Recent Results from CDMS II, Status and Future of the SuperCDMS Experiment

S. Scorza[1] *for the SuperCDMS Collaboration*

[1]Department of Physics, Southern Methodist University, Dallas, TX, US

DOI: http://dx.doi.org/10.3204/DESY-PROC-2013-04/scorza_silvia

The CDMS II collaboration operated an experiment consisting of cryogenic Ge and Si detectors designed for the direct detection of Weakly Interacting Massive Particle (WIMPs) dark matter from 2003 - 2008. Currently the SuperCDMS collaboration is operating 9 kg of advanced iZIP germanium detectors with larger mass and improved background discrimination in the CDMS II cryostat. In this talk I will discuss the latest results from the CDMS II experiment and present the current status and plans of the new SuperCDMS experiment.

1 Introduction

There are substantial evidences that dark matter is present at all scales in the universe and also a compelling motivations to believe that it consist mainly of non-baryonic objects [1] . The latest Planck results are pointing out that dark matter is contributing for about 27% of the total Universe amount [2]. The most promising dark matter particle candidate is a WIMPs: stable particles which arise in several extensions of the Standard Model of electroweak interactions [3]. Typically they are presumed to have masses between few tens and few hundreds of GeV/c^2 and a scattering cross section with a nucleon below 10^{-42} cm^2.

The Cryogenic Dark Matter Search (CDMS) Collaboration has pioneered the use of low temperature phonon-mediated detectors to detect the rare scattering of WIMPs on nuclei and distinguish them from backgrounds. With this powerful technology, operating deep underground in the Soudan mine in Minnesota, CDMS II has provided the most sensitive WIMP search in the world, and this technology has the greatest discovery potential because it has achieved nearly background free performance. The SuperCDMS program includes a scaling up of the CDMS detector technology in several phases. For each phase of SuperCDMS, not only does the target exposure need to increase but also, to maintain maximum improvement in sensitivity as a function of exposure time, we desire a zero background experiment for each phase.

The direct detection principle consists in the measurement of the energy released by nuclear recoils produced in an ordinary matter target by the elastic collision of a WIMP from the Galactic halo. The main challenge is the expected extremely low event rate (<1 evt/kg/year) due to the very small interaction cross section of WIMPs with ordinary matter. Another constraint is the relatively small deposited energy (<100 keV). The dominant background for direct dark matter search experiment are electronic recoils induced by gamma, alpha and beta particles. In addition, since the WIMP signal that we want to detect has the same proprieties of a nuclear recoil, neutrons and muon induced neutrons are the irreducible background.

In order to measure low energy recoils, cryogenic detectors - high purity Ge and Si crystals for CDMS II and high purity Ge crystals only for SuperCDMS - are employed. The simultaneous measurements of phonon and ionization signal allows an event by event discrimination between the electronic recoils which represent the main background and the nuclear recoils produced by neutrons and WIMPs. The ionization signal, corresponding to the collection on electrodes of electron-hole pairs created by the energy loss process, depends on the particle type whereas the phonon signal reflects the total energy deposit.

2 CDMS II: silicon detector results

During 2003-2008 the collaboration operated CDMS II, an array of Ge and Si detectors located at the Soudan Underground Laboratory [4] Results from data recorded between July 2007 and September 2008 in the silicon detectors will be discussed, whereas the results from Ge detectors for the same data set have been described in previous publications [5], [6].

The advantage of Si material as target is its low atomic mass: in searches for WIMPs of relatively low mass due to more favorable scattering kinematics, a WIMP of mass of 40 GeV/c2 will transfer more recoil energy to a Si nucleus than a Ge nucleus on average.

The CDMS II installation consist of 11 Si detectors. Three of them were excluded from the WIMP-search analysis: two due to wiring failures that led to incomplete collection of the ionization signal and one due to unstable response on one of its four phonon channels. The data recorded by the 8 Si detectors represent a total raw exposure of 140.2 kg-days. Background estimate, likelihood analysis and post unblinding checks are detailed in [7].

Left panel of Fig. 1 illustrates the data recorded with (bottom) and without (top) the phonon timing criteria which, providing z-position information for each event, allows to discriminate nuclear recoils form surface events which can leak into the signal region. Three WIMP-candidate events were observed with recoil energies of 8.2, 9.5, and 12.3 keV. The events were well separated in time and were in the middle of their respective tower stacks. After unblinding, extensive checks of the three candidate events revealed no analysis issues that would invalidate them as WIMP candidates.

The interpretation of these three WIMP-candidate event in terms of upper limits on the spin-independent WIMP-nucleon scattering cross section at the 90% confidence level (C.L.) is shown in the right panel of Fig. 1. The present data set an upper limit of 2.4 $\times 10^{?41}$ cm^2 for a WIMP of mass 10 GeV/c^2.

A likelihood analysis that includes the measured recoil energies of the three events favors by 3 sigma the WIMP hypothesis over that of an accidental fluctuations of known background. The resulting best-fit region from this analysis (68% and 90% confidence level contours) on the WIMP-nucleon cross-section is shown in the right panel of Fig. 1. While the results does not rise to the level of discovery it does warrant further investigations.

The CDMS collaboration is currently probing this region of WIMP nucleon cross section versus WIMP mass more completely out with our operating germanium detectors in the SuperCDMS experiment in the same Soudan underground environment with higher mass and better discrimination power.

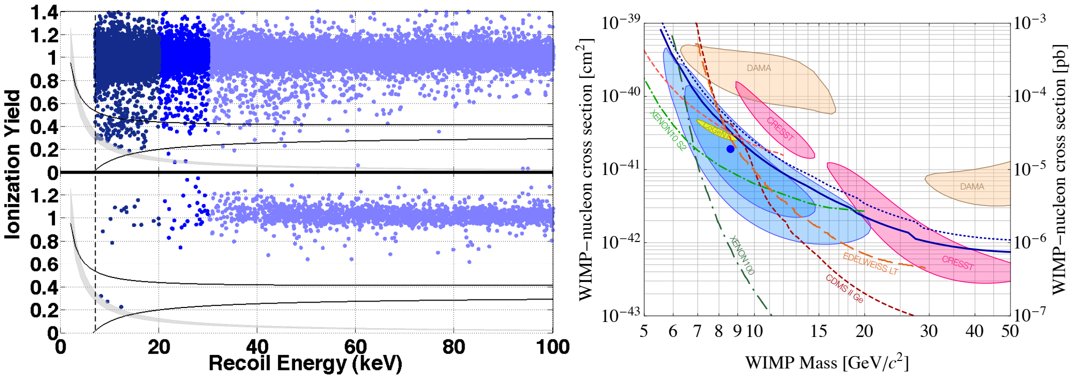

Figure 1: Left panel shows the ionization yield versus recoil energy in all detectors included in this analysis for events passing all signal criteria except (top) and including (bottom) the phonon timing criterion. The curved black lines indicate the signal region (-1.8σ and +1.2σ from the mean nuclear recoil yield) between 7 and 100 keV recoil energies. The gray band shows the range of ionization energy thresholds. Blue shades of colors refer to different recoil energy ranges of 720, 2030, and 30100 keV (dark to light). Right panel shows the experimental upper limits (90% confidence level) for the WIMP-nucleon spin-independent cross section as a function of WIMP mass.

3 The SuperCDMS Soudan experiment

SuperCDMS aims to reach a sensitivity in the WIMP-nucleus interaction detection better than 0.003 counts/kg·d for recoil energy above 8 keV. To reach this goal, background rejection and discrimination are necessary. SuperCDMS backgrounds includes gamma particles, beta particles and neutrons from cosmic rays and natural radioactivity. Thanks to simultaneous measurements of charge and phonon signals iZIP detectors can discriminate gammas from WIMPs at high efficiency, because WIMPs interact with nuclei and gammas with electrons. The iZIP detector consists of a 3-inch diameter x 1-inch thick Ge substrate (7.6 x 10^{10} cm^{-3} purity). Detector features are detailed in previous publications [8], [9].

The main limiting background of the experiment comes from interactions occurring just underneath the collecting electrodes: essentially low energy β-rays due to ^{210}Pb contamination (^{222}Rn daughter)of the detector surface and/or in the vicinity of the detectors. The incomplete charge collection of these events can mimic nuclear recoils.

Evidences of a ^{210}Pb contamination in CDMS detectors have been shown in previous data [5]: ^{222}Rn decays to ^{210}Bi, emitting X-rays conversion electrons with energies below 60 keV falling precisely within the energy range of interest for WIMP searches. ^{210}Bi decays to ^{210}Po with emission of a beta with an end-point at 1.1 MeV. Finally, ^{210}Po decays to ^{210}Pb via a 5.3 MeV alpha with a range of 20 μm, accompanied back-to-back by the recoil of the ^{210}Pb nucleus (40 nm) with a kinetic energy of 103 keV.

With the iZIP detector technology, surface events are tagged by the presence of charge on only one side charge electrode of the detector. For events occurring in the bulk of the crystal, the iZIP measures the number of electrons that travel across the detector to one charge electrode

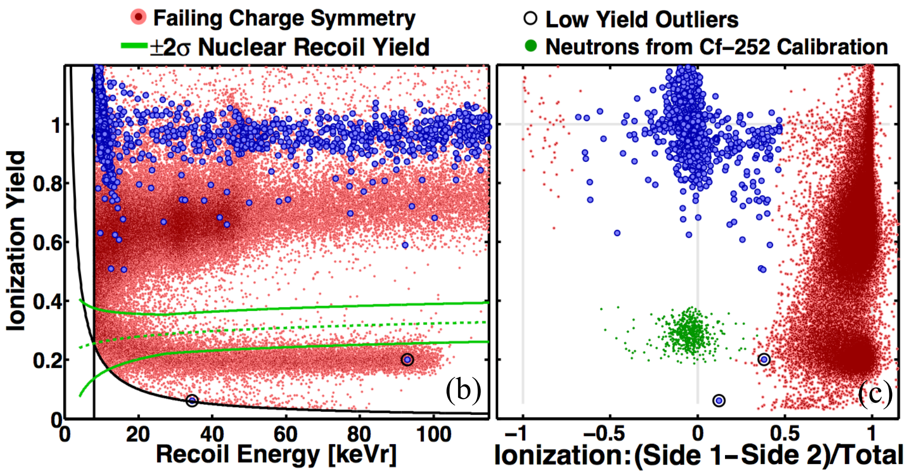

Figure 2: Left and right panels show the same data from ~900 live hours of detector T3Z1 with the ^{210}Pb source facing side 1. The symmetric charge events are represent as the large blue dots and occurs in the interior of the crystal. The events which fail the symmetric charge cut (small red dots) include surface events from betas, gammas and lead nuclei incident on side 1 from the source. The two blue dots with circles around them are outliers that show a very low charge yield and just satisfy the symmetry requirement. Left panel shows the projection in the (Y, E) plane of the data recorded and the right panel shows, in addition to those data, the nuclear recoils from neutrons from a ^{252}Cf source (green, low yield).

while at the same time measuring the number of holes traveling in the other direction to the electrode on the opposite side of the crystal. The two charge signals are therefore symmetric. Then, iZIP detector have the ability to reject surface events from bulk ones just performing a cut based on charge signal: *symmetric cut* means that the charge signal is equally shared on both sides of the detector. Three separate populations: bulk electron recoil, bulk nuclear recoil (taking advantage of different yield value between electronic and nuclear recoil) and surface electron recoil were defined using the the charge symmetric cut.

In order to verify and quantify the surface event power rejection capabilities of the iZIP detectors two detectors have been equipped with a ^{210}Pb implanted Si wafer with an activity of 1000 Pb decays per day. Left panel of Fig. 2 shows the ionization yield (ratio of ionization signal to phonon signal normalized to electron recoil events from the gamma source) as a function energy of events recorded for detectors equipped with Pb source. It consist of 37.6 live time days. Green lines represent the $\pm$ 2 σ ionization yield range of neutrons. The hyperbolic black line is the 2 keVee ionization threshold whereas the vertical black line is the recoil energy threshold (8 keVr). Electrons from ^{210}Pb (below 60 keVr) and 210Bi (mostly above 60 keVr) are distinctly separated from ^{206}Pb recoils (low yield, below 110 keVr).

In addition to the data in left panel of Fig. 2, the right panel also shows nuclear recoils from neutrons from a ^{252}Cf source (green, low yield). Nuclear recoils as bulk events show a symmetric ionization response between sides like the bulk electron recoils at higher yield. They are thus nicely discriminated from the surface events via the symmetric charge cut.

In 37.6 live time days (from March to July 2012), no events are leaking into the signal region into 50% fiducial volume in the energy range 8-115 keVnr This result limits surface events leakage to 1.7 x $10^{-}5$ @90% C.L., [10].

As with the standard CDMS detectors described in detail in [5], the phonon measurement provides z-position information for each event via the timing difference between rising edges of the phonon pulses. Phonon timing rejection capabilities of the iZIP detector have been tested and demonstrated to be preserved from the standard ZIP detector [11].

3.1 The SuperCDMS SNOLAB experiment

The SuperCDMS Soudan projected sensitivity will reach nearly an order of magnitude more sensitive than the CDMS II result. Extending the sensitivity by another order of magnitude will require a new, cleaner facility located farther underground, to reduce the neutron background that may ultimately limit our Soudan experiment. It will also require a substantial increase in Ge detector mass. This future SuperCDMS SNOLAB project will construct a new experimental apparatus, in the SNOLAB laboratory in Sudbury, Ontario, Canada.

One effective way to mitigate the challenge posed by nuclear recoils induced by neutrons in dark matter experiments is to employ active neutron vetoes. Such a strategy would improve the sensitivity of an experiment which would otherwise be limited by neutron backgrounds by vetoing a large fraction of the neutron induced recoils. In addition, it would provide sensitive in situ measurements of the true neutron environment in which the detectors are operating. This direct assay capability would allow experiments to convincingly demonstrate that low neutron backgrounds have been achieved. A neutron veto system with a very high detection efficiency can be produced by surrounding a dark matter detector with a layer of liquid scintillator. SuperCDMS collaboration is proposing to build active neutron veto shielding at SNOLAB underground laboratory.

Ongoing studies are assessing the necessity and feasibility of including a neutron veto in the SuperCDMS SNOLAB design.

SuperCDMS SNOLAB will extend the sensitivity by over an order of magnitude with an increased target mass of 200 kg and suppression of backgrounds through better shielding design, materials selection, and materials handling as well as the added depth to suppress backgrounds from cosmic-ray showers.

References

[1] G. Bertone, D. Hooper, J. Silk, Phys. Rept.**405** (2005), 279-390, arXiv:hep-ph/0404175 [hep-ph].

[2] P.A.R. Ade and others [Planck Collaboration], Astronomy & Astrophysics (2013) [arXiv:1303.5062 [astro-ph]].

[3] J. Hellis, J.S. Hagelin, D.V. Nanopoulos, K. Olive, and M. Srednicki, Nucl. Phys.**B238** (1984), 453.

[4] D. Akerib et al. (CDMS Collaboration), Phys.Rev., **D72**, 052009 (2005), arXiv:astro-ph/0507190 [astro-ph].

[5] Z. Ahmed et al. (CDMS), Science, **327**, 1619 (2010).

[6] Z. Ahmed et al. (CDMS), Phys.Rev.Lett. **106**, 131302 (2011).

[7] R.Agnese et al. (CDMS), CDMS Collaboration, arXiv:1304.4279 [astro-ph].

[8] P.L. Brink, et al, *Nucl. Instrum. Methods Phys. Res.* **A559**, 414-416 (2006).

[9] M. Pyle, et al, *AIP Conference Proceedings* **#1185**, 223-226 (2009).

[10] R.Agnese et al. (SuperCDMS) , arXiv: 1305.2405" [astro-ph].

[11] M. Pyle and others, LTD13 Conference Proceedings, **1185** (2009), 223.