The Future of CDMS: SuperCDMS Soudan, SuperCDMS SNOLAB, & GEODM DUSEL + iZIP Huge Detector Advance

KITP - December 18, 2009

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Spokesperson for SuperCDMS
Stanford - KIPAC
Archive submission problem
New - arXiv:0912.3592
also on CDMS website at
http://cdms.berkeley.edu/
CDMS-II pre-unblinding analysis

- Classic Timing Cuts
- Optimum sensitivity ~0.6 event leakage
- Optimum cuts for each detector (x2 exposure)
- Reach 2E-44 cm²
Sensitivity of Future Detectors
# SuperCDMS Schedule

<table>
<thead>
<tr>
<th>Year</th>
<th>CDMS-II 4 kg Ge 2E-44 cm²</th>
<th>Detector R&amp;D 3&quot; dia x 1” mZIP</th>
<th>ST1 test</th>
<th>SuperCDMS Soudan 15 kg Ge 5E-45 cm²</th>
<th>Detector R&amp;D 100 mm dia x 33.3 mm iZIP</th>
<th>Detector Fabrication</th>
<th>SuperCDMS SNOLAB 100 kg Ge 3E-46 cm²</th>
<th>NSF DUSEL R&amp;D for GEODM</th>
<th>Detector Fabrication for GEODM 1500 kg iZIP</th>
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From CDMS to SuperCDMS to GEODM

CDMS II
- 7.5 cm x 1 cm ~ 0.23 kg / det
- 15 detectors = 3.5 kg

SuperCDMS Soudan
- 7.5 cm x 2.5 cm ~ 0.60 kg / det
- 25 detectors = 15 kg

SuperCDMS SNOLAB
- 10 cm x 3.3 cm ~ 1.4 kg / det
- 84 detectors = 120 kg

Ge Observatory for Dark Matter
GEODM DUSEL
- 15 cm x 5 cm ~ 5 kg / det
- 300 detectors = 1500 kg
SuperCDMS Soudan
SuperCDMS Soudan approved

- ST1 now operating
- ST2 now complete

Use same five tower striplines and electronics to operate 15 kg of Ge inner detectors instead of 3 kg of Ge for CDMS-II
Detector Improvements

✓ **SuperTower** = five 1-inch thick detectors + two 1-cm thick ionization only detectors

✓ **Increase thickness** (2.5 x).
  ➡ better surface/volume
  ➡ increase manufacture

✓ **Optimize Al fin design** (increase Al coverage)
  ✓ enhance phonon signal to noise

✓ **Optimize phonon sensor layout**
  ➡ better rejection of surface events

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Phonon Sensor Layout

- Events at large radius have delay times similar to events at intermediate radius.
- Effect due to phonons reflecting off outer cylindrical walls back into central region of detector.

- New metric compares start times of inner 3 channels to the start time of outer channel, breaks degeneracy.
Detector performance versus MC

SuperCDMS detector

Detector Monte Carlo
SuperTower 1 taking data

- ST1 Soudan data
- 4 of 5 ST1 mZIPs operating well (one channel failed)
- Alpha rates meet specifications of less than 0.3 alphas per day per detector
- Plan to take huge calibration data sets through end of 2009
STI Surface Testing

Before Timing Applied

After Timing Applied

1 inch detector (G9F)

Recoil Energy (keV)

Ionization Yield

133Ba
252Cf

133Ba
252Cf
iZIP Detector Advance
IZIP Interleaved Design

- Interleaved electrodes and phonon sensors on both sides of the detector.
- Alternating +2V/ground (-2V/ground, opposite side) phonon sensors.
iZIP double-sided design

- Interleaved charge and phonon on both sides
- Demonstrated 3” dia x 1”
- For SNOLAB baseline is 100 mm dia x 33.3 mm (Ortec & Umicore accepting orders)
Surface charge discrimination demonstrated

• less than 1:1000 surface electrons leak into bulk

10^9 Cd source 100 betas/sec
Remarkable phonon properties

- two separate events on left and right hand side
- top is top side and bottom is the bottom side
- note that after 500 µs all channels identical
- position information in leading part
Summed phonon channels

- Two traces in each plot correspond to summed phonon pulses on top (blue) and bottom (red)
- Left event close to bottom and right event close to top
- Top $T_c = 105\pm3$ mK & bottom $T_c = 46\pm2$ mK
Deconvolution removes TES time constants

- Top with $T_c = 105$ mK has $\tau_{ETF} = 20$ µs deconvolute to 10 µs
- Bottom with $T_c = 46$ mK has $\tau_{ETF} = 60$ µs deconvolute to 10 µs
Phonon total sum

- Summing top and bottom for each event produces pulses that are remarkably proportional to energy

- As shown in right leading edge, only minor leading edge differences
Phonon discrimination better than mZIP

- In addition phonon symmetry and timing better with iZIP than with mZIP- 1:3,000 demonstrated
Yield rejection

- 1000:1 rejection of low yield Surface Events

- Due to cosmogenic neutron leakage, misidentification study on NR band surface events impossible
Surface Rejection Estimates

- Naively expect Yield Leakage to anticorrelate with Q & P discrimination
- Naively expect some correlation between Q & P discrimination

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<tr>
<td>Yield Leakage</td>
<td>1:3000</td>
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<tr>
<td>Q symmetric</td>
<td>1:1000</td>
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<tr>
<td>P $\chi^2$ Leakage</td>
<td>1:3000</td>
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<tr>
<td>Total Surface–NR Leakage</td>
<td>1:3e6–1e10</td>
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Radial Fiducial Volume

• e\&h n0 efficiency: 
  \(55 \pm 2 \pm 10\%\)
• h only n0 efficiency: 
  \(85 \pm 2 \pm 10\%\)

• Huge Funnel for e collecting electrode
• Shared events: e >> h
• Lateral charge diffusion for e >> h
Indirect gap semiconductors

- Conduction electrons in valleys along [111] for Ge and have very anisotropic effective masses

- Holes have minimum energy at center of zone so behave more isotropically
Model valley energy

- Elliptical potential wells given by

\[ \varepsilon_k = \hbar^2 \left\{ \frac{(\delta k_1)^2}{2m_\parallel} + \frac{(\delta k_2)^2}{2m_\perp} + \frac{(\delta k_3)^2}{2m_\perp} \right\} \]

where for Ge

\[ m_\parallel = 1.58 \, m_e \]
\[ m_\perp = 0.081 \, m_e \]

nearly a factor of 20!
Oblique propagation necessary

- Electric field along [100]
  \[ e\vec{E} = \frac{d\vec{p}}{dt} \]
  so that change in momentum is along [100] since
  \[ \vec{p} = \vec{m} \cdot \vec{v} = m_\perp \vec{n}_\perp + m_\parallel \vec{n}_\parallel \]

- However, change in velocity is nearly along perpendicular to [111] since
  \[ \vec{v} = v_\perp \hat{n}_\perp + v_\parallel \hat{n}_\parallel \]
Drift velocity direction

- For each valley the drift velocity vector is

\[
\begin{pmatrix}
  v_x \\
  v_y \\
  v_z 
\end{pmatrix} = \frac{2e[\varepsilon \tau(\varepsilon)]}{3m_e kT} \begin{pmatrix}
  m_e / m_\parallel & 0 & 0 \\
  0 & m_e / m_\perp & 0 \\
  0 & 0 & m_e / m_\perp 
\end{pmatrix} \begin{pmatrix}
  E_x \\
  E_y \\
  E_z 
\end{pmatrix}
\]

and for

\[
\vec{E} = E \left( \sqrt{1/3} \hat{x} + \sqrt{2/3} \hat{y} \right)
\]

we obtain

\[
\vec{v} = \frac{2e[\varepsilon \tau(\varepsilon)]}{3m_e kT} E \left( \sqrt{1/3} \frac{\hat{x}}{1.59} + \sqrt{2/3} \frac{\hat{y}}{0.081} \right) = v_\varepsilon \left( 0.363 \hat{x} + 10.08 \hat{y} \right)
\]

which is 2 deg from y-axis which is perpendicular to [111] and back towards [100].
Oblique propagation simulation
Qualitatively similar features
Electrons and Holes behave differently

Charge symmetry cut for e side

Charge symmetry cut for h side

$^{109}$Cd source 100 betas/sec
iZIP for Soudan
SuperCDMS Soudan (3 more STs)

<table>
<thead>
<tr>
<th>ST 3 - 5 mZIPs</th>
<th>ST 4 - 5</th>
<th>ST 5 - 5</th>
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<tbody>
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<td>Ge</td>
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SuperCDMS Soudan (iZIP)

ST 3 - 5 mZIPS

ST 3 - 4 mZIPS

ST 5 - 3 iZIPS

x2 fiducial volume

$^{210}$Pb source with 2000 dcys/d
SuperCDMS SNOLAB
100 kg Ge
12 \times 7 = 84 \text{iZIP}
10 \text{ cm dia} \times 3.3 \text{ cm thick}
SUF (17 mwe), Soudan (2090 mwe), & SNOLab (6060 mwe)

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

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

- At SNOLab
  - 6060 mwe
  - < 1 n/y/ton
Schematic of new ‘SNObox’
Future SuperCDMS SNOLAB project

- Plan SuperCDMS SNOLAB

- new advanced Ge iZIP design looks very promising for 100 kg experiment

- new higher radiopurity cryosystem with improved shielding

- We have strong endorsement from PA SAG of our SNOLAB strategy - complementary with other intermediate-scale experiments (Xenon 100, LUX, WARP140,...)
Relationship of GEODM to SuperCDMS

- Best case DUSEL 4800’ in 2015 and 7400’ in 2017
- All direct detection experiments need intermediate phase
- Ge 100 kg at SNOLAB enables future 1.5 ton at DUSEL
- Engineering for future GEODM at DUSEL
- S4 NSF proposal for large detector engineering
- Need DOE partnership for engineering program

<table>
<thead>
<tr>
<th>Year</th>
<th>DUSEL</th>
<th>CDMS II (4kg Ge, 2e-44)</th>
<th>SuperCDMS Soudan (15 kg Ge, 5e-45) NSF+DOE</th>
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<tbody>
<tr>
<td>2008</td>
<td>SI</td>
<td>SI</td>
<td>SuperCDMS Soudan Detector Fabrication</td>
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<td>2009</td>
<td>S5</td>
<td>CDMS II Current</td>
<td>SuperCDMS Soudan</td>
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<td>2010</td>
<td>MREPC</td>
<td>CDMS II Final</td>
<td>SuperCDMS SNOLAB Detector Fabrication</td>
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<td>2011</td>
<td>DUSEL start</td>
<td>4850t</td>
<td>SuperCDMS SNOLAB (100 kg, 3e-46) NSF+DOE</td>
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<tr>
<td>2012</td>
<td>7400t</td>
<td>15kg @ Soudan</td>
<td>SuperCDMS SNOLAB</td>
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<td>2013</td>
<td>100kg @ SNOLAB</td>
<td>1.5T @ DUSEL</td>
<td>SuperCDMS SNOLAB</td>
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<td>2014</td>
<td>1.5T @ DUSEL</td>
<td>100kg @ SNOLAB</td>
<td>SuperCDMS SNOLAB</td>
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<td>1.5T @ DUSEL</td>
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<td>1.5T @ DUSEL</td>
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<td>1.5T @ DUSEL</td>
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<td>2018</td>
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CDMS Mass [GeV/c^2] vs. \sigma SI [cm^2]

\chi^0_1,
Summary

• Nero-zero background strategy very successful and vital for maintaining discovery potential

• SuperCDMS Soudan 15 kg improves sensitivity by another factor of x5 beyond CDMS-II

  • Probing central supersymmetry region

  • Complementary to LHC and indirect detection

• New iZIP detector provides dramatic improvement in surface electron rejection

  • Enables 100 kg Ge at SuperCDMS SNOLAB and 1500 kg Ge at GEODM DUSEL