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Status of the Cryogenic Dark Matter Search Experiment

Z. Ahmed · D.S. Akerib · M.J. Attisha · C.N. Bailey · L. Baudis · D.A. Bauer · P.L. Brink · P.P. Brusov · R. Bunker · B. Cabrera · D.O. Caldwell · C.L. Chang · J. Cooley · M.B. Crisler · P. Cushman · M. Daal · F. DeJongh · R. Dixon · M.R. Dragowsky · L. Duong · R. Ferril · E. Figueroa-Feliciano · J. Filippini · R.J. Gaitskell · S.R. Golwala · D.R. Grant · R. Hennings-Yeomans · D. Holmgren · M.E. Huber · S. Kamat · S. Leclercq · R. Mahapatra · V. Mandic · P. Meunier · N. Mirabolfathi · H. Nelson · R.W. Ogburn · M. Pyle · X. Qiu · E. Ramberg · W. Rau · A. Reisetter · R.R. Ross · T. Saab · B. Sadoulet · J. Sander · R.W. Schnee · D.N. Seitz · B. Serfass · K.M. Sundqvist · J.-P.F. Thompson · G. Wang · S. Yellin · J. Yoo · B.A. Young

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N. Mirabolfathi for the CDMS collaboration.

M.J. Attisha · R.J. Gaitskell · J.-P.F. Thompson
Brown University, Providence, USA

D.S. Akerib · C.N. Bailey · P.P. Brusov · M.R. Dragowsky · D.R. Grant · R. Hennings-Yeomans · S. Kamat · R.W. Schnee
Case Western Reserve University, Cleveland, OH, USA

D.A. Bauer · M.B. Crisler · F. DeJongh · R. Dixon · D. Holmgren · E. Ramberg · J. Yoo
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

R.R. Ross · B. Sadoulet
Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

B.A. Young
Santa Clara University, Santa Clara, CA 95052, USA

P. Cushman · L. Duong · X. Qiu · A. Reisetter
University of Minnesota, Minneapolis, MN 55455, USA

P.L. Brink · B. Cabrera · C.L. Chang · J. Cooley · R.W. Ogburn · M. Pyle · S. Yellin
Stanford University, Stanford, CA 94305, USA

M. Daal · J. Filippini · V. Mandic · P. Meunier · N. Mirabolfathi (✉) · H. Nelson · R.R. Ross · B. Sadoulet · D.N. Seitz · B. Serfass · K.M. Sundqvist
University of California, Berkeley, CA 94720, USA
e-mail: mirabol@cosmology.berkeley.edu

Abstract The Cryogenic Dark Matter Search experiment (CDMS) is using Phonon+ Ionization detectors to search for Dark Matter in the form of Weakly Interactive Massive Particles (WIMPs). We report the current status of the experiment and its perspective to achieve the sensitivity goal of the cross section: $\sigma_{\text{WIMP-nucleon}} \sim 1 \times 10^{-44}\ \text{cm}^2$ (Spin independent).

Keywords Dark Matter · WIMP · Transition Edge Sensor (TES)

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1 Introduction

Over the last decade, a variety of cosmological observations have led to the construction of a concordance model of cosmology. In this very successful model, 23% of the Universe is composed of nonbaryonic dark matter [1]. Weakly Interactive Massive Particles (WIMPs) represent a generic class of candidates for this dark matter [2].

The Cryogenic Dark Matter Search (CDMS) seeks to detect WIMPs via their interaction with nuclei in crystals of Ge or Si at millikelvin temperatures. CDMS uses ZIP (Z-sensitive ionization and phonon) detectors [3] to discriminate between electron-recoils (most backgrounds) and nuclear-recoils (WIMPs and neutrons) on an event-by-event basis via a simultaneous measurement of ionization and athermal phonons. Bulk and surface electron-recoils are rejected using the relative amplitudes and timings of these signals. In particular the phonon timing parameters are faster for events occurring close to the ionization electrodes (Fig. 1 left).

Since its installation at Soudan deep underground laboratory (2090 meters-water-equivalent), CDMS has completed two WIMP-search runs. The first run with one

R. Bunker · D.O. Caldwell · R. Ferril · R. Mahapatra · J. Sander
University of California, Santa Barbara, CA 93106, USA

M.E. Huber
University of Colorado at Denver and Health Sciences Center, Denver, CO, USA

S. Leclercq · T. Saab
University of Florida, Gainesville, FL 32611, USA

Z. Ahmed · S.R. Golwala · G. Wang
California Institute of Technology, Pasadena, CA 91125, USA

L. Baudis
RWTH Aachen University, Aachen 52074, Germany

W. Rau
Queen's University, Kingston, ON K7L 3N6, Canada

E. Figueroa-Feliciano
Massachusetts Institute of Technology, Cambridge, MA 02139, USA

L. Baudis
Zurich University, Winterthurer str. 190, Zürich 8057, Switzerland

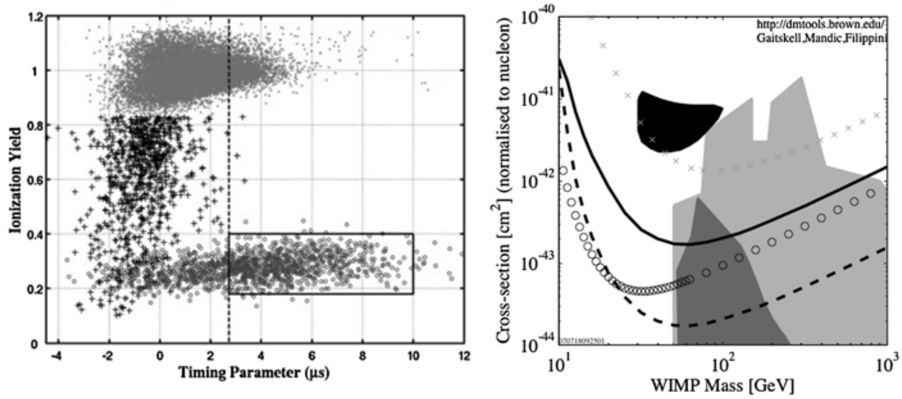

Fig. 1 (*Left*) Ionization yield versus phonon timing parameter. *Gray dots* are the bulk electron-recoil events from a ^{133}Ba source, *black cross* are the near-surface electron recoils with lower yield but faster phonon pulses and the *gray circles* are nuclear recoils from ^{252}Cf. The *rectangle* indicates approximately the WIMPs signal region. (*Right*) Upper limits on the Spin-independent WIMPs-nucleon interaction; CDMS two previous runs combined [4]: *black*; CDMSII final projected: *black dash*; Xenon [5]: *circle*; EdelweissI [6]: *cross*. Filled regions indicate MSSM [7] (*light gray*) and CMSSM [8] (*medium gray*) models, as well as an interpretation of the DAMA/NaI annual modulation signal [9] (*black*)

stack of six ZIPs (called a Tower): 4 × 250 g Ge and 2 × 100 g Si, and the second with two Towers: 6 × 250 g Ge and 6 × 100 g Si. Detector response to electron-recoils and nuclear-recoils was calibrated *in situ* using radioactive gamma (^{133}Ba) and neutron (^{252}Cf) sources. A total of 52.6 and 74.5 live-days of WIMP search data were acquired from the first and the second runs respectively, yielding: 52.6 + 96.8 kg-days exposure before cuts. A blind analysis was performed for the data of each run in which the nuclear recoil region was masked while the various analysis cuts were completed. Single WIMP candidates were found in each run consistent with the expectations for misidentified near surface electron-recoils [4, 10]. These results, with one event found in each of the two runs, may be combined and interpreted in terms of limits on the WIMP-nucleon interaction (Fig. 1 left).

2 CDMSII 5-Tower Run

In August 2004 after nearly a year at 50 mK the experiment was warmed up to install several new upgrades. Chief among these were three new detector towers (18 more ZIPs) adding 3.25 kg of Ge to the previous 1.5 kg Ge ZIP detectors, 18 additional flexible circuits (strip-lines) to read them out and a Gifford-McMahon cryocooler to mitigate their extra heat load and to reduce the liquid helium consumption.

The first CDMS WIMP search run (since October 2006) with five ZIP towers was stopped on March 2007. A total of 430 kg·days WIMP exposure (before cuts) was accumulated during that period. An additional 223 kg·days has been accumulated since March 2007 making the total CDMSII five-tower exposure accumulated up to this time ∼653 kg·days before cuts. The blind analysis for this data is still ongoing and expected to be finalized this fall. Except for a short period when the CDMSII

^{3}He-^{4}He dilution refrigerator was warmed to 4 K for circulation cleaning on March 2007, it has been cold since July 2006 and is planned to run for at least another year.

3 CDMSII: A Background Free Experiment

The dominant background observed in CDMSII at Soudan consists of electrons from radioactive contamination on the detector surfaces, which we refer to as "betas" reflecting the likelihood that most of these events arise from beta decay. We are expecting a better background rejection with respect to the previous CDMS runs mainly because:

(A) Newer ZIPs in Tower 3, 4 and 5 are cleaner The analysis of the previous CDMSII data suggests that the total rate of surface events in the energy range 10–40 keV is 1.7 $\mathrm{kg}^{-1}\mathrm{day}^{-1}$, of which 0.21 $\mathrm{detector}^{-1}\mathrm{day}^{-1}$ are single-scatter events, having a hit in one ZIP detector alone. Detailed studies of the surface events show that the bulk of this rate is due to decays of ^{210}Pb deposited by airborne radon. Our detectors are exposed to radon during fabrication, mounting and testing. We observe alpha particles in our detectors at a rate of 0.4 $\mathrm{detector}^{-1}\mathrm{day}^{-1}$. We identify the predicted beta component by looking at coincident betas between nearest-neighbor detectors and their correlation to the corresponding alpha rates (Fig. 2). Using this method we are finding a factor of $\sim$3 less radon contamination in our newest detectors which we can associate with the newer detectors being exposed less to radon during fabrication and testing.

(B) More uniform phonon parameters A detailed description of the ZIP detectors is given in [3]. Athermal phonons in a ZIP are measured by four sensors. Each phonon

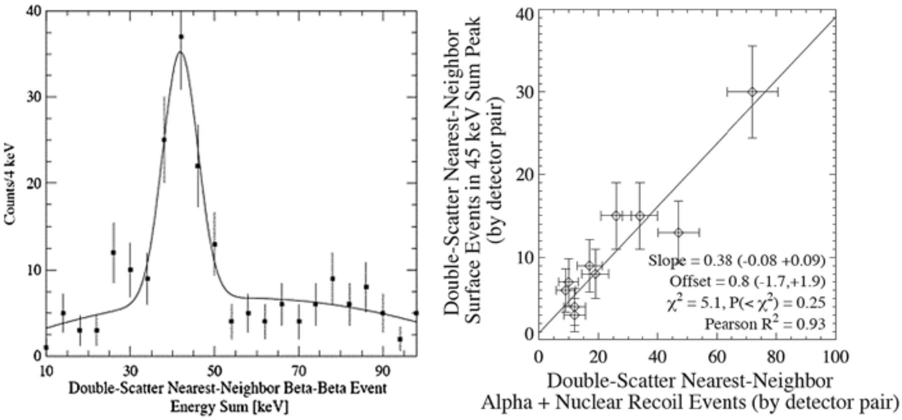

Fig. 2 (*Left*) 45 keV peak in the sum energy spectrum of beta-beta coincidences in neighboring detectors due to ^{210}Pb. The ^{210}Pb decay is rather complicated due to variety of emissions. Hence a broad peak at 45 keV is a reasonable expectation. (*Right*) Correlation of number of events in the 45 keV nearest-neighbor beta-beta sum peak vs. number of alpha events coincident between the same neighbors (alpha seen in one member of the pair, recoiling ^{206}Pb in the other)

sensor covers one quadrant of one planar face of a disc shape Ge or Si absorber (diameter = 7.5 cm, thickness = 1 cm). The four phonon sensors are independently read out. Thus, one can use the relative amplitudes and delays of the four athermal phonon sensors to localize events in the absorber.

An important aspect of the ZIPs is the dependence of the measured athermal phonon signal on the position of the events. A solution to achieve uniform detector response is to correct the phonon parameters with respect to event location, i.e. to make a lookup table of correction factors for the detector. Comparing these local averages with the desired values provides the correction [11]. Therefore it is very important for the phonon sensors to perform similarly, so that the differences between the phonon parameters depend only on the position of the events in the absorber.

In order to achieve a uniform phonon response for our current run, a new Phonon sensor tuning procedure using a real-time analysis feedback tool was developed [12]. Figure 3 shows the comparison between the timing parameter distributions among the four phonon-sensors (same detector) between the previous and the current CDMS runs.

In addition to the event position, the phonon pulse parameters may also depend on the recoil energy [11]. Compared to the previous CDMS analysis where this energy dependence would be corrected independent of the position of the events, we have included energy to the lookup table parameters for our most recent analysis. Our preliminary analysis shows that using this method, the detector response is indeed more uniform.

Whereas the previous CDMS analysis corrected this energy dependence independently of the position of the events, our most recent analysis now includes energy in the lookup table parameters. Our preliminary analysis shows that using this method indeed results in a more uniform detector response.

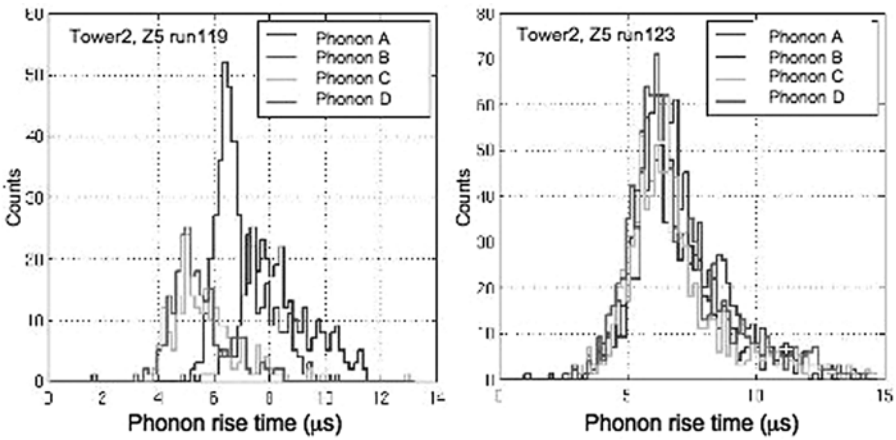

Fig. 3 (Color online) With the new phonon sensor tuning procedure the distributions of the phonon timing parameter become more uniform in the current CDMS data (*Right*) compared to the previous data (*Left*). Shown on both plots are the timing-parameter histograms for the four phonon sensors. Each histogram contains only events occurring in the region of the detector covered with the corresponding phonon-sensor (quadrant A, B, C or D)

With these improvements available, we expect to have a more uniform detector phonon response hence to increase our signal cut efficiency.

4 Conclusion

CDMSII is currently running with 30 ZIPs and aims to accumulate ∼1500 kg day of WIMP search exposure by the end of 2008. In addition to several upgrades to its previous setup at the Soudan deep underground laboratory, CDMSII now has better control of its backgrounds. With conservative estimates of background rejection efficiencies (2 misidentified event per 10^6 bulk gammas and 2 per every 10^3 surface betas) and considering all known background sources and rates, CDMSII should stay background-free and should detect WIMPs if: $\sigma_{\text{WIMP-nucleon}} > 1 \times 10^{-44}\ \text{cm}^2$.

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