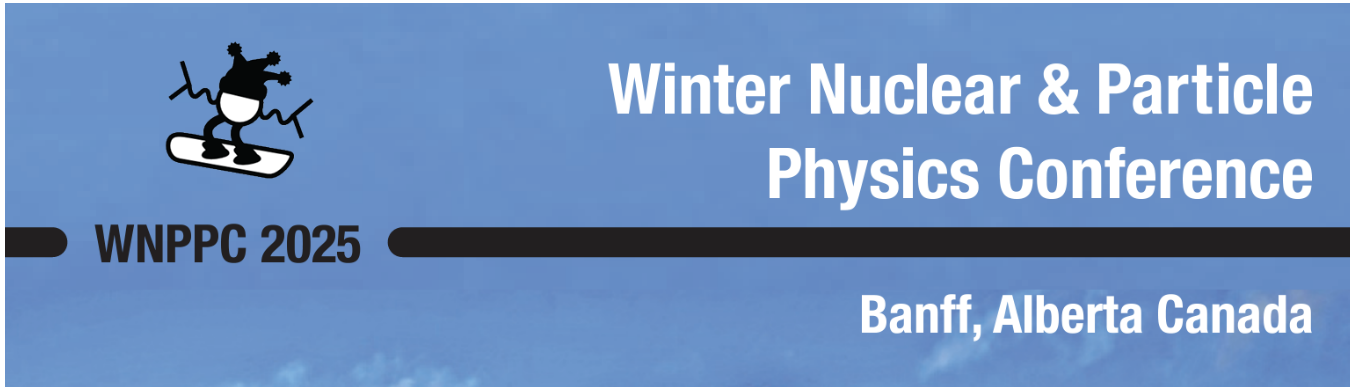


Characterizing SuperCDMS detectors in the CUTE facility at SNOLAB

Ariel Zuñiga-Reyes (U. Toronto)
on behalf of the SuperCDMS collaboration

February 13-16, 2025

UNIVERSITY OF TORONTO

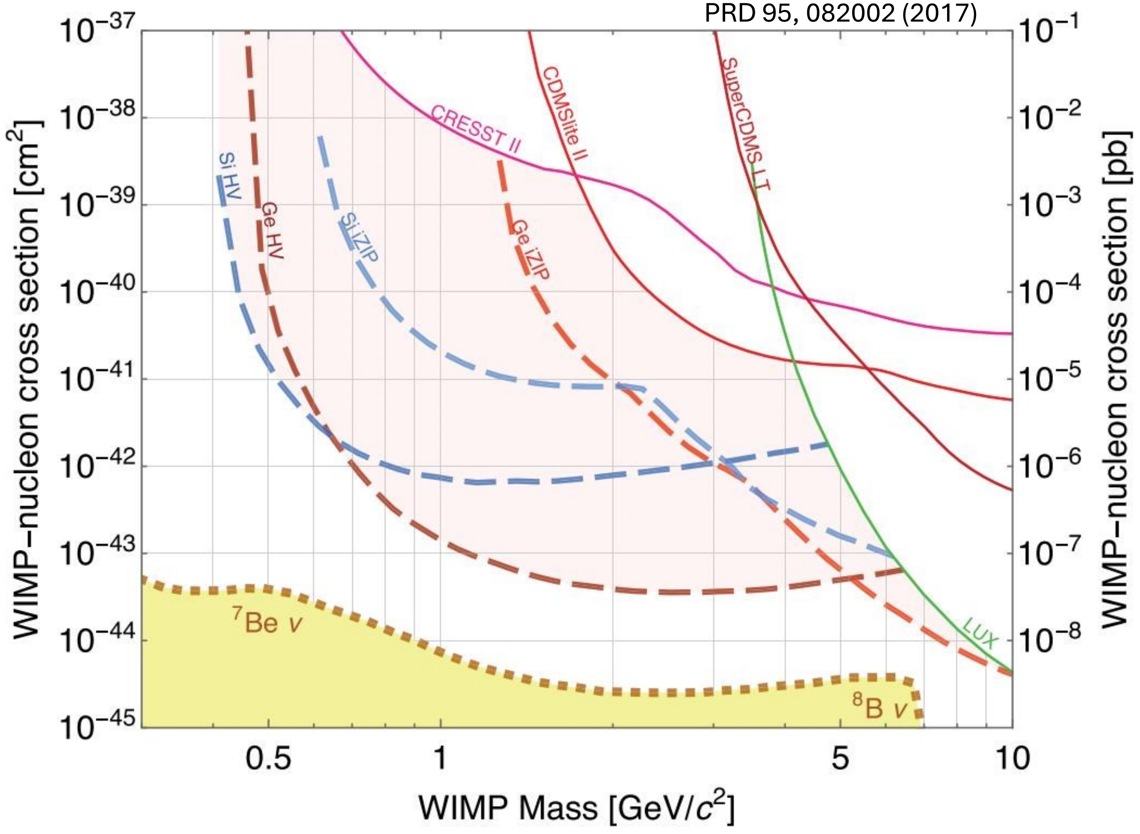
SUPER CDMS

CUTE FACILITY

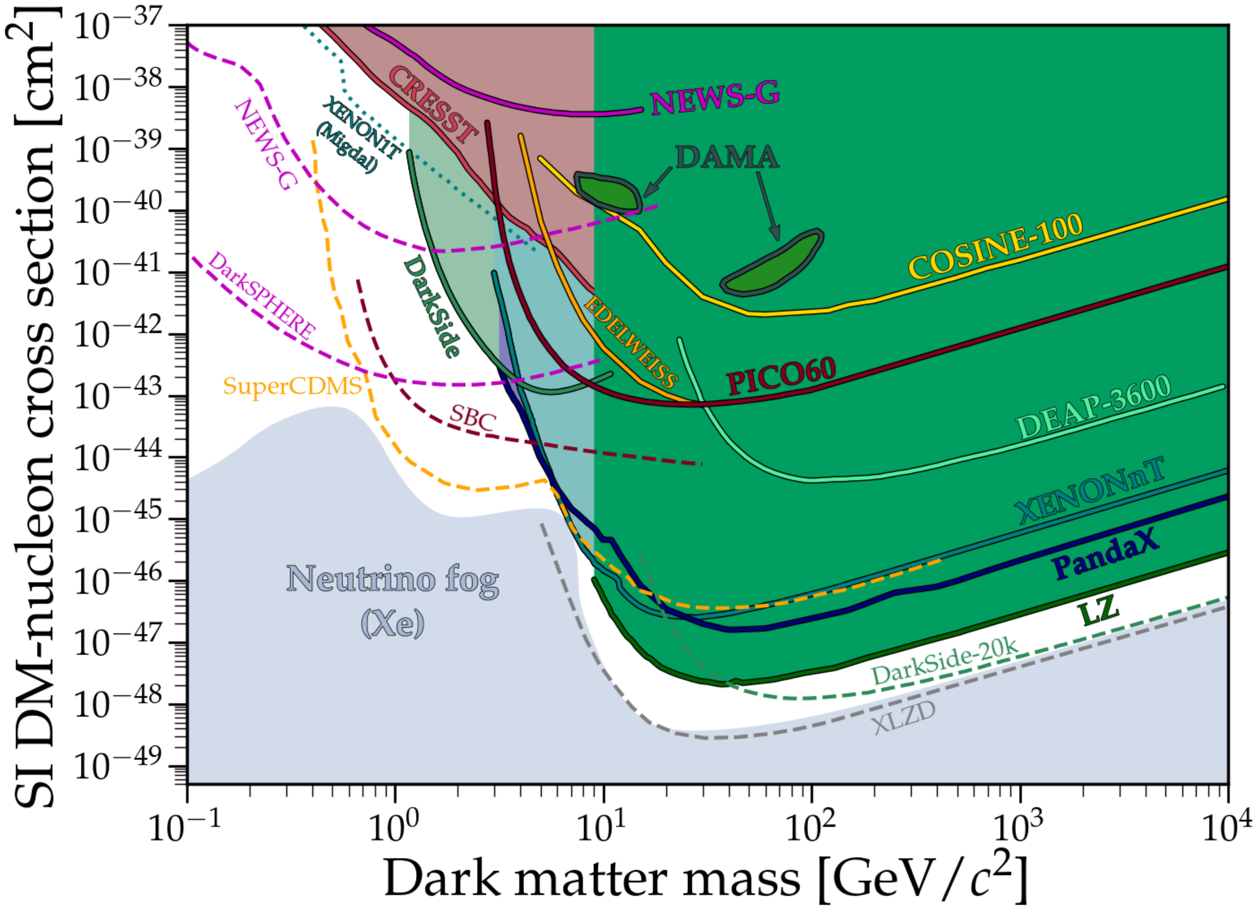
SuperCDMS science reach

Primary science goal: search for nucleon-coupled dark matter in the 0.5 - 5 GeV/c² mass range

PRD 95, 082002 (2017)

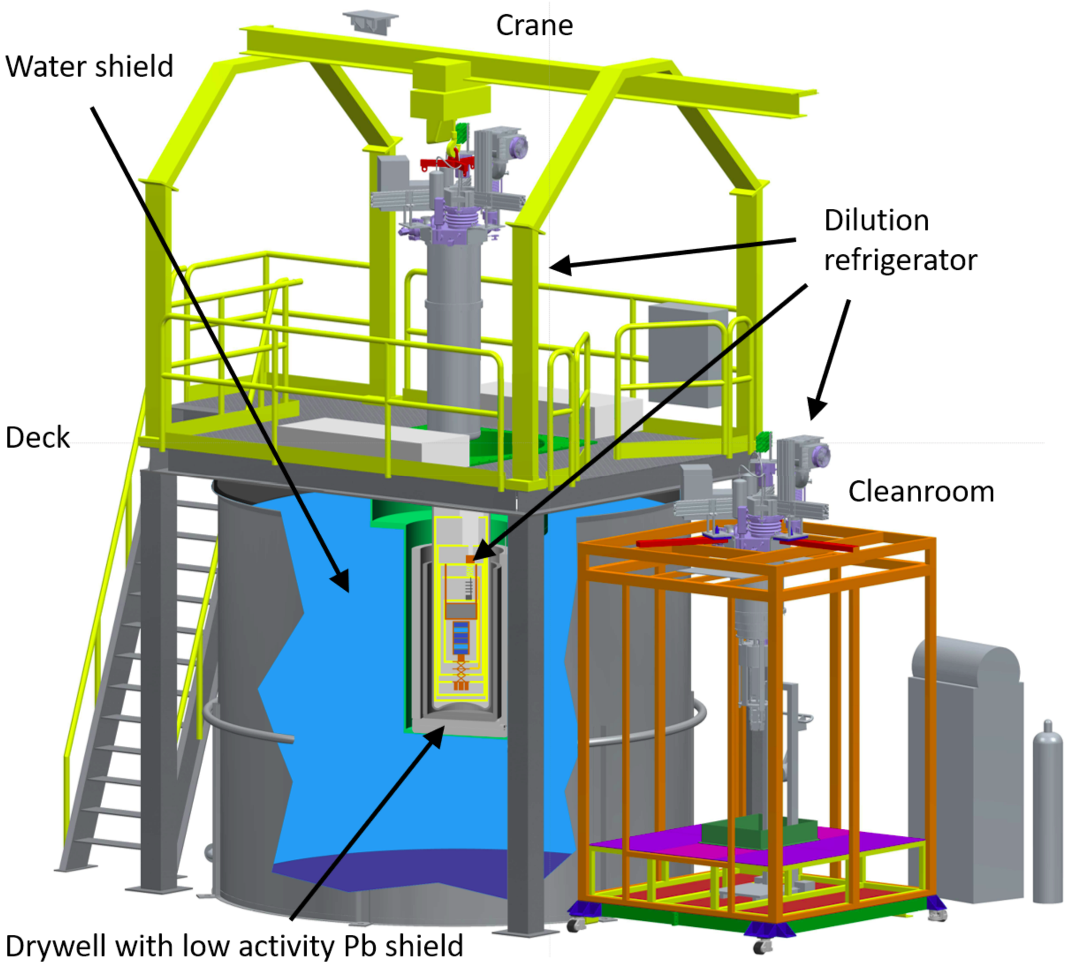


Credit: cajohare/**DirectDetectionPlots**

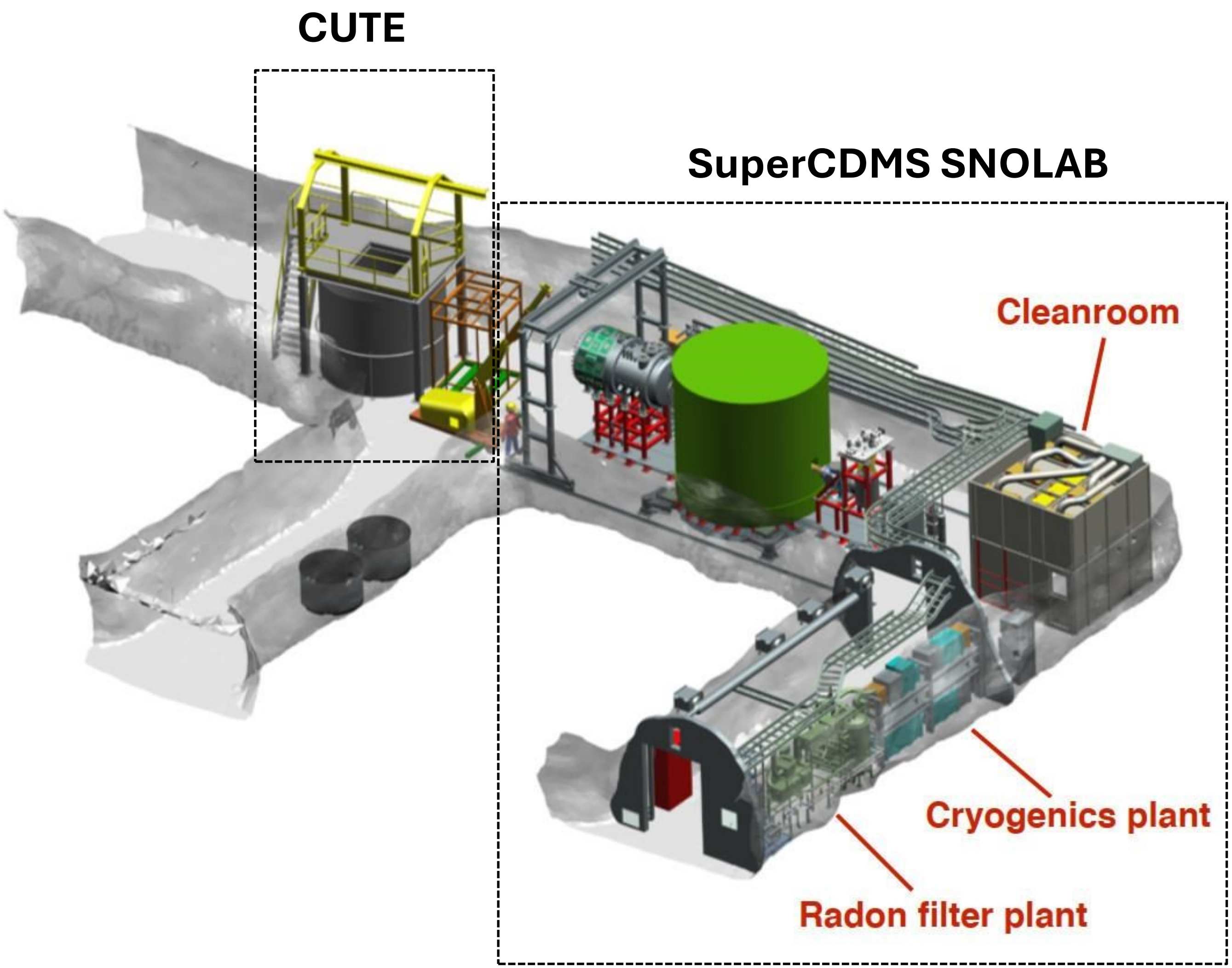


Secondary science goals: Sub-GeV DM via electron scattering, Axion-Like Particles, ^{8}B solar neutrinos observation, etc.

Cryogenic Underground TEst facility (CUTE)



Super Cryogenic Dark Matter Search experiment @ SNOLAB



The journey of SuperCDMS detectors

- Detectors assembled at SLAC and delivered underground in 2023.
- **At SLAC (0-5 m.w.e.):**
  - High trigger rate ~ 35 Hz/detector (pile-up, saturation) and very short testing time to avoid cosmogenic exposure.
- **At SNOLAB (~ 6000 m.w.e):**
  - Less cosmic ray backgrounds (~2 μ/m^2/week)
  - Opportunity to test SCDMS systems in CUTE before the main experiment is operational (e.g. detectors).
  - CUTE testing experience can inform on useful analyses, operational logistics, train personnel, etc.

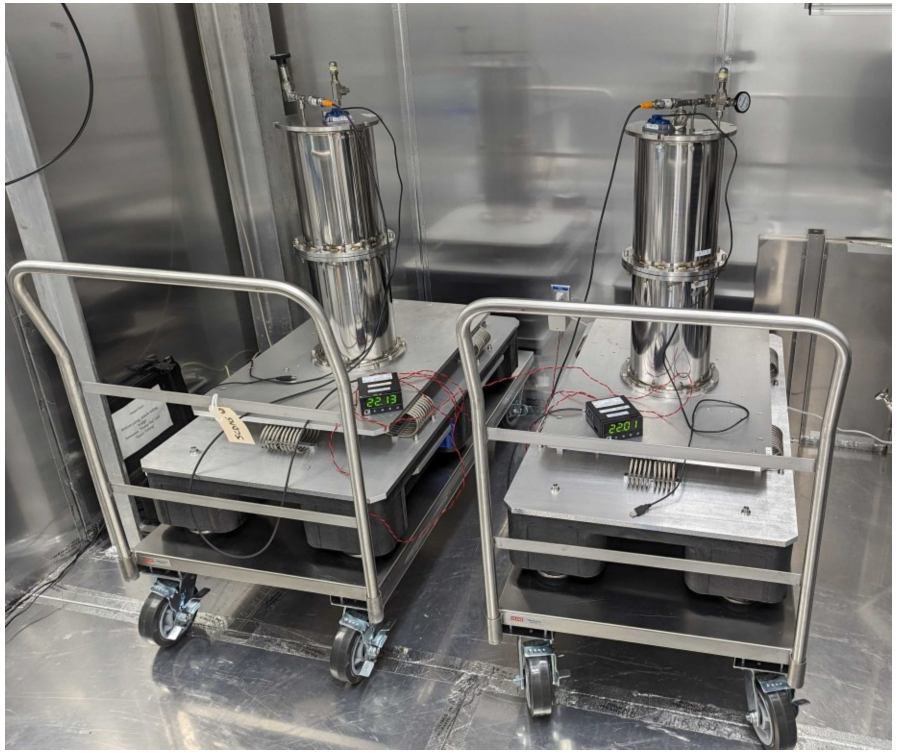
SLAC > Tucson > El Paso > Dallas > Memphis > Sault Ste. Marie > SNOLAB

Indirect +5 000 km truck route to SNOLAB with low altitude to prevent exposing the detectors against too much cosmogenic activation.

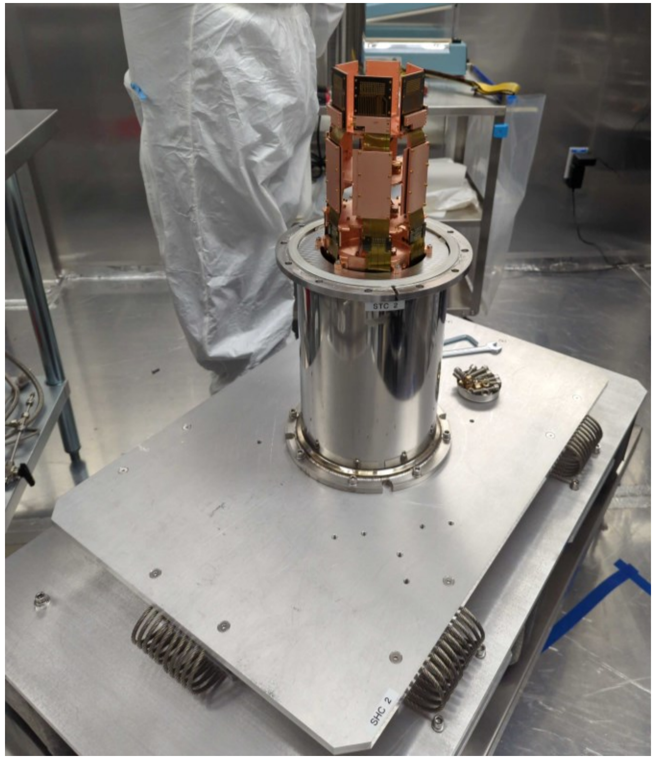
Detector towers in SuperCDMS low-radon cleanroom

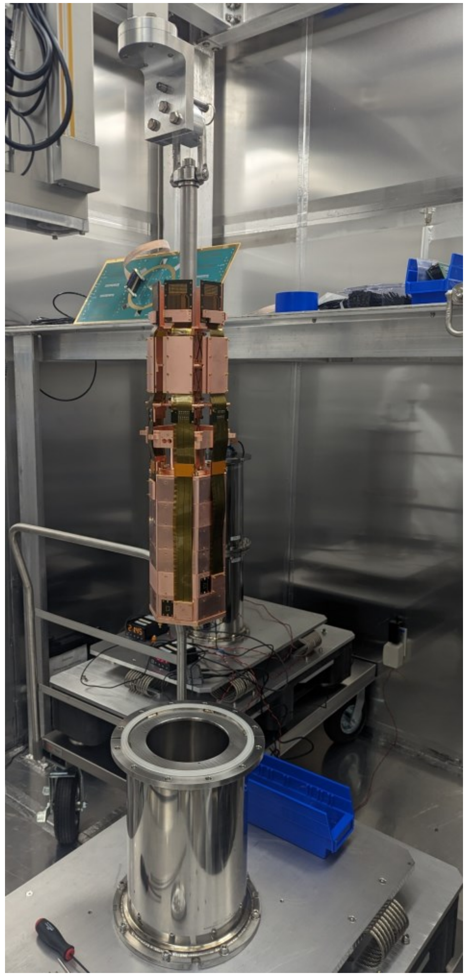
Radon (lab air): ~ 130 Bq/m^3
Radon (cleanroom air): < 1 Bq/m^3

Transport cart & storage container



Tower extraction





Assembly stand

Transferring the detector tower to CUTE

Goal:

Install and operate one SuperCDMS high-voltage (HV) tower in CUTE

Challenges:

- The tower is fragile. Jolts/vibrations could damage wire-bonds and tensioned coax wires in the tower.
- Not expose the tower to a non-cleanroom environment (avoid dust or radon contamination).
- Insert tower into the CUTE cleanroom (1.84 m x 1.84 m x 2.3 m).
- Emergency plan in case of a “call to refuge”.

Distance between cleanrooms

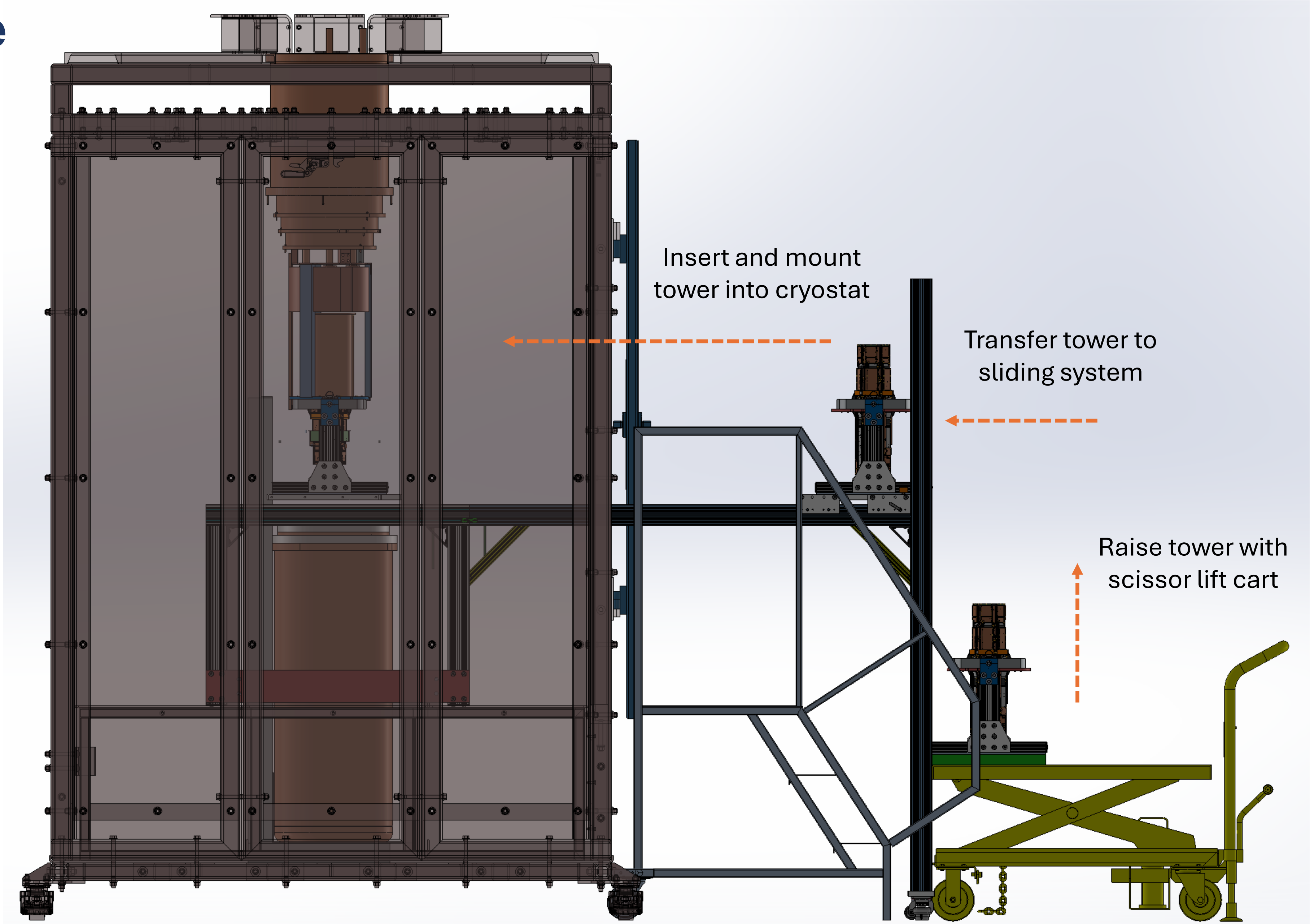
CUTE cleanroom

Preparation phase

Installation carefully planned and modelled

Performed a fitting test of all components to be used

Conducted a rehearsal installation with an equivalent weight



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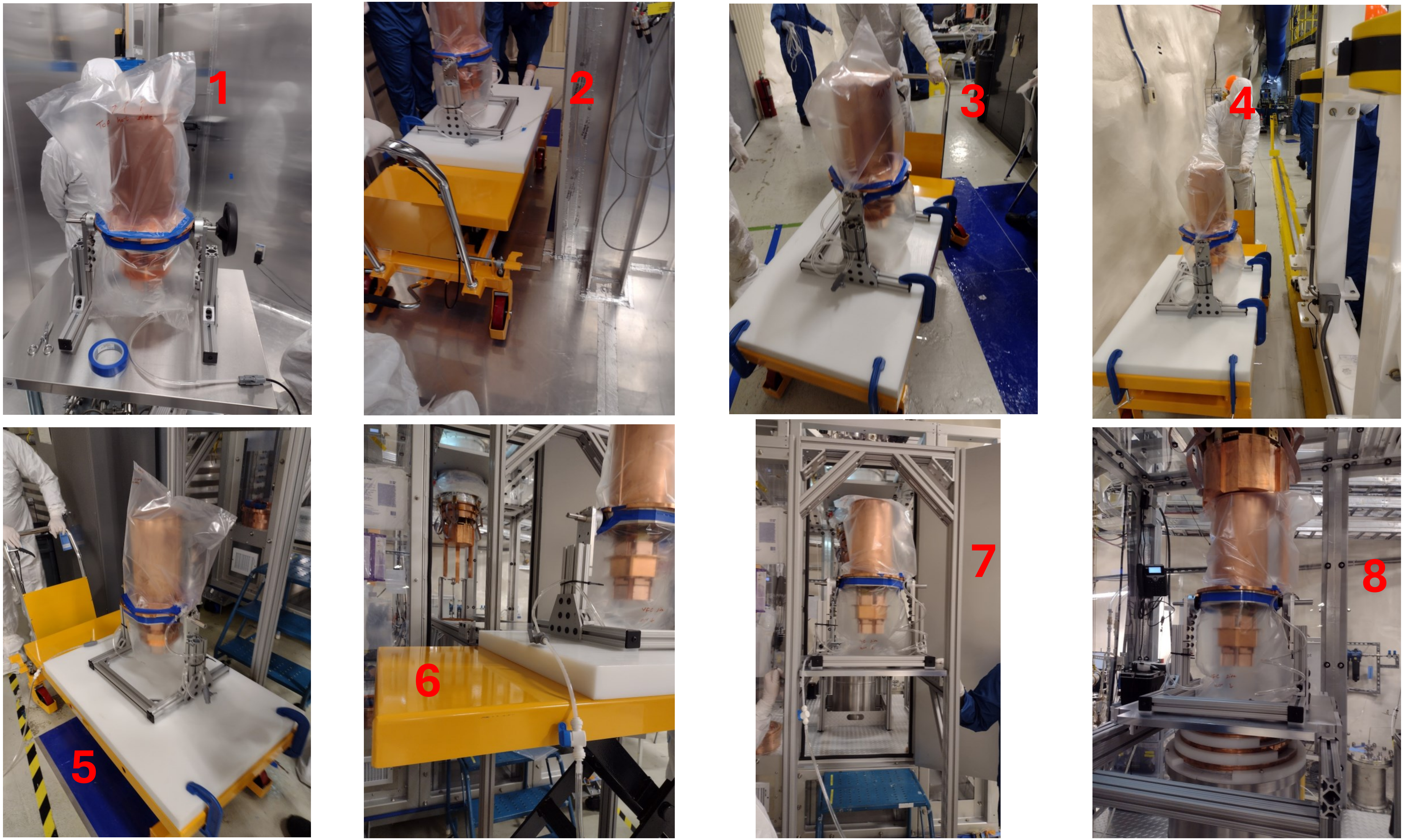
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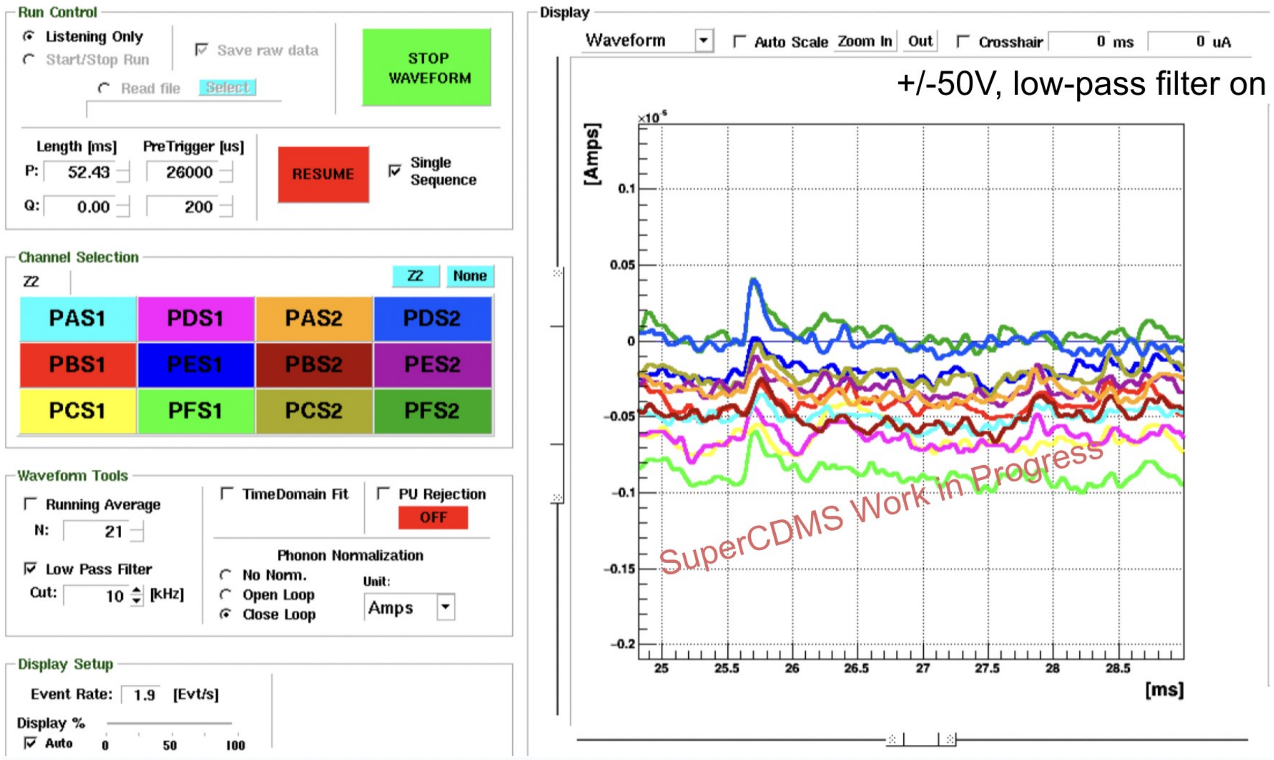
Detector operation

- HV Tower #3 (2 Si / 4 Ge crystals) tested from Oct. 2023 - Mar. 2024.
- Operated at multiple bias voltages (up to 100 V).
- ~2 months of calibration data
- ~2 weeks of low background data.



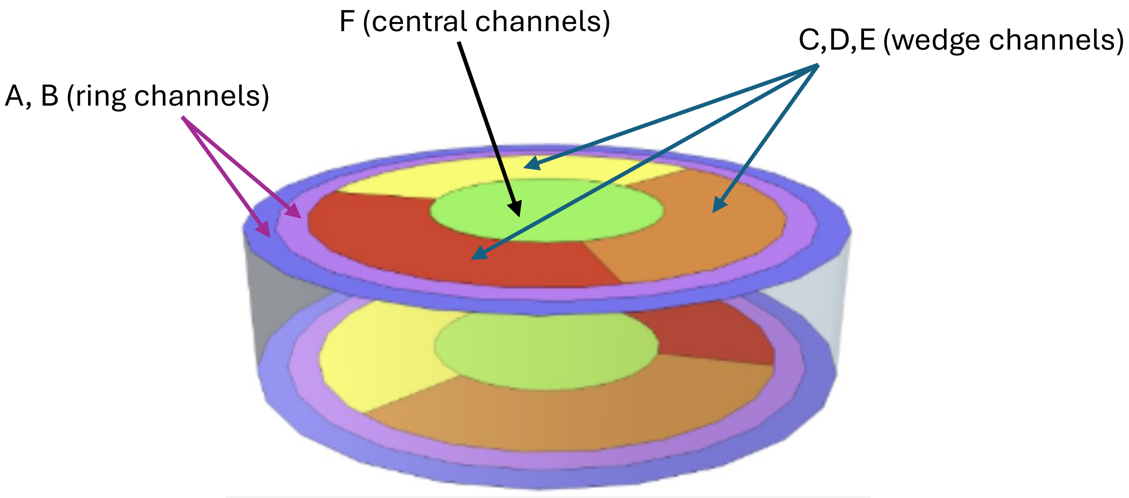
Some analysis tasks

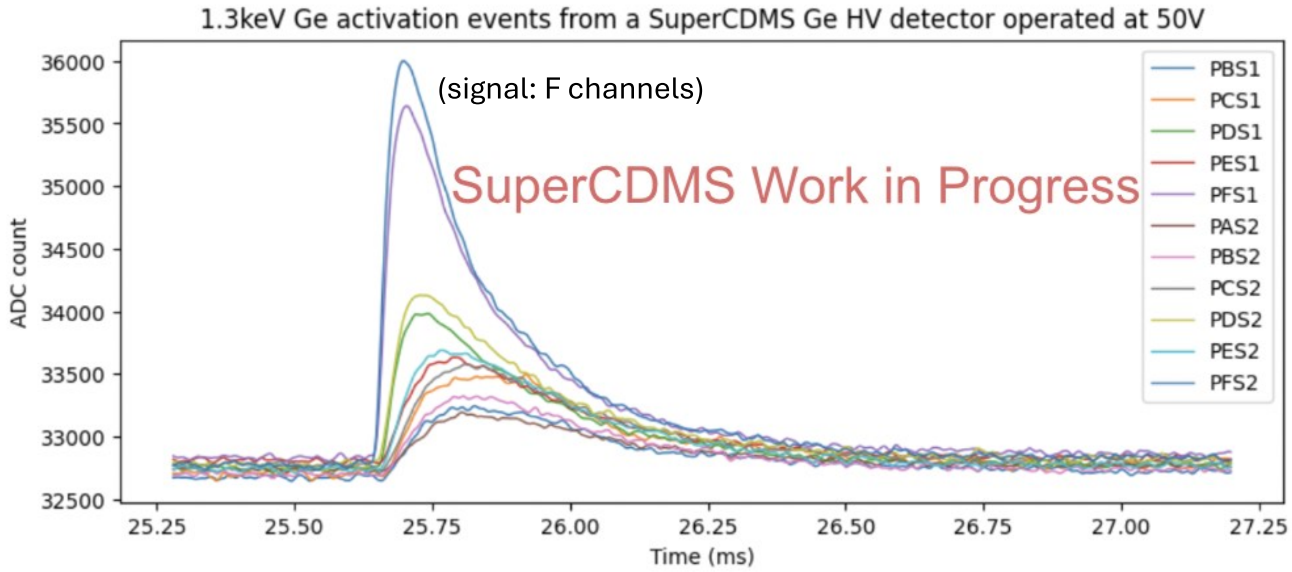
- Identifying features in the energy spectrum for calibration (i.e. Ge activation peaks, Si Compton steps)
- High Voltage amplification study
- Detector efficiency calculation
- Noise characterization (CUTE vs SLAC, readout electronics, effect of lab WiFi, etc.)

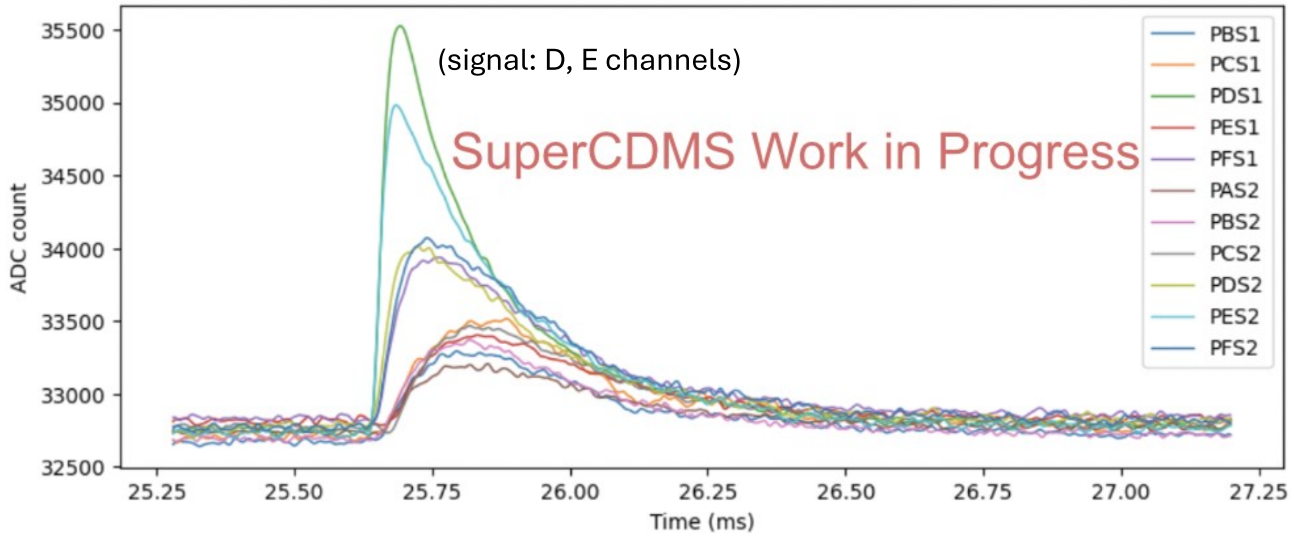
HV detector signals

Two events detected by a Ge detector operated at +/-25 V during CUTE tower testing.

The raw pulses of different channels suggest strong position dependence. This will be exploited to obtain a fiducial volume cut.







Ge calibration

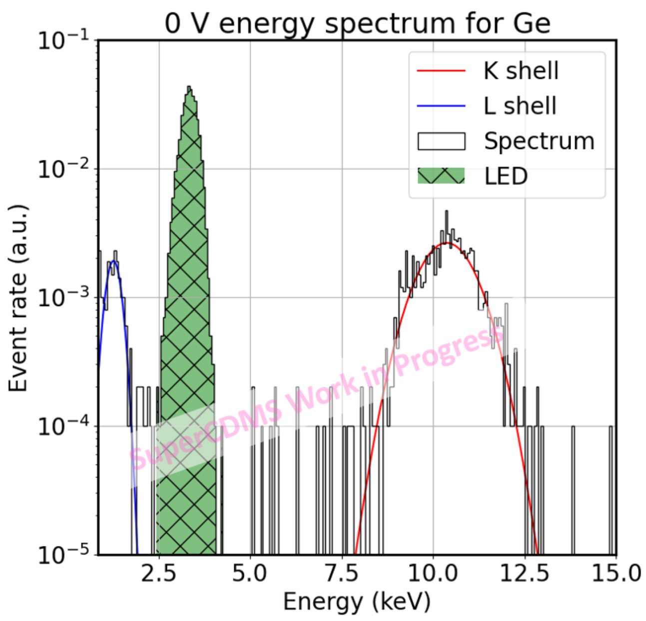
Peaks from neutron activation allow calibrating the detector response to low-energy electron recoils

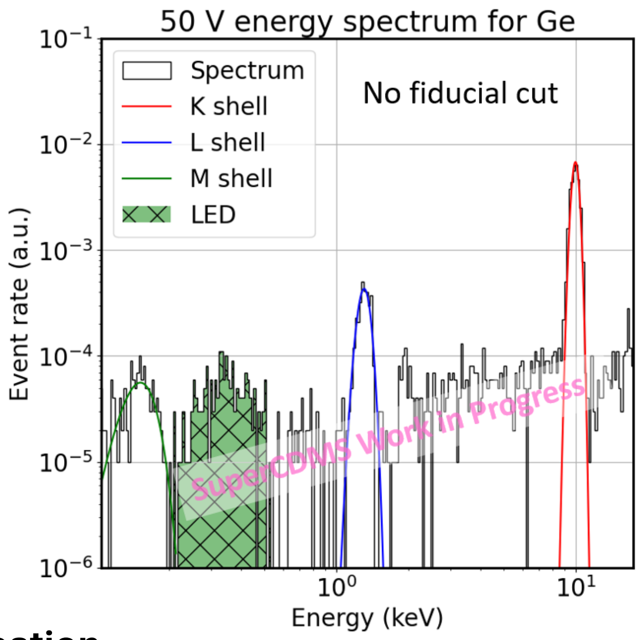
^{252}Cf neutron source

- $^{70}Ge + n \rightarrow {}^{71}Ge$ **(half-life 11.43 d)**

Electron-capture decay:

$^{71}Ge + e \rightarrow {}^{71}Ga + \nu_e$

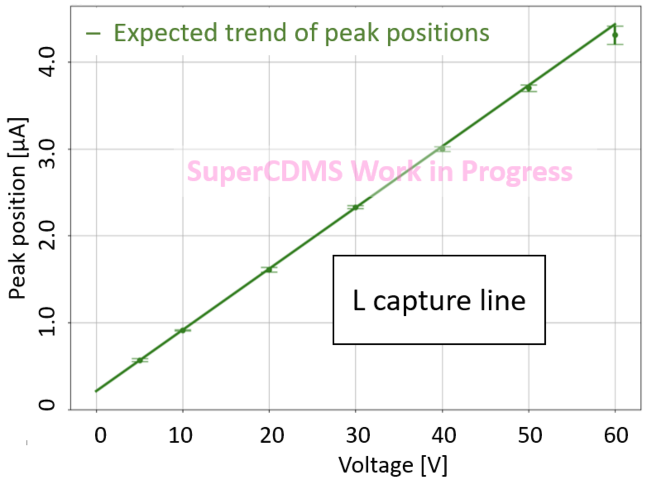


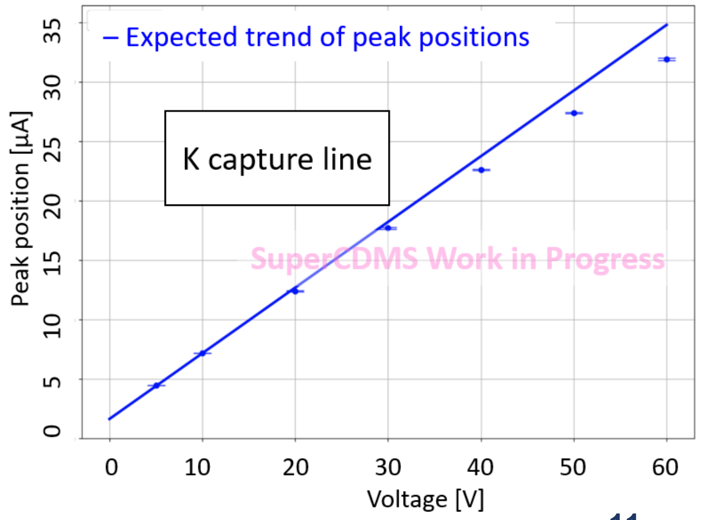


Binding energies:

- K-shell: ~10.37 keV
- L-shell: ~1.3 keV
- M-shell: ~0.16 keV

HV amplification





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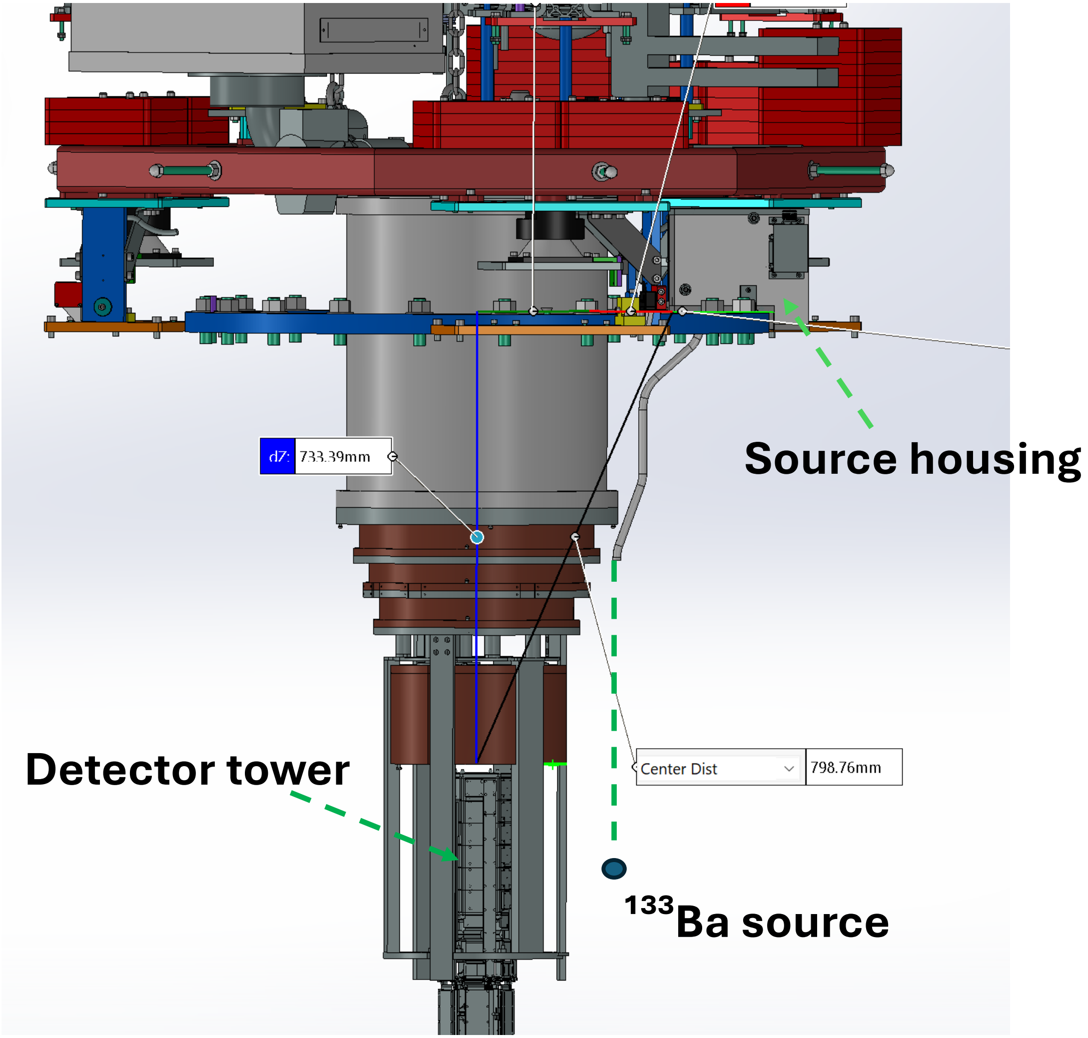
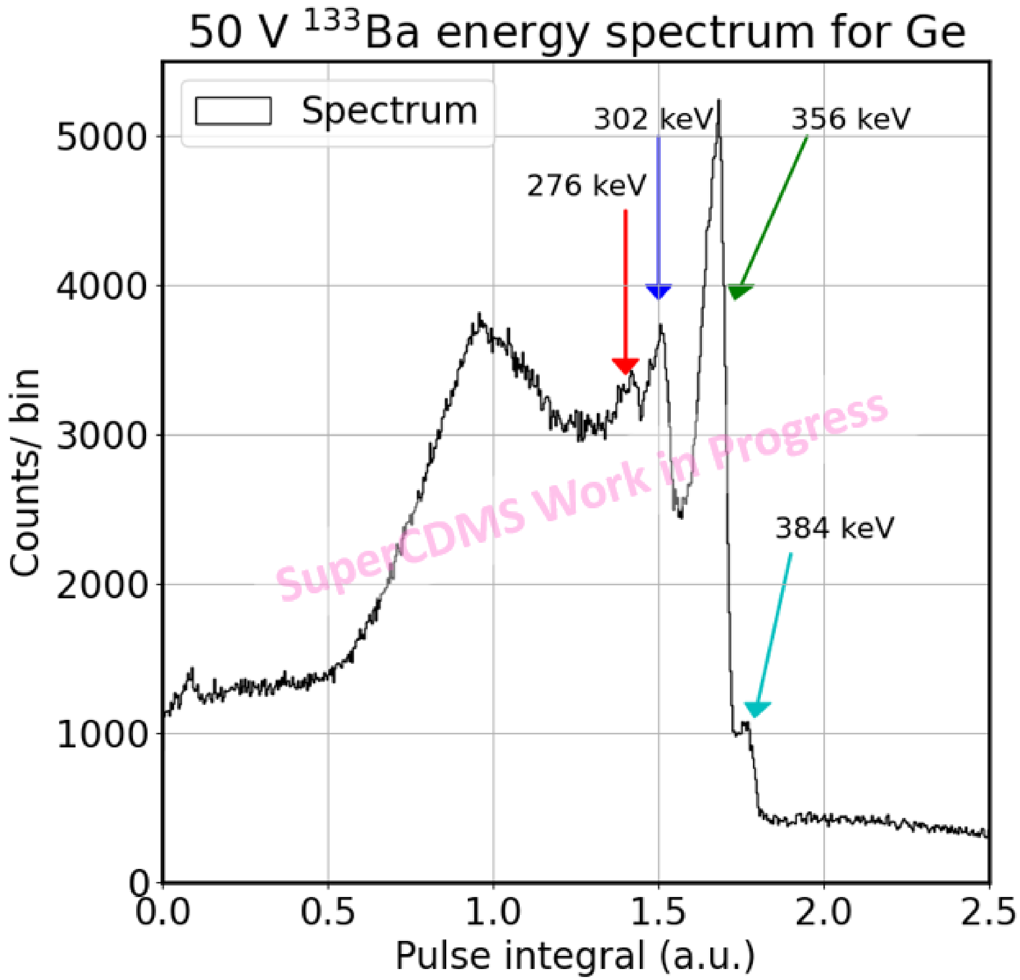
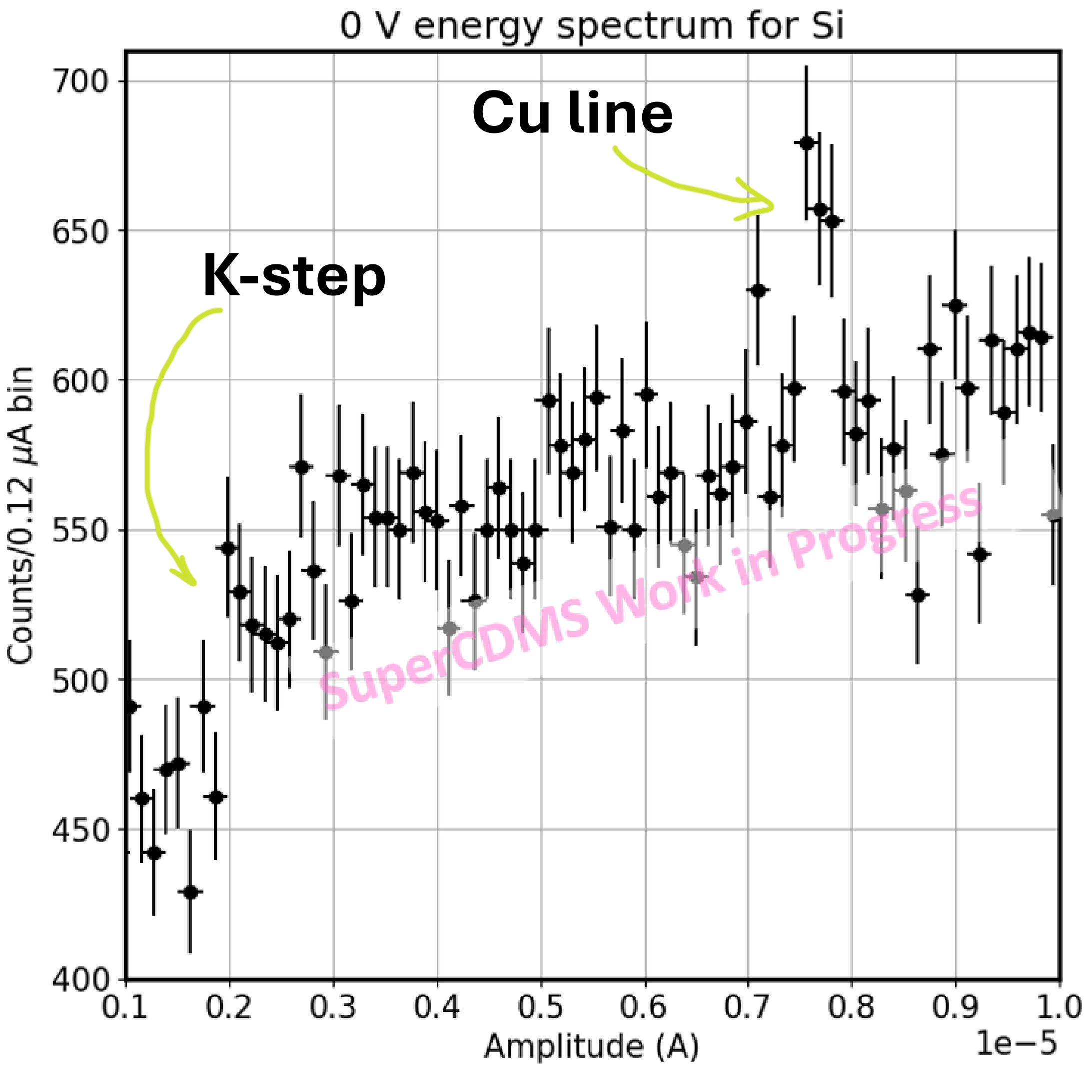
Ge calibration



Possibility of high-energy calibration by deploying a ^{133}Ba γ-ray source



Si calibration



Si detectors lack suitable activation lines for the low-energy calibration.

Alternative approach: Si Compton steps produced by ^{133}Ba gammas for calibration down to 100 eV.

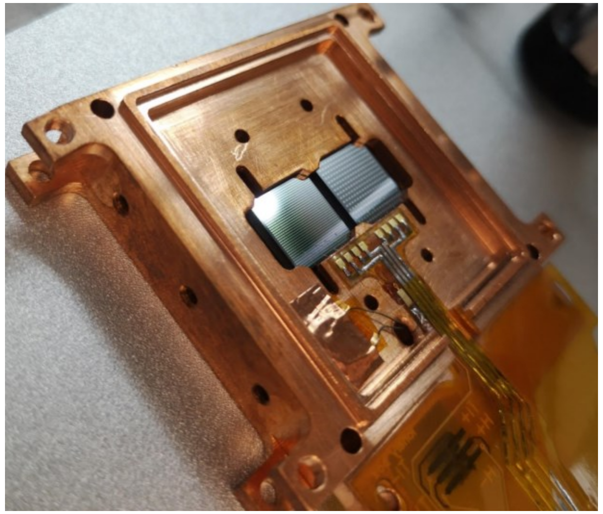
Features:

- 1.8 keV Compton step (photon interactions with K-shell e-).

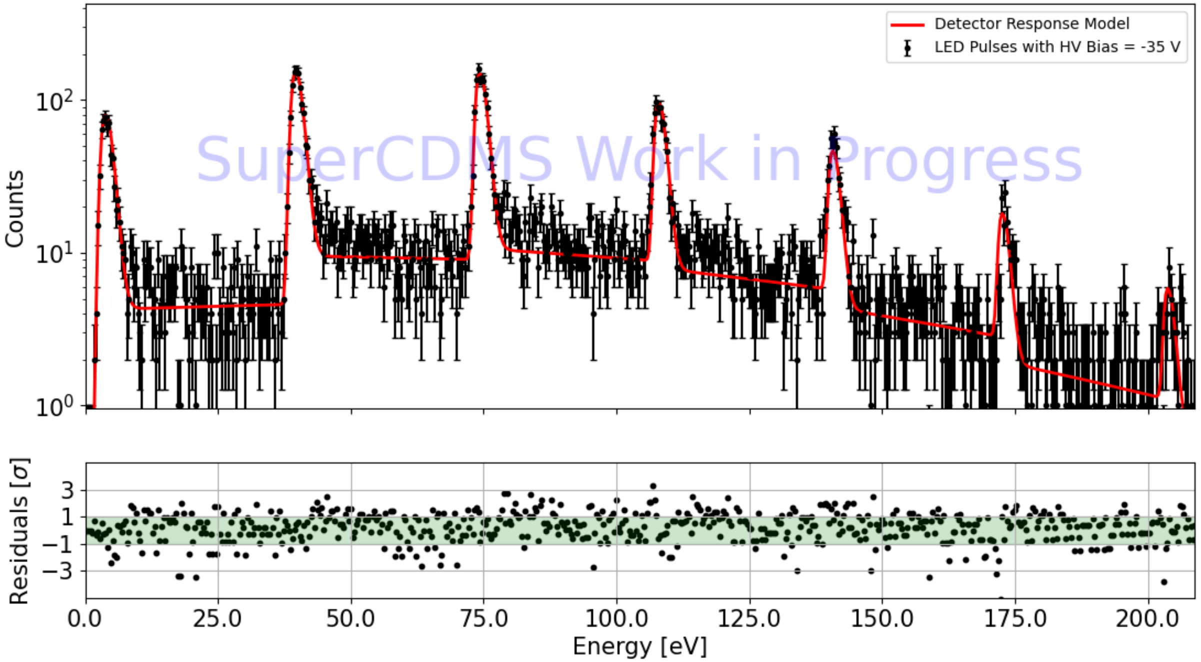
- 8.1 keV X-ray fluorescence line (photon interactions with copper, e.g. detector housing).

High Voltage eV-sensitive (HVeV) sensors

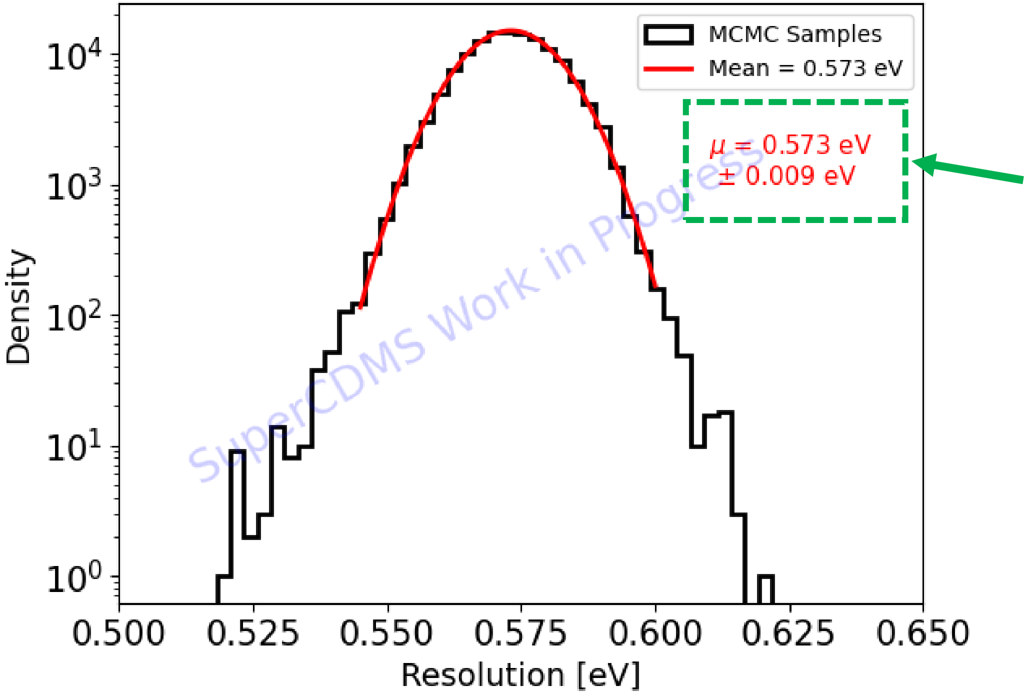
- Gram-scale silicon SCDMS HVeV detectors operated in CUTE last year achieved an **astonishing sub-eV energy resolution**.
- Data analysis currently ongoing.



Detector calibration: fit of the detector response model (red) to LED data (black)
Peaks represent e-/hole pairs created by LED photons



Sample of the posterior of the resolution from MCMC chain



Final remarks

Significant progress in the construction of SuperCDMS SNOLAB.

- All detector towers already underground
- Data taking expected to commence in the 2nd semester of 2025.

Major milestone for the collaboration: successful testing of a HV tower in the CUTE facility.

- Accomplished the tower installation despite many challenges.
- Satisfactory operation of the detectors over four months. Valuable data collected.
- Data analysis in progress.
- Demonstrated the possibility of performing low- and high- energy calibration of the detectors. Paper in preparation.

R&D SCDMS detectors tested at CUTE (HVeV)

- Achieved an incredible energy resolution (0.573 ± 0.009 eV). Stay tuned for future results!

SuperCDMS collaboration meeting @ SNOLAB (Summer 2024)

Thanks for your attention