

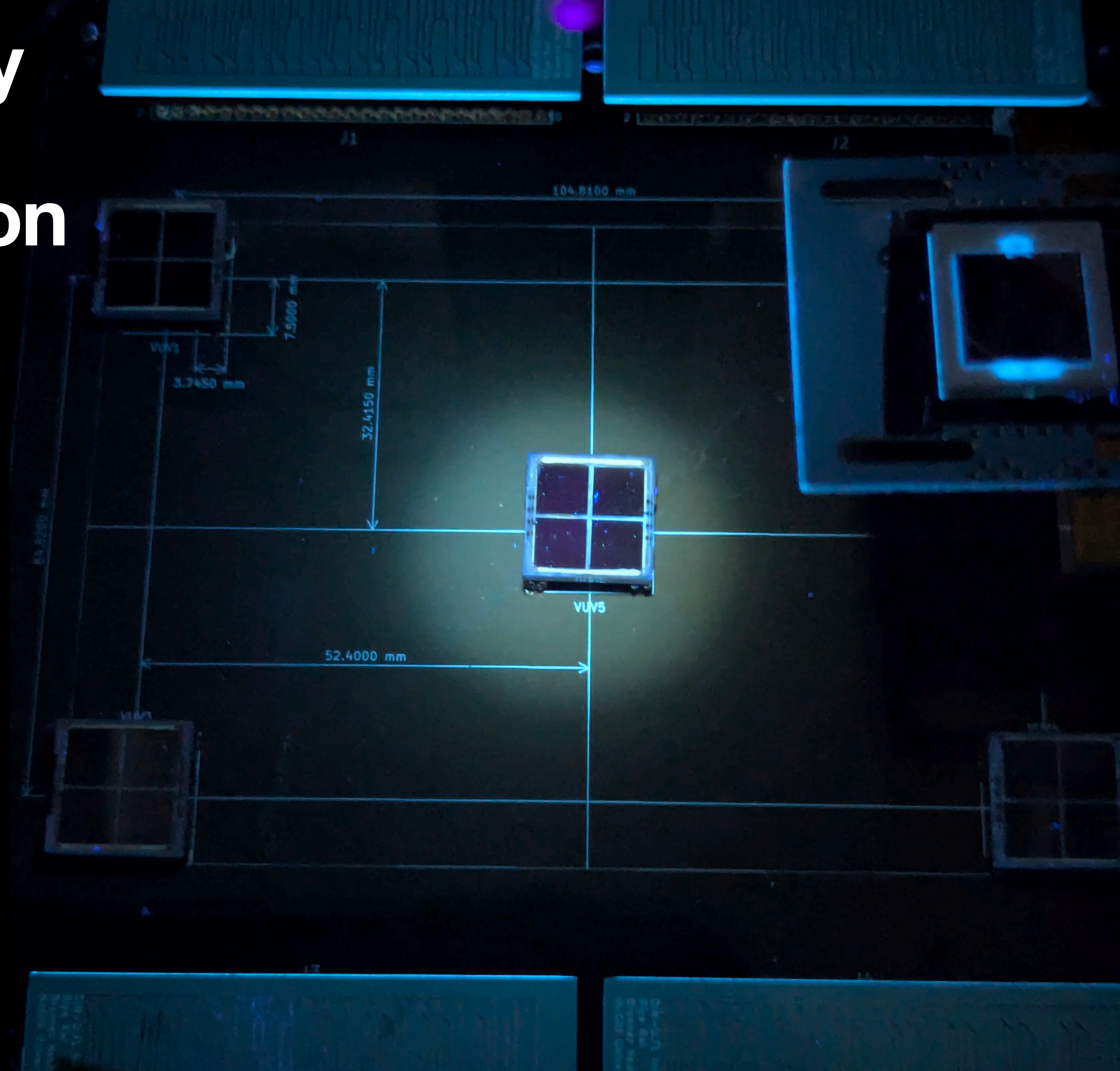
# Vacuum UV Stability Measurements of SiPMs at Liquid Xenon Temperature

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Brunner Neutrino Lab  
McGill University

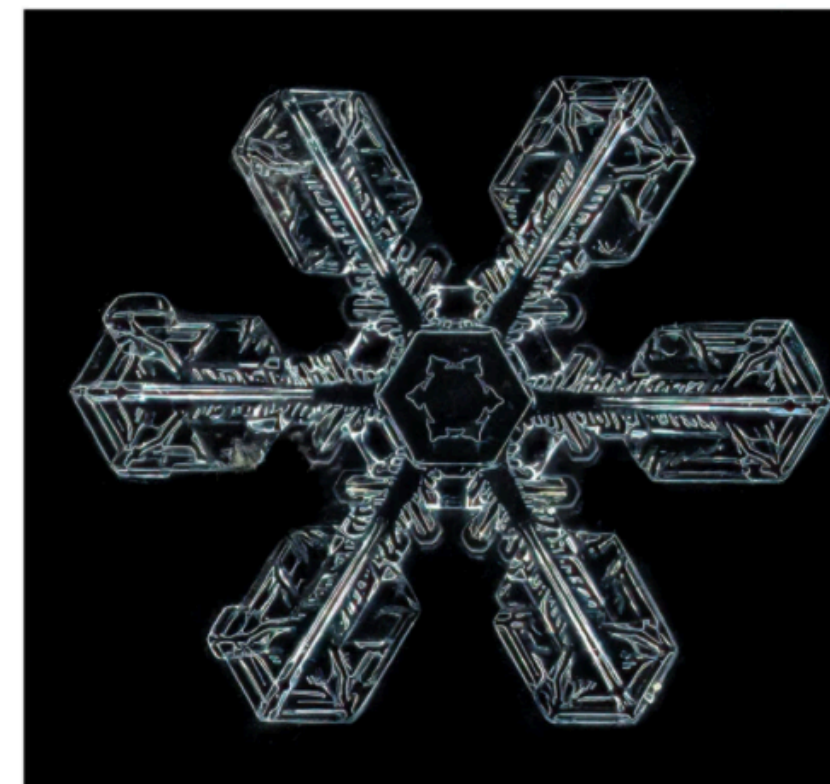
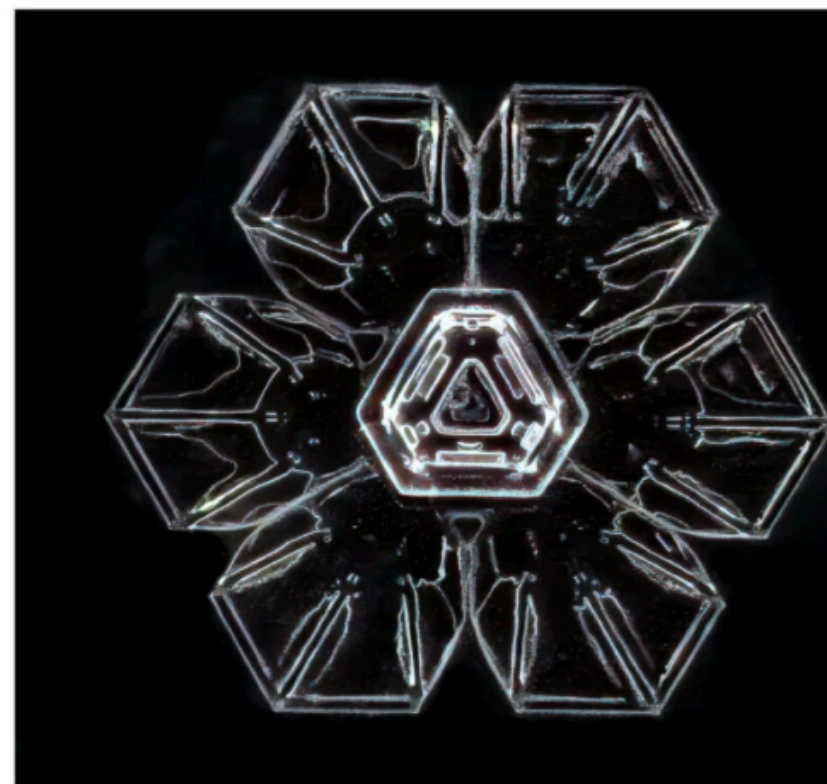
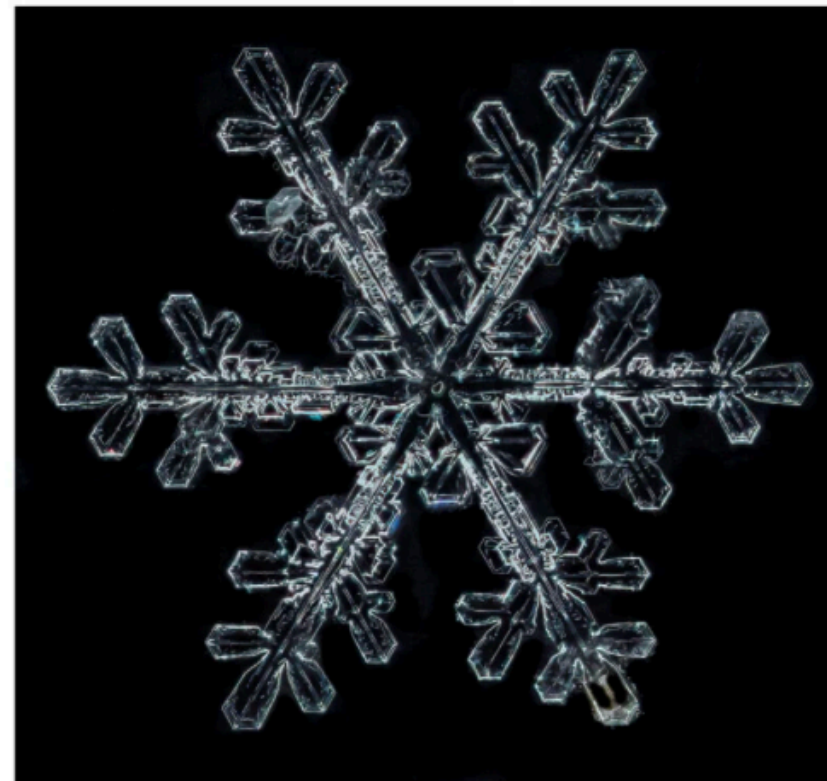
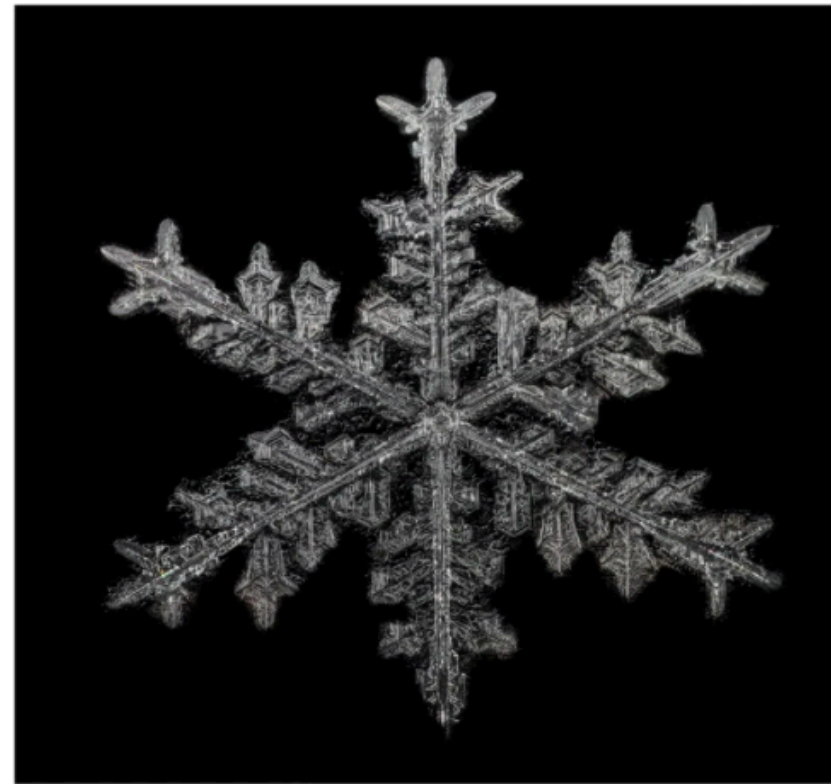


WNPPC 2026  
13th February 2026





# Nature Loves Symmetry!





Matter - Antimatter symmetry leads to a universe with only photons



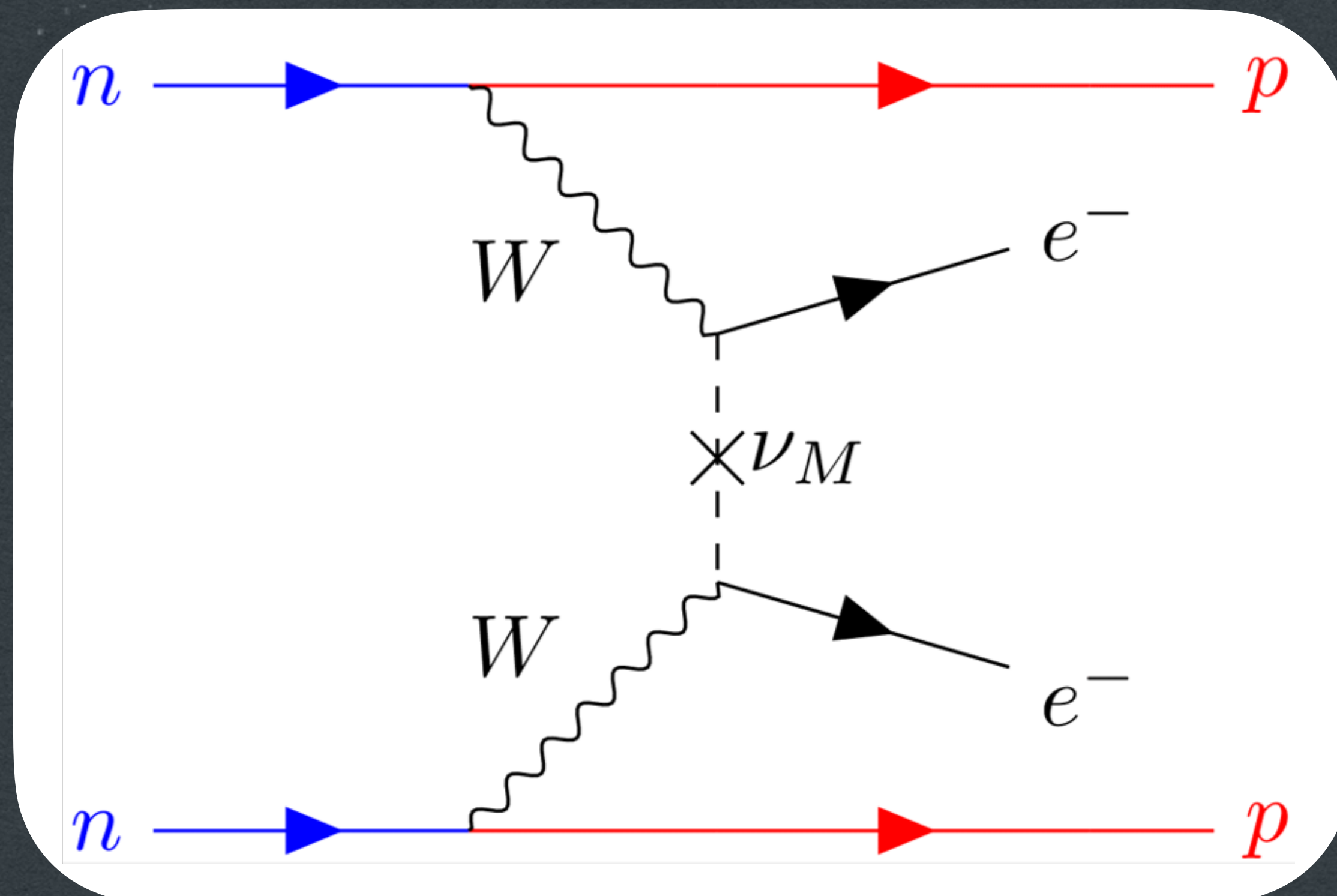
The background of the slide is the Hubble Ultra Deep Field image, which shows a vast field of galaxies. The galaxies are of various shapes and sizes, including spiral, elliptical, and irregular forms. They are scattered across a black background, with some appearing as bright, distinct objects and others as faint, distant points of light. The colors of the galaxies range from yellow and orange to blue and purple, representing different wavelengths of light captured by the Hubble Space Telescope.

Result of  $1/10^{10}$  primordial matter - antimatter asymmetry



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  $0\nu\beta\beta$



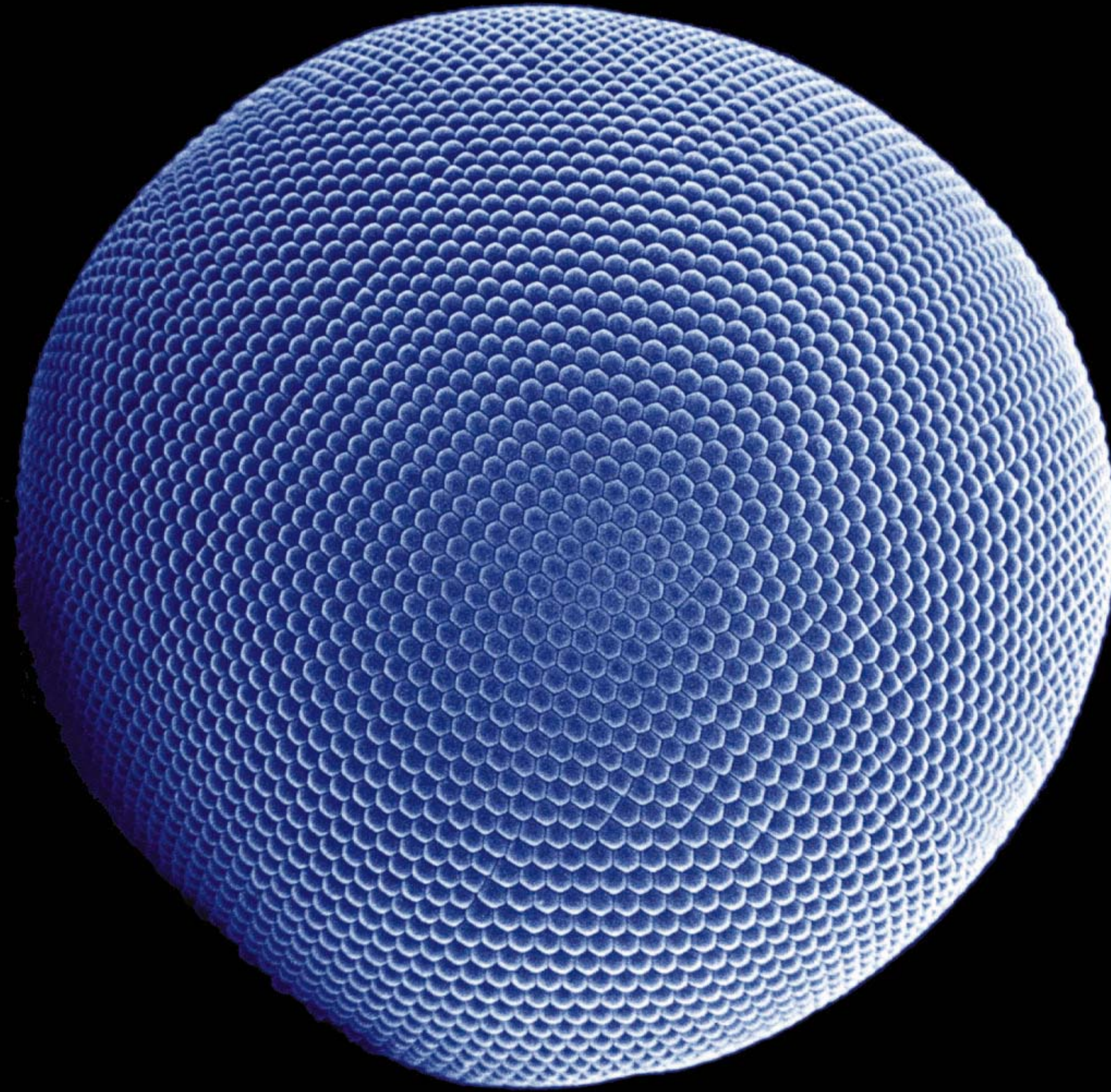
Observation of  $0\nu\beta\beta$  always implies new physics!

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

**nEXO** 



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

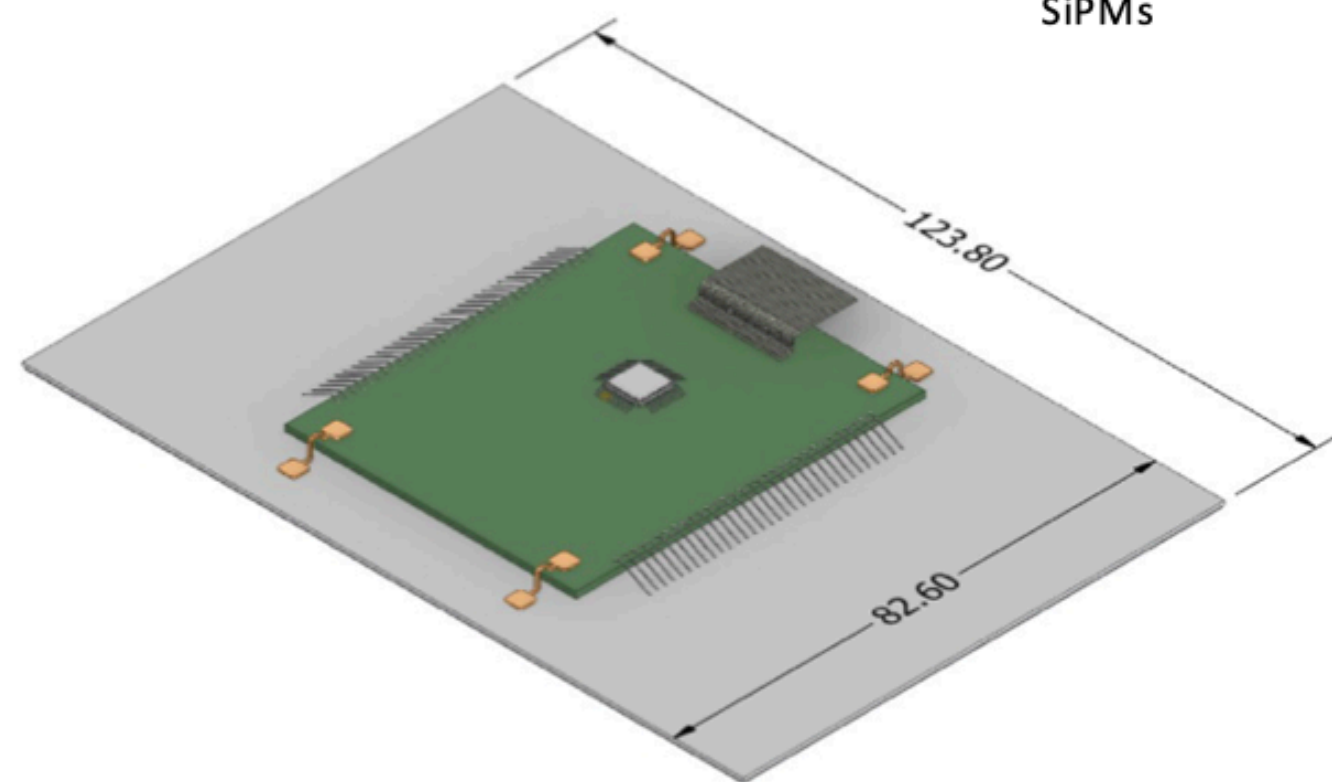
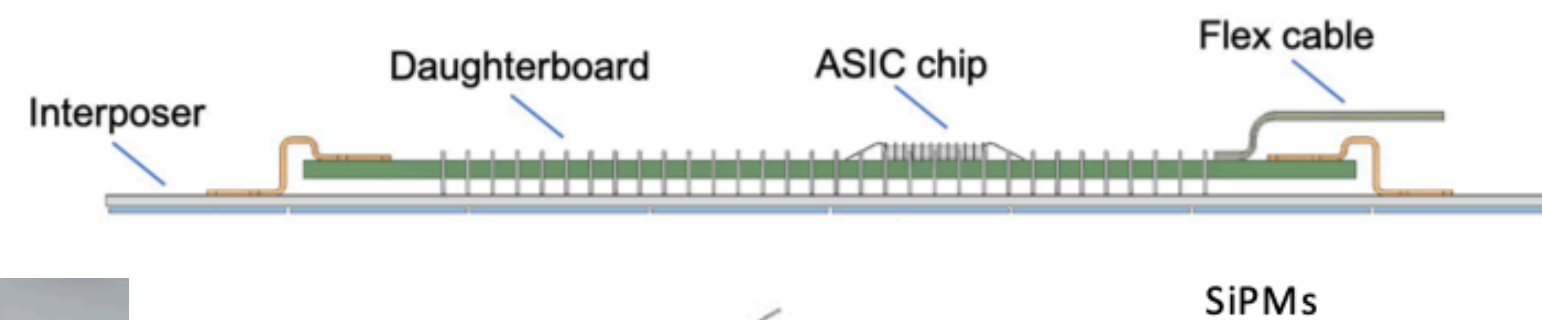


Compound eye of an antarctic krill



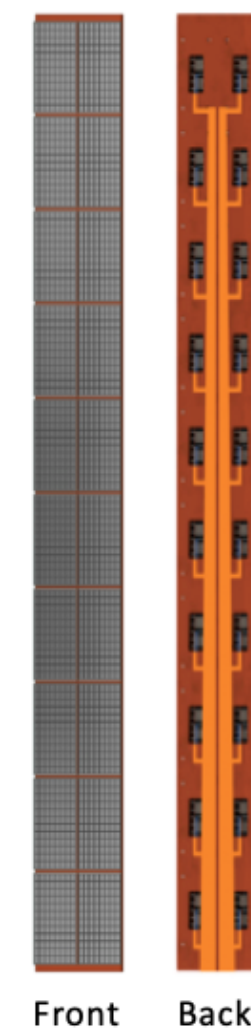
# nEXO Photodetection System Concept

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

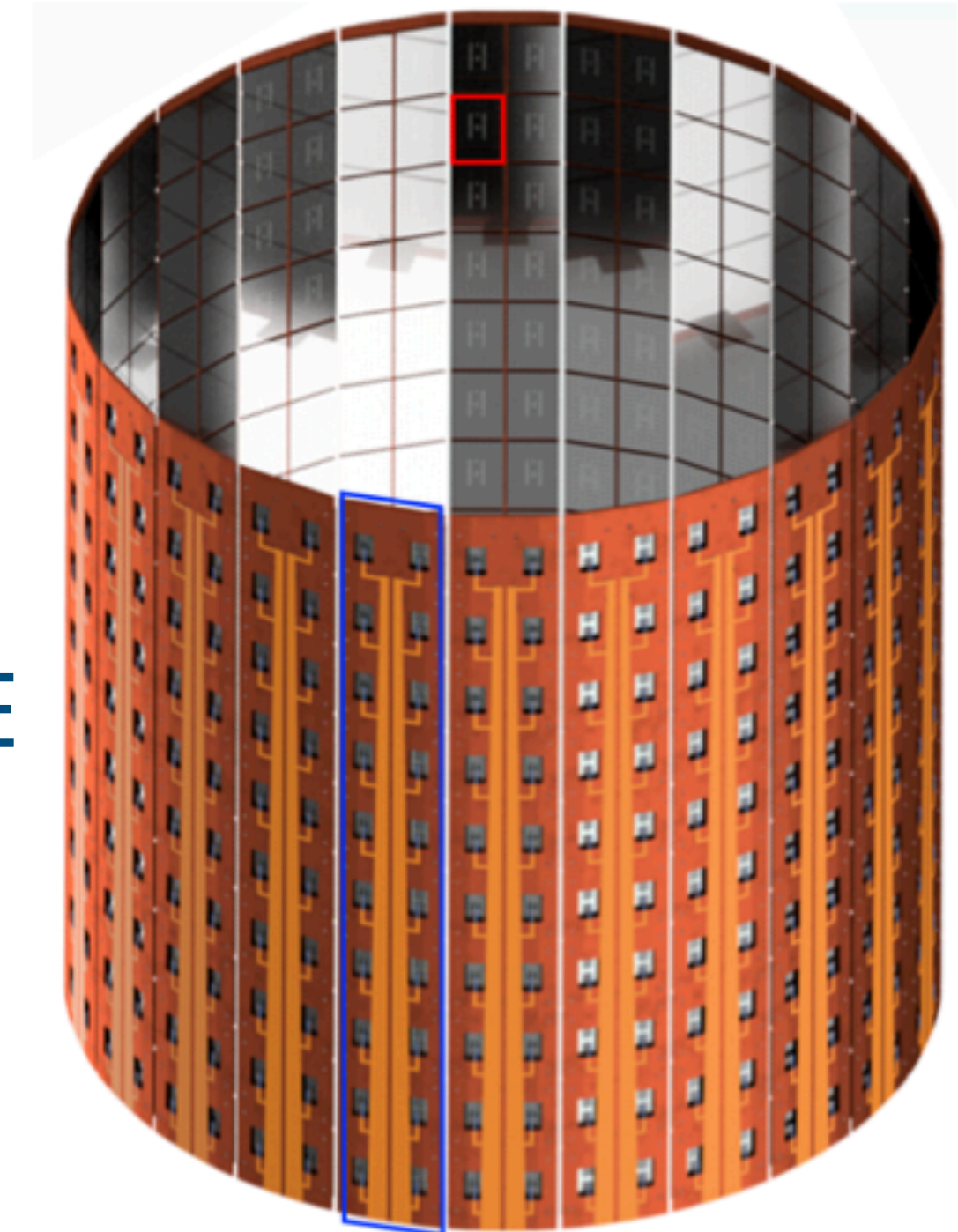
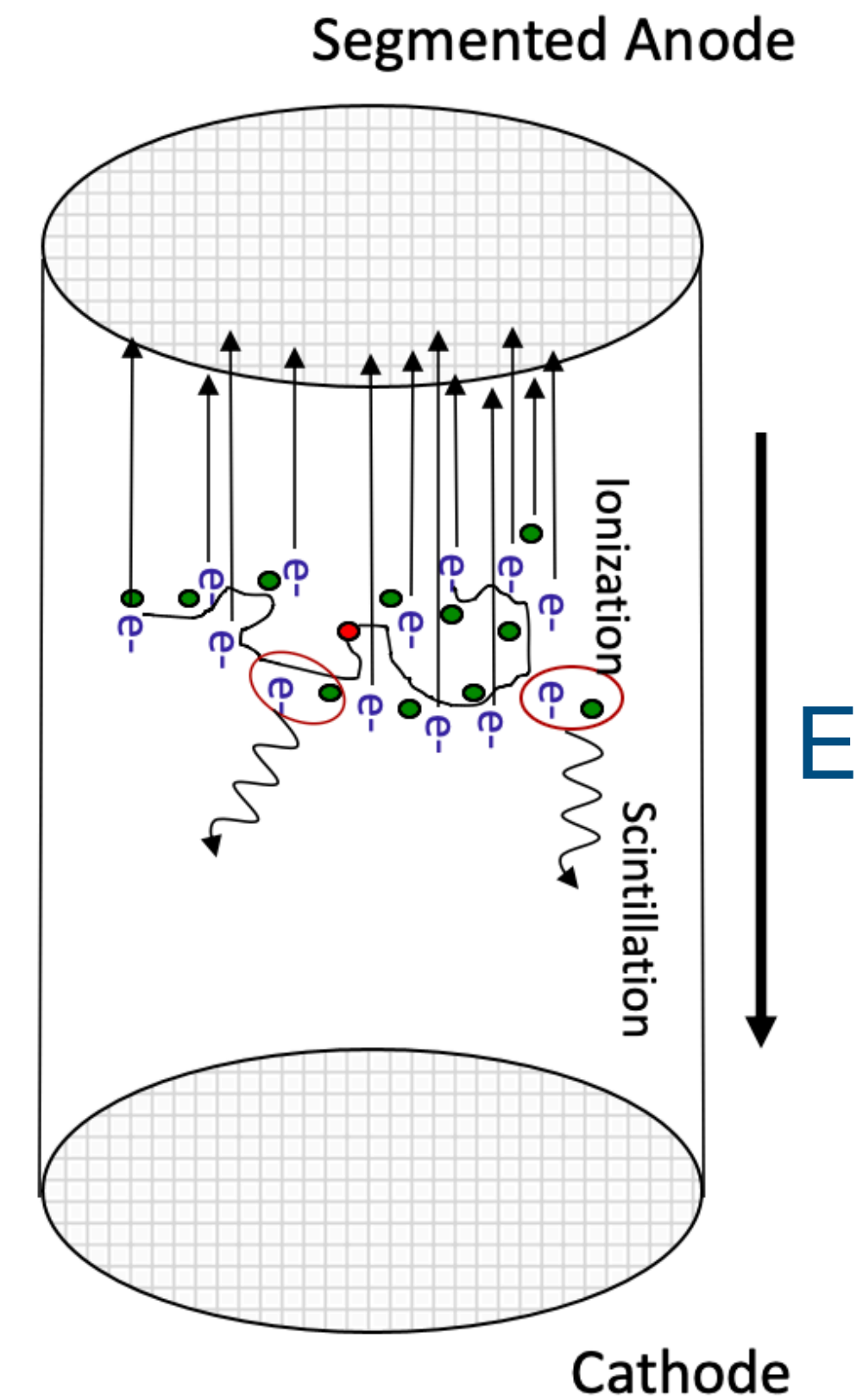


SiPM

Tile with 96 (1 x 1 cm<sup>2</sup>) SiPMs



20 Tiles per Stave



Barrel with 24 staves

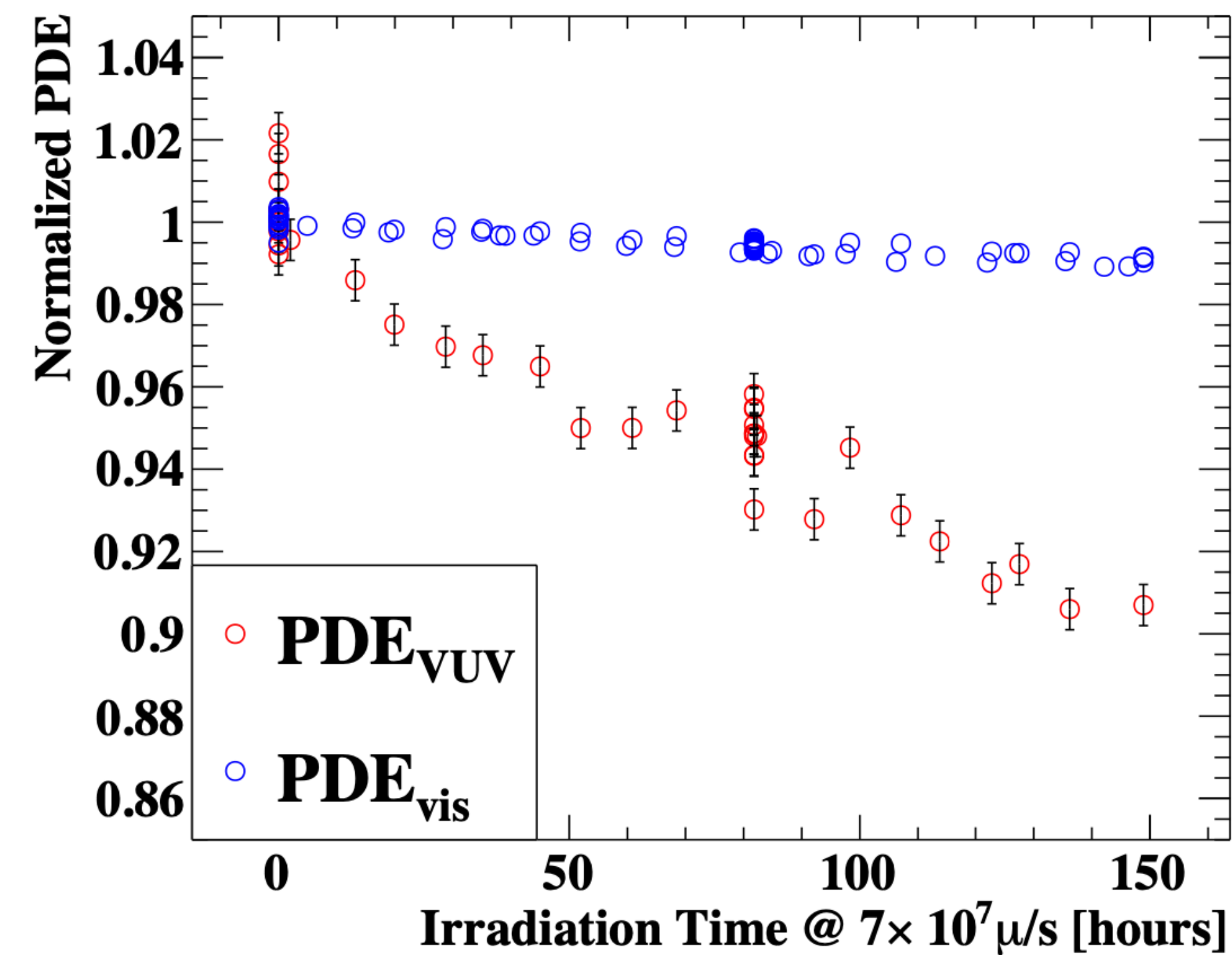


# Unexpected PDE decrease Observed in MEG II

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

K. Ieki<sup>a</sup>, T. Iwamoto<sup>a</sup>, S. Kobayashi<sup>a,\*</sup>, Toshinori Mori<sup>a</sup>, S. Ogawa<sup>a</sup>, R. Onda<sup>a</sup>, W. Ootani<sup>a</sup>, K. Shimada<sup>a</sup>, K. Toyoda<sup>a</sup>

<sup>a</sup>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

$1 \times 10^{-4}$  Gy

Neutron

$3 \times 10^6$  cm<sup>-2</sup> (1 MeV equivalent)

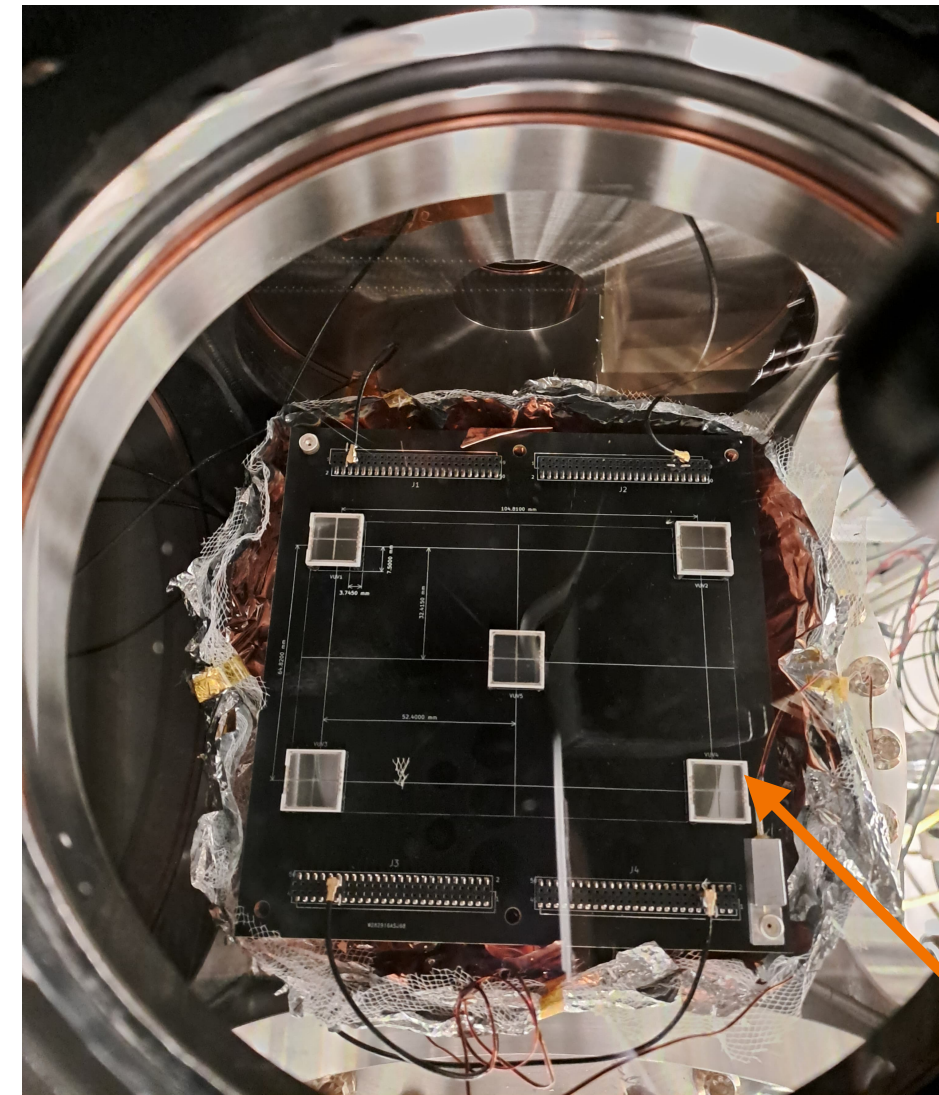
VUV photon

$6 \times 10^{10}$  mm<sup>-2</sup> =  $1.5 \times 10^{-5}$  mJ/mm<sup>2</sup>

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

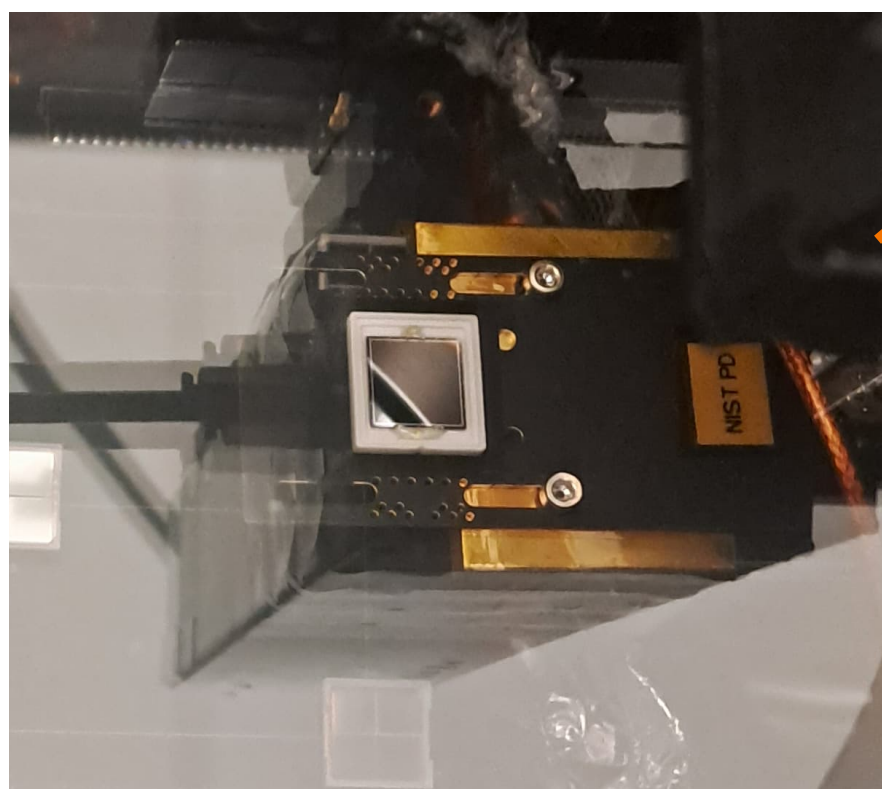


# Cryogenic Setup to Characterise SiPMs at McGill

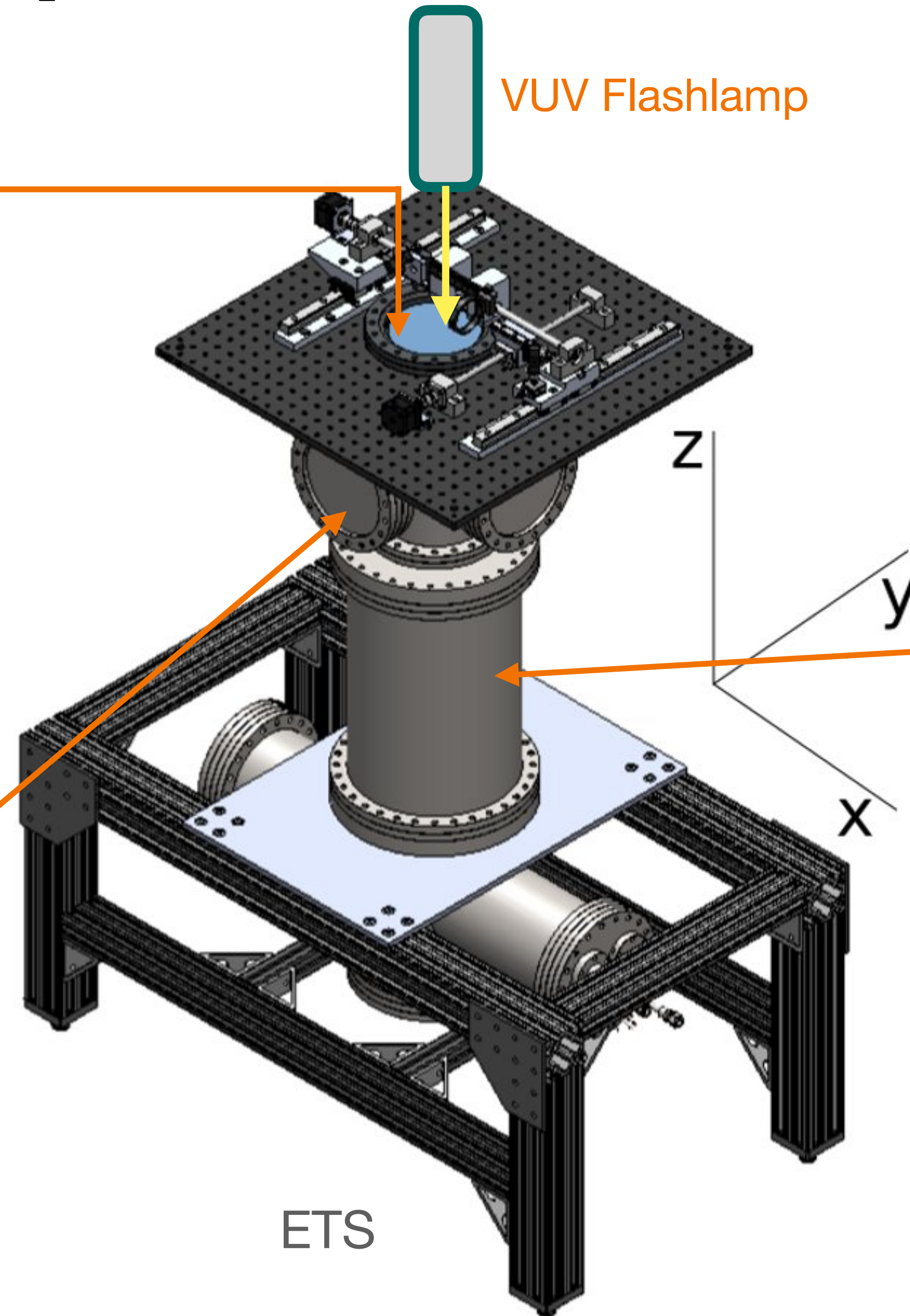


SiPMs

SiPM tile mounted on the cryostat cold head

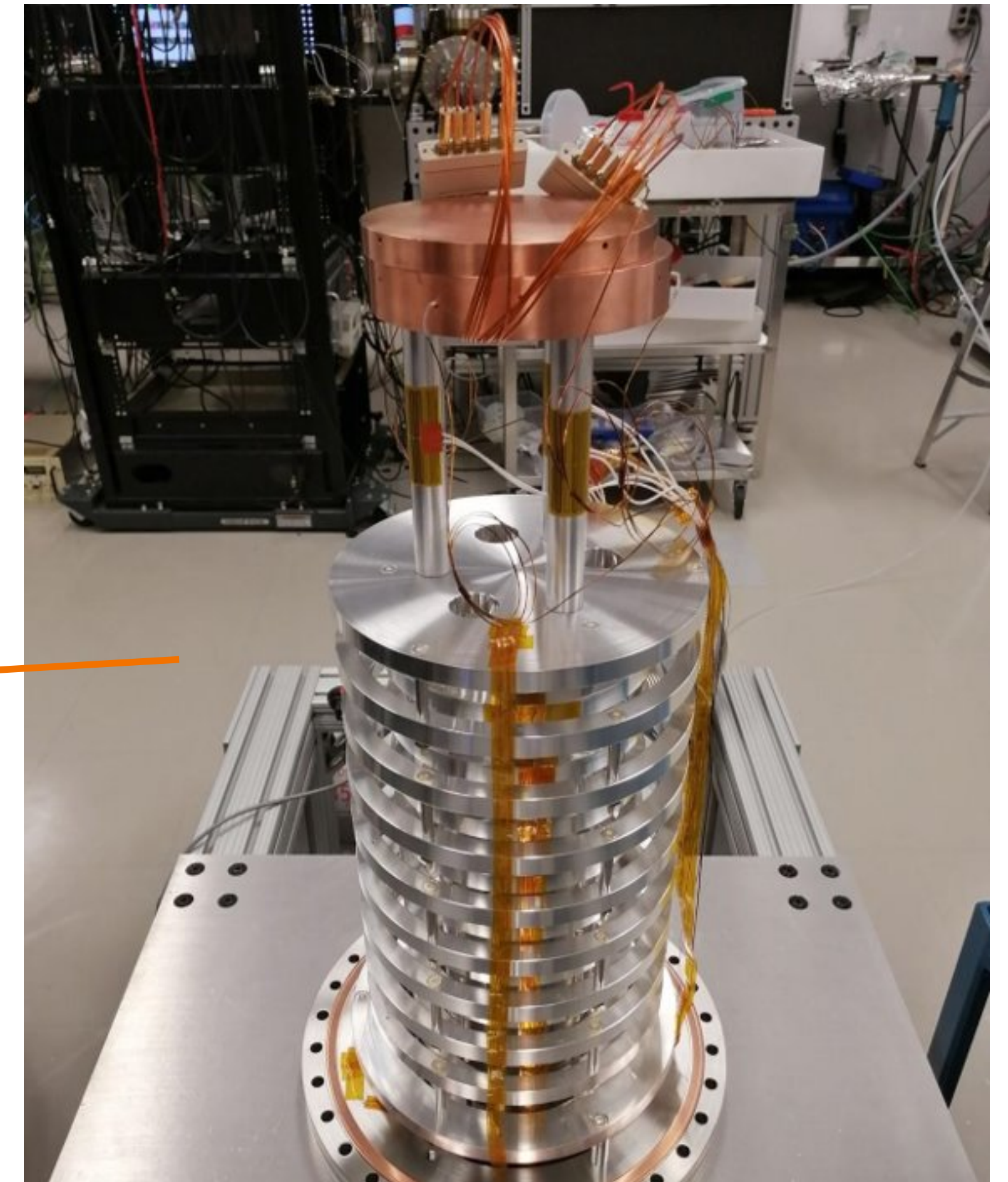


Photodiode mounted on cryostat side flange



VUV Flashlamp

ETS



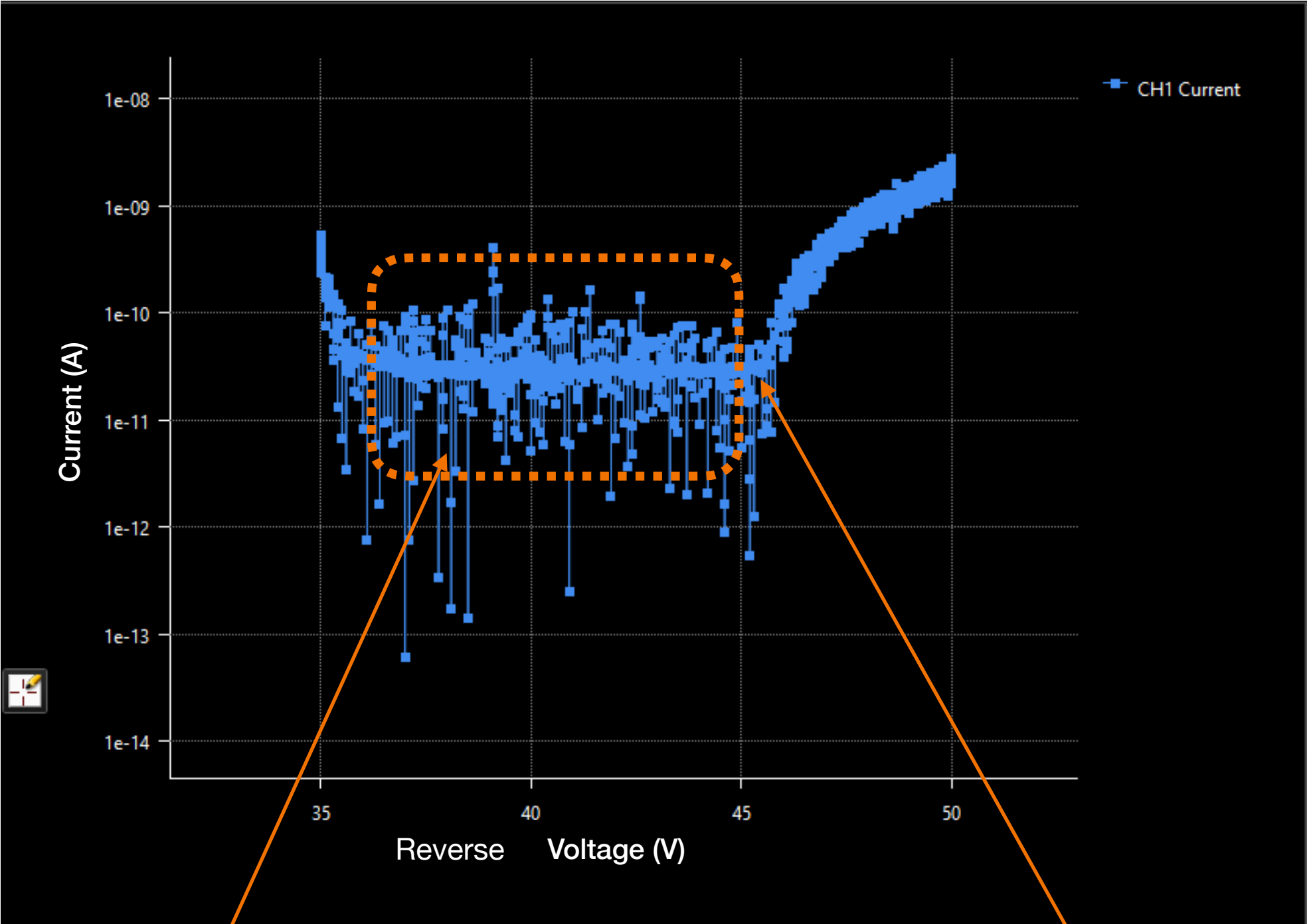
Environmental Test Stand (Cryostat)

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



# SiPM Characteristics

IV Measurements



Leakage Current

Breakdown Voltage

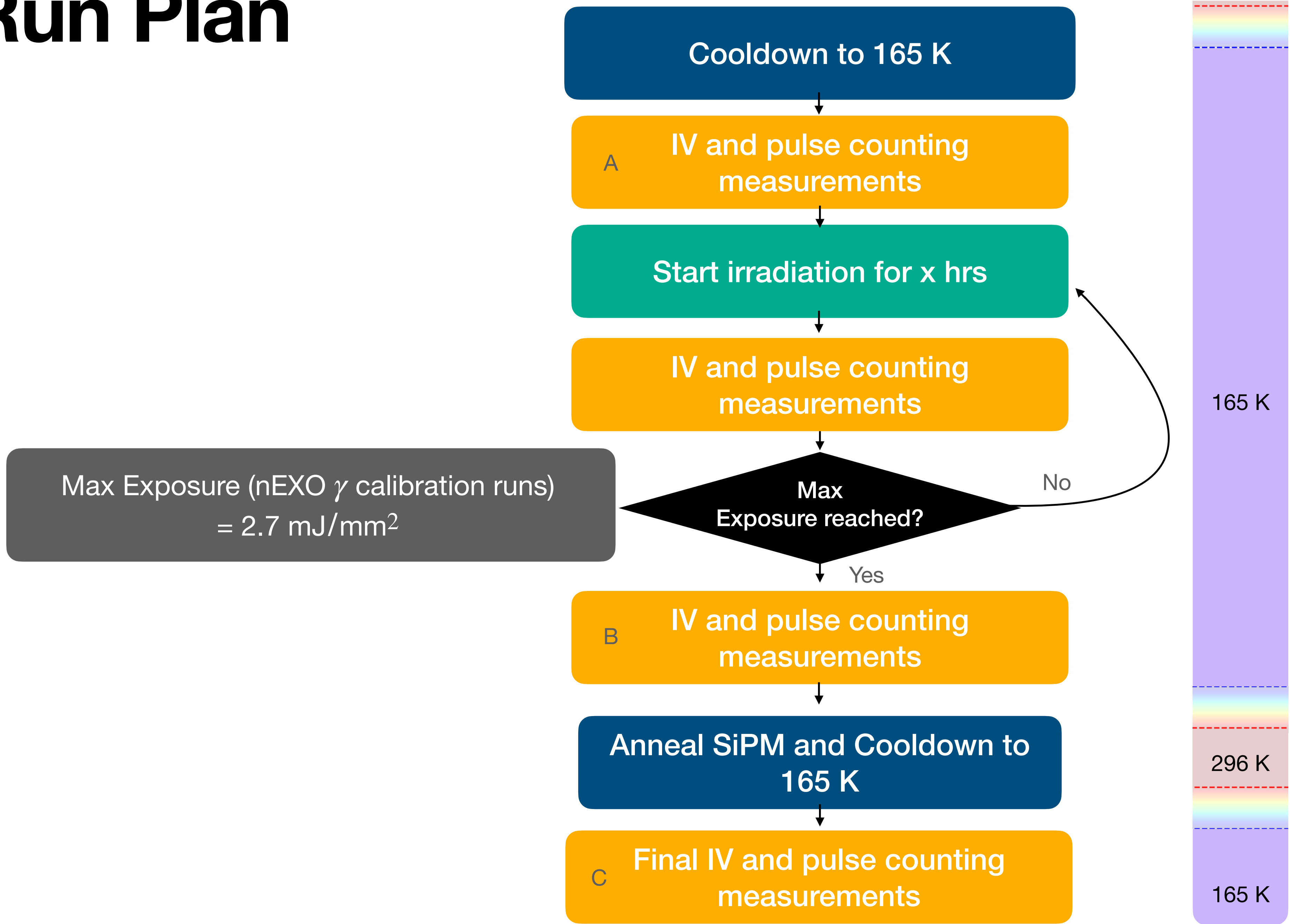
Pulse Mode Measurements



Pulse due to a single photo electron (SPE)



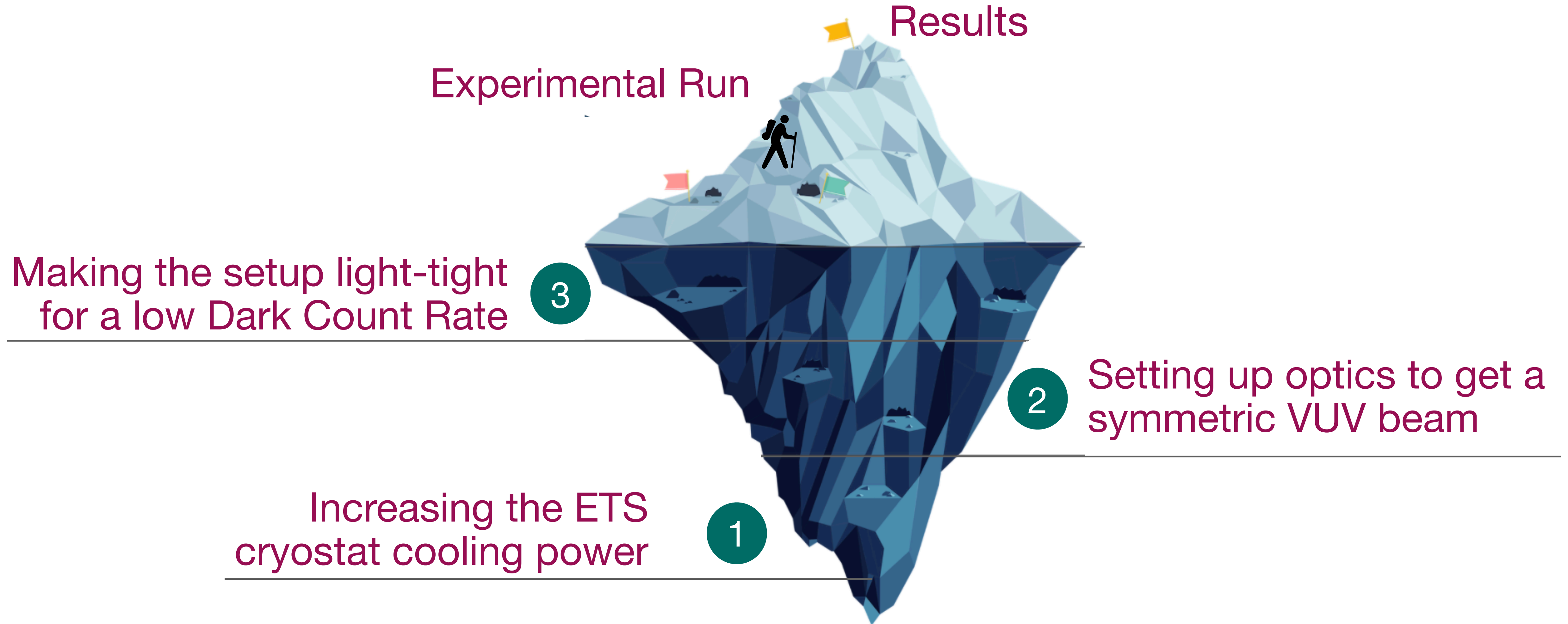
# Run Plan





# But wait... it can't be that easy

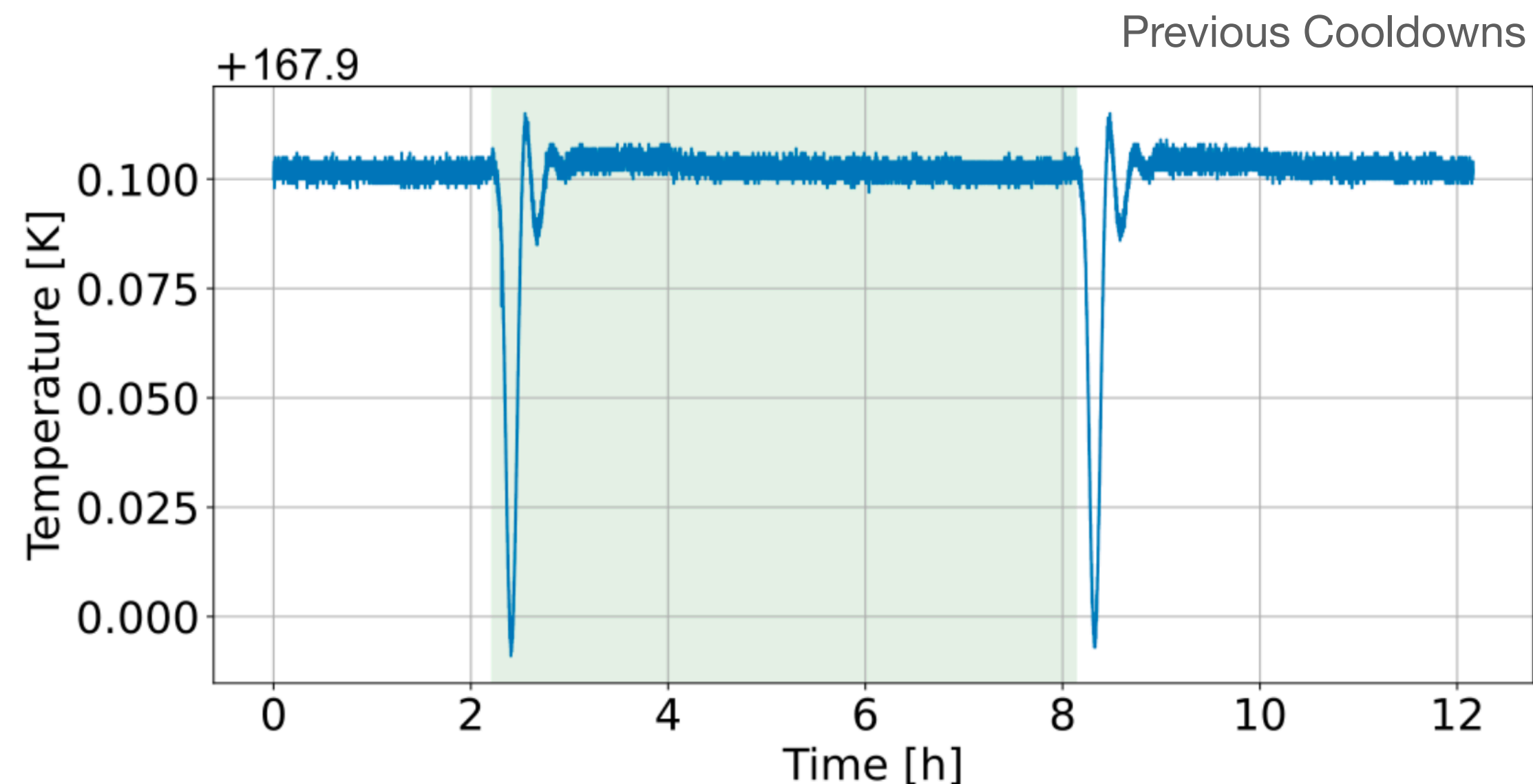
## Major Challenges



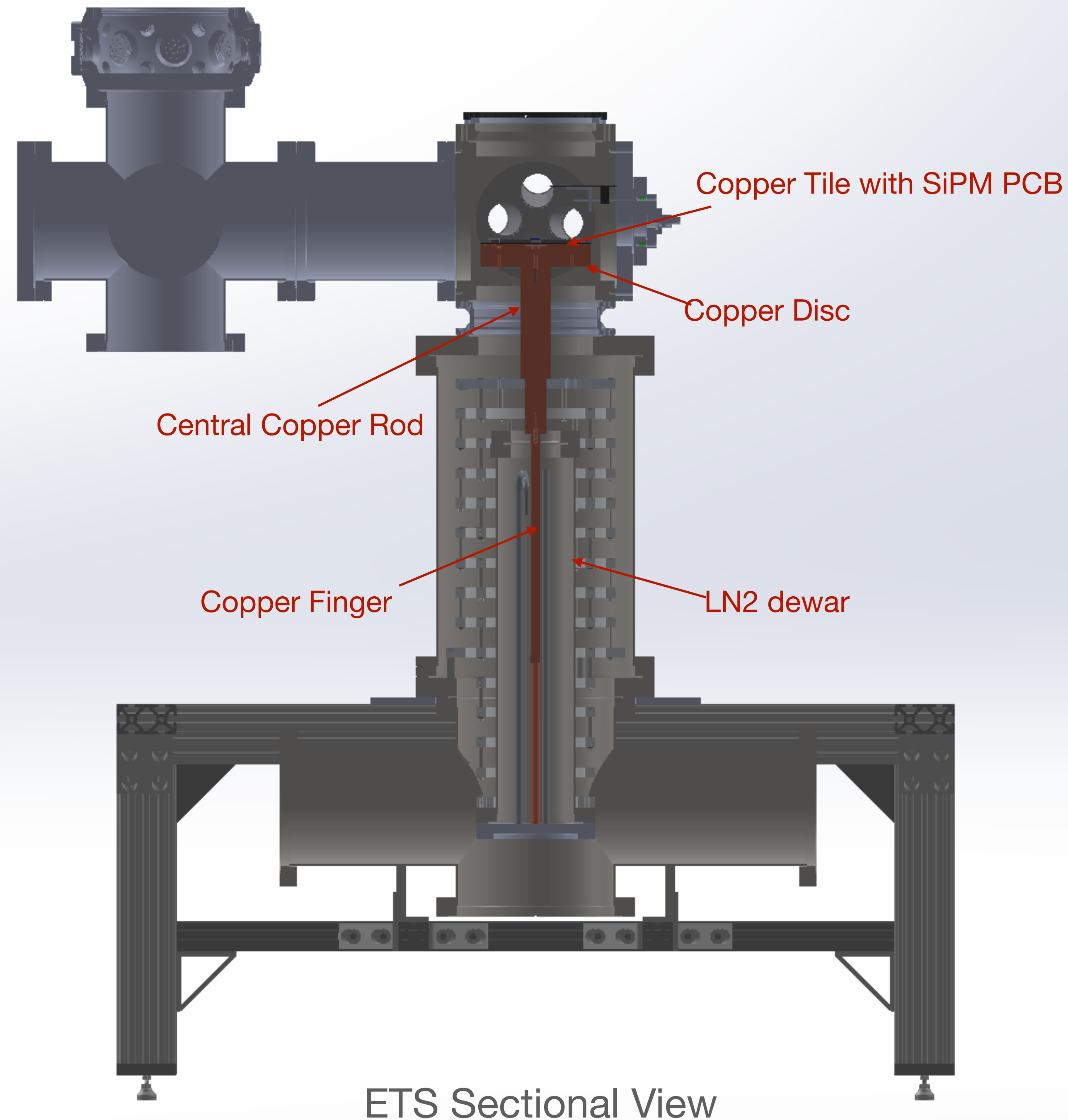


# Hardware Upgrade

- 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



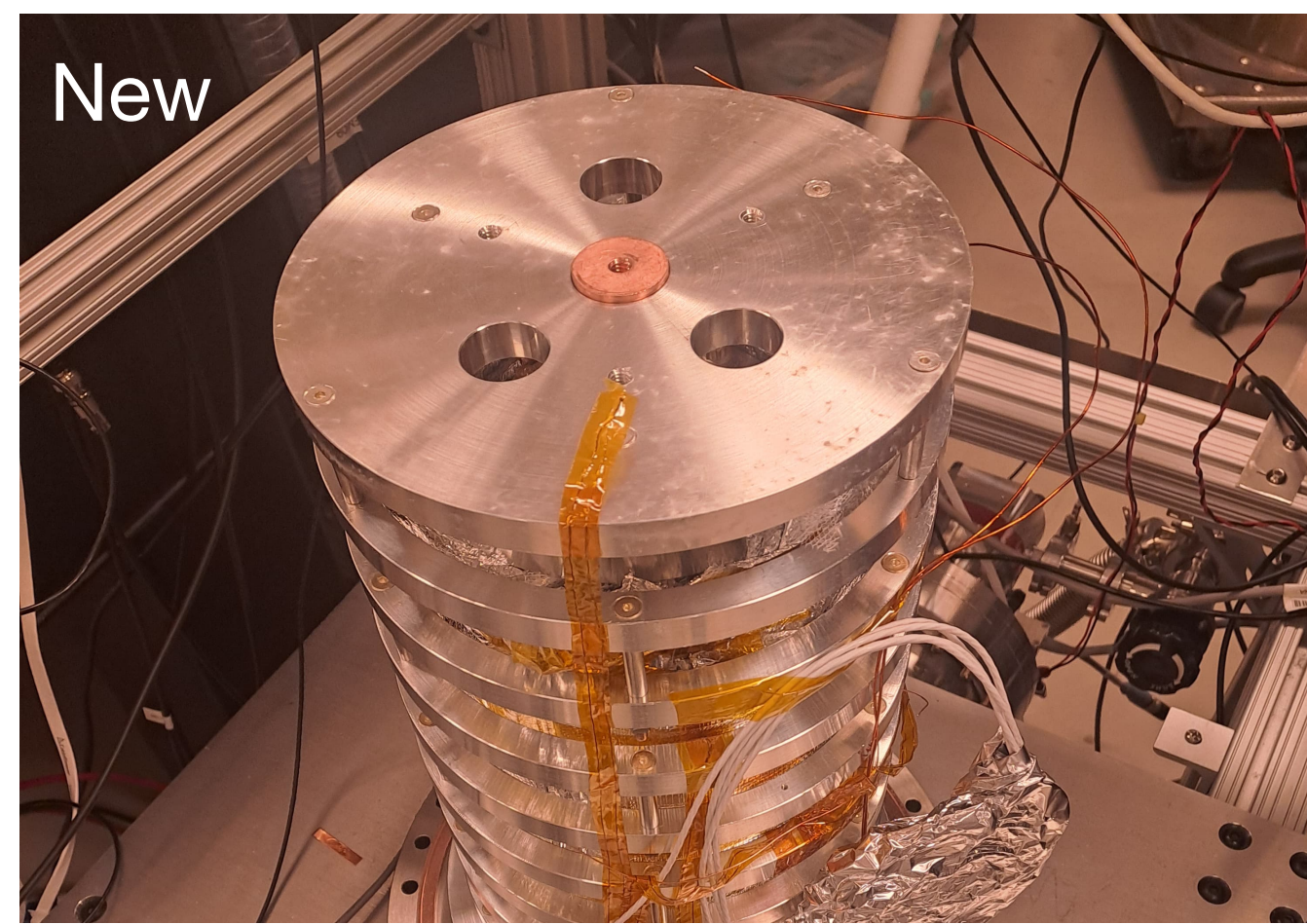
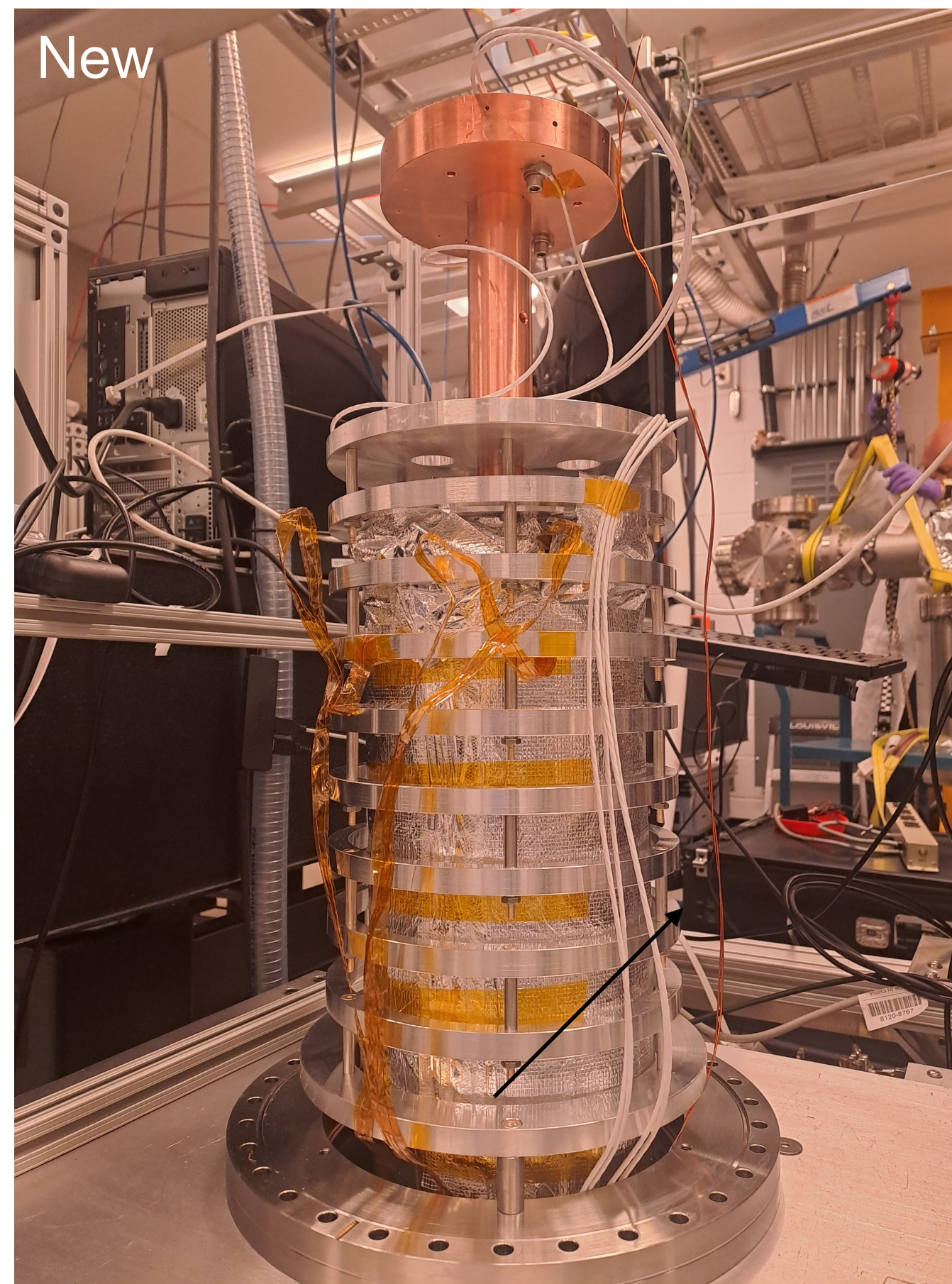
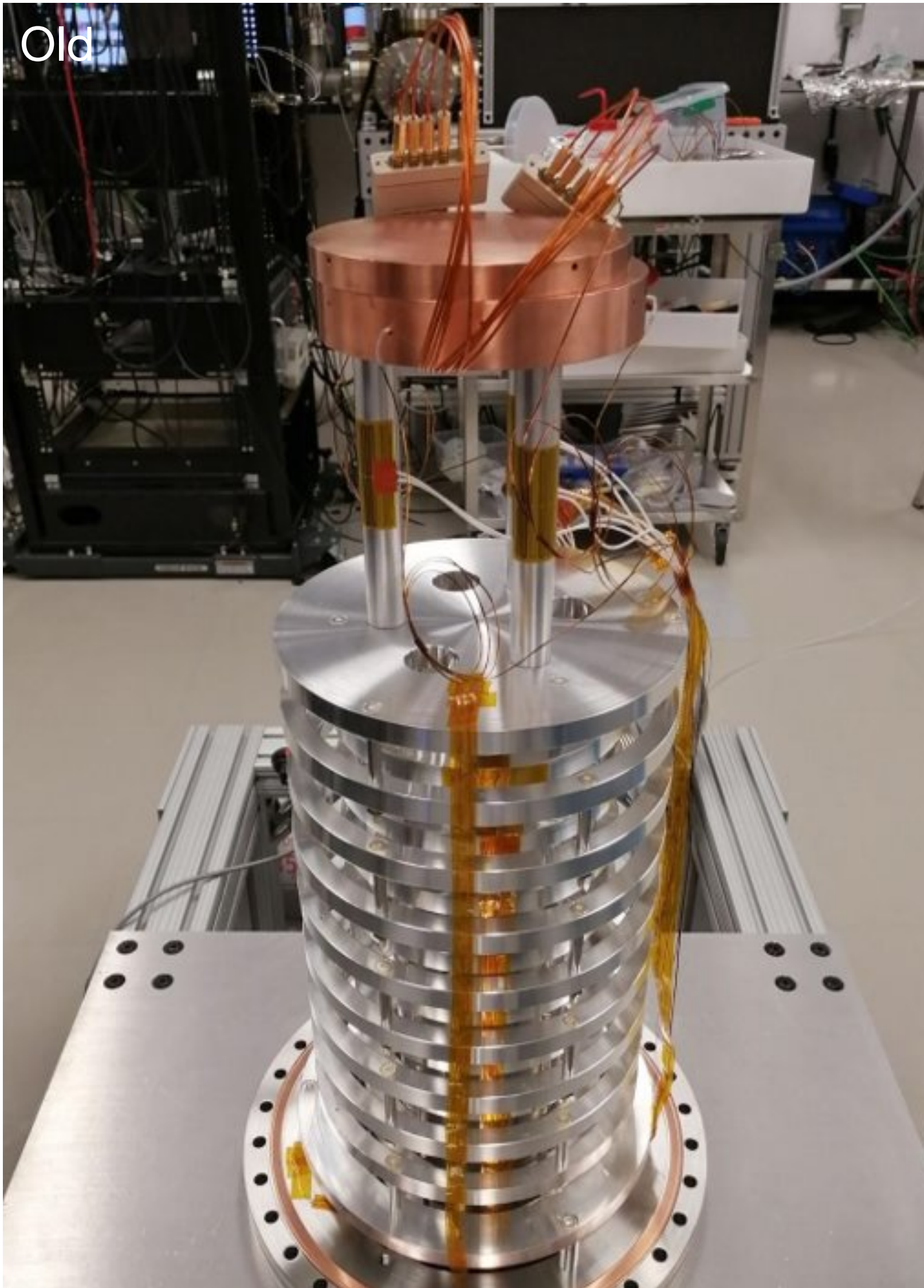
(PhD Thesis) Darroch, Lucas. "Testing silicon photomultipliers with vacuum-ultraviolet light for nEXO." (2025).





# Upgrade 1

## Central Copper Rod



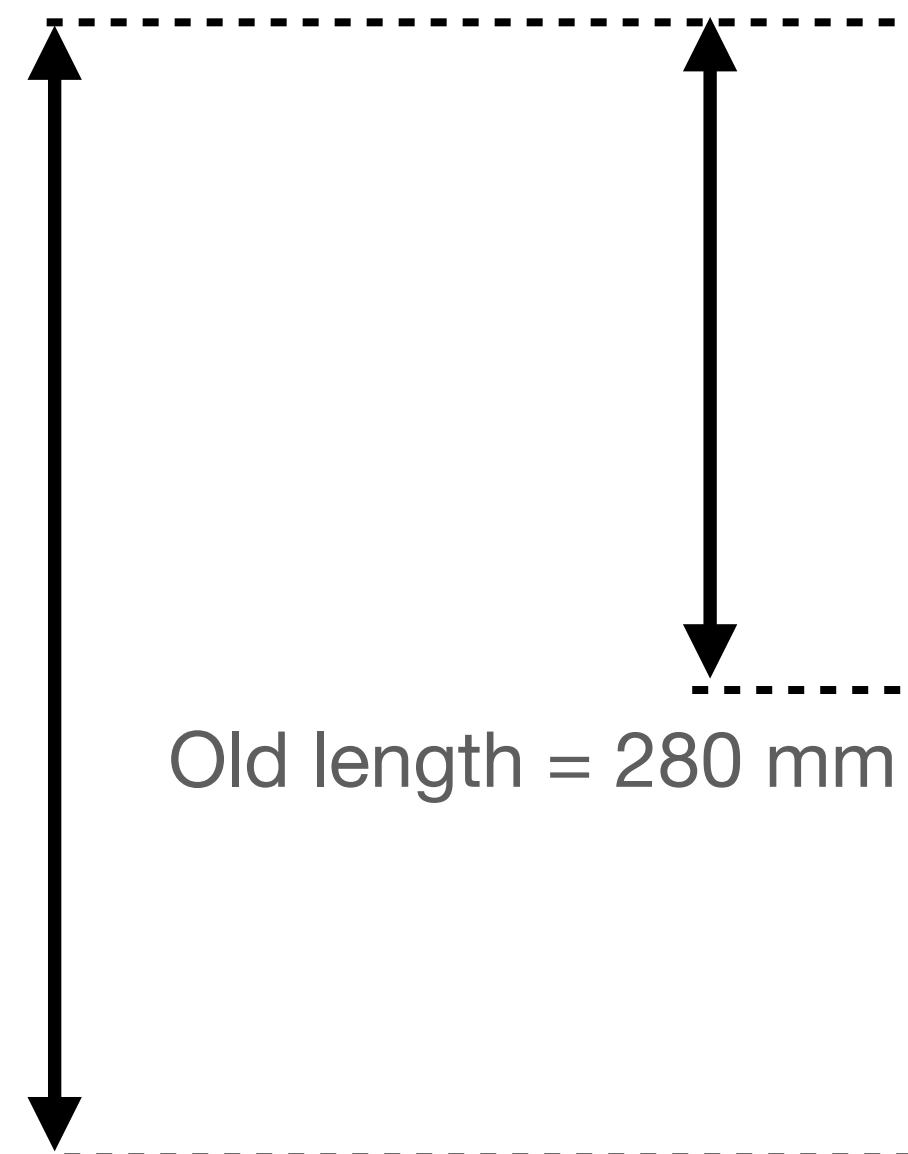
- Central rod is copper, more efficient heat conduction than aluminium
- Increased surface area for conduction
- Central copper rod bypasses the top aluminium plate



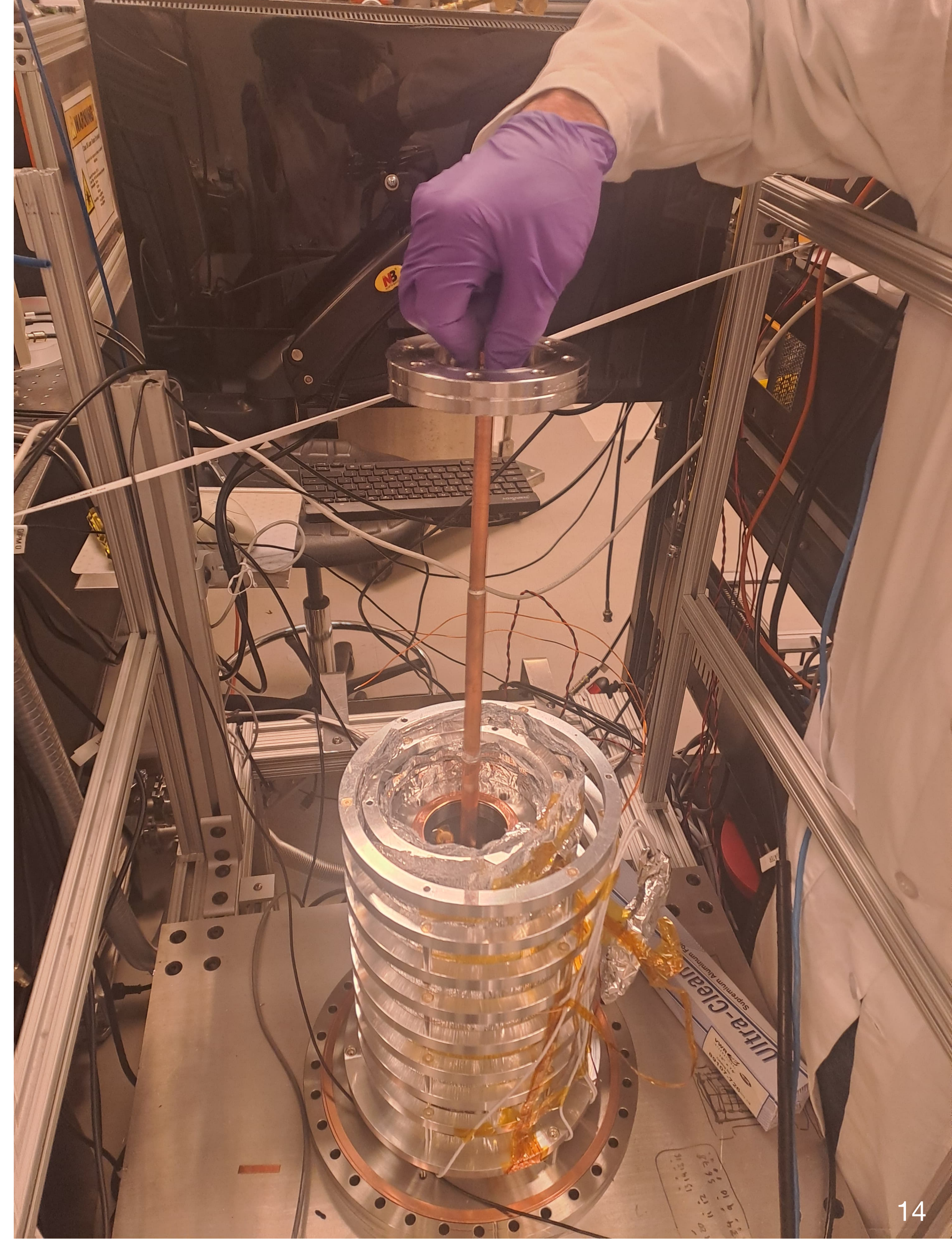
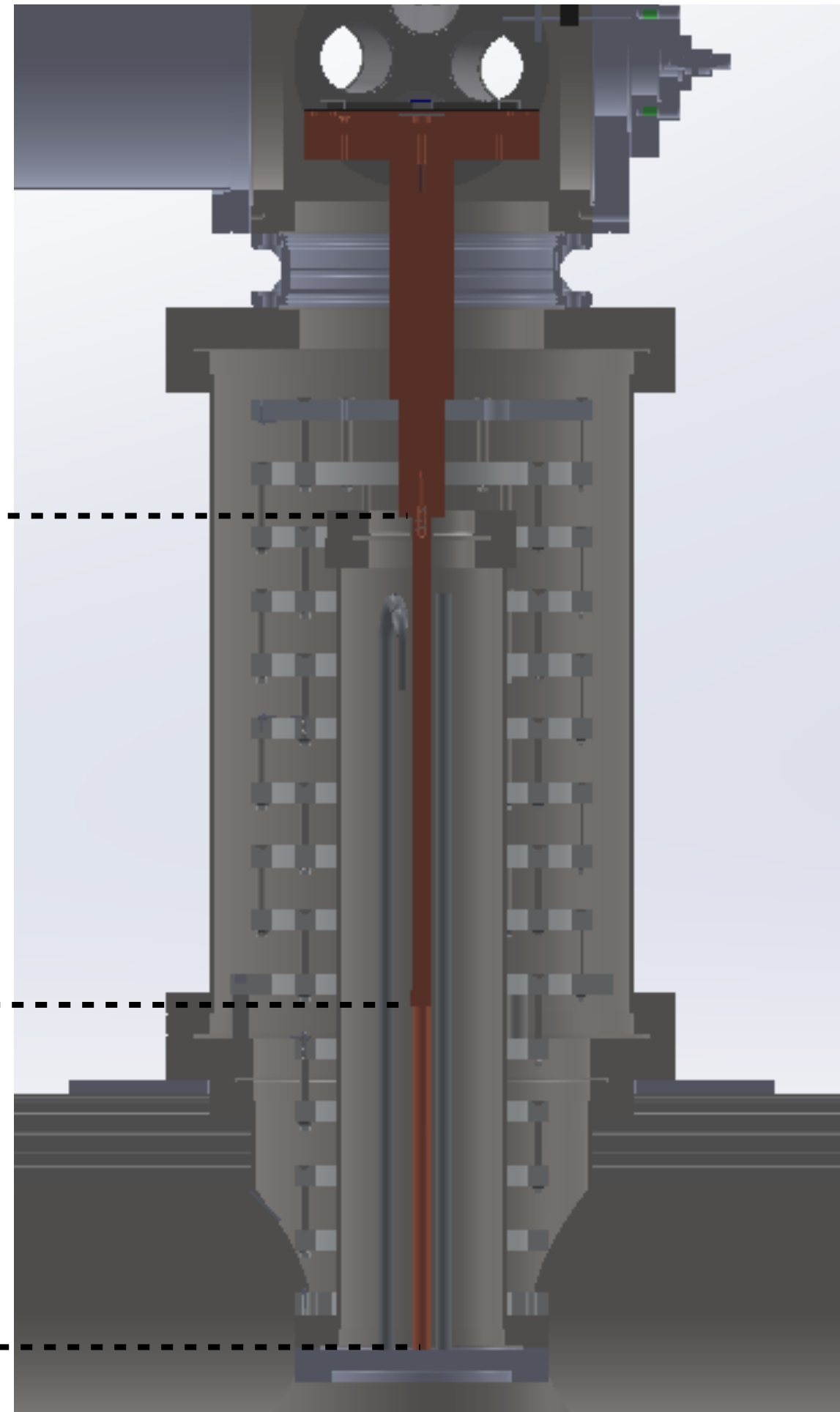
# Upgrade 2

## Extending the Copper Finger

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

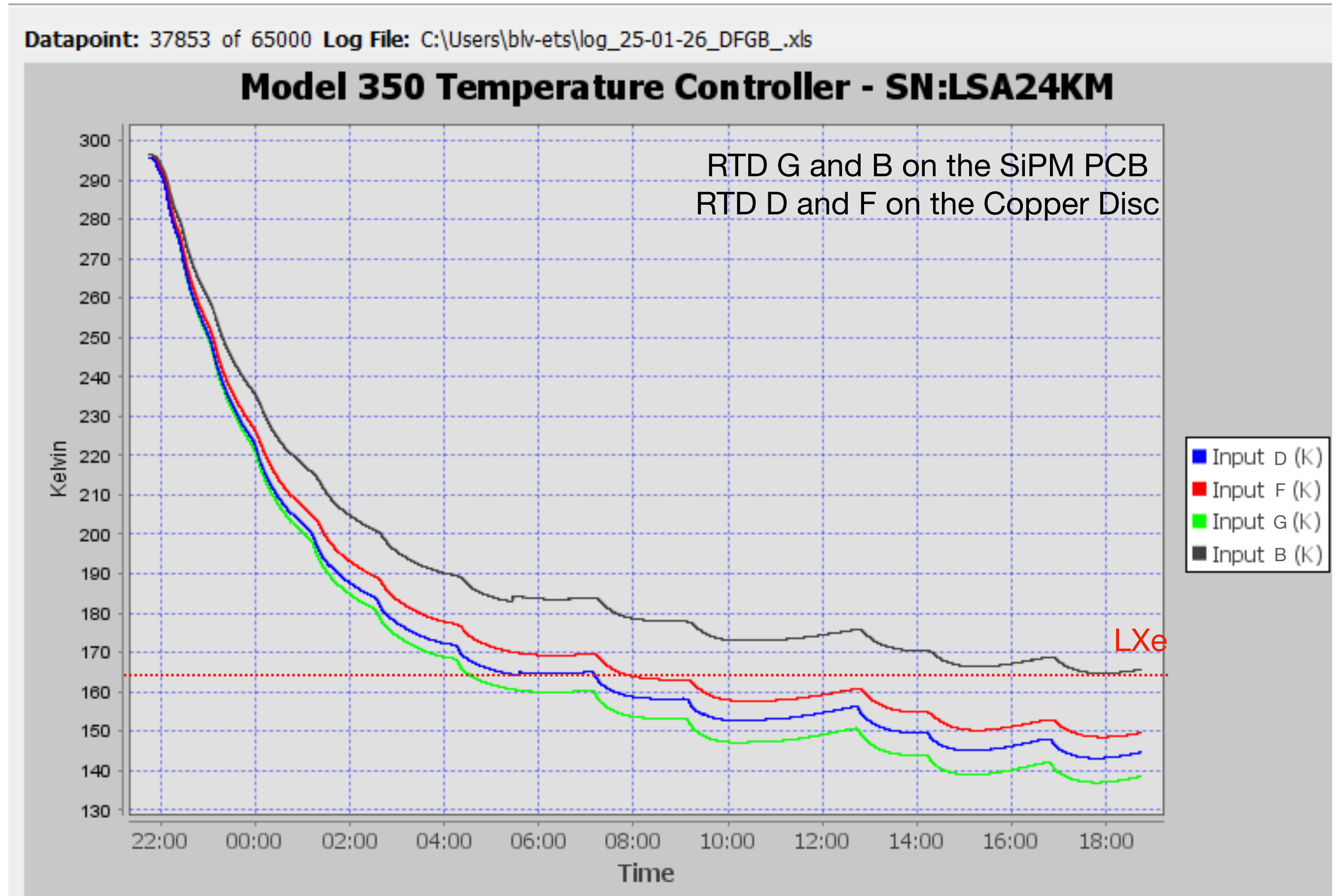
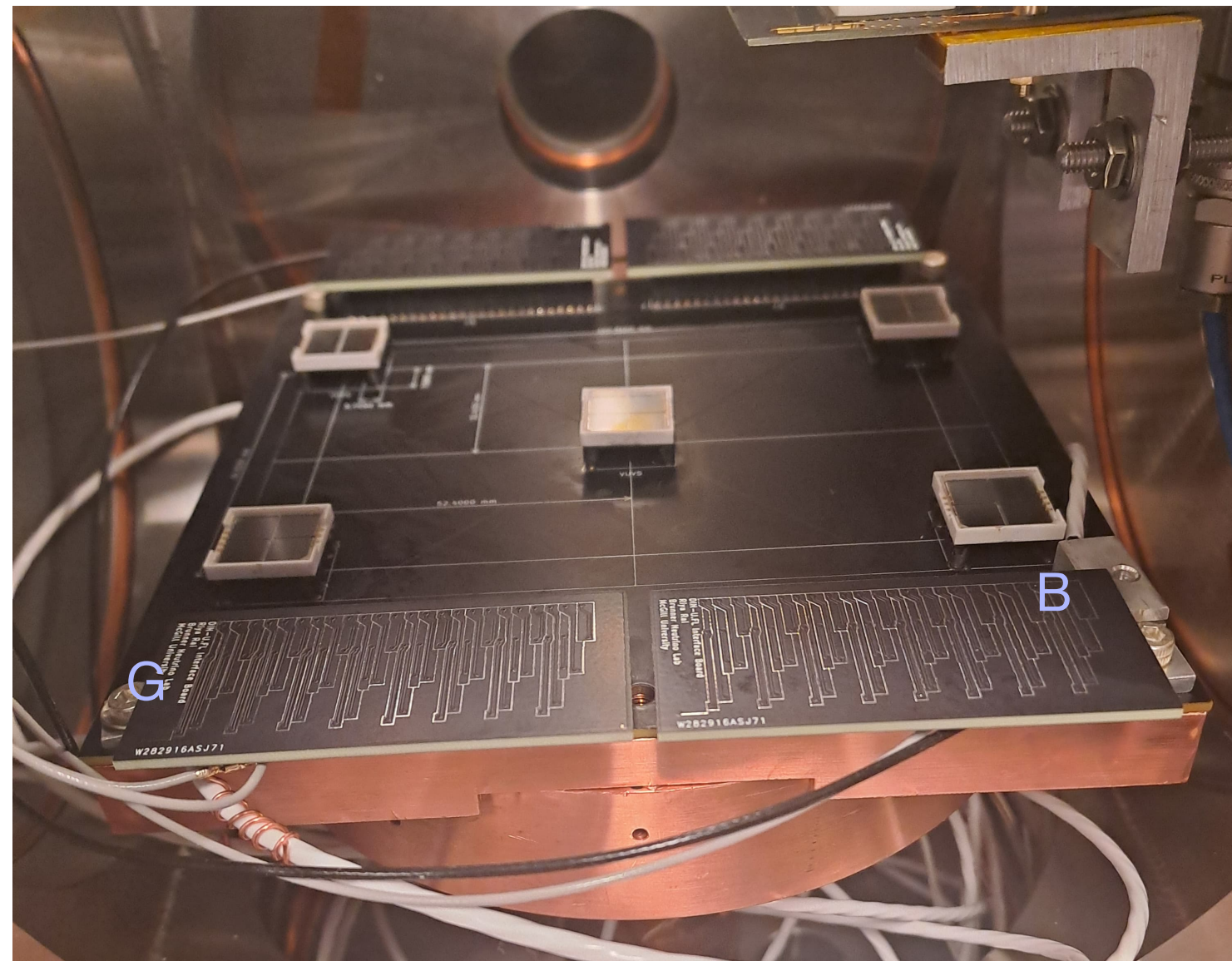
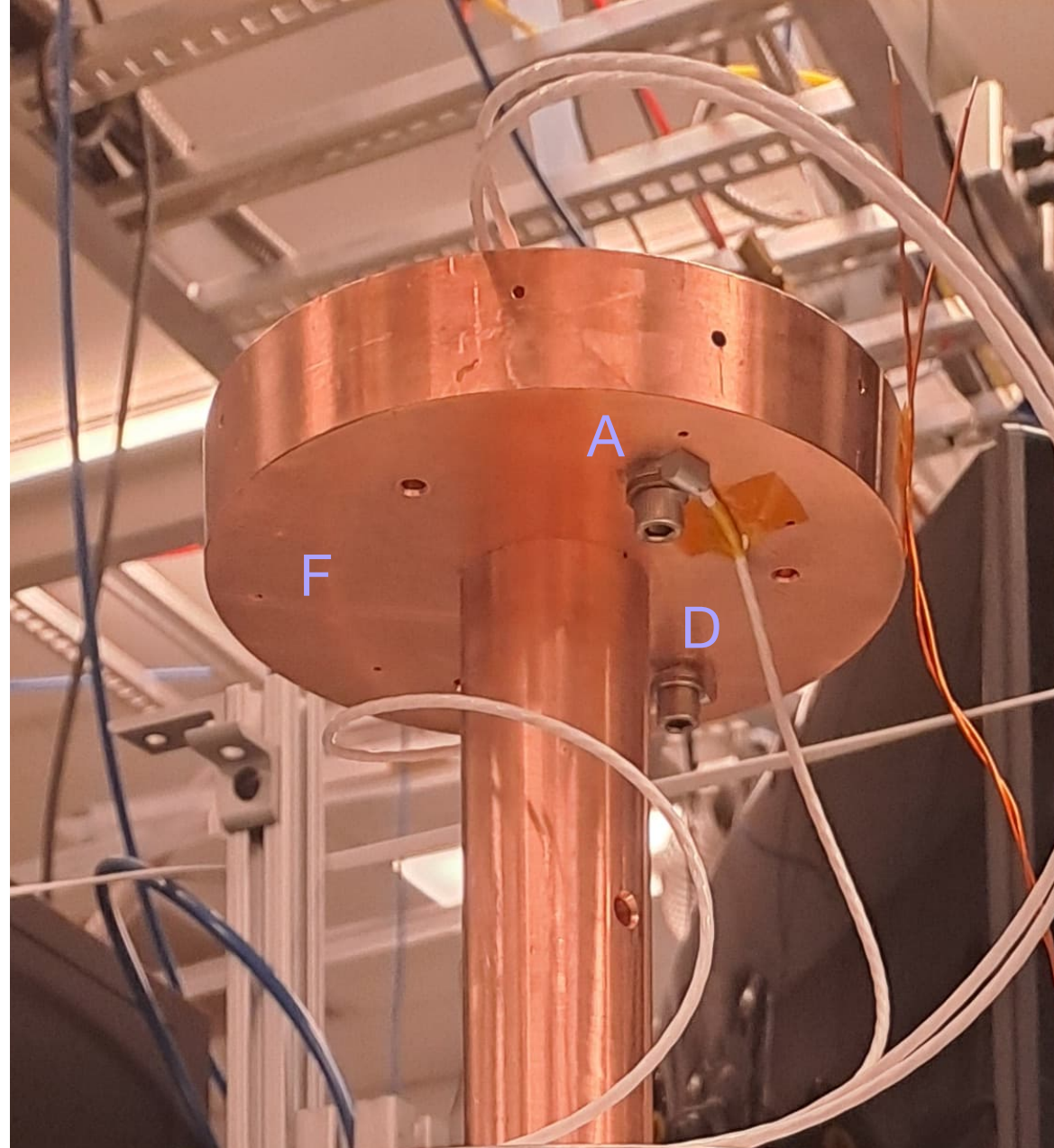


New length = 480 mm





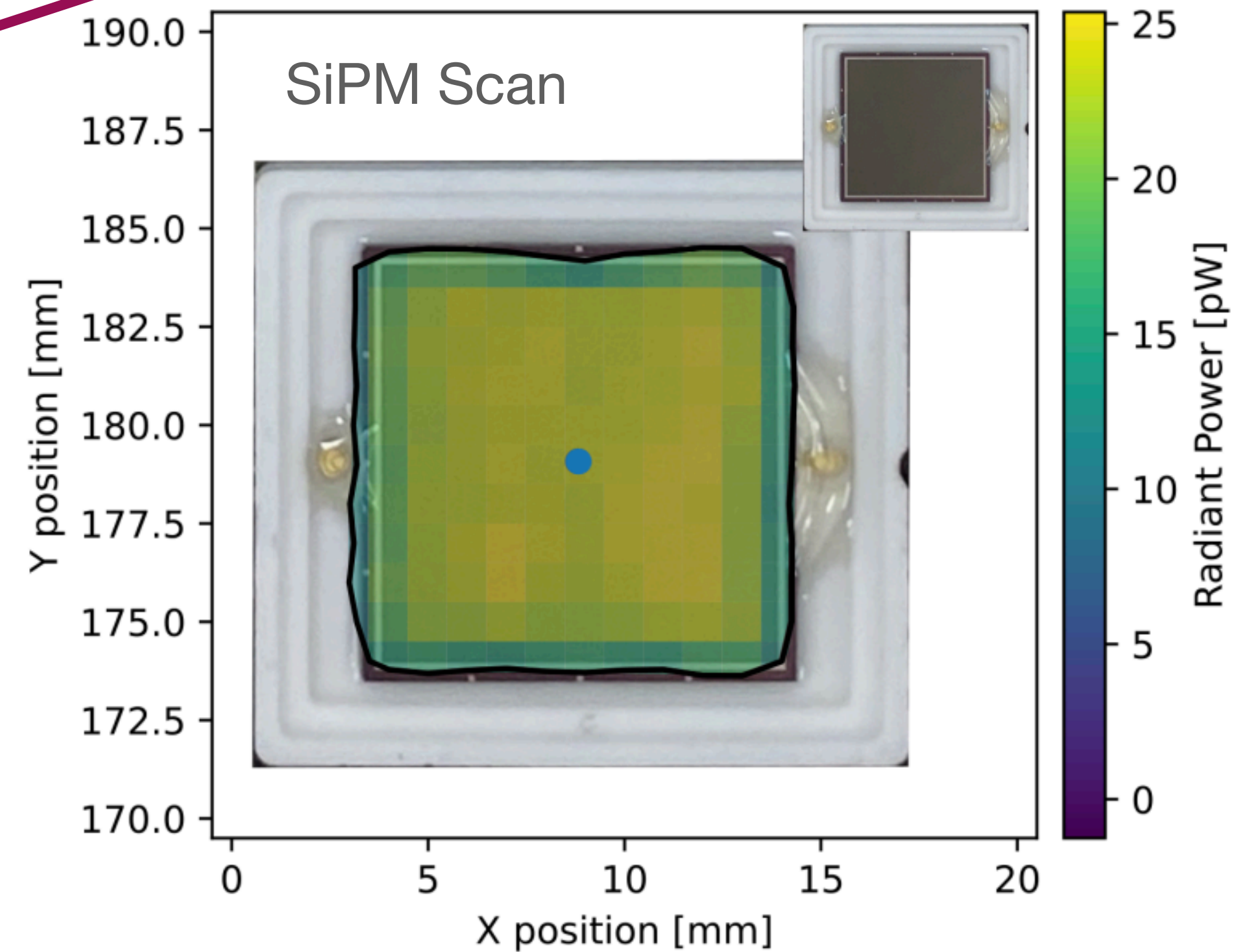
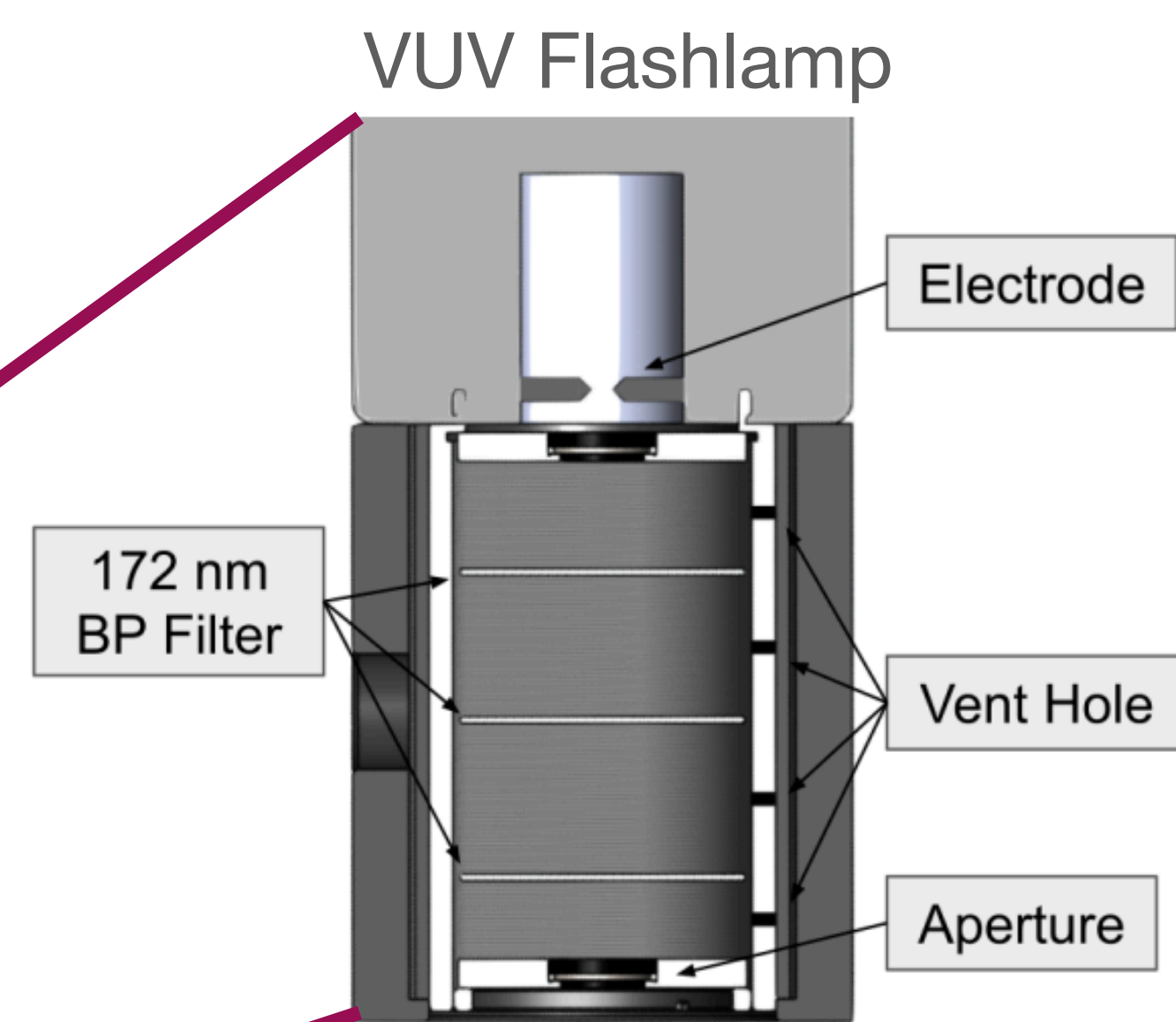
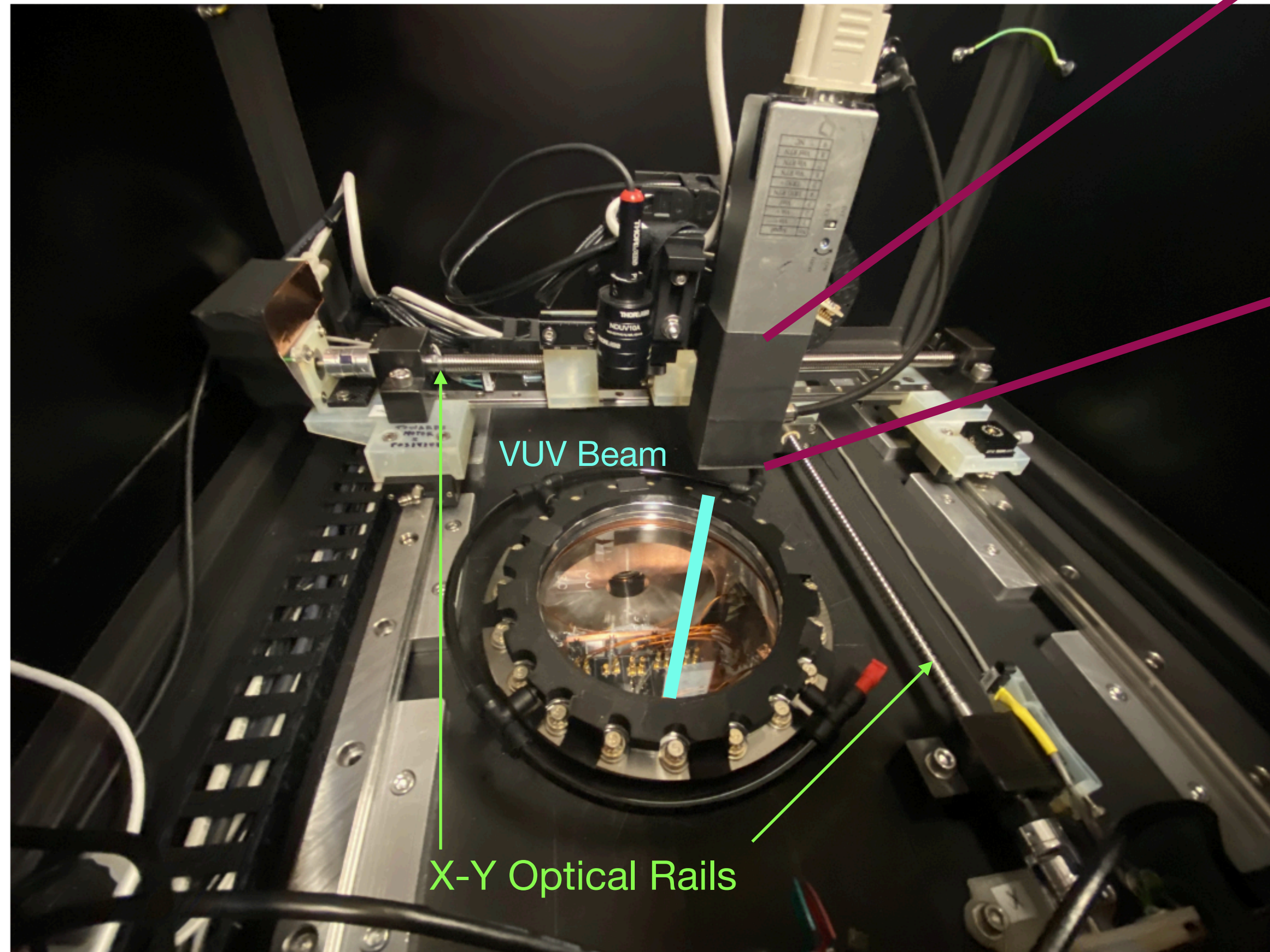
# Results



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



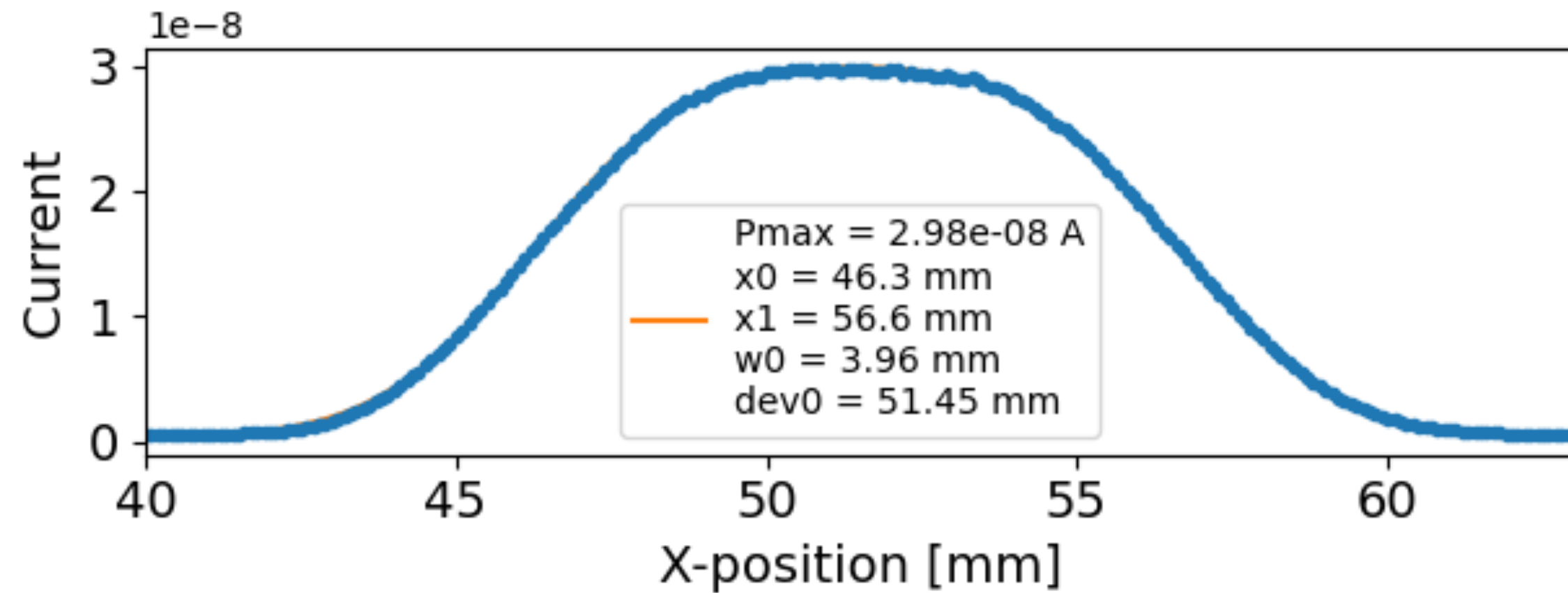
# ETS Scanning system



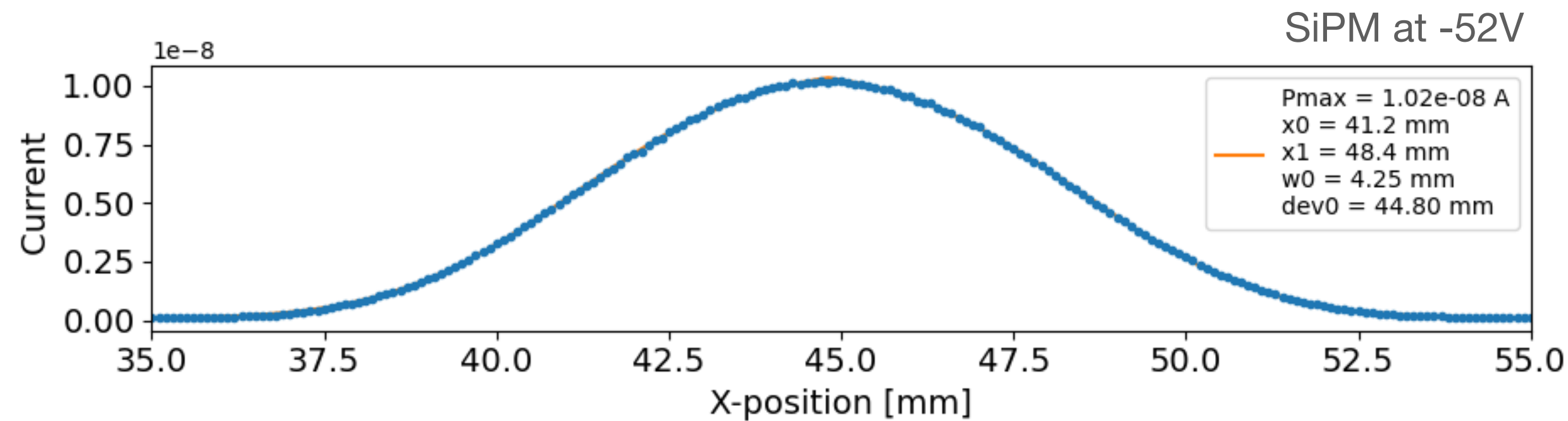


# VUV Stability Calibration

## Beam calibration using Photo Diode Scanning



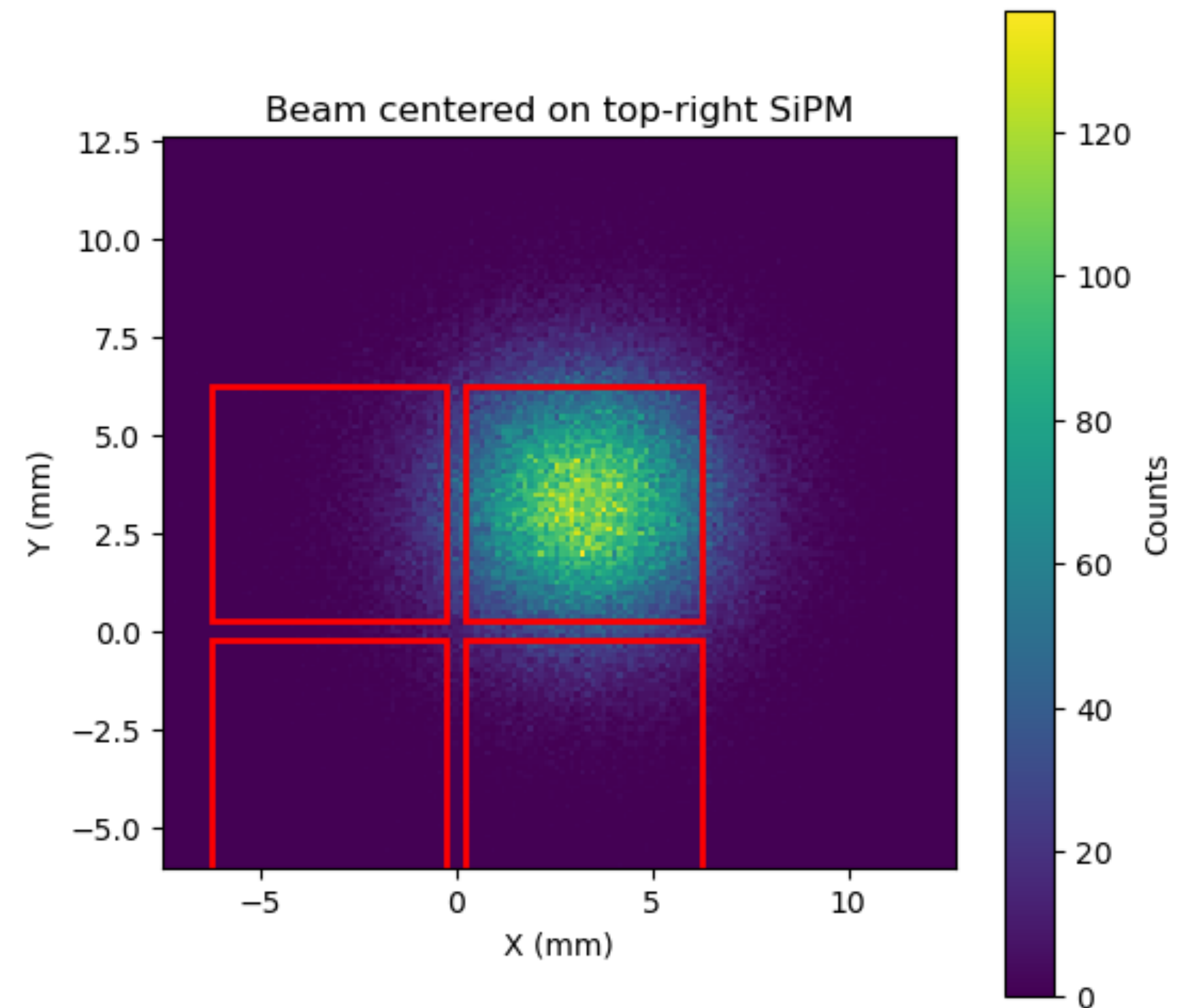
## Beam calibration using SiPM Scanning



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



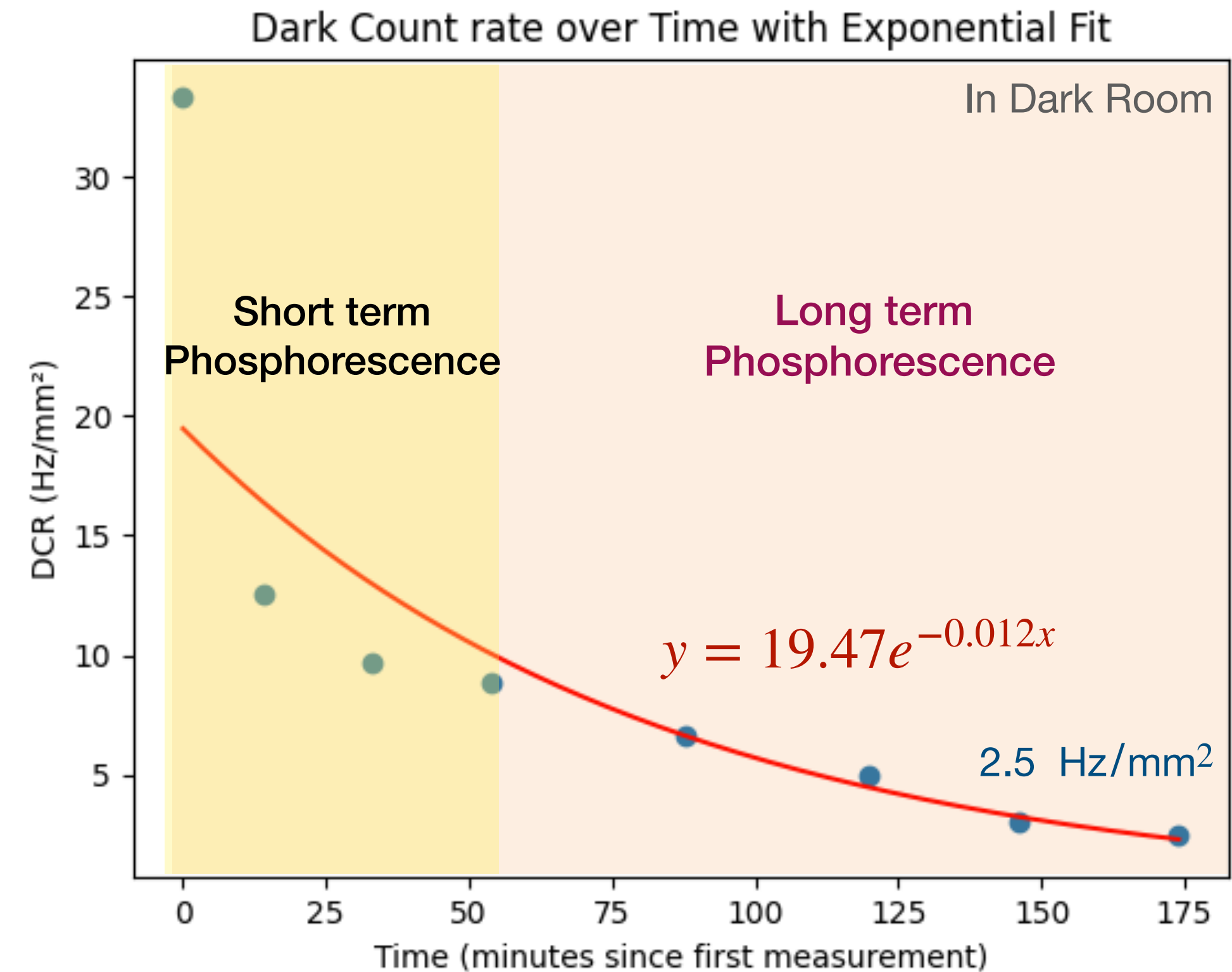
# Light Leak Tests

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



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  $0.6 \text{ Hz/mm}^2$
- Need to cover all parts which phosphoresce.





# Summary

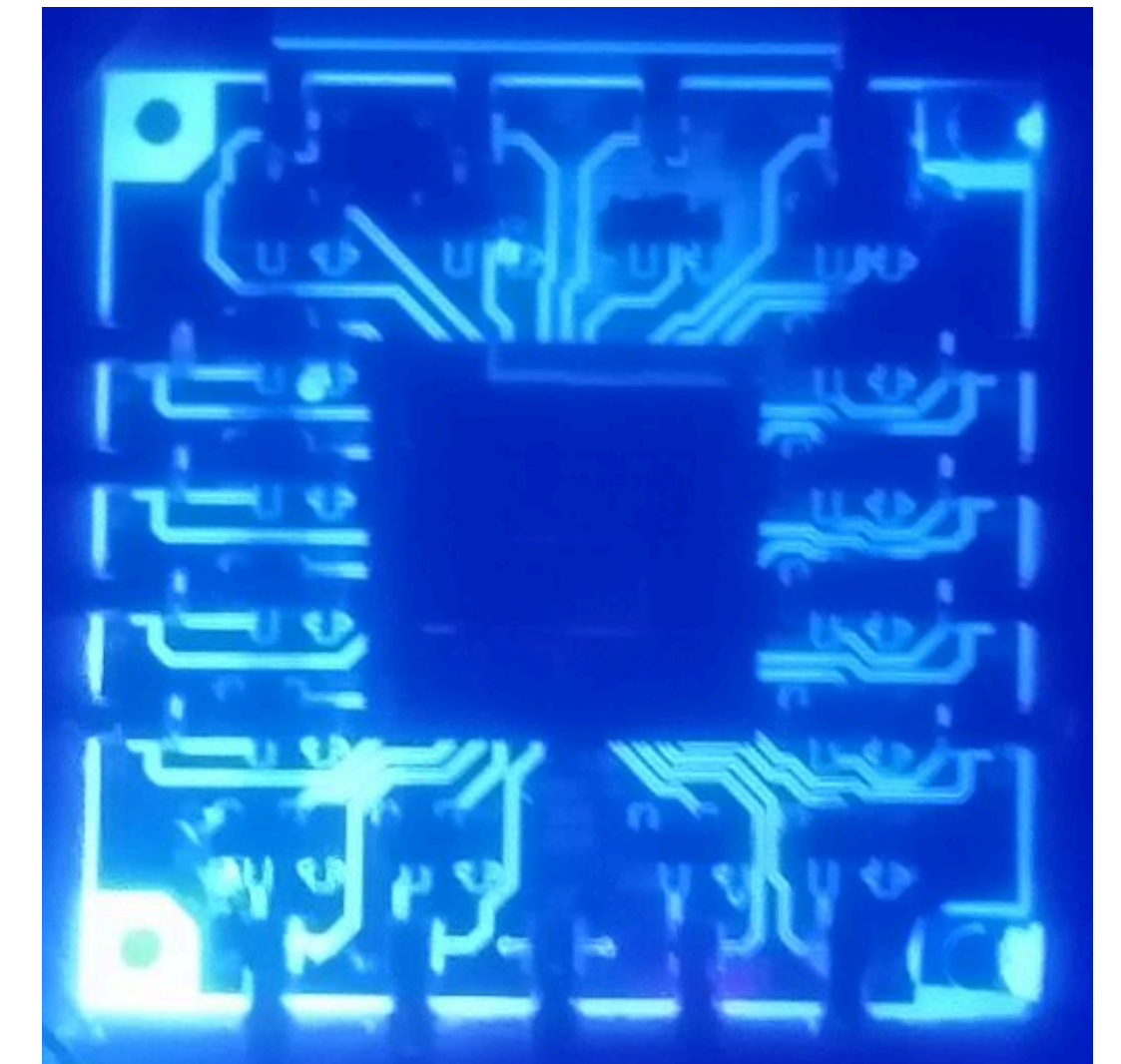
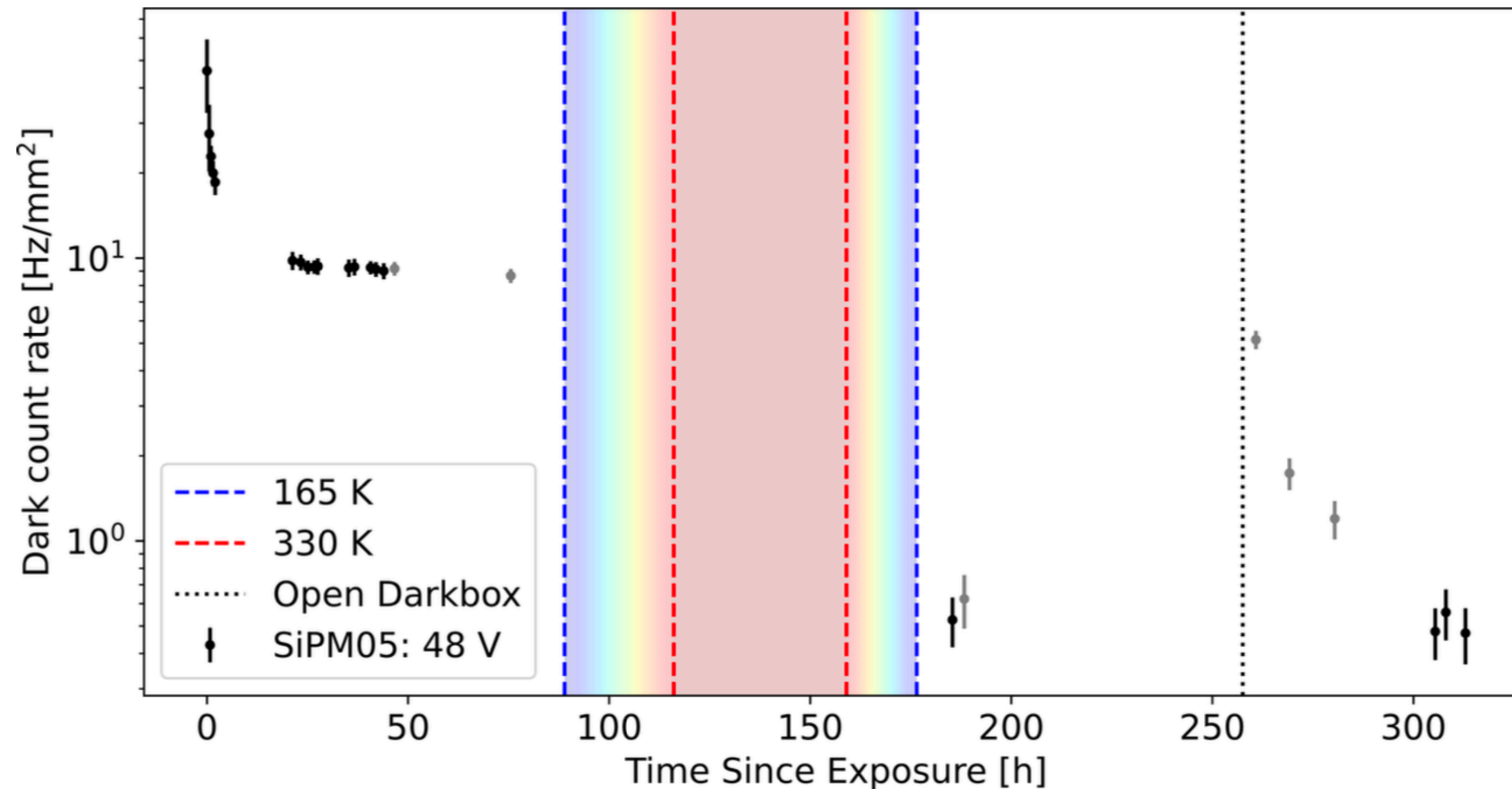
- The ETS has been upgraded for efficient and powerful cooldowns to 165 K
- Calibration measurements for the VUV tests completed
- We have measured low enough DCR, will soon complete stability measurements



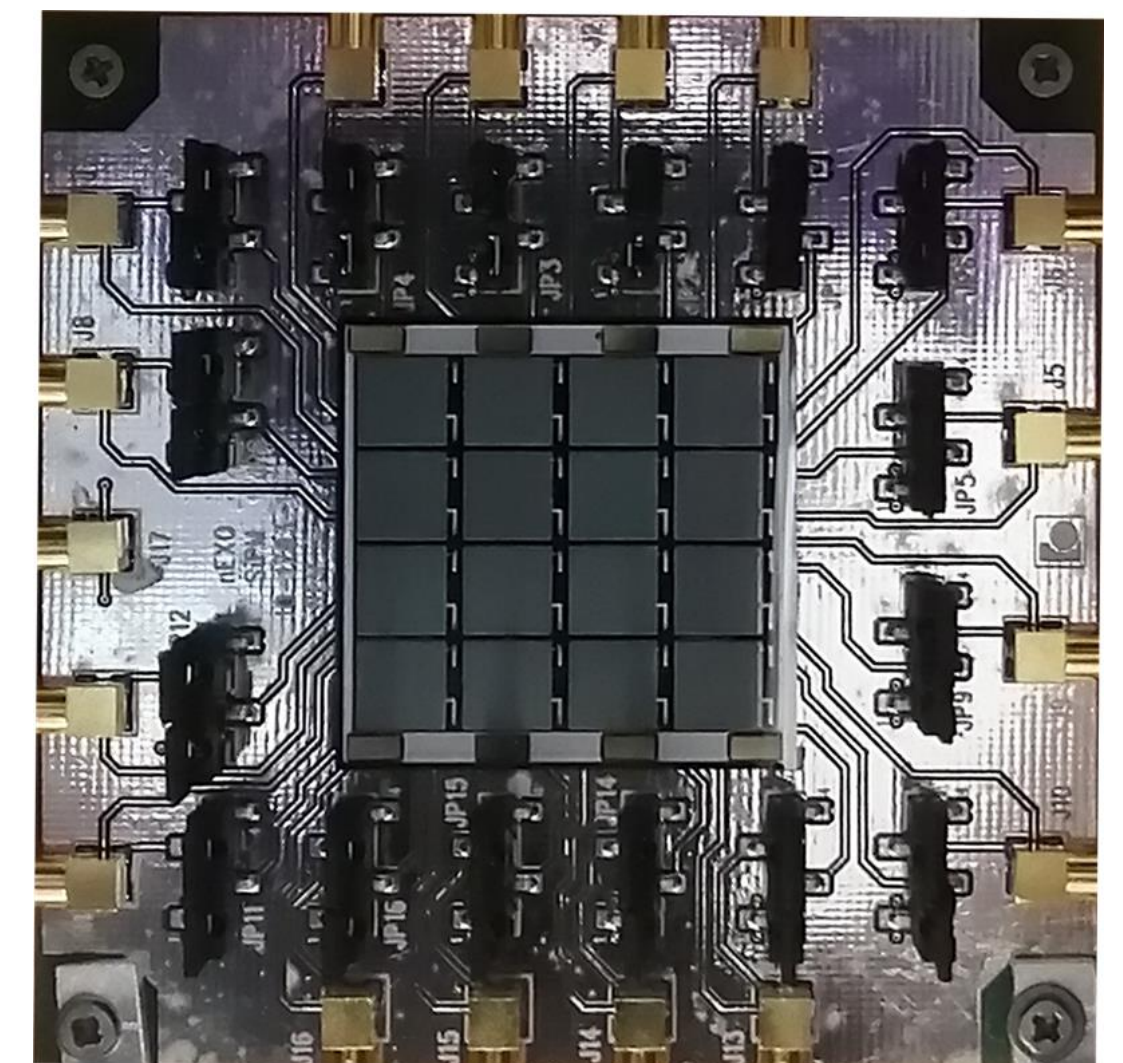


# Phosphorescence and DCR measurements

Previous Tests at McGill



Phosphorescence on the PCB



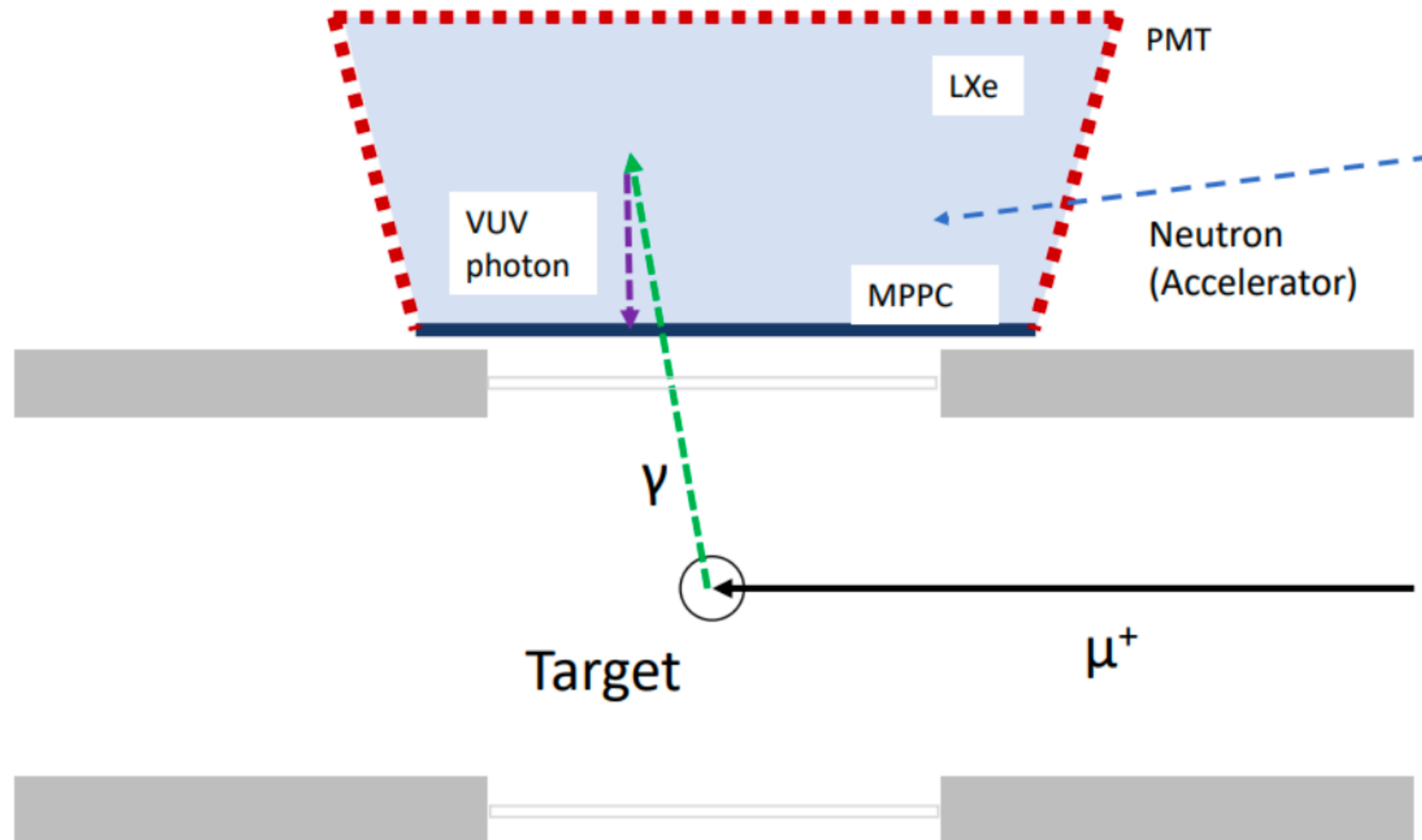
SiPMs tested previously at McGill

- 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





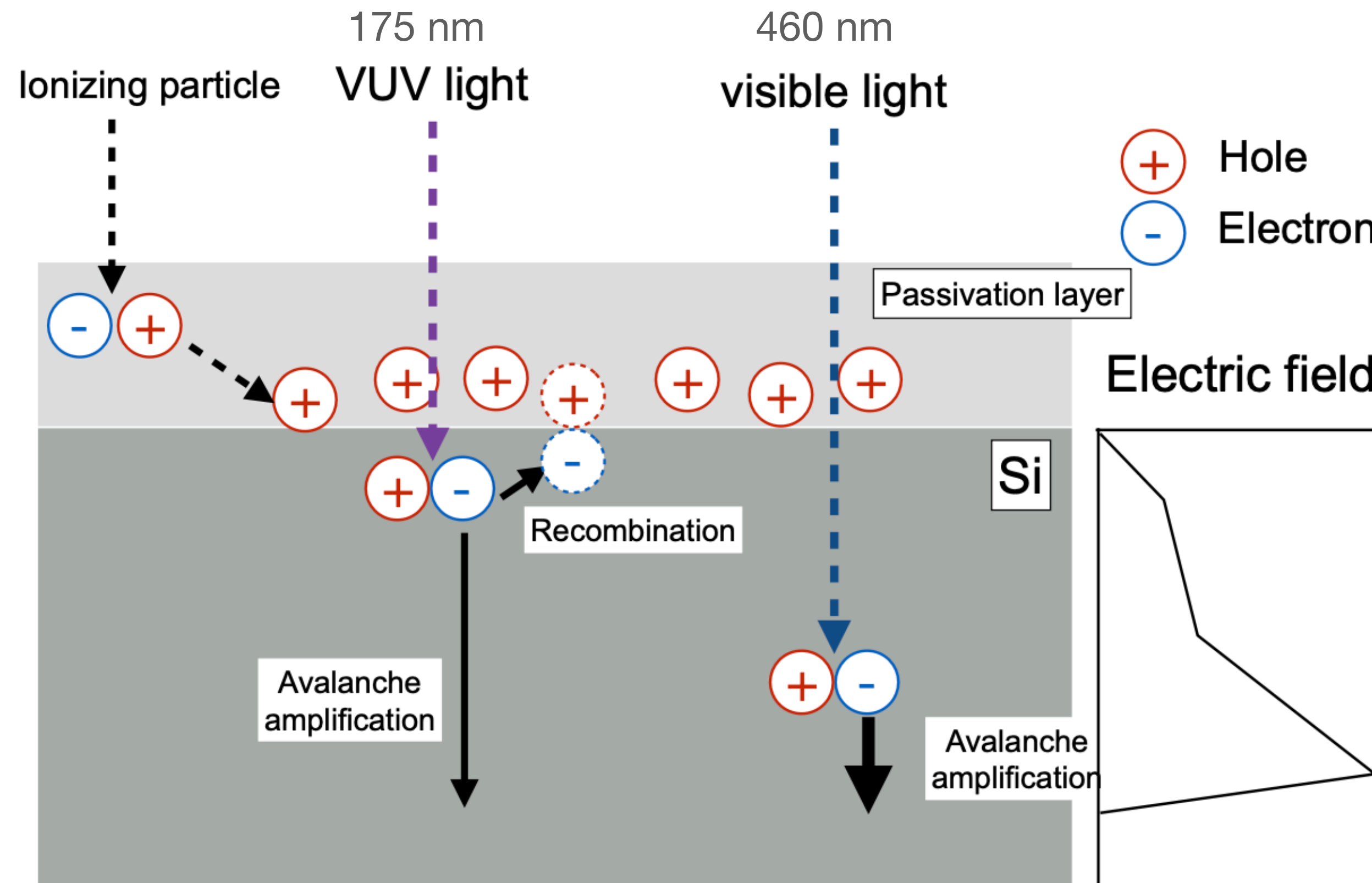
EXTRA

# 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  $\text{SiO}_2$  layer of the SiPM
3. Surface currents generated because of trapped holes in Si
4. Ionisation threshold of  $\text{SiO}_2$  is 9eV.
5. Causes increased leakage current, possibly lower PDE

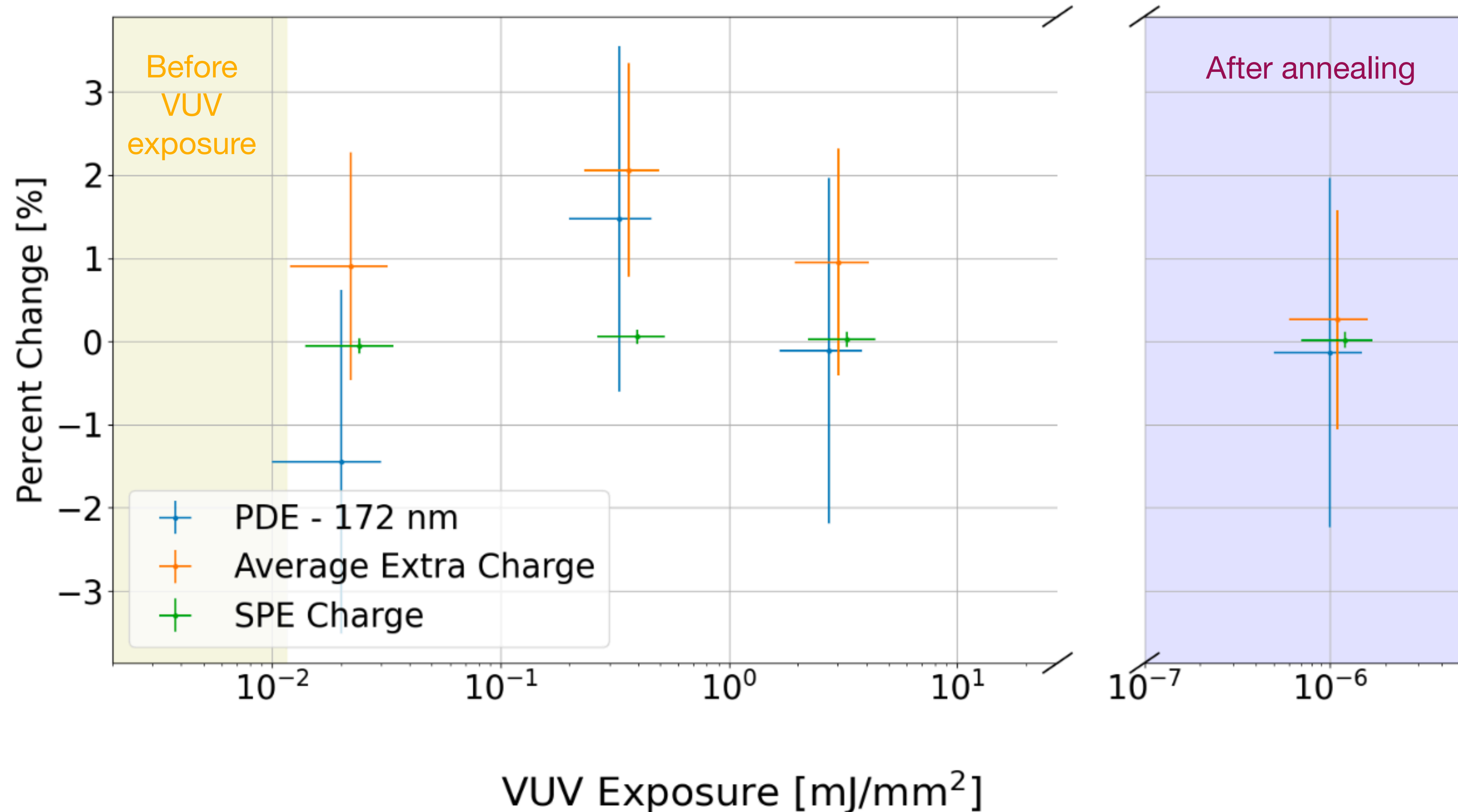
## Non-Ionising Damage

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



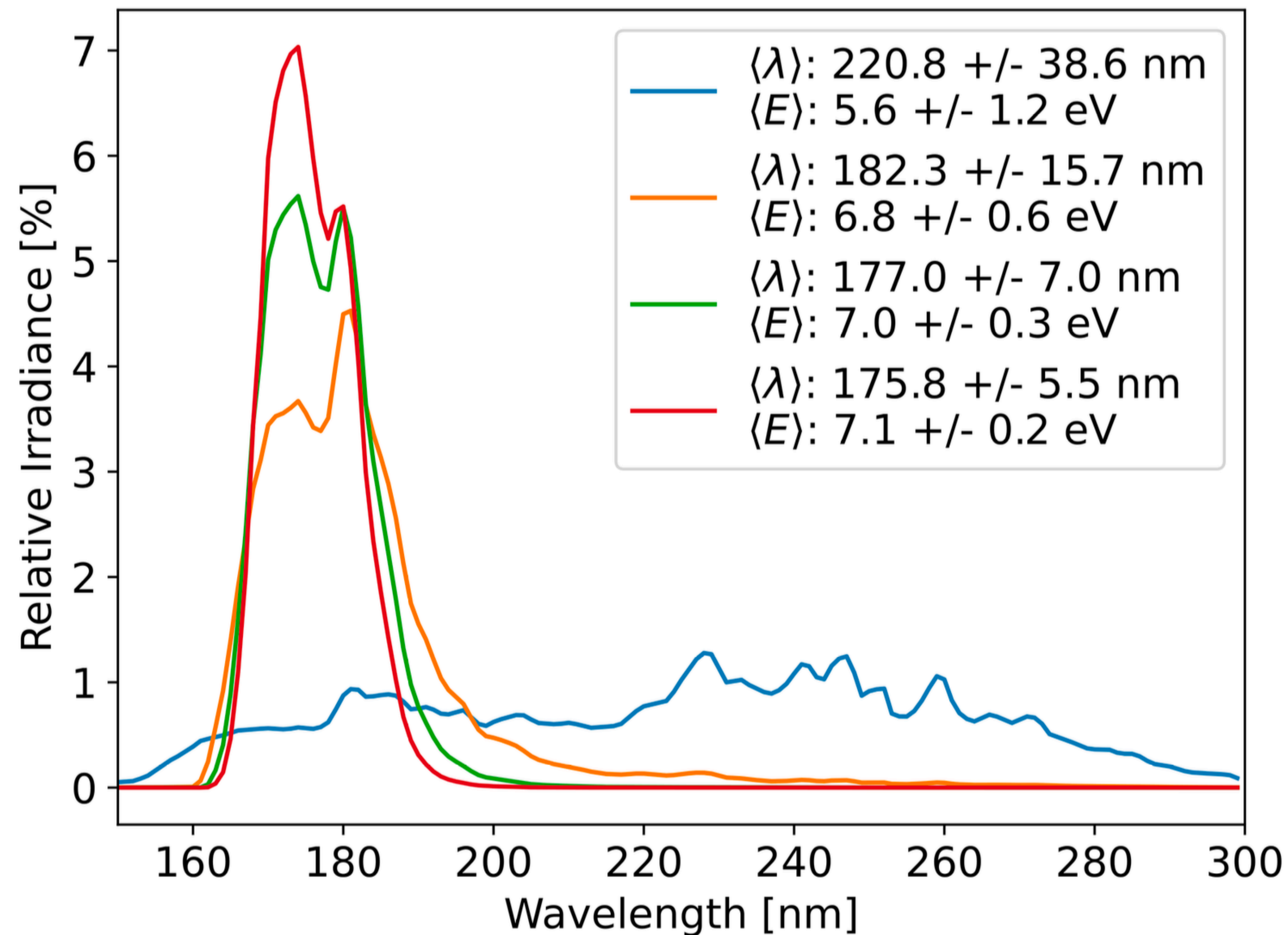
# Previous Ionisation Damage Measurements

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).