SuperCDMS

From Soudan to SNOLAB

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<th>Cooper Radius</th>
<th>Velocity</th>
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<tr>
<td><strong>Observed</strong></td>
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Zwicky

Dark Energy (>70 %)

Dark Matter (~23 %)

Luminous Matter (< 1 %)

Ordinary Matter (~ 4 %)

CMB

W. Rau – IPP AGM 2014
Dark Matter

Predicted by SUSY:
Neutralino
Universal extra dimensions:
Kaluza-Klein particles

Here, but not yet observed in nature:
Weakly interacting WIMP
(Weakly Interacting Massive Particle)

Large scale structure of the Universe:
Slowly moving (‘cold’)

Interaction with ordinary matter:
Nuclear Recoils
(most backgrounds: electron recoils)

Not observed in accelerator experiments:
Massive

Predicted by SUSY:
Neutralino
Universal extra dimensions:
Kaluza-Klein particles
SuperCDMS Technology

- Phonon signal (single crystal): measures energy deposition
- Ionization signal (semiconductor): quenched for nuclear recoils (lower signal efficiency)
- Combination: efficient rejection of electron recoil background

Phonon signal Charge signal

Electron recoil (ER) Nuclear recoil (NR)

Ionization vs Recoil for a Ge ZIP: $^{252}$Cf

Electron recoils from β’s and γ’s

Nuclear recoils from neutrons
In Vacuum

- Electron gains kinetic energy
  \((E = q \cdot V \rightarrow 1 \text{ eV for } 1 \text{ V potential})\)

In Matter

- Deposited energy in crystal lattice: Neganov-Luke phonons
  \(\propto V, \#\text{ charges}\)

- Luke phonons mix charge and phonon signal \(\rightarrow\) reduced discrimination
- Apply high voltage \(\rightarrow\) large final phonon signal, measures charge!!
- ER much more amplified than NR
  \(\rightarrow\) gain in threshold; dilute background from ER
CDMS History

1998 - 2002
SUF, 10 mwe
- CDMS @ SUF
  - 6 detectors
  - 1 kg Ge (30 kgd)
  - $\sigma < 3.5 \times 10^{-42} \text{ cm}^2$

2003 - 2009
Soudan, 2000 mwe
- CDMS II @ Soudan
  - 30 detectors
  - ~4 kg Ge (400 kgd)
  - $\sigma < 2 \times 10^{-44} \text{ cm}^2$

2009 - 2014

2017?
- SuperCDMS @ Soudan
  - 15 (bigger) detectors
  - ~9 kg Ge (~2500 kgd)
  - $\sigma < 3 \times 10^{-45} \text{ cm}^2$

SNOLAB, 6000 mwe
- SuperCDMS @ SNOLAB
  - $\mathcal{O}$ (100) detectors
  - ~100 kg Ge / ~10 kg Si
  - $\sigma \approx 10^{-46} \text{ cm}^2$

exposures are after all cuts!
SuperCDMS Collaboration

California Institute of Technology
Massachusetts Institute of Technology
Santa Clara University
Stanford University
University of British Columbia
University of Colorado Denver
University of Minnesota

CNRS/LPN
SLAC/KIPAC

Fermi National Accelerator Laboratory
PNNL
Queen’s University
Southern Methodist University
Texas A&M
Universidad Atómica de Madrid
University of California, Berkeley
University of Evansville
University of Florida
University of South Dakota
Implementation

- Germanium single crystals (620 g modules)
- Thermal readout: superconducting phase transition sensor (TES); $T_c = 50 – 100$ mK
- Charge readout: Al electrode; interleaved with phonon sensors
- Low bias voltage (4 V) in regular operation

Basic configuration
Implementation

- Germanium single crystals (620 g modules)
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Implementation

- Germanium single crystals (620 g modules)
- Thermal readout: superconducting phase transition sensor (TES); $T_c = 50 – 100$ mK
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- Low bias voltage (4 V) in regular operation
  One detector: $\sim 70$ V for some time
Implementation (CDMS setup)

- Stack detectors (3) to mount ("tower")
- 5 towers deployed in cryostat (~9 kg Ge)
- Shielded with polyethylene (for neutrons), Pb (gammas) and muon veto (cosmic radiation)
- Located at Soudan Underground Lab (Minnesota) to shield from cosmic radiation
Detector Performance

- **Surface events**
  - $^{210}$Pb source
  - 65,000 betas
  - 0 events leakage
  - 15,000 surface NRs

- **Trigger Efficiency (good detector)**

- **Sample of low background gamma data**
  - 10.3 keV (Ge)
  - Cosmogenic activation
Past Analysis Approaches

- "Classic" CDMS approach: minimize expected BG (<1 for data set under analysis) → threshold ~10 keV ($E_{\text{recoil}}$: use Q signal for Luke correction)
- Low-threshold extension: strongly rising WIMP spectrum at low E → improved sensitivity in spite of BG (no surface event discrimination; $E_{\text{NR}}$: Luke correction based on mean yield)
- CMDMSlite: no discrimination, but even lower threshold; BG diluted ($E_{\text{NR}}$: based on Lindhard model)
Results – before 2014
SuperCDMS Soudan – Latest Data

Low-threshold method, but now with:

- Surface event rejection with charge signal (interleaved electrodes) AND phonon signal (sensors on top and bottom!)
- Edge event rejection with charge signal (was available in CDMS) AND phonon signal (new sensor layout)
- New Analysis method for improved efficiency (Boosted Decision Tree)

- Background Model to train BDT (cosmogenics, $^{210}$Pb chain): MC to get distributions; use scaled pulses + real noise to generate `events' (gammas for BG, neutrons for signal)
- Optimize tree for different WIMP masses (5, 7, 10, 15 GeV/c$^2$)
- BG model only for BDT training; efficiency measured with neutrons
SuperCDMS Soudan – Results and Future

- BG model predicts ~6 events – BUT: difficult to make good prediction in this low energy range → only set upper limit
- “Open box”: observed 11 events
- 3 highest energy events in detector with shorted outer charge channel

- Probe new parameter space between 4 and 6 GeV/c²
- Incompatible with CoGeNT interpretation as NR signal from WIMPs

- Standard (high threshold) analysis in progress / additional CDMSlite data collected
- DM search until fall (expect to be limited by cosmogenic/radiogenic BG by then)
- Systematic studies until spring 2015
SuperCDMS at SNOLAB

- Setup for ~400 kg detector mass for later upgrade
- EURECA indicated interest in contributing additional target mass
- Shielding includes neutron veto (scintillator)

- Timing: start construction in early 2015; takes ~2 years to build
- Funding: $3.4M from CFI / waiting for G2 decision in the US (expected anytime now)