Dark Matter Search with a low-threshold SuperCDMS HVeV detector

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Introduction

SuperCDMS uses cryogenic phonon-based detectors to look for a wide range of Dark Matter (DM) candidates

- Direct detection of DM with energy from eV to 10 GeV
- Nuclear-recoil and electron-recoil DM
Low-energy excess in multiple phonon-based DM searches


SuperCDMS-CPD

G. Angloher et al., EPJC 77:637 (2017)
Also in HVeV ERDM searches

- Unknown sources also observed in multiple **charge based**
  dark matter searches with SuperCDMS-HVeV detector
- **Questions:**
  - Are these two groups of unknown sources related?
  - What information can we extract from these events?
  - If they’re background, would this lead to ways to eliminate one or both?

(Maybe) Electrode and sidewall leakages

Unknown sources

SuperCDMS HVeV detector
Measuring energy with phonon sensors on silicon/germanium crystal

- 2.7 eV baseline resolution, 9.2 eV threshold [1]
  - Best in class
- By measuring the background at different voltages with the same setup, we can better understand the nature of the unexplained excess
  - Quantified by $\epsilon_{\text{eff}}$, the average energy to create an electron-hole pair
    - $n_{\text{eh}} = \frac{E_{\text{Recoil}}}{\epsilon_{\text{eff}}}$

The recoil energy is effectively amplified by $G_{\text{NTL}}$ via the NTL effect[2].

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HVeV detector with 0V/60V/100V bias

- Detector operated in a surface lab at Northwestern University
- O(1) gram-day exposure at 0 V, 60 V and 100 V [1]

![Graph showing raw exposure vs. time for 0V, 60V, and 100V biases.]

Similar excess around ~100 eV as on slide 3

![Graph showing recoil energy distribution for SuperCDMS HVeV detector at 0V.]

“Normal” and “Anomalous” events in 0V and HV data

Some events have pulse shape close to the expected shape (from laser calibration). → Orange contour in the $\chi^2$ plot.

Two anomalies observed:
1. Long-tail pulses@0V
2. Burst events@HV

**0V:**
Events have longer decay time than laser (photon) events

**HV:**
Primary pulse followed by small amplitude pulses. We call these burst events
0V-HV comparison: Pulse shape

Burst events can behave like long-tail events if there is no NTL gain.
0V-HV comparison: Energy spectra

\[ E_{\text{phonon}} = E_{\text{recoil}} \cdot \left(1 + eV_{\text{NTL}}/\varepsilon_{\text{eff}}\right) \]

Energy spectrum scales with \( G_{\text{NTL}} \).

By looking for the \( G_{\text{NTL}} \) where the spectra match each other best, we can measure the effective charge pair creation energy \( \varepsilon_{\text{eff}} \) of the background events.
0V-HV comparison: Energy spectra

- We scale the HV spectra with different $G_{NTL}(\epsilon_{\text{eff}})$
- Minimize the $\chi^2$ between 0V spectrum and the scaled HV spectrum.
- Data favors $\epsilon_{\text{eff}} \sim 4-5$ eV
  - Just a rough estimate; uncertainty not quantified

Note: calculated energy of the burst events is close to the energy of the primary pulse.
Energy of the secondary pulses in HV burst events

Energy of secondary pulses are compatible with single electron-hole pair events (100 eV) with a recoil energy of ~2 eV.

Events in the 2\textsuperscript{nd} and 3\textsuperscript{rd} peak have a rate compatible with pile-up from 1\textsuperscript{st} electron-hole pair events.
A model of HV burst events

The HVeV detector holder is made of PCB which contains SiO$_2$.

Secondary pulses: $\sim$2 eV

Primary pulse: $\epsilon_{\text{eff}} \sim$4-5 eV

Coincidence of burst

In a new setup, we have four detectors in the same cavity:

We see coincidence of burst events in multiple detectors.

Burst events are likely to have external origin, since they are usually seen in more than one detector.

Comprehensive data analysis ongoing. Stay tuned!
Conclusion

- We see low energy excess in SuperCDMS HVeV detector
- 0V-HV comparison:
  - The excess at 0V in HVeV detector can be partly explained by burst events seen at HV
- Burst events are likely to have an external origin:
  - Most burst events have coincidence events in other detectors
  - Luminescence of SiO₂ in PCB may be one of the origins
  - This accounts for a good fraction of the unknown events in the HVeV ERDM search

Next steps:
Designing a new detector payload scheme with
- Minimal use of PCB/insulator
- Maximal detector coincidence tagging capability
Backup slides
Events that are compatible with PCB hypothesis

We see a group of ultra-slow (~10 ms) pulses in 0V and HV data.
1. They have ~100 times longer decay time than the events happen in detector crystal
2. A series of single electron-hole events can happen along the slow pulse in HV data
A paper on source of low-energy background


Three sources of low-energy background arising from interaction of high-energy particles:

- Cherenkov radiation
- Transition radiation
- Luminescence

Different experiments may have different dominating background origins.
0V-HV comparison: Pulse shape

The averaged 60 V pulse shape shows a prolonged decay time like the averaged 0 V events.

The long decay time cannot be explained by saturation (blue line).
Experimental setup

Readout board SQUIDS (~1.3K)
GGG heat sinking (~300mK)
Detector Box (~50mK)
Nb Can location
Energy estimator

MF = area of purple+yellow region
Cuts

Livetime cut

Baseline after live-time cuts, 60 V data

Pulse width cut

Average pulse width [sample]