SuperCDMS: The Next Generation

Rupak Mahapatra
UC Santa Barbara
for the CDMS Collaboration
Outline

• CDMSII @Soudan : Overview
  – Results
  – Lessons Learned

• SuperCDMS @ SNOLab : Improvements
  – Deeper Site
  – Bigger Detectors, More Mass
  – Cleaner Detectors
  – Improved Cryogenics
  – Improved Electronics/DAQ

• Outlook
CDMSII Recent and Current Runs

- Published 2-T Data: world best sensitivity $\sim 10^{-43}\text{cm}^2$
- 5 Tower run underway
- Already collected 500 kg-days of Live Time in just concluded 5-T run. Results out this summer.
- Expected Live Time to double by end of year
- Sensitivity $\sim 10^{-44}\text{cm}^2$
CDMS Rejection Techniques

Background = Yield\_leakage * Timing\_leakage.

Improvement in either leads to reduced background
Lessons Learned from CDMSII

• Backgrounds:
  – Primary $\beta$ background source identified as $^{210}$Pb from Radon exposure
  – Neutron background will dominate for high mass runs

• Detectors:
  – Surfaces have reduced ionization collection, leading to surface events faking nuclear recoils
  – Phonon collection area (Al) needs to be higher for better timing

• Cryogenics
  – Significant maintenance of dilution refrigerator
  – Not very robust cryogenics. Expensive to run
SuperCDMS Detector Requirements

• Reduced cost/Kg. Detector
  – Cost is from production and testing

• Lower $\beta$ Backgrounds: Reduction and Rejection
  – Reduction in radioactive contamination
  – Rejection using Detector Improvements
  – Rejection of irreducible background using Analysis Improvements

• Planning for up to 40X Improvement
SCDMS Detector: Bigger is Better

- Cost of production/testing
  - 1/3 less per Kg. mass

- Background dominated by surface $\beta$. Reduce surface/volume
  - 1/3 less per Kg. mass

- 4 Prototypes made and tested. Soudan validation planned

\[ \text{.25 Kg Ge} \quad \Rightarrow \quad \text{x2.54} \quad \Rightarrow \quad \text{(x3 after fiducial volume cut)} \quad \Rightarrow \quad \text{.64 Kg Ge} \]
Photolithography Changes

NEW: 0 Required Wirebonds !!!
Reduced Surface Ionization Loss

• Ionization collection is not complete for surface events. Some surface events sufficiently low yield to show up inside signal band

• Hydrogenated aSi layer on the detector provides reduced charge back diffusion

• Expected to reduce ionization loss by 2x, thus leading to 2x Improvement in Yield based rejection
MAXIMUM ACTIVE AL COVERAGE

- x2.5 Active Al change
- Higher Al coverage means higher fast phonon absorption
- Better Timing Discrimination
Data From Prototype SCDMS ZIP

- First data from 1” Si ZIP showing reconstructed location of 109Cd events and spectrum
Reduction of Radon induced $\beta$

• Primary $\beta$ background comes from $^{210}$Pb implanted on detectors, from Radon exposure

• Very strict protocol in place to minimize Radon exposure during processing and handling. Active reduction of Radon from air at handling units using HEPA filters

• Have shown with newer T3-T5 detectors that Radon induced background has been improved by almost a factor of 3!
Improved $\beta$ Rejection by Analysis

- Remaining, irreducible, $\beta$ background must be rejected in analysis
- Multi-variable $\chi^2$ likelihood method with timing, partition discriminators

Higher Efficiency
**β Background Improvements Summary**

- **Background rejection**: x4
- **Analysis discrimination**: x2
- **Background reduction**: x5
- **Total Improvement**: x4 \* x5 = x20
- **Production rate per kg**: x5

Table 2: Targeted improvement factors over CDMS II advanced analysis levels (see Section 3.2) to achieve SuperCDMS 25 kg sensitivity with zero background from internal sources. The cosmogenic fast-neutron background is eliminated by the SNO-LAB overburden of 6000 mwe.

- Need x20 of this x40 total for the SuperCDMS 25 kg target background
- Expect x2.5 from additional thickness and x2 from better control of Rn
- Expect x2.5 from additional thickness and x2 from improved fabrication efficiency
- Increase phonon collection area x2 and new H-a-Si electrodes suppress charge back-diffusion x2
- Expect at least an additional x2 from advanced timing analyses

* need only x20 out of x40 for $10^{-45} \text{cm}^2$
How about Neutron Background?

- Neutrons from cosmic rays are irreducible background
- At SUF
  - 17 mwe
  - 0.5 n/kg-d
- At Soudan
  - 2090 mwe
  - 0.05 n/kg-y
- At SNOLab
  - 6060 mwe
  - 0.2 n/ton-y
Soudan Cryogenics System

Dilution Refrigerator
(< 50 mK)

Cryocooler (77K and 4K)

Icebox (Detector Cold Volume)
SuperCDMS Cryogenic System

Exploring cryocooler system with little or no cryogen servicing
Shielding and Veto

Veto mainly to identify neutrons from radioactivity

Inner shielding with vacuum to maintain cleanliness

1 meter thick polyethylene shield to moderate neutrons
New Warm Electronics

• One card replaces functions for old front end, trigger & filter and digitizer!
• Controlled and read over Ethernet
• Prototype tested with present system
• Noise remains to be improved

Continue to trigger $\gamma$ Calibration at 100Hz
SuperCDMS in SNO Lab

SuperCDMS
25 kg Experiment
<table>
<thead>
<tr>
<th>Background Events</th>
<th>Rate</th>
<th># Evts</th>
<th>Rate</th>
<th># Evts</th>
<th>Rate</th>
<th># Evts</th>
<th>Inefficiency (singles)</th>
<th>Rate</th>
<th># Evts</th>
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<tbody>
<tr>
<td><strong>CDMS II T 1-5 at Soudan</strong></td>
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<tr>
<td>4.0 kg × 485 d (raw 1,300 kg-d)</td>
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<tr>
<td>gammas</td>
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<td>n/a</td>
<td>147</td>
<td>130,000</td>
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<td>2.0E-5</td>
<td>0.01</td>
<td>1</td>
<td>2.0E-5</td>
<td>0.01</td>
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<tr>
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<td>1.1E-2</td>
<td>7</td>
<td>1.5E-4</td>
<td>0.09</td>
<td>1</td>
<td>1.5E-4</td>
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<td><strong>SuperCDMS ST6 1-2 at Soudan</strong></td>
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<td>7.5 kg × 550 d (raw 2,800 kg-d)</td>
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<tr>
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<td>n/a</td>
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<td>2.1E-5</td>
<td>0.03</td>
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<td>n/a</td>
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<td>n/a</td>
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<td>0.03</td>
<td>1</td>
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<td>0.03</td>
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<td>1.5E-4</td>
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<td><strong>SuperCDMS ST6 1-5 at Soudan</strong></td>
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<tr>
<td>gammas</td>
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<td>n/a</td>
<td>147</td>
<td>1,550,000</td>
<td>1.0E-7</td>
<td>2.1E-5</td>
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<td>1,714</td>
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<td>n/a</td>
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<td><strong>SuperCDMS ST6 1-7 at SNOLAB</strong></td>
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<tr>
<td>27 kg × 1000 d (raw 18000 kg-d)</td>
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<tr>
<td>gammas</td>
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<td>n/a</td>
<td>68</td>
<td>860,000</td>
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<td>n/a</td>
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<td>2,000</td>
<td>2.5E-4</td>
<td>5.8E-5</td>
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<td>n/a</td>
<td>1.5E-5</td>
<td>0.13</td>
<td>1</td>
<td>1.5E-5</td>
<td>0.13</td>
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<td>neutrons (muon-induced)</td>
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<td>0.60</td>
<td>4.5E-7</td>
<td>0.004</td>
<td>1</td>
<td>5.0E-7</td>
<td>0.004</td>
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</tbody>
</table>

**Essentially Background Free!!!
Why is it important to stay background-free?

Systematics of background subtraction limit sensitivity prematurely!
Conclusions

• CDMSII 5-Tower run first half just concluded with 5 times more data
  • Results in summer. Eventually 10X data. Reach below $10^{-44}\text{cm}^2$

• 4 Prototype 1” SuperCDMS detectors constructed and tested
  • Significant improvements in timing and yield based rejections
  • Bigger detector reduces production/testing costs by ~3X
  • Bigger detector reduces surface $\beta$ contamination/kg by ~3X

• Primary source of $\beta$ background identified as Radon
  • Steps to reduce Radon exposure has already demonstrated a 3X reduction in $\beta$ background in new CDMSII towers (T3-T5)

• Strong analysis improvements to reject irreducible $\beta$ background

• SuperCDMS will continue to operate in background free environment
  • ~40X improvement expected compared to CDMSII (T1-T2) detectors

• Very exciting SuperCDMS 25 Kg. future, with sensitivity reach $10^{-45}\text{cm}^2$
  • Complementarity with LHC SUSY searches
SuperCDMS Collaboration

Collaboration is growing; 3 new groups added!

CDMS Institutions
DOE Laboratory
Fermilab
NIST

DOE University
CalTech
Florida
Minnesota
MIT
Stanford
UC Santa Barbara

NSF
Case Western Reserve
Colorado (Denver)
Santa Clara
UC Berkeley

Canada
Queens