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Recent Results from WIMP-search analysis of CDMS-II data

Zeeshan AHMED* **California Institute of Technology**

E-mail: zahmed@caltech.edu

for the CDMS collaboration

The Cryogenic Dark Matter Search experiment (CDMS-II), at Soudan Underground Laboratory, employed an array of germanium and silicon low-temperature particle detectors to identify nuclear recoils from elastic scattering of Weakly Interacting Massive Particles (WIMPs). We report results from the analysis of WIMP-search data acquired between October 2006 and July 2007. No events were observed. Combined with previous CDMS-II data, this results in an upper limit on the WIMP-nucleon spin-independent interaction cross-section of 4.8×10^{-44} cm^2 at 90% CL for a 60 GeV/c^2 WIMP. CDMS-II ended operations in March 2009, to be upgraded to SuperCDMS with 2.5 times more massive detectors that have improved background rejection. The first set of such detectors has been deployed at Soudan and is taking data. Since these results were reported at EPS 2009, the full CDMS-II exposure has been analyzed and has led to a lower limit on the WIMP-nucleon interaction cross-section than the one reported here.

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1. Introduction

Cosmological evidence [1] indicates that only ∼4% of energy density of the universe is comprised of baryons, although more than 25% is contained in matter. The missing matter or dark matter is likely not only non-baryonic, but non-relativistic at the time of structure formation. One candidate for cold dark matter is Weakly Interacting Massive Particles (WIMPs) [2], well-motivated from a cosmological thermal relic framework and independently from proposed extensions of the Standard Model such as Supersymmetry [3, 4, 5].

WIMPs are expected to have scattering cross-sections on the order of the weak scale, and masses around ∼100 GeV/c^2 [6]. As dark matter particles they would constitute diffuse halos around galaxies with isothermal velocities [7]. Terrestrially, they would appear to originate from the direction opposite to that of the Solar System's motion through the Milky Way with an average velocity of 270 km/s. WIMPs would elastically scatter of nuclei in particle detectors thus producing a roughly exponential energy deposition spectrum, averaged around few tens of keV, with an interaction rate of < 0.1 events/kg/day [8, 9] .

2. CDMS-II Experiment

The Cryogenic Dark Matter Search (CDMS) experiment conducted searches for WIMP-induced nuclear recoils using an array of 19 germanium (250 g) and 11 silicon (100 g) low-temperature (∼50 mK) particle detectors [10, 11]. Each detector was a cylindrical disk, 7.6 cm in diameter and 1 cm thick. Particle interactions in a detector generated ionization as well as athermal phonons. An electric field across the detector separated the resulting electrons and holes which were collected on electrodes patterned on the flat faces, producing an ionization energy measurement. Phonons were collected in four superconducting thin-film absorber circuits and the energy was read out using tungsten transition-edge sensors (TESs) coupled with superconducting quantum interference devices (SQUIDs).

The ionization yield, or the ratio of charge to phonon energy depositions, provided the primary discrimination between electron recoils and nuclear recoils to better than 10^{-4} misidentification rate. For events within 10μm of a detector surface, charge collection was suppressed and ionization yield was reduced. Additional discrimination was obtained from the promptness of phonon pulses; surface events had faster pulses than bulk events. Combining ionization yield and phonon timing, bulk electron recoils were rejected to better than 10^{-6} misidentification rate and surface electron recoils to better than 10^{-2}. This is illustrated in the left pane of fig. 1 using calibration data.

In order to suppress ambient photons and radiogenic neutron rates, the entire experimental apparatus was surrounded by layers of lead and polyethylene. Finally, the experiment was situated at the Soudan Underground Mine at a depth of 2090 m.w.e. to suppress muon flux. An active plastic scintillator veto further tagged remaining incident muons which interacted in the apparatus to generate cosmogenic neutrons [10].

3. Results

We report results from WIMP-search data acquired in optimally performing Ge detectors between October 2006 and July 2007, with a raw exposure of 362 kg-days. A blind analysis was

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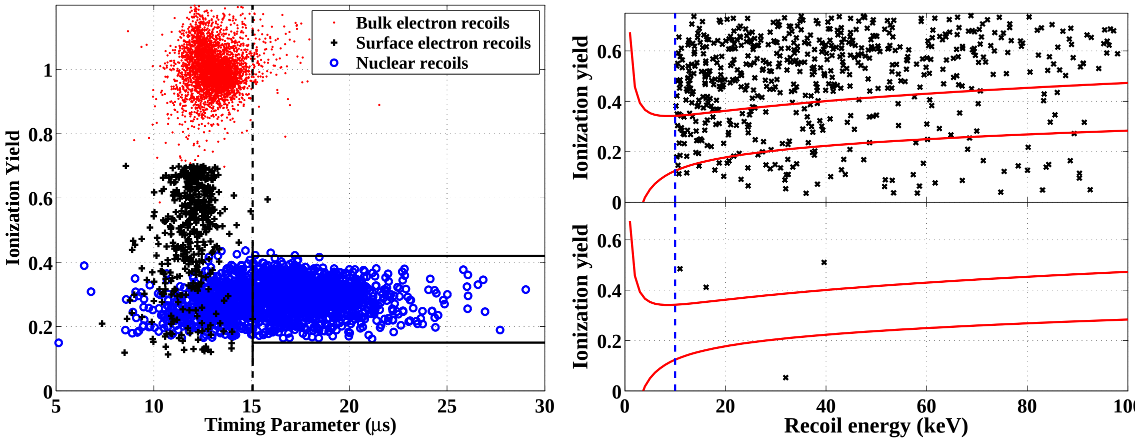

Figure 1: [Left] Ionization yield versus timing parameter for calibration data in a typical Ge detector. Bulk electron recoils (red dots) and low yield surface events (black +) from a ^{133}Ba source, and neutron induced nuclear recoil events (blue ∘) from a ^{252}Cf source show strong dependence on ionization yield and timing parameter. The vertical dashed line indicates minimum timing parameter for this analysis. The boxed region shows the approximate signal region. Reproduced from Ref.[11]. **[Right]** Top: Ionization yield versus recoil energy in all detectors included in this analysis for events passing all cuts except the ionization yield and timing cuts. The signal region between 10 and 100 keV recoil energies was defined using neutron calibration data and is indicated by the curved lines. Bulk-electron recoils have yield near unity and are above the vertical scale limits. Bottom: Same, but after applying the timing cut. No events are found within the signal region.

performed on this dataset to prevent bias. Calibration data from ^{133}Ba and ^{252}Cf sources were used to define the signal region. Furthermore, definition of physics cuts, calculation of their efficiencies, and characterization of detector response was done only using calibration data and WIMP-search events outside the blinded signal region. WIMP candidates were defined as events with recoil energies between 10 keV and 100 keV, within the detector fiducial volume, anti-coincident with muon veto activity, having interacted only in a single detector in the apparatus, within 2σ of the mean ionization yield of calibration-neutron events and having failed a surface event cut based on phonon pulse timing.

The expected background contribution from surface events was $0.6^{+0.5}_{-0.3}(\mathit{stat.})^{+0.3}_{-0.2}(\mathit{syst.})$, estimated using surface-event-cut pass-fail ratios measured on calibration surface events and WIMP-search events outside the signal region. The cosmogenic and radiogenic neutron background were together constrained to <0.1 events for the entire exposure, based on Monte Carlo simulations. The WIMP-equivalent (60 GeV/c^2) exposure after cuts was 117 kg-days.

With the analysis finalized, the blind signal region was unmasked on Feb 4, 2008. No WIMP candidates were observed as shown in right pane of fig.1. This null observation combined with previous CDMS-II data sets an upper limit on spin-independent WIMP-nucleon interactions of 4.6×10^{-44} cm^2 at 90% CL for a 60 GeV/c^2 WIMP [11], based on standard galactic halo assumptions [13]. Figure 2 shows this limit plotted along with other recent results and favored parameter space under various theoretical models.

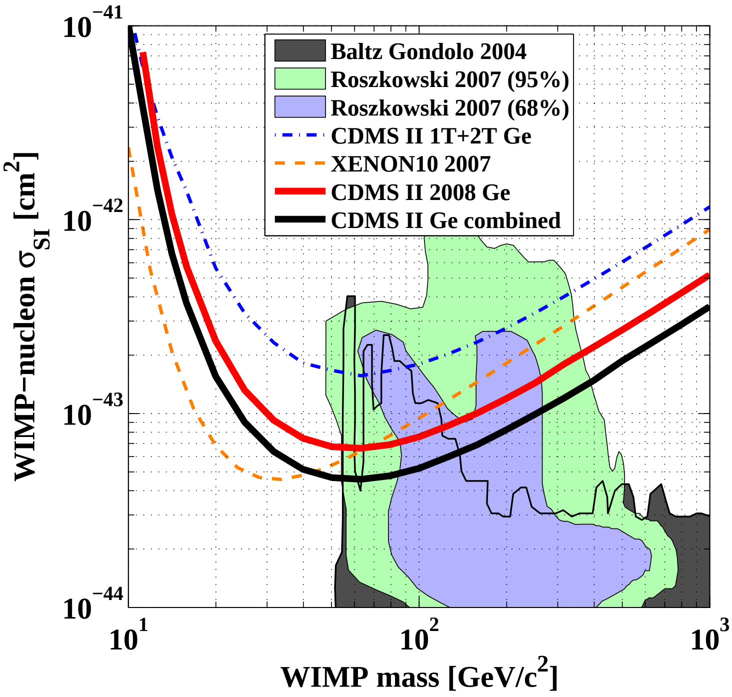

Figure 2: WIMP-nucleon spin-independent cross-section upper limits (90% CL) vs. WIMP mass from this result, previous CDMS-II results and from XENON-10 [12]. Shaded regions represent favored supersymmetric parameter space.

4. Current Status

CDMS-II ended operations in March 2009, and is being upgraded to SuperCDMS Soudan. CDMS-II detectors are being replaced with new ones, 2.5 times more massive than the old ones and with phonon sensors redesigned for better surface event rejection. The first tower of new detectors has already been deployed and is taking data at Soudan. By Summer 2010, 15kg of Ge detectors will be deployed in SuperCDMS with the goal of probing WIMP-nucleon cross-sections of 5×10^{-45}cm^2 [14].

Since the reporting of this result at EPS 2009, the analysis of the remaining WIMP-search dataset from CDMS-II (through July 2008) has resulted in stricter upper limits on WIMP-nucleon interactions, along with the observation of two WIMP-candidate events, albeit with a non-negligible likelihood of being background [15].

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