Performance results of Ge high-voltage detectors tested at the CUTE facility

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On behalf of the SuperCDMS collaboration

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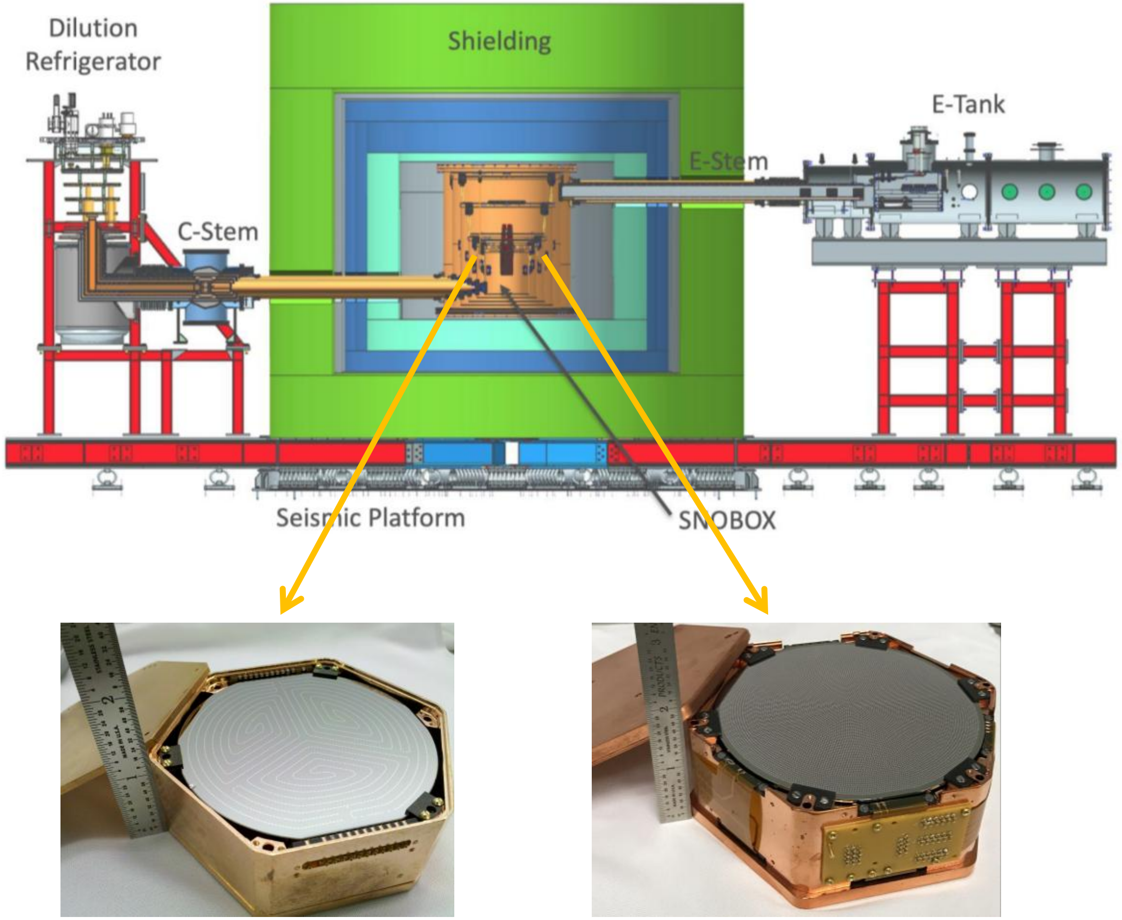
SuperCDMS at SNOLAB

- Goal: search for **low-mass** (sub-GeV) dark matter with **cryogenic** particle detectors at SNOLAB
- Two detector designs with Ge and Si targets

iZIPs	High Voltage (HV)
Charge and phonon readout, nuclear recoil discrimination	Phonon readout only, offers **low energy threshold**



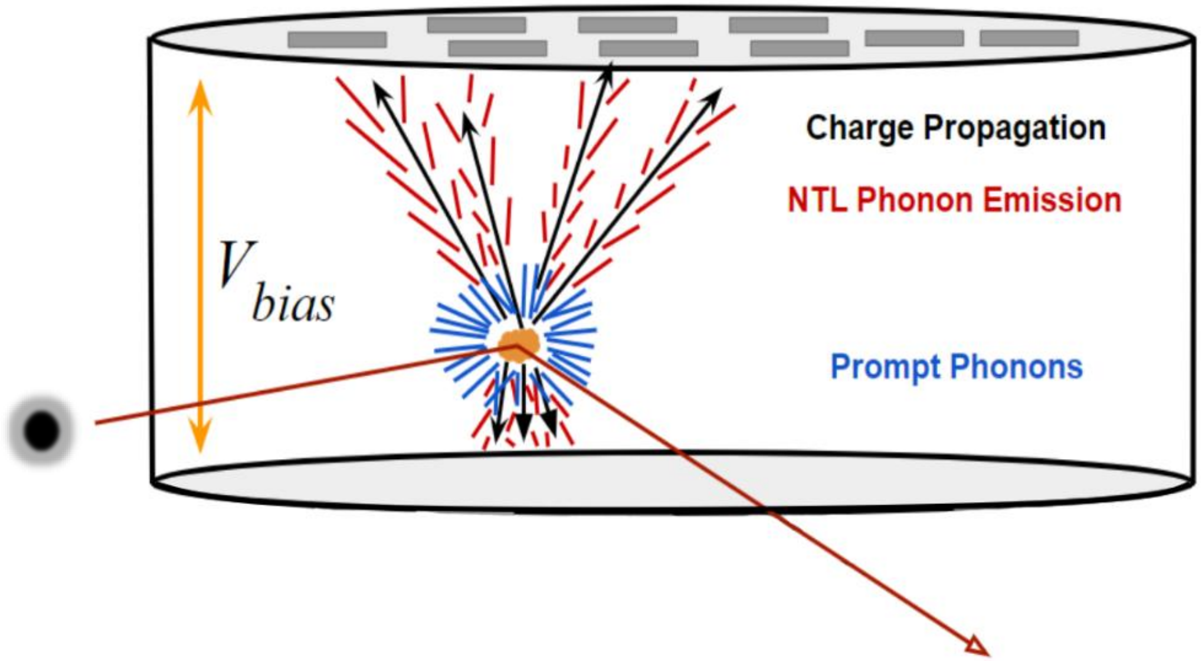
iZIP HV

HV Detector Operation Principle

- **Neganov-Trofimov-Luke (NTL) Effect:** phonon signal amplification

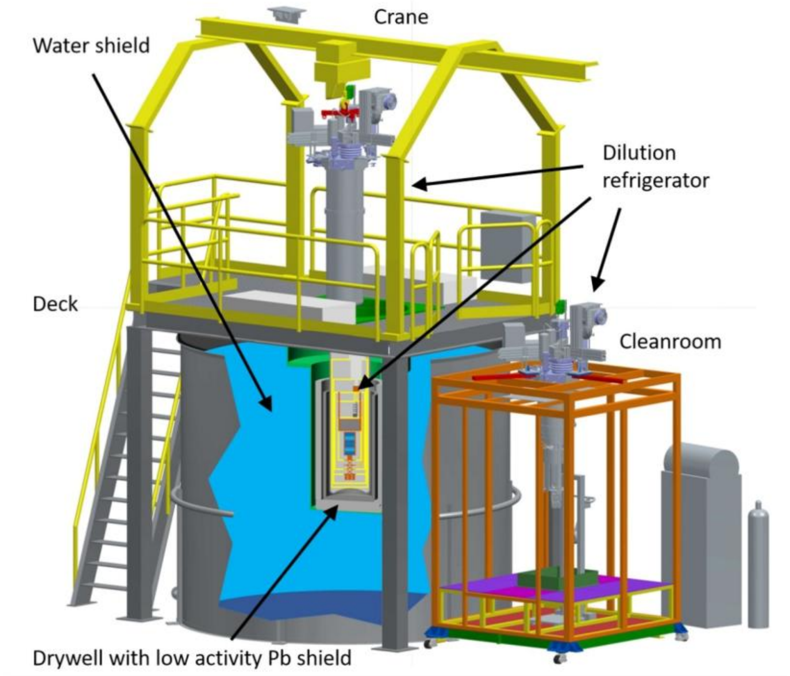
Total Phonon Energy — Recoil/Interaction Energy — # of e-h pairs — Applied Voltage

$$E_T = E_r + E_{NTL} = E_r + n_{eh} e V_b$$

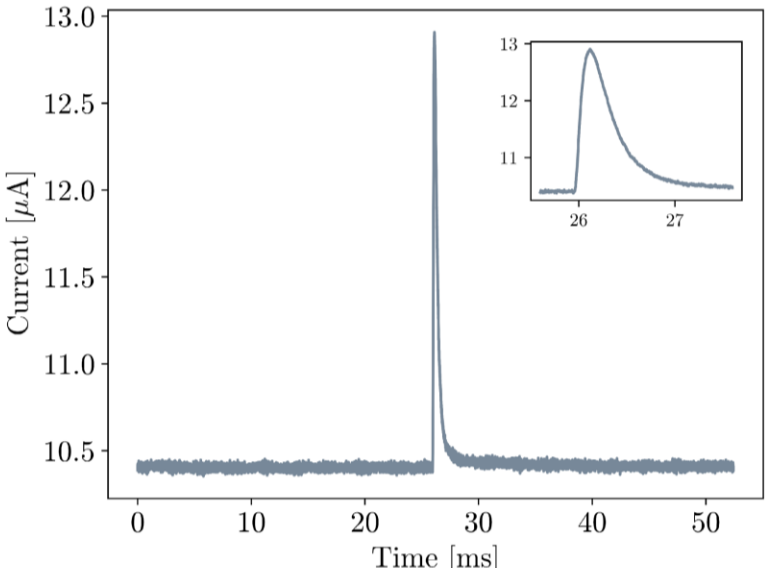


Detector Testing at CUTE

- Low background testing facility
- Tested **4 Ge and 2 Si** HV detectors (only 3/4 Ge detectors usable)
- First major analysis: **calibrating** Ge detectors
  - Pulse amplitude/integral ∝ energy
  - Find a conversion to energy using activation features

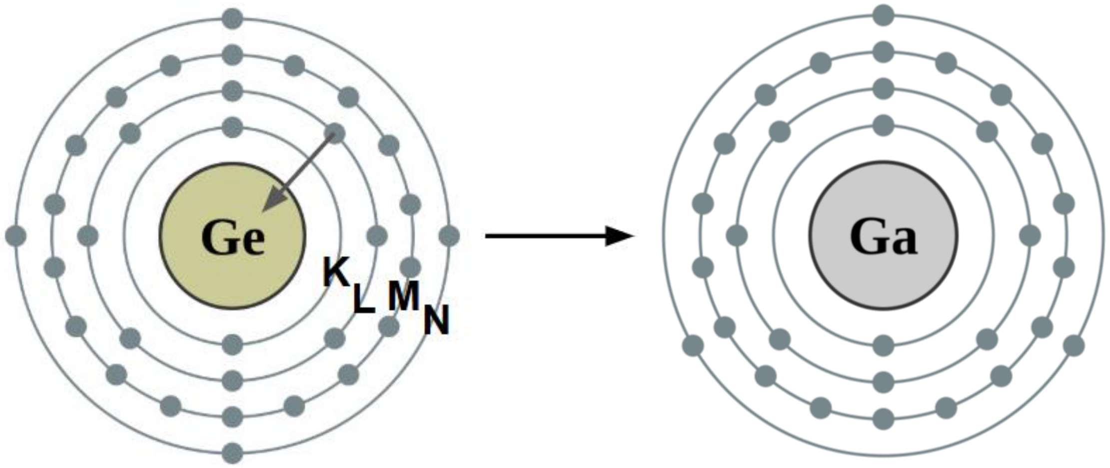


Raw pulse in a phonon sensor



Ge Activation

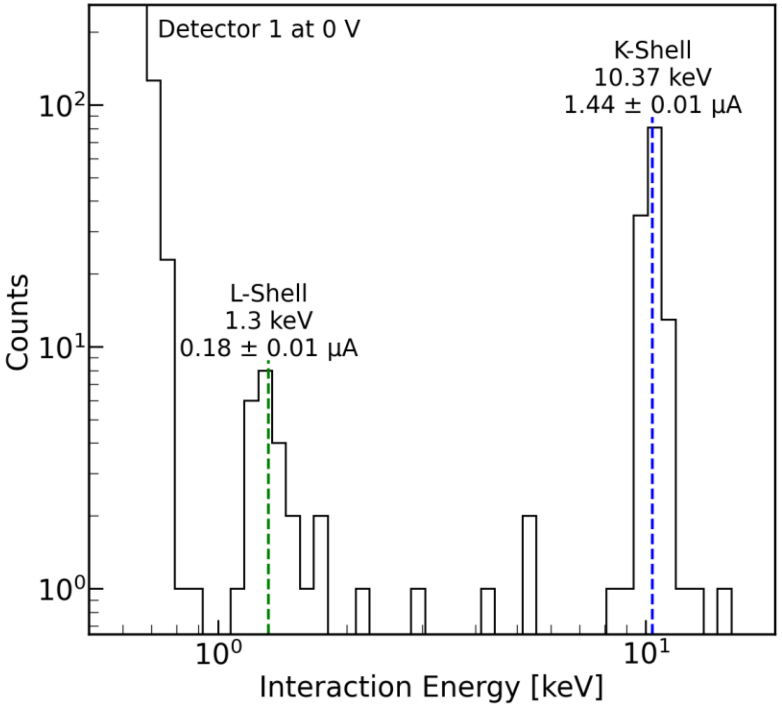
1. Neutron capture: $^{70}Ge \rightarrow {}^{71}Ge$
2. Decay via electron capture:
   - $^{71}Ge \rightarrow {}^{71}Ga + \nu_e + \gamma$ / Auger e$^-$
   - Half-life of ~11 days
3. Produces monoenergetic electron recoils

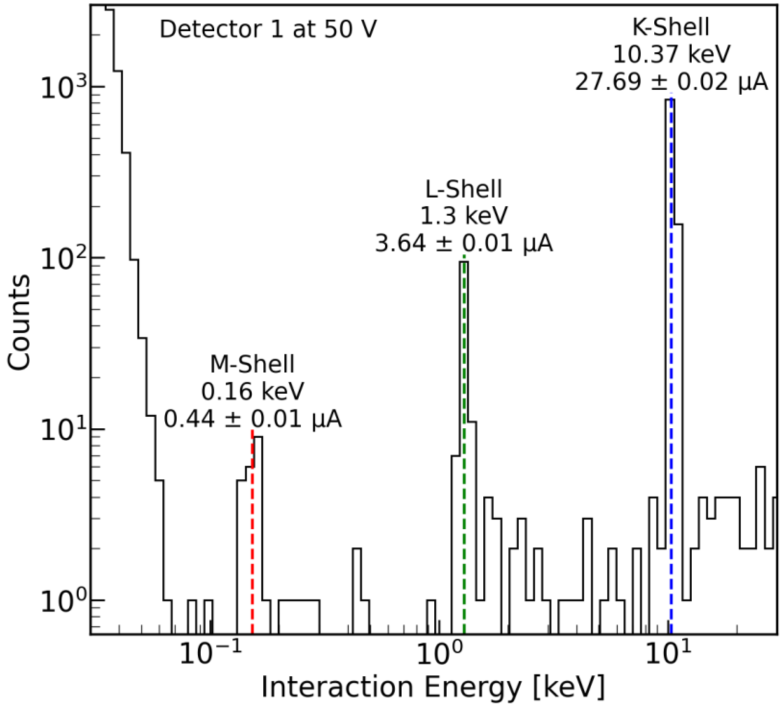


Shell	Peak Position [keV]
K	10.37
L	1.30
M	0.160

Low Energy Calibration and Detector Resolution

- Gaussian fits to activation peaks after quality cuts yield calibration factors
- Goal energy resolution: 50 eV

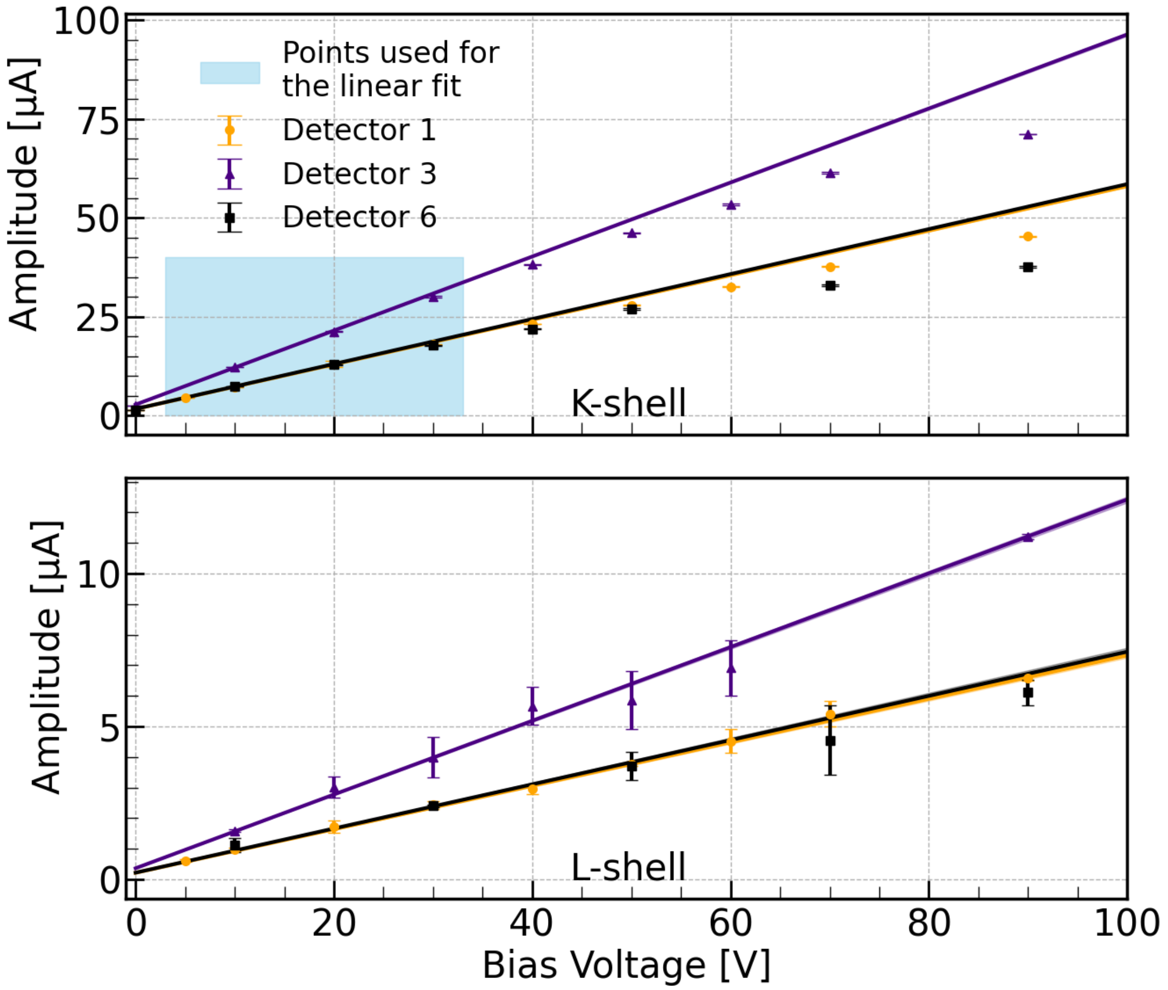




Detector	Best measured resolution [eV]
1	89.2 ± 0.7
3	80.2 ± 1.0
6	167 ± 14

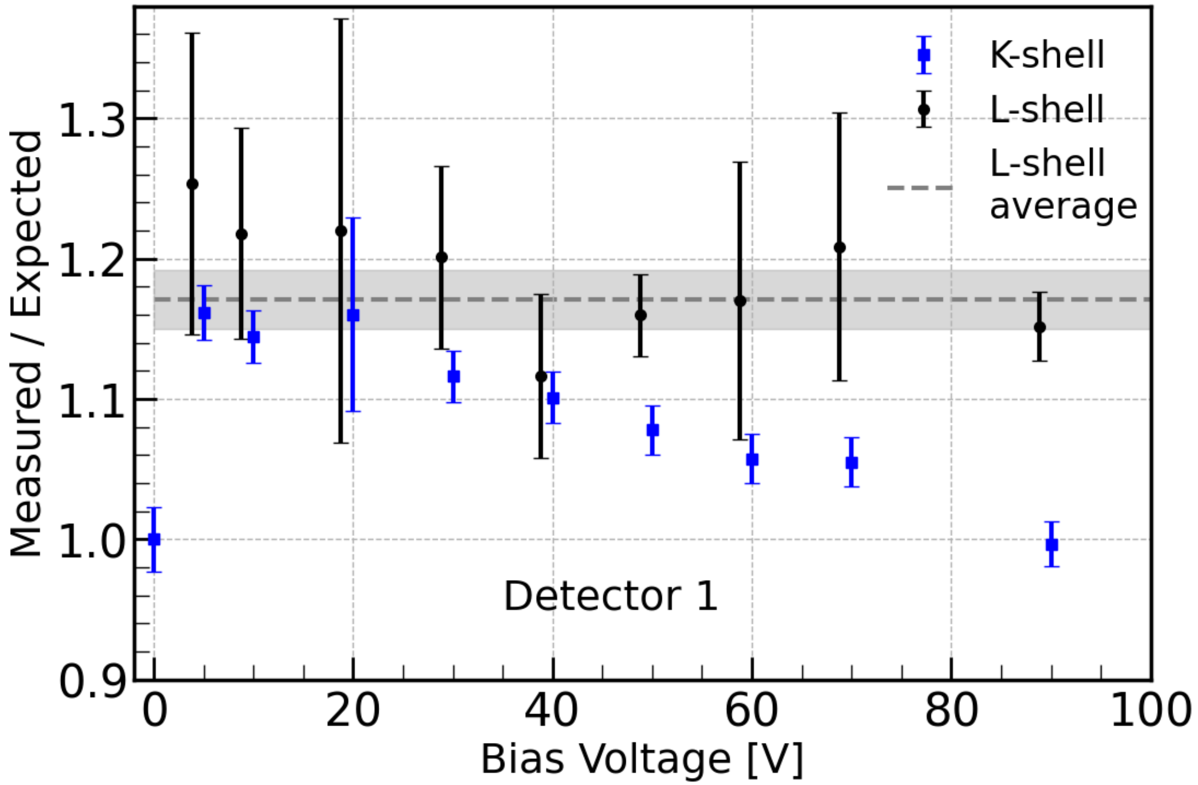
Effect of applying voltage

- **Expectation:** peak position evolves linearly with voltage (NTL effect)
- **Observation:** L-shell consistent with linearity, K-shell is non-linear due to saturation



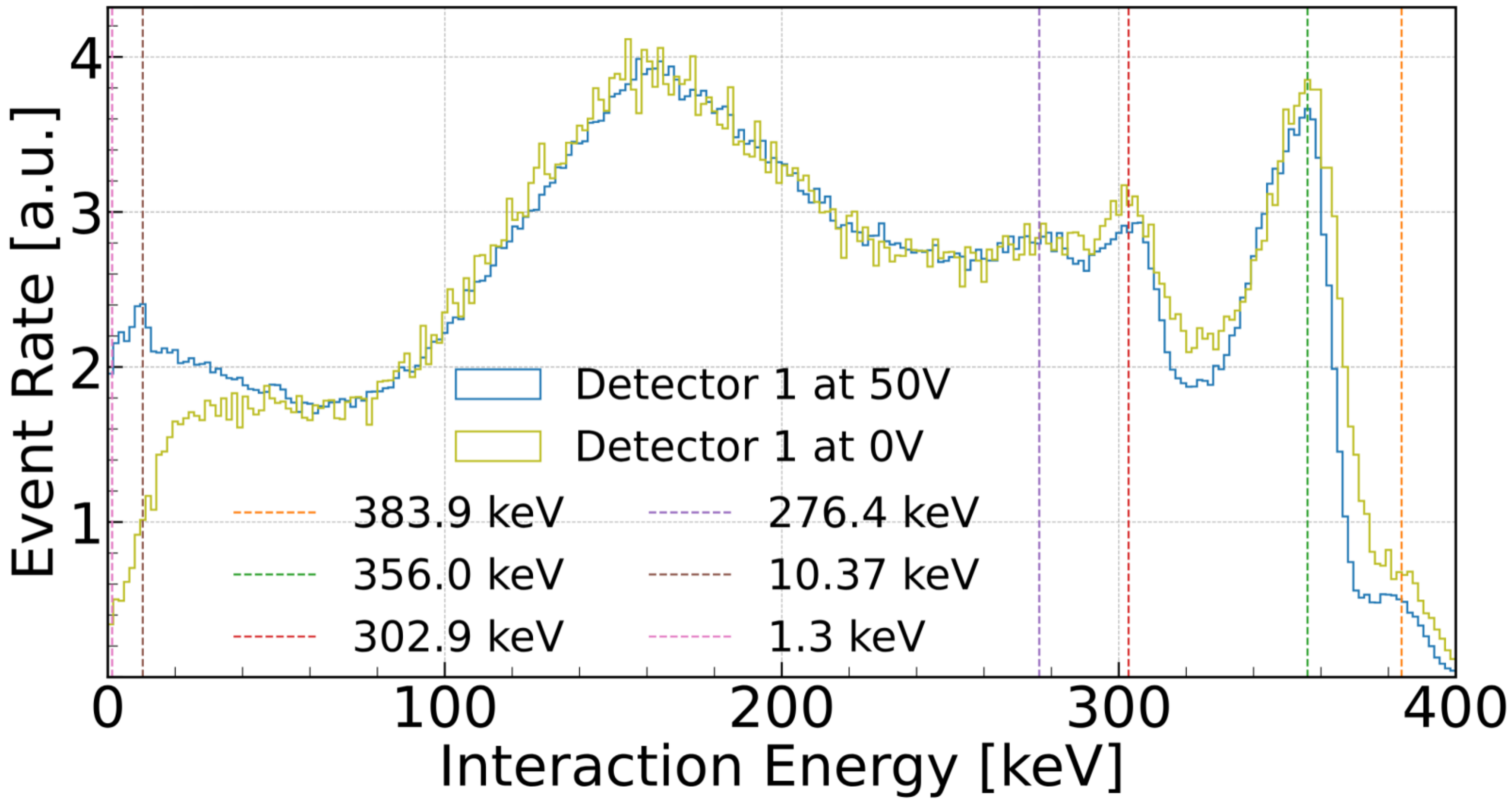
Effect of applying voltage

- **Expectation:** peak position evolves linearly with voltage (NTL effect)
- **Observation:** L-shell consistent with linearity, K-shell is non-linear
- Amplification via the NTL effect was larger than expected by about 17%



High Energy Calibration

- Spectral peaks from ^{133}**Ba source** used to calibrate at high energies
- Despite of saturation at these high energies, we can calibrate using the pulse integral



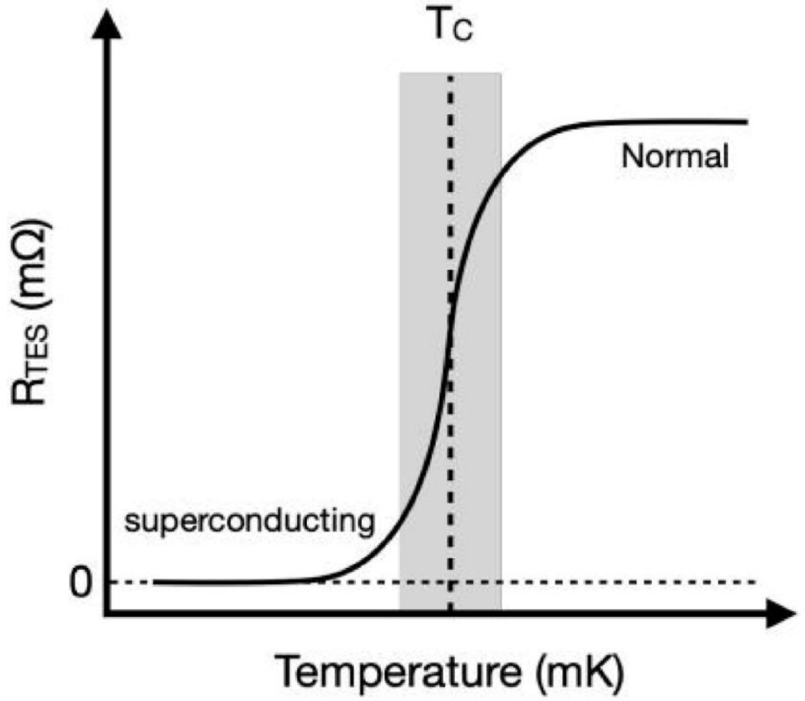
Conclusions

- Successfully calibrated and characterized Ge detectors in the low and high energy regions
- Voltage dependence of detector response up to 90 V was examined
- Additional electronic filtering developed to reduce the noise and improve resolution for SuperCDMS SNOLAB
- Publication in progress

BACKUP

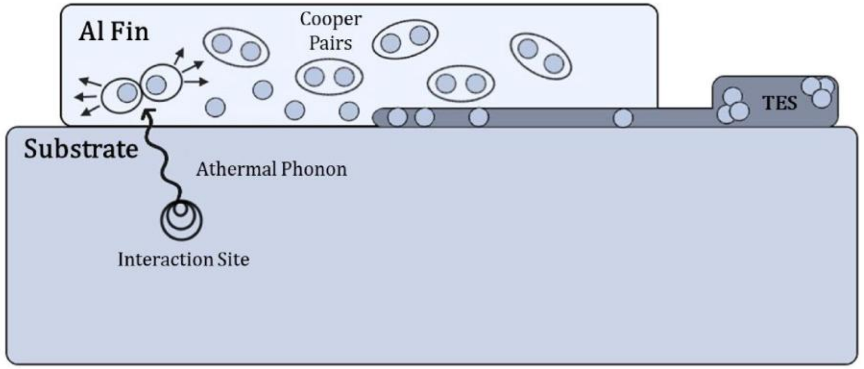
Transition Edge Sensors (TES)

- Phonon readout is through tungsten TESs



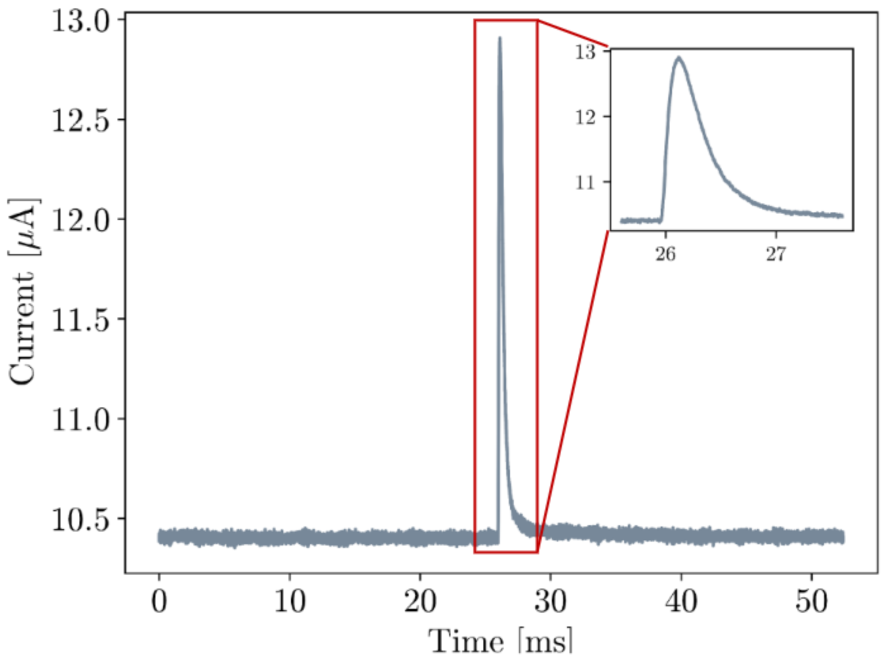
Phonon Readout

- Quasiparticle-trap-assisted Electrothermal feedback TESs (QETs) to maximize the surface area for phonon collection without increasing TES heat capacity
- Al fins have a much higher T_c (~1.2 K) so remains superconducting
- Phonon energy must be at least 350 μeV (binding energy of Al)



Data Collection and Processing

- Each energy deposit measured as a raw pulse collected in units of current
- Optimal filter applied to each trace as data is processed to extract the amplitude and other useful quantities
- Optimal filter: fits a fixed pulse shape to each event in frequency domain; frequency weighted by the signal-to-noise ratio



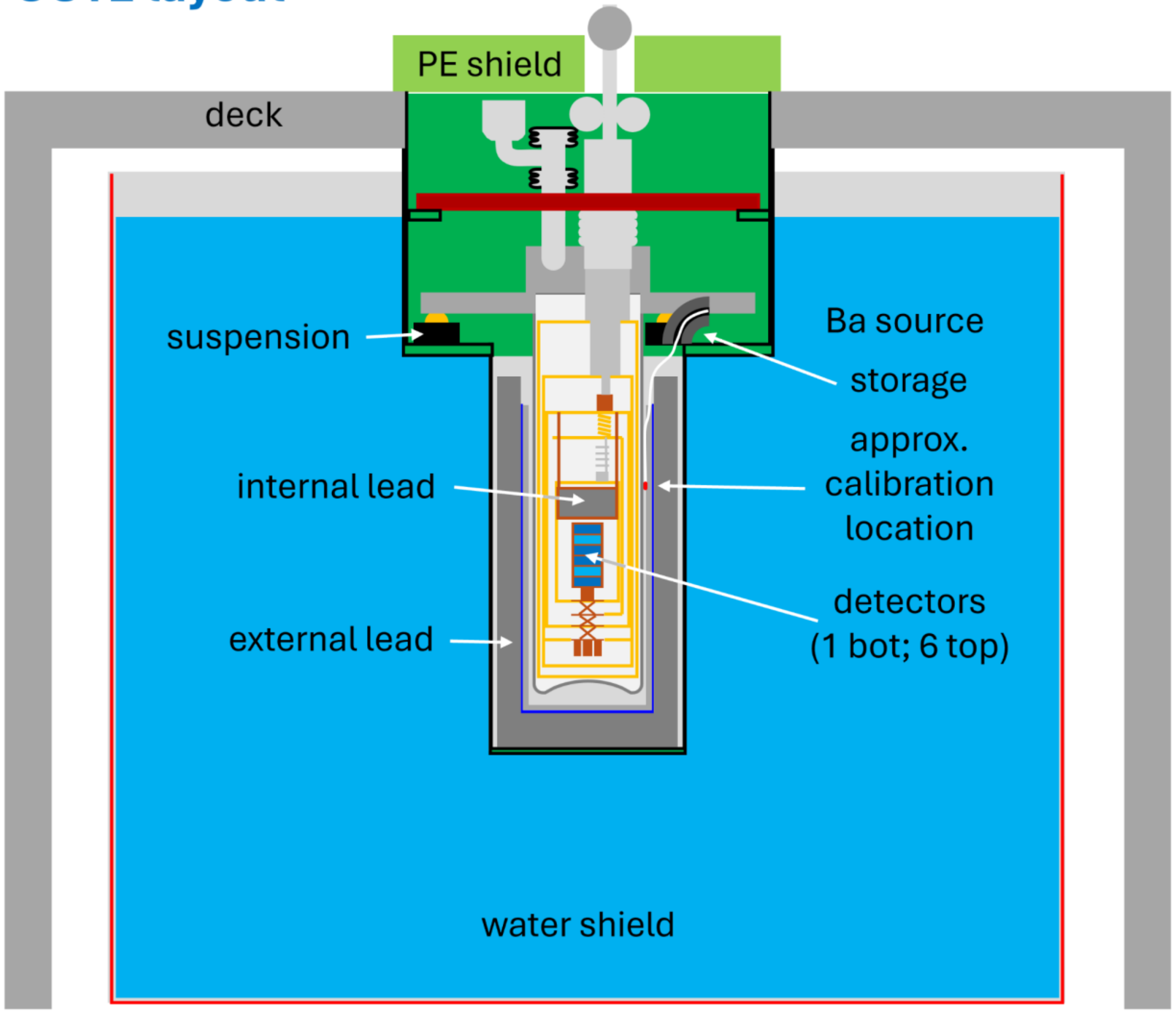
SuperCDMS Shielding

- Outer Neutron Shield: 60 cm Water Tanks top and sides, high density polyethylene bottom
- Radon barrier
- Gamma Shield: 20 cm low activity lead
- Inner Neutron Shield: 30 cm polyethylene
- Six copper cans act as an additional shield and couple to the stages of the dilution fridge

CUTE Shielding

- Payload is easily accessible
- Outer water tank, sides and bottom
- Two layers of lead shielding inside
- Polyethylene shield at the top that can be moved away
- Lead plug inside at the top
- Nested copper cans

CUTE layout



Low Energy Calibration

- Performed an unbinned NLL fit to each activation peak
- Extract a linear calibration factor
- For 50 V data, had to linearize the energy scale using the integral estimator (which was found to be linear to higher energies than the amplitude)