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# SuperCDMS Experiment at SNOLAB: Current Status and Recent CUTE Results

**Moaaz Elwan**[a,1,*]

[a] *University of Florida - Department of Physics, 2001 Museum Rd, Gainesville, FL, USA*

*E-mail:* moaaz.elwan@ufl.edu

The Super Cryogenic Dark Matter Search (SuperCDMS) experiment at SNOLAB explores dark matter candidates in the mass range of 1-10 GeV/c$^2$. The experiment will deploy a total of 24 detectors with silicon and germanium substrates, 2 km deep underground in SNOLAB, Canada. The detectors are arranged in four towers, combining the low-threshold sensitivity of high-voltage (HV) phonon detectors with the excellent background discrimination of phonon-charge (iZIP) detectors. The combination will give SuperCDMS a world-leading edge in the search for low-mass, low-cross-section dark matter candidates. Over the past year, SuperCDMS completed testing a single HV tower at the Cryogenic Underground TEst facility (CUTE). The CUTE run, which concluded in February 2024, demonstrated the ability to conduct in-situ operations including characterization, calibration, and exploration of Neganov-Trofimov-Luke (NTL) phonon amplification. This contribution will highlight key results from CUTE, along with the current status and prospects of the first SuperCDMS science run.

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[1] On behalf of the SuperCDMS collaboration.
[*] Speaker



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## 1. Introduction

The Super Cryogenic Dark Matter Search (SuperCDMS) experiment is a direct detection search for weakly interacting massive particles (WIMP) dark matter (DM) candidates with low masses. The current science focus is on nucleon-coupled particles with masses below 10 GeV/$c^2$ and electron-coupled candidates, such as axion-like particles (ALPs) and dark photons (DP), in the 100 eV/$c^2$ to 1 MeV/$c^2$ mass range. The collaboration consists of more than 100 researchers from 28 institutions in 6 countries.

The experiment is located 2 km underground at SNOLAB, providing approximately 6000 m.w.e. of overburden suppressing cosmic-ray-induced backgrounds like muons and fast neutrons as indicated in Figure 1 adapted from [1]. In addition to the primary experimental setup, SuperCDMS utilizes the Cryogenic Underground TEst facility (CUTE) for testing prototypes, developing calibration and commissioning procedures, and operating a single detector tower.

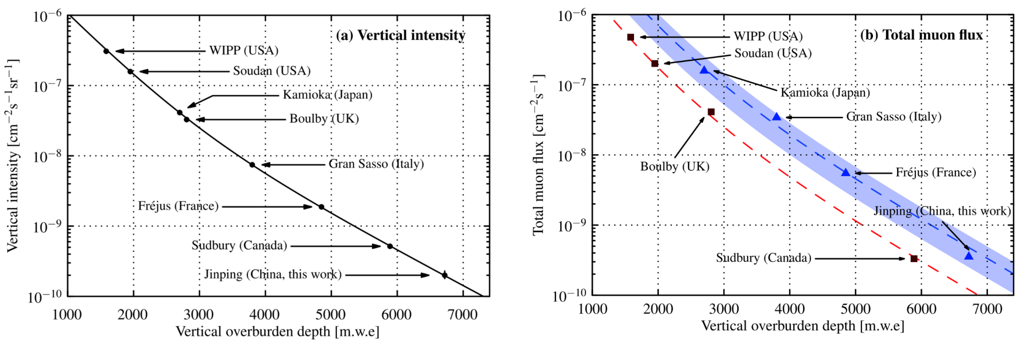


**Figure 1:** The vertical intensity (a) and total muon flux (b) at different underground laboratory sites. The red dashed line in (b) is the empirical formula for the down mine shaft case. The blue dashed line and shade in (b) are the fitting result and uncertainty.

The SuperCDMS SNOLAB installation is designed to operate under ultra-low background conditions. Hence, the shielding is multilayered, consisting of an outer water tank, active radon purge systems, ultrapure lead, and polyethylene layers. The entire apparatus is mounted on a seismic isolation platform to mitigate vibrational noise. The innermost region, the SNOBOX, consists of nested copper cans housing four detector towers (total mass of $\sim$ 30 kg), each composed of six detectors. A detailed discussion of the experimental setup can be found in [2].

Readout electronics, cryogenic systems, and calibration sources are located outside the shielded volume and are connected through dedicated stems as shown in Figure 2.

## 2. Athermal Phonon Technology

SuperCDMS detectors detect energy depositions by measuring the resulting phonons and ionization charge. Phonon detection is based on Quasiparticle-trap-assisted Electrothermal-feedback Transition-edge sensors (QETs). Energy depositions generate athermal phonons that propagate to superconducting aluminum fins, breaking Cooper pairs. The quasiparticles are then collected in tungsten films held around the transition temperature ($T_c$ ~45 mK). The resistance to tungsten increases on the transition curve as it heats up, modulating the current through the QET circuit.

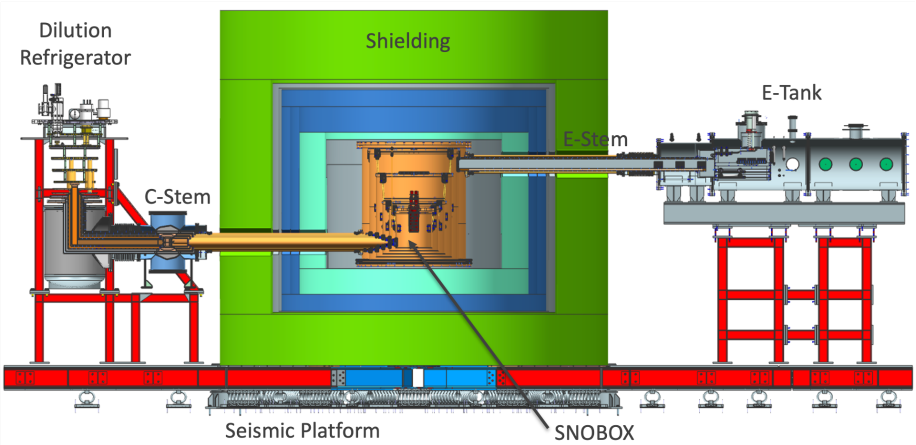


**Figure 2:** Overview of the SuperCDMS SNOLAB experiment setup.

The change in current is detected through a SQUID array. Figure 3 describes the overall readout scheme.

The produced signal is a pulse whose amplitude is proportional to the deposited energy. The rise time is governed by the LR time constant of the circuit, while the fall time depends on the thermal conductance and heat capacity of the sensor. This means signals only vary in amplitude, enabling high fidelity in energy reconstruction through an optimal filter.

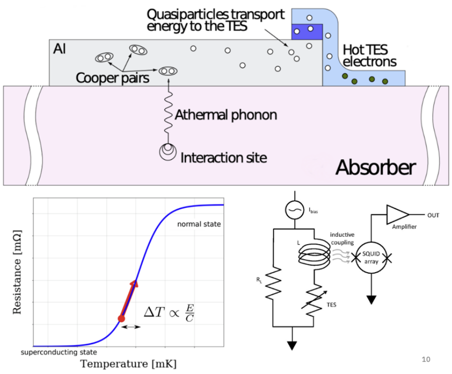


**Figure 3:** A general schematic of detector physics with the top plot showing propagation of phonons to the TESs. The two lower plots show the TES response (left) and the SQUID readout scheme (right).

Three types of detectors employ this technology within SuperCDMS. The first is the HV detectors. They are operated at high bias voltages to enhance phonon signals ($E_{ph}$) via the Neganov-Trofimov-Luke (NTL) effect, amplifying the deposited recoil energy ($E_r$) as described in equation 1. These detectors do not sense charges directly and are optimized for low-threshold and high-resolution measurements, making them suitable for probing low-mass DM candidates.

The second is the iZIP detector, which measures both ionization and phonon signals and operates at low bias voltages (~8 V). They offer background discrimination capabilities, depending on whether the event was due to electron recoil or nuclear recoil. That is because the ionization yield ($y(E_r)$) is identically 1 for electron recoil, through which most backgrounds interact.

$$E_{ph} = E_r[1 + \frac{eV}{\epsilon} y(E_r)] \quad \begin{array}{c}\text{where } V \text{ is applied bias voltage,}\\ \epsilon \text{ is the energy to create an electron-hole pair}\end{array} \tag{1}$$

The HVeV detectors are gram-scale R&D devices with single electron-hole resolution. They are sensitive to sub-GeV DM models, including ALPs and dark photons, and can be operated at very high bias voltages up to 140 V [3]. The resolution of the phonon energy was measured to be 3–5 eV, with a charge resolution of around 0.1 electron-hole pairs [4].

## 3. Tower Testing at CUTE

Between October 2023 and March 2024, a single SuperCDMS tower was deployed and operated at CUTE for testing. The primary objectives were to test the detectors' in situ operation, develop calibration protocols, and examine the data acquisition and monitoring systems' needs. The results of these tests are critical input for the commissioning of SuperCDMS SNOLAB to achieve its target sensitivity. The deployed tower (Tower 3) has 4 Ge and 2 Si HV detectors ordered from bottom to top (labeled detector 1 to detector 6). One of the Ge detectors (Detector 4) was not operational during tower testing due to multiple issues with the SQUID performance and readout cable.

### 3.1 Germanium Calibration

#### 3.1.1 Low-Energy Calibration

A $^{252}$Cf neutron source was used to activate germanium detectors, producing $^{71}$Ge through neutron capture. The subsequent electron-capture decay of $^{71}$Ge to $^{71}$Ga results in the emission of a cascade of X-rays and Auger electrons. The most prominent energy signatures are mono-energetic peaks at 0.16, 1.33, and 10.4 keV, corresponding to the M-, L-, and K-shells, respectively.

The L- and K-shell peaks were observed all across detector 1 and detector 3 at both 0 V and 50 V bias, with the M-shell peak only observed under HV operations. Detector 6 was operated at 0 V for low-energy calibration runs with only the K-shell peak observed due to a degraded resolution. Figure 4 references the tower configuration and phonon spectra for different detectors for the low-energy calibration.

#### 3.1.2 High-Energy Calibration

A $^{133}$Ba gamma source was used to calibrate the detectors at higher energies. The spectra in Figure 5 are generated from the linearized spectra of an integral estimator. The emission lines of $^{133}$Ba were observed and successfully calibrated the detectors up to ~400 keV.

#### 3.1.3 Resolution Performance

The baseline resolution of the detectors is a key factor in determining the sensitivity reached in the DM search, since it defines the threshold of the analysis. For SuperCDMS SNOLAB to achieve its projected sensitivity published in [2], detectors are expected to have baseline resolutions around ~50 eV. The energy resolutions were measured at 0 V in a single-detector data-taking configuration. We see that the resolutions of detector 1 and detector 3 are close to the target and are consistent with the measured $T_c$ of these detectors as reported in Table 1. However, detector 6 resolution is worse than expected due to excess noise.

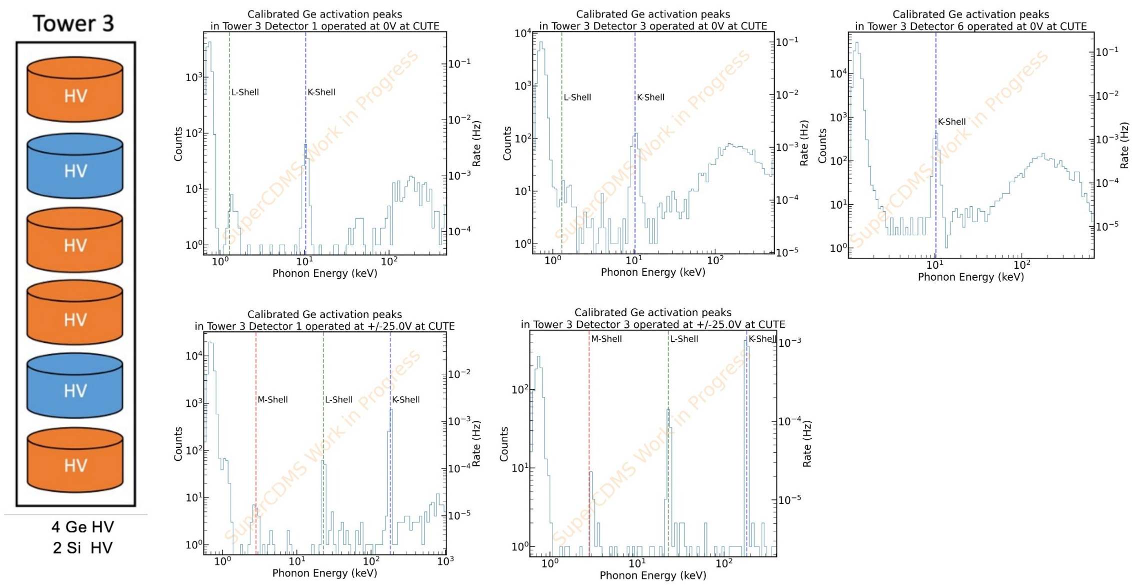


**Figure 4:** (Left) The detector tower arrangement with the type of target substrate indicated. (Right) The calibrated phonon spectra for detectors 1, 3, and 6, respectively, under applied voltage bias of 0V (top) and 50V (bottom).

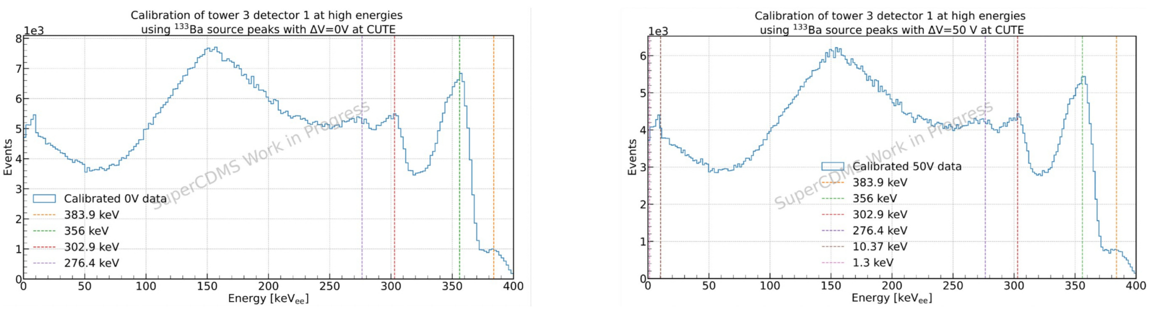


**Figure 5:** The spectra for high energy calibration of detector 1 using an integral estimator calibrated in energy deposition units.

Through the analysis, we can infer that the deficient resolution of detector 6 can be attributed to operational issues, specifically readout electronic noise and subthreshold IR leakage. The reported baseline resolutions are expected to improve at the SuperCDMS SNOLAB compared to the CUTE facility, which is a wide-scope facility and not optimized for SuperCDMS HV detectors.

### 3.1.4 NTL Linearity

The SuperCDMS SNOLAB science reach is dependent on the HV response of the detectors. During previous iterations of CDMS using different detector designs at the CDMS Soudan and CDMSlite experiments, some detectors broke down at around 30 V [5]. Furthermore, observations from Si HVeV runs have shown around 30% signal over-amplification from the expected value of equation 1 [6]. This motivated the study of phonon signal amplification through the NTL effect. A voltage scan from 0 to 90 V was applied at the end of the tower testing campaign. The positions of

| Detector | Resolution (eV) |
|---|---|
| Z1 | 84.6 ± 0.7 |
| Z3 | 73.2 ± 1.0 |
| Z6 | 307.7 ± 13.0 |

**Table 1:** A summary of measured baseline resolutions of the operational Ge detectors. These values are Work In Progress results (final published results may vary).

the K- and L-shell peaks were tracked as a function of voltage.

The L-shell peak positions are found to be linear throughout the voltage range, whereas the K-shell peaks remain linear up to 40 V. The deviation from linearity is attributed to the saturation of pulses (see Figure 6). The positions of the K-shell peaks in the linear region were then used to extrapolate an expected position at 0V bias. The expected position turned out to be ∼ 10% higher than the measurement in agreement with [6]. We do not offer an explanation for this observation in this work. Dedicated studies and experimental setups are required to test any plausible hypothesis.

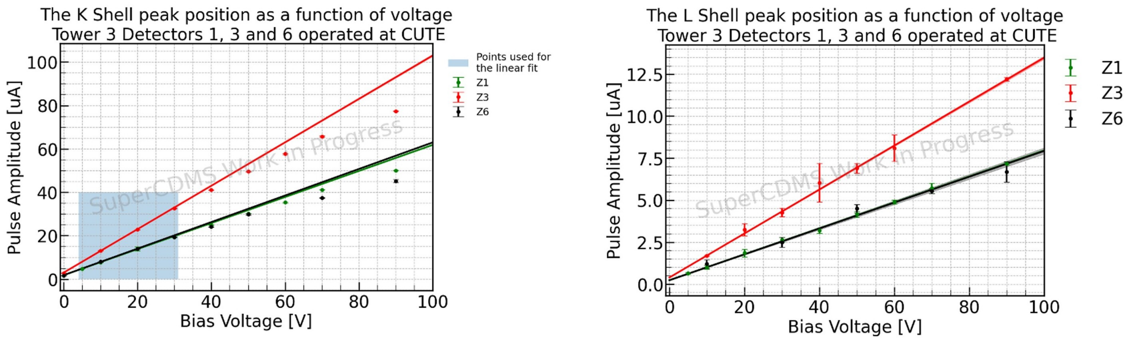


**Figure 6:** Calibration peak position as a function of applied voltage bias for both the K- (left) and L-shell peaks (right). The lines correspond to a linear fit of all points of the L-shell and points within the shaded region for the K-shell datasets.

### 3.2 Silicon Calibration

The calibration for the Si detectors is more difficult than for the Ge detectors due to the lack of activation lines. To calibrate the detectors, they were irradiated with $^{133}$Ba gamma source. The concept relies on observing steps in the Compton scattering spectra, including a K-shell Compton step at ∼1.8 keV observed at both 0V and HV, and hints of an L-shell step in a HV configuration. Additionally, the gamma rays induce fluorescence in the copper housing of the detectors at ∼8 keV. Figure 7 shows the K-shell step and Cu X-ray peak.

## 4. SuperCDMS SNOLAB Status

The installation of the SuperCDMS SNOLAB infrastructure is nearing completion, with the end of equipment installation by Fall 2025. Detector commissioning is set to start soon after from Fall 2025 to early 2026, when stable-run operation marks the beginning of the first science run. The complete data collection operation is planned for the period through October 2029.

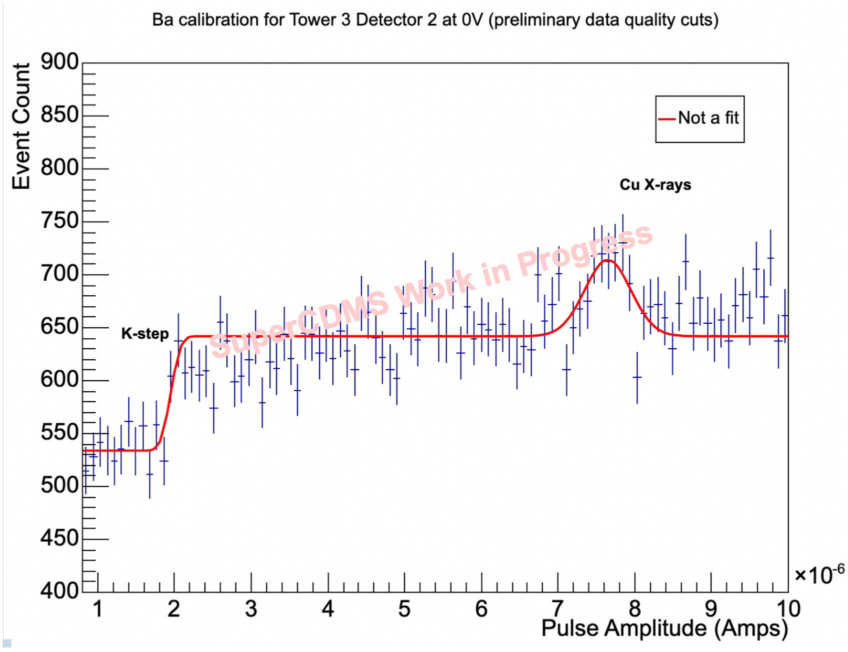


**Figure 7:** A plot showing the K-step and Cu X-rays structure observed while calibrating Tower 3 Detector 2 at 0V. The main purpose of the solid line is to guide the eyes rather than to extract information. The error bar is indicative of the statistical uncertainty in each bin.

The experiment aims to reach world-leading sensitivity, especially for candidates below 10 GeV/c$^2$ for spin-independent WIMP-like DM candidates. The sensitivity for DP absorption models is also anticipated to uncover a large unexplored parameter space. The Sensitivity for ALPs, however, is not as significant, as projections do not improve on the limits set by astrophysical observation. More detailed discussion about projected sensitivity can be found in [2]. Figure 8 shows the target science reach.

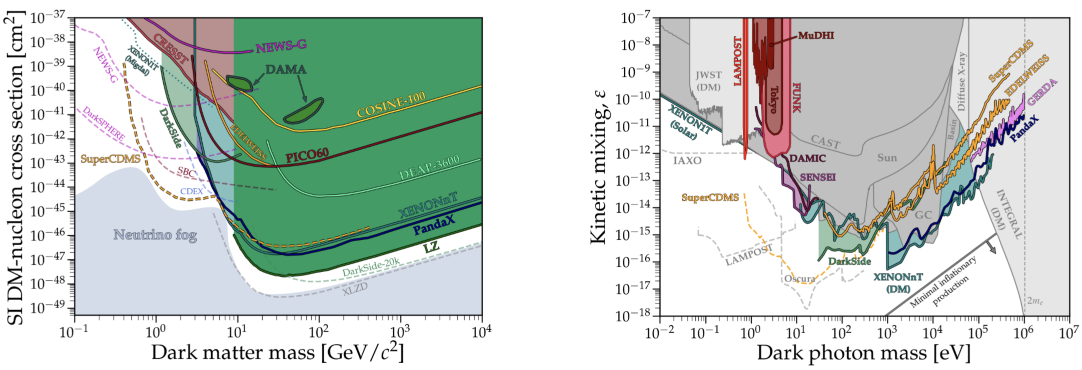


**Figure 8:** Projected sensitivity for DM search for spin-independent nucleon coupled DM candidates (left) and DP candidates (right). Solid lines present current limits while dashed lines indicate projected sensitivity. The plot is generated using Ciaran O'Hare's library found in [7]. The plot was generated from published limits before April 2025.

## 5. Conclusion

The SuperCDMS SNOLAB experiment is approaching the final stages of installation and is on track for commissioning and science operations. Results from Tower 3 testing at CUTE successfully demonstrate a calibration strategy, detector operation readiness, and establishment of an analysis infrastructure. These efforts are a major step toward the experiment's physics goals in probing low-mass DM candidates with world-leading sensitivity.

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