Cryogenic detector monitoring and calibration with internally mounted LEDs

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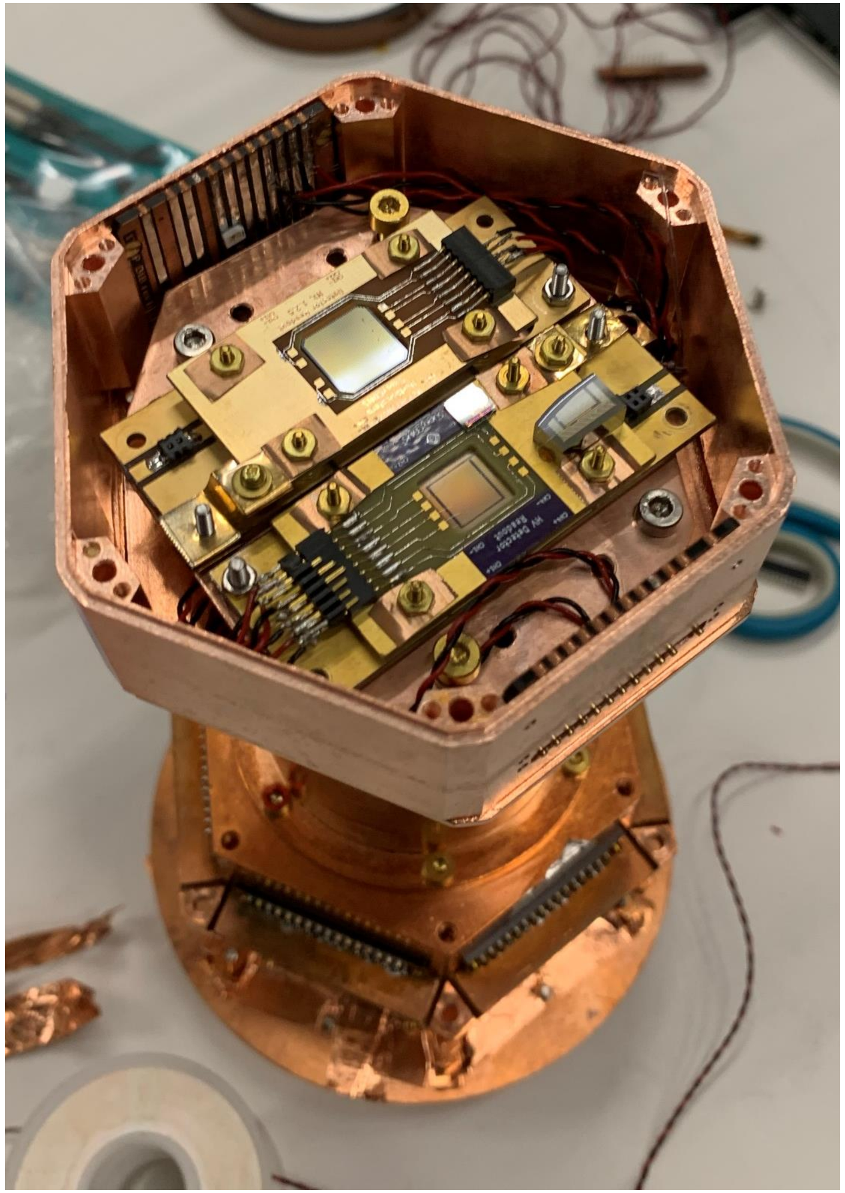
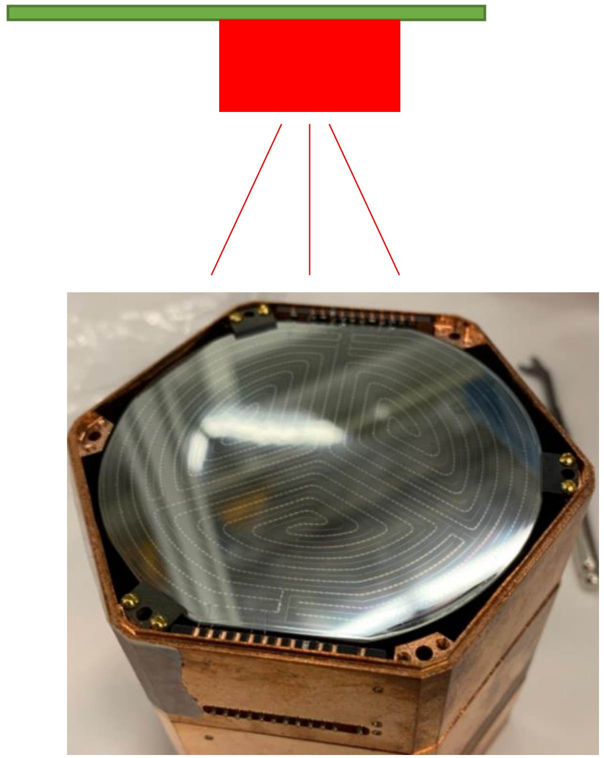
Introduction

- DM searches are pushing to lower and lower thresholds
- SuperCDMS HVeV program has developed small (gram-scale) detectors with ~3 eV resolution
- Applying voltage across detectors produces secondary phonons from drifting charges (Neganov-Trofimov-Luke effect), leading to effective resolution well below the bandgap
  - Can resolve individual electron-hole pairs
- We are studying the behaviour of such low-threshold detectors
  - QP.4 – doi.org/10.1016/j.nima.2020.163757
  - NF-C – arXiv:2012.12430



Applications of LEDs to cryogenic detectors

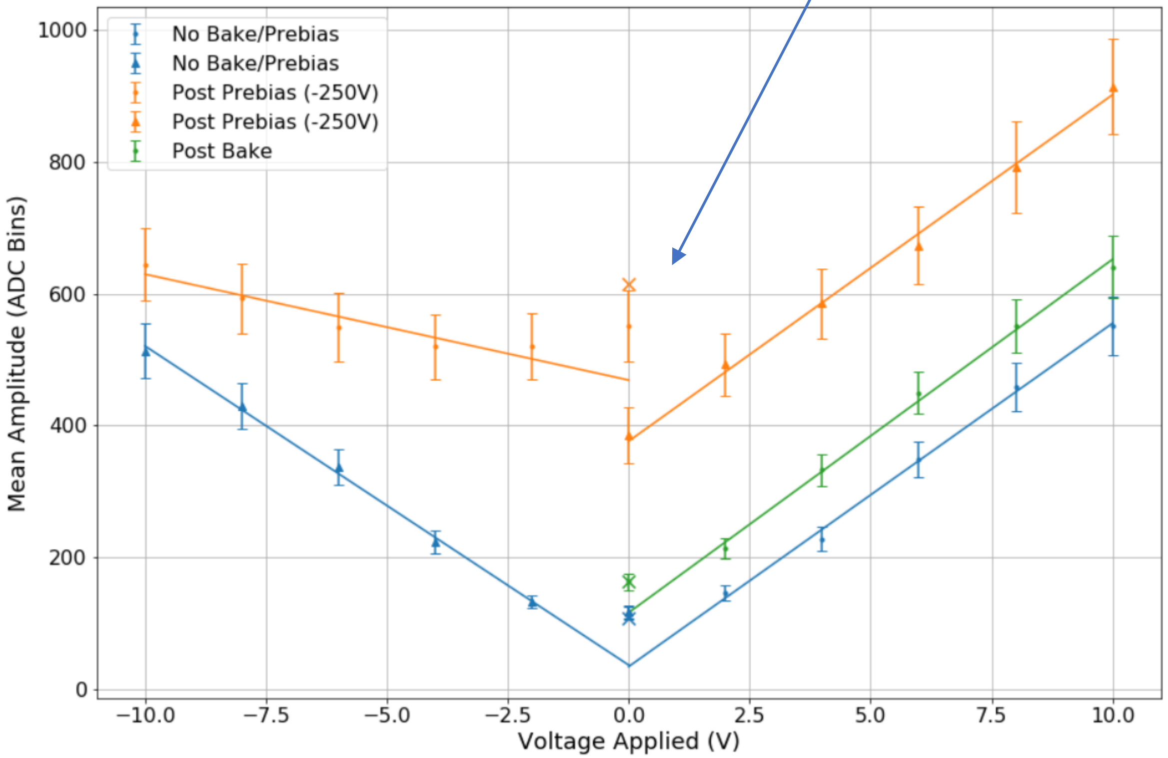
- Prepare detector by “baking/flashing” the detector
- Monitor detector stability
- Calibration of detector at $\lesssim 20\ \mathrm{eV}$
- Measure detector response to different photon energies above and below the bandgap



Baking the detector

- Cryogenic semiconductor detectors accumulate space charges at surfaces or impurities
- When operated with voltage bias, space charges lead to internal counter field
  - Observe NTL amplification even near 0 V
- SuperCDMS uses high photon flux from LEDs to 'neutralize' detectors

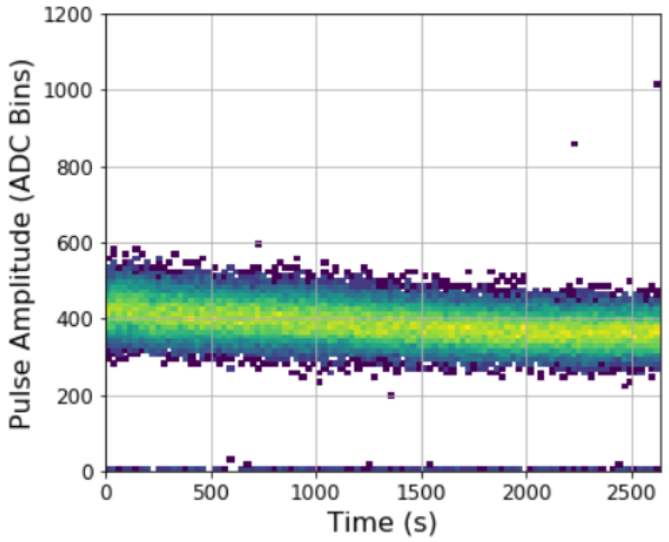
Charge built up after -250 V applied



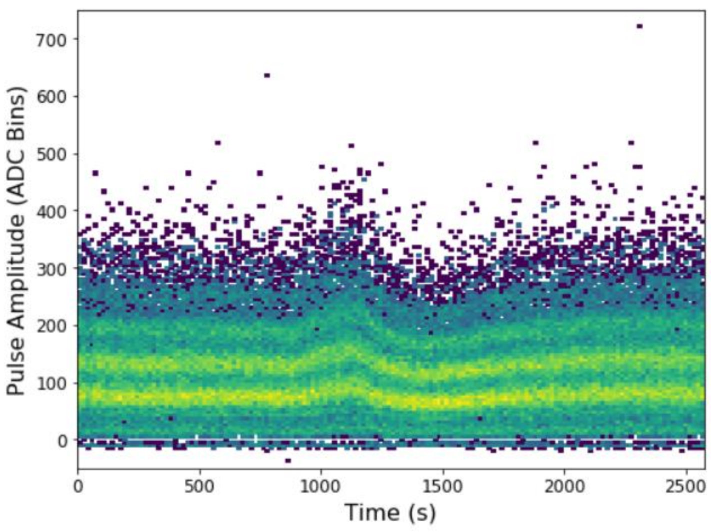
Measured amplitude of LED pulses varies with applied voltage on detector due to NTL gain.

Detector stability

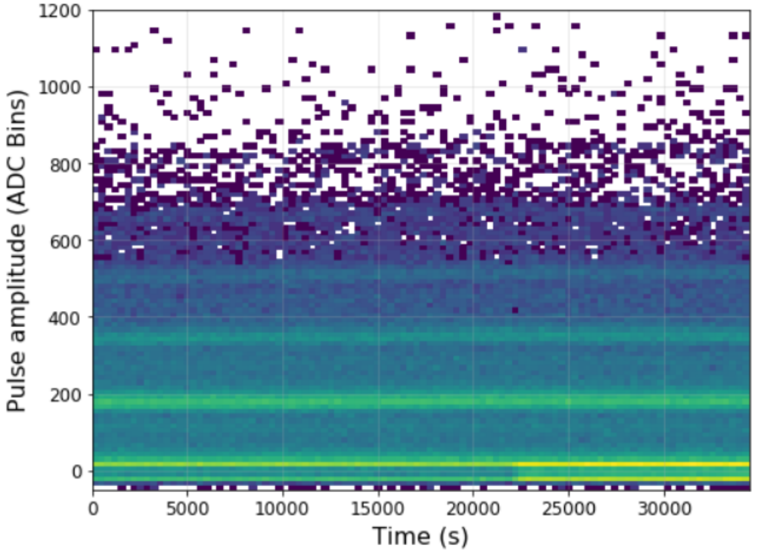
LED pulses can be used to generate constant energy pulses to monitor detector performance over time



Detector settling after change of voltage over 45 minutes

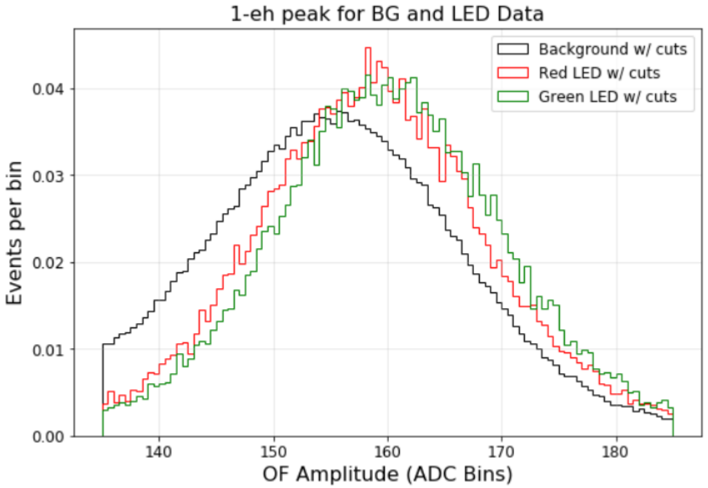


Change of environmental conditions led to fluctuation in measured amplitude



LED Operating steadily for 10 hours

Calibration



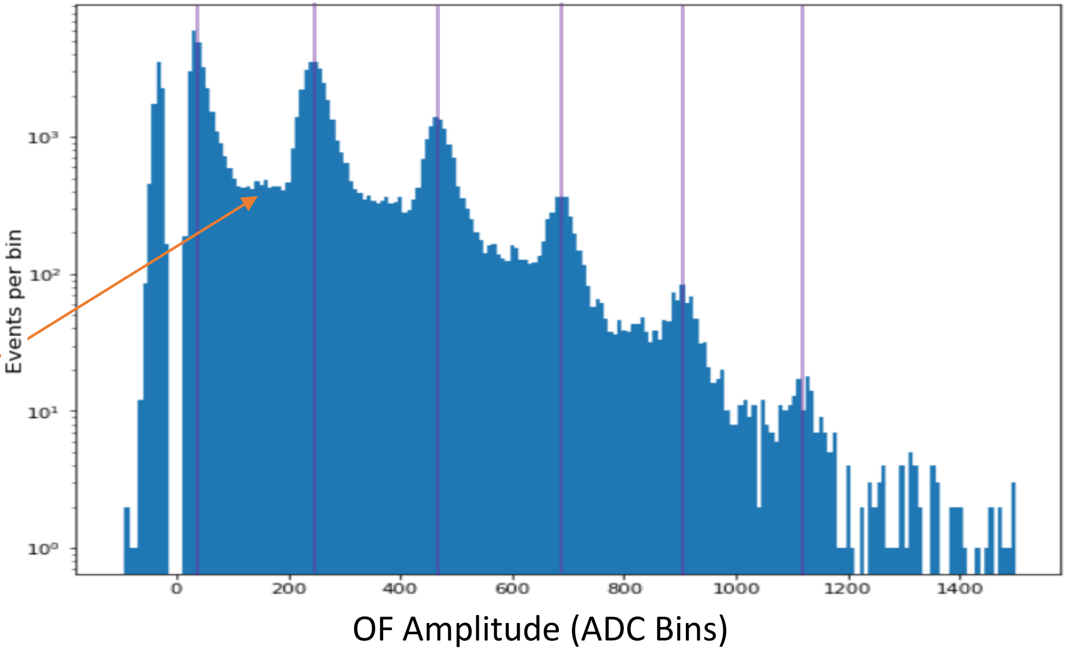
Energy of eh pair peaks due to NTL gain is as follows

$$E_{measured} = N_{eh}(E_{photon} + e \cdot V_{NTL}) + E_{surface}$$

Don't miss this!

- V_{NTL} is applied voltage bias
- $E_{surface}$ is offset due to direct absorption of photons in sensor, as seen in offset on N=0 peak.

Fill in due to charge-trapping/impact ionization and infrared photons

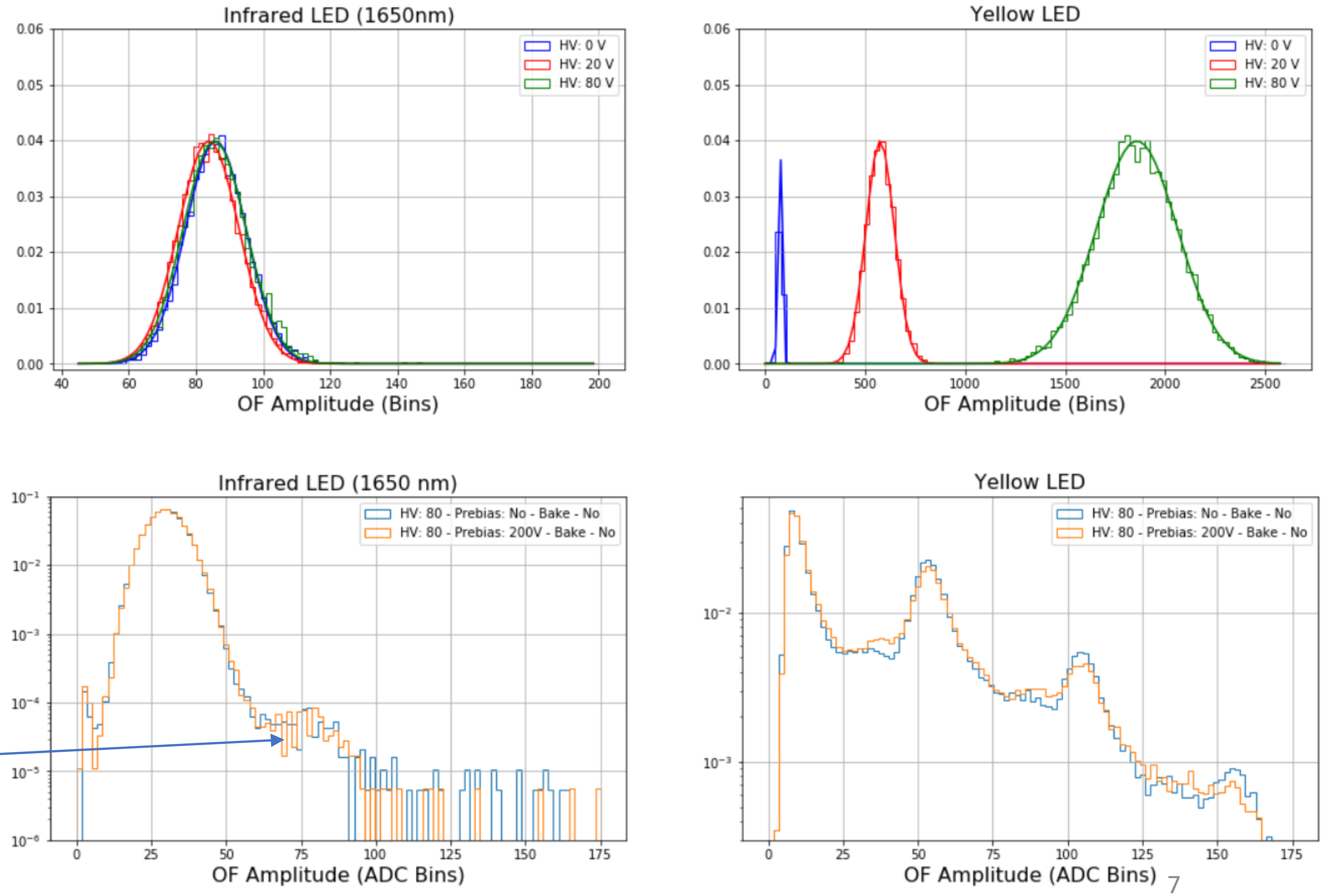


Sub-gap Infrared LEDs

IR and Yellow LED at low and high amplitudes

Sub-gap IR (0.75 eV) photons still generate pulses on Si detector (bandgap = 1.2 eV)

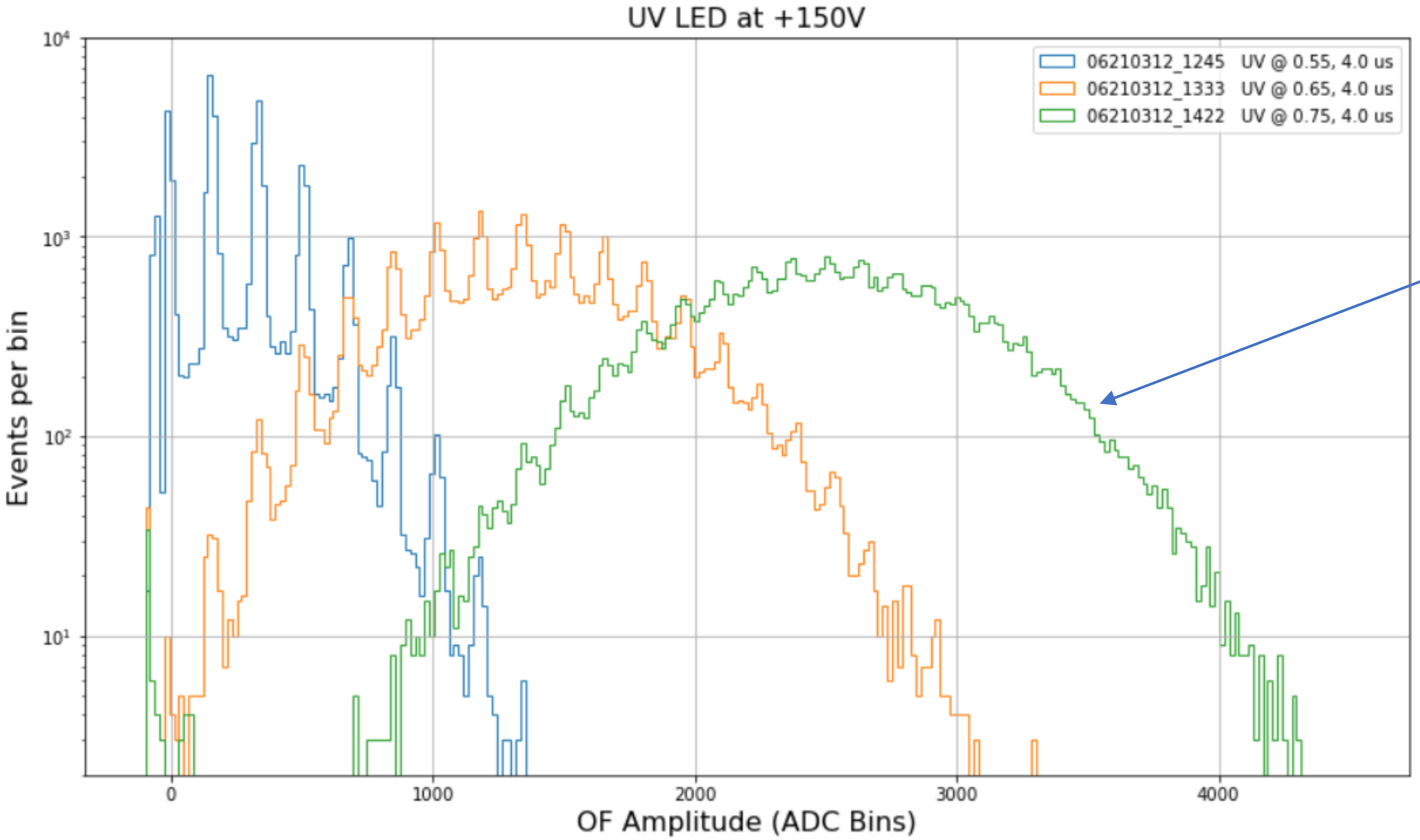
- Most likely due to hits directly on aluminium fins, other mechanisms to be investigated
- No NTL amplification is observed
- No eh pairs are observed



Shoulder likely due to pileup with 1 eh background

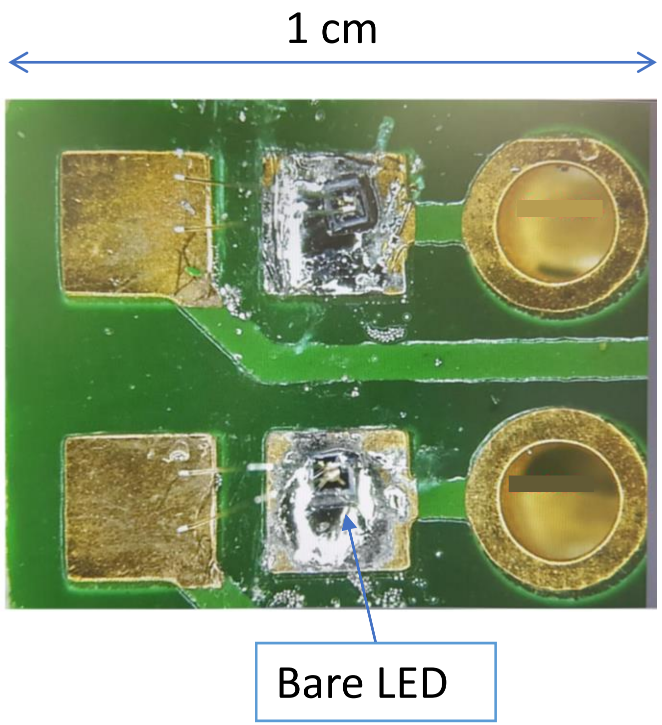
IR blocking filter vs Unfiltered

- So far, datasets have only shown up to the 5th peak
  - Above this the fill-in washes out the peak.
- What happens if we block the infrared emitted by the LEDs self-heating?



Nearly 25 eh pairs!
~3.75 keV

Challenges and Outlook



- While some LEDs have demonstrated excellent stability, others have been observed to have variable amplitude over time
- Some LEDs (esp. infrared in epoxy casing) only survive a couple cooldowns before failing, others in casing have yet to fail after >10
  - Testing new LEDs that are completely bare requiring wire bonds
- A new setup is being built to house multiple LEDs with IR blocking filters for testing position dependence
- Further study of how the energy of emitted photons changes for LEDs at mK temperatures