Low-threshold WIMP search at SuperCDMS

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Low-mass WIMP search

Interesting regions of the parameter space still unexplored at low WIMP masses

Sneutrino DM (Cerdeño, Peiró, Robles) arxiv 1404.2572
The *SuperCDMS* paradigm

Measure phonon and ionization produced by a Ge nucleus recoiling against a WIMP interaction

\[
E_Q = Y E_R
\]

\[
E_P = E_R + \frac{V}{\epsilon} E_Q
\]

If external voltage bias \( V \) is applied, work done on ionization charges is released to the crystal as phonons (Luke phonons).

Ionization yield \( Y \) allows NR/ER discrimination.

\( \epsilon = 3.0 \text{ V in Ge} \)
SuperCDMS detectors

15 cylinders of monocrystalline Ge, arranged in 5 stacks
Radius 3.8 cm, height 2.5 cm
0.6 kg each (9 kg total)
Operating at ~50 mK
Electric field in the bulk

(Arrmost) parallel electric field in the bulk (⇒ symmetric charge propagation for recoils occurring in the bulk)
Curved electric field near surfaces (⇒ asymmetric charge propagation for recoils occurring near surfaces)
Vertical fiducialization

Instrumenting both detector sides enables rejection of events near surfaces.
Radial fiducialization

Segmentation in the radial direction of the read-out sensors enables rejection of events on sidewalls.
Detector instrumentation

Ionization read-out channels

Phonon read-out channels

Phonons carry some information about the charge propagation ($\Rightarrow$ allow complementary fiducialization)
Shielding

Outer and inner layer of polyethylene (neutron moderation)
Outer and inner layer of lead (gamma absorption)
Radiopure Cu for supporting structures inside the shielding
Shielding

Pannels of scintillating plastic, full solid angle (*muon veto*)
713.5 m of rock overburden (Soudan mine, MN, USA)
Low-threshold WIMP search

Study recoil energies near trigger threshold $E_R \in [1.5, 10] \text{ keV}$ ($\Rightarrow M_{\text{WIMP}} \in [5, 15] \text{ GeV}$)

Use only 7 detectors with lowest trigger thresholds

577 kg days of exposure (October 2012-July 2013)
Low-threshold WIMP search

Use full background rejection capabilities (NR/ER discrimination and fiducialization), in the limit of their resolution

Resolution effects included in data modeling (pulse simulation)
Backgrounds

\(\alpha\)'s, \(\beta\)'s and heavy nuclei produce **surface events**

Main source: \(^{210}\text{Pb} \text{ decays}\) on surfaces in the detector vicinity

**Suppressed ionization** with respect to bulk events

Limited ionization-based fiducialization

Degraded discrimination based on ionization yield
**Backgrounds**

Compton scattering of MeV-scale $\gamma$'s produce bulk events. Main source: nuclear decays in shielding and inner structures. Also, **1.3 keV $\gamma$'s** produced by L-shell capture inside detectors. Degraded discrimination based on ionization yield.

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![Spectrum from MeV-scale $\gamma$'s](image1)

*Simulation*

Approx. signal region

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![Spectrum from 1.3 keV $\gamma$'s](image2)

*Simulation*

Approx. signal region
Event selection

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![Graph showing efficiency vs. Lindhard nuclear-recoil energy and total phonon energy](image)

The graph illustrates the efficiency as a function of the Lindhard nuclear-recoil energy and total phonon energy. Different curves represent various selection criteria and data quality thresholds. The red curve represents the full selection except the cut on multivariate discriminators.
Multivariate discriminators

Combine phonon-based fiducialization and ionization yield

4 discriminators, optimized for 5, 7, 10 and 15 GeV WIMPs

Events are required to satisfy cut on at least one discriminator

Results for discriminator optimized for a 10 GeV WIMP
Events after unblinding

Found 11 events after unblinding
Some disagreement in detectors with compromised channels
Good agreement otherwise
**Exclusion limit (90% CL)**

Result competitive with those from other experiments
New parameter region explored below 6 keV
Conclusions

• SuperCDMS includes fiducialization using 1) symmetry of ionization measurements and 2) phonon signal
• WIMP search using full background rejection capabilities near threshold
• Use of multivariate techniques including phonon-based fiducialization
• Good agreement between data and the expected background except in detectors with compromised channels
• Exclusion limit competitive with other current results
BACKUP MATERIAL
Surface event rejection

Performance of vertical fiducialization checked on two detectors irradiated by $^{210}$Pb sources

$^{210}$Pb $\rightarrow$ $^{210}$Bi + $\beta$ $\rightarrow$ $^{210}$Po + $\beta$ $\rightarrow$ $^{206}$Pb + $\alpha$

No event found in NR band after vertical fiducialization!
Ionization model

Mean ionization energy from $^{252}$Cf neutron calibration data

most detectors similar to or slightly below Lindhard
Multivariate discriminators
Exclusion limit without T5Z3
SuperCDMS-SNOLAB

• Deployed on a deeper site
• ~100 kg Ge payload
• R&D efforts to increase resolution of ionization and phonon measurements
• Include active neutron shield using Gd-loaded scintillator
• Aiming towards low-mass WIMPs
SuperCDMS-SNOLAB