# Infrared Photon Interactions in SuperCDMS Detectors

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# Overview

- Introduction
- SuperCDMS Experiment and Detectors
  - Charge and Phonon measurements
  - Neganov-Luke Amplification
- Motivation
- Methodology
- Results
- Conclusion

# Introduction – SuperCDMS experiment

Super Cryogenic Dark Matter Search (SuperCDMS)
searches for evidence from low energy dark matter interactions in cylindrical Ge and Si detectors operated at ~45 mK.

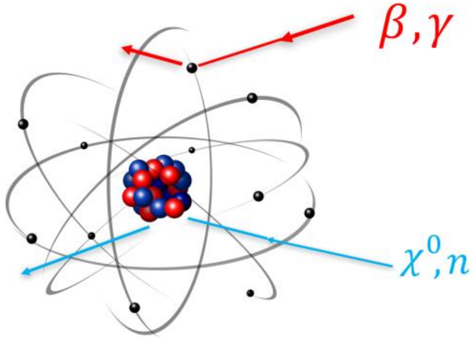
Two types of signals are detected:

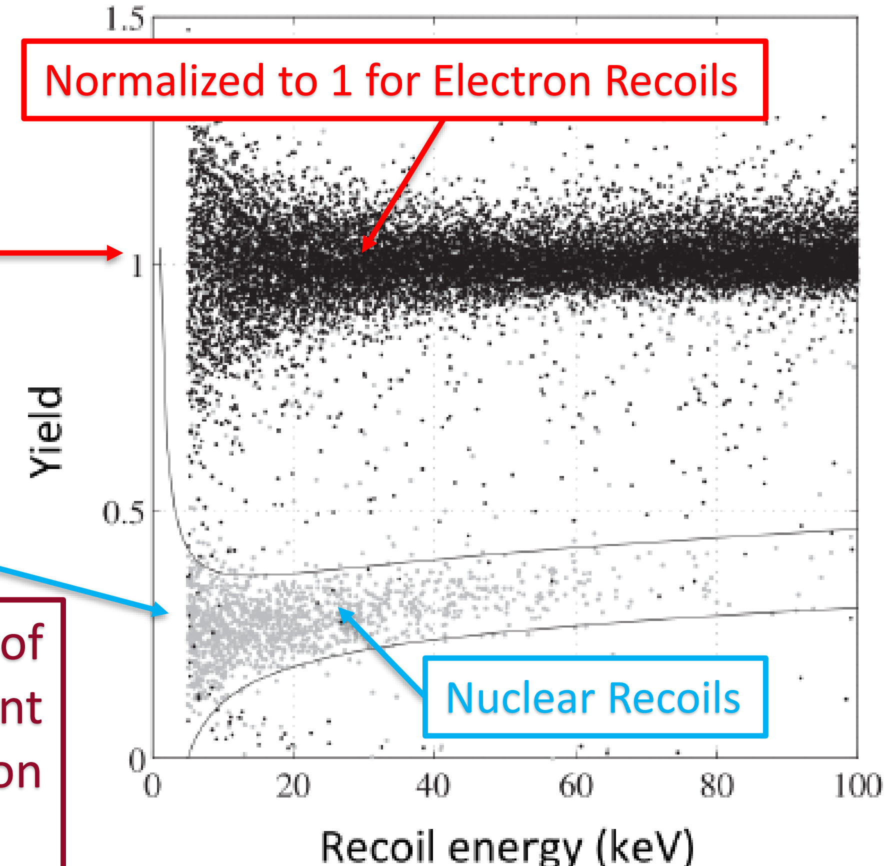
- *Phonon signal:* phonons propagate to the surface and are measured with Transition Edge Sensors (TESs).

- *Charge signal*: electron-hole pairs created in the interaction drift through an electric potential and are collected at the crystal surface.

# SuperCDMS Detectors, event-by-event discrimination

Ionization Yield = $E_Q/E_r$
($E_Q$ : *charge signal;* $E_r$ : *recoil energy*)
is different for different event types
(electron vs. nuclear recoils)

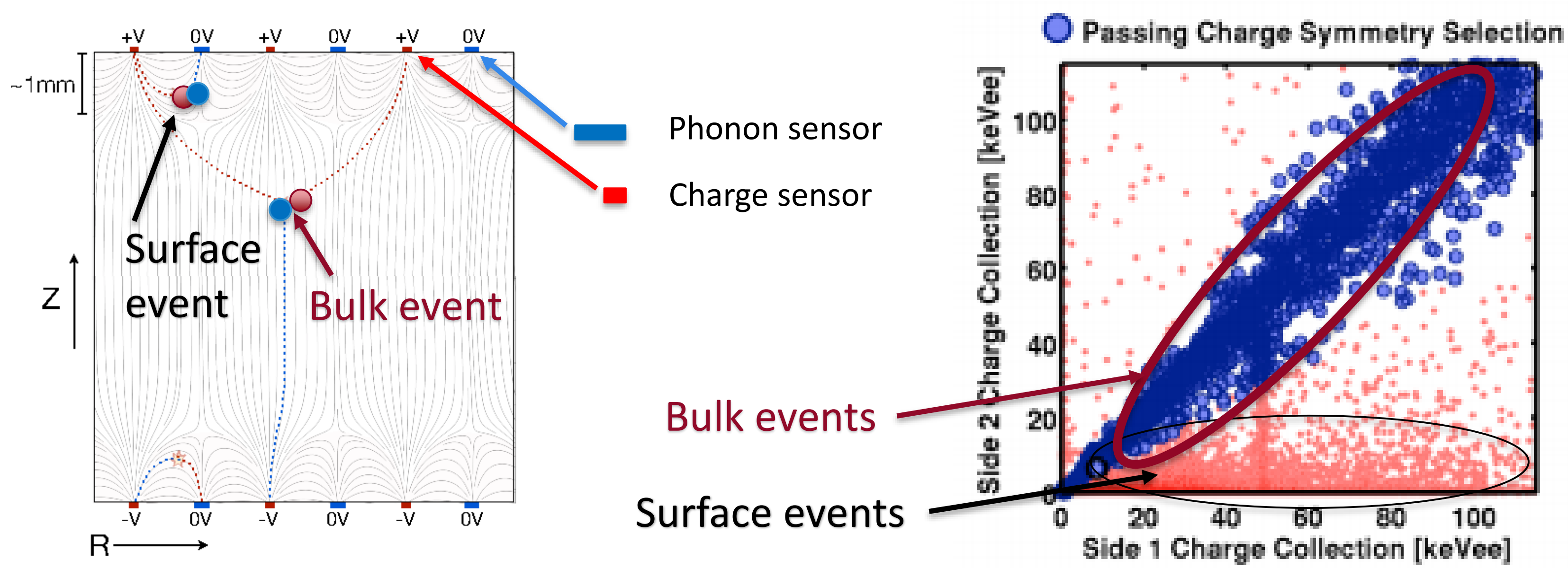



The simultaneous measurement of phonon and charge provides an efficient tool to discriminate against the electron recoil background

# Charge Measurement - iZIP mode configuration

- Phonon sensors are grounded.
- Charge sensors are biased at ±2 V
- Bulk event → charge collected on both sides
- Surface event → charge collected on one side only



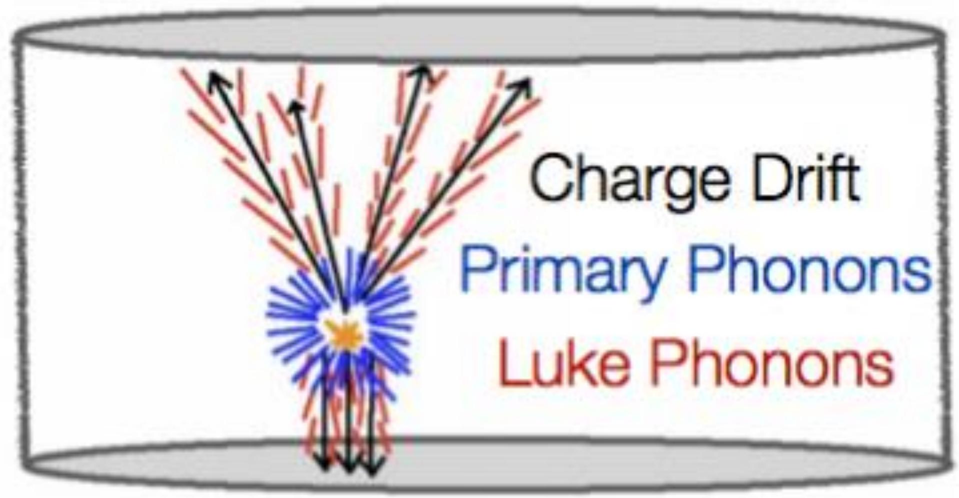
# Neganov-Luke Amplification (HV – mode)

If high voltage is applied across the crystal:

gain extra phonon signal, proportional to the number of charges and applied voltage

Although we do not get a signal from charge sensors in this mode (i.e: we lose discrimination ability) we gain a lower threshold

$$E_{total} = E_r(1 + \frac{eV_b}{\varepsilon})$$



# Detector Calibration & Stability Monitoring

- Using radioactive sources mounted outside the cryostat
  - Calibrate energy scale based on photon energy of source
  - Monitor the detector stability during the run period

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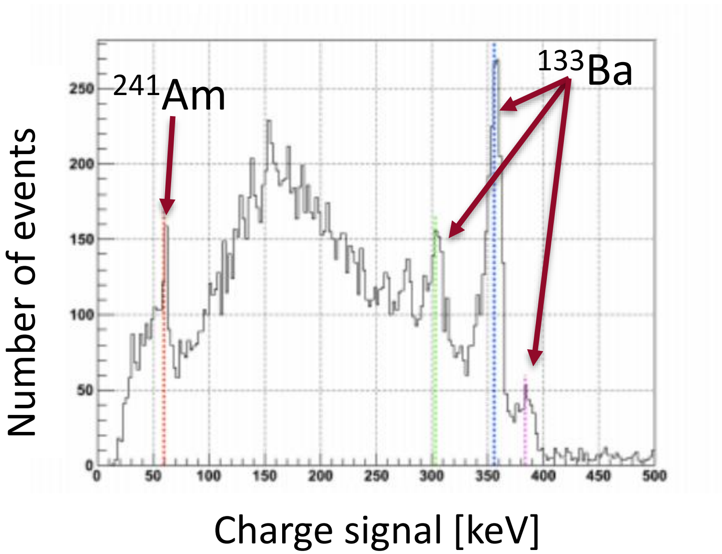
# Motivation

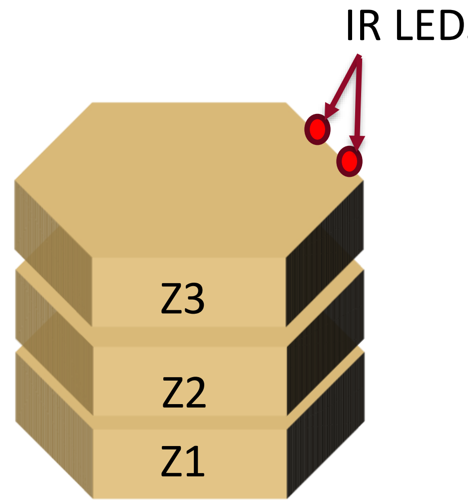
- The new generation of SuperCDMS experiment is aiming for low-mass WIMPs which requires:
  - Detectors with lower energy threshold
  - New low-energy calibration method
    - However, low energy gammas can not penetrate the cryostat shielding
    - And the process of monitoring detector stability takes several hours

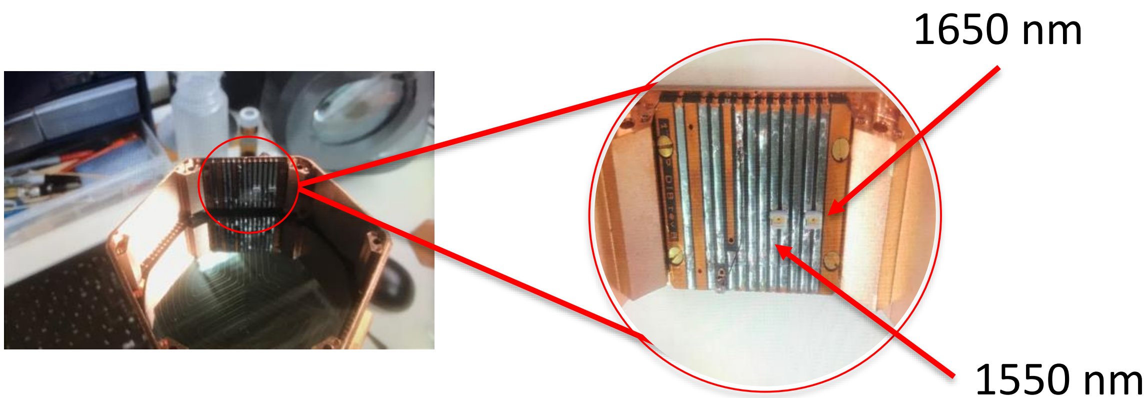



Our main goal is to investigate the possibility of using IR photons to calibrate Ge detectors at the low-energy scale, and to monitor the stability of the future SNOLAB detectors

# Method (1)

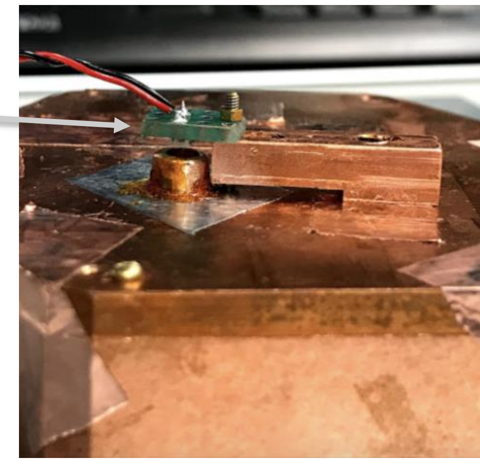
- Use a tower consisting of 3 detectors
- 2 LEDs of wavelengths 1650 nm & 1550 nm were installed on an empty detector housing
- The selection of the LED wavelength was based on the energy band gaps of Ge
- Two detectors used in this measurement are: **Z1** and **Z3**
- The LEDs were closer to Z3

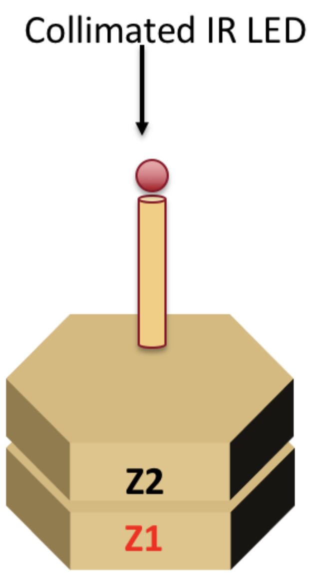


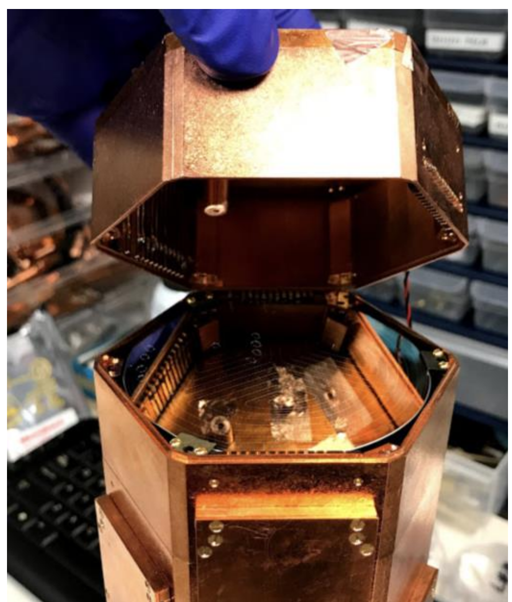



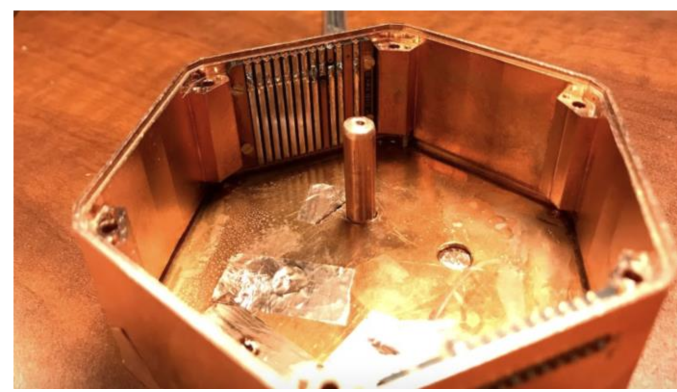
# Method (2)

- An LED (1650 nm) with collimator was installed at the top of the detector's lid
- Two detectors were used in this measurement; **Z1** and **Z2**
- The LED was shining at the top surface of Z2





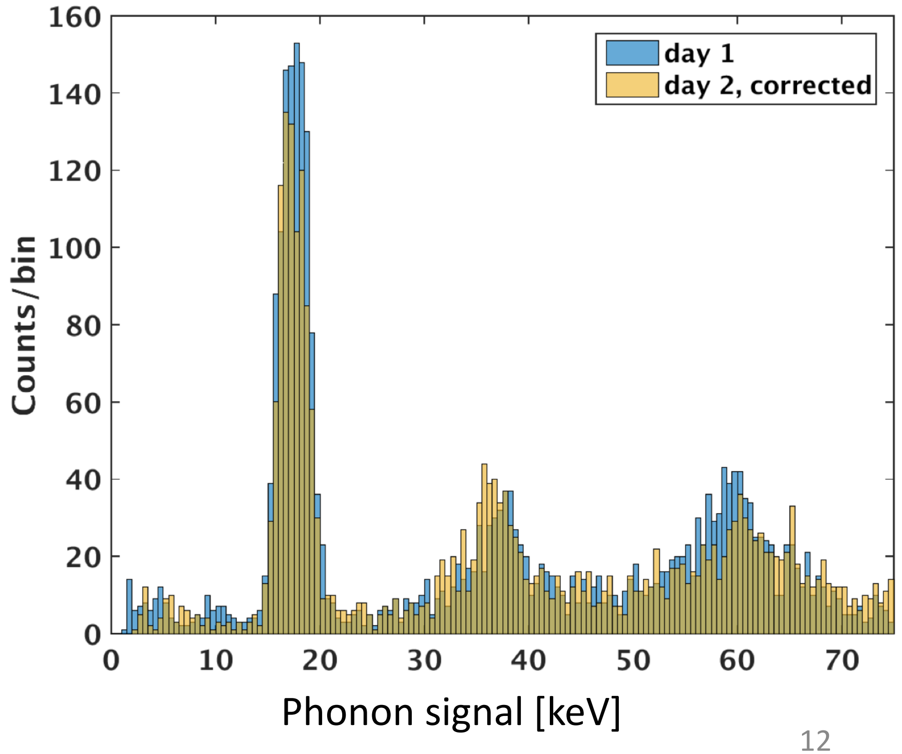





# Monitoring Detector Stability

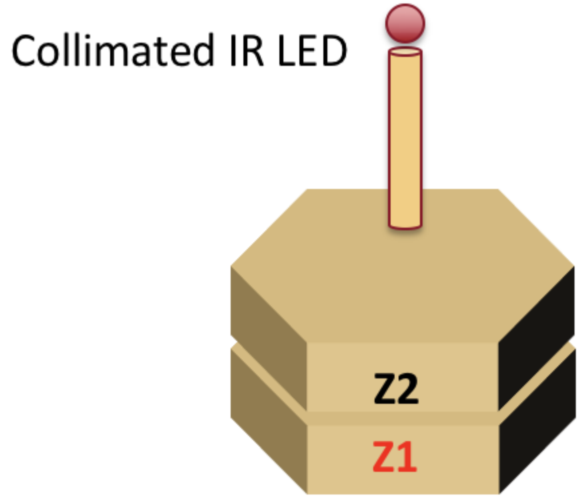
- LED signal was controlled by changing the LED bias voltage
- LED was operated in pulse mode at a fixed pulse width and frequency

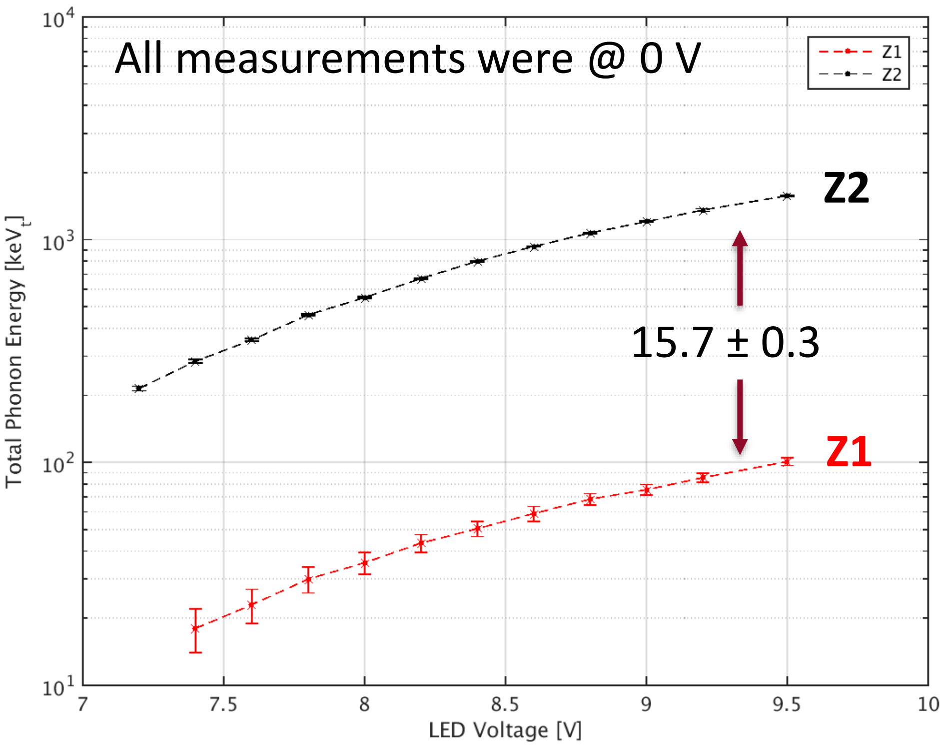
- Stability of LED signal: The energy of LED pulses was measured on two different days for the same LED settings to confirm the stability of LED signal over time
- The energy of LED pulses were identical, within uncertainty



# Towards Low Energy Calibration

- Amplitude ratio between near and far detector is independent of pulse energy.
- Use this *shadowing* to produce low-energy pulses in far detector.

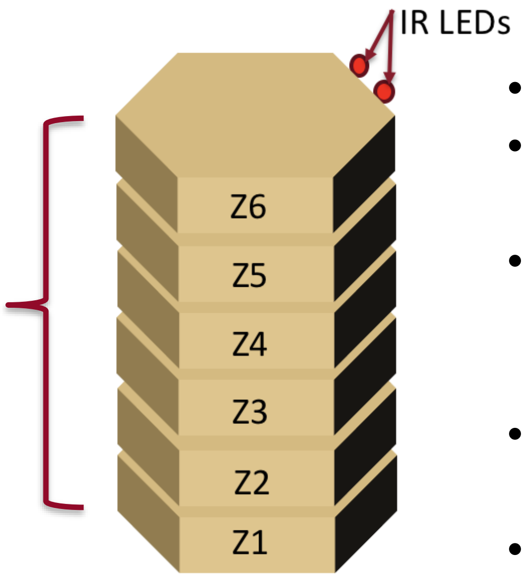


# Future Goals

1. Use CUTE (Cryogenic Underground TEst facility) to establish LED base stability monitoring for SuperCDMS SNOLAB
2. Develop an LED based calibration scheme for low energies

SuperCDMS SNOLAB uses towers of 6 detectors




- Use shadowing
- Measure amplitude ratio at high energy
- Reduce pulse to lowest calibrated energy in near detector
- Get lower energy point in far detector
- Iterate

3. Improve understanding of IR photon interaction in Ge:
   - Measure LED emission spectrum at low temperature (4 K)
   - Measure penetration depth and Luke amplification for IR photon pulses

# Conclusion

- Signal from IR LEDs is stable within the experimental uncertainty
- SuperCDMS SNOLAB tower consists of a stack of 6 detectors, which increases the shadowing effect and helps reduce the energy of IR pulses
- CUTE will be the location to perform most of the future measurements; because it will hold the first SuperCDMS SNOLAB tower and it will have the new readout electronics
- Further tests are needed to better understand the interaction of IR photons in our Ge detectors

THANK YOU

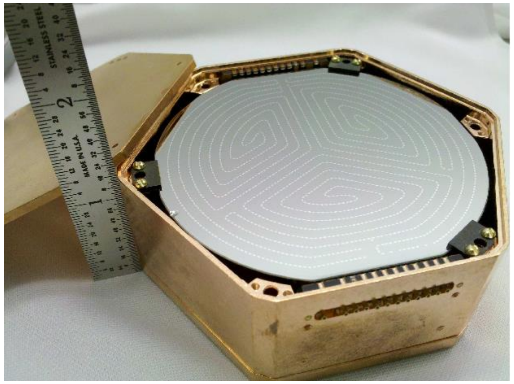
Questions?

# Backup slides

# SuperCDMS Detectors

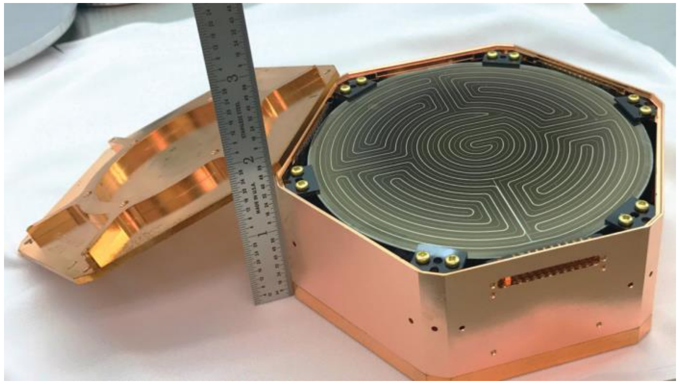
Detectors at Soudan

- mass: 620 g
- 8 phonon and 4 charge sensors on both surfaces
- Total mass: 9.3 kg



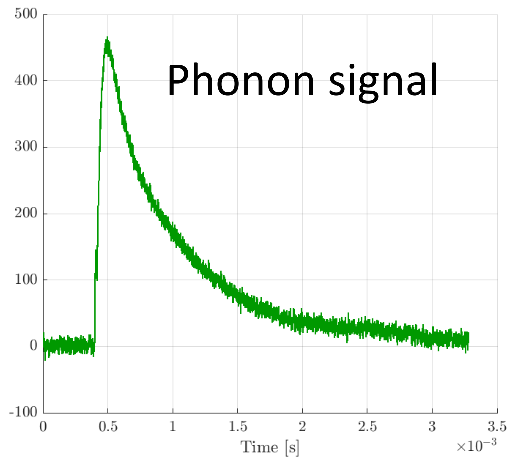
Detectors at SNOLAB

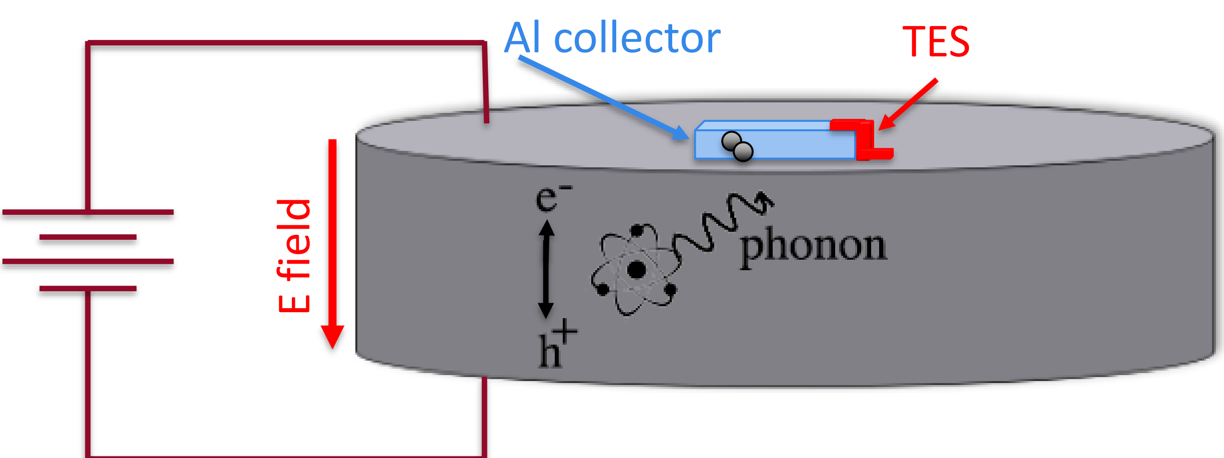
- mass: 1.3 kg
- 12 phonon and 4 charge sensors on both surfaces
- Total mass: ~ 30 kg



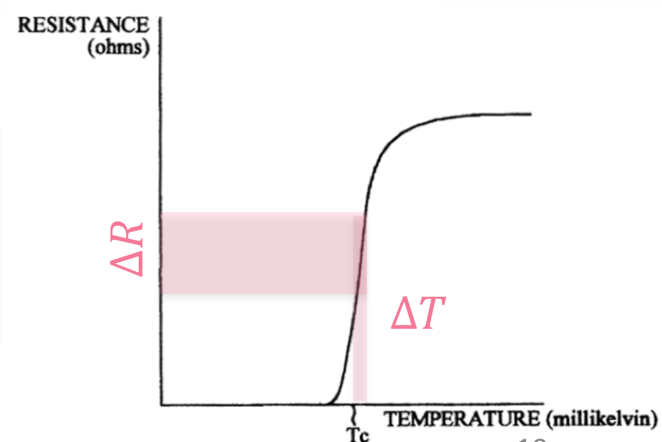
# Phonon Measurement

- Measuring recoil energy via lattice vibrations (phonons)
  - Phonons propagate through the crystal
  - They break Cooper pairs to form quasiparticles in Al electrode
  - Diffusion of quasiparticles to a TES increases its temperature



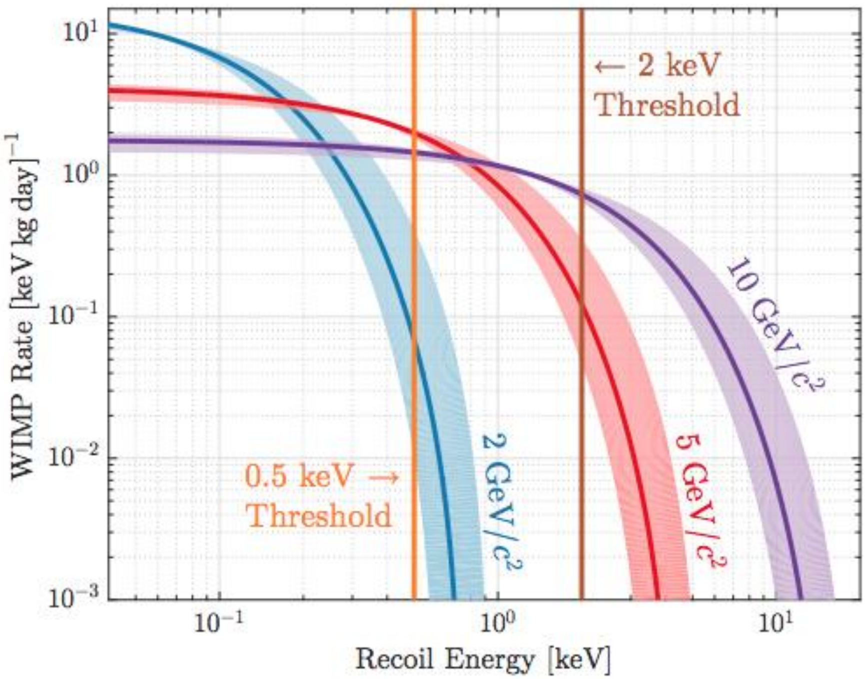




*{Cartoon drawing - not to scale}*

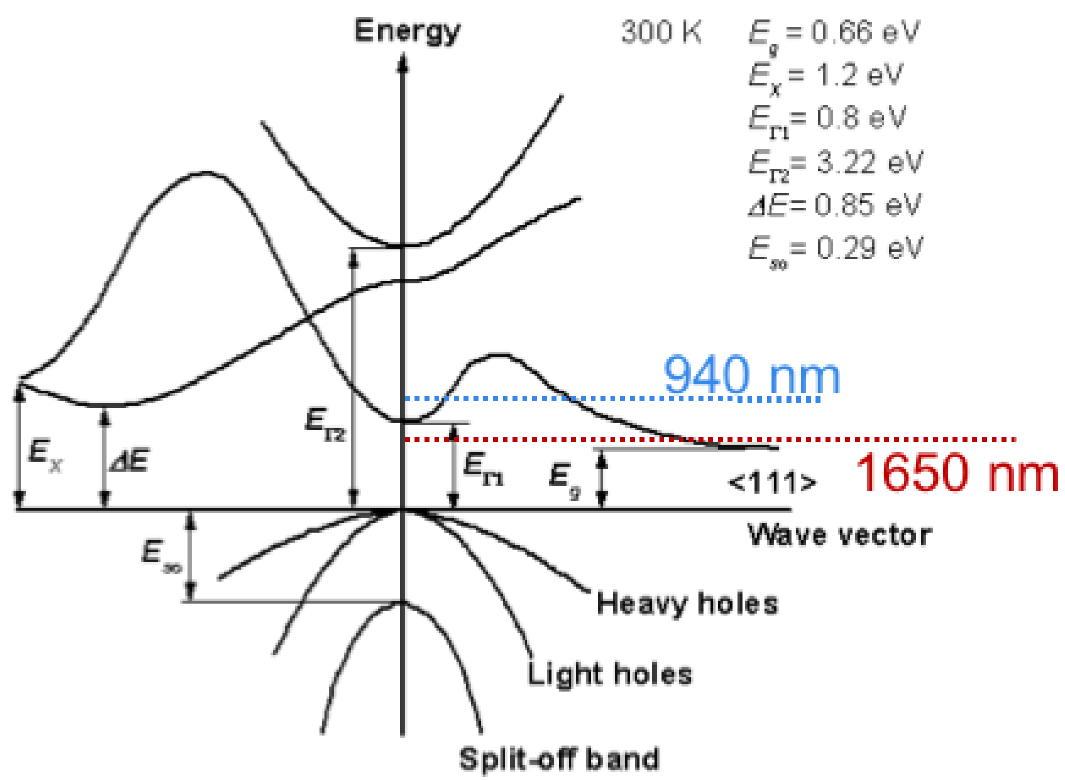


# Why do we need a lower threshold?

- A lower threshold increases the experiment's sensitivity to a lower mass WIMPs.

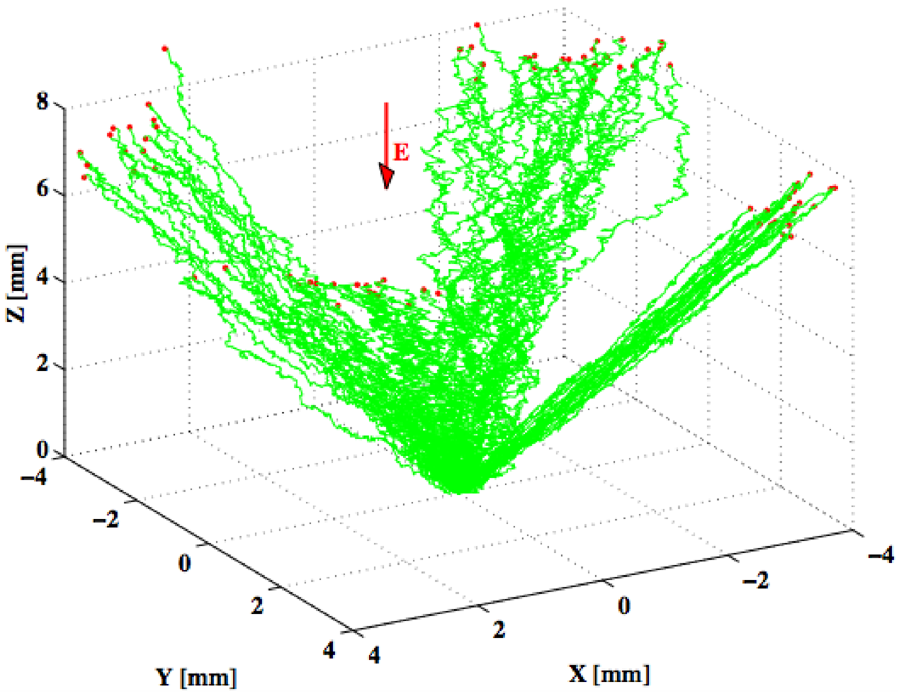


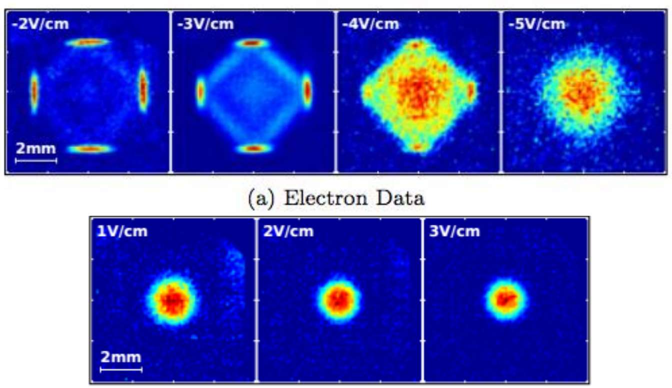
# Ge band-gap structure



# Oblique electron propagation

- Each one of the groups corresponds to a minimum in the conduction band for germanium
- Higher electric field makes the electrons effectively go more along the electric field lines

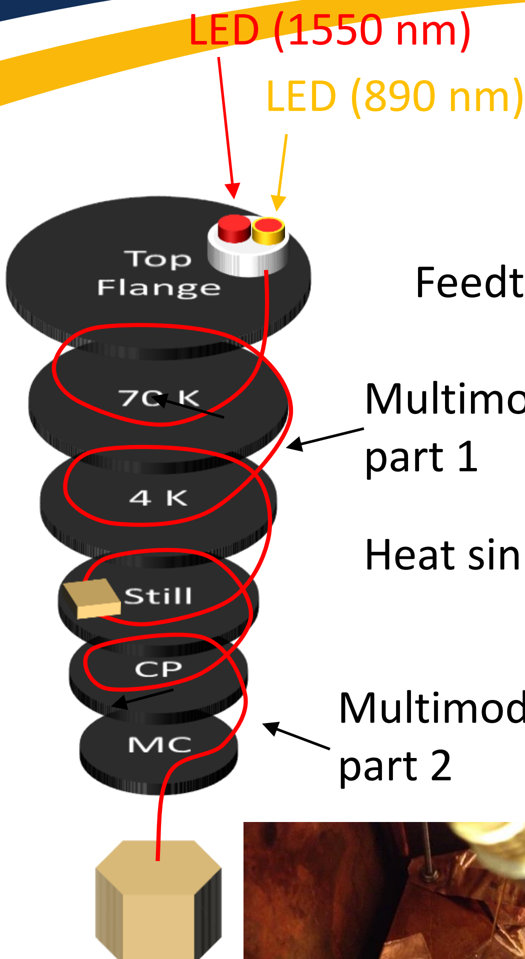


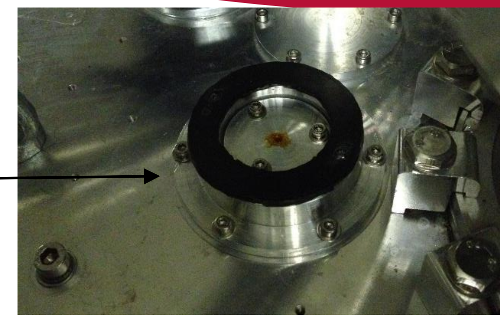

(a) Electron Data

(b) Hole Data

# Experimental Setup (I) – Optical Fiber

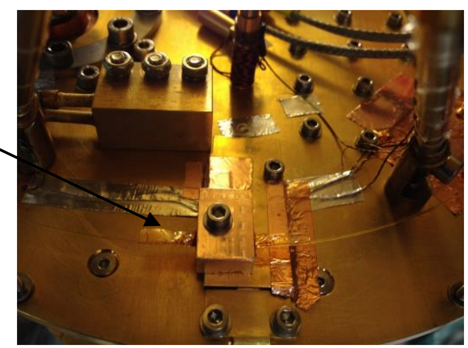



Feedthrough

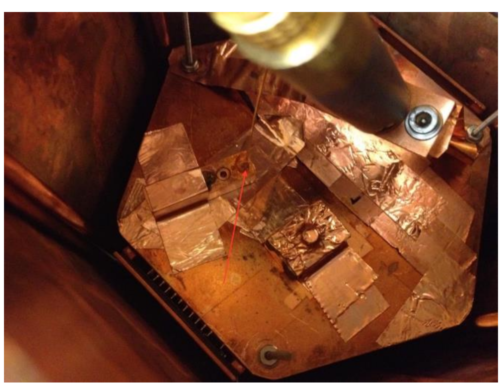


Multimode fiber part 1

Heat sink



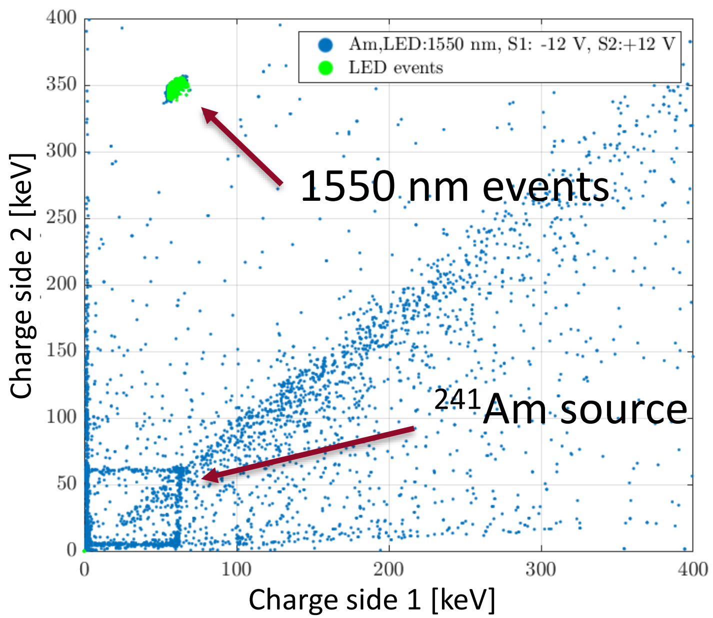
Multimode fiber part 2



# Test with Optical Fiber

- Used two wavelength LEDs (890 nm and 1550 nm), compare to 60 keV gammas from $^{241}$Am.

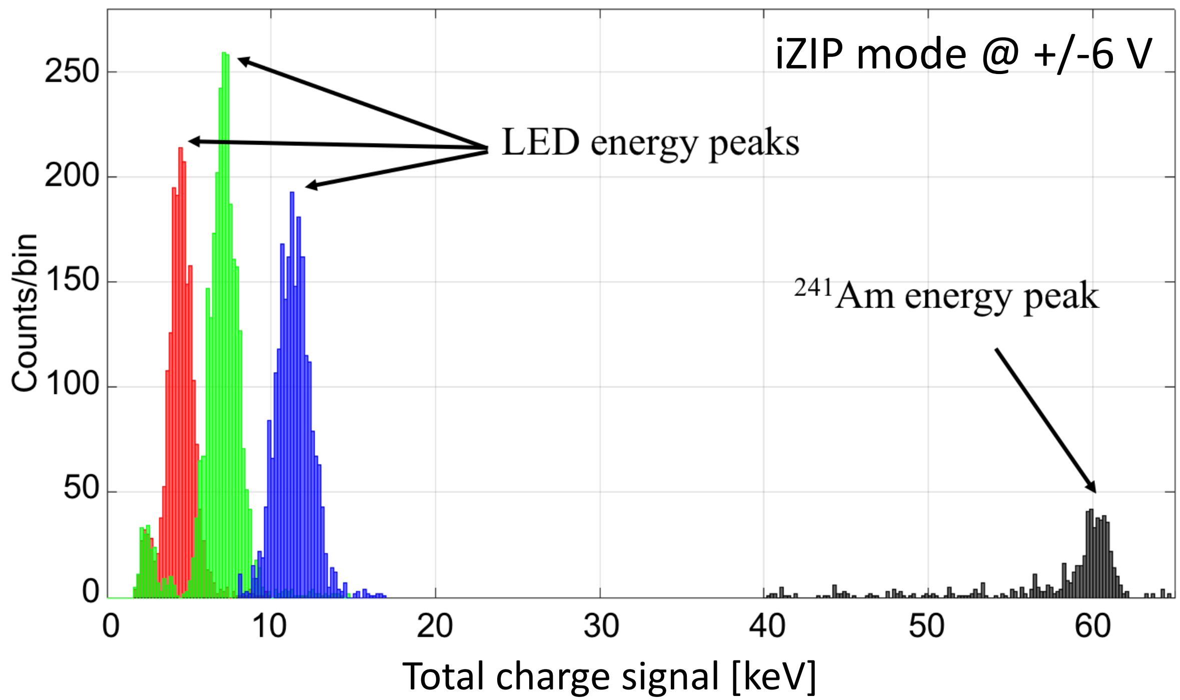
- 890 nm: absorbed at surface (few μm); 1550 nm penetrates partially through the surface field (~1 mm).



# Establishing Low-Energy Scale

- We were able to tune the LED setting down to ~ 4 keV

LED: 1650 nm

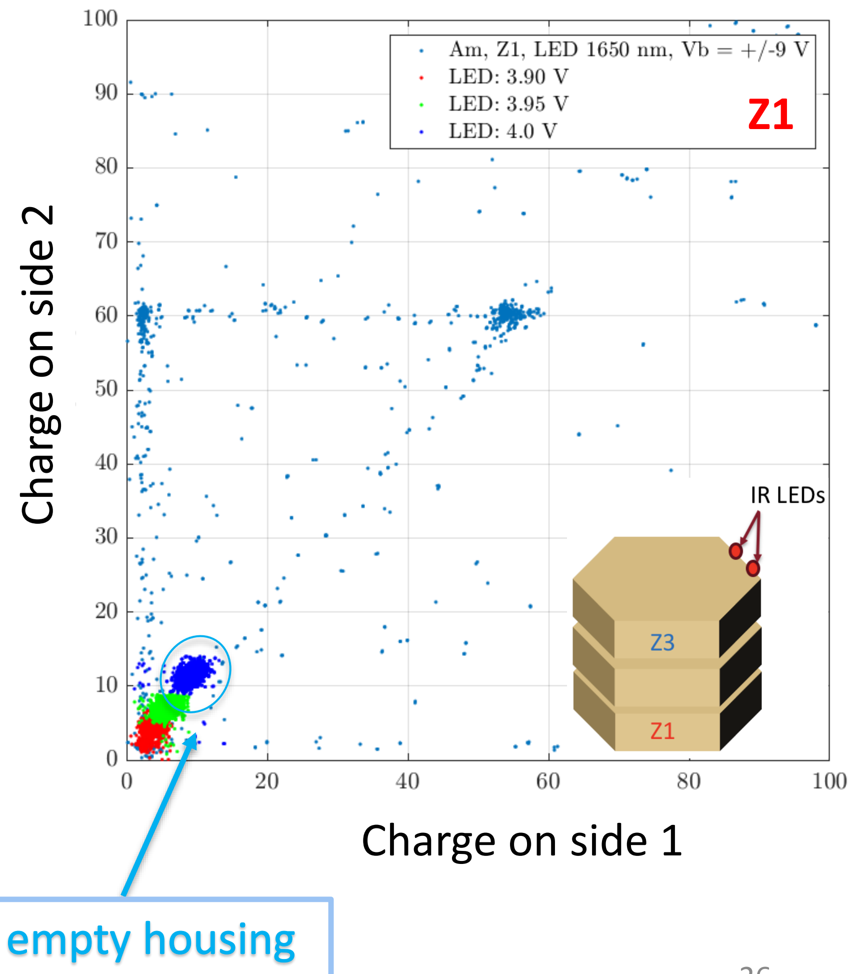


# Penetration depth vs. LED position

- Charge carriers collected on side 2, and on side 1 are equal (symmetric)
- Q2:Q1 ~ 1

➔ Indication for:

- bulk interactions
- photons might be bouncing inside the tower, causing interaction to occur at both sides of the detector

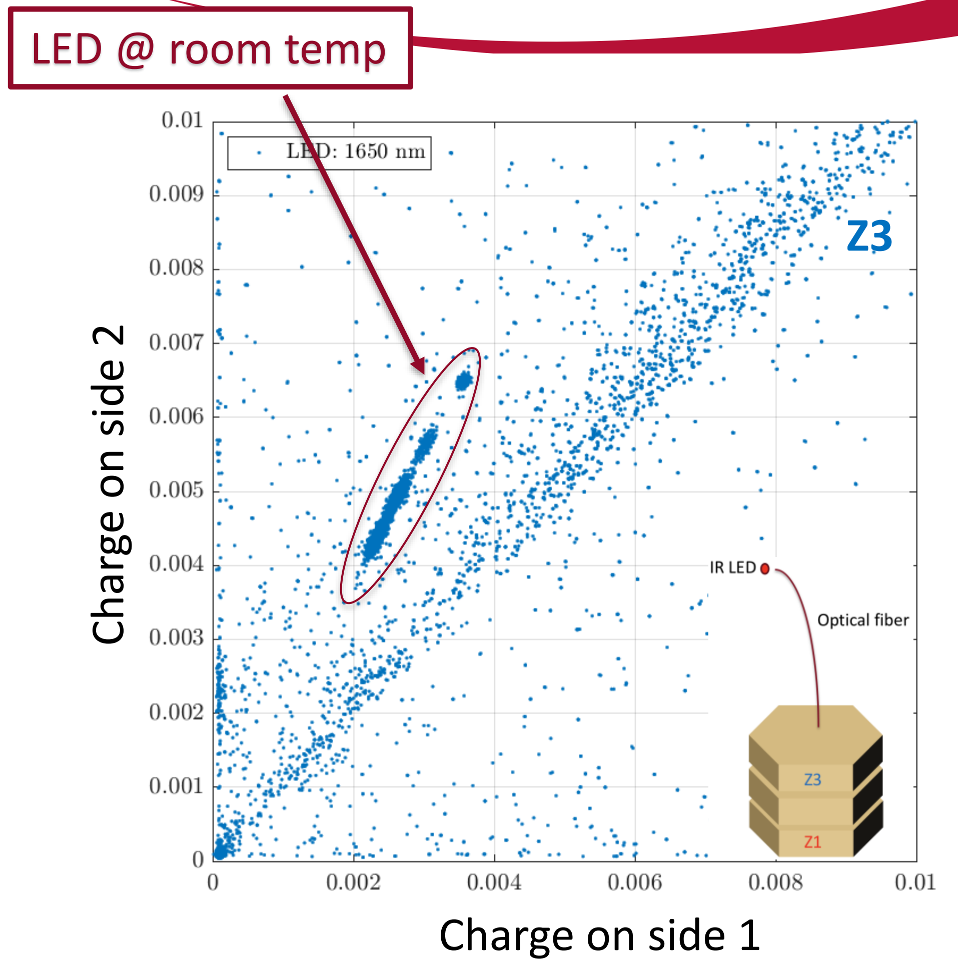


# Penetration depth vs. LED position

- Charge carriers collected on side 2 are greater than side 1 (events closer to side 2)
- Q2:Q1 ~ 1.8

➔ Indication for:

- near bulk interactions
- more realistic position information compared to the cold setup



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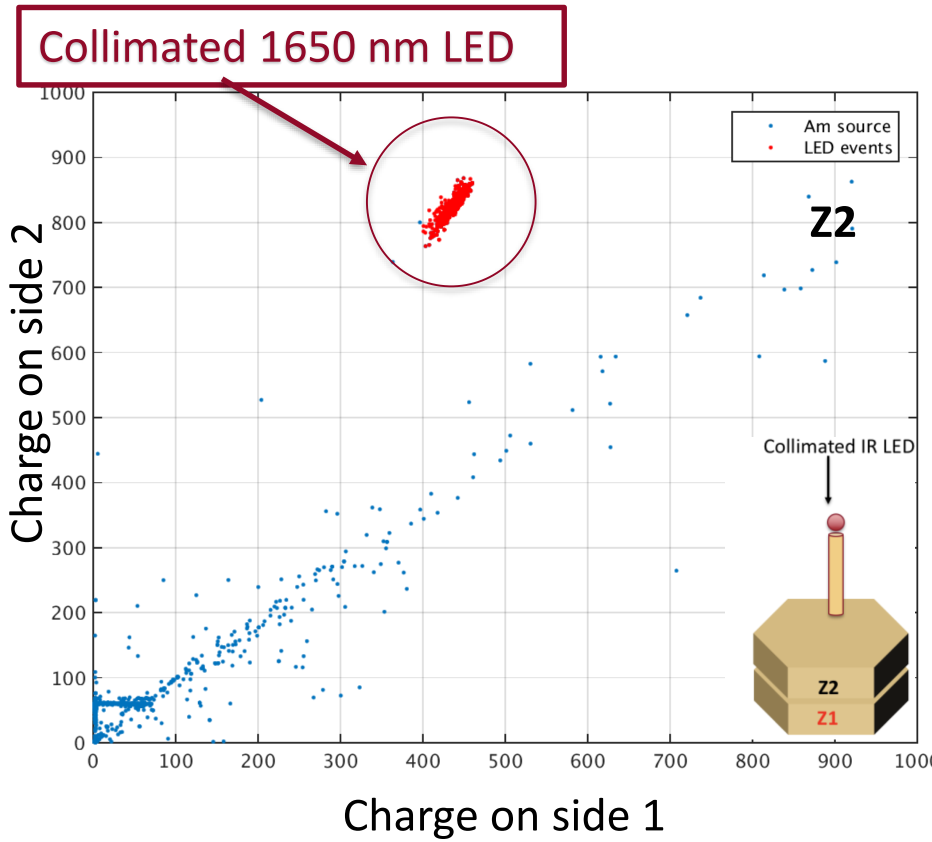

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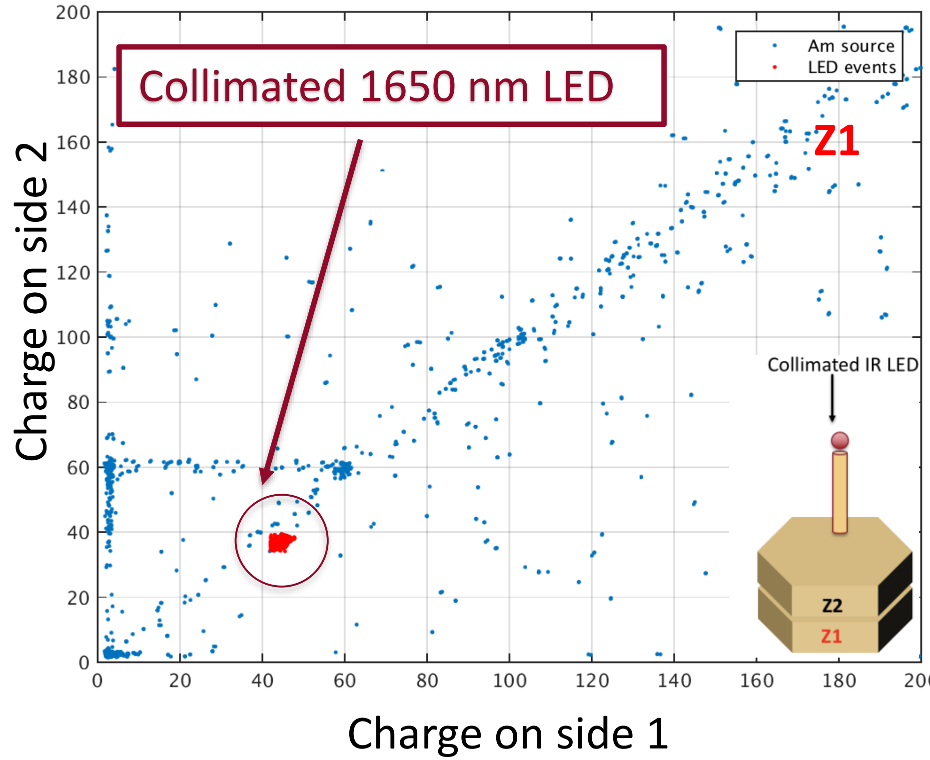
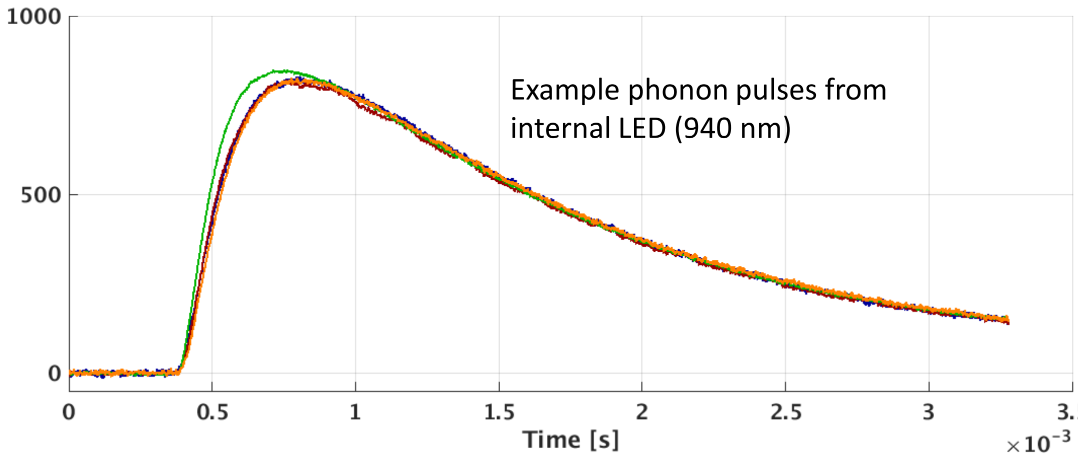
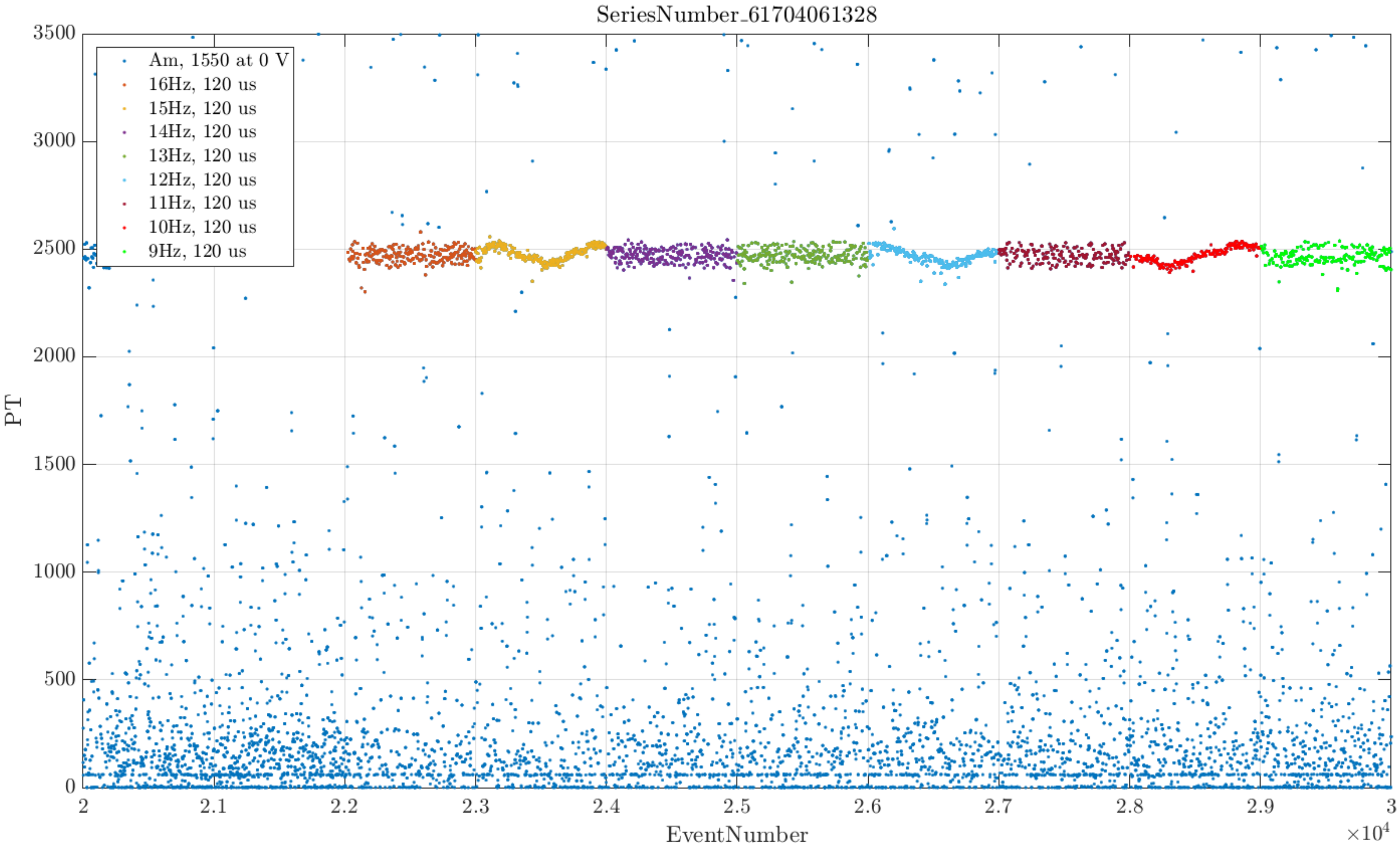


# Test with internal LED

- Also tried to use internal LEDs (940 nm).
- We could see LED induced pulses without heating detector.



# Effect of 60 Hz noise on the LED signal



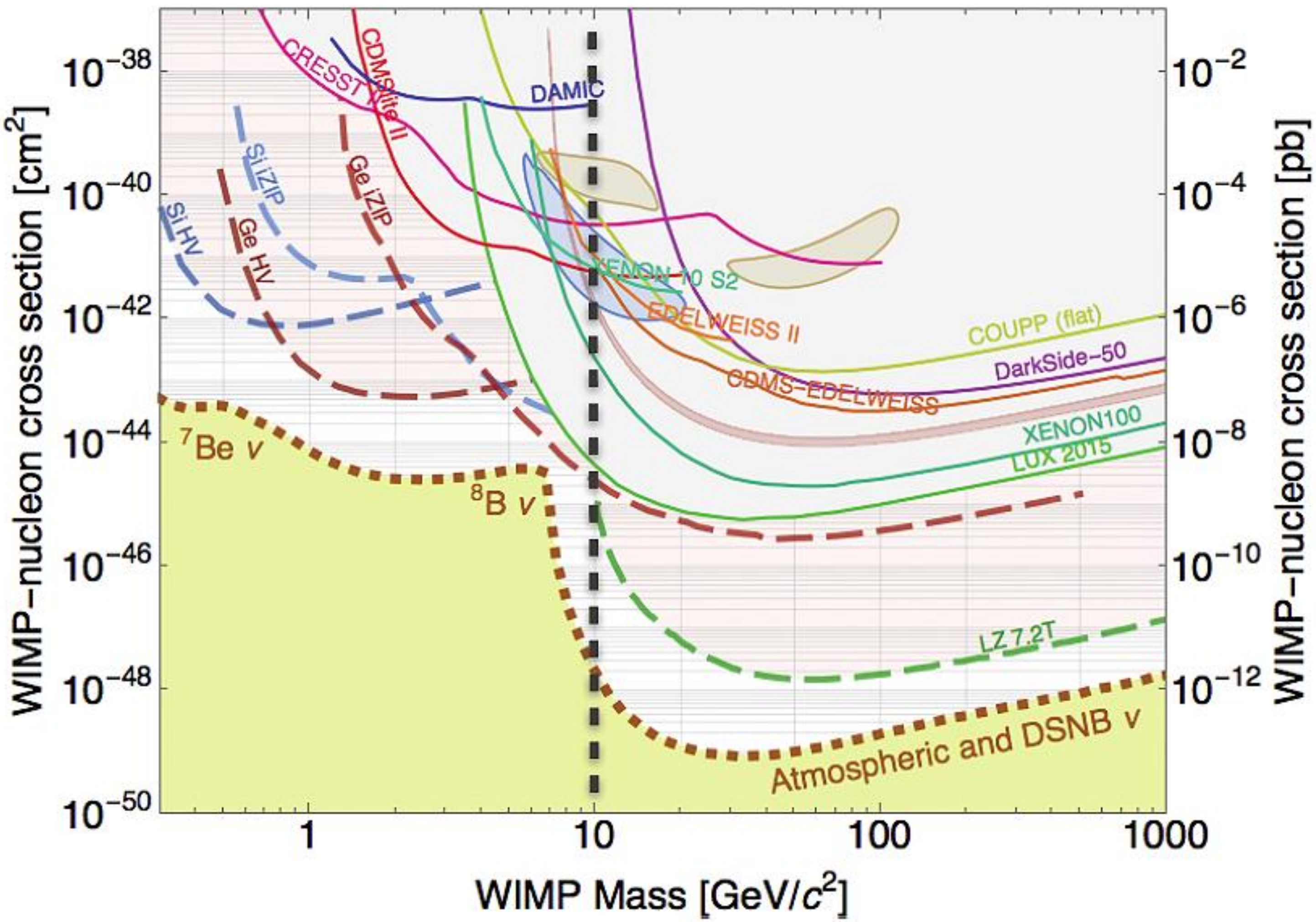
# IR photon penetration depth in Ge crystal

**TABLE 1.** Characteristics of the infrared LEDs.

| **LED reference** | **L8245** | **L7850** | **L7866** |
|---|---|---|---|
| Emission wavelength (μm) | 1.65 | 1.45 | 1.30 |
| Photon energy (eV) | 0.75 | 0.86 | 0.95 |
| Absorption length in Ge (μm) [9,10] | 1.7e5 | 400 | 1 |

http://dx.doi.org.proxy.queensu.ca/10.1063/1.3292341

# SuperCDMS Results



# Towards Low Energy Calibration

- Lowest LED settings: ~10 keV$_\gamma$ in near detector (Z3), limited by phonon noise, not LED control
- Much smaller signal in Z1
- Measure Z1 : Z3 signal ratio at high LED setting
- Ratio expected to be constant (probability for photon to reach Z1 depends on geometry)
- Infer energy in Z1 at lowest LED setting (though cannot be measured with present detector/electronics)