Investigation of the low energy excess in SuperCDMS HVeV detectors and its potential subtraction for enhanced dark matter sensitivity

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High voltage operation of phonon-mediated detectors

The Neganov Trofimov Luke (NTL) effect

\[ P_t = E_r + N_{eh} eV_b \]

Maxwell-Boltzmann distribution has a steep falling edge

SuperCDMS HV detectors will provide the greatest sensitivity to GeV-scale dark matter at SNOLAB due to NTL amplification.
HV detectors in action

- HVeV = prototype of the SuperCDMS SNOLAB HV detector
  - four 1-gram detectors were deployed at the Northwestern Experimental Underground Site (NEXUS)
  - single-charge resolving
  - observed greatly reduced rates of ionizing backgrounds after the removal of an FR4 PCB board
    - we learned that the PCB board was the source of secondary photons
  - non-ionizing backgrounds may dominate the remaining energy spectrum above single charge events: the “low energy excess”

\[ P_t = E_r + N_{eh} eV_b \]
The non-ionizing low energy excess: 0QLEE

Many low background experiments observed a rising spectrum of unknown source at low energy.

SuperCDMS has observed greatly decreased rates of ionizing backgrounds in HVeV detectors and may now be limited by 0QLEE.

Hypothesized to be due to stress events in the substrate and film.

Technique description and sensitivity estimate

Example data analysis: Cs-137 and background data

Summary

\[ P_t = E_r + N_{eh}eV_b \]
Sensitivity projection with 0QLEE subtraction

\[ P_t = E_r + N_{eh} e V_b \]

- As a phonon-mediated detector architecture, HV detectors should also suffer from this low energy excess

0V operation may be used to identify the contribution of the low energy excess \textit{in situ} and subtract it for enhanced charge-producing dark matter sensitivity

\begin{itemize}
  \item \textbf{blue} and \textbf{red} assume 0QLEE can be completely subtracted
\end{itemize}

SuperCDMS Work in Progress
Sensitivity projection with OQLEE subtraction

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- As a phonon-mediated detector architecture, HV detectors should also suffer from this low energy excess

- **0V operation may be used to identify the contribution of the low energy excess *in situ* and subtract it for enhanced charge-producing dark matter sensitivity**

- largest systematic uncertainty on the sensitivity is expected to arise from the yield function, which is extrapolated from the IMPACT yield function

**blue** and **red** assume OQLEE can be completely subtracted

**SuperCDMS Work in Progress**
Recall: HV operation will amplify the phonon response of a particle event via NTL gain

\[ P_t = E_r + N_{eh} eV_b \]
0V operation, Cs-137 source

- $\chi^2$-energy plot shows the various kinds of events that are seen in 0V operation

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\[
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HV operation, Cs-137 source

- $\chi^2$-energy plot shows the various kinds of events that are seen in HV operation

$$P_t = E_r + N_{eh}eV_b$$

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Summary
0V vs HV comparison, Cs-137 source

\[ P_t = E_r + N_{eh} eV_b \]

- $\chi^2$-energy plot after all data quality cuts shows rough consistency between the 0V and HV $\chi^2$-distributions versus energy.

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Summary
0V vs HV comparison, background data

\[ P_t = E_r + N_{eh} eV_b \]

- 0V vs HV background data for one HVeV detector after all data and pulse quality cuts
- Kolmogorov-Smirnov test is applied 5\(\sigma\) above the first eh peak
  - 100V fails the KS test – is the spectra perhaps composed of other ionizing events?

Ideas:
- Could use more statistics; this is 30% of data
- What component of the HV data are well-collected charge producing events?
  - Partition cut may help for identifying bulk events
  - Studying the relative rate of saturated events in 0V vs HV may help to understand the effect of the NTL boost
- Could still consider subtraction of 0QLEE, but would then be background limited by the remaining spectrum

Technique description and sensitivity estimate
Example data analysis: Cs-137 and background data

Summary
Summary & outlook

- HV detectors are sensitive to both ionizing and non-ionizing backgrounds.
- With greatly decreased rates of ionizing backgrounds, SuperCDMS HVeV backgrounds may be dominated by the 0QLEE.
- Subtracting the 0QLEE can lead to enhanced sensitivity.
- May yet be other backgrounds in the HV data in excess of the 0V spectrum → requires further study.

Technique description and sensitivity estimate
Example data analysis: Cs-137 and background data

Summary