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Status and Results from the Cryogenic Dark Matter Search (CDMS)

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Abstract. The Cryogenic Dark Matter Search (CDMS) experiment utilizes novel cryogenic particle detectors for a direct search of dark matter particles in the form of WIMPs in our galaxy. The detectors are able to discriminate between nuclear and electron recoils through the simultaneous measurement of ionization and phonons. We report on the latest results from several kg-day exposure of Ge and Si detectors. Despite exposure times that are 100 times smaller than previous experiments, our sensitivity is comparable to the currently reported dark matter limits.

1. Introduction

A significant effort has been expended in the past few years by the CDMS collaboration to develop cryogenic detectors sensitive to few keV energy depositions expected for the direct interaction of WIMP particles. Event rates are expected to be as low as 0.001 events/(kg day), or even lower, for some SUSY WIMP scenarios[1]. As a result, the detectors for this task must have good energy sensitivity and low internal radioactivity in addition to active background rejection capabilities. In typical low background experiments, the background rates are dominated by alpha, beta, and gamma emissions from nearby radionuclide contaminants or from cosmogenic sources. All of these backgrounds produce electron recoils. In contrast, WIMPs, and neutrons predominantly scatter off nuclei.

In mid–1996 CDMS began running its first detectors at SUF. An overview of the CDMS experiment and a summary of previous results can be found in [2] and references therein.

2. Description of Experiment

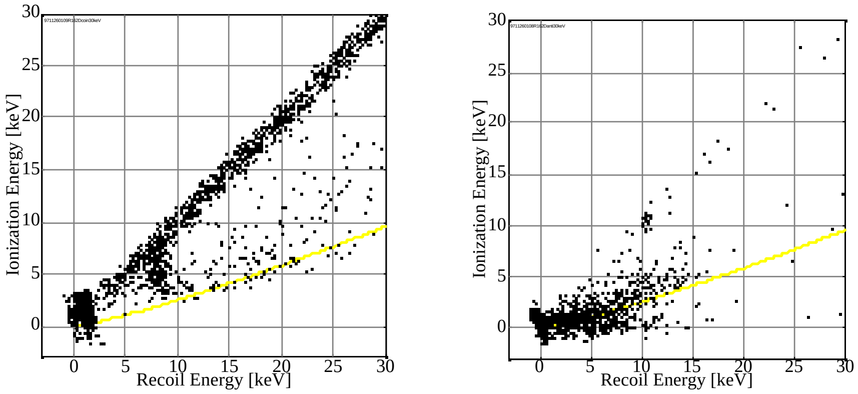
The experiment is located at the Stanford Underground Facility (SUF) which sits 10.6 meters below ground. Because of the muon flux at this relatively shallow depth an active muon veto surround the detectors, as well as Pb and polyethylene passive shielding. The detectors are operated at a temperature of 20 mK in a set of concentric copper cans at the end of a dog-leg extension connected to an Oxford 400 dilution refrigerator [3].

The CDMS detectors consist of ultra-pure crystals of Ge and Si. When a particle interacts within a crystal, the energy of the recoiling nucleus or electron appears in the form of phonons and electron-hole pairs. The simultaneous measurement of both of these quantities for each event in the crystals allows the discrimination of nuclear recoil events (signal) from electron recoils (background)[4]. For a given deposited energy, measured by the phonon signal, less ionization is generated by events recoiling off nuclei than off electrons. The charge measurement is made by applying a small electric field (~1 $\mathrm{Vcm^{-1}}$) across the crystal and measuring the charge which drifts across the detector.

Two techniques are used by CDMS to measure the phonon energy. The first type, known as BLIPs (Berkeley Large Ionization and Phonon-based detectors) [5], utilize neutron transmutation doped Ge thermistors (NTD) eutectically bonded to 165 g Ge crystals. The second type, known as FLIPs (Fast Large Ionization and Phonon-based detectors) [6], utilize W/Al QETs (Quasiparticle trapping assisted Electrothermal feedback Transition edge sensors). This type of sensor covers large areas of 100 g Si or 250 g Ge crystals with Al phonon collector pads. The quasiparticles generated, when phonons are absorbed in the Al, are trapped into a parallel array of W resistive meanders. The release of energy causes an increase in W resistance which is observed as a current pulse with a high speed SQUID array [7]. Because of the speed/segmentation of this type of sensor, X-Y imaging of the initial event location to within a few millimeters is possible.

3. Gamma, Neutron Calibration and Low Background Results

As discussed in the previous section gamma/nuclear recoil discrimination in the detectors is achieved by measuring the ratio of the charge and phonon signals for each event. The detectors run at SUF have shown ~99% gamma background rejection (using an external ^{60}Co photon source) in the range 15–45 keV recoil energy for BLIP [5,8] and 30–100 keV for FLIP [2]. The detector response for nuclear recoils is measured using a ^{252}Cf neutron source. Improvements in the BLIP phonon trigger now lowers the discrimination threshold to ~5 keV recoil. In addition, the FLIP phonon collector geometry has now been improved giving a factor of 10 gain in signal size [6], giving comparable performance to that of BLIPs.



(a) (b)

Figure 1. Plots of recoil energy versus ionisation energy for 0.78 kg–days of exposure of a 165 g BLIP at SUF. (a) shows events coincident, and (b) anticoincident, with the muon veto. The line shows the expected region for nuclear recoil events.

Figure 1 shows recoil energy versus ionisation energy for events in BLIP during part of a background run at SUF. Figure 1(a) shows events coincident with the muon veto. The main diagonal band are gamma events in the BLIP. There appear to be a large number of nuclear recoil–like events lying close to the grey line. (Compare also Fig. 1(b) of [8] for a neutron source calibration). These off-axis events arise from the interaction of electrons, ejected from surrounding material by muons, with the surface of the Ge detector. The low energy electrons land in an ionization dead layer at the surface of the Ge detector. This layer has been estimated to be between 10–30 µm [9]. Figure 1(b) shows the same plot for muon anticoincident events. The cosmogenic activation of the Ge can be seen as an event distribution just above 10 keV in both channels. The population of events lying along the nuclear recoil line below 20 keV recoil is due to ~10^6 atoms of tritium on the surface of the detector. The smaller number of events (~10 per live day in the range 20–100 keV) at higher energies close to the line could be due to electrons emitted from surface contamination such as ^{40}K from accidental sweat contamination, ^{137}Cs, ^{14}C, and ^{210}Pb from Rn plating.

Low background energy spectra for a 165 g Ge BLIP (left) and 100 g Si FLIP (right) are shown in Fig. 2. The local gamma background (anti-coincident with the muon veto) in BLIP is 3 events/(keV kg day) (20–50 keV). The bottom line in both plots shows the events that occur in the nuclear recoil window of acceptance. In BLIP these events are due to the poor charge collection associated with the surface electron background. In FLIP the events appear consistent with misidentified gammas (as estimated from the gamma calibration), and a possible unvetoed neutron signal (~0.5 events). This will be studied further, with higher statistics and lower thresholds, in future Si FLIP runs. The installation of a larger number of detectors will also permit the unambiguous identification of neutrons due to the observation of their multiple scattering.

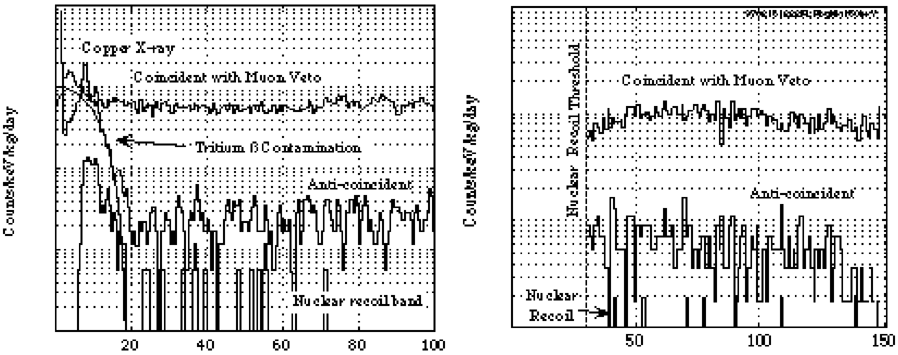


Figure 2. Background recoil energy spectra for 1.74 kg–days of a 165 g Ge BLIP (left) and 0.52 kg-days of 100 g Si FLIP (right). In both cases the upper line is the rate of events coincident with the muon veto. The middle line is the rate anti-coincident with the veto. The lowest line is the event rate in the nuclear recoil band.

4. Conclusions & Current Dark Matter Limits

The data from the first four runs of BLIP and FLIP detectors at SUF have been encouraging.

However, the Ge BLIP detector has shown that electron recoils very near its surface lead to events of lower charge yield than the same events deeper inside the crystal. This causes a decreased effectiveness in the rejection of beta backgrounds. In the next few runs we intend to directly address this contamination. Firstly, by further cleaning steps of the BLIP surfaces just prior mounting the detectors. Secondly, using an active shielding strategy involving mounting the detectors more closely together. We will also continue to look at ways of eliminating the ionization dead layer [9].

Recent improvements in FLIP technology have increased the phonon sensitivity by a factor of 10, over that shown in Fig. 2, giving energy thresholds of ~keV. The next low background run will include a 100 g Si FLIP of this new type. In addition, we are currently fabricating 250 g Ge FLIP devices. We plan to be running 1 kg of both BLIPs and FLIPs at SUF by Fall 1998.

Figure 3 shows our current results on dark matter limits (for Si FLIP and Ge BLIP targets). They are comparable to previous Ge ionization results [10] and NaI [11] which were obtained after much longer exposure times. The region of possible WIMP cross sections predicted using Minimal Supersymmetry Models (MSSM) is shown. Also shown are lines representing the calculated sensitivities for 100 kg–days Ge target exposure in the CDMS I (Stanford) and 5000 kg–days in CDMS II (Soudan) experiments.

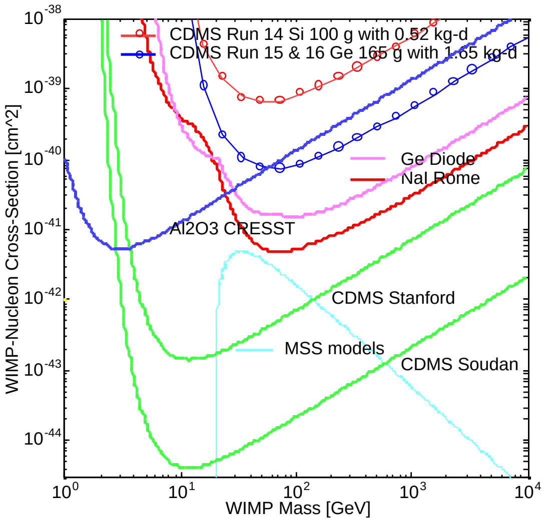


Figure 3. WIMP exclusion plot for scaler WIMP–nucleon cross–section versus WIMP mass. The experiments exclude the regions above the lines (see text for details). The present CDMS limits are shown as lines with circles. The lines marked CRESST, CDMS Stanford and CDMS Soudan are projected sensitivities for those experiments.

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References

Further information and CDMS preprints of many of the references below can be obtained at **http://cfpa.berkeley.edu**

[1] Jungman G *et al.* 1996 *Phys. Rept.* 267 195-373
[2] Barnes P *et al.* 1996 *Nucl. Instrum. Methods* **A 370** 233; S. W. Nam *et al.* 1997 *Proceedings of the 7th International Workshop on Low Temperature Detectors* (Munich, Max Planck Institute of Physics) (LTD7) 217
[3] Taylor J D *et al.* 1996 *Advances in Cryogenic Engineering* **41** 1971
[4] Shutt T *et al.* 1992 *Phys. Rev. Lett.* **69** 3531
[5] Gaitskell R J *et al.* LTD7 *ibid.* 221; Shutt *et al.* 1992 *Phys. Rev. Lett.* **69** 3425
[6] Clarke R M *et al.* LTD7 *ibid.* 229; Davies A K et al. LTD7 *ibid.* 227
[7] Nam S *et al.* 1996 *Nucl. Instrum. Methods* **A 370** 187
[8] R. J. Gaitskell *et al.*, 1996 *Proceedings of the First International Workshop on The Identification of Dark Matter* (London, World Scientific)
[9] Shutt T LTD7 *ibid.* 224
[10] Beck M *et al.* 1994 *Phys. Lett.* **B 336** 141
[11] Bernabei R et al. 1996 *Phys. Lett.* **B 389** 757