Current and Future Dark Matter Searches with SuperCDMS

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CDMS: WIMP Detection Strategy

Direct Detection:
Search for WIMP signal via nuclear recoil elastic scattering in the detector.

State-of-the-art detector:
- Low temperature (< 50 mK) semiconductor detectors;
- Read out phonons from the recoil together with ionization signal.

Background Reduction and Rejection:
Goal = Maintain “<1 event expected background”
- Go deeper to reduce cosmogenic muons
- Active muon veto
- Shielding and material-purity
- Powerful background discrimination in the analysis
• Soudan Underground Lab, USA (2090 m.w.e. depth)
CDMS-II Experiment

- Soudan Underground Lab, USA (2090 m.w.e. depth)
- 5 Towers of 6 detectors (4.6 kg Ge, 1.1 kg Si)
- Active/passive shielding against muons and environmental radioactivity.
Passive shielding:
• Pb: shielding from $\gamma$’s
• Polyethylene: moderate neutrons from fission and from $(\alpha,n)$ interactions from U/Th decays
• Copper: shielding from $\gamma$’s.

Active shielding:
• Muon veto to reject events from cosmic rays.
**Z-sensitive Ionization Phonon Detector (ZIP)**

**Phonon side:**
- 4 quadrants of phonon sensors
- provide phonon energy and position info

**Charge side:**
- 2 concentric electrodes (inner and outer)
- provide ionization energy and veto

Nuclear/ Electron recoil discrimination:

Signature of Nuclear Recoil: reduced ionization relative to phonon signal.
Surface Events Discrimination

Low-yield ER surface events

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Introduce:

phonon timing parameter = phonon pulse risetime + offset from ionization pulse
CDMS-II Results

- Spectrum-averaged exposure after all cuts is 194 kg-days
- 2 events in the NR band pass the timing cut

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Result:
- $7.0 \times 10^{-44} \text{ cm}^2 \text{ @ } 70 \text{ GeV/c}^2$
- $3.8 \times 10^{-44} \text{ cm}^2 \text{ @ } 70 \text{ GeV/c}^2$
  (combined with previous CDMS data)

EDELWEISS:

- Laboratoire Souterrain de Modane, France (4800 m.w.e. depth)
- 10x400 g Ge bolometers @ 20 mK
  - Ionization measurement
  - Heat measurement
- Threshold 20 keV

- Total exposure 384 kg-days (comparable to 379 kg-days of CDMS-II total)
- Observed 5 candidate events
- Expected background ~3 events
To combine limits:
• Sum exposure-weighted efficiencies;
• Combine events regardless of experiment of origin;
• Calculate the limit.
Agreed on the method before exchanging data!
Strongest limit: $3.3 \times 10^{-44} \text{ cm}^2$ for 90 GeV/c$^2$ WIMP

Improvement up to a factor 1.6 above 50 GeV/c$^2$
To reach the goals we need:
• increase mass
• decrease background leakage

· CDMS-II (completed)
  o 4 kg Ge for ~2 years
  o $3.8 \times 10^{-44} \text{ cm}^2$

**Current phase:**
• SuperCDMS @ Soudan
  o 10 kg Ge for ~2 years
  o $5 \times 10^{-45} \text{ cm}^2$

**Future:**
• SuperCDMS @ SNOLAB
  o 100 kg Ge for ~3 years
  o $3 \times 10^{-46} \text{ cm}^2$
To reach the goals we need:
• increase mass
• decrease background leakage

Redesign the detectors!
Redesigned detector: **interleaved Z-dependent Ionization and Phonon detector (iZIP):**

- 4 charge channels
- 8 phonon channels

Appears to meet needs of SuperCDMS @ SNOLAB.

**iZIP improvements:**

- Detectors are x2.5 thicker;
- Optimized phonon sensor layout;
- Modified phonon mask;
- Interleaved charge electrodes and phonon sensors on both sides of the detector.

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76 mm x 25 mm
0.6 kg
Interleaved charge electrodes and phonon sensors on both sides of the detector:
Interleaved charge electrodes and phonon sensors on both sides of the detector:

Charge channels can be used to reject surface events.

Surface Events:
Ionization signal appears only on one side of the detector.

Bulk Events:
Equal but opposite ionization signal appears on both sides.

Ionization lines
Phonon sensors

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iZIP: Charge Discrimination

Interleaved charge electrodes and phonon sensors on both sides of the detector:

Charge channels can be used to reject surface events.

Surface Events:
Ionization signal appears only on one side of the detector.

Bulk Events:
Equal but opposite ionization signal appears on both sides.

Surface event discrimination is $>10^4:1$

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Yield-only discrimination of surface events in NR band is $>10^3:1$.

Discrimination starts to degrade at $\sim 10$ keV.

Measurements of yield and charge asymmetry combined discrimination are limited by neutron background events in NR band.

Data taken at Test Facility above ground with NR background of $\sim 7$ evt/hr
iZIPs @ Soudan

• iZIP detectors are arranged in SuperTowers
• The first iZIP SuperTower was installed at Soudan in October 2010:

CDMS-II Tower  iZIP SuperTower

- S12
- G37
- S10
- G35
- G34
- G38

- Z1
- G48
- Z2
- G47
- Z3
- G52
• iZIP detectors are arranged in SuperTowers
• The first iZIP SuperTower was installed at Soudan in October 2010:
  o engineering run with the goal to perform background assessment
  o run was interrupted due to the fire in mine shaft in March 2011
  o collected data to assess stability of the detectors underground and improve operation of iZIPs in the future runs

CDMS-II Tower

iZIP SuperTower

wafers with Pb-210 on top and bottom
(for engineering run to assess discrimination against surface events)
iZIPS @ Soudan

- iZIP detectors are arranged in SuperTowers
- The first iZIP SuperTower was installed at Soudan in October 2010:
  - engineering run with the goal to perform background assessment
  - run was interrupted due to the fire in mine shaft in March 2011
  - collected data to assess stability of the detectors underground and improve operation of iZIPS in the future runs
- Approved to deploy a total of 5 iZIP SuperTowers at Soudan.

CDMS-II Tower

iZIP SuperTower

wafers with Pb-210 on top and bottom (for engineering run to assess discrimination against surface events)
• SuperCDMS @ Soudan will eventually become background limited due to cosmogenic neutrons;
• to get to $\sim 3 \times 10^{-46}$ cm$^2$ (100 kg of Ge phase) need to move to deeper site.
SuperCDMS @ SNOLAB

- SuperCDMS @ Soudan will eventually become background limited due to cosmogenic neutrons;
- to get to $3 \times 10^{-46} \text{ cm}^2$ (100 kg of Ge phase) need to move to deeper site.

Detector Test Facility @ SNOLAB:
- need a shielded underground TF to characterize detectors w/o the presence of limiting neutron background;
- background achievable @ SNOLAB with 5’ of water shielding (MC simulations):
  - $<1$ Hz of external gammas
  - $<1$ neutron/day
- short turn-around time between runs.
Summary

- CDMS-II has completed operation:
  - has set a limit of $3.8 \times 10^{-44} \text{ cm}^2 @ 70 \text{ GeV/c}^2$ on WIMP-nucleon spin-independent cross-section;
  - observed 2 candidate events in the first analysis of the final data taken between July 07 and Sept. 08;
  - cannot claim nor reject these events as possible WIMPs;
  - CDMS and EDELWEISS collaborations have produced a common analysis of their results that gives improved constraint on WIMPs heavier than 50 GeV/c$^2$.

- New generation of CDMS advanced detectors, iZIP:
  - meets requirements for SuperCDMS @ Soudan to reach WIMP-nucleon cross-section of $5 \times 10^{-45} \text{ cm}^2$ for 60 GeV/c$^2$ WIMPs with $<1$ expected background event;
  - SuperCDMS @ Soudan is expected to install 5 iZIP SuperTowers and resume operations later this year.

- Intend to start running 100 kg at SNOLAB in 2015.
Backup Slides
iZIP: Phonon Pulse Shape Discrimination

**Additional background rejection technique:**

- Phonon pulse shape for surface ER events look different than for bulk NR;

- Pulse shape quantities are included into calculated $\chi^2$ function for event;

- Discrimination based on $\chi^2$ difference between surface ER and NR events is $10^4:1$ with ~60% NR passage efficiency.
• Environmental $^{222}$Rn in air can deposit long-lived $^{210}$Pb $\beta$ source on surfaces

$^{210}$Pb, 22 yr

- 63.6 keV
  - BR 16$\pm$3%

- $^{210}$Bi$^*$
  - $\gamma$
    - 46.539 keV
      - 4.25$\pm$0.04%

- Expected signatures:
  - low-energy $\beta$ decay, but final state of 17 keV decay results in peak $\sim$46 keV
  - delayed 1.16 MeV $\beta$ from $^{210}$Bi
  - delayed $^{210}$Po $\alpha$

- 16.96 keV, BR 84$\pm$3%

- Mostly Auger electron emission
- 24.6$\pm$0.8% emit Flourescent x-rays

Extraction by H. Nelson


Nucl. Data Tables A4, 1 (1968)
Nucl. Data Tables A6, 235 (1969)
Nucl. Data Tables A9, 119 (1971)