FIRST DARK MATTER RESULTS
FROM THE CDMS 5-TOWER RUN AND THE PATH TOWARDS
\[ \sigma = 10^{-45} \text{ cm}^2 \] WIMP SENSITIVITY

Tarek Saab
for the CDMS Collaboration

SUSY 08, Seoul, Korea
The CDMS Collaboration

- Caltech
- Case Western Reserve
- FNAL
- Florida
- LBNL
- MIT
- NIST
- Queen’s

- Santa Clara
- Stanford
- Syracuse
- UC Berkeley
- UC Denver
- UC Santa Barbara
- Minnesota
- Zurich
**PRINCIPLES OF DIRECT DETECTION**

**Input from Particle Physics**

\[ \sigma_0 = \left( \frac{m_r}{m_{\chi-p}} \right)^2 A^2 \sigma_{\chi-p} \]

**Knowledge of Nuclear Structure**

\[ F^2(Q) = \left( \frac{3 j_1 (qR_1)}{qR_1} \right)^2 \exp \left( - (qs)^2 \right) \]

**Our choice of Target Nucleus**

\[ m_r = \frac{m_{\chi} m_N}{m_{\chi} + m_N} \]

\[ m_{\chi-p} = \frac{m_{\chi} m_p}{m_{\chi} + m_p} \]

\[ \frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{\sqrt{\pi} v_0 m_{\chi} m_r^2} F^2(Q) T(Q) \]

**Input from Astrophysics**

\[ T(Q) = \exp \left( -v_{min}^2/v_0^2 \right) \]

\[ v_{min} = \sqrt{\frac{E_R m_N}{2m_r^2}} \quad v_0 \approx 220 \text{ km/s} \]
WIMP HUNTING

- Elastic scattering of a WIMP from a nucleus deposits a small, but detectable amount of energy ~ few x 10 keV
- Featureless exponential energy spectrum
  - no obvious peak, knee, break, ...
  - that determines $M\chi$
- **Expected rate $\ll 0.01$/kg-day**
- Radioactive background million times higher
- Background Reduction/Rejection is key

WIMP DIFFERENTIAL EVENT RATE

$M\chi = 100$ GeV/$c^2$
$\sigma_{\chi-N} = 10^{-45}$ cm$^2$

Counts $[\#10^{-6}$/kg/keV/day$]$}

Low→no Background a Must for WIMP Discovery
DETECTOR PHYSICS TO THE RESCUE

WIMPs and Neutrons scatter from the Atomic Nucleus

Photons and Electrons scatter from the Atomic Electrons

image by Mike Attisha - Brown University
TWO TYPES OF RECOIL

Signal

Nuclear Recoils

$E_r \sim 10$ keV

$v/c \approx 10^{-3}$

Dense Energy Deposition

Background

Electron Recoils

$v/c \approx 0.3$

Sparse Energy Deposition

Density/Sparsity: Basis of Discrimination
DISCRIMINATION STRATEGIES

Phonons
10 meV/ph
100% energy

Ionization
~ 10 eV/e
20% energy

Scintillation
~ 1 keV/γ
few % energy

CUORE
CRESST I
TeO₂, Al₂O₃, LiF

CDMS
EDELWEISS
Ge, Si

NAIAD
DAMA
ZEPLIN I
DEAP
CLEAN
XMASS

CRESST
ROSEBUD
CaWO₄, BGO
ZnWO₄, Al₂O₃ ...

ZEPLIN II, III
XENON, LUX
WArP, ArDM
SIGN

Xe, Ar, Ne

DRIFT, DM-TPC,
IGEX, COUPP
COSME, ANAIS

Ge, CS₂, C₃F₈
CDMS: THE BIG PICTURE

Use shielding and discrimination to maintain a Background Free experiment with cryogenic semiconductor detectors

- Shielding
  - Passive: Mine Depth, Pb, Poly
  - Active: muon veto shield

- Energy Measurement/Discrimination
  - Phonon (Full recoil energy)
  - Ionization (Reduced for nuclear recoil wrt electron recoils)

- Position measurement (x,y,z)
  - From phonon pulse timing
CDMS APPARATUS

- Surround detectors with active muon veto
- Use passive shielding to reduce $\gamma/n$
  - Overburden reduces $\mu$-induced neutrons
  - Polyethylene for low-energy neutron
  - Lead and Copper for gammas
- 5 Towers now installed and taking data
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Z-SENSITIVE IONIZATION PHONON DETECTORS

Transition Edge Sensors (TES)
Operated at ~40 mK for good phonon signal-to-noise

Phonon side: 4 quadrants of athermal phonon sensors
Energy & Position (Timing)

Charge side: 2 concentric electrodes (Inner & Outer)
Energy (& Veto)

3” (7.6 cm)
Ge: 250 g
Si: 100 g
EXCELLENT ENERGY, POSITION RESOLUTION
EXCELLENT ENERGY, POSITION RESOLUTION

Detector Calibration

\textbf{Am}^{241}:
\begin{align*}
\gamma & 14, 18, 20, 26, 60 \text{ keV}
\end{align*}

\textbf{Cd}^{109} + \text{Al foil}:
\begin{align*}
\gamma & 22 \text{ keV}
\end{align*}
EXCELLENT PRIMARY ($\gamma$) BACKGROUND REJECTION

- Radioactive source data defines the signal (NR) and background (ER)
- Yield = Ionization/Phonon
  Most effective Particle ID
- $>10^4$ Rejection of $\gamma$
- Drooping events from $\beta$ Ionization collection incomplete on surface. Yield can be sufficiently low to pollute the signal region
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Need extra handle to reject $\beta$s in signal region
SURFACE $\beta$ REJECTION

Faster down conversion of athermal phonons at surface provides faster phonon signal for $\beta$s.

Cut chosen at a level to contribute $\sim 0.5$ event total leakage to WIMP candidate.
NET CDMS REJECTION
YIELD + TIMING PROVIDE EXCELLENT (>MILLION:1)
REJECTION OF E-M BACKGROUND

~15σ Away from Signal Band
CDMS 5-TOWER DATA AT SOUDAN
CDMS @ Soudan

4 hours drive North of Minneapolis
SOUDAN IN THE MORNING
SOUDAN IN THE EVENING
THE CDMS COLLABORATION

CDMS Institutions

National Laboratory
- Fermilab
- NIST

US University
- CalTech
- Case Western
- Colorado (Denver)
- Florida
- Minnesota
- MIT
- Stanford
- Santa Clara
- Syracuse
- UC Berkeley
- UC Santa Barbara

International
- QUEENS
- Zurich
FIVE TOWER RUNS (2006-8)

- 30 ZIPs (5 Towers) installed in Soudan icebox:
  - 4.75 kg Ge, 1.1 kg Si

- Combination of Ge and Si Detectors
  - Neutron background measurement
  - WIMP Mass Measurement
  - Ge more sensitive to higher mass WIMPs.
  - Si to lower mass WIMPs
Published Results

Four successful 5-T data runs so far:

- Run 123 (10/06-3/07): 430 kg-d Ge (raw)
- Run 124 (4/07-7/07): 224 kg-d Ge (raw)
- Run 125 (7/07-1/08): 465 kg-d Ge (raw)
- Run 126 (1/08-05/08): 273 kg-d Ge (raw)

- Run 127 just started...

>10x the 2-Tower exposure so far!

Results shown today are for 123+124 data

Will more than double the exposure with data in the can...
WIMP CANDIDATE: BLIND ANALYSIS

All cuts set blind, without looking at the signal.
i.e. we do not look at events which are:
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i.e. we do not look at events which are:

- Inside the good fiducial volume
WIMP CANDIDATE: BLIND ANALYSIS

All cuts set blind, without looking at the signal. i.e. we do not look at events which are:

- Inside the good fiducial volume
- In the Nuclear Recoil Band

![Graph showing Ionization Yield vs Phonon Recoil Energy with selected regions marked as Good Inner Fiducial Vol](image-url)
WIMP CANDIDATE: BLIND ANALYSIS

All cuts set blind, without looking at the signal. i.e. we do not look at events which are:

- Inside the good fiducial volume
- In the Nuclear Recoil Band
- Not a Multiple Scatter
All cuts set blind, without looking at the signal. i.e. we do not look at events which are:

- Inside the good fiducial volume
- In the Nuclear Recoil Band
- Not a Multiple Scatter
- Not a surface event: phonon timing cut

**Phonon Delay**

**Phonon Risetime**

**Surface Event**

**Nuclear Recoil**

**WIMP CANDIDATE: BLIND ANALYSIS**
EXPECTED $\beta$ LEAKAGE

- ~300:1 Rejection is chosen on calibration Data
  - Provides Near Optimum Sensitivity
- WIMP side bands show 200:1 Rejection
- Difference dominated by differences in phonon/charge side rejection and $\beta$ energy spectrum in calibration
- Expected Leakage $\sim 0.6 \pm 0.5$ events
- Uncertainty on Leakage Preliminary and Conservative
# Expected Neutron Background

## Cosmogenic
- 8 Vetoed nuclear recoil multiples observed
- No Vetoed Singles Observed
- Use MC Predicted singles/multiples ratio and vetoed to unvetoed ratio
- Expect < 0.1 unvetoed neutron background

## Fission/alpha-N
- Fission neutron < 0.1 from Pb counting
- Alpha-N < 0.03 from Uranium in Poly

Expect Total Neutron background < 0.2 events
EFFICIENCIES

TOTAL EFFICIENCY WITH RESPECT TO FULL DETECTOR MASS
All cuts set and frozen!

Expected Events:
77 ± 15 single scatters in NR

THE WIMP SEARCH DATA: GE

PRIOR TO, 4TH OF FEB, 2008
97 singles in signal region before applying surface cut
OPEN THE BOX:
SURFACE EVENT CUT
MIDNIGHT PST, 4TH OF FEB, 2008

Expected Background: 0.6 ± 0.5 surface events and < 0.2 neutrons

0 observed events
SPIN-INDEPENDENT EXCLUSION LIMIT

$10^{-7}$ pb

Projected

Spin-independent cross section [cm$^2$]

WIMP mass [GeV/$c^2$]

Projected

CDMS II Ge combined

CDMS II 2008 Ge

XENON10 2007

CDMS II I1+2T Ge Reanalysis

Ruiz et al. 2007 68% CL

Ruiz et al. 2007 95% CL

Baltz Gondolo 2004
CDMS 5-TOWER RESULTS

- Zero Events Observed! (654 kg-days of raw data)
- Best Spin-Independent limit above $40\text{GeV}/c^2$ WIMP Mass
- ~Twice the exposure of current analysis waiting in analysis pipeline. Double again by end 2008
- Will surpass target sensitivity of $2 \times 10^{-44}\text{cm}^2$
- Preprint available @ http://cdms.berkeley.edu and on arXiv article id 0802.3530
LOOKING AHEAD TOWARDS
\[ \sigma = 10^{-45} \text{ CM}^2 \]
BASELINE DETECTOR FOR SUPERCDMS

CDMS-II ZIPs:
3" dia x 1 cm => 0.25 kg of Ge

Existing ZIPs

SuperCDMS ZIPs:
3" dia x 1" => 0.64 kg of Ge

ZIPs for SuperCDMS
## GE Detector Mass Scaling

<table>
<thead>
<tr>
<th>Project</th>
<th>Ratio</th>
<th>kg/det</th>
<th># Det</th>
<th>Total kg</th>
<th>Fiducial</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDMS II</td>
<td>x 1</td>
<td>0.25</td>
<td>16</td>
<td>4.0</td>
<td>50%</td>
</tr>
<tr>
<td>SCDMS 25 kg</td>
<td>x 2.5</td>
<td>0.64</td>
<td>42</td>
<td>27</td>
<td>80%</td>
</tr>
<tr>
<td>R&amp;D SCDMS 1000 kg</td>
<td>x 10</td>
<td>2.5</td>
<td>228</td>
<td>570</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>x 20</td>
<td>5.0</td>
<td>228</td>
<td>1140</td>
<td>90%</td>
</tr>
</tbody>
</table>
DISLOCATION FREE GE NEEDED FOR 6 IN DETECTORS

- 1 cm thick by 30 mm diameter dislocation free crystal from E.E. Haller illuminated with $^{241}$Am source operated at ~40 mK
- Excellent resolution and charge collection efficiency
ZERO BACKGROUND NECESSARY FOR DISCOVERY
FIRST DARK MATTER RESULTS FROM THE CDMS 5-TOWER RUN AND THE PATH TOWARDS $\sigma = 10^{-45}$ CM$^2$ WIMP SENSITIVITY

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SUSY 08