

Background discrimination in new iZIP detectors at SuperCDMS

Silvia Scorza for the SuperCDMS Collaboration

Department of Physics, Southern Methodist University, Dallas, TX 75275-0175

E-mail: sscorza@mail.smu.edu

Abstract. SuperCDMS is a direct dark matter search experiment in the Soudan Underground Laboratory (Minnesota, USA). Cryogenic germanium detectors are used to identify rare nuclear recoils induced by elastic scattering of WIMPs from our Galactic halo. The detectors measure phonon and ionization signals simultaneously, allowing an event-by-event discrimination between the electronic recoils, tracers of electromagnetic background, and nuclear recoils originated by neutrons and WIMPs. To further increase the background discrimination power, novel detectors with a special interleaved electrode scheme have been tested and installed. I will present the background rejection performances achieved, giving the resulting improvement in the sensitivity of the experiment for spin-independent WIMPs interactions.

1. Introduction

First indications for the existence of dark matter were already found in the 1930s [1]. By now there is strong evidence [2] to believe that a large fraction (more than 80%) of all matter in the Universe is dark (interacts very weakly with electromagnetic radiation, if at all - no photon coupling) and that this dark matter is predominantly non-baryonic. Weakly Interacting Massive Particles (WIMPs) are one of the leading candidates for dark matter. WIMPs are stable particles which arise in several extensions of the Standard Model of electroweak interactions [3]. Typically they are presumed to have masses between few tens and few hundreds of GeV/c^2 and a scattering cross section with a nucleon below 10^{-6} pb .

The SuperCDMS experiment (Cryogenic Dark Matter Search), situated in the Underground Laboratory in the Soudan Mine (Minnesota), is dedicated to the direct detection of WIMPs. The direct detection principle consists in the measurement of the energy released by nuclear recoils produced in an ordinary matter target by the elastic collision of a WIMP from the Galactic halo. The main challenge is the expected extremely low event rate ($< 1 \text{ evt/kg/year}$) due to the very small interaction cross section of WIMPs with ordinary matter. Another constraint is the relatively small deposited energy ($< 100 \text{ keV}$). In order to measure low energy recoils, SuperCDMS employs cryogenic detectors (high purity Ge crystal) with simultaneous measurements of phonon and ionization signal. The ionization signal, corresponding to the collection on electrodes of electron-hole pairs created by the energy loss process, depends on the particle type whereas the phonon signal reflects the total energy deposit.

SuperCDMS aims to reach a sensitivity in the WIMP-nucleus interaction detection better than 0.003 counts/kg·d for recoil energy above 10 keV. To reach this goal, background rejection and discrimination are necessary. SuperCDMS backgrounds includes gamma particles, beta

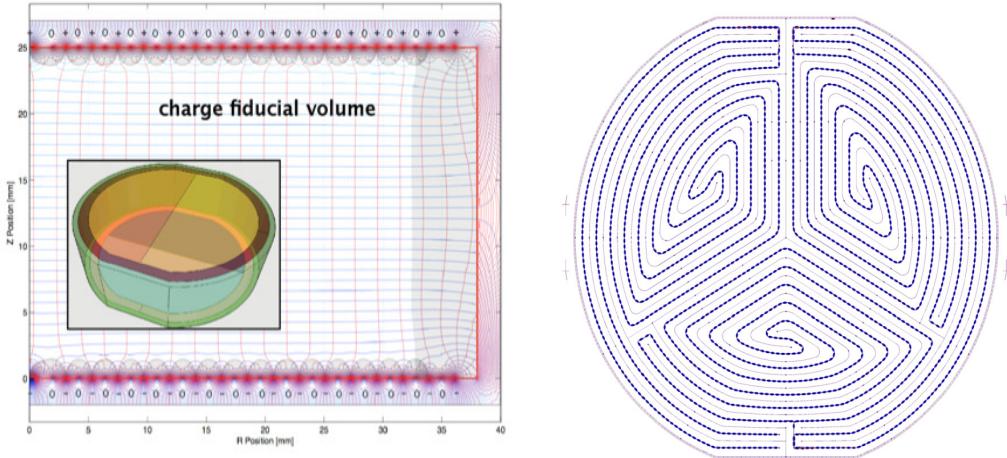


Figure 1. Left panel: Finite Element Model (FEM) calculation (azimuth symmetry axis at $R=0$) of electric field lines and equipotential surfaces for the case of +2 V (-2 V) applied to top (bottom) electrodes of Ge 1-inch thick iZIP. The charge fiducial volume (non-shadowed area) is defined by the inner charge electrodes. Inset: A schematic of new iZIP phonon channels geometry which has two inner phonon channels and one outer phonon channel on each surface. Right panel: The top side layout interleaved charge and phonon mask design where the outer two charge (phonon) rings form the charge (phonon) guard ring.

particles and neutrons from cosmic rays and natural radioactivity. Thanks to simultaneous measurements of charge and phonon signals iZIP detectors can discriminate gammas from WIMPs at high efficiency, because WIMPs interact with nuclei and gammas with electrons.

The main limiting background of the experiment comes from interactions occurring just underneath the collecting electrodes: essentially low energy β -rays due to ^{210}Pb contamination of the detector surface and/or in the vicinity of the detectors. The incomplete charge collection of these events can mimic nuclear recoils.

2. iZIP detector design

The iZIP detector consists of a 3-inch diameter x 1-inch thick Ge substrate ($7.6 \times 10^{10} \text{ cm}^{-3}$ purity). The electron-hole pairs collection is provided by four charge channels (inner and outer on both sides). The phonon measurement is provided by eight photolithographically channels. There are four channels on each side of the detector: three inner phonon channels and one outer phonon ring channel for a better radius determination. The bottom channels are rotated 60 degrees from the top channels. The high impedance charge signal electrodes are interleaved with low impedance phonon sensors on both sides (right panel of Fig. 1)[4]. The electrode formed by the phonon sensors is at ground and not instrumented for ionization.

With the iZIP detector technology, surface events are tagged by the presence of charge on only one side charge electrode of the detector. For events occurring in the bulk of the crystal, the iZIP measures the number of electrons that travel across the detector (left panel of Fig. 1) to one charge electrode while at the same time measuring the number of holes traveling in the other direction to the electrode on the opposite side of the crystal. The two charge signals are therefore symmetric.

3. Background Power Rejection

The results here shown have been obtained exposing an iZIP detector to an internal ^{109}Cd (~ 100 Hz) source, and external ^{252}Cf neutron and ^{133}Ba gamma sources at a surface detector test facility.

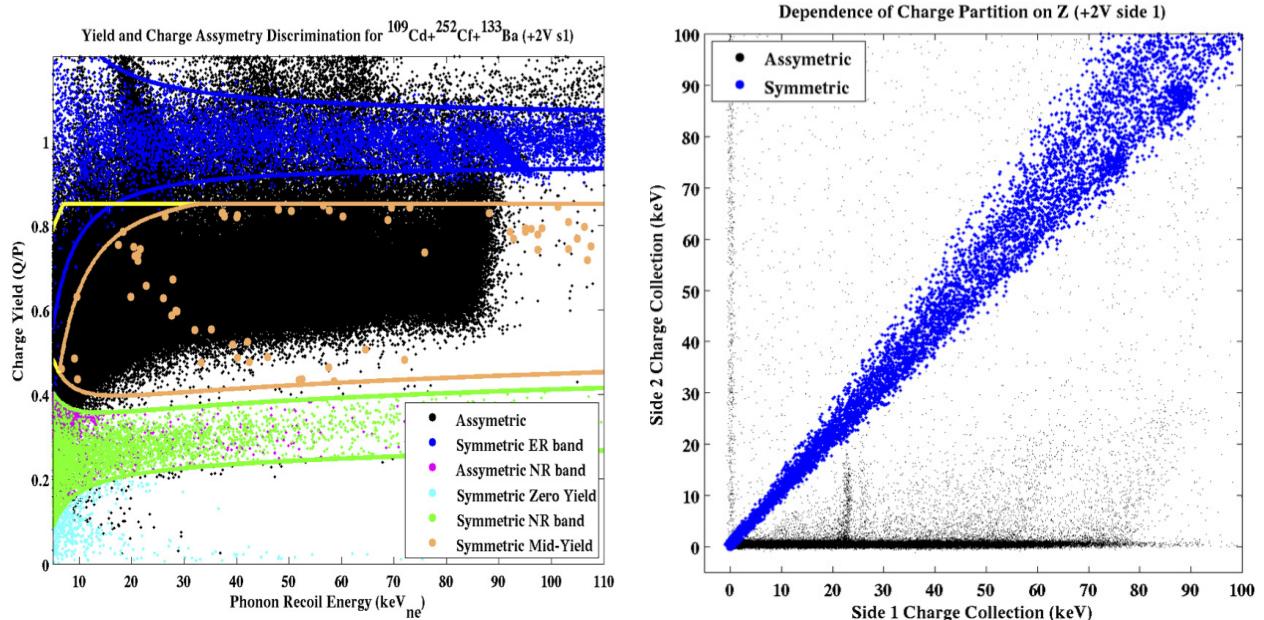


Figure 2. Left panel: Projection in the (Y, E) plane of the events recorded during neutron and gamma calibrations. The thick lines represent the 90% nuclear (in green) and electronic (in blue) recoil zones. Light orange lines represent the mid-yield region where inelastic neutron scatters have been recorded. Black events are excluded by the symmetric cut. They represent β -rays due to ^{109}Cd source. Right panel: Charge signals on the source side electrode (x axis) versus opposite side electrode (y axis). Source side electrode at +2V (collects electrons) is shown. Events which pass the symmetric charge cut are in blue.

Left panel of Fig. 2 shows the ionization yield (ratio of ionization signal to phonon signal normalized to electron recoil events from the gamma source) as a function energy of events recorded for calibration performed with neutron and gamma sources. Surface samples are contaminated with cosmogenic neutron in the nuclear recoil band (~ 7 evt/h). The electron signal from a Ba calibration run can be found in the right panel of Fig. 2. It shows the ability to reject surface events from bulk ones just performing a cut based on charge signal: “symmetric cut” means that the charge signal is equally shared on both sides of the detector. Three separate populations: bulk electron recoil, bulk nuclear recoil (taking advantage of different yield value between electronic and nuclear recoil) and surface electron recoil were defined using the the charge symmetric cut.

Direct discrimination studies on surface events which have leaked into the nuclear recoil are disturbed by the high neutron background due to cosmogenic. However, we found that low yield surface events could be rejected with a misidentification rate of $< 1 \times 10^{-4}$ (90% C.L.) by the symmetric charge cut.

As with the standard CDMS detectors described in detail in [5], the phonon measurement provides z-position information for each event via the timing difference between rising edges of the phonon pulses. Phonon timing rejection capabilities of the iZIP detector have been tested

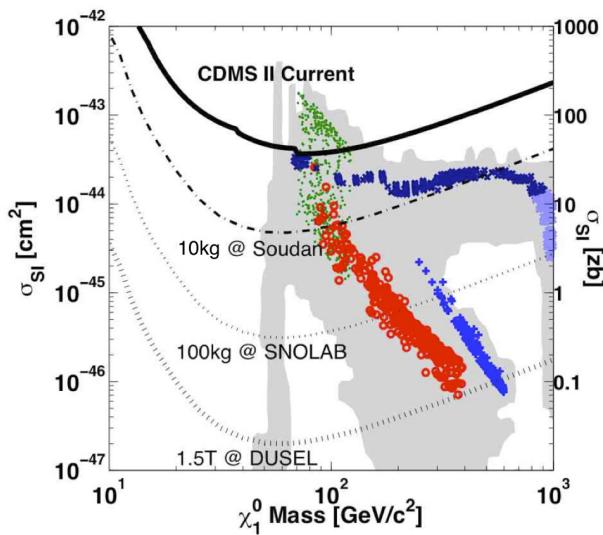


Figure 3. Limits on the cross-section for spin-independent scattering of WIMPs on nucleons as a function of WIMP mass from CDMS published data and SuperCDMS perspectives.

and demonstrated to be preserved from the standard ZIP detector [6].

Finally, by combining charge symmetry yield and phonon timing rejection, the iZIP design easily meets the discrimination requirements for the next stage of SuperCDMS experiment (expected sensitivity shown in Fig. 3).

4. Conclusion and Perspectives

The result shown at surface test facility demonstrate the very high rejection capabilities of these robust detectors due to the improved electrode scheme for charge signal and the new layout phonon sensors. Provided the surface event rejection is efficient enough (by both charge and phonon signal cuts), the combination of fiducial mass to be installed and neutron screening/rejection should enable to reach sensitivities at the level \sim few 10^{44}cm^2 in the next year (see Fig.3).

References

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