Present Results and Future Goals of the Cryogenic Dark Matter Search

T.A. Perera[*], D. Abrams[†], D.S. Akerib[*], D.A. Bauer[**], A. Bolozdynya[*], P.L. Brink[†], R. Bunker[**], B. Cabrera[†], D.O. Caldwell[**], J.P. Castle[†], C. Chang[†], R.M. Clarke[†], M.B. Crisler[‡], R. Dixon[‡], D. Driscoll[*], S. Eichblatt[‡], R.J. Gaitskell[§], S.R. Golwala[¶], E.E. Haller[||], J. Hellmig[¶], D. Holmgren[‡], M.E. Huber[††], S. Kamat[*], C. Maloney[¶], V. Mandic[¶], J.M. Martinis[‡‡], P. Meunier[¶], S.W. Nam[‡‡], H. Nelson[**], M.C. Perillo Isaac[¶], R.R. Ross[¶], T. Saab[†], B. Sadoulet[¶], J. Sander[**], R.W. Schnee[*], T. Shutt[§§], A. Smith[||], A.H. Sonnenschein[**], A.L. Spadafora[¶], G. Wang[*], S. Yellin[**] and B.A. Young[¶¶]

[*]*Department of Physics, Case Western Reserve University, Cleveland, OH 44106, USA*
[†]*Department of Physics, Stanford University, Stanford, CA 94305, USA*
[**]*Department of Physics, University of California, Santa Barbara, Santa Barbara, CA 93106, USA*
[‡]*Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
[§]*Department of Physics and Astronomy, University College of London, Gower Street, London WC1E 6BT, UK*
[¶]*Center for Particle Astrophysics, University of California, Berkeley, Berkeley, CA 94720, USA*
[||]*Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[††]*Department of Physics, University of Colorado, Denver, CO 80217, USA*
[‡‡]*National Institute of Standards and Technology, Boulder, CO 80303, USA*
[§§]*Department of Physics, Princeton University, Princeton, NJ 08544, USA*
[¶¶]*Department of Physics, Santa Clara University, Santa Clara, CA 95053, USA*

Abstract.
The Cryogenic Dark Matter Search (CDMS) uses Ge and Si detectors to search for Weakly Interacting Massive Particles (WIMPs) via their elastic-scattering interaction with atomic nuclei. The present results from CDMS give limits on the spin-independent WIMP-nucleon elastic-scattering cross section that exclude previously unexplored parameter space above 10 GeV/c^2. The second phase of the CDMS experiment, scheduled to start in January 2002, is expected to improve on the present sensitivity by more than two orders of magnitude.

INTRODUCTION

Weakly Interacting Massive Particles (WIMPs) are ideal candidates for nonbaryonic cold dark matter in the galactic halo [1]. The Cryogenic Dark Matter Search (CDMS) is designed for direct detection of WIMPs via their elastic-scattering interaction with atomic nuclei. The expected spectrum of nuclear-recoil energies is a falling exponential, with mean energies ranging from a few to tens of keV. The expected event rate is lower than 1 per kg day.

Due to the low event rate, effective shielding of photon, electron, and neutron backgrounds is essential. The CDMS I experiment is located in the Stanford Underground Facility at a depth of 10.6 m. In addition to the reduction in cosmic-ray-induced backgrounds at this depth, photon and neutron backgrounds are further reduced by layers of lead and polyethylene respectively. Scintillator paddles surrounding the lead are used to identify and veto events caused by muon interactions within the shield. The detectors are operated at temperatures close to 20 mK using a Kelvinox 400 dilution refrigerator. For the purpose of reducing radioactive backgrounds, the detectors are housed in a separate cryostat, made from radio-pure copper, thermally anchored to the refrigerator.

CDMS detectors are disk-shaped Ge and Si crystals with typical diameters of 6-8 cm and thicknesses of $\sim$1 cm. Phonons and charge carriers resulting from particle interactions are measured separately. The phonon and charge signals can be used to reconstruct the recoil energy from the interaction. The amount of ionization per unit recoil energy is referred to as the ionization yield. The ionization yield for electron recoils is about a factor of three higher than the ionization yield for nuclear recoils. Therefore, WIMPs and neutrons, which scatter off nuclei, are clearly separated in ionization yield from photons and electrons, which comprise the majority of backgrounds (see Figure 1a for example). At present, photons and surface electrons are rejected with efficiencies $>$99% and $>$95% respectively [2, 3].

Two types of detector technology have been used in CDMS. They differ in the phonon-measurement technique. Berkeley Large Ionization and Phonon (BLIP) detectors measure thermal phonons through Ge-NTD thermistors mounted on the detectors [2]. Z-sensitive Ionization and Phonon (ZIP) detectors, which use QETs, are sensitive to athermal phonons [4, 5]. The ionization signal is measured by drifting the electron-hole pairs in an electric field. The electrodes are radially segmented in two to distinguish between inner and outer scatters within a detector.

RESULTS FROM RECENT DATA RUNS

The present CDMS results are due mainly to the outcome of a 1999 data run using a stack of four Ge BLIP detectors [2, 6]. Data from the top detector in the stack are excluded due to electron contamination on its surfaces. Events with ionization signal in the outer electrodes are also excluded due to ambient electron backgrounds and poor ionization yield in the outer electrodes. Several data-quality cuts are used to remove pileup events and periods with high electronics noise.

Figure 1a shows the ionization yield vs. recoil energy for veto-anticoincident events in the three uncontaminated detectors. Only events with scatters in one detector are shown. Once all the cut efficiencies are accounted for, this data set corresponds to 10.6 kg days. The circled points represent 13 single-scatter nuclear recoils identified in the data. Figure 1b shows ionization yield in each detector for veto-anticoincident double-scatters. The four circled points are tagged as nuclear recoils in both detectors.

The four multiple-scatter nuclear recoils indicate the presence of a neutron background since the WIMP multiple-scatter probability is vanishingly small. Four veto-anticoincident nuclear-recoil candidates were also observed in a 1.5 kg day data set from

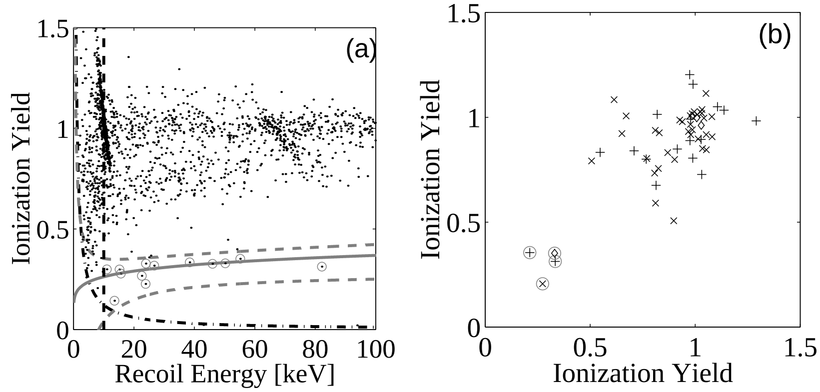

FIGURE 1. (**a**) Ionization yield vs. recoil energy for veto-anticoincident single scatters contained in the inner electrodes of the 3 uncontaminated Ge detectors. Thirteen events (*circled*) lie within the nominal 90% nuclear-recoil acceptance region (*dashed curves*), above both the 10 keV analysis threshold (*dashed line*) and the threshold for separation of ionization signal from amplifier noise (*dot-dashed curve*). The expected position of nuclear recoils (*solid curve*) is also shown. (**b**) Scatter plot of ionization yields for multiple scatters in the top/middle (*crosses*), middle/bottom ($\times's$), or top/bottom (*diamonds*) detectors. Four events (*circled*) are tagged as nuclear recoils in both detectors.

a Si ZIP detector [4]. Since the WIMP scattering cross section in Si is almost an order of magnitude lower than in Ge, while the neutron scattering cross section is similar, these events are also indicative of a neutron background.

Based on the multiple scatters and the Si events, the neutron contribution to the Ge-single-scatter rate can be estimated using a neutron Monte Carlo simulation. The dominant veto-anticoincident neutron background arises from muon interactions in the surrounding rock. Simulations of neutrons from high-energy muon interactions yield neutron detection rates and recoil-energy spectra similar to the observed ones. However, the absolute rate of events predicted by the Monte Carlo is not used due to the uncertainty in the neutron production rate. Only the multiples/singles and Ge/Si ratios from the Monte Carlo are used. These ratios indicate that all 13 single-scatter nuclear recoils are consistent with being neutrons. The reliability of the Monte Carlo has been checked using a neutron-source calibration and the veto-coincident neutron background.

The full statistical analysis includes the neutron rate as a free parameter which is conservatively projected out in making the exclusion plot of Figure 2. CDMS I data exclude new parameter space for the spin-independent WIMP-nucleon cross section above 10 GeV/c^2 at a 90% CL. Every point in the 3σ region from the DAMA-annual-modulation experiment is excluded at $>$75% CL.

CDMS II

The second phase of the CDMS experiment is scheduled to commence in January 2002 in the Soudan mine in nothern Minesota. The Soudan mine is located at a depth of 713 m ($\sim$2000 m.w.e.). The large reduction in cosmic-ray muons at this depth is expected to improve the present dark-matter sensitivity by two orders of magnitude. The newer

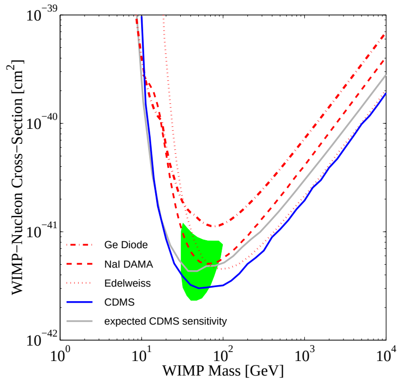

FIGURE 2. 90% CL upper limits on the spin-independent WIMP-nucleon cross section from CDMS (*solid*), Ge diode experiments (*dash-dotted*) [7, 8], DAMA pulse-shape analysis [9] (*dashed*), and Edelweiss [10] (*dotted*) . Because the observed number of multiple scatters is larger than expected, the limit from this analysis is lower than the CDMS expected (median) sensitivity (*light curve*). Also shown is the DAMA 3σ allowed (*shaded*) region [11].

ZIP technology will be used in CDMS II detectors [12, 13]. The position information available from ZIP detectors [14, 5] will be useful in further improving the rejection of surface electrons.

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