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Further results from the CDMS experiment

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Abstract

The Cryogenic Dark Matter Search (CDMS) experiment utilizes discriminating detectors where both the recoil energy and ionization produced by each particle event are simultaneously measured. Here we present our latest results from operating 4 Ge (4 x 250 g) and 2 Si (2 x 100 g) detectors at the shallow Stanford site. Our new WIMP exclusion limit excludes new parameter space for low-mass WIMPS.

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1. Introduction

In its Dark Matter search the CDMS experiment utilizes Ge and Si detectors where both the ionization and phonon signal from a recoil event are simultaneously measured. This allows for excellent discrimination between bulk nuclear and electron recoils [1]. For CDMS II the phonon sensors are only sensitive to the initial athermal phonon flux generated by an event [2]. This allows an additional discrimination handle for rejecting surface recoil events [3]. These detectors are referred to as ZIP (Z-dependent Ionization and Phonon) detectors and will be deployed by CDMS II at its deep site in Soudan, Minnesota [4].

2. SUF Run 21

In preparation of running the ZIP detectors at the deep-site we ran our first detector package module (Tower 1) at the Stanford Underground Facility (SUF) where the overburden is 16 meter water equivalent. A full description of the facility and details of the shielding may be found in Refs. [1,5]. All six detectors (4 Ge each 250 g, 2 Si each 100 g) were fully operational. The detector at the bottom of the stack (labeled Z6) was a Si detector with significant C-14 contamination from a prior calibration and essentially served as a veto against multiple scatters. Three of the Ge detectors demonstrated excellent discrimination ability above an analysis threshold of 5 keV recoil energy. The fourth Ge detector, at the top of the stack (labeled as Z1), was ion-implanted prior to our improved Tc mapping technique (see Ref. [2]), and was analyzed with a threshold of 20 keV. The position dependence of the athermal phonon pulse shapes within these detectors, and the calibration efforts required are described in the accompanying paper [3], along-with some studies of surface electron recoil calibrations.

During the course of 2001 and 2002 at SUF we obtained 65.8 livedays at a 3 V ionization bias, 28.3 kg-days after cuts. A data set at 6 V bias, with similar exposure, will be reported later. For the 3 V data set external source calibrations established the following discriminating power of the Tower 1 detectors: photon rejection > 99.98% (5-100 keV) and electron rejection > 99% (10-100 keV) for Z2 through Z5. Requiring at least 80% of the ionization energy to be contained within the inner disk region of the detector and having phonon sensor risetime > 12 □s for Ge and > 6 □s for Si gave an energy-dependent cut efficiency for nuclear recoil events varying from 10-15% at 5 keV to 40-45% at 20 keV to 50-60% at higher energies.

A recoil energy histogram for the 20 veto-anticoincident Ge single-scatter nuclear-recoil events is shown in Fig. 2, for the 3 V bias low-background data set. Some of these nuclear recoil events could include contamination from surface electron events. Likelihood fits to the risetime and yield distributions for surface events from the extensive gamma calibrations with Co-60 suggest that the expected number of such events is 1.2 for the Ge detectors in this data set.

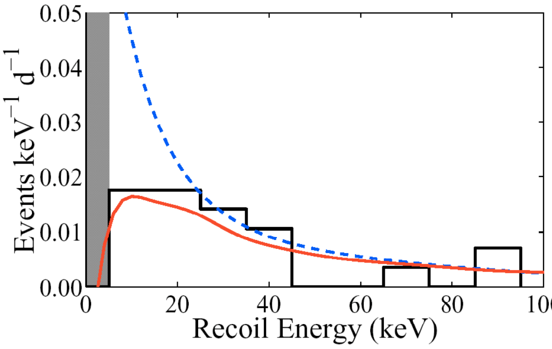

Fig. 1. Histogram of the 20 observed single-scatter nuclear recoil candidates in the 4 Ge ZIPs. The dashed curve is the Monte Carlo simulation predicated shape for the incident neutrons at SUF. The solid curve includes the detector efficiencies and is normalized to the 20 events. All the nuclear recoils observed could be consistent with neutron scattering events. Note that a WIMP with mass below 40 GeV/c^2 is unable, kinematically, to produce events with recoil energy as high as 30-40 keV. Thus the events in this energy range actually observed must be due to neutrons and results in our impressive exclusion limit for low-mass WIMPs.

In Fig. 3 we plot the 90% CL excluded parameter space for the WIMP-nucleon cross-section for this 3 V bias low background data set. The likelihood ratio approach used [5] accounts for the observed number of Ge single scatters as constrained by the two observed triple scatter events, the 1 non-nearest-neighbor double scatter, and the two single-scatter nuclear recoil events in the Si detector included. The neutron Monte Carlo simulations predict 16 Ge single scatter neutron events per 3 multiple-detector neutron events. Thus all the nuclear recoil events observed may be neutron scatters.

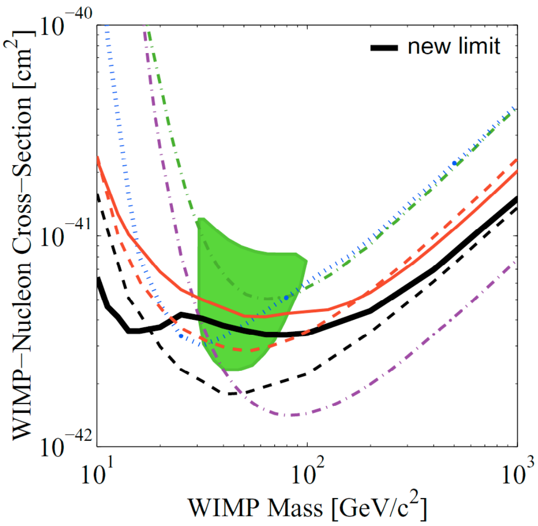

Fig. 2: Spin-independent WIMP-nucleon cross-section vs. WIMP mass. The regions above the curves are excluded at 90% CL. Solid, thick black curve: limit from most recent analysis including statistical subtraction of the neutron background. Solid red curve: limit from this analysis without statistical subtraction of the neutron background. Dashed curves: CDMS expected sensitivity (median simulated limit). Blue dotted curve: previous CDMS upper limit [1]. Above 30 GeV c^{-2}, the EDELWEISS [6] (purple dot-dashed curve) experiment provides more sensitive limits. Details of the standard Halo model and discussion of DAMA results (green) can be found in Refs. [1,5].

The median expected sensitivity indicated in Fig. 3 is calculated from the expected neutron background of 3.3 multiple-scatters, 18 single scatters in Ge, and an expected background in Si of 0.8 electrons and 3.6 neutrons.

The results from the 3 V bias data set of SUF Run 21 are consistent with our previous report [1] that we are now dominated by the external neutron flux at this shallow site. The factor of 2.3 reduction in the flux compared to Run 19 due to the addition of extra internal polyethylene was predicted by the neutron simulations and has now been confirmed.

3. Outlook

The detector package from SUF run 21 (Tower 1) is now installed in the deep-site Soudan facility, along-with a second tower comprised of 4 Si and 2 Ge ZIPs. Further details of the expected performance at the deep site may be found in the accompanying paper [5]. The anticipated reduction of the gamma and neutron backgrounds (factors of 2 and 100 respectively) at this deep-site present exciting prospects for our continuing Dark Matter search.

Acknowledgments

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With great sadness we note the passing of Prof. Ron Ross, he was the chief designer of our cryogenic system and a gentle man. We will miss his presence and contributions to our experiment.

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