Calibrating SuperCDMS Si HVeV Detectors Using Compton Steps for Low Mass Dark Matter Searches

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Introduction

SuperCDMS SNOLAB is focused on searching for the low-mass dark matter candidates having masses ≤ 10 GeV/c^2 [1]. The experiment will be using two types of Ge and Si detectors referred to as HV (High Voltage) and iZIP (interleaved Z-sensitive Ionization and Phonon sensor) detectors.

A precise energy calibration of all detectors in the low energy ($\approx$ keV) range is necessary in order to analyze signals from low mass dark matter interactions. In Ge detectors, we can use the neutron activation lines for energy calibration. However, in Si detectors, we do not have suitable low-energy activation lines. One can use the Si Compton steps (1.8 keV for the K shell, 0.15 keV and 0.1 keV for the L shells) that can be observed in the energy spectrum for calibration. These steps result from the Compton scattering process, below the atomic binding energies of the electron shells [3]. Our work focuses on investigating the Compton steps in the prototype gram-scale SuperCDMS Si HVeV detectors. We will be examining the K shell Compton step at 1.8 keV, where the non-linear detector response becomes significant, necessitating a detailed study of this behavior.

HVeV detector and the data sets

HVeV detectors [2] are gram-scale ($\approx$ 1 g) phonon sensitive detectors with an excellent energy resolution ($\mathcal{O}$(eV)) and up to $\mathcal{O}$(100 keV) scale dynamic range. Energy depositions from particle interactions generate charge carriers and primary phonons. The athermal phonon signal is sensed by the Transition Edge Sensors (TESs) [2] located at the top of the detector. The detectors were operated in Fermilab's NEXUS (Northwestern Experimental Underground Site) facility. Two sets of data were obtained for calibration. In the first set, a ^{137}Cs ($\approx$ 662 keV gamma) source was used to study the Compton steps and in the second set, a Light Emitting Diode (LED) ($\approx$ 2 eV optical photons) source was used to study the non-linearity of the detector response at keV energies and to validate the position of the Compton steps using cross-calibration.

Simulated and experimental spectra

A Geant4 simulation [4] of the detector response was performed with a single HVeV detector. The energy spectrum in our region of interest ($\mathcal{O}$(keV)) as obtained from simulation is shown in Fig. 1 (left). A Cu X-ray peak at 8.1 keV (due to the Cu housing of the detector) and a Si K shell Compton step at 1.8 keV are visible in the spectrum. The detector response to 662 keV gammas from ^{137}Cs was obtained at 0 V bias voltage experimentally. This spectrum is investigated for Compton steps in the $\mathcal{O}$(keV) range and is shown in Fig. 1 (right). We use a pulse-integral based energy-estimator (determines the integral below the pulse in an analysis window of $\approx$13.1 ms) because of its large dynamic range $\mathcal{O}$(100 keV). When the HVeV detectors are operated in HV mode by applying a detector bias of $\mathcal{O}$(100V), they are sensitive to the single charge excitation inside the crystal. The distinct e^-h^+ pair peaks obtained from an LED

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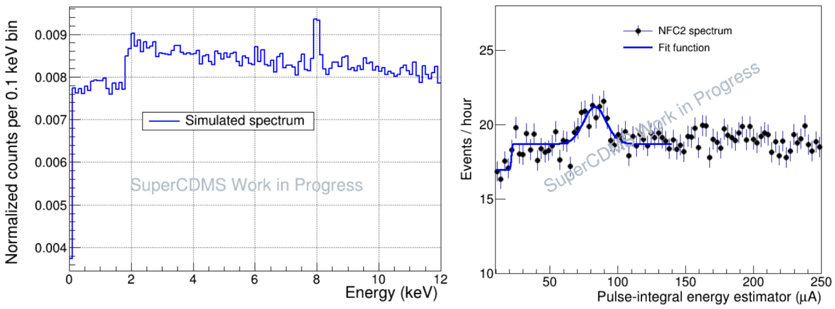

FIG. 1: (left) Simulated detector response to 662 keV gammas featuring Cu X-ray peak and K shell Compton step. (right) Experimental spectrum featuring a peak and a step structure.

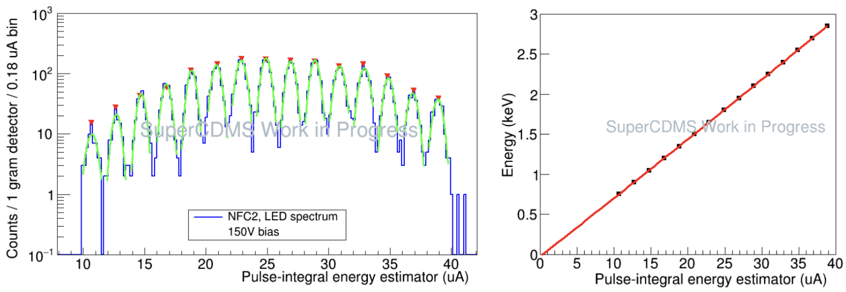

FIG. 2: (left) LED spectrum at 150V bias voltage in Integral based energy estimator. (right) Energy calibration for Integral estimator.

run can be seen in Fig. 2 (left). These e^-h^+ peaks are used for the energy calibration at lower energies (Fig. 2 (right)). The current scale (measured as the first e^-h^+ peak position in the spectrum in the unit of current) between Cs data and the LED data was changed because of the addition of the LED source to the detector payload. In order to match the current scales between the two calibration campaigns, a scan of detector Working Points (WPs) in the transition region is performed while taking LED data, followed by a linear WP correction.

Outlook

Our next goal is to apply the WP correction on the LED calibration to validate the position of the K shell Compton step. The L shell Compton step (≈ 0.1 keV and 0.15 keV) is being analyzed using a pulse amplitude-based energy estimator that provides better energy resolution at the cost of a lower dynamic range. Finally, a combined energy estimator featuring both pulse-integral and pulse-amplitude estimators will be used to study both K shell and L shell Compton steps simultaneously.

References

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