The SuperCDMS Experiment at SNOLAB

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On behalf of the SuperCDMS collaboration

15th International Workshop on the Identification of Dark Matter IDM2024

10 July, 2024

SUPER CDMS

Emmy Noether-Programm

DFG Deutsche Forschungsgemeinschaft

KIT Karlsruher Institut für Technologie

UHH Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

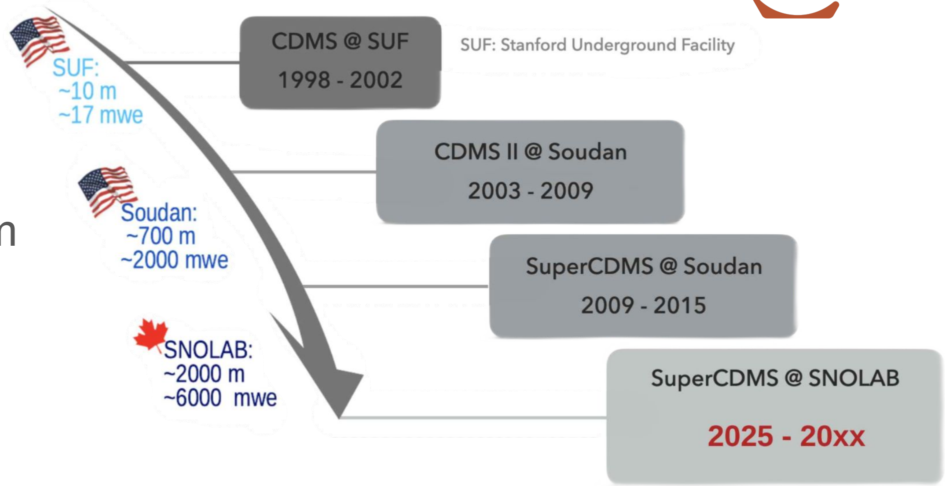
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

SuperCDMS collaboration

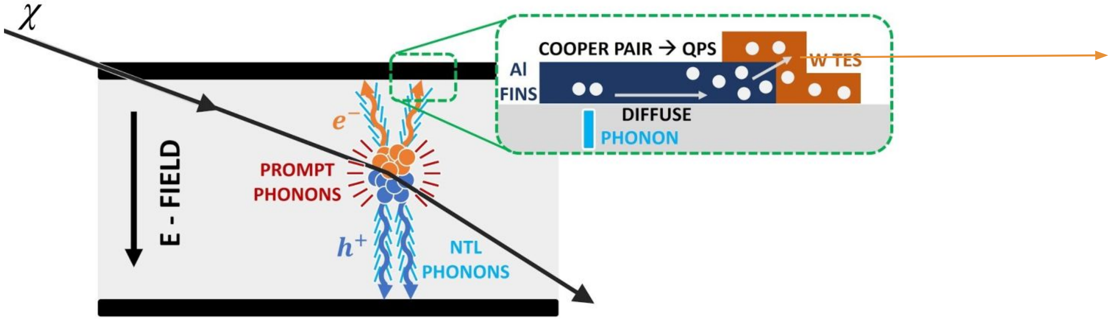
@SuperCDMS
https://www.snolab.ca/experiment/supercdms/

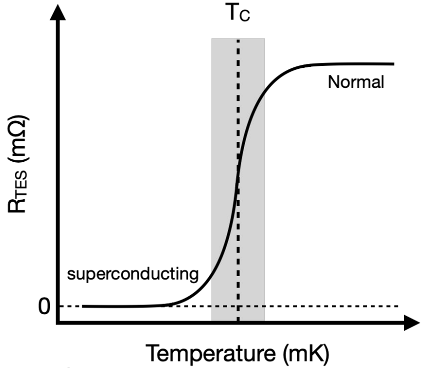
SuperCDMS experiment

- **Super C**ryogenic **D**ark **M**atter **S**earch experiment
- Use <u>semiconductor</u> crystal detectors
  Si and Ge
- Operate at <u>cryogenic</u> temperature
- Measure energy deposition in the form of <u>phonons and ionization</u>
- Search for <u>sub-GeV DM</u>
- Recent publications:
  - First measurement of the nuclear-recoil ionization yield in silicon at 100 eV // arXiv:2303.02196
  - A Strategy for Low-Mass Dark Matter Searches with Cryogenic Detectors in the SuperCDMS SNOLAB Facility // arXiv:2203.08463 (Snowmass)
  - Effective Field Theory Analysis of CDMSlite Run 2 Data // arXiv:2205.11683
  - Investigating the sources of low-energy events in a SuperCDMS-HVeV detector // arXiv:2204.08038
  - Constraints on dark photons and axionlike particles from the SuperCDMS Soudan experiment // arXiv:1911.11905
  - Search for Low-Mass Dark Matter with CDMSlite Using a Profile Likelihood Fit // arXiv:1808.09098
  - A Search for Low-mass Dark Matter via Bremsstrahlung Radiation and the Migdal Effect in SuperCDMS arXiv:2302.09115



Detection principle





Source: E. Fascione's thesis

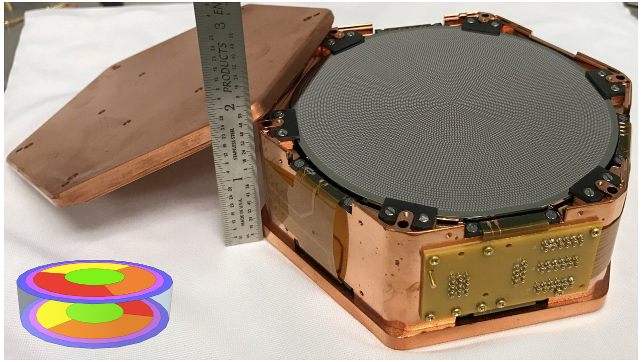
- Particle interactions produce electron-hole (eh) pairs and prompt phonons
- Voltage bias across detector allows eh pairs to drift, creating Neganov-Trofimov-Luke (NTL) phonons $E_{total} = E_{recoil} + (N_{eh} \cdot e \cdot V_{bias})$
- Energy from prompt and NTL phonons ➞ phonon sensor (QETs)
- Drifting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

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

SuperCDMS detectors

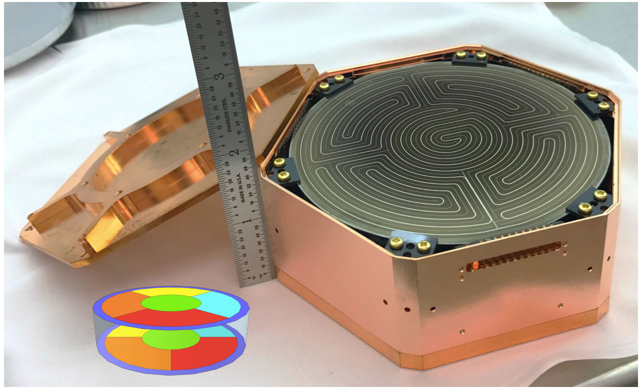
High Voltage (HV)

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



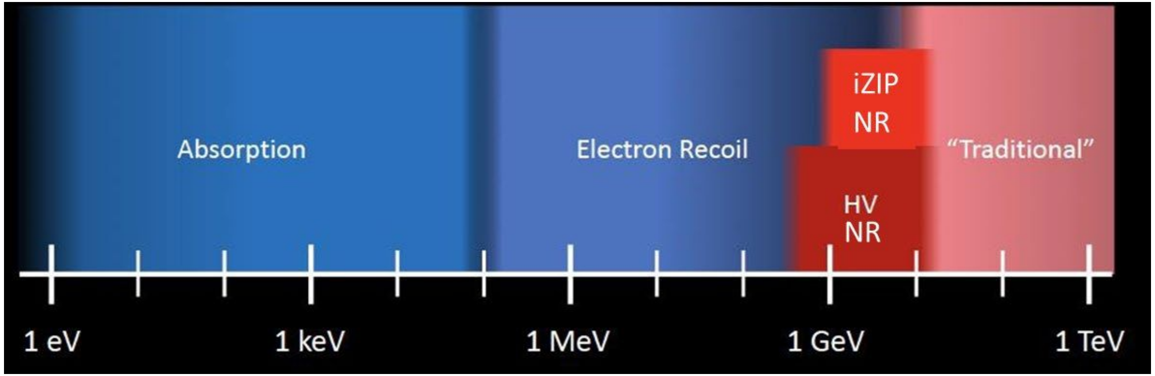
Interleaved Z-sensitive ionization phonon (iZIP)

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



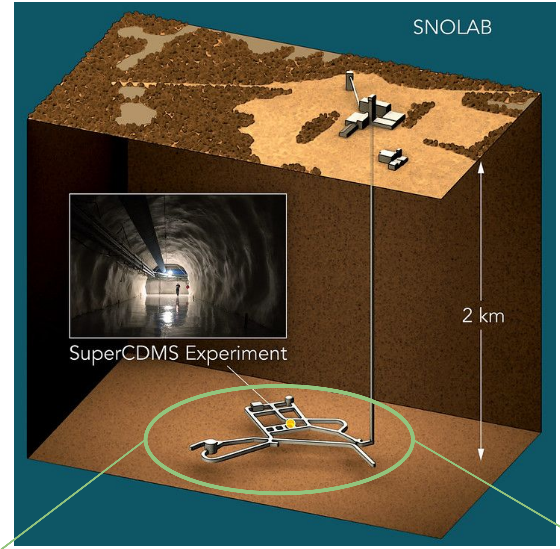
SuperCDMS science search

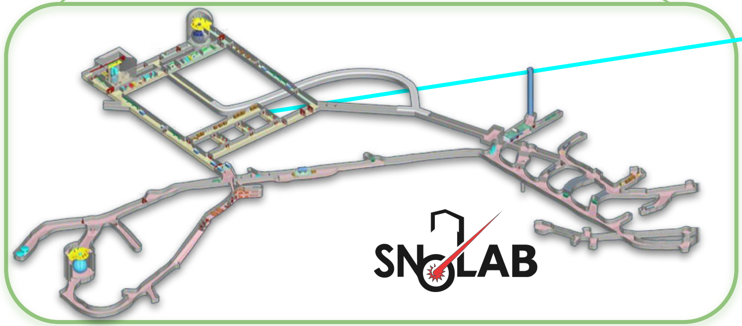
Nuclear recoil	iZIP, ER background free	>5 GeV/c^2
	iZIP, limited ER/NR discrimination	>1 GeV/c^2
	HV, no discrimination	~0.3 - 10 GeV/c^2
Electron recoil	HV, no discrimination	~0.5 MeV/c^2 - 10 GeV/c^2
Absorption (dark photons, ALPs)	HV, no discrimination	~1 eV/c^2 - 500 keV/c^2 (peak search)



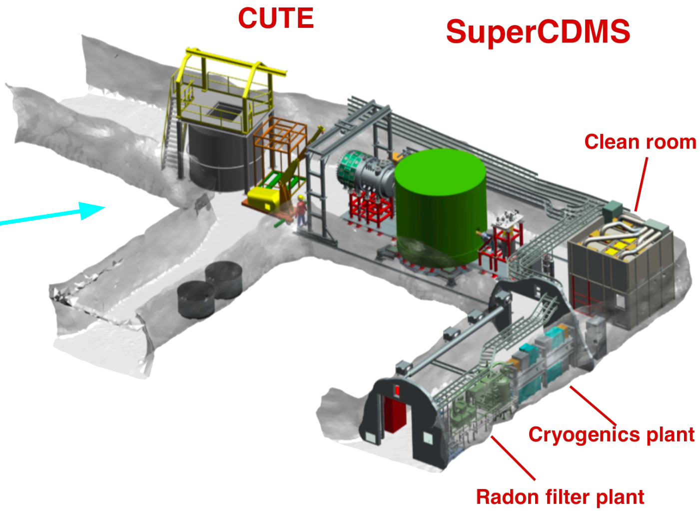
Refer to arXiv:2203.08463 (Snowmass) for sensitivity forecast

SNOLAB underground laboratory



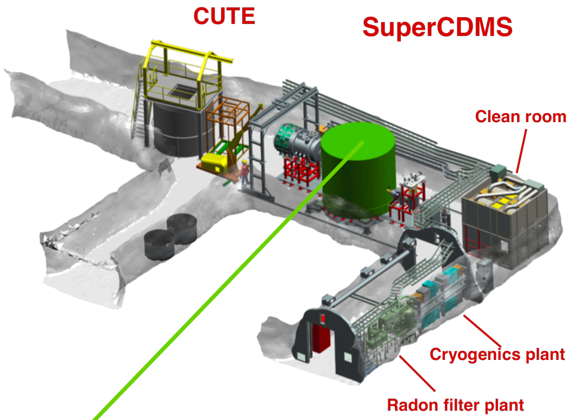


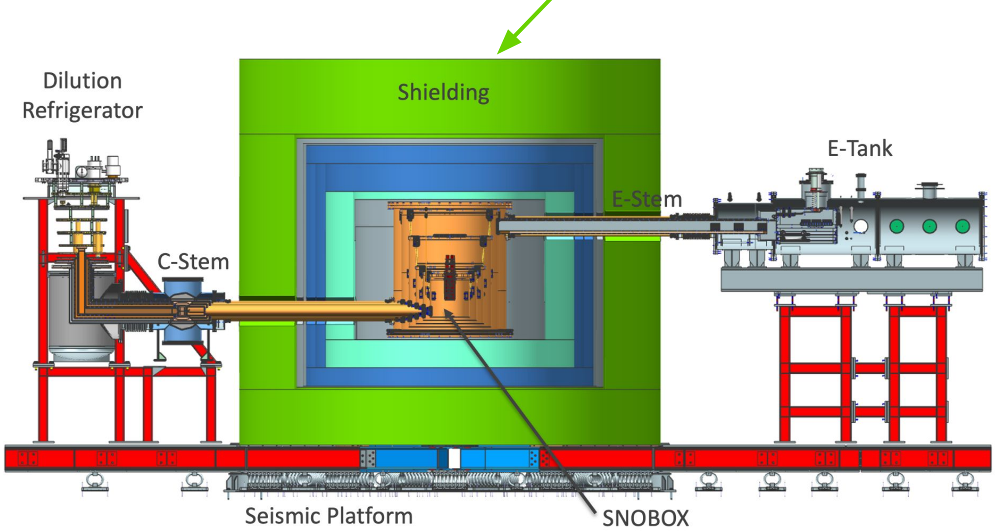
- Located in Sudbury, Canada
- Has 2km rock overburden / ~6000 mwe
- Hosts low background experiments



SuperCDMS SNOLAB

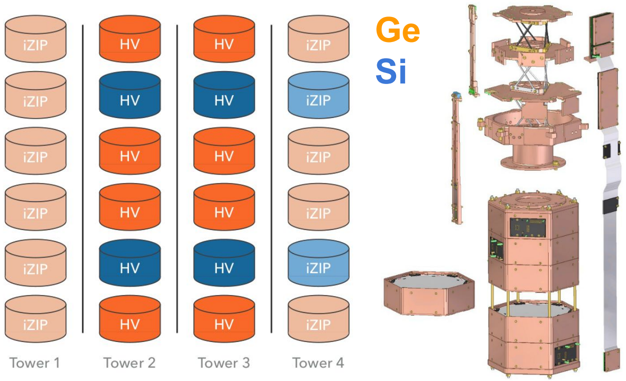
- Under construction at SNOLAB
- Dilution refrigerator ~15mK
- Class 2000 clean room

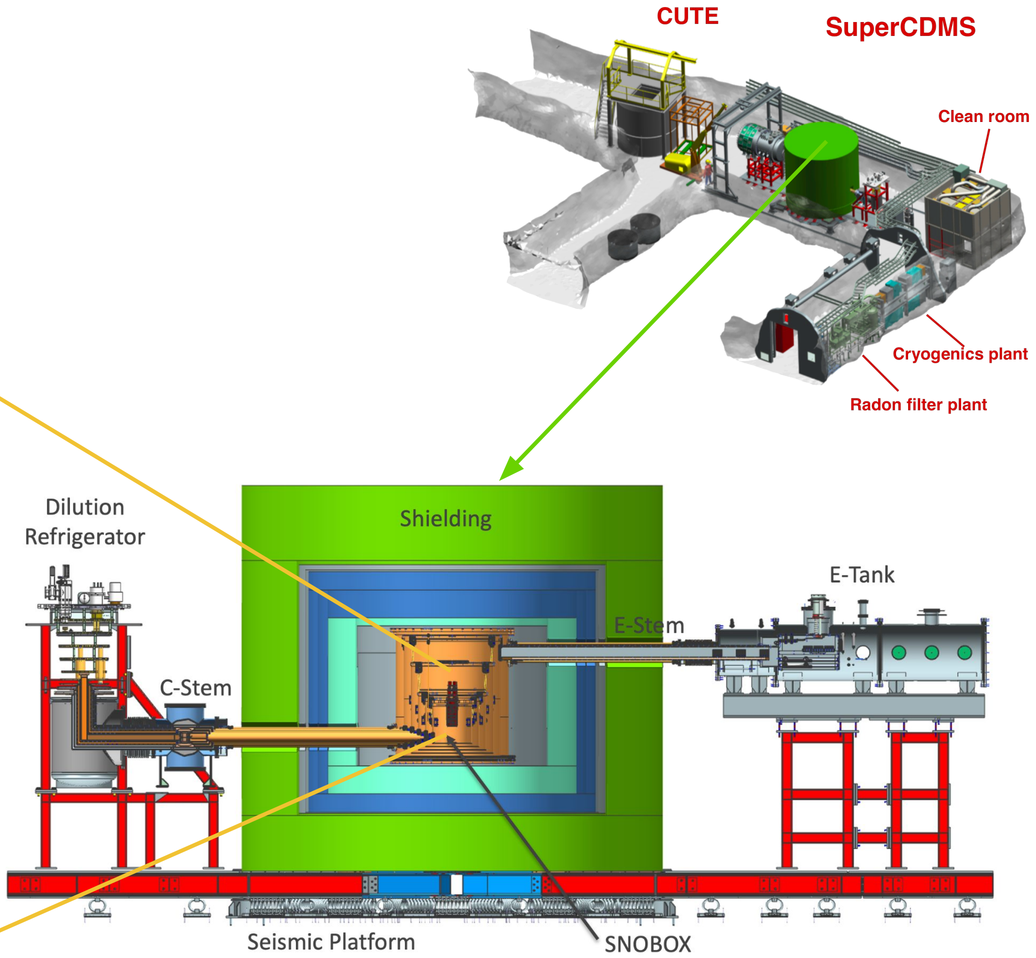




SuperCDMS SNOLAB

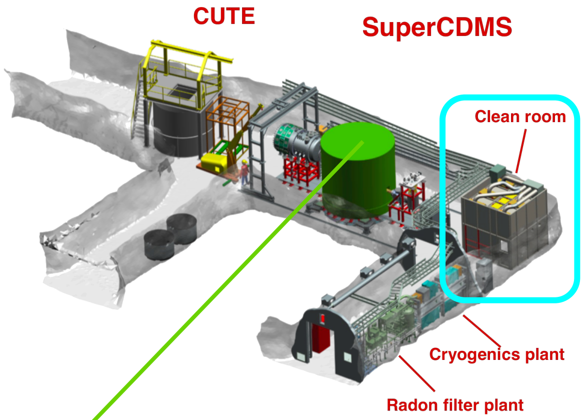
- Under construction at SNOLAB
- Dilution refrigerator ~15mK
- Class 2000 clean room
- Payload:
  - 4 towers with 6 detectors each
  - 2 iZIP and 2 HV towers
  - ~30kg in total

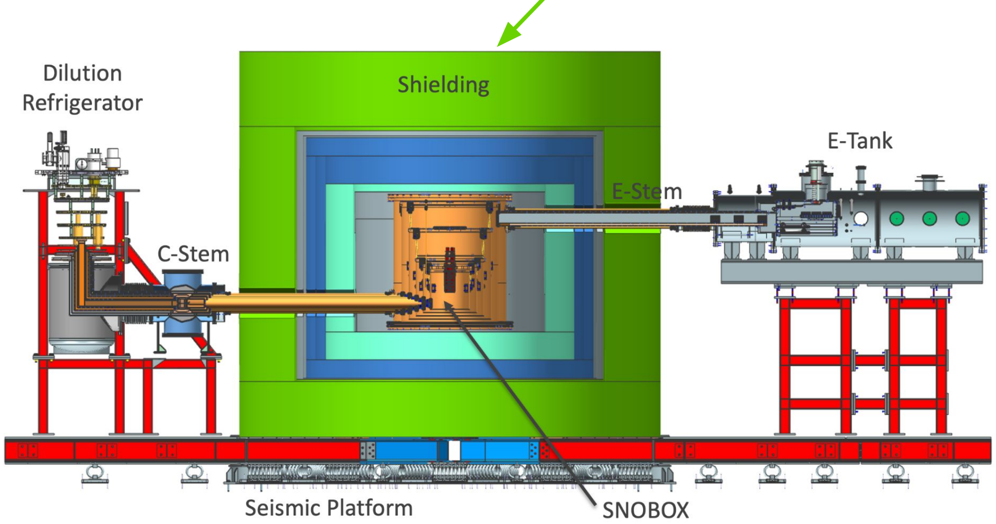




SuperCDMS SNOLAB installation status

- All towers underground ✔





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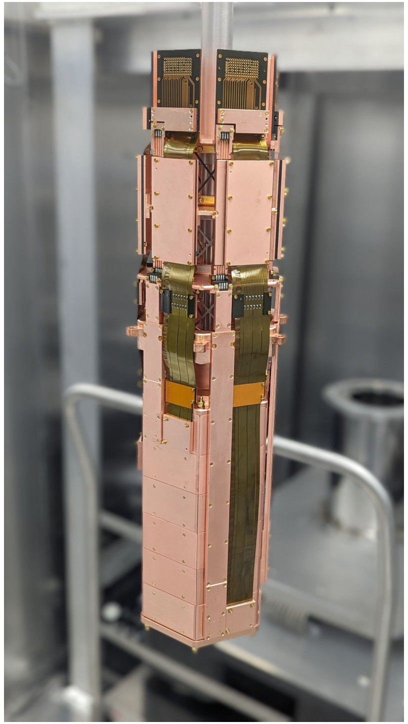
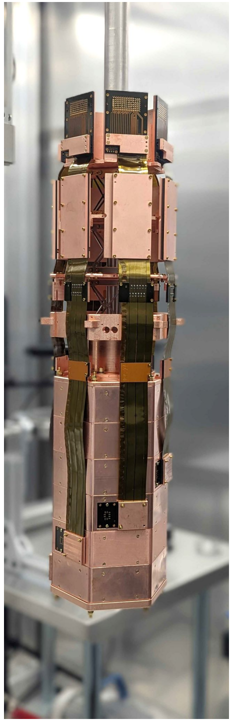
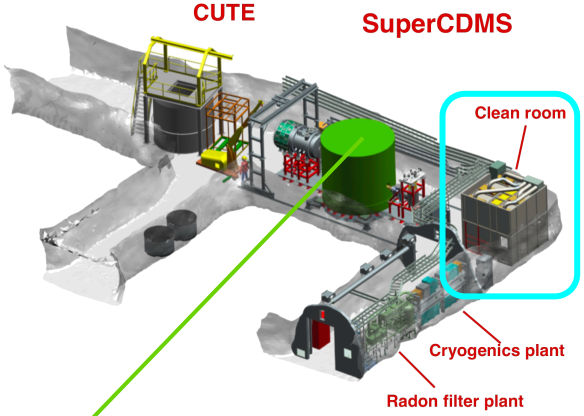
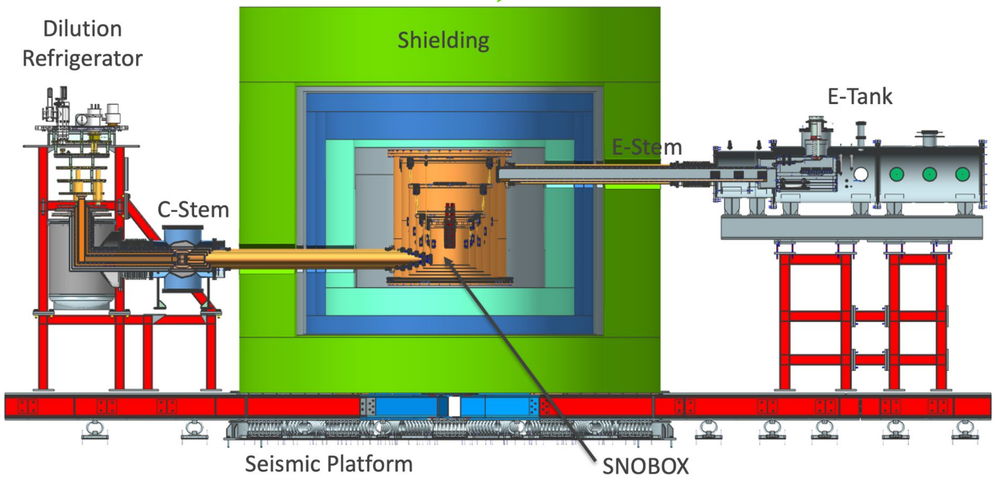


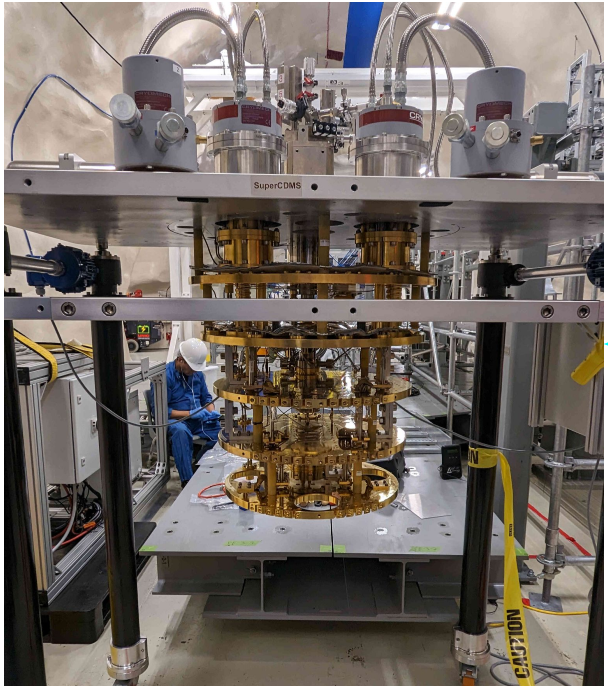


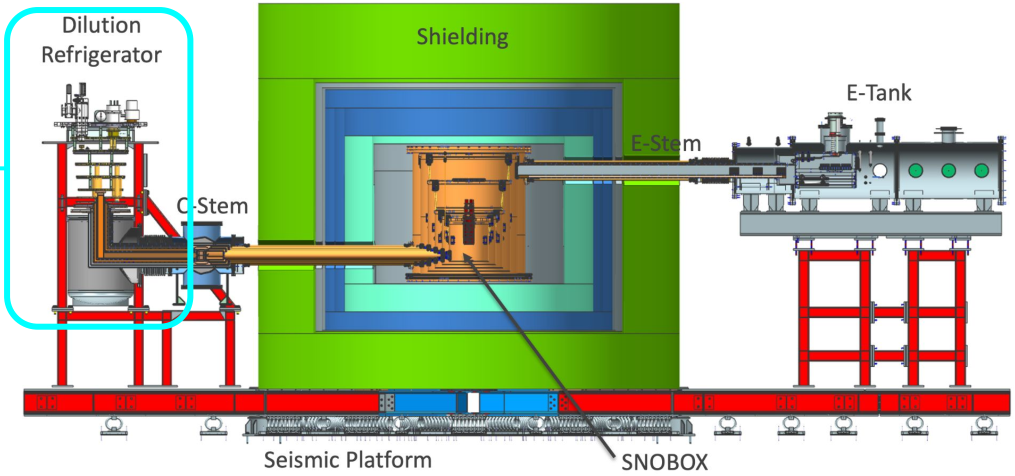


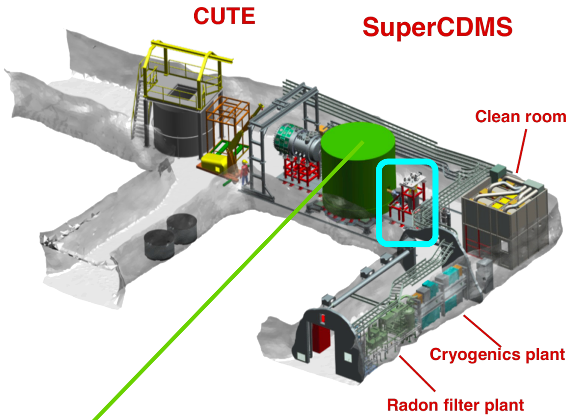


SuperCDMS SNOLAB installation status

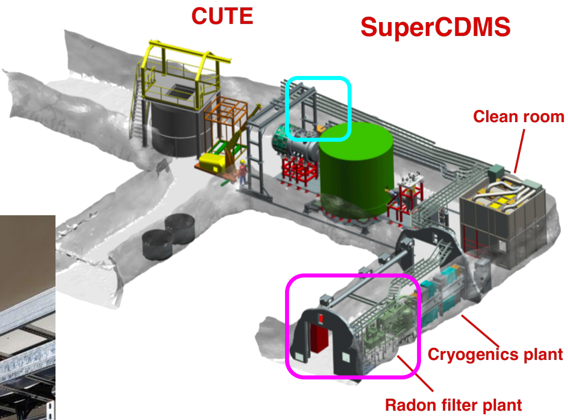
- Dilution refrigerator commissioning ✔







SuperCDMS SNOLAB installation status



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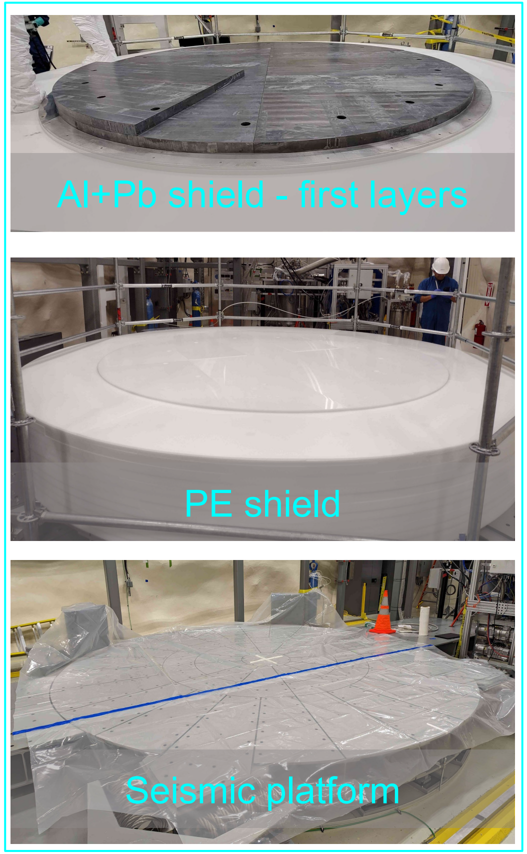

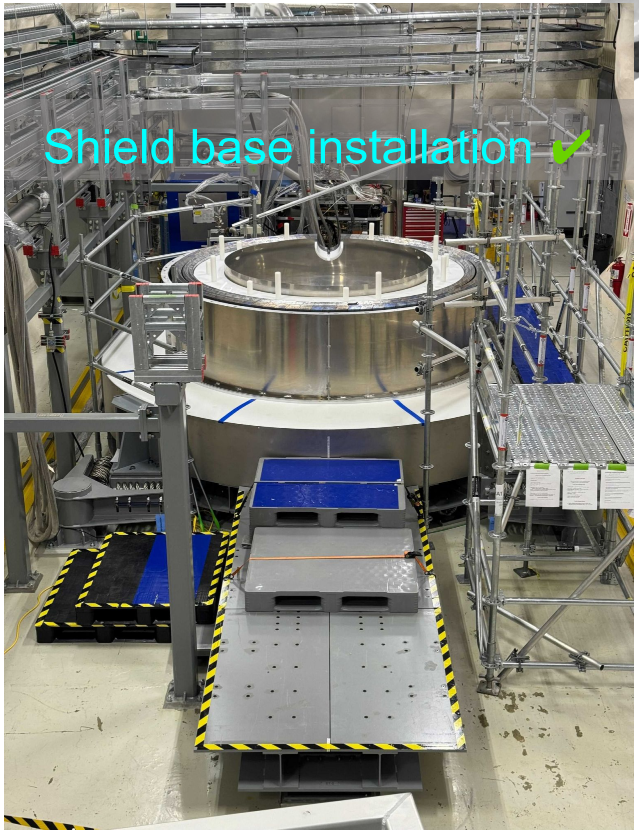

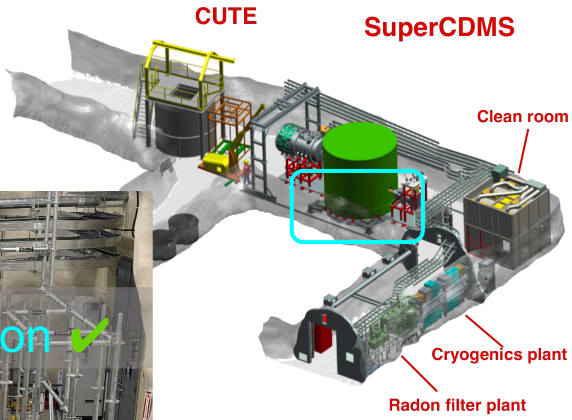

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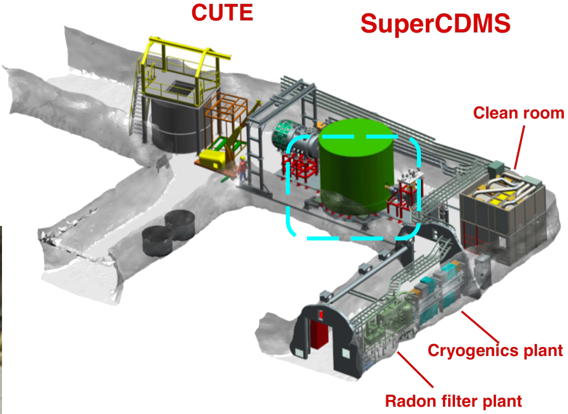
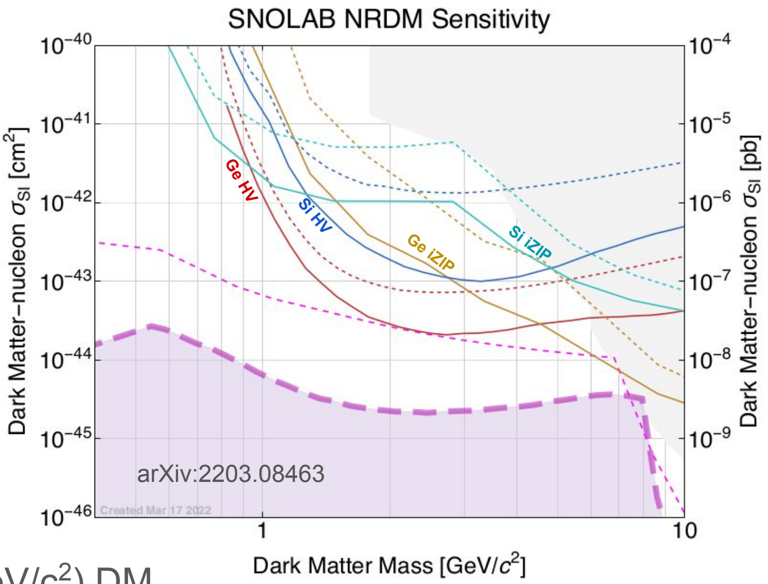


Exciting times ahead!

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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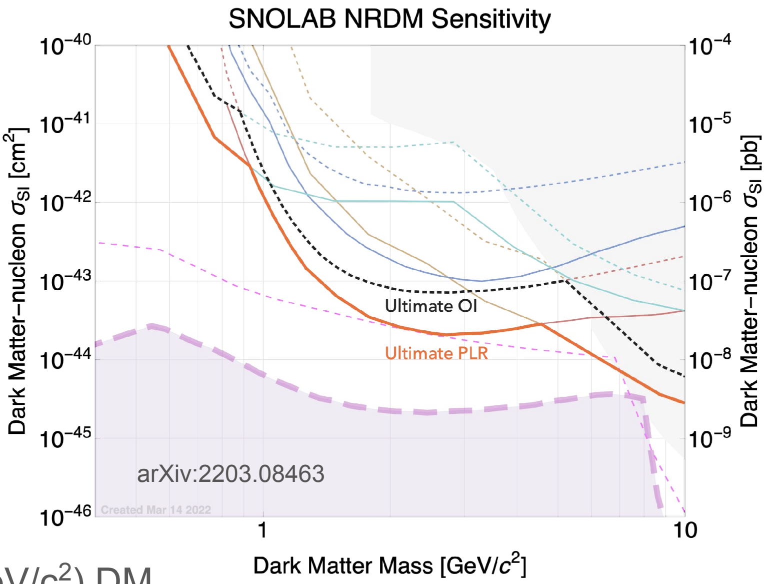

- Aiming for world leading sensitivity to low mass ($\lesssim$ 10 GeV/c^2) DM
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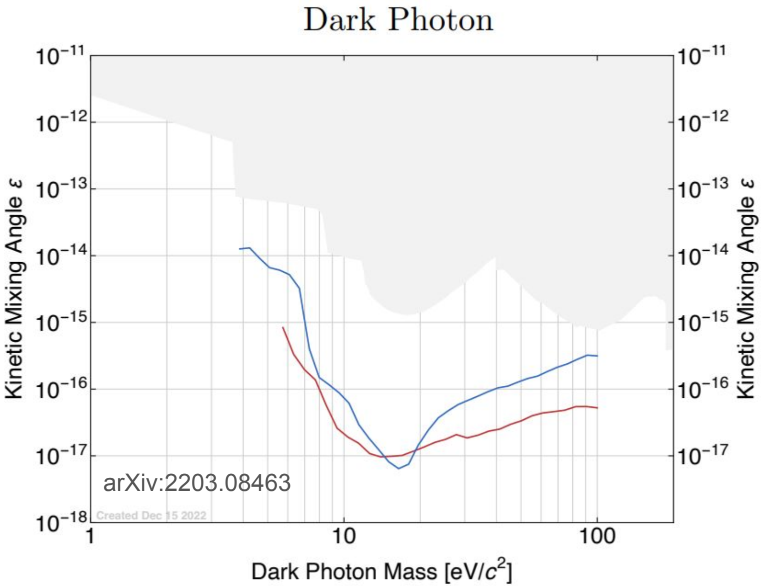
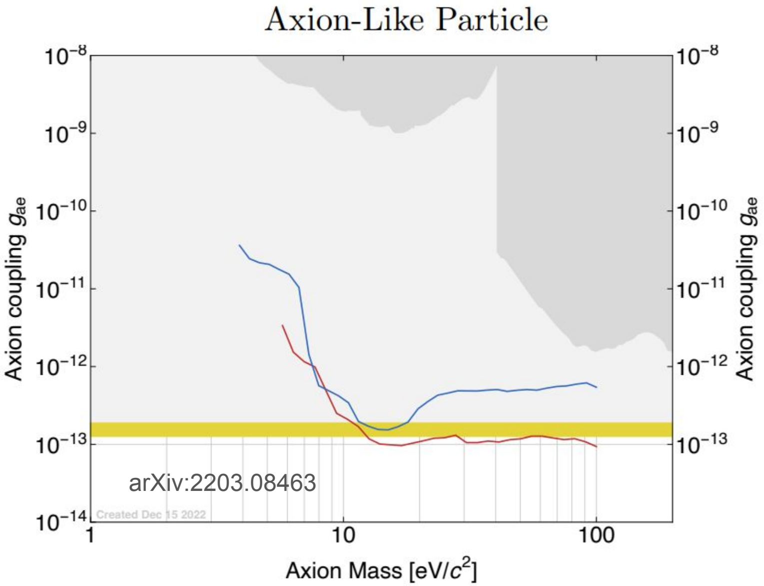
SuperCDMS SNOLAB projected sensitivity for ERDM

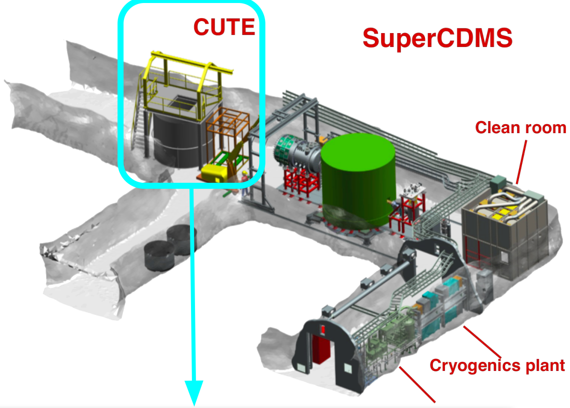
- PLR-based 90% CL projected sensitivities for Electron Recoil
- HV detectors: **Si** / **Ge**

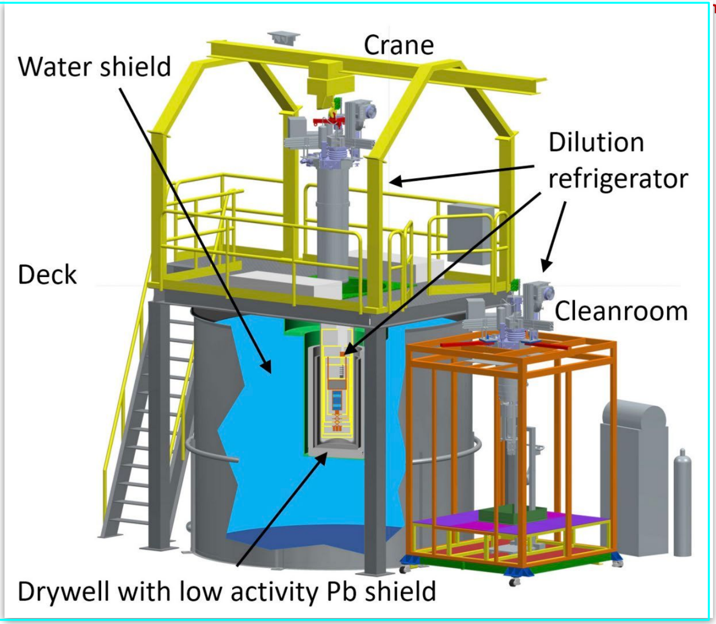




Tower testing at CUTE, SNOLAB

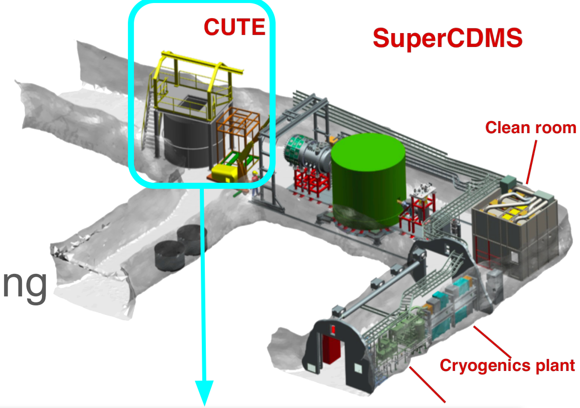
- **C**ryogenic **U**nderground **TE**st facility



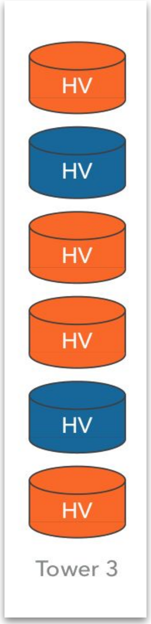


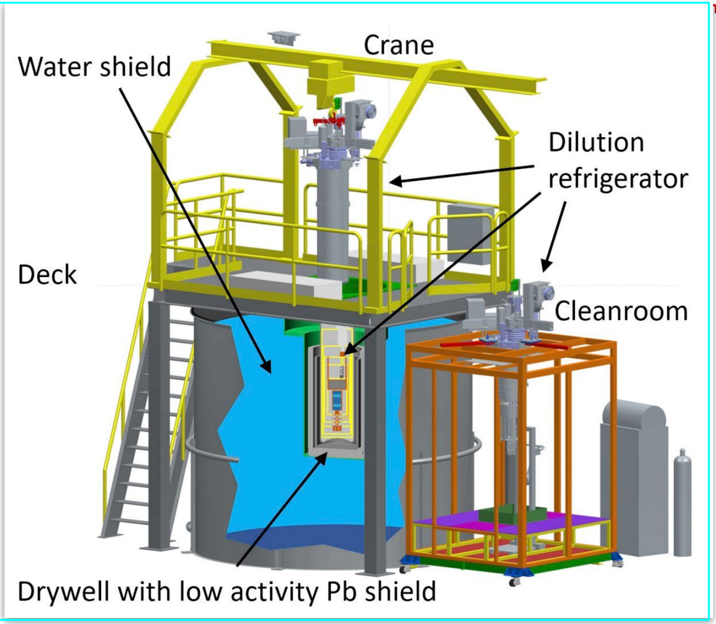
Tower testing at CUTE, SNOLAB

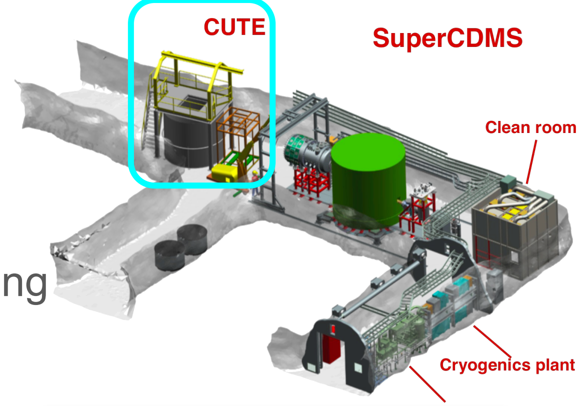
- **C**ryogenic **U**nderground **TE**st facility
- SuperCDMS HV tower hosting 4 Ge and 2 Si detectors testing completed in Mar'24 ✔



Ge
Si





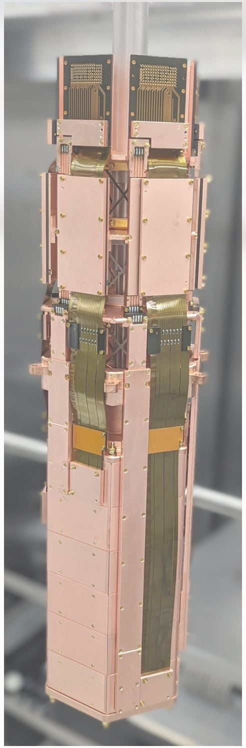


Tower testing at CUTE, SNOLAB

- **C**ryogenic **U**nderground **TE**st facility
- 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.

Summary

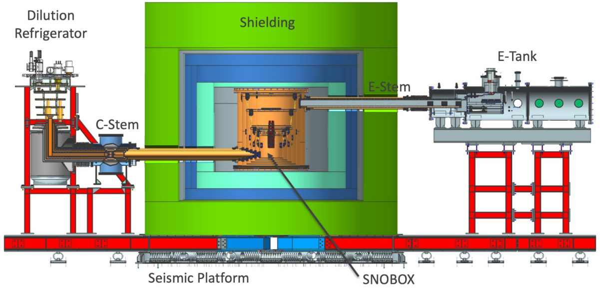
- ➔ SuperCDMS experiment: direct DM detection, targeting sub-GeV DM masses
- ➔ Under construction at SNOLAB
- ➔ Cryogenic Si/Ge detectors
    - iZIP: background rejection
    - HV: low threshold
- ➔ Detector tower testing recently completed at CUTE facility at SNOLAB
    - Several analyses in-progress to better understand our detectors
    - Expecting early science results by next year!
- ➔ SuperCDMS SNOLAB experiment commissioning in 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				Nuclear Recoil ($\times 10^{-6}$)	
	Ge HV	Si HV	Ge iZIP	Si iZIP	Ge iZIP	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 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