SuperCDMS HVeV Detector Characterization

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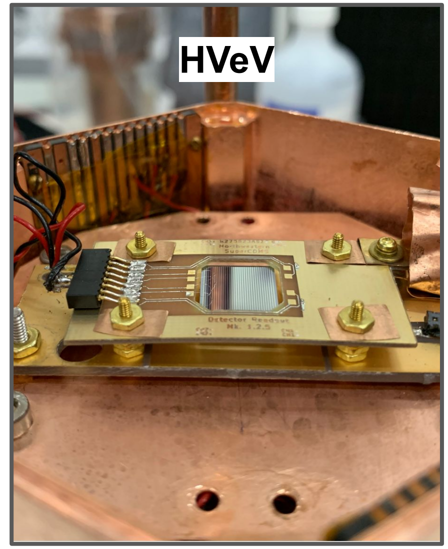
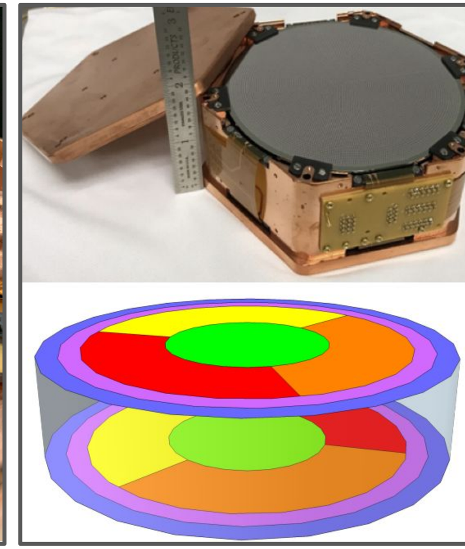
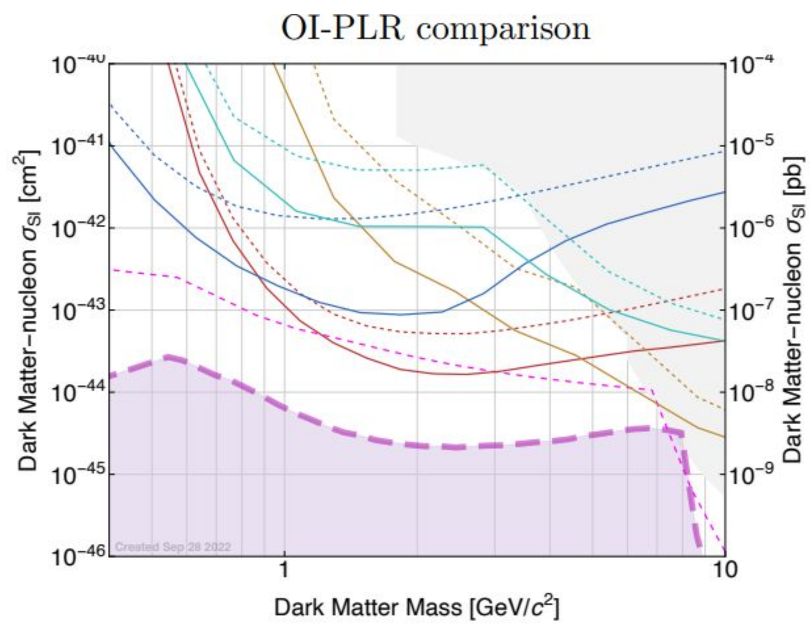
Super Cryogenic Dark Matter Search (SuperCDMS) Assumptions and Hopes

- Dark matter may interact with regular matter weakly
- Can interact with the bulk of the detector through electron or nuclear recoil
- With low/controlled background environment, this interaction can be measured.
- In SuperCDMS, one detector type is the **HV** detector
- Cryogenic Ge and Si crystals to measure phonons via QETs
- Large HV detectors for sufficient exposure and small HVeV with better resolution

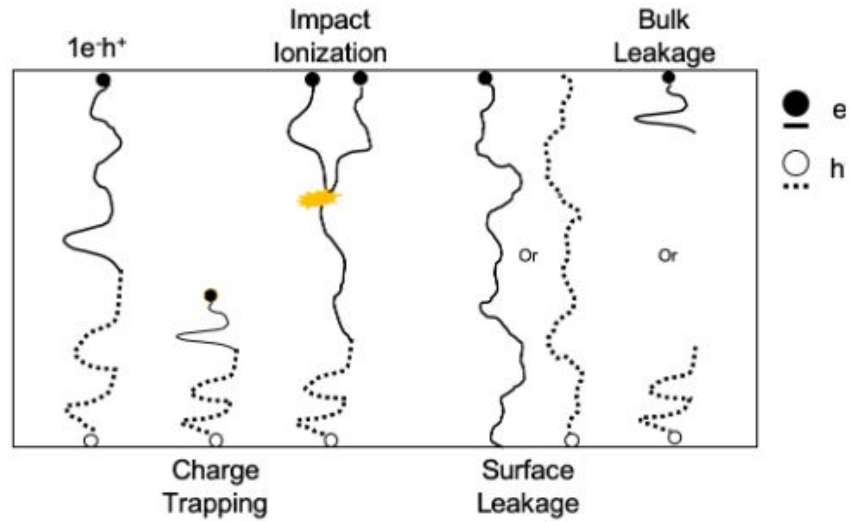


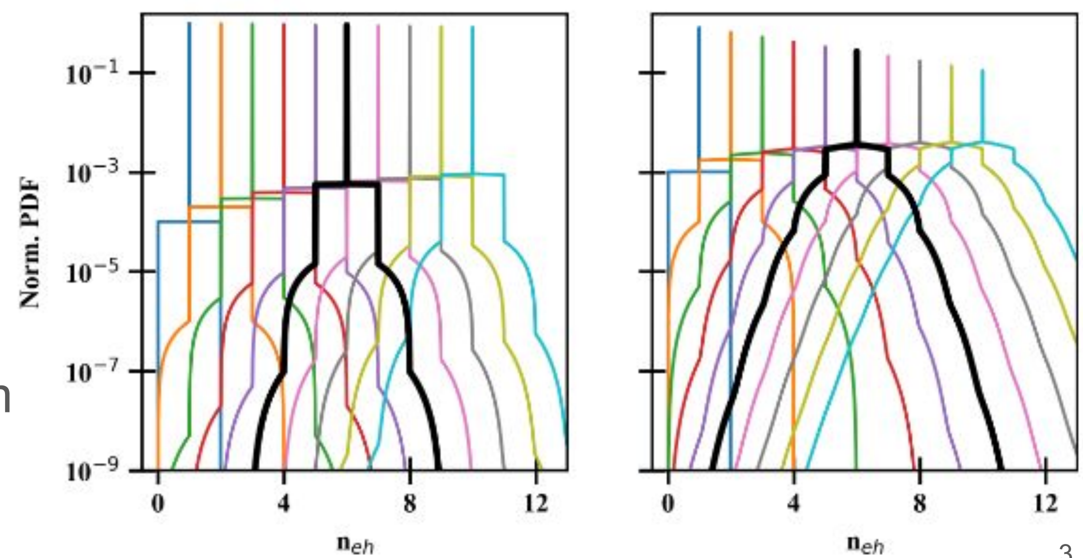




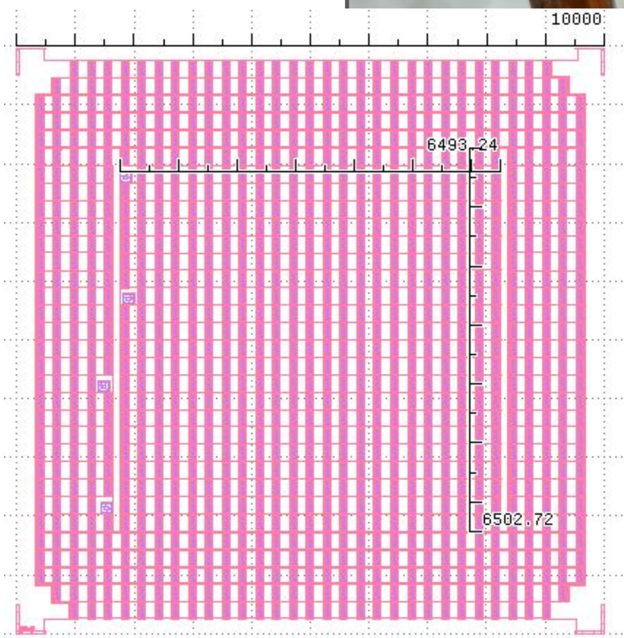
HVeV Detectors and NTL Effect

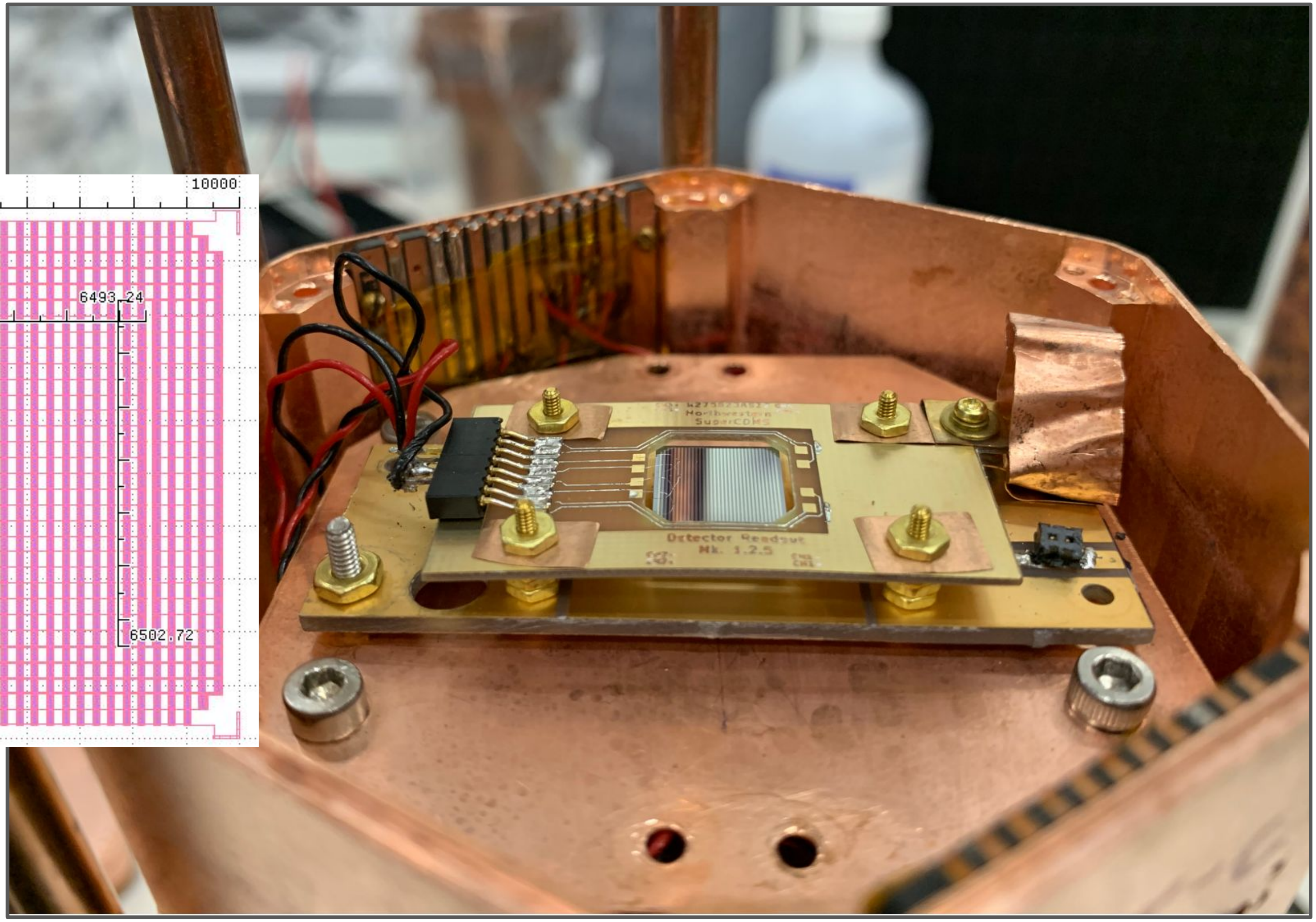
- **High-purity Si or Ge lattice**
- **High bias voltage (100-200V)**
- **NTL amplification**
  - e/h pairs drift across lattice and produce phonons
  - Measured energy quantized by phonon-mediated amplification of charge carriers
- **Additional crystal effects**
  - Charge trapping
  - Impact ionization
- **Background**
  - Random coincidence from external backgrounds





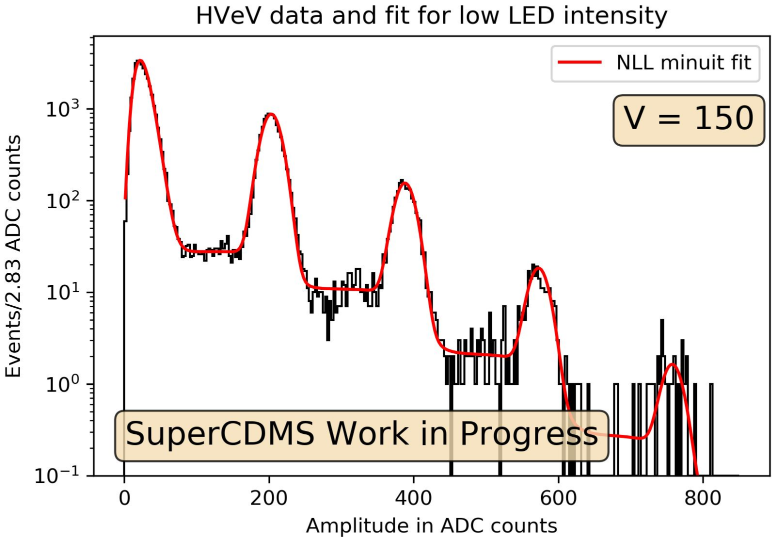
HVeV NF-C Detector at TRIUMF

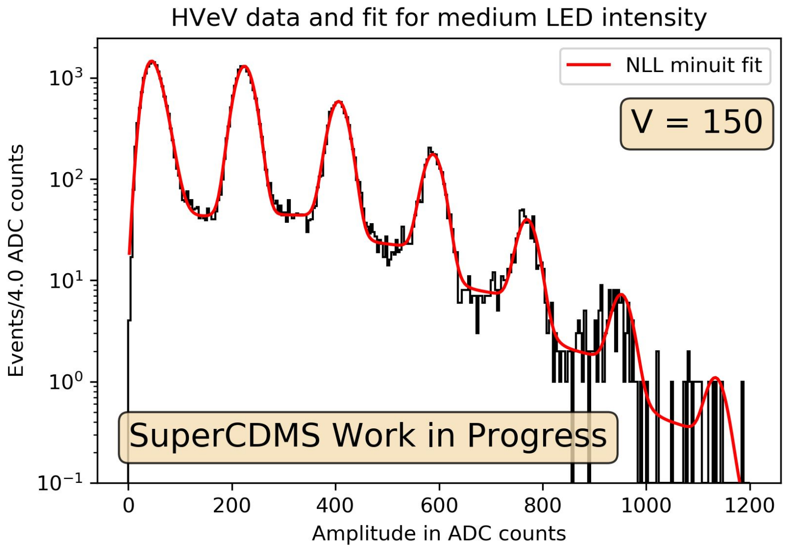


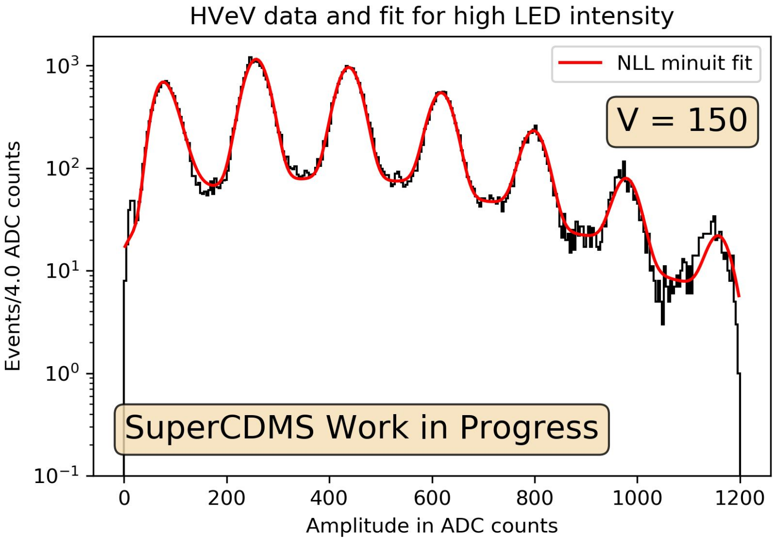


HVeV Calibration Data from TRIUMF

- Calibration using UV LED (~4 eV) at different intensities
- Shone towards center of detector
- 2 channels (inner and outer)
- Model fit on aggregate of both channels for total phonon signal

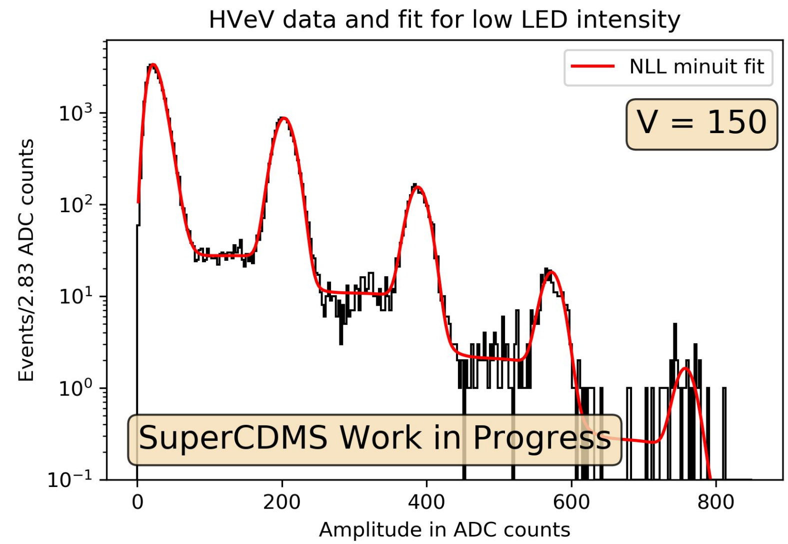


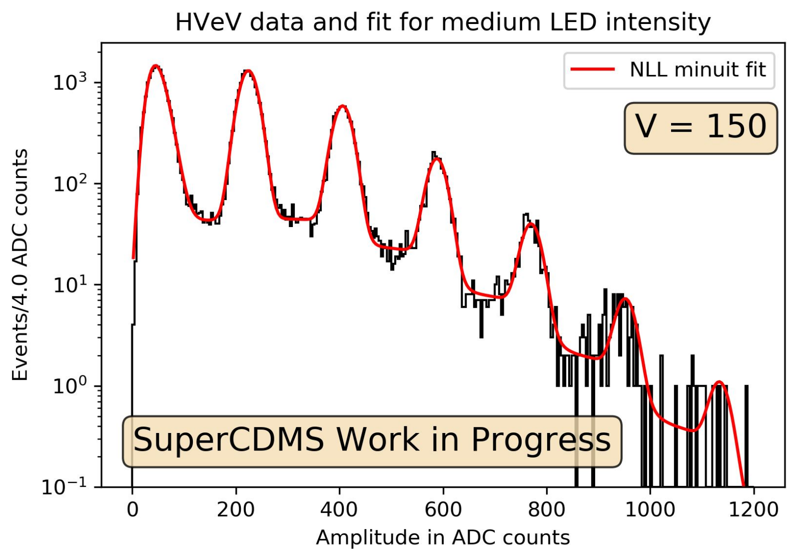


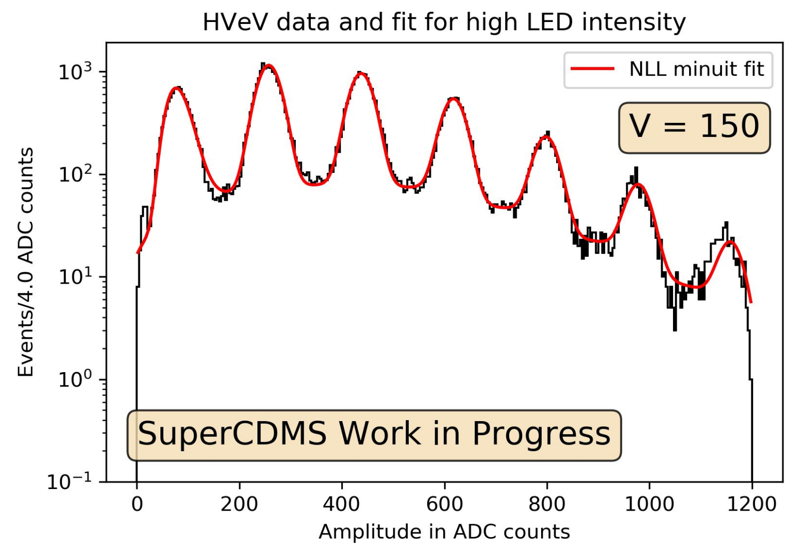


Fit Results for Different LED Intensities

- Fit for Poisson lambda (LED intensity), detector resolution (width of peaks), charge trapping and impact ionization, background, etc.
- **Puzzle: detector resolution** and **peak positions** change with LED intensity?

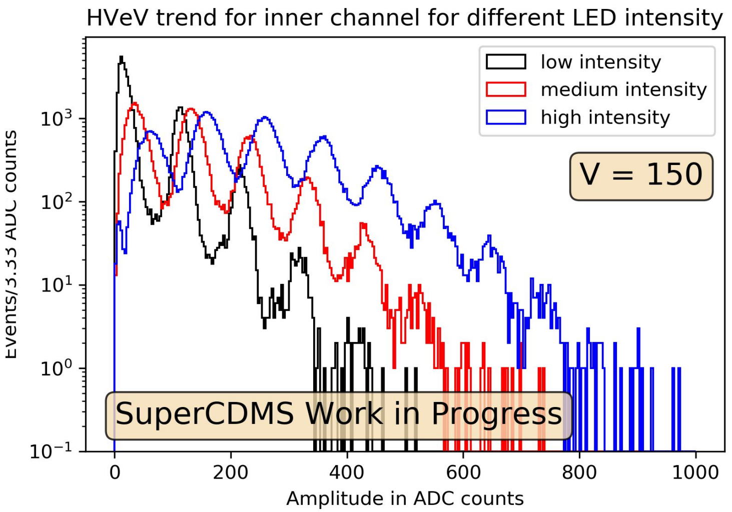


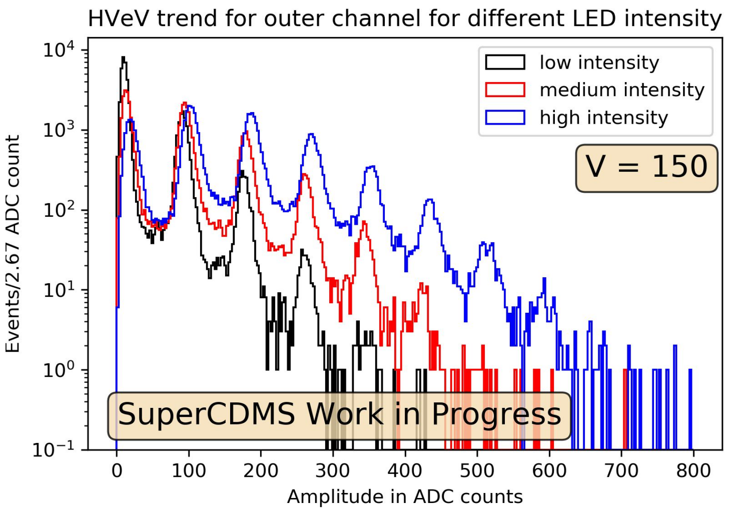




Inner Channel vs. Outer Channel Spectra

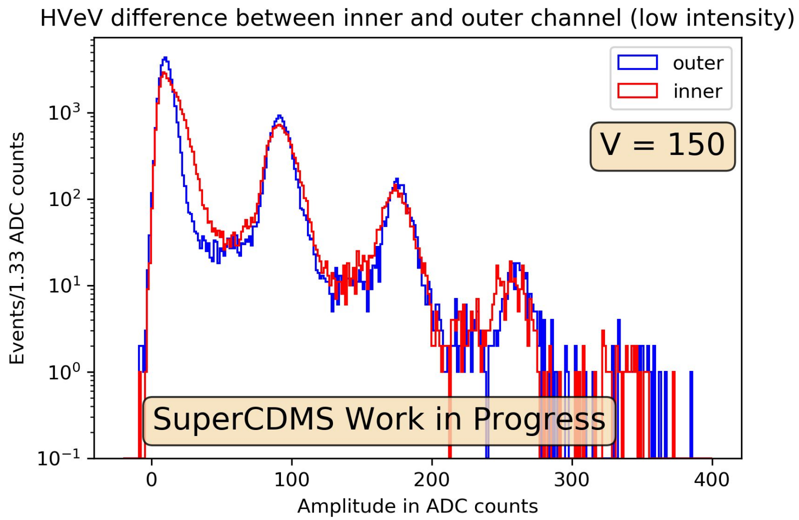
- LED is collimated on the center of detector (inner channel).
- More photons are hitting inner channel vs. outer channel.
- Peak positions variation is more pronounced for inner channel.
- Peak width (detector resolution) also varies!
- Phenomenon is based on # photons hitting detector.

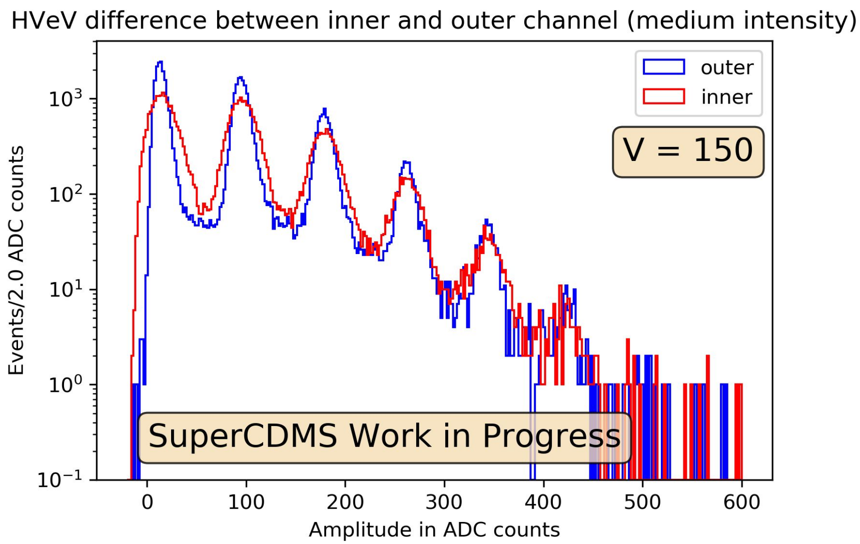


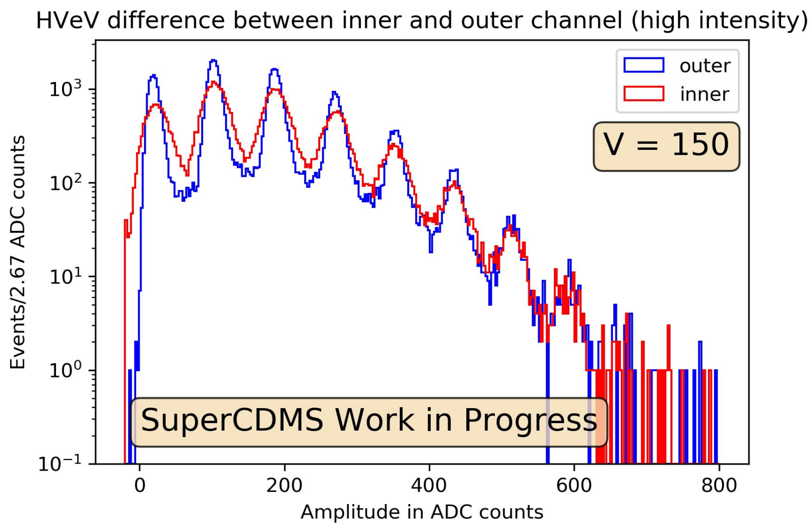


Inner Channel vs. Outer Channel Spectra

- Clear variation in peak widths
- Worse resolution for higher LED intensities
- What is going on here?







Non-Quantized Heating Model

- **Hypothesis:**
  - Some photons are absorbed as heat with no e/h pairs (follows Poisson process)
  - High statistics => Gaussian
- **Expectation:**
  - Linear increase for peak position
  - Square-root increase for peak width

$$\mathrm{E}_{\mathrm{NTL}} = N_{\mathrm{NTL}} Bh\nu(1 + \frac{V_{\mathrm{bias}}}{h\nu})$$

$$\mathrm{E}_{\mathrm{heat}} = Bh\nu f \lambda_{\mathrm{LED}}$$

$$\sigma_{\mathrm{heat}} = Bh\nu \sqrt{f\lambda_{\mathrm{LED}}}$$

$$\mathrm{E} = \mathrm{E}_{\mathrm{NTL}} + Bh\nu f \lambda_{\mathrm{LED}}$$

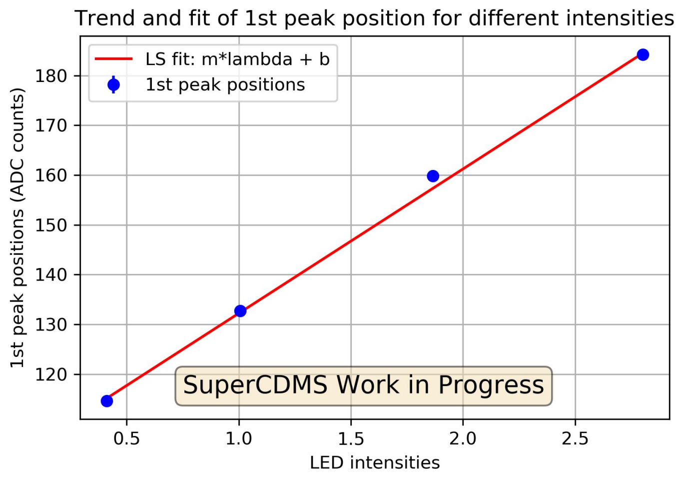
$$\sigma^2 = \sigma^2_{\mathrm{NTL}} + B^2 (h\nu)^2 f \lambda_{\mathrm{LED}}$$

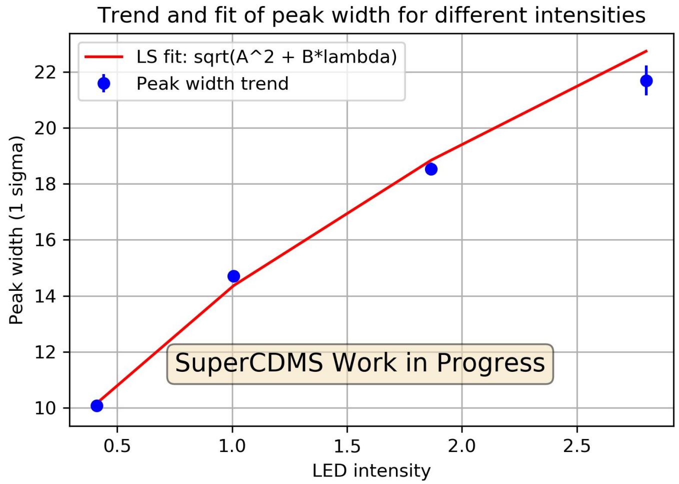
N_{NTL} - # of e/h pairs produced
B - conversion factor from eV to ADC counts
V_{bias} - bias voltage across the crystal
hv - energy of a single calibration photon in eV
f - conversion factor from Poisson lambda to # of photons

Non-Quantized Heating Model Verification

- Fits for peak positions and widths resemble the data
- Compute the constants in the formulation (e.g. B, f)
- Dark Matter limit (LED intensity => 0)
- Estimation of detector resolution for Dark Matter

$$E = E_{NTL} + Bh\nu f\lambda_{LED}$$
$$\sigma^2 = \sigma^2_{NTL} + B^2(h\nu)^2 f\lambda_{LED}$$





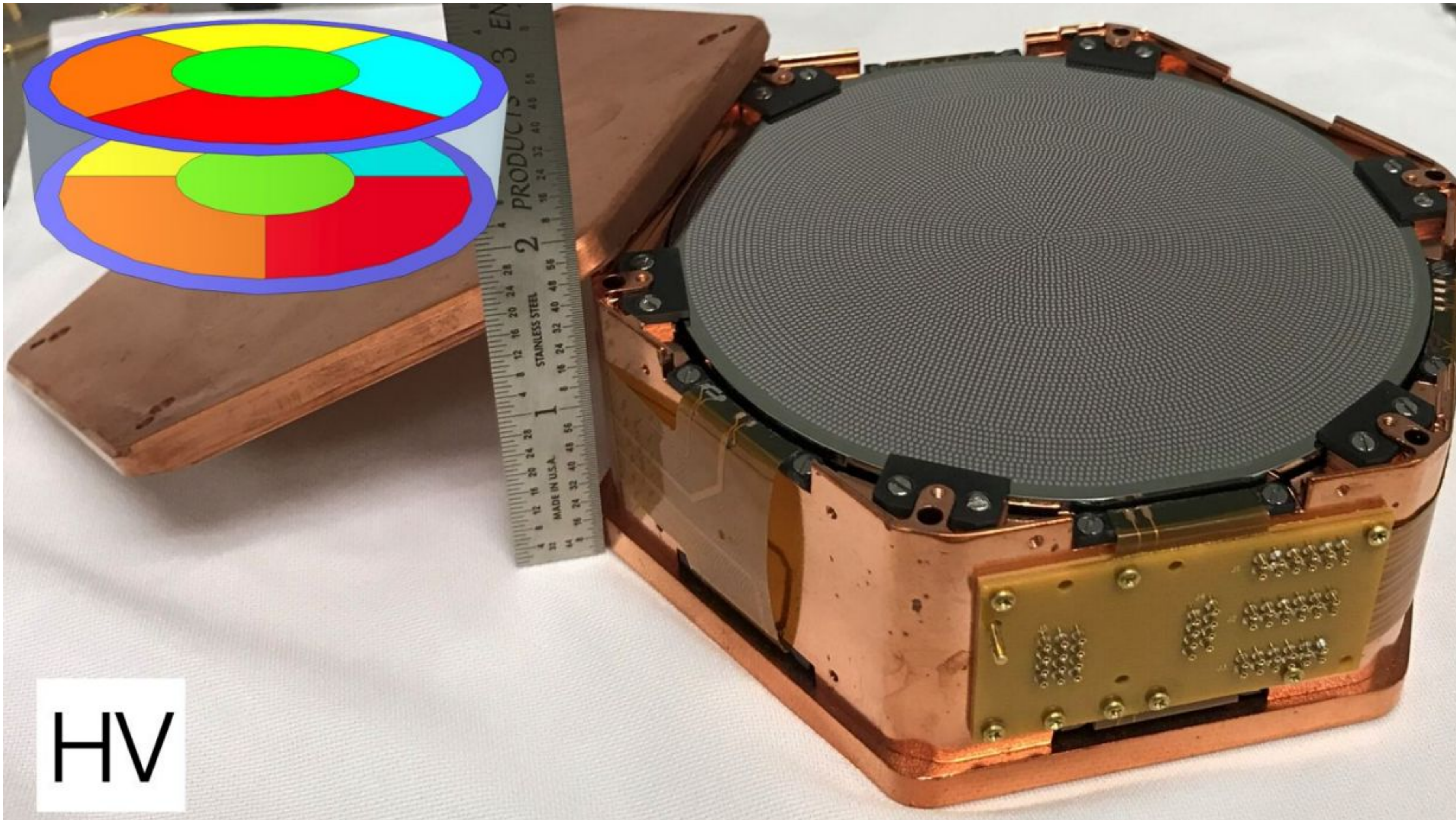
Non-Quantized Heating Sources and Future Testing

- **Hypothesis 1: Some photons are absorbed in the QET**
  - **QET**: **Q**uasi-particle trap-assisted **E**lectrothermal feedback **T**ransition edge sensor
  - QET covers 50% of detector surface
  - QET has higher sensitivity to photons (QET efficiency)
  - LED was collimated at QET side
- **Hypothesis 2: Some e/h pair are trapped on the surface**
  - UV penetration depth on Si is 0.01 um
  - Simulation suggests trapping of e/h pairs on the near surface
  - Trapped e/h pairs may be reabsorbed as heat before amplification
- **Future testing:**
  - Shining the LED on the backside of detector (no QET)
  - Using other colors and look for correlation
  - Test different polarities (e.g. +/- 150 V)
  - Current runs at TRIUMF aim at answering these questions

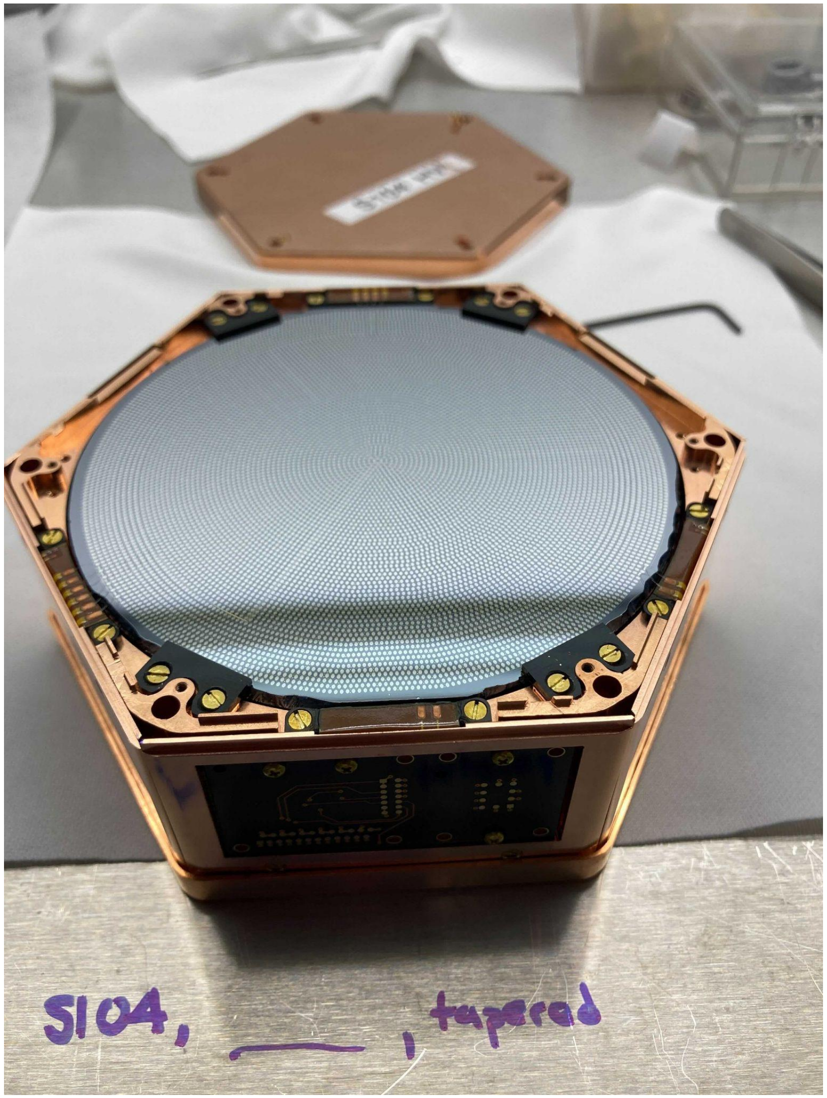
Thank you!

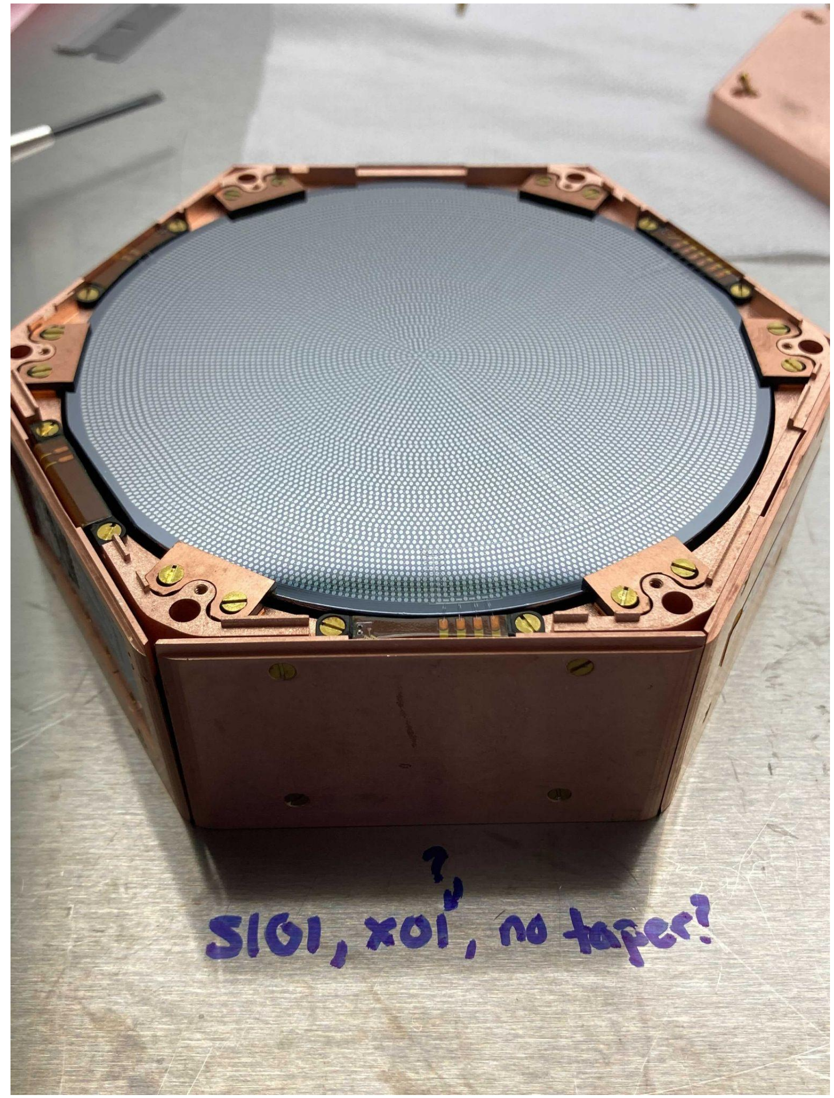
Backup Slides

Appendix 1: HV Detectors

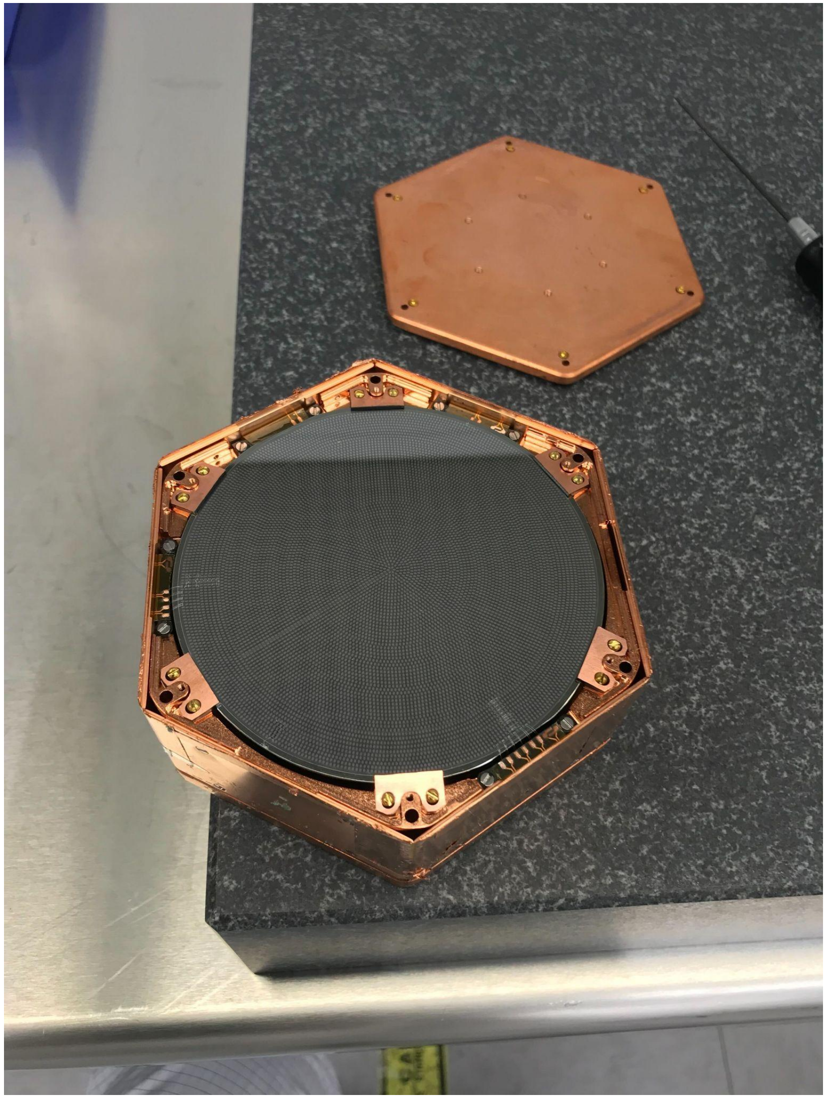


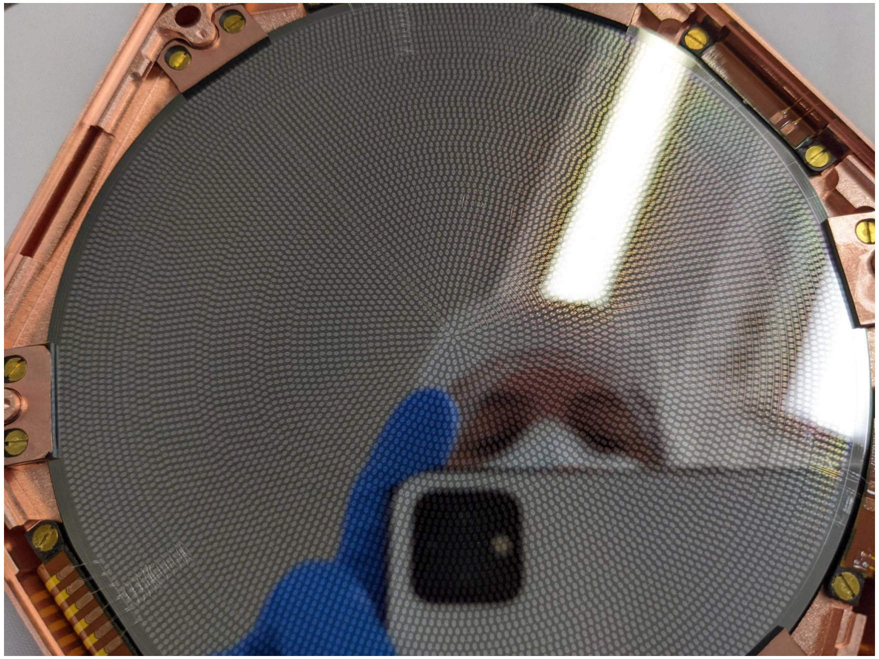
Appendix 2: More HV Detectors





Appendix 3: Even More HV Detectors





Appendix 4: UV LED and filter

- UV LED is 4 eV => 310 nm
- UV LED is shining through thin Al film (~20 nm). UV that makes it through the Al film passes through UV transparent glass.
- The LED is shining through small hole to centered at the inner channel of the detector.