Photo-neutron Calibration of SuperCDMS Detectors

V. Iyer* and on behalf of SuperCDMS collaboration
National Institute of Science Education and Research, HBNI, Jatni - 752050

SuperCDMS Overview

Super Cryogenic Dark Matter Search (SuperCDMS) is a direct dark matter search experiment that makes use of low temperature solid state detectors to search for rare scattering of Weakly Interacting Massive Particles (WIMPs) with atomic nuclei. The now decommissioned SuperCDMS Soudan experiment consisted of 15 germanium detectors arranged in five towers of three detectors each. The total detector mass was about 9 kg, and the operating temperature was about 50 mK. The Soudan underground laboratory has an overburden of 2090 m.w.e. which strongly reduces backgrounds from cosmic rays. SuperCDMS is among the most sensitive experiments in the world in direct detection of WIMP dark matter below 10 Gev/c^2 [1]

Detector Physics

WIMPs elastically scatter off a nucleus causing a nuclear recoil and also generating electron hole pairs during this process. The ratio between the energy used to produce electron hole pairs, E_Q and the total recoil energy, E_R, is called ionization yield, Y=E_Q/E_R. γs and βs scatter primarily off electrons, producing electron recoil (ER) with a $Y\simeq1$ while WIMPs and neutrons scatter primarily off the nuclei, generating nuclear recoil (NR) with a $Y<1$. Part of the energy transferred during the scattering process is released in the form of lattice vibrations called phonons.

An applied bias voltage V, makes the charges drift towards the electrodes. This mechanical work done on the electron-hole pairs by the field is released to the lattice as Neganov-Luke phonons [2], E_{luke}. SuperCDMS detectors measure E_Q and total phonon energy E_P=E_R+E_{luke}= $E_R(1+qVY/\epsilon)$ where q is the charge of an electron and ϵ the average energy to create an electron hole pair. At lower bias voltages ($\leq$4 V), each event will have an equitable balance between Luke phonons and primary phonons. This fact, coupled with sufficient ionization and phonon resolution allows discrimination of ERs and NRs via the measured yield. At higher bias voltages, a lower energy threshold is obtained but the ionization resolution is not sufficient for yield discrimination. The SuperCDMS Soudan detectors were operated in two modes, the interleaved Z-sensitive Ionization and Phonon detectors (iZIP) run at 4 V and the CDMS low ionization threshold experiment (CDMSlite) detectors run at much higher voltages between 25 V and 70 V.

Motivation for calibration

When the ionization yield is not measured, knowledge of the nuclear recoil scale is necessary for establishing the WIMP mass scale. CDMSlite makes use of the Lindhard model to predict its yield. The formalism [3] can be written as follows:

$$Y = \frac{k \cdot g(\varepsilon)}{1 + k \cdot g(\varepsilon)}$$
$$g(\varepsilon) = 3\varepsilon^{0.15} + 0.7\varepsilon^{0.6} + \varepsilon$$
$$\varepsilon = 11.5E_R/Z^{7/3}$$

Here Z is the atomic number of the recoiling nucleus, ε a reduced energy term, E_R is the recoil energy and k describes the electronic energy loss fixed at 0.157 for Ge using the original Lindhard theory.

The model works well at recoil energies greater than 10 keV. As seen in Fig. 1, measurements below 10 keV to date show data points scattered around a Lindhard model for a chosen k. Work from this calibration will provide data as low as $\sim$ 1 keV, an energy regime in which only few data points exists so far.

*Electronic address: vijayiyer@niser.ac.in

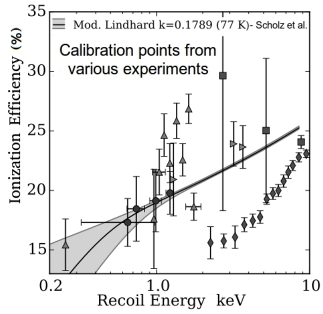

FIG. 1: Ionization yield obtained in germanium at low recoil energies. The black solid line is for k=0.1789 [4]

The motivation for a dedicated calibration of the SuperCDMS detectors comes from the fairly wide uncertainty in the CDMSlite exclusion curve seen in Fig. 2.

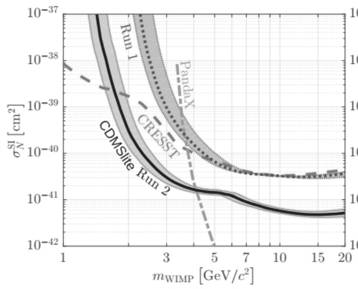

FIG. 2: Exclusion curves from WIMP search data of CDMSlite Run 1 (dotted line and associated uncertainty band) and Run 2 (black solid curve and associated uncertainty band) [1]

Photo-neutron Calibration

The calibration technique here involves using a high rate ^{88}Y or ^{124}Sb gamma source placed next to a Be absorber. Both ^{124}Sb and ^{88}Y emit γs (1.69 MeV and 1.84 MeV respectively) above the threshold for a ^{9}Be(γ,n) reaction, which is around 1.66 MeV. In case of the Sb-Be setup, the maximum spread in the neutron energies in all directions is between 22.8 and 24.1 keV, whereas in case of the Y-Be setup, its between 151 and 159 keV. Since we only detect neutrons emitted in the forward direction and reaching our detectors, the spread in the neutron energies are much lesser than the maximum possible spread. Hence we can consider the neutrons reaching the detectors as quasi-monoenergetic. In case of ^{124}Sb the maximum recoil in Ge is around 1.3 keV and for ^{88}Y around 8.1 keV. By studying the recoils of Ge nucleus from these quasi-monoenergetic neutrons, the response of our detectors can be calibrated.

Analysis

Data was taken in both iZIP and CDMSlite mode. After developing various quality cuts, neutron spectra from our data were analyzed. Since multiple neutron scatters blur the single scatter edge at maximum recoil energy, simulations will be used to identify the single scatter endpoint. With the completion of yield extraction, two more calibration points at 1.3 keV and 8.1 keV can be added to the parameter space shown in Fig 2.

Future Work

This work is important as yields deduced from this measurement will reduce the uncertainty on WIMP spin independent interaction cross section limits obtained with CDMSlite detectors as shown in Fig 1. An improved understanding of our detector response is also crucial while moving forward to the next SuperCDMS run at SNOLAB which will employ more HV (dedicated CDMSlite) detectors in an attempt to probe light dark matter with mass as low as 0.5 GeV/c^2

References

[1] R. Agnese et.al. (SuperCDMS Collaboration), Phys. Rev. Lett. 116, 071301(2016); arXiv:1707.01632

[2] B. Neganov et.al., Otkryt. Izobret. 146, 215 (1985); P. Luke, J. Appl. Phys. 64, 6858(1988)

[3] D. Barker, D.-M. Mei, Astropart. Phys. 38, 1(2012)

[4] B.J. Scholz et. al., Phys. Rev. D94 (2016)