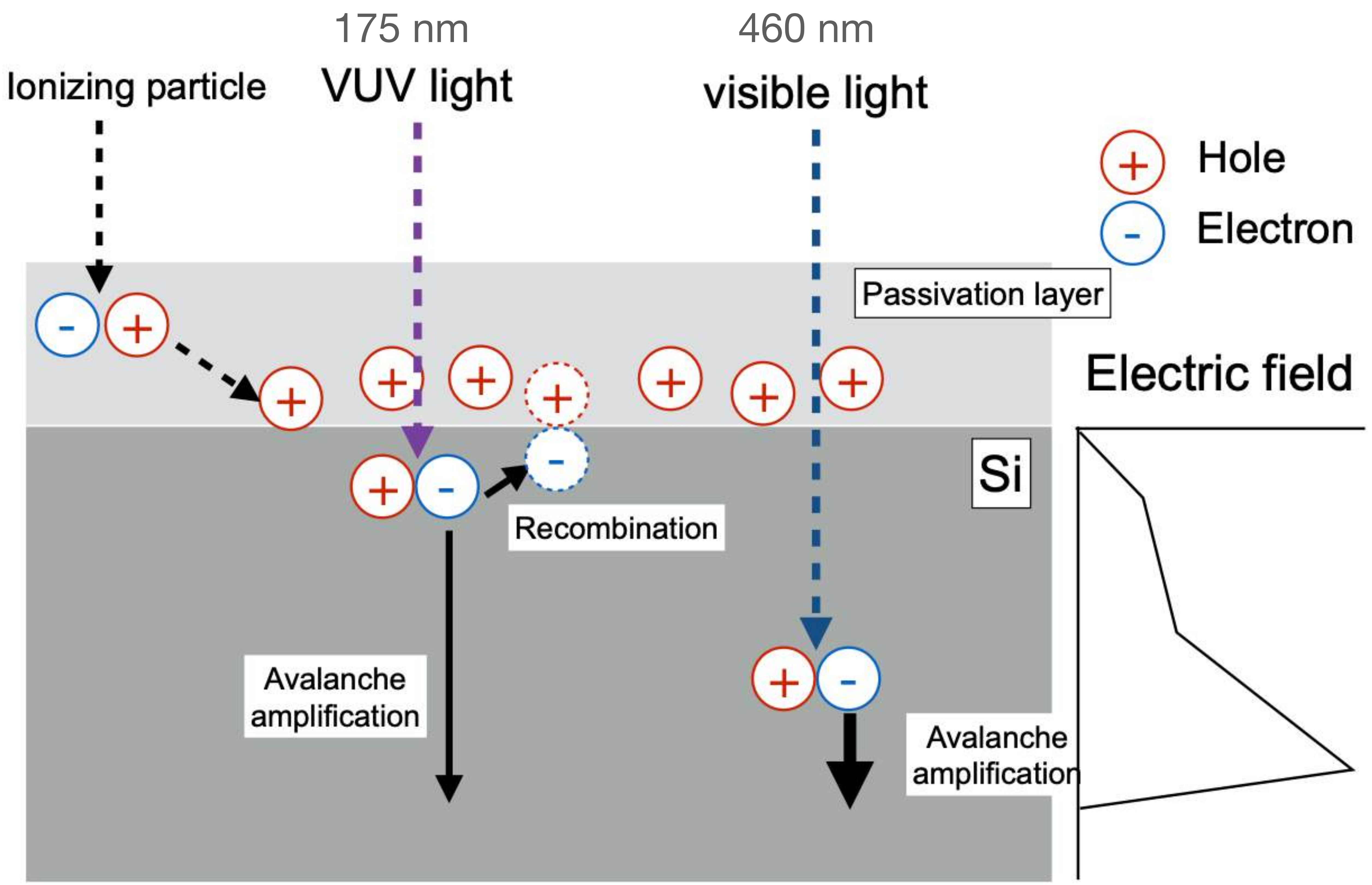
Ieki, K., et al. "Study on degradation of VUV-sensitivity of MPPC for liquid xenon scintillation detector by radiation damage in MEG II experiment." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1053 (2023): 168365.

Unexpected Sipm Damage

MEG II - HPK SiPM (S10943-4372) at 165 K

10 % decrease in photo detection efficiency (PDE) for VUV light

1% decrease in PDE for visible light exposure



- VUV light has a short attenuation length (6 nm)
- Visible light has a longer attenuation length (280 nm)

VUV light causes extensive ionisation surface damage

Ionising and Non-Ionising Radiation Damage

Ionising Damage

1. Energy transferred by ionisation, forming an electron hole pair in Si
2. Takes place on the top SiO_2 layer of the SiPM
3. Surface currents generated because of trapped holes in Si
4. Ionisation threshold of SiO_2 is 9eV.
5. Causes increased leakage current, possibly lower PDE

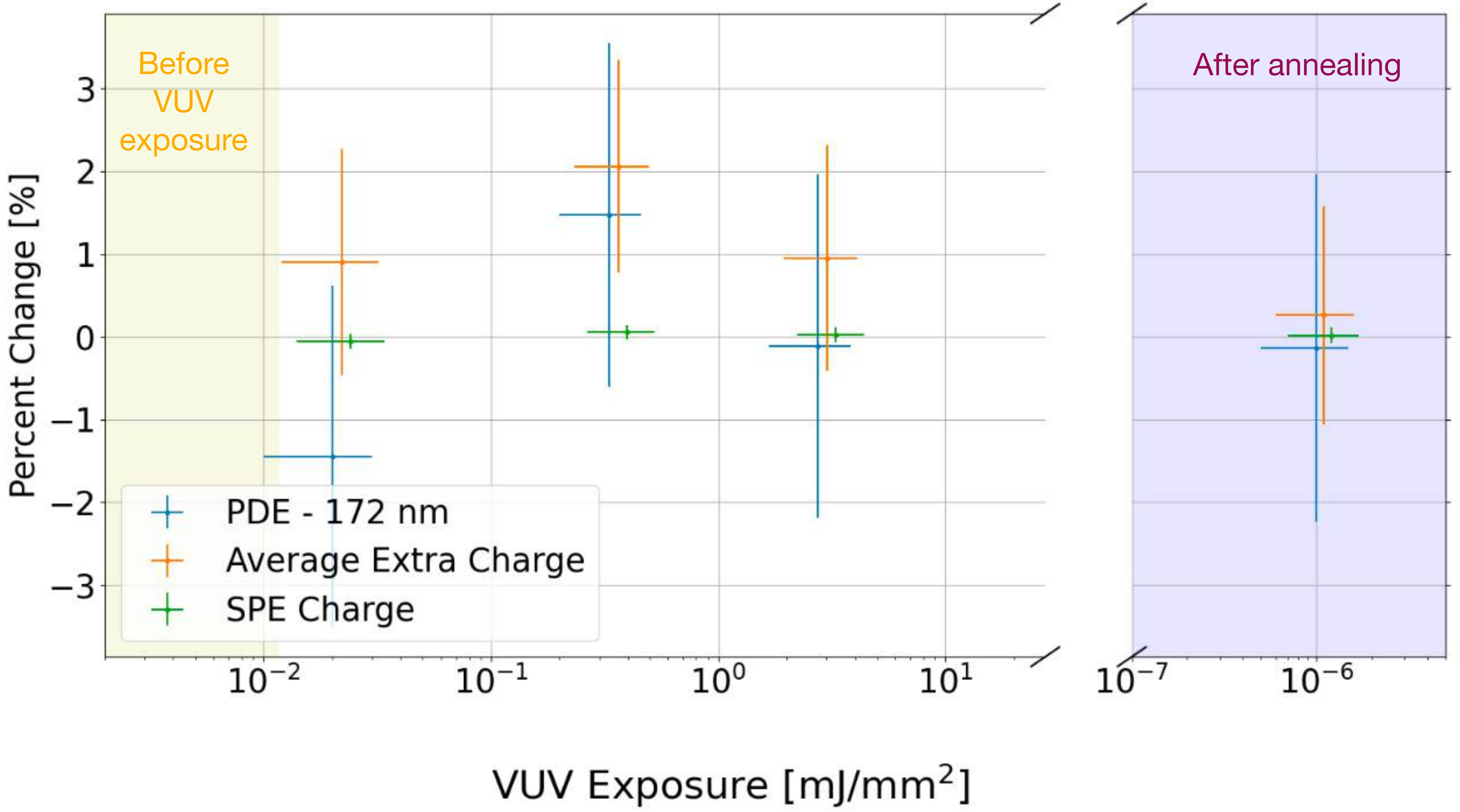
Non-Ionising Damage

1. Energy transferred in lattice by displacing an Si atom, leaving a vacancy
2. Takes place in the bulk of the device
3. May cause afterpulsing due to increased defects in the lattice.
4. Damage threshold of 25 eV
5. Causes increased dark count rate and leakage current

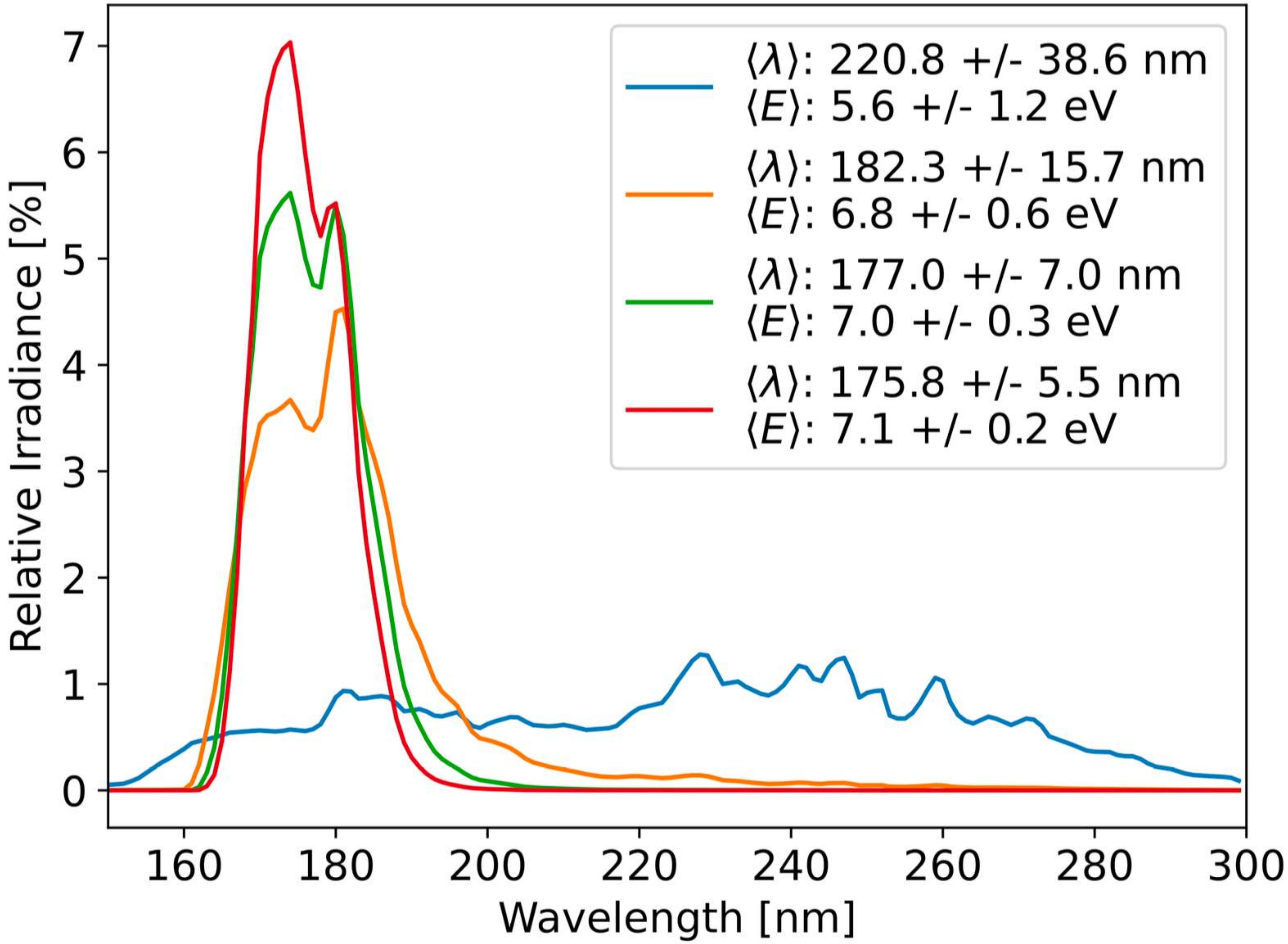
(PhD Thesis) Darroch, Lucas. "Testing silicon photomultipliers with vacuum-ultraviolet light for nEXO." (2025).

Previous Ionisation Damage Measurements

No change seen in PDE, SPE or Average Extra Charge



Flashlamp Emission Spectra



(PhD Thesis) Darroch, Lucas. "Testing silicon photomultipliers with vacuum-ultraviolet light for nEXO." (2025).