Future Ideas for SuperCDMS at SNOLAB

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SuperCDMS Collaboration

University of California, Berkeley
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University of Florida
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University of South Dakota
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Southern Methodist University
Stanford University
Texas A&M
University of British Columbia/TRIUMF

Fermi National Accelerator Laboratory
NISER
NIST
Northwestern University
PNNL
Queen’s University
Santa Clara University
SLAC/KIPA
South Dakota School of Mines & Technology
SNOLAB

California Institute of Technology
CNRS/LPN
Durham University

NIST
Northwestern University
PNNL
Queen’s University
Santa Clara University
SLAC/KIPA
South Dakota School of Mines & Technology
SNOLAB
SuperCDMS Technology

The SuperCDMS SNOLAB Project

Long-term goals

Potential detector developments

Other ideas
Detectors

**Phonon Readout:**
Tungsten TES

**Semiconductor operated at few 10s of mK**

Add: charge readout (few V)
Background discrimination
Threshold < 10 keV

< 1 background event for whole exposure

Electron recoils: background
Nuclear recoils: signal

Ionization vs Recoil for a Ge ZnIP : $^{55}Cf$
Detectors

Semiconductor operated at few 10s of mK

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Nuclear recoils: signal

Phonon signal
Charge signal

Ionization vs Recoil for a Ge ZIP: $^{252}$Cf
Neganov-Luke Effect

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

Deposited energy in crystal lattice:
Negovan-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

Phonon Readout:
Tungsten TES

Add: charge readout (few V)
Background discrimination
Threshold < 10 keV

Neganov-Luke Effect

- In Vacuum
  - iZIP
  - Electron

- 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
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SuperCDMS SNOLAB - W. Rau - TAUP 2017
Detectors

- **Phonon Readout:** Tungsten TES
  - Add: charge readout (few V)
  - Background discrimination
  - Threshold < 10 keV
  - Remove surface background
  - < 1 background event for whole exposure

- **Phonons from drifting charges**
  - Threshold < 0.1 keV (phonon)
  - Effective threshold: few hundred eV (NR)

- **Electron recoils:** background
- **Nuclear recoils:** signal

- **Charge signal:**
  - Ionization vs Recoil for a Ge Zn: 552Cf

- **Semiconductor operated at few 10s of mK**

- **iZIP**

- **HV**
Implementation (SNOLAB setup)

6 detectors → 1 tower
Implementation (SNOLAB setup)

- Fridge to provide <15 mK at the detector
- Mounted on spring-loaded platform (seismic isolation)
- Detector volume (space for up to 31 “towers”)
- Signal vacuum feedthroughs
- Cold finger
- 6 detectors → 1 tower
- Initial Payload:
  - 1 Ge iZIP tower (6 Ge)
  - 1 Ge/Si iZIP tower (4 Ge/2 Si)
  - 2 HV towers (4 Ge/2 Si each)
- Additional cooling (50 K/4 K)

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Tentative Schedule

2019
SuperCDMS construction

2020
New Detector R&D
Neutron veto R&D (?)

2021
Acquire funding
(Canada/US/?)

2022
Build and test
new detectors

2023

2024

2025
Prepare for
next phase

Start of SuperCDMS Operations

Start next phase

- Start operations of SuperCDMS SNOLAB in 2020
- Parallel to Operations:
  - develop improved detectors
  - acquire funding
  - produce new detectors, readout electronics etc.
- Conclusion SuperCDMS SNOLAB presently planned for 2025
- BUT: installation of improved detectors possible much earlier (e.g.: present HV detectors are expected to be background limited after about 2 year; may replace them if we have better ones by then)
Goal

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Detector Developments – Re-gain Discrimination

- Combine ideas of iZIP and HV detectors:
  Electric field configuration as in iZIP, but pure phonon readout

![iZIP](image1)
![HV](image2)

Diagram showing:
- Primary phonons
- Phonon sensors
- Detector
- Interaction
Detector Developments – Re-gain Discrimination

- Combine ideas of iZIP and HV detectors:
  Electric field configuration as in iZIP, but pure phonon readout

Ratio of signals gives information about ratio of primary to NL phonons

Phonon sensors – biased

Strong field region

Detector

Weak field region
Detector Developments – Re-gain Discrimination

- Single Electron-hole Pair Luke gain (SEPL) method
- Need excellent energy resolution ($\ll e \times \text{bias voltage}$)

Graph showing energy levels:
- $\mathcal{O}(1 \text{ eV})$ Electron Recoil (1 eh pair)
- Few eV Electron Recoil (2 eh pairs)
- +100 eV (Luke Gain)
- +200 eV (Luke Gain)
Detector Developments – Re-gain Discrimination

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Possible issues:
• Spontaneous release of trapped charges (either electrons or holes)
• Impact ionization of shallow states in the bulk
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Detector Developments – Neutron Veto

- If ER background is removed, we need to worry again about neutrons
- Replace inner neutron shield by **active veto detector**

- Most important role: tag neutrons from inner part of experiment
- Additional role: tag residual neutrons from outside; muon veto
- Boron or Gadolinium loaded scintillator
- Readout with SiPM + fiber (for low radioactivity)
- Some R&D work on B-loaded scintillator is already completed
Detector Developments – Neutron Veto

- Modular tanks, LAB (organic scintillator), loaded with \( \sim 30\% \) trimethyl borate (TMB)
- Readout: wavelength shifting fibers coupled to SiPM (\( \sim 1000\); 4 fibers/SiPM)

- Prototype (1/4 scale) built at Fermilab
- Performance very promising
- Alternative designs are being considered (Gd loaded liquid scintillator; solid scintillator)
Electron Interacting Dark Matter

- With single eh-pair sensitivity we can search for Electron Interacting Dark Matter:
  - Maximum velocity of the electron: $2 \times v_{\text{escape}} \approx 1200 \text{ km/s} = 4 \times 10^{-3} c$
  - Maximum kinetic energy: $E_e = \frac{1}{2} m_e v_e^2 = 4 \text{ eV}$
  - Real world more complicated:
    - Moderately higher energy transfer possible
    - Requires very low leakage current (injected charge carriers look like single eh pairs) and ER background

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Electron Interacting Dark Matter

- Search for DM particles down to the MeV scale:

- Sensitivity depends on mediator mass
- Also sensitive to dark photons, axion like particles etc.
Other Detector Types

- Still in discussions with EDELWEISS and CRESST for the potential to include their detectors into the SuperCDMS setup

  CRESST III: CaWO4, scintillating cryo-detector
  24 g/detector; cryogenic light detector
  lowest energy threshold achieved so far: 20 eV
  Presently at Gran Sasso; default plan is to continue, but may join if there are show-stoppers

- New idea: scintillator with low band gap (GaAs(Si)) + single photon detector (setup very similar to CRESST)
  - Similar threshold as Ge/Si
  - No issue with leakage current
  - Penalty: scintillation efficiency, photon collection efficiency (factor of a few)

- Other ideas are out there – SuperCDMS is modular and adaptable to the change in the scientific landscape
Cryogenic Underground TEst facility (CUTE)

- Well shielded test facility, next to SuperCDMS
- Presently under construction
- Expected background $\mathcal{O}(5)$ events/keV/kg/day below $\sim 10$ keV

- Test all new detector concepts in low-background environment before installing in SuperCDMS
- Minimizes down-time of the experiment
## Conclusions

- **SuperCDMS SNOLAB**: small payload, about an order of magnitude shy of the neutrino floor
- **BUT**: has extra capacity (up to 200 kg)
- Detector improvements may allow us to re-gain ER/NR discrimination at very low energy
- This will allow us to reach the neutrino floor (need large payload)
- At the same time: reach to lower energies and thus lower mass WIMPs
- Search for electron-interacting DM
- Discussions with EDELWEISS/CRESST about joining forces
- New detector ideas for very low mass reach, search for dark photons ...