Dark Matter Search Results from the Silicon Detectors of the Cryogenic Dark Matter Search Experiment

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The SuperCDMS Collaboration

http://cdms.berkeley.edu
The Dark Matter Problem

- The Missing Mass Problem:
  - Dynamics of stars, galaxies, and clusters
  - Rotation curves, gas density, gravitational lensing
  - Large Scale Structure formation

- Wealth of evidence for a particle solution
  - MOND has problems with Bullet Cluster
  - Microlensing (MACHOs) mostly ruled out

- Non-baryonic
  - Height of acoustic peaks in the CMB ($\Omega_b$, $\Omega_m$)
  - Power spectrum of density fluctuations ($\Omega_m$)
  - Primordial Nucleosynthesis ($\Omega_b$)

- And STILL HERE!
  - Stable, neutral, non-relativistic
  - Interacts via gravity and (maybe) other mediator(s) with standard model particles
The CDMS-II Experiment

ZIP Detectors

- **Z**-sensitive **I**onization and **P**honon mediated
- 230 g Ge or 106 g Si crystals
  (1 cm thick, 7.5 cm diameter)
- Photolithographically patterned to collect athermal phonons and ionization signals
- Direct xy-position imaging
- Surface (z) event rejection from pulse shapes and timing
- 30 detectors stacked into 5 towers of 6 detectors

CDMS-II Exposure

  - 42.7 kg-days in 4 Si detectors
  - 55.9 kg-days in 6 Si detectors
- July 2007 - Sep. 2008
  - 140.23 kg-days in 8 Si detectors
CDMS II Surface Background Rejection

- Most backgrounds (e, γ) produce electron recoils.
- WIMPs and neutrons produce nuclear recoils.
- Ionization yield (ionization energy per unit recoil energy) strongly depends on recoil type.
- Particles that interact in the “surface dead layer” result in reduced ionization yield.
- These surface events can be rejected through a pulse shape rise time cut.
Background Estimate

- **Neutrons**
  - Indistinguishable from WIMPs!
  - Cosmogenic: active veto
  - Radiogenic: passive shielding & materials screening
  - < 0.13 expected events

- **Surface events**
  - Discriminate using phonon timing
  - Optimize in 3 energy bins
    - 7-20, 20-30, 30-100 keV
  - 0.47 expected events estimated before unblinding.
Shades of blue indicate the three separate timing cut energy ranges.
Unblinding Results - after timing cut

Shades of blue indicate the three separate timing cut energy ranges.

- Candidate 1
- Candidate 2
- Candidate 3

Ionization Yield vs. Recoil Energy (keV)
Unblinding Results - Yield vs Timing

Shades of blue indicate the three separate timing cut energy ranges.

- Candidate 1
- Candidate 2
- Candidate 3

Surface Event Distribution

Neutron Distribution

Normalized Yield

Normalized Timing
Three Events!

Detector T4Z3

Ionization Yield vs. Recoil Energy (keV)

Detector T5Z3

Ionization Yield vs. Recoil Energy (keV)

Surface Event Distribution

Neutron Distribution

Normalized Yield

Normalized Timing

Candidate 1

Candidate 2

Candidate 3
### Candidate 1

<table>
<thead>
<tr>
<th>Detector</th>
<th>Recoil Energy</th>
<th>Yield</th>
<th>Charge Signal to Noise</th>
<th>Single Scatter Probability</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4Z3</td>
<td>9.51 keV</td>
<td>0.27</td>
<td>4.87 σ</td>
<td>96.1%</td>
<td>July 1, 2008</td>
</tr>
</tbody>
</table>

#### Raw Phonon Traces

![Raw Phonon Traces](image)

#### Raw Ionization Traces

![Raw Ionization Traces](image)
Candidate 2

<table>
<thead>
<tr>
<th>Detector</th>
<th>Recoil Energy</th>
<th>Yield</th>
<th>Charge Signal to Noise</th>
<th>Single Scatter Probability</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4Z3</td>
<td>12.29 keV</td>
<td>0.23</td>
<td>5.11 $\sigma$</td>
<td>99.7%</td>
<td>Sep 6, 2008</td>
</tr>
</tbody>
</table>

Raw Phonon Traces

Raw Ionization Traces

Raw Phonon Traces: Phonon Channel: A, B, C, D

Raw Ionization Traces: Q-inner, Q-outer
Candidate 3

<table>
<thead>
<tr>
<th>Detector</th>
<th>Recoil Energy</th>
<th>Yield</th>
<th>Charge Signal to Noise</th>
<th>Single Scatter Probability</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5Z3</td>
<td>8.20 keV</td>
<td>0.32</td>
<td>6.66 σ</td>
<td>99.7%</td>
<td>March 14, 2008</td>
</tr>
</tbody>
</table>

**Raw Phonon Traces**

**Raw Ionization Traces**
Post-Unblinding Checks

- After unblinding, the data quality was re-checked.
  - Events occurred during high-quality data series
  - Events were well-reconstructed
  - Checked energy in other detectors to verify events were single scatters
- Surface event background estimated from the tails of three different NR sideband distributions to be:
  \[ 0.41^{+0.20}_{-0.08}(\text{stat.})^{+0.28}_{-0.24}(\text{syst.}) \]
- Checked for the possibility of $^{206}\text{Pb}$ recoils from $^{210}\text{Po}$ decay, and limited this to be <0.08 events.
Profile Likelihood Analysis

- Incorporated data-driven background models into a WIMP+background likelihood analysis.

- Monte Carlo simulations of the background-only model indicate the probability of a statistical fluctuation producing three or more events anywhere in our signal region is 5.4%.

Note: these are the Normalized Distributions!

0.7 expected events Surface + n + Pb
Profile Likelihood Analysis - cont.

Testing our known background estimate against a WIMP+background hypothesis

\[ q_0 = -2 \log \left\{ \frac{\mathcal{L}(m_\chi, \sigma_{\chi-n} = 0, \hat{\nu})}{\mathcal{L}(\hat{m}_\chi, \hat{\sigma}_{\chi-n}, \hat{\nu})} \right\} = 2 \log \left\{ \frac{\mathcal{L}(H_1)}{\mathcal{L}(H_0)} \right\} \]

- A likelihood ratio test favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (p-value: 0.19%, \(\sim 3\sigma\)).

- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c\(^2\) and WIMP-nucleon cross section of \(1.9 \times 10^{-41}\) cm\(^2\).
• It's very important to check if the WIMP+background actually fits the data well.

• The goodness of fit of the known-background-only hypothesis is 4.2%

• The goodness of fit of the WIMP+background hypothesis is 68.6%
A profile likelihood analysis favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (~3σ, p-value: 0.19%).

We do not believe this result rises to the level of a discovery, but does call for further investigation.

The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9x10^{-41}cm^2.
Next Steps: SuperCDMS Soudan!
Conclusions

- Analysis of a 140.23 kg-day exposure of the CDMS-II Si detectors has been performed.

- Three events were seen in the signal region with a total expected background of <0.7 events.

- An optimal gap analysis sets a limit for the spin-independent WIMP-nucleon cross section of 2.4x10^{-41} cm^2 for a WIMP mass of 10 GeV/c^2.

- Monte Carlo simulations of the background-only model indicate that the probability of a statistical fluctuation producing three or more events anywhere in our signal region is 5.4%.

- A profile likelihood analysis favors a WIMP + background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (~3σ, p-value: 0.19%).

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