Results from the 1998-1999 Runs of the Cryogenic Dark Matter Search

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The Cryogenic Dark Matter Search (CDMS) uses low-temperature Ge and Si detectors to search for Weakly Interacting Massive Particles (WIMPs) via their elastic-scattering interaction with atomic nuclei while discriminating against interactions of background particles. CDMS data from 1998 and 1999 with a relaxed fiducial-volume cut (resulting in 15.8 kg-days exposure on Ge) are consistent with an earlier analysis with a more restrictive fiducial-volume cut. Twenty-three WIMP candidate events are observed, but these events are consistent with a background from neutrons. Resulting limits on the spin-independent WIMP-nucleon elastic-scattering cross-section are lower than those of any other experiment for WIMPs with masses between 10–70 GeV c^{-2}. Under the assumptions of standard WIMP interactions and a standard halo, the results are incompatible with the annual-modulation signal of DAMA at 99.99% CL in the asymptotic limit.

1. The CDMS Experiment

The Cryogenic Dark Matter Search (CDMS) is an experiment to search for Weakly Interacting Massive Particles (WIMPs), an excellent candidate for the universe's nonbaryonic, cold dark matter [1–6]. CDMS detectors discriminate between WIMP-induced nuclear recoils and electron recoils caused by interactions of background particles [7]. The ionization yield Y (the ratio of ionization production to recoil energy of a particle interaction) is much smaller for nuclear recoils than for electron recoils, particularly for electron recoils away from the detector's surfaces. The disk-shaped CDMS BLIP [7] and ZIP [8] detectors each measure phonons and charge carriers separately to determine the recoil energy and ionization yield for each event. The drift field for the ionization measurement is supplied by an annular outer electrode and a disk-shaped inner electrode that define an inner fiducial region that is shielded from low-energy electron sources.

The low expected rate of WIMP interactions necessitates operation of the detectors underground in a shielded, low-background environment [9]. A nearly hermetic, 99.9% efficient plastic-scintillator veto is used to identify and reject events due to muon-induced particles, most noteably neutrons capable of producing the keV nuclear recoils that would mimic WIMP signals. However, relatively rare, high-energy neutrons produced outside the veto may "punch through" the shielding and yield secondary neutrons that produce keV nuclear recoils. The flux of these neutrons is measured by counting the number of nuclear-recoil events that multiple-scatter in two or more detectors, and by measuring the rate of nuclear-recoil events in Si detectors, since WIMPs neither interact much in Si nor multiple-scatter.

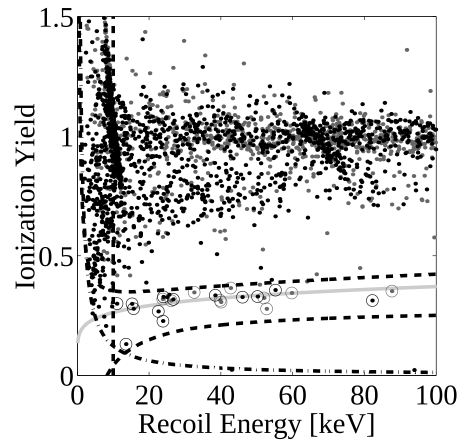

Figure 1. Ionization yield (Y) vs. recoil energy for unvetoed single scatters in the 3 Ge detectors. Solid curve: expected position of nuclear recoils. Dashed curves: mean nominal 90% nuclear-recoil acceptance region. Dashed line: 10 keV analysis threshold. Dot-dashed curve: mean threshold for separation of ionization signal from amplifier noise. Circled points: nuclear recoils.

2. Results from the New Analysis

We have recently completed a new, detailed analysis [10] of two data runs described previously [11]. Between 1998 and 1999, 99.4 livedays of low-background data were obtained using 3 165 g Ge BLIP detectors. Data-quality, nuclear-recoil acceptance, and veto-anticoincidence cuts reduce the exposure by 45%. The original analysis included only events fully contained in the inner electrodes. The less restrictive cut for the current analysis includes events with any energy in the inner electrodes. This cut results in a $\sim$40% larger final Ge exposure of 15.8 kg d [10].

As shown in Fig. 1, 23 unvetoed single-scatter nuclear-recoil candidates are observed between 10–100 keV. Four Ge multiple-scatter nuclear-recoil candidates are also observed (Fig. 2). These multiple-scatter events are almost certainly neutrons, since the WIMP multiple-scatter rate and the misidentified electron-recoil multiple-scatter rate are both negligible.

An earlier run [12], consisting of 1.5 kg d exposure of an early-design 100 g Si ZIP detector in 1998, probably also measures the neutron background. Four nuclear-recoil candidates are observed. These events cannot be due to WIMPs. WIMPs yielding the observed Si nuclear-recoil rate would cause many more nuclear recoils in the Ge data than are observed. An electron calibration suggests that the number of misidentified surface events is small. However, because this calibration used a collimated source and was taken under different conditions than the low-background data, the 90% CL upper limit on the expected number of misidentified surface events including systematic uncertainties is 7.3 events.

Normalizing a neutron Monte Carlo simulation by the 27 total Ge nuclear-recoil events yields a prediction of about 4.6 Si recoils and 2 Ge multiple scatters, in good agreement with observations. To calculate the excluded region for the WIMP mass M and WIMP-nucleon cross section σ, we include conservative estimates of systematic

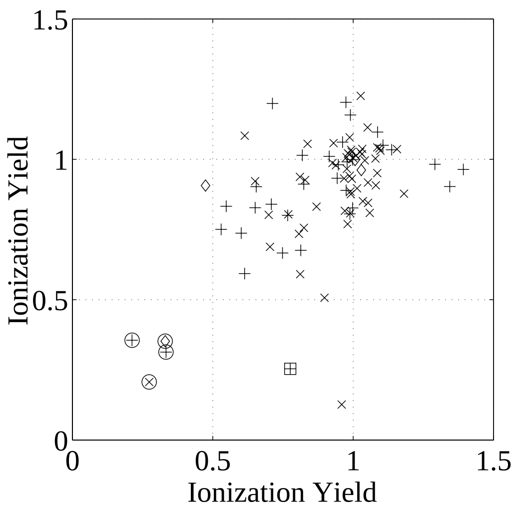

Figure 2. Scatter plot of ionization yields for veto-anticoincident double-scatters in the top and middle (+), top and bottom (◇), or middle and bottom (×) Ge detectors. Circled (boxed) events are tagged as a nuclear recoil in each (one) detector. Both events with ionization yield $Y < 0.45$ in only one of the two detectors hit have the low-yield hit in the outer electrode, consistent with expectations for misidentification of electron recoils in the outer electrode.

errors on the fraction of neutrons that multiple scatter, and on the number of the Si neutron candidates that may be misidentified electon-recoil background events.

Figure 3 displays the resulting upper limits on the spin-independent WIMP-nucleon cross section. These limits are lower than those of any other experiment for WIMPs with 10 GeV $\mathrm{c}^{-2} <$ $M < 70$ GeV c^{-2}. According to the calculations presented in [6,18], these limits do not appear to exclude any parameter space consistent with the minimal supersymmetric standard model, allowed by accelerator constraints, and yielding dominant WIMP dark matter.

At 90% CL, these data do not exclude the complete parameter space reported as allowed at 3σ

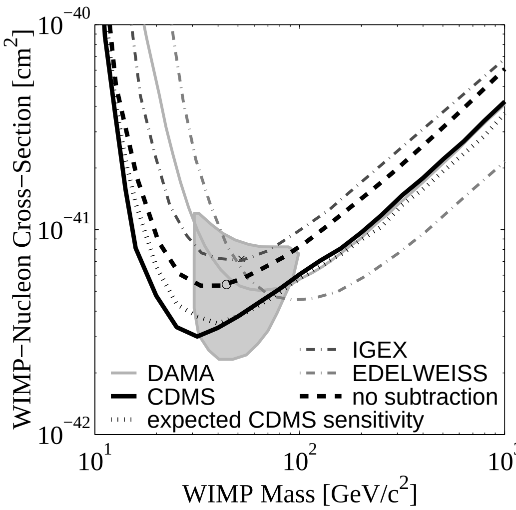

Figure 3. Spin-independent σ vs. M. The regions above the curves are excluded at 90% CL. CDMS limits (solid dark curve) are the most sensitive upper limits for WIMPs with masses in the range 10–70 GeV c^{-2}. Limits calculated ignoring all knowledge about the neutron background (dashed curve) would still be the most sensitive upper limits of any experiment for WIMPs with masses between 10–45 GeV c^{-2}. The dotted curve indicates the predicted CDMS sensitivity given expected backgrounds of 27 neutron events in Ge and 7.2 electrons and 4.6 neutrons in Si. Solid light curve: DAMA limit using pulse-shape analysis [13]. The most likely value for the WIMP signal from the annual-modulation measurement reported by the DAMA collaboration [14], calculated including (not including) the DAMA limit using pulse-shape analysis, is shown as a circle (as an x). The DAMA 3σ allowed region not including the DAMA limit [14] is shaded. Above 70 GeV c^{-2}, the EDELWEISS experiment [15] provides the most sensitive limits (light dot-dashed curve). Limits from the IGEX experiment [16] are shown as a dark dot-dashed curve. All curves are normalized following [17], using the Helm spin-independent form-factor, A^2 scaling, WIMP characteristic velocity $v_0 = 220$ km s^{-1}, mean Earth velocity $v_E = 232$ km s^{-1}, and $\rho = 0.3$ GeV c^{-2} cm^{-3}.

by the annual-modulation measurement of the DAMA collaboration. However, compatibility between the annual modulation signal of DAMA and the absence of a significant signal in CDMS (or in another experiment) is best determined by a goodness-of-fit test, not by comparing overlap regions of allowed parameter space. Under the assumptions of standard WIMP interactions and halo, and under the approximation that statistics are large, a likelihood-ratio test indicates the annual-modulation signal of DAMA (as shown in Fig. 2 of [14]) and CDMS data are incompatible at 99.99% CL. Furthermore, even under the assumption that none of the CDMS events are due to neutrons, the CDMS data and the DAMA signal are incompatible at 99.8% CL. Simply put, a spin-independent WIMP-nucleon cross-section that would give rise to the annual-modulation amplitude $A = 0.022$ events kg^{-1} keV^{-1} observed by DAMA averaged over 2–6 keV electron-equivalent energy should yield > 3 events kg^{-1} day^{-1} in Ge, incompatible with the 23 CDMS events in 15.8 kg d even if none of the events are due to neutrons. If part of the annual modulation observed by DAMA is due to something other than WIMPs, or if the distribution of WIMPs locally is different than assumed, or if WIMP interactions are different than assumed (*e.g.* not spin-independent elastic scattering), the CDMS and DAMA results may be compatible.

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