CDMS and SuperCDMS

SLAC Summer Institute
August 2, 2007
Blas Cabrera
Co-Spokesperson CDMS & Spokesperson SuperCDMS

- CDMS-II science results - less than 1 evt / kg of Ge / month
- Status of CDMS-II 5-Tower run - target < 1 evt / kg of Ge / year
- SuperCDMS 25 kg experiment
  - Two SuperTowers at Soudan (DOE & NSF started FY07)
  - SuperCDMS 25 kg at SNOLab (review FY08 for FY09 start)
- EDELWEISS and CRESST status & plans leading to EUREKA
- Comparisons with liquid experiments: XENON, WArP, COUPP
- Conclusions
Composition of the Cosmos

- Dark matter forms structure of universe
- Dark Energy - expands 73%
- WMAP best fit

Diagram:
- Dark Matter - clumps 23%
- Free H & He - warm 3%
- Stars + gas 0.5%
- Ghostly neutrinos 0.3%
- Heavy elements - us 0.03%
Numerical simulations for DM Halos

- The phase-space structure of a dark-matter halo: Implications for dark-matter direct detection experiments, e.g., A. Helmi, S. White, and V. Springel
  PRD 66, 063502 (2002)

- Solar system moves with respect to zero mean velocity halo at 220 km/s
What is the dark matter?

- neutrino $\nu$ – hot DM
- neutralino $\chi$
- “generic” WIMP
- axion $a$
- axino $\tilde{a}$
- gravitino $\tilde{G}$
- wimpzilla, ...

L. Roszkowski
The Signal and Backgrounds

Signal (WIMPs)

Nucleus Recoils

$E_r \approx 7 \times 10^{-4}$

$E_r \approx 10$’s KeV phonons

Neutrons also interact with nuclei, but mean free path a few cms

Background (gammas)

Electron Recoils

$E_r$ $v/c \approx 0.3$

ionization

Surface electrons from beta decay can mimic nuclear recoils

$\chi^0$
• Variety of techniques search for WIMP dark matter - interesting sensitivity
• Several have the potential to reach $10^{-44}$ cm$^2$ soon and $10^{-46}$ cm$^2$ in future
Discrimination strategies

- Most particle physics experience in MeV range
- Direct detection requires keV scale

Phonons
10 meV/ph

CRESST
Scintillation
$\sim 1$ keV/γ

CDMS
Ionization
$\sim 10$ eV/e

EDELWEISS

Sub-K low threshold
large mass >$$

DAMA
ZEPLIN I
DEAP
CLEAN

Scintillation
higher threshold &
large fluctuations

ZEPLIN
XENON
WArP, ArDM

Noble liquids high threshold but large mass <$$$

need both to confirm results
CDMS Collaboration

CDMS-II at Soudan (2090 mwe)

- At SUF
  - 17 mwe
  - 0.5 n/d/kg
- At Soudan
  - 2090 mwe
  - 0.6 n/y/kg
- At SNOLab
  - 6060 mwe
  - 1 n/y/ton
CDMS-II Soudan facility
Run 118 (1T) & Run 119 (2T) in Soudan
CDMS Active Background Rejection

Detectors with excellent event-by-event background rejection

- Measured background rejection:
- 99.995% for EM backgrounds using charge/heat
- 99.4% for β’s using pulse risetime as well
- Much better than expected in CDMS II proposal!

Tower of 6 ZIPs
- Tower 1
  - 4 Ge
  - 2 Si
- Tower 2
  - 2 Ge
  - 4 Si

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Blas Cabrera - Stanford University
Really Cool Detectors: ZIPS

250 g Ge or 100 g Si crystal
1 cm thick x 7.5 cm diameter
Photolithographic patterning
Collect athermal phonons:
Crystal lattice vibrations
Speed of sound in crystal ~ 1 cm/ms
results in measurable delays between
the pulses of the 4 phonon channels
=> distinguish surface from bulk events

Z-sensitive
Ionization and
Phonon-mediated

Measure ionization in low-field
(~volts/cm) with segmented
contacts to allow rejection of
events near outer edge

1 µm tungsten
380 µm x 60 µm aluminum fins
Model ZIP Detector Signal

- Charge & Phonon signals occur on a similar timescale
- Phonon pulse time of arrival allows for event position reconstruction
- 20 keV event in a Si & Ge ZIP

**Si ZIP**

EXCELLENT S/N FOR 20 KeV TRUE RECOIL ENERGY

**Ge**

EXCELLENT S/N FOR 20 KeV TRUE RECOIL ENERGY
ZIP Phonon Position Sensitivity

Am^{241}:
\gamma 14, 18, 20, 26, 60 keV

Cd^{109} + Al foil:
\gamma 22 keV
Energy calibration of Ge ZIP with $^{133}$Ba source

Excellent agreement between data and Monte Carlo
Nuclear recoil calibration: Ge&Si ZIPs w/ $^{252}$Cf

Nuclear recoils in Ge ZIP

Nuclear recoils in Si ZIP

Excellent agreement between data and Monte Carlo
WIMP search data (5 Ge ZIPs ~53 kg-d)

Prior to phonon pulse shape timing cuts

After timing cuts, which reject most electron recoils

10.4 keV Gallium line

Background ESTIMATE: 0.37 ± 0.20 (sys.) ± 0.15 (stat.) electron recoils, 0.05 recoils from neutrons expected
Is the Candidate Event Just Background?

- Very likely so!
- Event occurred during run when its detector, Z11, suffered reduced ionization yield
  - Worst run for this detector
- In hindsight, our cuts on bad data periods for single detectors weren't strict enough
  - Some other detectors, without candidates, had similarly bad periods
- Will improve data quality screening for next run

### Ionization Yield vs. Time

![Graph showing ionization yield over time with a candidate event marked.]
Improvements in Surface Event Rejection

- Significant improvements in our analysis of phonon timing information
  - Surface event rejection improved by x3; kept pace with exposure increase!
  - Cuts are set from calibration data (blind analysis)
- We still have more discrimination power available as needed
  - Can continue to keep backgrounds < 1 event as more data accumulates
  - This is the real strength of CDMS detectors!

Chi-square (background pulse shape) - Chi-squared (neutron pulse shape)
How the detectors work

- Measure both heat and ionization produced
Develop detailed detector MC

- Compare signal collected in one quadrant versus x-y averaged over z for real ZIP T1Z5 (left) and simulated mZIP (right)
Scientific reach of CDMS at Soudan

- CDMS II - Current
- CDMS II - Projected
- ZEPLIN-1
- Edelweiss
- SUSY Models
- DAMA
- new XENON10 preprint
- http://dmtools.brown.edu
- Gaitskell&Mandic

Cross-section [$\text{cm}^2$] (normalised to nucleon)

WIMP Mass [GeV]
Sensitivity issues for Ge and Xe

limits at low mass very sensitive to threshold effects

limits at high mass robust

WIMP Mass [GeV]

WIMP-Nucleon Cross-Section [cm²]

10 keVr analysis threshold
include 5-10 keVr

4.5 keVr threshold with \( Q = 0.19 \)

~8 keVr threshold with variable \( Q \)
Spin Dependent WIMP limits

Spin-sensitivity from $^{73}\text{Ge}$ (J=9/2, 7.7%) and $^{29}\text{Si}$ (J=1/2, 4.7%)

For further details see PRD D73, 011102 (2006)
Five Towers now in Soudan

Tower 1:
4 Ge & 2 Si

Tower 2:
2 Ge & 4 Si

Tower 3:
4 Ge & 2 Si

Tower 4:
4 Ge & 2 Si

Tower 5:
5 Ge & 1 Si
CDMS Detector Operation [5-Tower]

WIMP search starts : Sat Oct 21 16:25:08 2006

WIMP sensitivity calc. assumptions

1. Spherical Halo Model (DM local density = 0.3 GeV/cm^3)
2. \(<v_{\text{Earth}}> = 250 \text{ km/sec} \times \text{ MB distribution}
3. Null observation & Zero background
4. Poisson statistics
5. 10keV analysis threshold (GeV)
6. 40% detection efficiency (assumed)
7. 653.22 [kg-day] = (19-3) Ge x 0.25 [kg] x 163.31 [day]

Pre-Preliminary
Estimated based on detector live time so far
CDMS internal use only

MSSM(Kim2002)
DAMA
XENON10 (NoBgSub)
CDMS2006PRL
CDMSST (today)
Proposal to DOE and NSF - May 06

SuperCDMS 25 kg Experiment

The SuperCDMS Collaboration
California Institute of Technology
Case Western Reserve University
Fermi National Accelerator Laboratory
Lawrence Berkeley National Laboratory
National Institute of Standards and Technology, Boulder
Queen’s University, Canada
Santa Clara University
Stanford University
University of California at Berkeley
University of California at Santa Barbara
University of Colorado at Denver and Health Sciences Center
University of Florida
University of Minnesota

• Spokesperson: Blas Cabrera
  Co-spokesperson: Dan Akerib
  Project Manager: Dan Bauer
  Chair of Board: Bernard Sadoulet
**Scientific reach of SuperCDMS 25 kg**

- Explore very interesting region which is complementary to LHC

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<thead>
<tr>
<th>Experiment</th>
<th>Cross-section sensitivity</th>
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<tr>
<td>CDMS II 2-T (2005)</td>
<td>$1.6 \times 10^{-43}$ cm$^2$</td>
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<tr>
<td>CDMS II 5-T (2007)</td>
<td>$2.1 \times 10^{-44}$ cm$^2$</td>
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<tr>
<td>SuperCDMS Detectors 2-ST at Soudan (2009)</td>
<td>$7.2 \times 10^{-45}$ cm$^2$</td>
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<tr>
<td>SuperCDMS 25 kg 7-ST at SNOLAB (2012)</td>
<td>$1.3 \times 10^{-45}$ cm$^2$</td>
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![Graph showing WIMP mass vs. cross-section comparison with different experiments and new SuperCDMS 25 kg events for LCC2](image)

The high discovery potential now includes 5 events for LCC2.
Sensitivity reach with full bkgd analysis

![Graph showing sensitivity reach with full background analysis.](image)

- CDMS 2007
- SuperCDMS 25kg 2012
- Current limit T1-2 Aug 04
- SuperCDMS Soudan 2009
- SuperCDMS 150kg
- No subtraction
- Background subtraction
- Zero background

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SUF (17 mwe), Soudan (2090 mwe), & SNOLab (6060 mwe)

- At SUF
  - 17 mwe
  - 0.5 n/d/kg

- At Soudan
  - 2090 mwe
  - 0.6 n/y/kg

- At SNOLab
  - 6060 mwe
  - 1 n/y/ton
SuperCDMS at SNOLab

★ SuperCDMS is approved to be sited at SNOLab
★ We have received strong interest from Canadian collaborators - Queens ...

New lab space
(under construction - ready in 2007)
SuperCDMS in Expanded Ladder Lab

SuperCDMS
25 kg Experiment
ST1&2 Soudan -> SNOLab like Tower 1 SUF -> Soudan

- Tower 1 (4 Ge & 2 Si) at SUF (Stanford) then at Soudan

19 neutron events at SUF

0 events at Soudan
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
1” thick ZIP processing at Stanford

dedicated sputtering system (in use)

aligner (in use) - plan new dedicated unit

spinner (in use)

dry etch (in use)
Data from UCB/Case TFs for Si 1” ZIP

- First data from 1” Si ZIP showing reconstructed location of $^{109}$Cd events and spectrum
Data from UCB/Case TFs for Ge 1” ZIP

- First data from 1” Ge ZIP showing $^{241}\text{Am}$ 60 keV gamma events in phonon vs charge.
Improved background rejection and reduction

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<tr>
<td>Background rejection</td>
<td>×4</td>
</tr>
<tr>
<td>Analysis discrimination</td>
<td>×2</td>
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<tr>
<td>Background reduction</td>
<td>×5</td>
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<tr>
<td><strong>Total Improvement</strong></td>
<td>= ×40</td>
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<tr>
<td>Production rate per kg</td>
<td>×5</td>
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Table 2: Targeted improvement factors over CDMS II advanced analysis levels (see Section 3.2) to achieve SuperCDMS 25 kg sensitivities with zero background from internal sources. The cosmogenic fast-neutron background is eliminated by the SNO-LAB overburden of 6000 mwe.

- to meet SuperCDMS 25 kg goals only need ×20 actual

Increase phonon collection area ×2 and new H-a-Si electrodes suppress charge back-diffusion ×2

Expect at least an additional ×2 from advanced timing analyses

Expect ×2.5 from additional thickness and ×2 from better control of Rn

Need ×20 of this ×40 total for the SuperCDMS 25 kg target background

Expect ×2.5 from additional thickness and ×2 from improved fabrication efficiency
Schematic of new 'SNObox'
• Variety of techniques search for WIMP dark matter - interesting sensitivity
• Several have the potential to reach $10^{-44}$ cm$^2$ soon and $10^{-46}$ cm$^2$ in future
Conclusion

• Soudan Towers 1&2 lead field by x10 - spin-independent limits PRL 2006 and spin dependent limits PRD RC 2006.
• XENON10 preprint now leads field by x2 at high mass
• Soudan Towers 1-5 will start mid-2006 and run through 2007 for an additional x10 improved sensitivity.
• We have a great horse race for discovering WIMPs
• Strong science case for ton scale direct detection major projects, as endorsed by Dark Matter SAG and P5.
• WE ARE APPROVED TO PROCEED WITH 2 OF 7 TOWERS FOR SuperCDMS 25 kg EXPERIMENT, AND REVIEWS DURING FY08 FOR APPROVAL OF REMAINING 5 TOWERS. WE CAN HELP MAINTAIN US LEAD IN THIS RESEARCH WHICH IS COMPLEMENTARY TO LHC AND FUTURE ILC.