Status and future of the CDMS experiment: CDMS-II to SuperCDMS

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Abstract. The Cryogenic Dark Matter Search experiment (CDMS-II) employs low-temperature Ge and Si detectors to detect WIMPs via their elastic scattering interactions with the target nuclei. No Dark Matter signal has been observed so far, resulting in a limit on the spin-independent WIMP-nucleon elastic scattering cross-section with a minimum of 1.6 x 10^{-43} cm^2 at a WIMP mass of 60 GeV c^{-2}. To increase the sensitivity, new one inch thick detectors have been developed which will be used in the SuperCDMS phase. SuperCDMS will be operated at SNOLAB with an expected sensitivity on the spin-independent WIMP-nucleon elastic scattering cross-section of 1 x 10^{-45} cm^2 at the 25 kg stage.

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I. The CDMS-II experiment

The Cryogenic Dark Matter Search experiment searches for non-luminous, non-baryonic WIMPs [1], that could form the majority of the matter in the universe [1, 2]. The kinetic energy imparted to a nucleus in an elastic WIMP-nucleon scattering event would range from a few keV to tens of keV. The small recoil energy, coupled with an expected low event rate, means that it is vital to suppress backgrounds effectively. Active and passive shielding are used to reduce backgrounds produced outside the experimental apparatus, leaving decays of radioactive contamination inside of the shielding as the dominant natural background. Gammas and electrons from these decays interact electromagnetically and can be discriminated against nuclear recoils. The remaining background comes from muon induced and spallation neutrons, which produce nuclear-recoil events identical to WIMPs. The 780 m (2090 mwe[2]) of rock overburden at the Soudan Underground Laboratory reduces the surface muon flux by a factor of 5 x 10^4. Monte Carlo simulations predict a total unvetoed rate of 0.05 ± 0.01 muon induced neutrons kg^{-1} y^{-1}. The muon induced neutrons, as well as neutrons produced by (α ,n) reactions and spallation from the contamination will ultimately limit the sensitivity of the experiment. The estimates for the neutron rates induced by the above processes are small enough to provide a neutron background free operation of the CDMS-II experiment for current and future runs at the Soudan site.

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[1] **W**eakly **I**nteracting **M**assive **P**articles
[2] meters water equivalent

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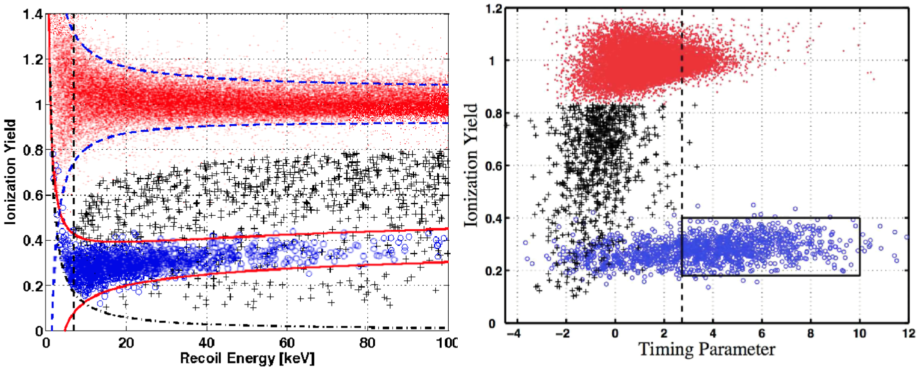

FIGURE 1. Ionization yield versus recoil energy (left) and phonon-timing parameter (right) for calibration data in a germanium detector. Three different classes of events are shown: ^{133}Ba gamma-calibration bulk (red dots) and surface (black crosses) events as well as nuclear recoils (blue circles) from ^{252}Cf neutron-calibration. In the left plot the nuclear- (red line) and electron-recoil band (blue/dashed) are shown with the analysis threshold (dashed/vertical) of 7 keV and the ionization threshold (black/dot dash). The box in the right plot indicates the background free, approximate signal region.

CDMS ZIP Detectors. Each CDMS ZIP (Z-sensitive Ionization- and Phonon-mediated) [3] detector is a cylindrical high-purity Ge or Si crystal, 1cm thick and 7.6 cm in diameter. A single Ge (Si) ZIP has a mass of 250 g (100 g). Two concentric ionization electrodes and four independent athermal phonon sensors are photolithographically patterned onto each crystal. A particle interacting in a ZIP detector can interact with an electron in the crystal, or with a nucleus. The interaction deposits energy into the crystal through charge excitations (electron-hole pairs) and lattice vibrations (phonons). The simultaneous ionization and phonon measurement with a ZIP detector not only allows an accurate measurement of the recoil energy independent of recoil type, but also distinguishes between the two types of recoils (electron-recoil and nuclear-recoil). The dimensionless ionization yield parameter, y, is the ratio of ionization energy to recoil energy, $y = E_Q/E_R$. Nuclear recoils produce fewer charge pairs, and hence less ionization energy, E_Q, than do electron recoils of the same recoil energy. The ionization yield for electron- and nuclear-recoils is determined by calibrations with a ^{133}Ba and a ^{252}Cf source providing the bands shown in figure 1. The simultaneous measurement of ionization and recoil energy therefore provides the possibility to identify and reject electron-recoil background events with $> 99.99\%$ efficiency. Since WIMPs are expected to interact with the target nuclei, the nuclear-recoil band defines the signal region.

Low-yield surface events. Events interacting in the first few microns of the crystal have an incomplete charge collection. Hence the ionization yield parameter is suppressed for such events, and they may leak into the signal region, mimicking nuclear recoils. These events, referred to as surface events, can be identified as a third population between the electron and nuclear band in figure 1 (left plot). Surface events are the most dangerous background and can limit the sensitivity of the experiment. To discriminate between surface and nuclear recoil events the timing properties of the phonon signals are used. The two parameters used in the analysis are the delay of the slower phonon signal with respect to the ionization signal and the risetime of the leading phonon sensor (which is the one with the largest signal amplitude). Since surface events have faster delays and risetimes than bulk nuclear-recoils, these two parameters can be used to cut out surface events and select nuclear recoils. This cut is defined on low-yield ^{133}Ba and ^{252}Cf calibration data as shown in figure 1 (right plot). In this figure the three populations can easily be identified and a background-free signal window is defined in the ionization yield - timing parameter space. Only single scatter nuclear-recoils in this signal window are considered as WIMP candidates.

Results from the CDMS-II setup

The CDMS-II setup was run with one tower containing four Ge and two Si ZIPs (Run118) and in a two tower setup with six Ge and six Si ZIPs (Run119). All cuts designed to select nuclear recoils were determined in a blind manner from *in situ* calibrations with external radioactive sources, without any prior knowledge of the event distribution in the signal region. A 64 keV and and 10.5 keV event were found in the signal region in the first and second run respectively, consistent with the estimated systematic background [4]. These results can be combined and interpreted as an upper limit on the spin-independent WIMP-nucleon elastic scattering cross-section (σ_{WN}) shown in figure 2. The first two runs with five towers (Run123/124) with 19 Ge and 11 Si ZIPs in the CDMS-II setup lasted from October 2006 to July 2007 accumulating 650 kg days of Ge raw exposure. After a short maintenance period Run125 was started, which is expected to accumulate an additional 1000 kg days of raw exposure until the end of 2008.

II. CDMS-II to SuperCDMS

To further increase the sensitivity of the CDMS experiment the total accumulated exposure has to be increased. This can be achieved by increasing the detector mass and the runtime of the experiment. For the SuperCDMS setup new 1 inch thick detectors have been developed and tested, providing an increase of a factor of 2.54 in mass with respect to the 1cm thick detectors used in the CDMS-II setup. The redesign of the phonon readout, which maximizes the active phonon collection area, and the hydrogenation of the amorphous silicon layer between the crystal and the electrodes, show improvements in the discrimination between surface events and nuclear-recoils. In addition, an improved analysis for a better surface event discrimination is in hand and being applied in a reanalysis of Run118/119 data. The first two super towers consisting each of six 1 inch thick detectors will be installed at the Soudan site at the end of 2008 to demonstrate the improved discrimination capabilities, and test if SCDMS can be operated with a background free signal region.

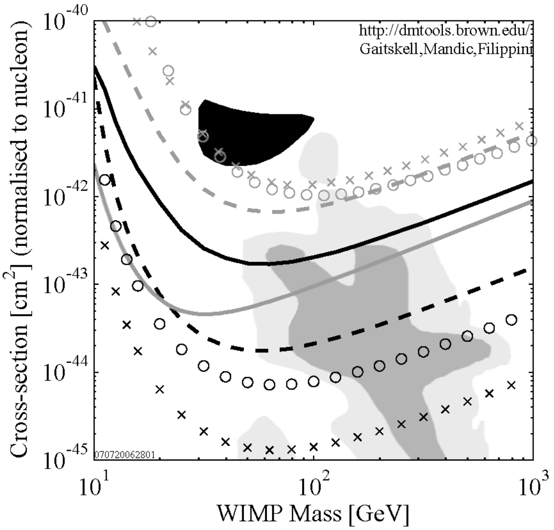

FIGURE 2: Upper limits on the WIMP-nucleon spin-independent cross-section; CDMS two previous runs combined (black/line) [4]; XENON (gray/line)[5]; ZEPLIN II [6] (gray/dashed); WARP [7] (gray/circle) and EDELWEISS (gray/cross) [8]. Also shown are the projected sensitivities for CDMS-II final (black/dashed); the two super tower run at Soudan (black/circle) and SCDMS 25 kg (black/cross). Filled region indicate CMSSM models (68% CL dark gray and 90% CL light gray)[10] and an interpretation of the DAMA/NaI annual modulation signal (black) [9].

At the SCDMS 25 kg stage seven super towers will be installed and operated at SNOLAB. SCDMS 25 kg aims to reach a sensitivity of 1 x 10^{-45} cm^2 at a WIMP mass of 60 GeV, as shown in figure 2.

CONCLUSIONS

The CDMS-II setup is currently running with 30 ZIPs and aims to accumulate roughly 1600 kg days of WIMP search exposure until the end of 2008. If no WIMP candidate events are found, it will reach a sensitivity of $\sigma_{WN} \sim 1$ x 10^{-44} cm^2. With the improvements on the hardware and the analysis the future phases of the CDMS experiment should stay background free. The next upgrade of the CDMS experiment to SuperCDMS 25 kg will be installed at SNOLAB increasing the sensitivity by one order of magnitude.

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