2 Search for Cold Dark Matter with CDMS-II

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(CDMS-II Collaboration)

The Cryogenic Dark Matter Search (CDMS II) experiment seeks to detect recoiling atomic nuclei (nuclear recoils) from WIMP scattering events using high-purity Ge (230 g) and Si (100 g) detectors kept at cryogenic temperature ($<$50 mK). Each detector is $\sim$10 mm thick disc with 76 mm in diameter, which is photolitographically patterned with sensors to detect the phonons and ionization generated by incident particles. These detectors can distinguish between nuclear and electronic recoils, since nuclear recoils generate less ionization than electronic recoils of the same deposited energy, allowing event-by-event rejection of background with a misidentification rate of less than one in 10^4.

CDMS II operated an array of 30 such detectors (19 Ge and 11 Si) in a low-radioactivity installation at the Soudan Underground Laboratory (713 m below the surface). While the depth of the experimental facility greatly reduces the rate of background events from particle showers induced by cosmic rays, the environmental radioactivity is shielded to negligible levels with concentric layers of lead and polyethylene. Data taken during four period of stable operation between July 2007 and September 2008 were analyzed, leading to the world's best upper limits on the WIMP-nucleon spin-independent cross section for WIMP masses above 42 GeV/c^2. These results have been recently published in Science (6).

The main contribution of our group is in the data analysis effort, with focus on basic data analysis, on understanding the various background sources and on the physics analysis with respect to standard dark matter candidates, inelastic dark matter models, dark matter interacting with electrons (2) and solar axion searches (3). In the following we present some of the highlights of our contributions, namely the results for standard WIMPs and for inelastic dark matter.

Due to their greater sensitivity to spin-independent WIMP scattering, only Ge detectors were used for the WIMP search. A total exposure of 612 kg-days was considered for the analysis. After detector calibration, a series of criteria to identify candidate WIMP-scattering events were defined. WIMP candidates were required to deposit 10-100 keV of energy in a single detector, have ionization and phonon characteristics of nuclear recoils and have no identifiable energy deposition in the scintillator shield that surrounds the passive shield layers. To avoid unconscious bias, a "blind analysis", in which the exact selection criteria were defined without prior knowledge of the content of the signal region or its vicinity was performed. The fraction of nuclear recoil events accepted by these selection criteria was measured using a calibration sample of nuclear recoil events induced by a ^{252}Cf source. The expected rate of background events from misidentified electronic recoils that happen within a few μm of the detector's surfaces is 0.8±0.1(stat)±0.2 (syst). Neutrons from cosmic rays and radioactivity of the detector materials are expected to generate an average of ∼0.1 nuclear recoils which would be indistinguishable from WIMP scatters.

After finalizing all event selection criteria, the signal region was "unblinded" and two candidate events at recoil energies of 12.3 keV and 15.5 keV were observed (Fig. 2.1 and Fig. 2.2). These events occurred during periods of nearly ideal experimental performance, were separated in time by several months, and took place in different detectors (T1Z5 and T3Z4). Although these candidate events thus match the expectations for WIMP scattering events, the probability to have observed two or more background events in this exposure is 23%. Hence, the results can not be interpreted as evidence for WIMP interactions, nor can either event be rejected as a WIMP scatter. These data constrain

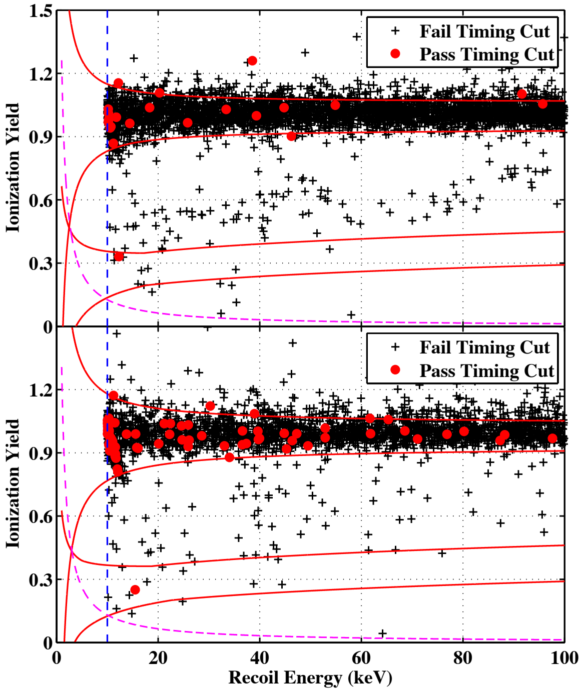

Figure 2.1: Ionization yield versus recoil energy for events passing all cuts, excluding yield and timing. The top (bottom) plot shows events for detector T1Z5(T3Z4). The solid red lines indicate the 2σ electron and nuclear recoil bands. The vertical dashed line represents the recoil energy threshold and the sloping magenta dashed line is the ionization threshold. Events that pass the timing cut are shown with round markers. The candidate events are the round markers inside the nuclear-recoil bands.

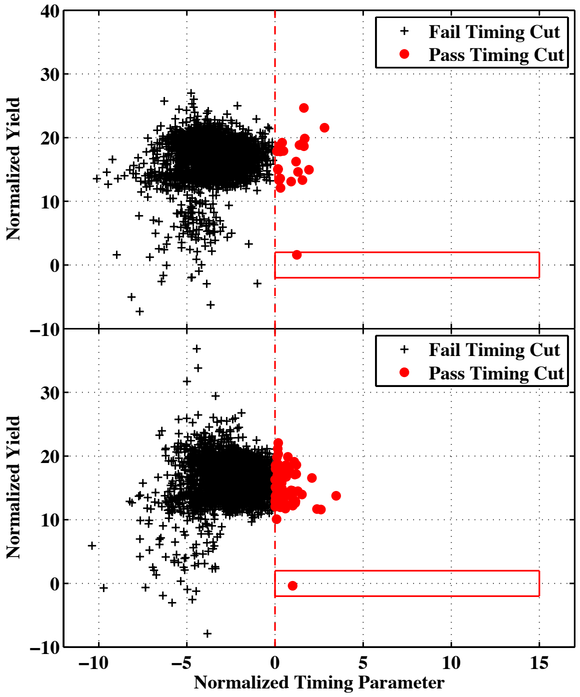

Figure 2.2: Normalized ionization yield (number of standard deviations from mean of nuclear recoil band) versus normalized timing parameter (timing relative to acceptance region) for events passing all cuts, excluding yield and timing. The top (bottom) plot shows events for detector T1Z5(T3Z4). Events that pass the phonon timing cut are shown with round markers. The solid red box indicates the signal region for that detector. The candidate events are the round markers inside the signal regions.

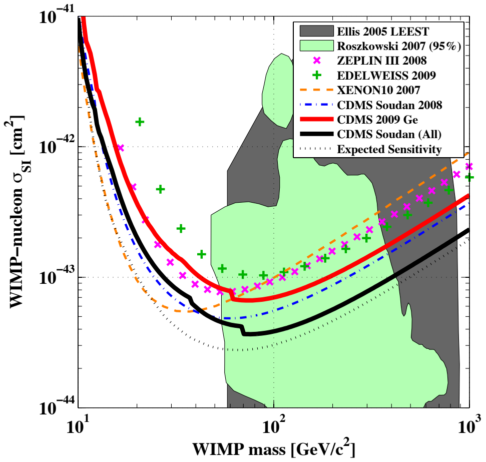

Figure 2.3: 90% C.L. upper limits on the WIMP-nucleon spin-independent cross section as a function of WIMP mass. The red (upper) solid line shows the limit obtained from the latest CDMS-II exposure analyzed. The solid black line shows the combined limit for the full data set recorded at Soudan. The dotted line indicates the expected sensitivity for this exposure based on our estimated background combined with the observed sensitivity of past Soudan data. Prior results from CDMS [4] and other experiments (see legend) are shown for comparison. The shaded regions indicate allowed parameter space calculated from certain Minimal Supersymmetric Models.

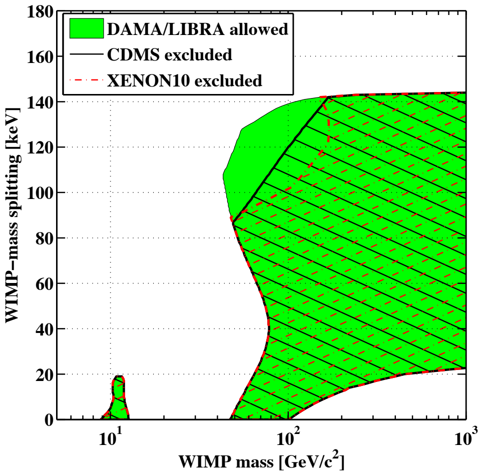

Figure 2.4: The shaded green region represents WIMP masses and mass splittings for which there exists a cross section compatible with the DAMA/LIBRA [7] modulation spectrum at 90% C. L. under the inelastic dark matter interpretation [5]. The excluded regions for CDMS II (solid-black hatched) and XENON10 [8] (red-dashed hatched) are shown.

the spin-independent WIMP-nucleon scattering cross section to be less than 7.0×10^{-44}cm^2 (3.8×10^{-44}cm^2 when combined with previous CDMS II results (4)) for a WIMP mass of 70 GeV/c^2 (Fig. 2.3).

The CDMS-II data were also analyzed under the hypothesis of WIMP inelastic scattering (5). In this model, which has been invoked to reconcile the annual modulation observed by DAMA/LIBRA (7) with null observations from other experiments, the WIMP-nucleon scattering occurs only via inelastic scattering with the dark matter particle transiting into an excited state. Thus, only WIMPs with sufficient energy to up-scatter into the excited state can scatter off nuclei in the detector. The mass splitting between the WIMP and its excited state is considered to be a free parameter; in order to explain the DAMA/LIBRA results, the splitting needs to be around 120 keV (6). Our analysis shows that CDMS II data disfavor all but a narrow region of the parameter space allowed by DAMA/LIBRA that resides at a WIMP mass of 100 GeV/c^1 and mass splittings of 90-140 keV (Fig. 2.4).

[6] Z. Ahmed et al. (CDMS Collaboration), Science **1186112** (2010).

[2] Z. Ahmed et al. (CDMS Collaboration), Phys. Rev. **D81**, 042002 (2010).

[3] Z. Ahmed et al., Phys. Rev. Lett. **103**, 141802 (2009).

[4] Z. Ahmed et al., Phys. Rev. Lett. **102**, 011301 (2009).

[5] D. Tucker-Smith, N. Weiner, Phys. Rev. **D64**, 043502 (2001).

[6] S. Chang, G.D. Kribs, D. Tucker-Smith and N. Weiner, Phys. Rev. **D79**, 043513 (2009).

[7] R. Bernabei et al., Eur. Phys. J. **C56**, 333 (2008).

[8] J. Angle et al., Phys. Rev. **D80**, 115005 (2009).