WIMP EXCLUSION RESULTS FROM THE CDMS EXPERIMENT

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In early 2000 CDMS set the most competitive exclusion limit for scalar-interaction WIMPs at the Stanford Underground Facility (SUF). A new search (CDMS II) is now commencing at the Deep-site Soudan Facility.

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1. Introduction

The CDMS collaboration is a direct-detection WIMP search experiment utilizing cryogenic Ge and Si detectors. The operation of these detectors at low temperatures (< 0.1 K) allows discrimination between nuclear and electron recoil events by simultaneously measuring the ionization and phonon signals generated by particle interactions.

Initial WIMP exclusion results were obtained by CDMS I at the shallow (16 mwe) Stanford Underground Facility (SUF) during the course of 1998-1999 and published in Ref. 1. A refined analysis was presented in Ref. 2. This paper will summarize the improvements as well as report on our latest endeavor: the selection of a more advanced detector technology, utilizing athermal phonon signals, to perform a Dark Matter search at the Soudan mine (2000 mwe) in Northern Minnesota.

2. CDMS I Results from SUF

In early 2000 the CDMS collaboration reported a WIMP exclusion limit that was inconsistent with the DAMA results – assuming standard halo and couplings – in Ref. 1. In order to resolve the controversy and reduce uncertainties in the CDMS results a number of analysis revisions were performed and recently reported in Ref. 2. The CDMS exclusion limit became slightly weaker, but the overall conclusion of an inconsistency with the DAMA results remained. Subsequently, other experiments have confirmed the CDMS conclusion and set even better exclusion limits, in particular EDELWEISS.[3]

The analysis revisions inbetween the publication of Refs. 1 and 2 can be grouped into three categories. The increase in the Ge detectors' fiducial volume by the inclusion of 'shared' events (events generating on ionization signal in both the inner and outer electrodes); a more conservative treatment of the Si detector's electron background; and minor improvements to the neutron Monte-Carlos required to perform the neutron statistical subtraction. Inclusion of the 'shared events' in Ref. 2 increased the net exposure from 10.6 kg-days to 15.8 kg-days, without introducing a degradation in the detectors' discrimination ability. With the improved agreement between the experiment's expected and achieved sensitivity, the actual WIMP exclusion limit became slightly weaker than that reported in Ref. 1. The other major contribution to the slight weakening of the reported CDMS I limit came from a reanalysis of electron calibration studies performed on the Si detector run in SUF Run 18. Although the 4 nuclear-recoil events observed in the 1.6 kg-day exposure are entirely consistent with being neutrons, the possibility of these events being low-yield electron events could not be strongly discounted. Paradoxically perhaps, ignoring the Si detector would now result in a stronger WIMP exclusion limit.

Figure 1 shows the WIMP-nucleon cross-section exclusion limit (90% CL assuming standard model halo) reported by CDMS in Ref. 2. The expected sensitivity is for the case of 27 expected neutron events in the 3 Ge BLIPs of SUF Run 19 and a background in the Si detector of 7.2 electrons and 4.6 neutrons from SUF Run 18.

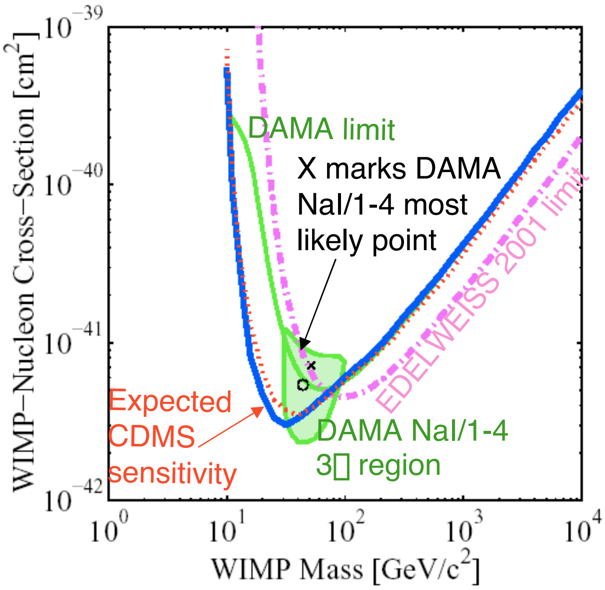

Figure 1. Exclusion limit on WIMP-nucleon cross-section from SUF Run 19, including larger fiducial volume[2]. The solid line is the CDMS I result, including neutron subtraction. The dotted line is the CDMS I expected sensitivity. The dot-dashed line is the EDELWEISS 2001 limit, which has since been exceeded by their 2002 limit[3] (not shown). For further details and relevance of the DAMA results shown see Refs. 1 and 2.

CDMS provided the most constraining upper limit of any experiment for WIMPS with a 10-70 GeV/c^2 mass range in 2001. The subsequent EDELWEISS 2002 limit now sets a better exclusion limit than CDMS above a WIMP mass of 35 GeV/c^2.

3. Soudan Detector Tower #1 performance in SUF Run 21

For the CDMS II deep-site Soudan facility the detector technology has been enhanced to include athermal phonon sensor readout. These sensors provide an additional discrimination parameter, the risetime of the phonon signal[3]. The first 'tower' of ZIP detectors planned to be run at the Soudan deep-site were initially characterized and screened in the SUF facility from July'01 to July'02. The tower consisted of a vertical stack of 6 ZIPs. The upper 3 are 250 g Ge ZIPs (Z1 – Z3), followed by a Si ZIP (Z4), a Ge ZIP (Z5) and the stack completed by another Si ZIP (Z6) at the bottom, which was known to be contaminated by C-14 from a prior beta calibration study. Details of these detectors' performance, which essentially exceeded all of our goals, can be found in the report by Saab[4] in these proceedings.

The powerful discrimination ability of these detectors is nicely demonstrated by considering multiple scattering events between the detectors. The yield parameter Y is the ratio of ionization energy (electron equivalent) to recoil energy. For gamma events we expect a value of $Y \sim 1$; whereas nuclear recoil events will have a $Y \sim 0.3$ as determined by in-situ external neutron source calibrations. Surface electron events, where incomplete ionization collection may occur, can have intermediate values of Y and at low recoil energies (<50 keV) start to 'leak' into the nuclear recoil band. This 'bad-y' leakage is problematic to setting a WIMP exclusion limit if the source rate for these beta sources is non-negligible.

In Fig. 2 we show multiple scattering events between non-nearest neighbours (nearest neighbour detectors have significant cross-talk in the cold-electronic hardware which is in the process of being analyzed and corrected for). A genuine nuclear recoil in one detector ($Y \sim 0.3$) also looks like a nuclear recoil event in a nearby detector. For the non-nearest neighbours plots shown there are negligible 'bad-y' events due to surface electron events. Contamination estimates from nearest neighbour bad-y scattering events are in progress.

At the shallow site of SUF we have the 'advantage' of an ongoing nuclear recoil calibration from muon-coincident, internal, neutrons. At 16 mwe the input to the Monte Carlo simulation assumes a production rate of 0.823 neutrons per unit volume per day for the copper shielding and 2.76 neutrons per unit volume per day for the lead shielding, both are within the muon veto shield whose efficiency to through-going muons is >99.94%.

After SUF Run 19 an additional polyethylene shield was inserted into the icebox. The data from SUF Run 21 confirmed that the muon anti-coincident (external) neutron dropped by the expected factor of 2.3 whereas the internal rate dropped by a factor of 3. Figure 3 shows a comparison of the energy spectrum predicted by the Monte Carlo for internal neutrons and data from SUF Run 21. Compared to our earlier publication,[1] the improved agreement between data and

MC in the relative hardness of the neutron recoil spectra is attributable to explicit inclusion of relevant cross-sections' angular dependencies.[2,5]

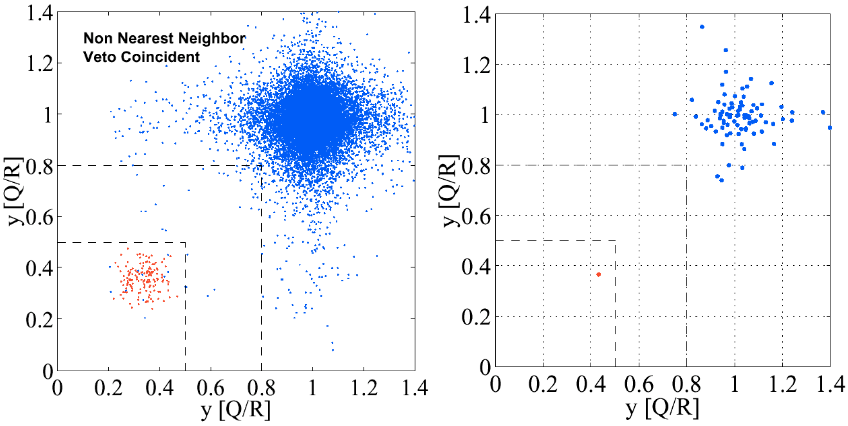

Figure 2. Multiple scattered events between non-nearest neighbouring detectors in the stack of Tower 1 run in SUF Run 21. (Left) Veto Coincident, MC predicts that 39% of all multiply scattered neutrons should be non-nearest neighbour, 44+/-3% observed in data, negligible beta-like contamination is evident. (Right) Veto Anti-coincident, MC predicts 2 neutron candidates, one observed. No beta-like contamination is apparent.

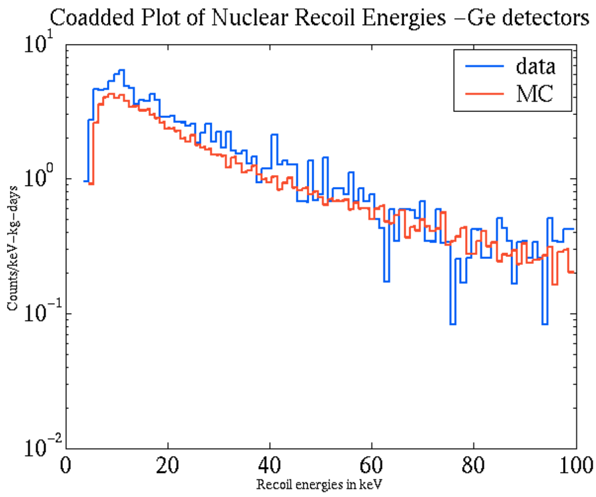

Figure 3. Comparison of muon-coincident (internal neutrons) nuclear recoil energy spectrum from Monte Carlo simulations including the same cuts as present in the data from the Ge ZIP detectors operated in SUF Run 21.

The reader should note that the improvements in the Monte Carlos over the last few years has had little perturbation on the relative ratio of Ge single scatter events to multiple scatter events first reported[1] and utilized in the neutron statistical background subtraction for the CDMS I SUF Run 19 data.[1,2]

For the data considered above from SUF Run 21, we observe 18 Ge single scatter events (muon anticoincident and accepted as a nuclear recoil event), 8 multiples and 2 Si singles (in one of the Si ZIPs, the other has a high level of beta contamination from C-14 and will not be considered further here). The full analysis has not been completed yet for SUF Run 21. Although we cannot report here any new WIMP exclusion limit, we comment that one can scale the results from SUF Run 19 where 23 Ge singles and 4 multiples in 15.8 kg days leads to a prediction of 17 Ge singles, 7 multiples, and 3 singles in the Si detector, for the 27 kg days of SUF Run 21 data considered here, indicative that our understanding of the backgrounds present at the SUF site are correct.

4. Future Operations

Tower 1 is awaiting the completion of commissioning of the cryogenic system at Soudan, which is expected to occur in early 2003. By this time we anticipate that a second tower of ZIP detectors will be available for deployment as well as Tower 1. The first planned science run at Soudan will comprise these two towers containing a total of 6 Ge and 6 Si ZIP detectors .

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