The SuperCDMS Dark Matter Search

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The Electroweak Scale: Unraveling the Mysteries at the LHC

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The History of (Super)CDMS

• CDMS started out in the early 90’s as the Pilot Dark Matter Experiment, a collaboration between Stanford University, U.C. Berkeley, and U.C. Santa Barbara

• Mid 90’s: The CDMS experiment is born. Located at the Stanford Underground Facility (very shallow depth), the collaboration had grown to 11 institutions (mostly by fission, but with some fusion). 13 events were observed in the signal region for an exposure of 28 kg-d. WIMP cross-sections larger than $\sigma \approx 3 \times 10^{-42} \text{ cm}^2$ for $m_\chi \gtrsim 50 \text{ GeV/c}^2$ were excluded. PRL 84, 5699 (2000).

• 2000: CDMS II is born. Mostly the same institutions but the number of people was growing. 1 event was observed in the signal region for an exposure of 20 kg-days. WIMP cross-sections larger than $\sigma \approx 4 \times 10^{-43} \text{ cm}^2$ for $m_\chi \gtrsim 60 \text{ GeV/c}^2$ were excluded. PRD 72, 052009 (2005).

• Jan 2010: The results from the initial analysis of the full CDMS II data set published. 2 events was observed in the signal region for an exposure of 1 kg-year. WIMP cross-sections larger than $\sigma \approx 4 \times 10^{-44} \text{ cm}^2$ for $m_\chi \gtrsim 70 \text{ GeV/c}^2$ were excluded. Science 327, 1619 (2010).
The Future of (Super)CDMS

• Since 2010: CDMS II has evolved into SuperCDMS. The collaboration has grown to 18 institutions and more people than can be listed on one slide. (Significant amount of fusion, but no need to worry about a chain reaction, we’re nowhere near the size of a collider collaboration yet.)

• SuperCDMS @ Soudan: 2012-2014. Operating 10 kg detector payload, anticipating a sensitivity of $\sigma \approx 5 \times 10^{-45}$ cm$^2$

• SuperCDMS @ SNOLAB: 2016-2020 (projected). Plan on operating 200 kg detector payload, anticipating a sensitivity of $\sigma \approx 8 \times 10^{-47}$ cm$^2$
The SuperCDMS Collaboration

California Institute of Technology
Queen's University
Southern Methodist University
Texas A&M University
University of California, Berkeley
University of Evansville
Fermi National Accelerator Laboratory
Santa Clara University
Stanford University
Universidad Autónoma de Madrid
University of California, Santa Barbara
University of Florida
Massachusetts Institute of Technology
SLAC / Kavli Institute for Particle Astrophysics and Cosmology
Syracuse University
University of British Columbia
University of Colorado, Denver
University of Minnesota
The Idiot’s Guide to Dark Matter Detection

• Step 1: Make a detector out of a material with which the WIMPs can interact (in this case Ge).

• Step 2: Figure out how to determine when an interaction occurs.

• Step 3: Sit back and count the events. Compare with theoretical predictions, publish paper, give talks.
The Slightly More Realistic Guide to Dark Matter Detection

• Step 1: Make a detector out of a material with which the WIMPs can interact (in this case Ge).

• Step 2: Figure out how to determine when an interaction occurs.
  • Step 2.5: Figure out how to measure some kinematical property of the interaction, i.e. recoil energy.

• Step 3: Sit back and obtain a spectrum. Make a more quantitative comparison with theoretical predictions, publish paper, give talks.

![WIMP Differential Event Rate](image)

$WIMP \ Differential \ Event \ Rate$

$m_\chi = 100 \ GeV/c^2$

$\sigma_{\chi-n} = 10^{-45} \ cm^2$

Counts/keV/kg/day

Recoil [keV]

0 50 100

$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$

Xe Si Ge
The Real World Guide to Dark Matter Detection

• Step 1: Make a detector out of a material with which the WIMPs can interact (in this case Ge).

• Step 2: Figure out how to determine when an interaction occurs.

  • Step 2.5: Figure out how to measure some kinematical property of the interaction, i.e. recoil energy.

• Step 3: Realize that for every potential WIMP interaction there are $\approx 10^{13}$ events from unwanted background sources.

• Step 4: Take a deep breath and think real hard about your career choice.

This is what makes dark matter searches very hard!
Sources of & Remedies for the Background

- The sources of background we face:
  - Radioactive decays from naturally abundant radio-isotopes
  - Radioactive decays from “created” radio-isotopes (i.e. activated materials)
  - Interactions from Cosmic rays and their induced daughter particles

- The solutions we can implement:
  - Work with the cleanest (most radio-pure) materials you can get to minimize the rate of backgrounds from within the detector and its closest components
  - Install passive (active) shielding to suppress (detect) background from the surroundings of the experiment
  - Minimize the fabrication & handling time of the detectors, to suppress activation due to surface cosmic ray fluxes
  - Go underground. the only way to escape the cosmic ray flux and its associated cosmogenic backgrounds
CDMS Observation Strategy

1. Try to suppress all backgrounds

- 780 m rock (2090 m water equiv.)
- Active veto: muon scintillator
- Polyethylene: neutron moderation
- Lead: shields gammas
- Ancient Lead: shields $^{210}$Pb betas
- Polyethylene: shields ancient lead
- Radiopure Copper inner can
- Radiopure Ge “target”

![Muon Intensity vs Depth](image)
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CDMS Observation Strategy

2. Identify the remaining backgrounds

• What is left after all that is done is a rate of ~ 1 event/kg/keV/day above a few keV hitting the detector.

• The ability to perform even-by-event discrimination (i.e. Particle ID in the language of collider physics) allows us to extract a small WIMP signal from the remaining event.

• This requires a difference in the behavior of signal and background interactions.
Detector Physics to the Rescue

Tarek Saab - SSI 2012

Wednesday, August 1, 12

image by Mike Attisha - Brown University
Even-by-event discrimination

Ratios (like Ionization/Phonon) have discrimination power!

$$\alpha, \beta, \gamma, n, \chi^0$$

$$v/c \approx 0.3$$

More Ionization

More Phonons

Nucleus

Electron
The CDMS Phonon & Ionization Signals

• A particle interaction in the detector creates a population of phonons and a population of electrons & holes.

• An electric field of a few V/cm across the detector causes the electrons (holes) to flow to the electrodes at the top (bottom) where they are measured with a charge amplifier.

• The phonons propagate to the surface where they are measured with a Transition Edge Sensor.
Event Discrimination and Energy Calibration

- A detailed understanding of the condensed matter processes is needed to fully understand the detector response and quantify the performance of the event discrimination cuts.

SuperCDMS Detector Monte Carlo

Phonon Monte Carlo Animation
The Evolving Detector - Mass

- As the experiment explores regions of lower WIMP-proton cross-section the mass of the detectors increases to keep improving to allow the necessary detector payload/exposure to be reached.

- **A CDMS II ZIP**
  - Single-sided
  - 1 cm thick x 3” diameter
  - 250 g mass

- **A SuperCDMS @ Soudan iZIP**
  - Double-sided
  - 2.5 cm thick x 3” diameter
  - 620 g mass

- **A SuperCDMS @ SNOLAB iZIP**
  - Double-sided
  - 3.3 cm thick x 4” diameter
  - 1.38 kg mass
The Evolving Detector - Sensor Design

- As the experiment explores regions of lower WIMP-proton cross-section the design and performance of the detectors must keep improving to allow the necessary sensitivity to be reached.

- A CDMS II ZIP
  - 4 phonon channels on one surface
  - 2 charge channels on other surface
  - Deploy 5 Towers of 6 detectors each
  - Total mass ~ 7.5 kg

- A SuperCDMS @ Soudan iZIP
  - 4 phonon & 2 charge channels on EACH surface
  - Deploy 5 Towers of 3 detectors each
  - Total mass ~ 9.3 kg

- A SuperCDMS @ SNOLAB iZIP
  - 6 phonon & 2 charge channels on EACH surface
  - Deploy 24 Towers of 6 detectors each
  - Total mass ~ 199 kg
Electron Recoil Rejection in CDMS II

- Using the ionization yield and phonon timing information, an electron recoil rejection of better than $10^{-6}$ was achieved.

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**Calibration γs**

**Surface βs**

**Calibration neutrons**

**Normalized Yield**

**Normalized Timing Parameter (μs)**
The New SuperCDMS Detectors: iZIP

- Interactions in the bulk of the detector create charge signals on both (top/bottom) sides {just like CDMS II}. 

![Diagram of iZIP detector with labels for electron and positron, fiducial volume, and depth or Z position.](image-url)
Electron Recoil Rejection in iZIPs
Surface Event Rejection Using the Charge Channels

• But, when an interaction occurs near the surface, a charge signal appears on one side only.
Performance of the Surface Event Rejection

Since March 2012, 80,000 events (65000 betas & 15000 Pb recoils) were collected during the current Soudan run. Using information only from the charge channel we have a demonstrated rejection of $< 2.9 \times 10^{-5}$ with a 65% cut efficiency.

<0.005 surface events over the entire exposure of the experiment.
The SuperCDMS@SNOLAB iZIP

- The first fully patterned 4” detector has been fabricated and is currently being tested.
Background Rejection keeps pace with Exposure

- Bulk photon rejection of $10^{-7}$
  Surface “beta” rejection of $10^{-5}$ achieved

- Muon veto not needed at SNOLAB, but a neutron veto/monitor could reduce dependence on shielding radio-purity

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Net Exposure</th>
<th>Cosmogenic Neutrons</th>
<th>Radiogenic Neutrons</th>
<th>Surface Events</th>
<th>Fiducial Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDMS I @ SUF</td>
<td>28 kg-d</td>
<td>18</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>CDMS II @ Soudan</td>
<td>1 kg-y</td>
<td>0.01</td>
<td>0.07</td>
<td>1.2</td>
<td>37%</td>
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<tr>
<td>SuperCDMS @ Soudan</td>
<td>6 kg-y</td>
<td>0.07</td>
<td>0.34</td>
<td>0.005</td>
<td>68%</td>
</tr>
<tr>
<td>SuperCDMS @ SNOLAB</td>
<td>385 kg-y</td>
<td>0.03</td>
<td>0.1</td>
<td>&lt; 0.24</td>
<td>73%</td>
</tr>
</tbody>
</table>

- $\sim 1$ n/kg/day
- $\sim 1$ n/kg/yr
- $\sim 1$ n/ton/yr

Depth (mwe)

Muon Intensity (m$^{-2}$y$^{-1}$)
The SuperCDMS Road Map

- The SuperCDMS program aims to probe the WIMP scattering parameter space down to below $\sigma \approx 10^{-46}$ cm$^2$ by the end of the decade.

- It is very easy to make projections (just take your current limit and divide by 100), BUT SuperCDMS is the only experiment so far to have demonstrated the rejection performance required to achieve the projected sensitivities.
Parting Thoughts

- New iZIP detectors meet Soudan surface event rejection requirements and are expected to exceed SNOLAB requirements.
- SuperCDMS Soudan detectors are cold and running.
- R&D for G2 SuperCDMS SNOLAB in progress.