The SNOLAB SuperCDMS experiment

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University of British Columbia - TRIUMF

UCLA Dark Matter 2023

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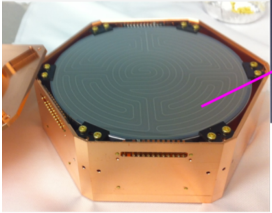
The SuperCDMS Collaboration

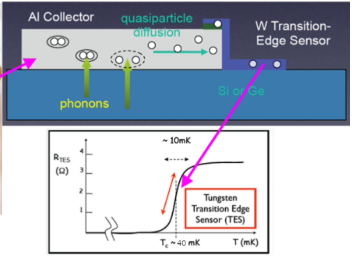
$\sim$ 100 scientists at 27 institutions from 6 countries

SuperCDMS detector technology

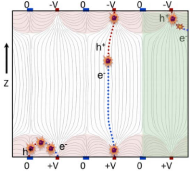
When a particle scatters in a Si/Ge crystal lattice its transferred energy is dissipated via **heat** and **ionization**. By measuring those, we'll have a clear signature of its interaction and we can infer its properties.

- **Phonons**, measured via Quasi-particle trap assisted Electrothermal feedback Transition edge sensors (QETs)





- **Charge**, measured via interleaved electrodes



SuperCDMS detectors

Interleaved **Z**-sensitive **I**onization and **P**honon detector (iZIP):

- 12 phonon, 4 charge channels
- Small bias voltage ($< 10\,\mathrm{V}$) across the detector
- Measurement of phonon and ionization signals for discrimination between nuclear and electron recoil events
- ~ 1 keV threshold with ER/NR discrimination power

High **V**oltage (HV) detector:

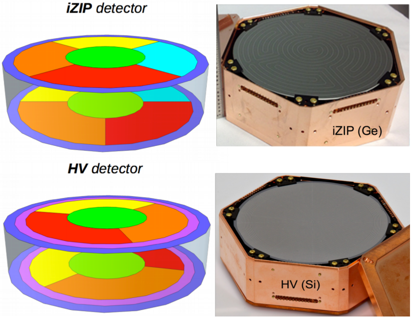
- Only 12 phonon channels
- Larger bias voltage ($\sim 100\,\mathrm{V}$) across the detector
- Dominant phonon energy contribution is from phonons created by drifting charges (Neganov-Trofimov-Luke (NTL) effect)
- Additional NTL energy boosts particle interaction signal without degrading resolution
- Push threshold down to ~ 100 eV, but no event by event ER/NR discrimination

SNOLAB SuperCDMS detectors

Successful campaign in Soudan finished, now moving to SNOLAB.

Detectors improvements:

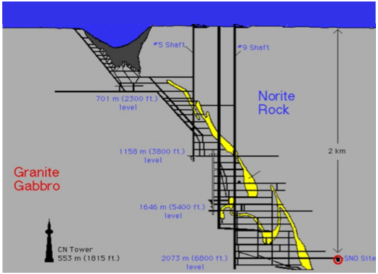
- Bigger (more fiducial volume) and higher purity (fewer radioactive impurities) crystals
  - Ge (1.4 kg crystals): larger exposure
  - Si (0.6 kg crystals): lower mass reach

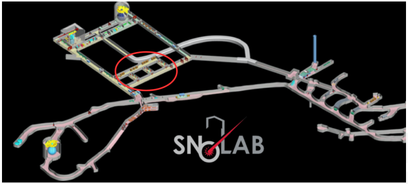


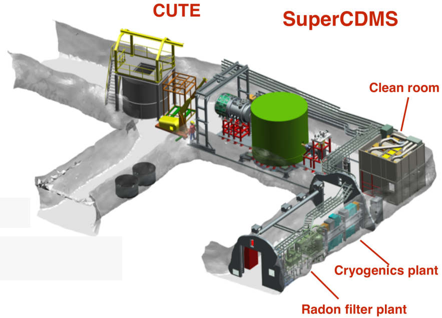
- Critical temperature T_c reduced from 90 to 40 mK, resolution scales as T_c^3
- Newly optimized QET geometry to enhance the phonon collection efficiency
- More channels for better event position reconstruction

Moving to SNOLAB

- 2 km underground (6800 m water equivalent)
- Cleanroom (class 2000 or better)
- Muon flux from cosmic rays reduced by a factor of 100 compared to the Soudan mine

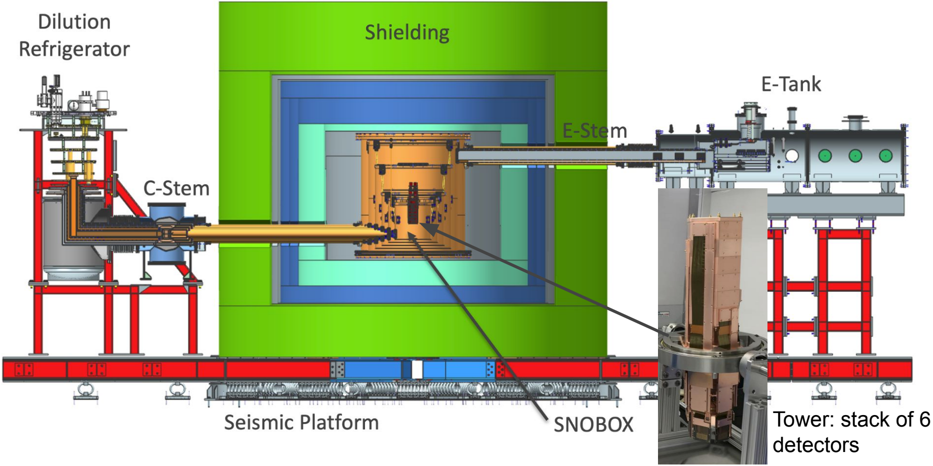




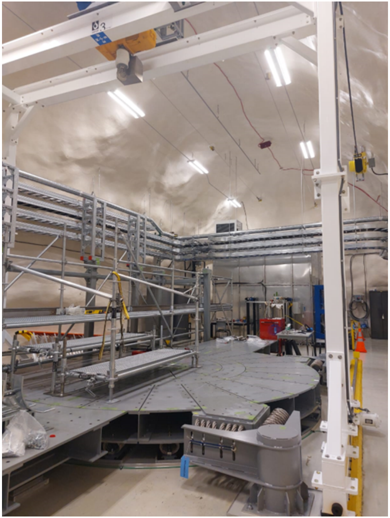


SuperCDMS SNOLAB Experiment

Initial payload: about 30 kg total, 4 towers with 6 detectors per tower (12 iZIP, 12 HV)



Installation is happening!



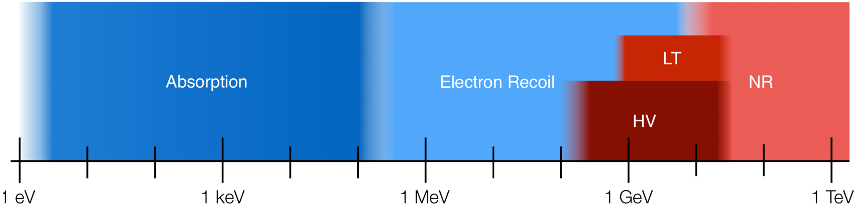
Fridge is underground and being tested now!

Radon filter system

Plan is to complete installation in 2024!

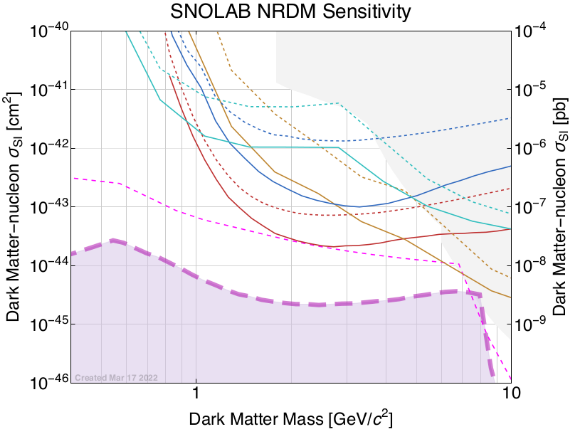
SuperCDMS sensitivity: a broadband DM search

Traditional Nuclear Recoil:	iZIP, Background free	>5 GeV
Low Threshold NR:	iZIP, limited discrimination	>1 GeV
HV mode:	HV, no discrimination,	~0.3 - 10 GeV
Electron recoil:	HV, no discrimination,	~0.5 MeV - 10 GeV
Absorption (Dark Photons, ALPs):	HV, no discrimination,	~1 eV - 500 keV ("peak search")



SuperCDMS SNOLAB nuclear recoil projected sensitivity (arXiv:2203.08463)

Estimate based on 4-y exposure and current knowledge of bkg



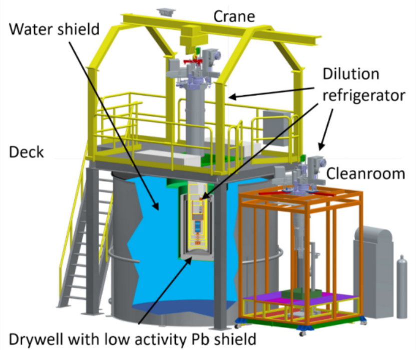
Optimum interval (dashed) and profile-likelihood ratio (solid), (red-brown) Ge HV; (blue) Si HV; (mustard) Ge iZIP; (cyan) Si iZIP, (magenta short dashed) single neutrino sensitivity

How do we get there?

Multiple, parallel efforts ongoing to make sure we reach world-leading sensitivity

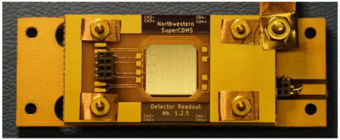
Not just installing SuperCDMS... the Cryogenic Underground TEst

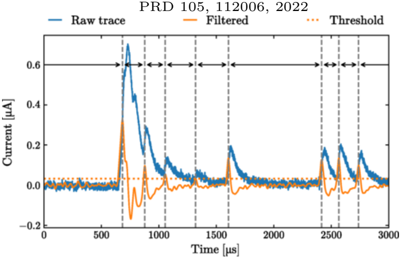
- Close collaboration with SuperCDMS
- Facility background level similar to the Soudan campaign
- Running right now prototypes of HV SNOLAB detectors to study performances
- Capacity of testing one SuperCDMS detector tower
  - Si prototype detector being tested now
  - HV tower to be tested this summer
- Possibility of early science result!



The HVeV program

- The HVeV are small gram scale R&D detectors:
  - Single electron-hole pair resolution devices!
  - Study of charge transport in Si and Ge
- Study of low energy excess background: **PRD 105, 112006, 2022**
  - Found contamination from burst events: high energy events followed by train of single charge events
  - Clues pointing to the production of eV luminence events from the PCB
  - Taking data with detector holder with no PCB now
- Furthermore, sensitivity to a variety of sub-GeV DM models with gram*day exposures
- Result of first DM search run underground (∼100 m) at the NEXUS (FNAL) test facility out soon!





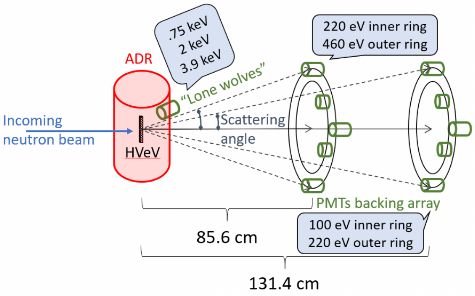
Understanding the Nuclear Recoil Scale: IMPACT

- Ionization yield $Y(E_{\text{Recoil}})$ is energy dependent and not well known at lower energies
- Necessary input for our understanding of the HV detector data

IMPACT

*I*onization *M*easurement with *P*honons *at* *C*ryogenic *T*emperatures

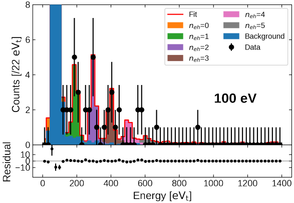
- Determination of the yield via measurement of the total phonon energy and kinematic measurement of the recoil energy via a coincident detection of the scattered neutron
- 55.7 keV neutrons beam at Triangle Universities Nuclear Laboratory
- Total phonon energy measured with Si HVeV detector at 100 V with ~ 3 eV resolution
- Set of liquid scintillator detectors coupled to 2-inch PMTs to measure scattered neutrons at various angles

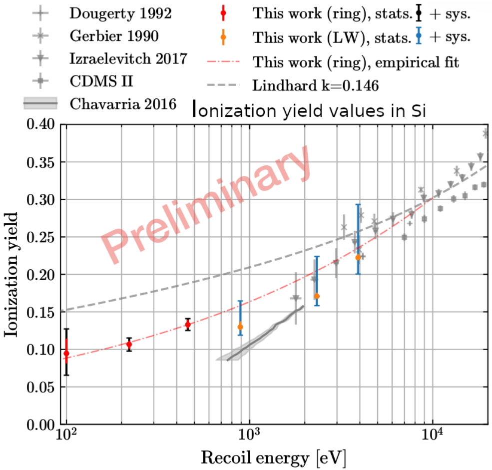


Understanding the Nuclear Recoil Scale: IMPACT

1. Measurement of total phonon energy spectrum for coincidence events
2. Simulation of recoil energy spectrum for coincidence events
3. Determine Y by fitting the simulation to the HV measurement

Example of fit, 100 eV
Single e-h sensitivity for NR!





Preprint released early this month!
arXiv:2303.02196 Working towards a Ge HVeV measurement.

Conclusion

- The SuperCDMS SNOLAB Project is entering in a very exciting phase:
  - Detector fab is complete and SNOLAB infrastructure is well advanced
  - Testing and characterization is happening at test facilities
- First results on the nuclear recoil scale at low energies
- The parameter space that SuperCDMS will explore in the next few years is world-leading and unique!
- Intense and fruitful R&D effort ongoing to already develop the detector technology for the future. Multiple avenues are being explore to push the sentitivity even further!
- Sunil's talk later today discusses what novel directions we are exploring with their expected sensitivity, looking even further ahead into the future of SuperCDMS!
- @SuperCDMS on Twitter to stay up-to-date on the recent developments!

$\boxed{\text{Backup}}$

Low energy excess hypothesis

Stress Induced Microfractures?

Detector under stress due to thermal contraction,manufacturing, etc.

Detector relaxes releasing phonon energy

- Evidence: Using glue with high thermal contraction stress can increase low energy event rate by x10^2
- Mitigation Plan: Decrease residual stress everywhere in detector