The SuperCDMS Experiment at SNOLAB

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On behalf of the SuperCDMS collaboration

TeV Particle Astrophysics conference

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SUPER CDMS

UBC THE UNIVERSITY OF BRITISH COLUMBIA

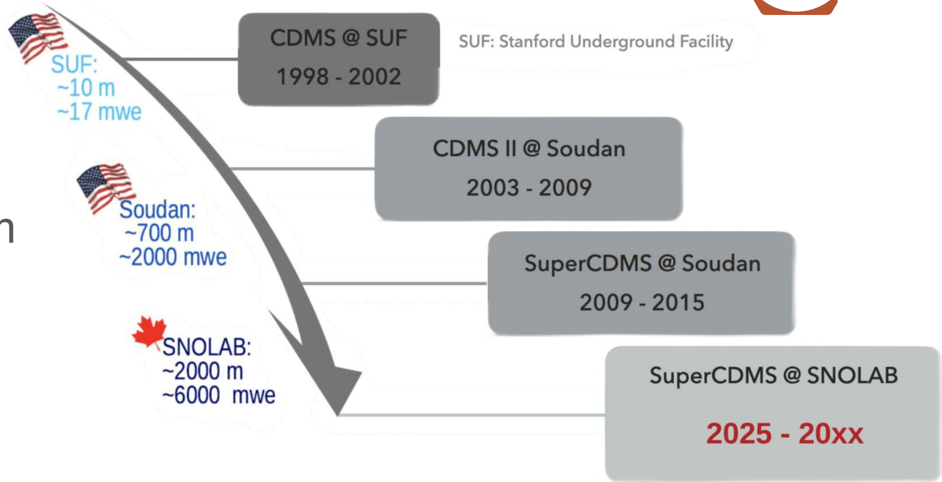
SuperCDMS collaboration

@SuperCDMS
https://www.snolab.ca/experiment/supercdms/

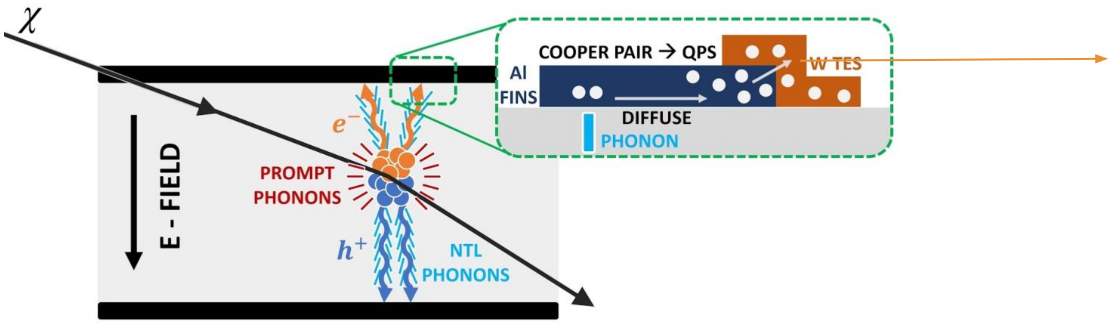
SuperCDMS experiment

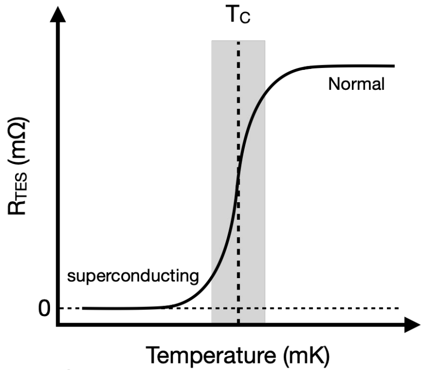
- **Super C**ryogenic **D**ark **M**atter **S**earch experiment
- Use semiconductor crystal detectors Si and Ge
- Operate at cryogenic temperature
- Measure energy deposition in the form of phonons and ionization
- Search for sub-GeV DM
- Recent publications:
    - Light dark matter constraints from SuperCDMS HVeV detectors operated underground with an anticoincidence event selection
    - G4CMP: Condensed matter physics simulation using the GEANT4 toolkit
    - Investigating the sources of low-energy events in a SuperCDMS-HVeV detector
    - Constraints on dark photons and axionlike particles from the SuperCDMS Soudan experiment

  Full publication list at: https://supercdms.slac.stanford.edu/science-results/publications



Detection principle





Source: E. Fascione's thesis

- Particle interactions produce electron-hole (eh) pairs and prompt phonons
- Voltage bias across detector allows eh pairs to drift, creating Neganov-Trofimov-Luke (NTL) phonons $E_{total} = E_{recoil} + (N_{eh} \cdot e \cdot V_{bias})$
- Energy from prompt and NTL phonons ➞ phonon sensor (QETs)
- Drifting eh pairs ➞ charge sensor (HEMTs)

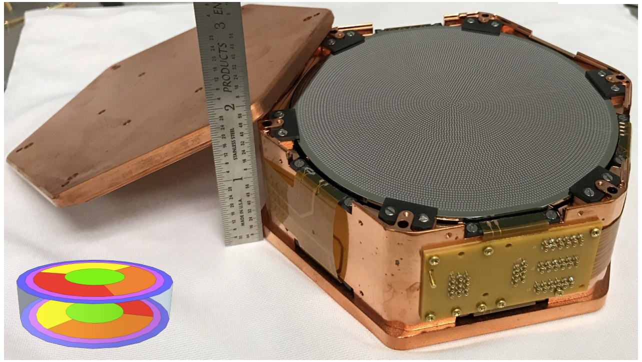
QET: Quasiparticle Trap Assisted Electrothermal Feedback Transition Edge Sensor
HEMT: High Electron Mobility Transistor

SuperCDMS detectors

High Voltage (HV)

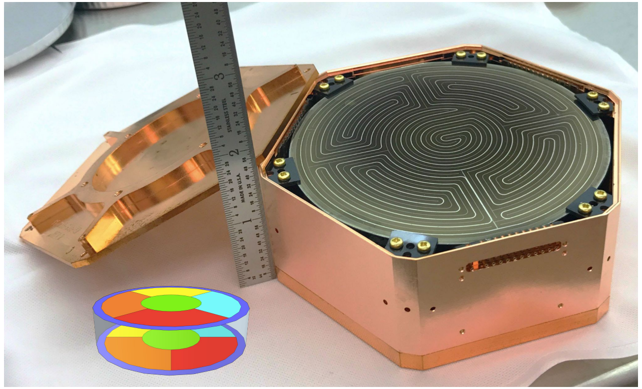
- 12 phonon channels
- Large bias voltage (~100 V)
- NTL amplification
  - low threshold ➞ low mass DM
  - no ER/NR discrimination
- Energy resolution O(10 eV)

ER: Electron recoil
NR: Nuclear recoil



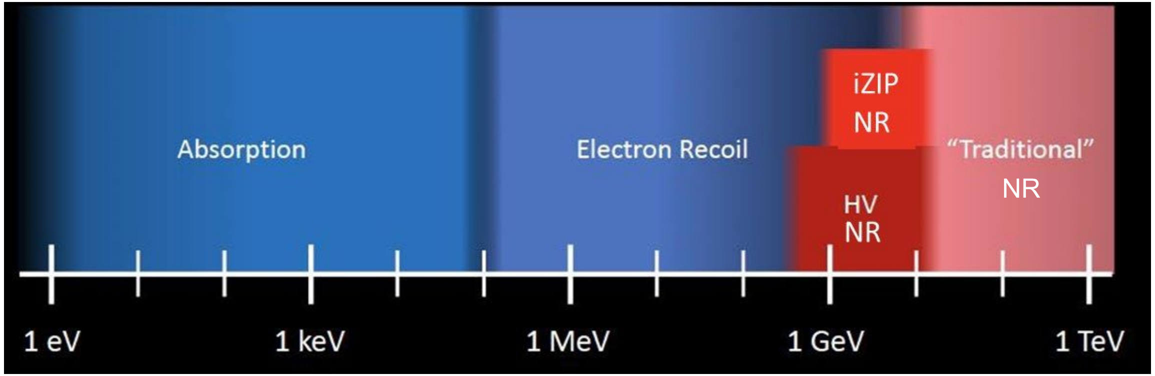
Interleaved Z-sensitive ionization phonon (iZIP)

- 12 phonon channels + 4 charge channels
- Small bias voltage (< 10 V)
- Measuring ionization + phonon
  - ER/NR discrimination
  - better background rejection



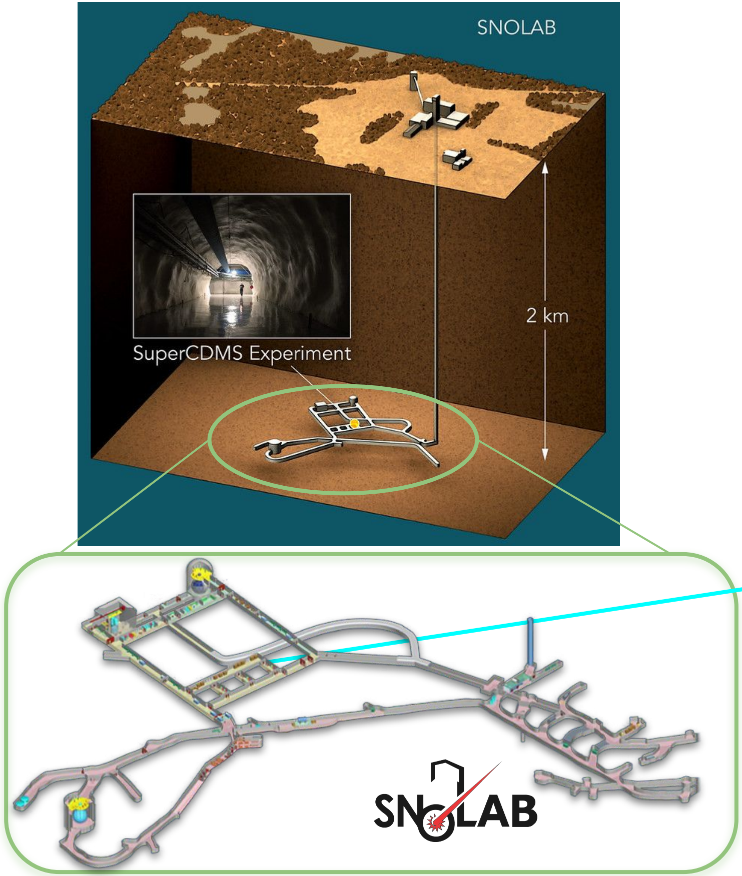
SuperCDMS science search

Nuclear recoil	iZIP, ER background free	>5 GeV/c^2
	iZIP, limited ER/NR discrimination	>1 GeV/c^2
	HV, no discrimination	~0.3 - 10 GeV/c^2
Electron recoil	HV, no discrimination	~0.5 MeV/c^2 - 10 GeV/c^2
Absorption (dark photons, ALPs)	HV, no discrimination	~1 eV/c^2 - 500 keV/c^2 (peak search)

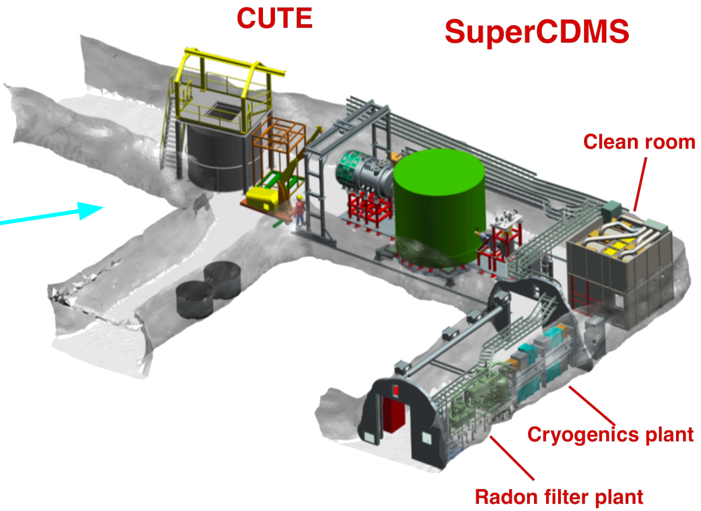


Refer to doi:10.1139/cjp-2024-0127 (Snowmass) for sensitivity forecast

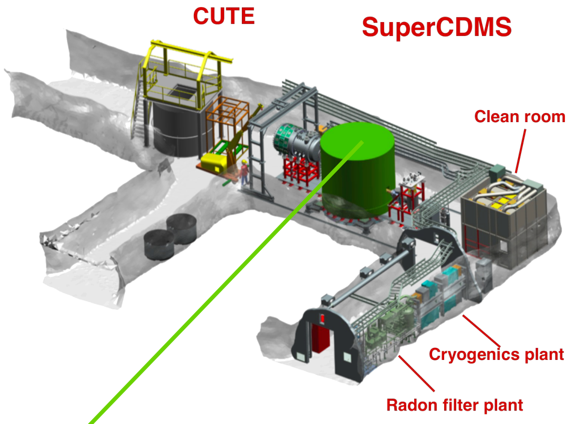
SNOLAB underground laboratory

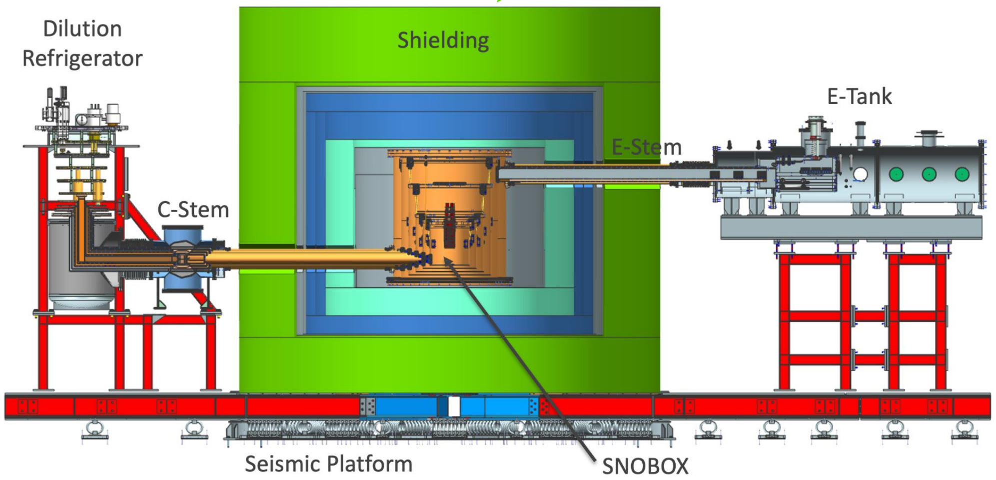


- Located in Sudbury, Canada
- Has 2 km rock overburden / ~6000 mwe
- Hosts low background experiments
- Class 2000 clean room



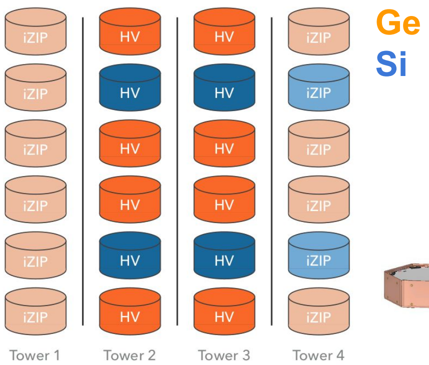
SuperCDMS SNOLAB

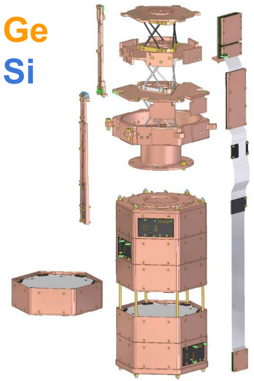


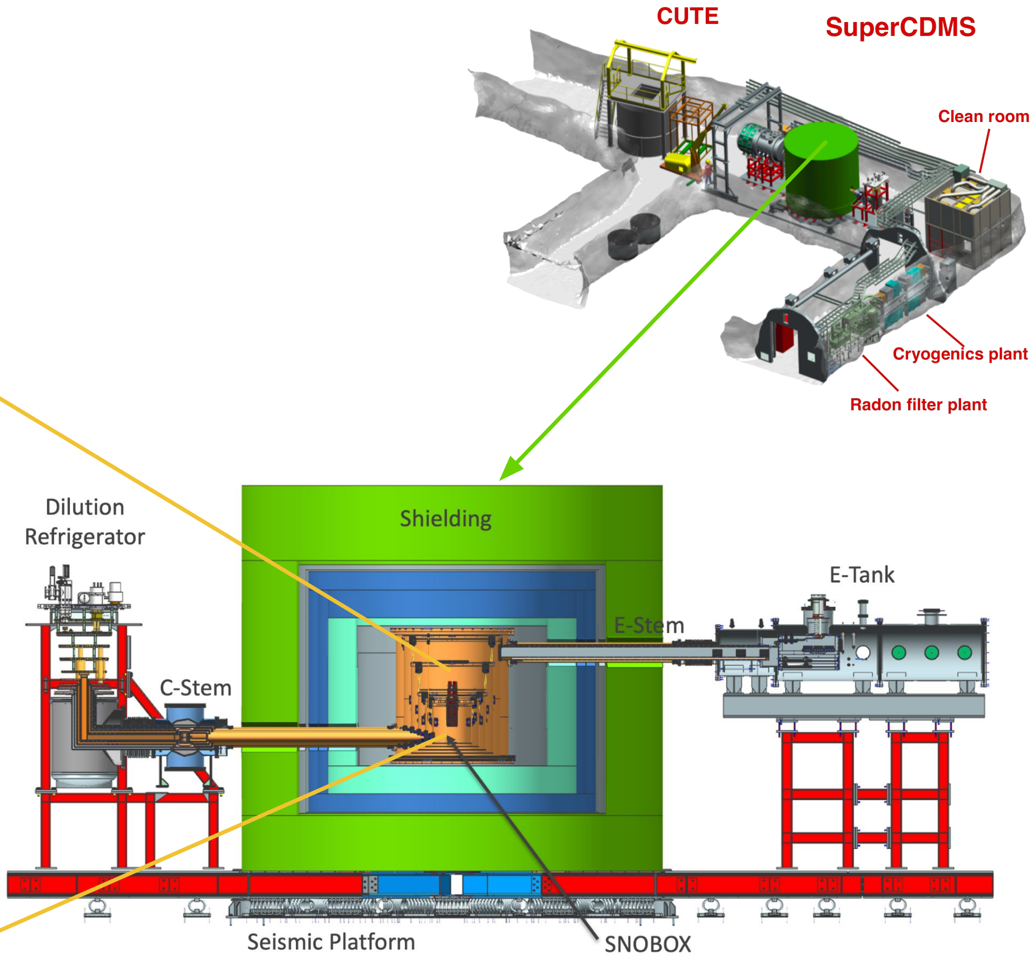


SuperCDMS SNOLAB

- Payload:
  - 4 towers with 6 detectors each
  - 2 iZIP and 2 HV towers
  - ~30kg in total

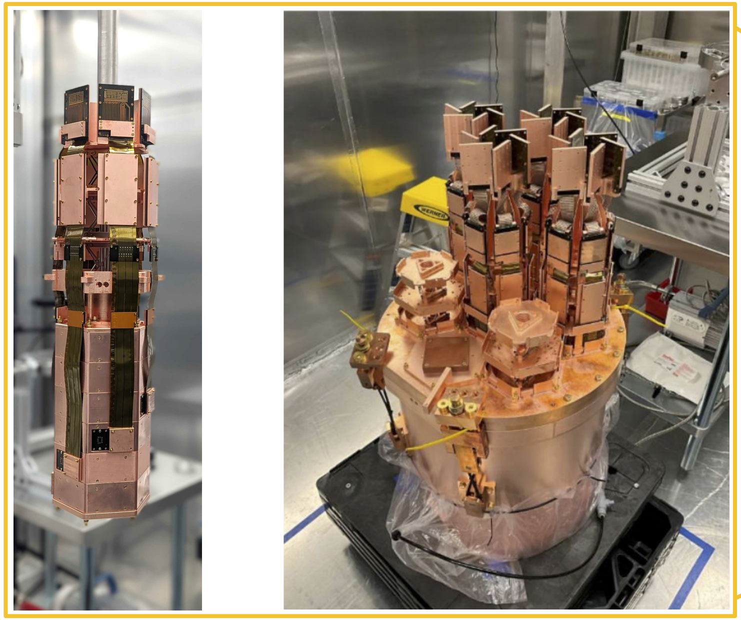


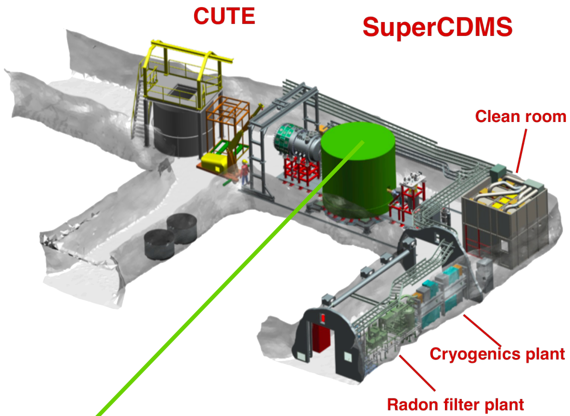


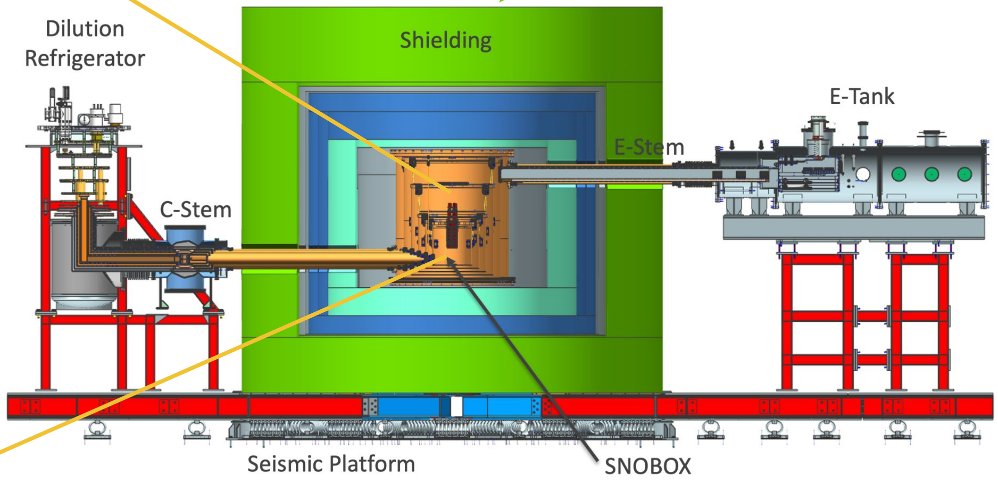


SuperCDMS SNOLAB installation status

- All towers in cryostat







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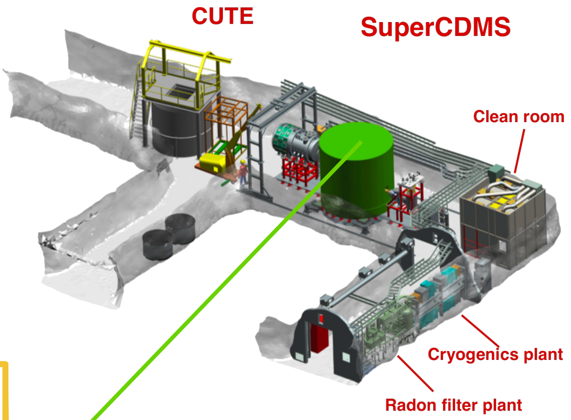
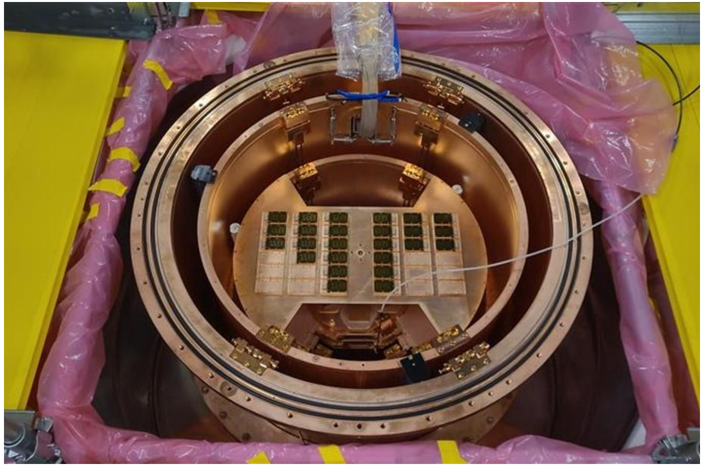
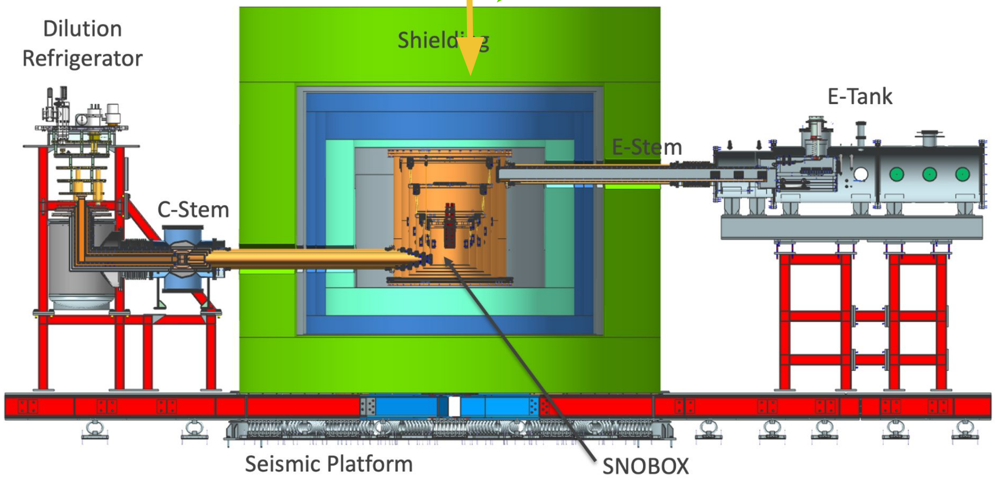
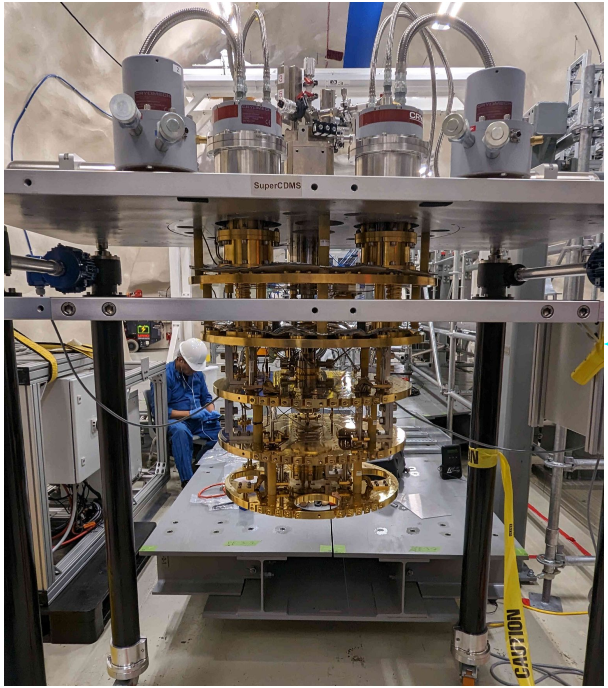


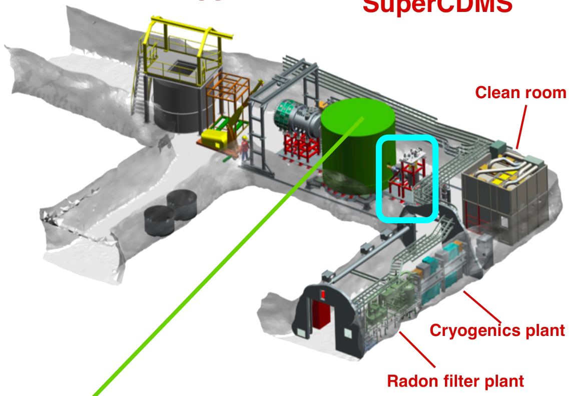


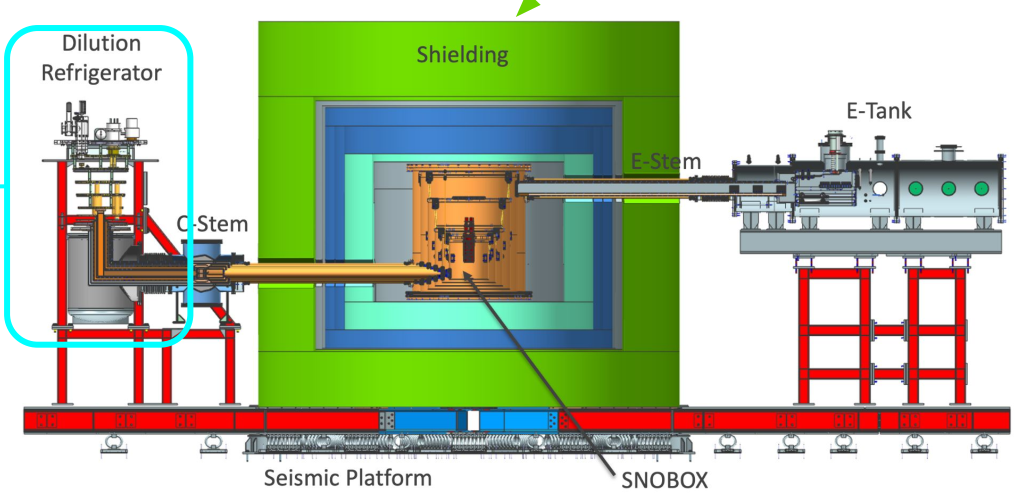


SuperCDMS SNOLAB installation status

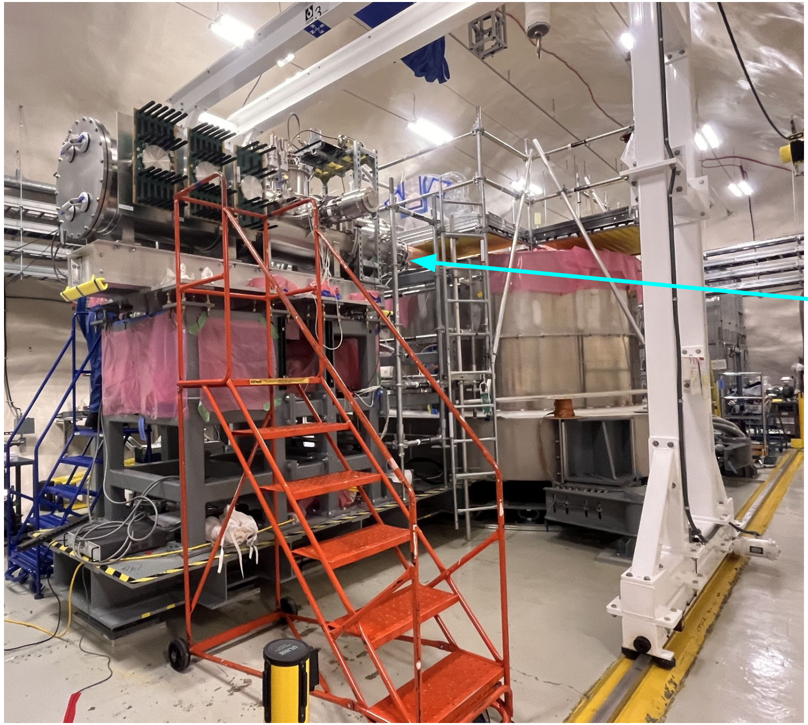
- Dilution refrigerator (~15mK) installed via C-stem

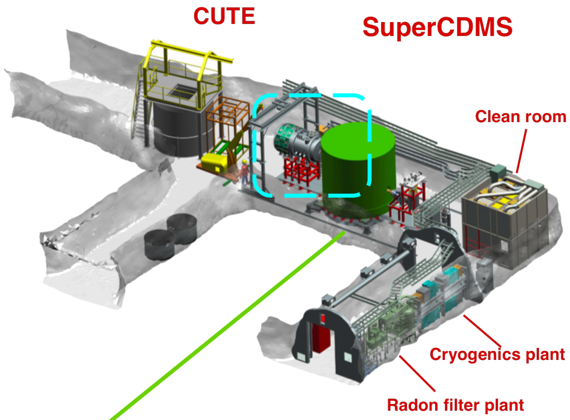


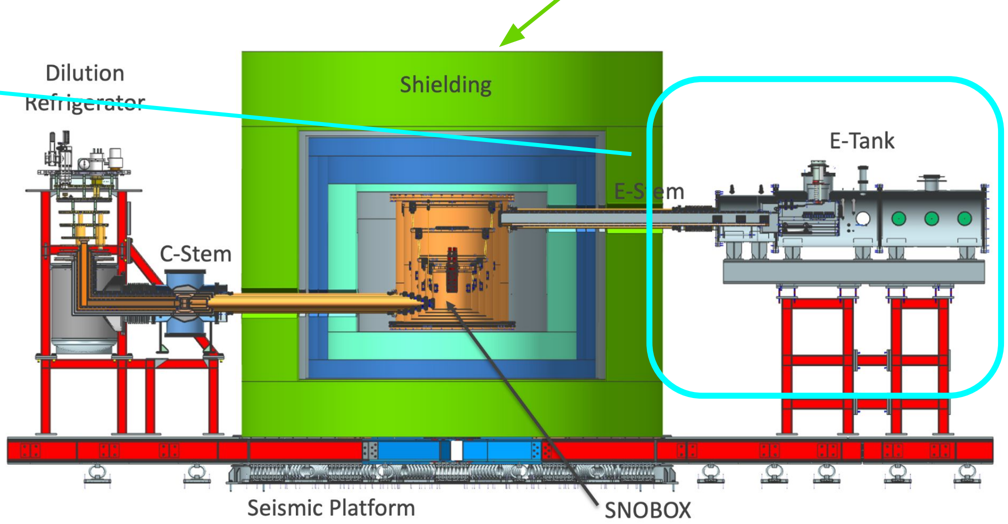




SuperCDMS SNOLAB installation status







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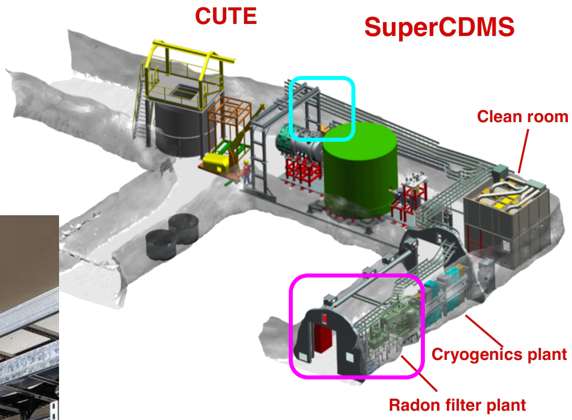
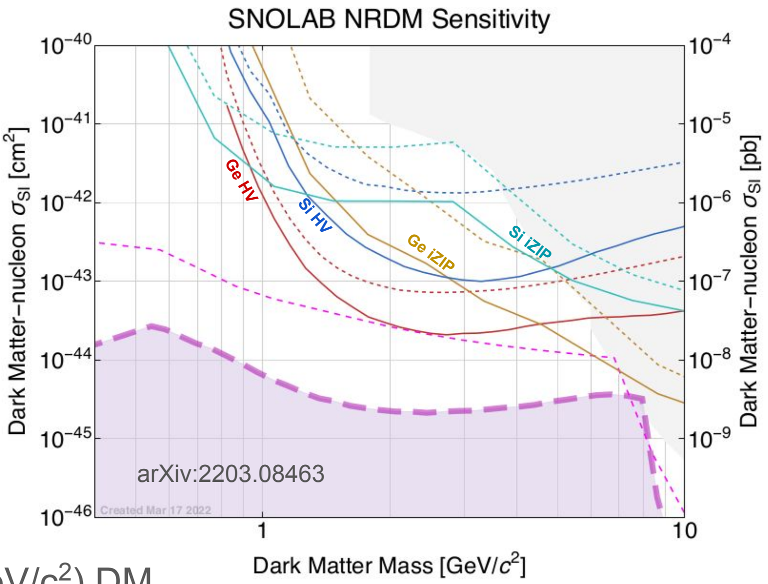


SuperCDMS SNOLAB projected sensitivity for NRDM

- The projected sensitivities for Nuclear Recoil
  - Optimum interval - dashed
  - Profile likelihood - solid

	Germanium	Silicon
HV	Low threshold for low mass DM, larger exposure Limited by tritium betas	Lowest threshold for low mass DM, sensitive for lowest DM masses Limited by ^{32}Si (and tritium) betas
iZIP	ER/NR discrimination, understand Ge background Limited by exposure	ER/NR discrimination, understand Si background Limited by exposure



- Aiming for world leading sensitivity to low mass ($\lesssim$ 10 GeV/c^2) DM
- Challenges: Understanding and modeling detector response, low-energy calibration

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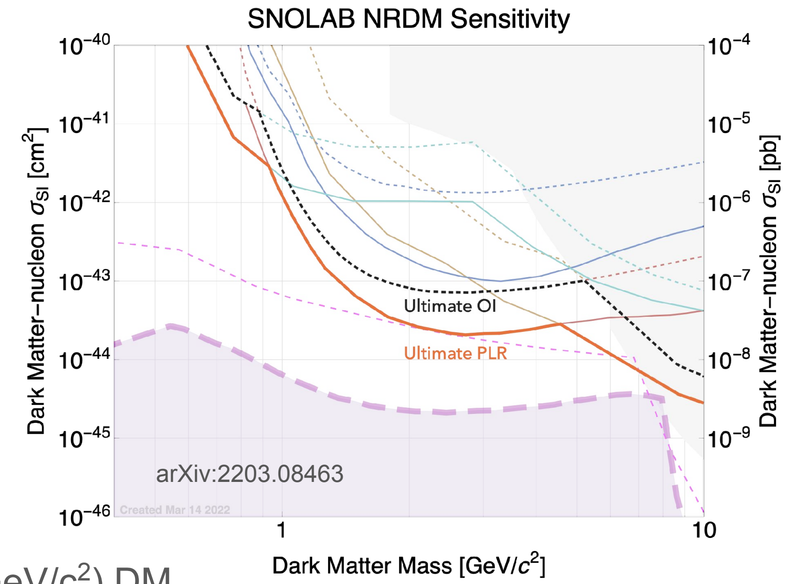

- Aiming for world leading sensitivity to low mass ($\lesssim$ 10 GeV/c^2) DM
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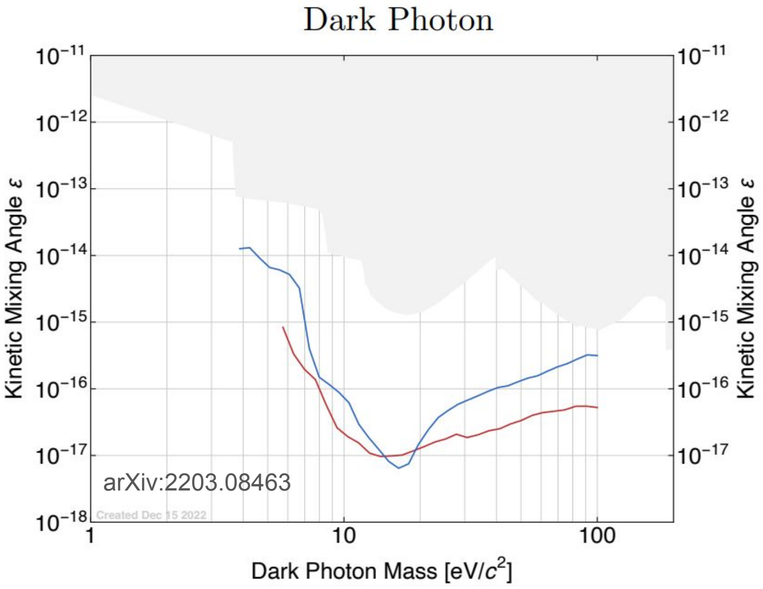
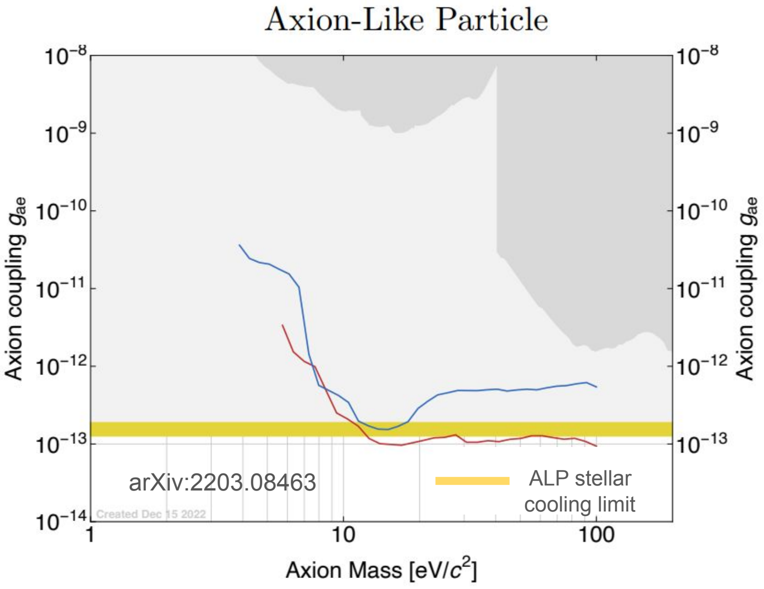
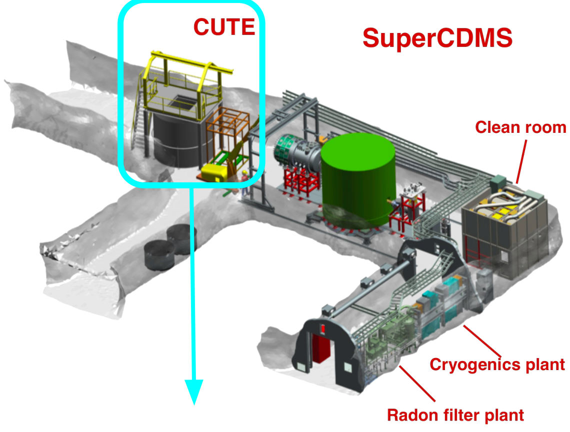
SuperCDMS SNOLAB projected sensitivity for ERDM

- PLR-based 90% CL projected sensitivities for Electron Recoil
- HV detectors: **Si** / **Ge**



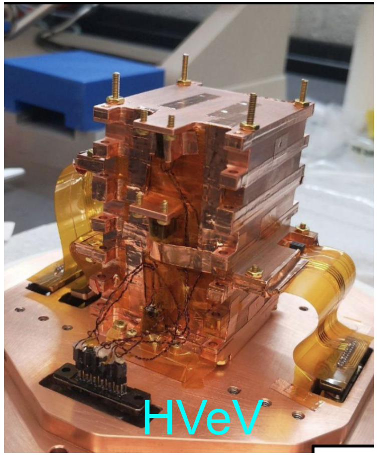


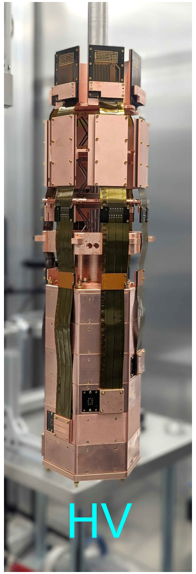
Testing program at CUTE, SNOLAB

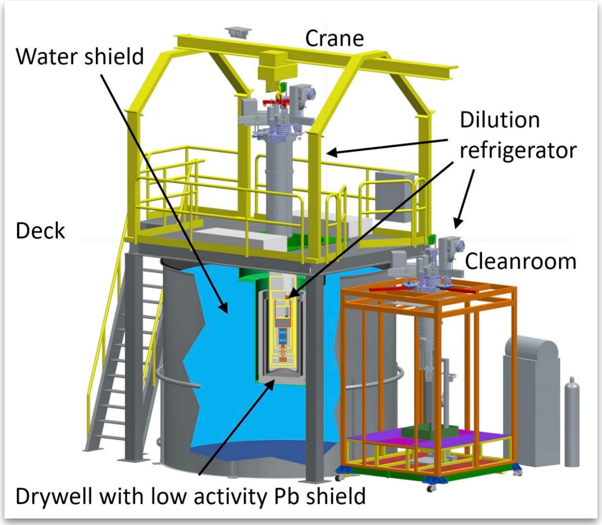


Cryogenic **U**nderground **TE**st facility

- SuperCDMS HV tower testing to understand detector characteristics - completed in Mar'24
- HVeV: 1 cm^2, gram-size detectors with eV baseline resolution: data-taking with 6 detectors to study Low Energy Excess (LEE) - completed in Sep'24







Summary

➔ SuperCDMS experiment: direct DM detection, targeting sub-GeV DM masses

➔ Cryogenic Si/Ge detectors

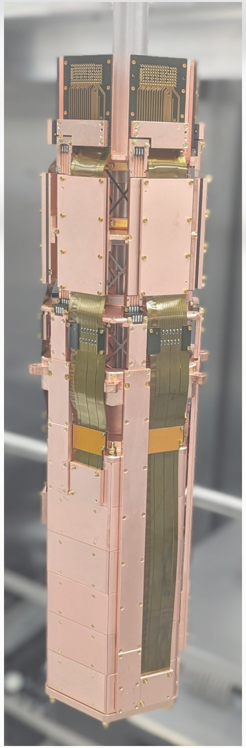
- iZIP: background rejection
- HV: low threshold

➔ Testing program at CUTE facility at SNOLAB

- HV detector tower testing
- HVeV testing

➔ Primary installation complete at SNOLAB and ready for cooldown

➔ Experiment commissioning at end of 2025



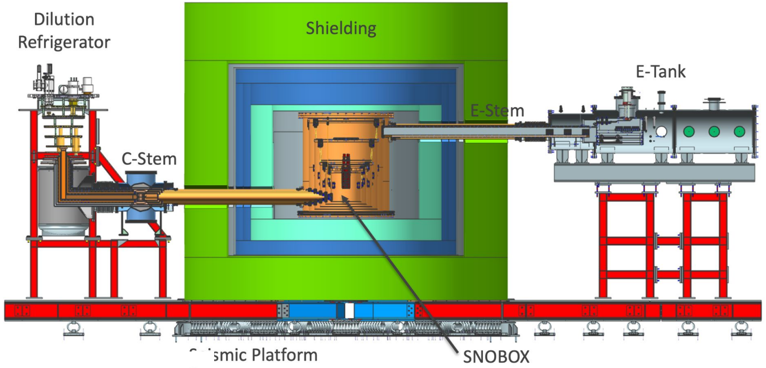
Stay Tuned!

Backup

SuperCDMS SNOLAB: Backgrounds

Cosmogenic
- Cosmic ray muons
- Spallation neutrons
- Activated materials

Environmental
- Airborne radon & daughters
- Radio-impurities in materials

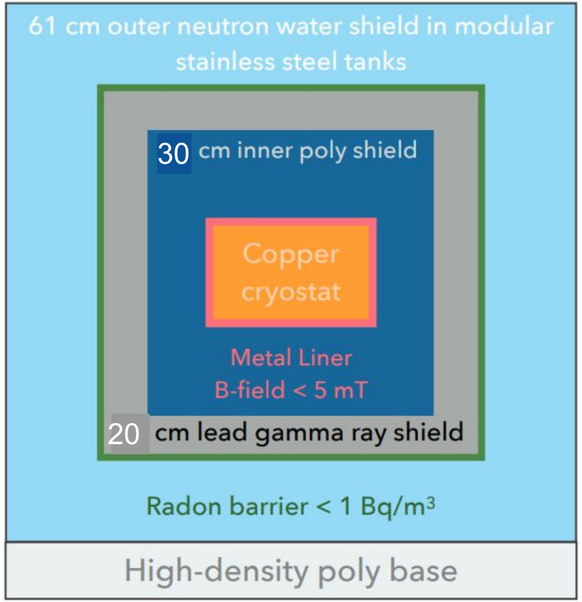


"Singles" Background Rates (counts/kg/keV/year)	Electron Recoil Ge HV	Electron Recoil Si HV	Electron Recoil Ge iZIP	Electron Recoil Si iZIP	Nuclear Recoil ($\times 10^{-6}$) Ge iZIP	Nuclear Recoil ($\times 10^{-6}$) Si iZIP
Coherent Neutrinos					2300.	1600.
Detector-Bulk Contamination	21.	290.	8.5	260.		
Material Activation	1.0	2.5	1.9	15.		
Non-Line-of-Sight Surfaces	0.00	0.03	0.01	0.07	–	–
Bulk Material Contamination	5.4	14.	12.	88.	440.	660.
Cavern Environment	–	–	–	–	510.	530.
Cosmogenic Neutrons					73.	77.
Total	27.	300.	22.	370.	3300.	2900.

Phys. Rev. D **95**, 082002

SuperCDMS SNOLAB: Shielding

- Outer neutron shield:
  - Reduce MeV neutrons from cavern wall by ~10^6, ~20 for μ-induced neutrons (GeV)
- Gamma-ray shield:
  - Reduces MeV gammas from cavern wall by ~10^5
  - Inner layer is 1cm ancient lead, ^{210}Pb < 1 Bq/kg
  - Reduce Bremsstrahlung ^{210}Bi in shield by factor of ~20
- Radon barrier:
  - Al sheet banded around the lead shield with taped joints
  - Reduce ~100 Bq/m^3 to <0.1 Bq/m^3 (mine air)
- Inner neutron shield:
  - Stacked 2" thick poly sheets
  - Reduces neutron rate by >10 μ-induced neutron from rock
  - Neutrons from lead
  - Absorbs backscatter from SNOBOX vacuum cans
  - No neutron "reflection" from lead
- Copper cans of Cryostat System:
  - 6.7 cm of copper in nested cans (SNOBOX)
  - Copper is radiopure compared to lead
  - Final gamma shield
  - Reduce residual gammas by ~25
  - Reduces Bremsstrahlung from ^{210}Bi β-decay by ~20



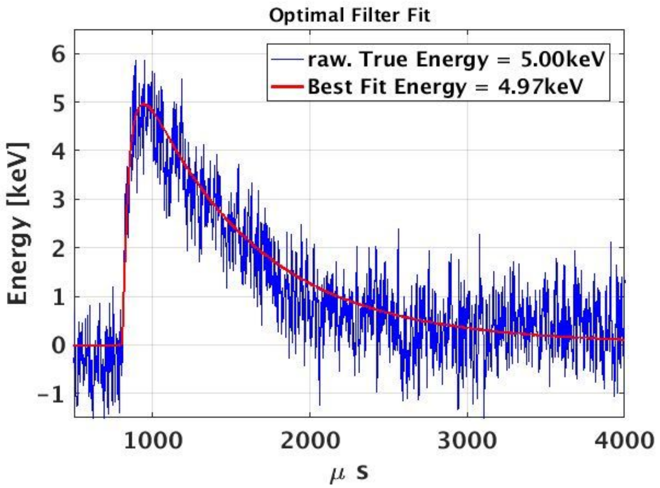
Slide credit: M. J. Wilson

Energy estimation (credit: W. A. Page)

$$S(t) = aA(t) + n(t)$$

- $S(t)$: signal
- a: pulse amplitude
- $A(t)$: known template
- $n(t)$: gaussian noise

Calculate a frequency-domain χ^2 : $\chi^2(a) = \sum_n \frac{|\tilde{S}_n - a\tilde{A}_n|^2}{J_n}$

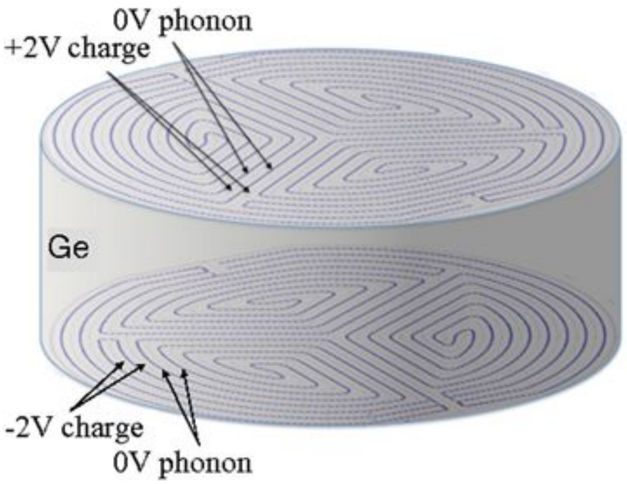


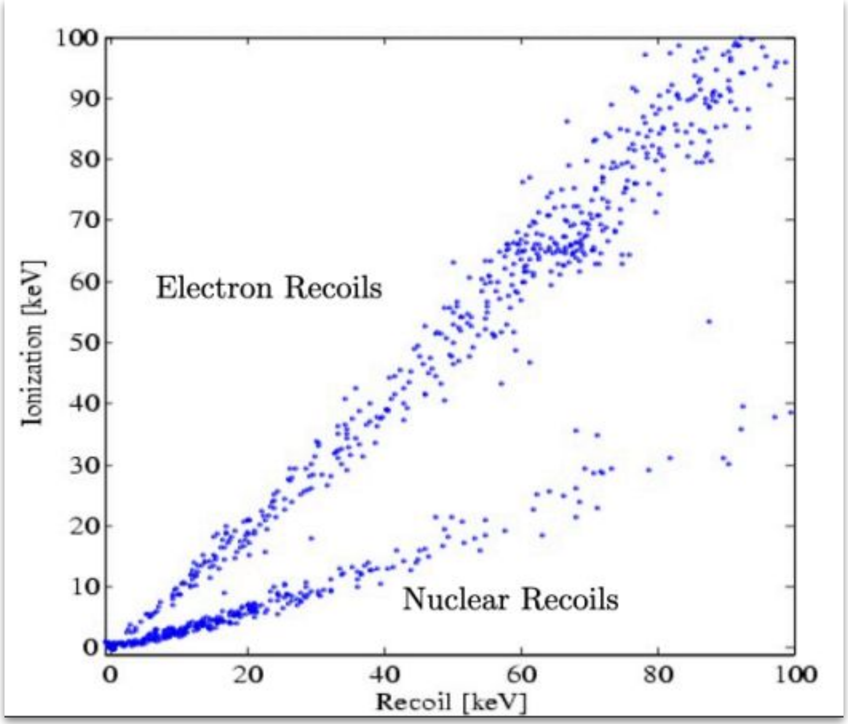
SuperCDMS SNOLAB: ER/NR

$$E_{ph} = E_R + \frac{Y(E_R)E_R}{\epsilon}e\Delta V$$

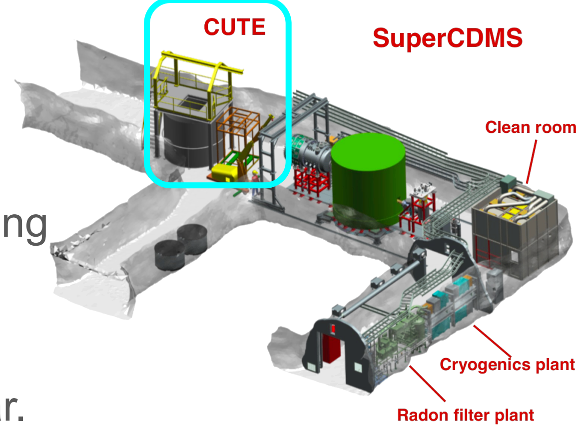
$Y(E_R) = 1$ –> ER

$Y(E_R) < 1$ –> NR

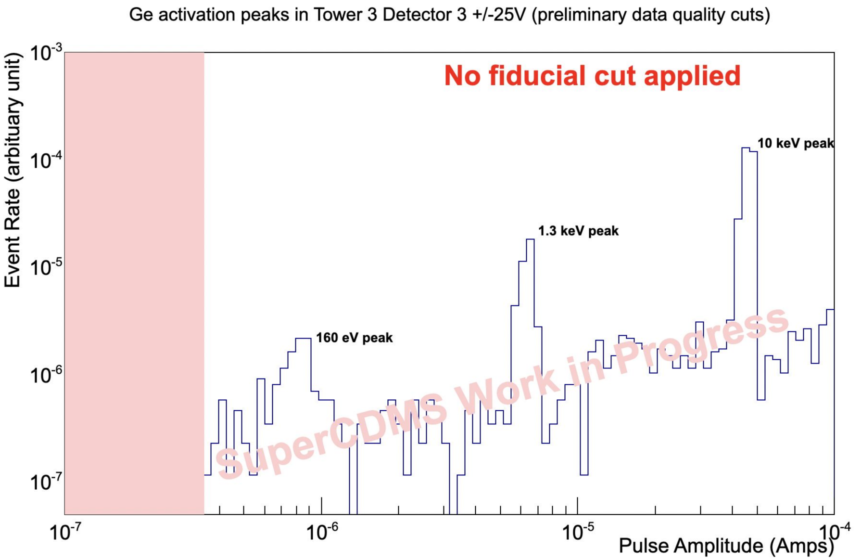




Tower testing at CUTE, SNOLAB



- SuperCDMS HV tower hosting 4 Ge and 2 Si detectors testing completed in Mar'24 ✔
- First time testing in low background environment
- Ongoing analysis efforts, possibility of early results next year.



SuperCDMS SNOLAB projected sensitivity for ER-LDM

- PLR-based 90% CL projected sensitivities for Electron Recoil
  - for heavy mediator (form factor F(q) = 1, left)
  - a light mediator (form factor F(q) = $1/q^2$, right)
- HV detectors: Si: blue; Ge: red