The SuperCDMS experiment at SNOLAB

On behalf of SuperCDMS,

Vijay Iyer

University of Toronto

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- Motivation
- SuperCDMS goals
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  - Backgrounds
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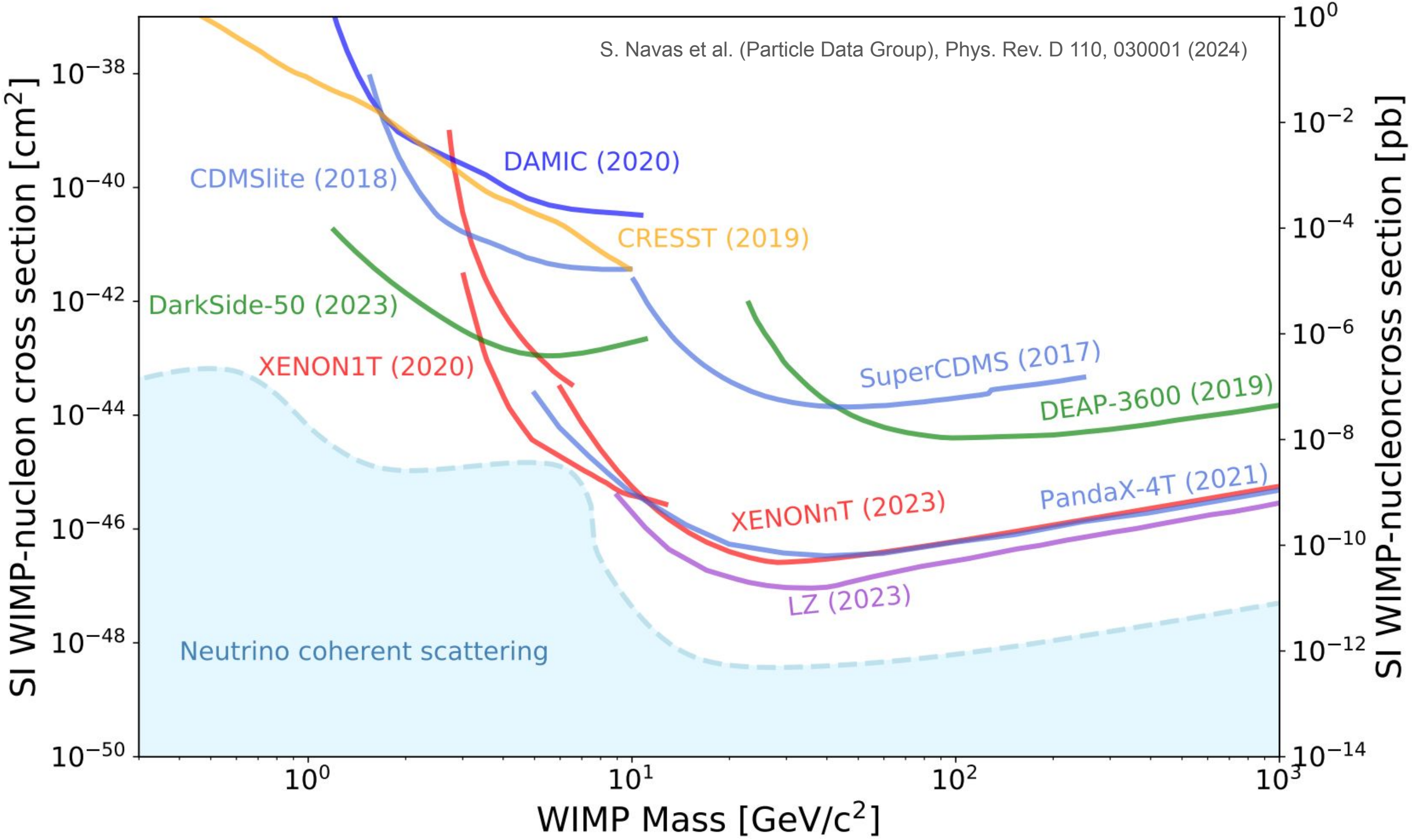
- Summary and outlook

Roma International Conference on AstroParticle Physics

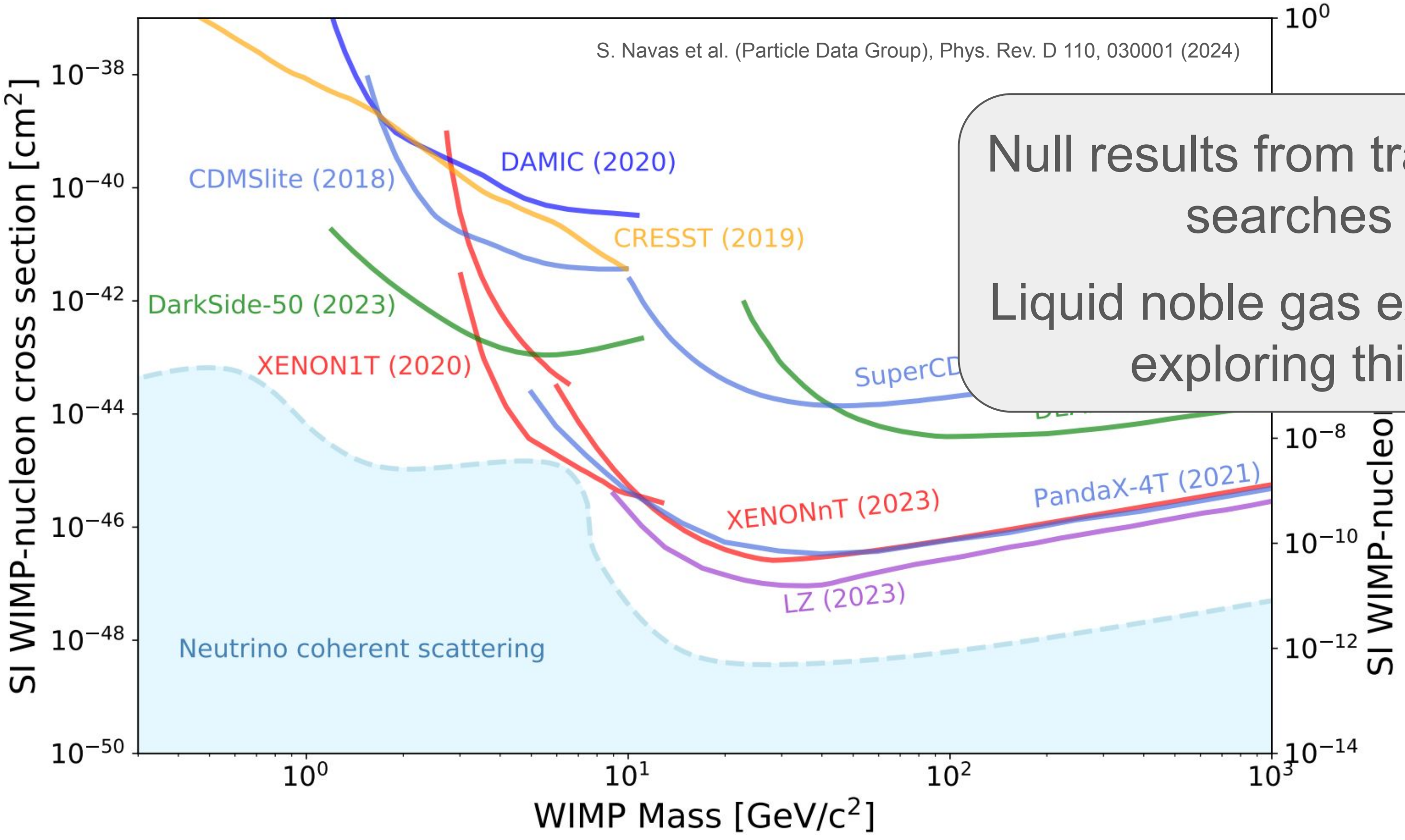
(23-27 September, 2024)

24 September, 2024

Motivation for sub-GeV dark matter search



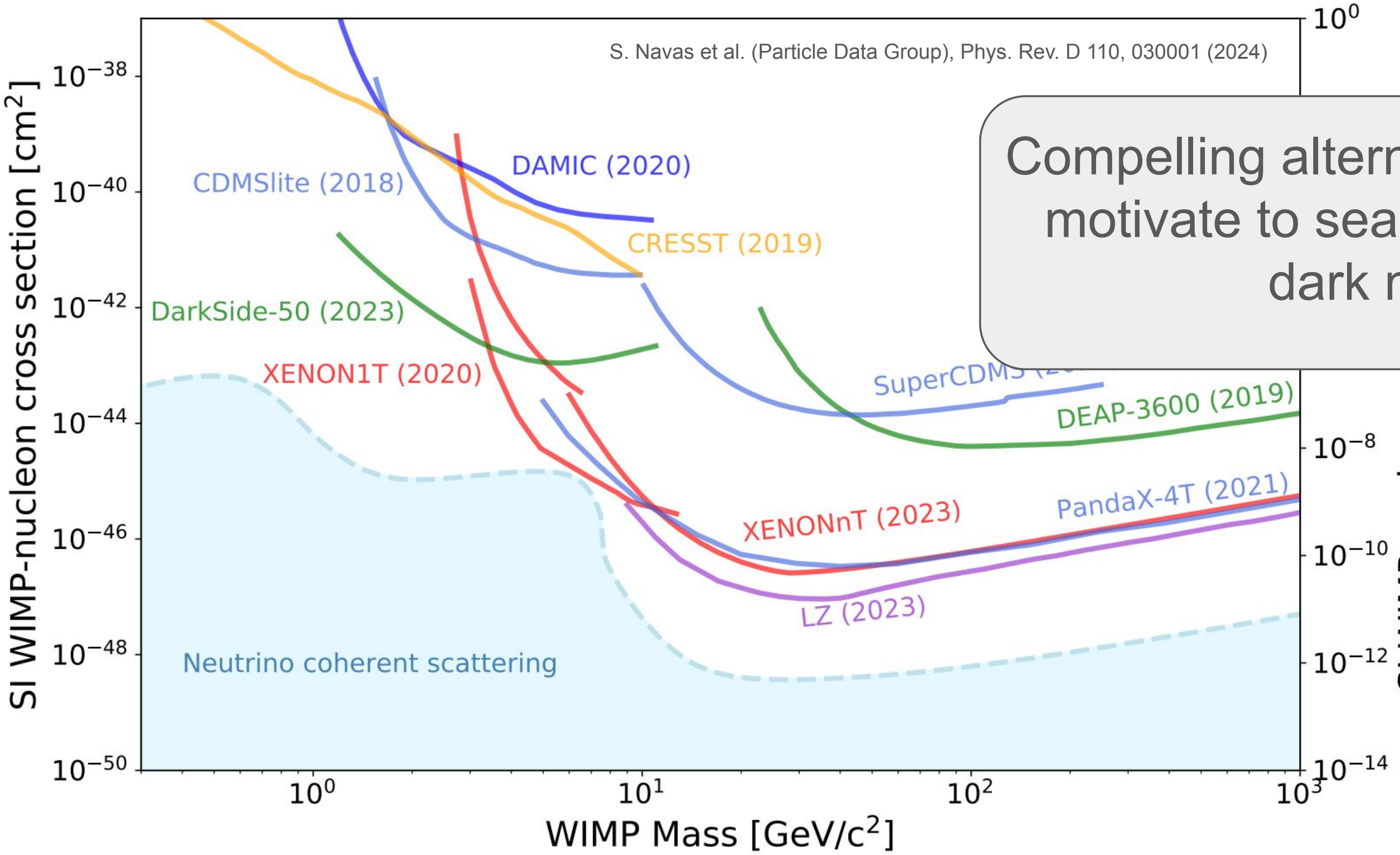
Motivation for sub-GeV dark matter search



Null results from traditional WIMP searches so far.

Liquid noble gas experiments are exploring this region.

Motivation for sub-GeV dark matter search



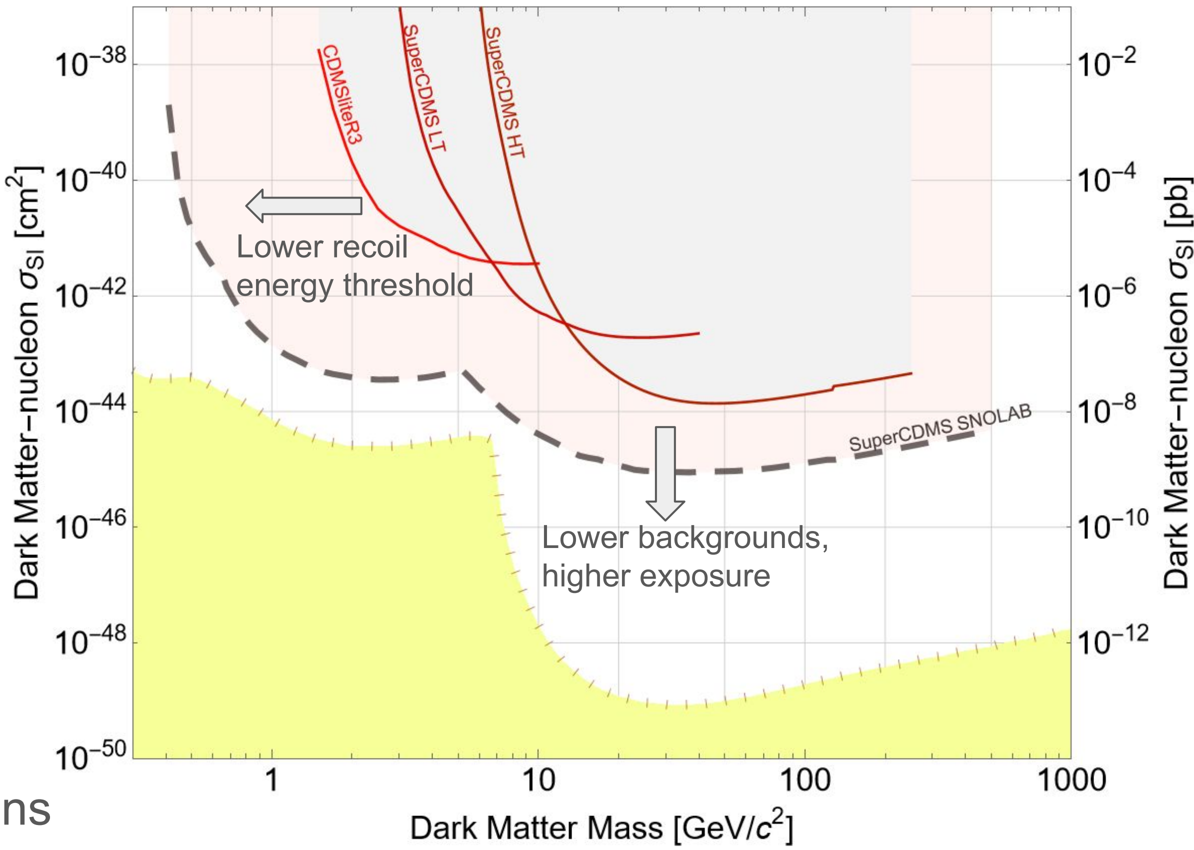
Compelling alternative models that motivate to search for sub-GeV dark matter.

Super Cryogenic Dark Matter Search Goals

- Search for dark matter with masses < 10 GeV/c^2.
- Observe CEνNS with future upgrades in design.

Challenges

1. Detectors
   a. Lower energy threshold
   b. Better energy resolution
2. Backgrounds
   a. Environmental
   b. Intrinsic
3. Commissioning and operations



Challenge 1

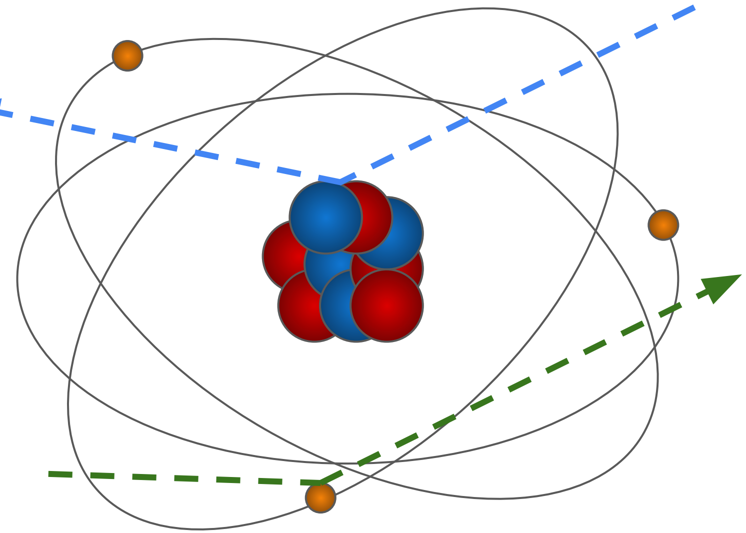
Building a sensitive detector.

Detectors

In most direct dark matter search experiments, there can be two types of interactions:

Nuclear recoils (NR)

- Particle interacts with nucleus
- Traditional “WIMP” dark matter signal
- Neutron background
- CEνNS



Electron recoils (ER)

- Particle interacts with atomic electrons
- Gammas, beta-particles and most other backgrounds
- Dark photon, axions signals

➢ Both NRs and ERs will produce signals based on the detector material: charge, heat, light.

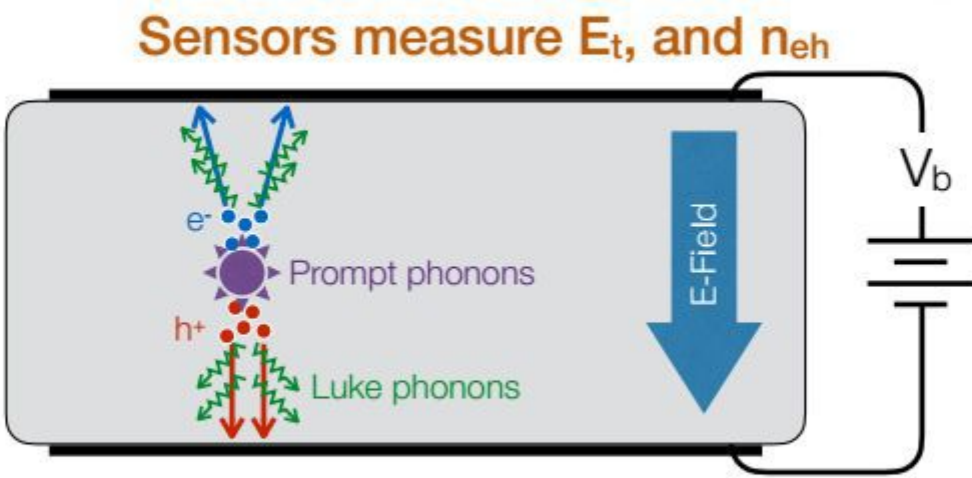
➢ Ability to discriminate between NRs and ERs allows us to reject several backgrounds.

➢ SuperCDMS will use two types of detector material - Ge and Si

➢ Can measure charge and heat signals.

Detectors

- Measures number of charges (n_{eh}) from the charge electrodes.
- Measures total phonon energy (E_t) from transition edge sensors (TES).
- Drifting electrons/holes across a potential (V_b) generates Neganov-Trofimov-Luke (NTL) phonons.



$$\underbrace{E_t}_{\text{Total phonon energy}} = \underbrace{E_r}_{\text{Primary recoil energy}} + \underbrace{n_{eh} q V_b}_{\text{NTL phonon energy}}$$

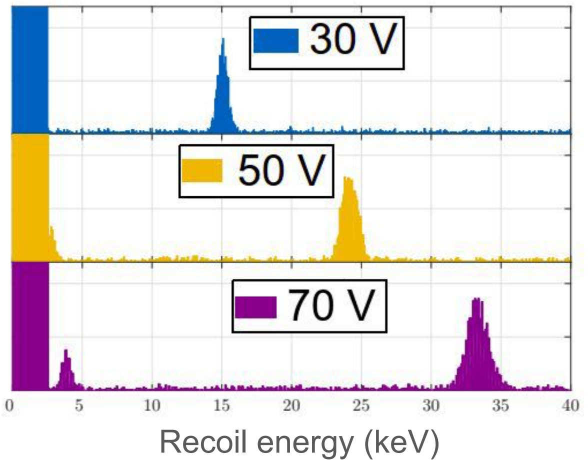
- Increasing V_b lowers recoil energy threshold.

Detectors

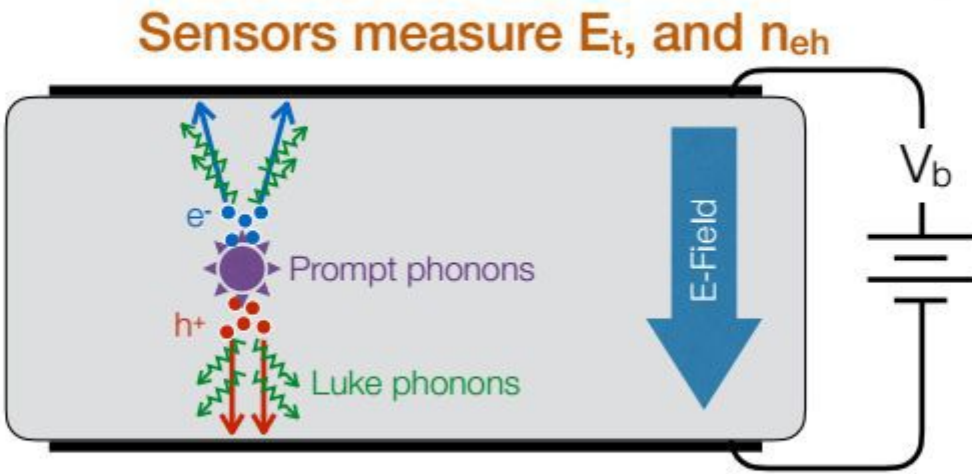
● Me… …ne
charg…

● Me…
transi…

● Drif… (V_b)
gener…
phon…



Source: SuperCDMS dissertations- Mark Pepin

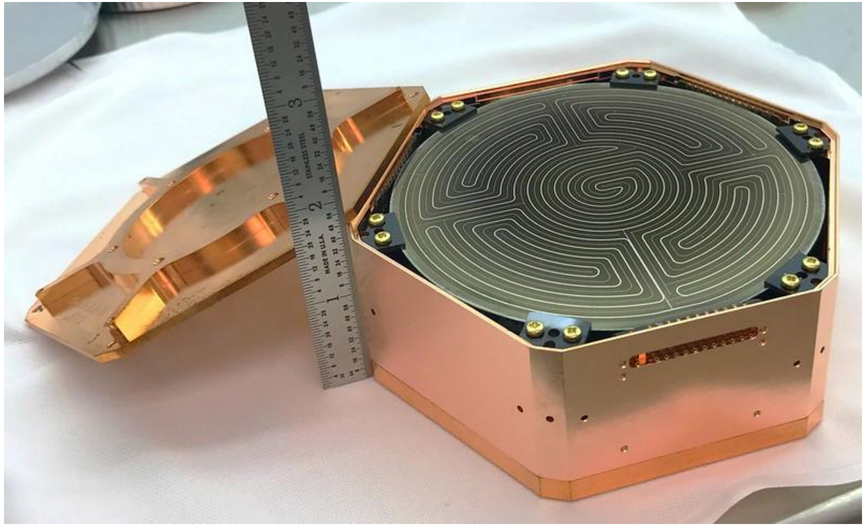


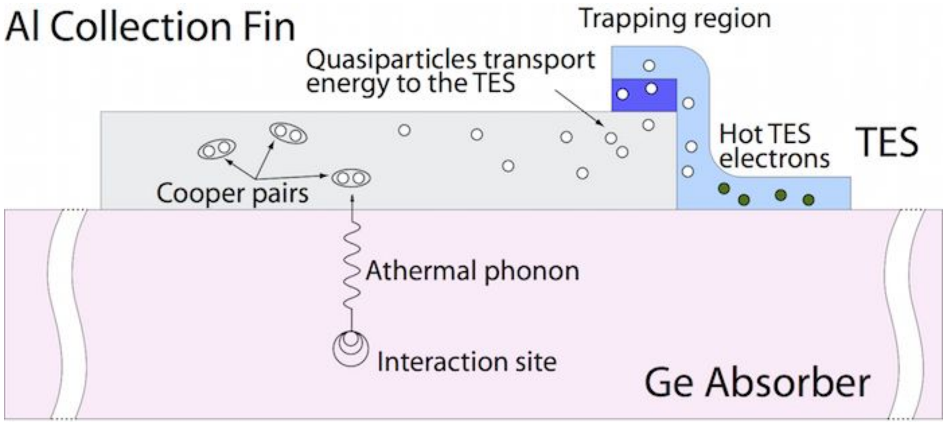
$$E_t = E_r + n_{eh} q V_b$$

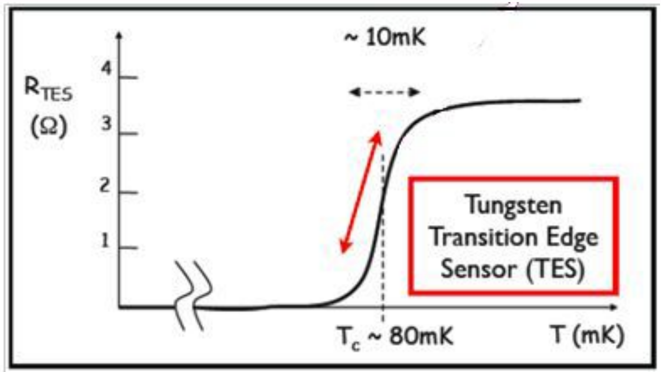
Total phonon energy — Primary recoil energy — NTL phonon energy

● Increasing V_b lowers recoil energy threshold.

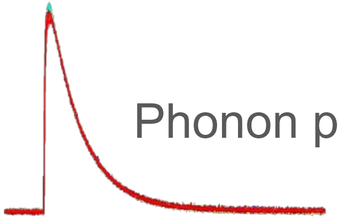
Detectors



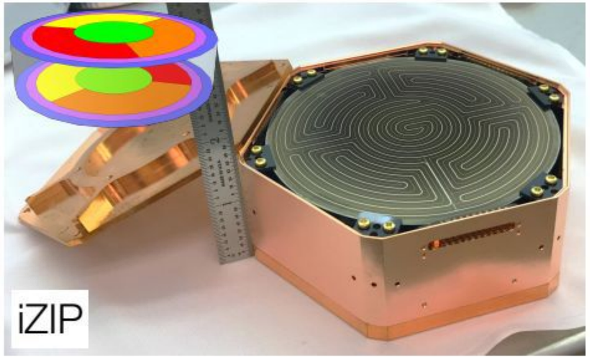




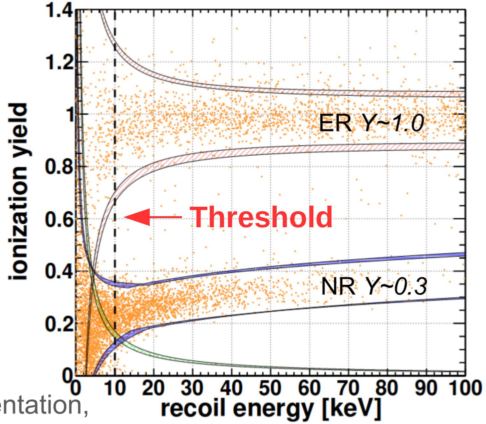
- Phonons are measured using Tungsten Transition Edge Sensors (TES)
- Operate at near superconducting temperature (T_c).
- Compared to Soudan, the SNOLAB detectors optimize the sensor geometry and T_c providing better energy resolution.



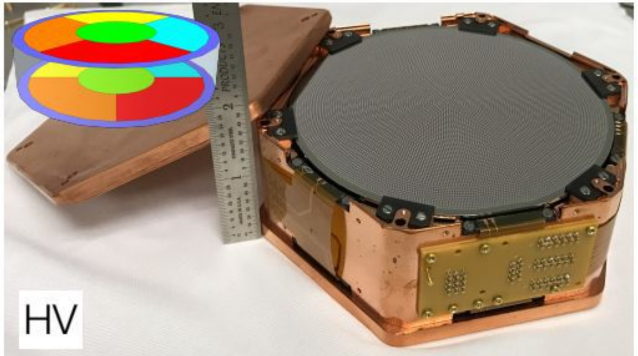
Detectors



- Useful for surface background rejection.
- 10 Ge and 2 Si iZIP detectors at SNOLAB.
- ER/NR discrimination.



E. Michielin, oral presentation, Lake Louise Winter Institute 2019



- Lower energy threshold compared to iZIPs.
- No ER/NR discrimination.
- 8 Ge and 4 Si HV detectors at SNOLAB.

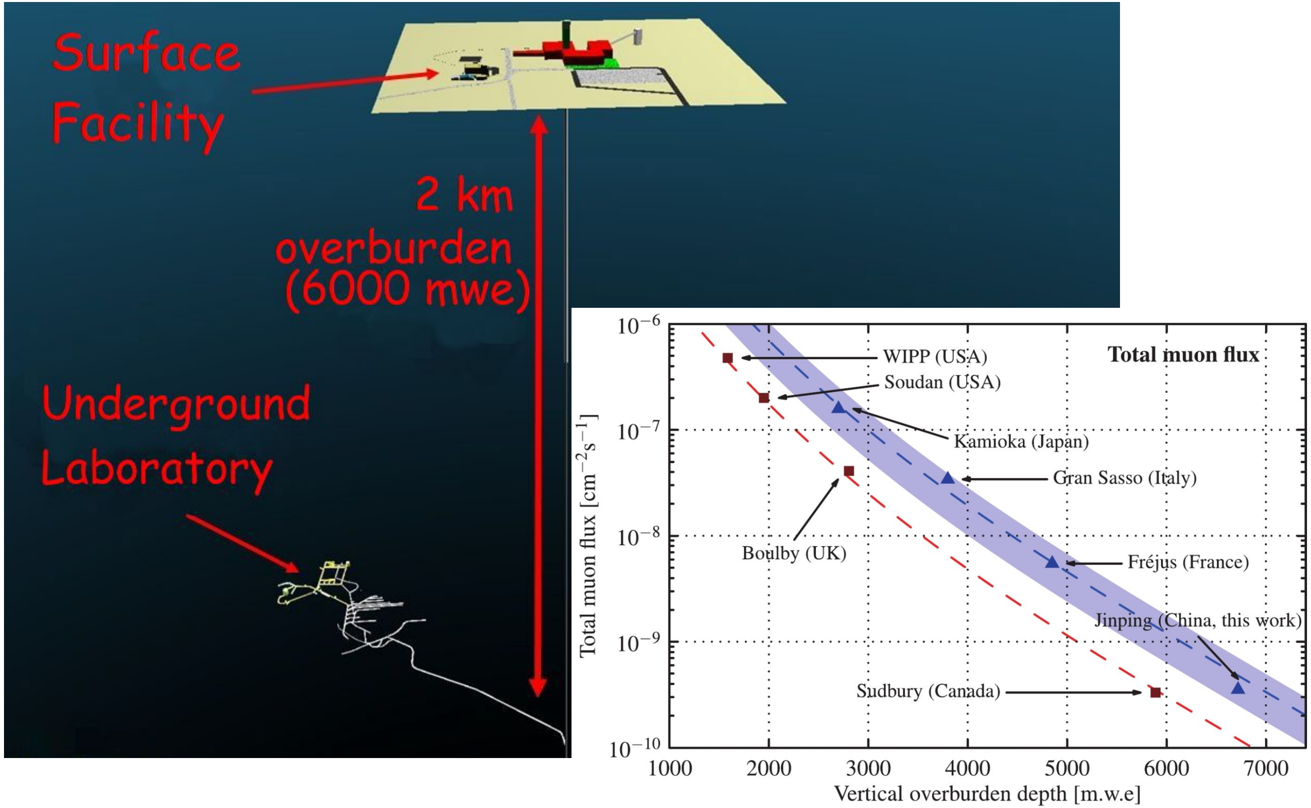
	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Phonon resolution (eV)	50	25	10	5
Ionization resolution (eV)	100	110	–	–
Voltage Bias (V)	6	8	100	100

Phys. Rev. D 95 (2017)

Challenge 2

Backgrounds

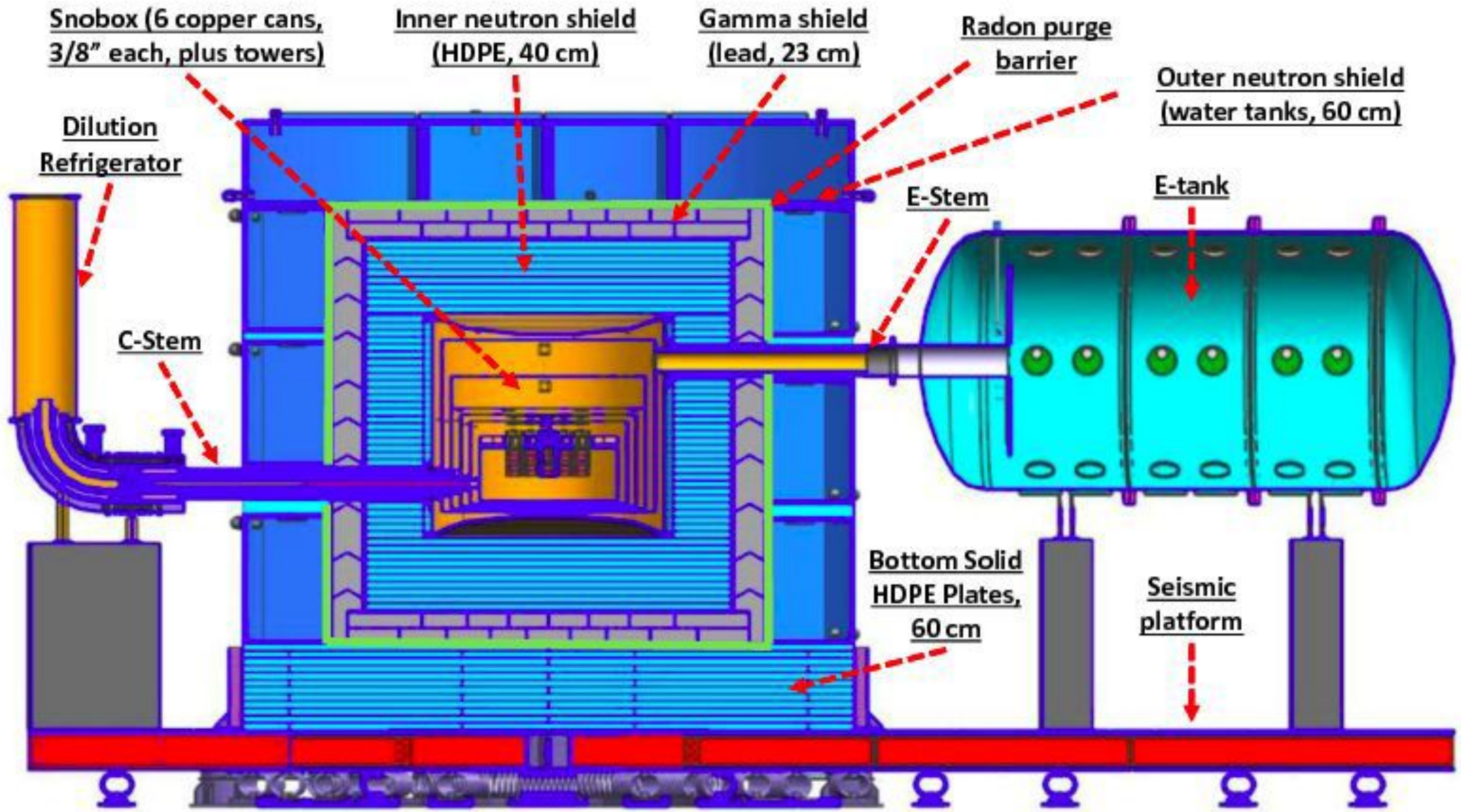
Backgrounds



Zi-yi Guo *et al* 2021 *Chinese Phys. C* 45 025001

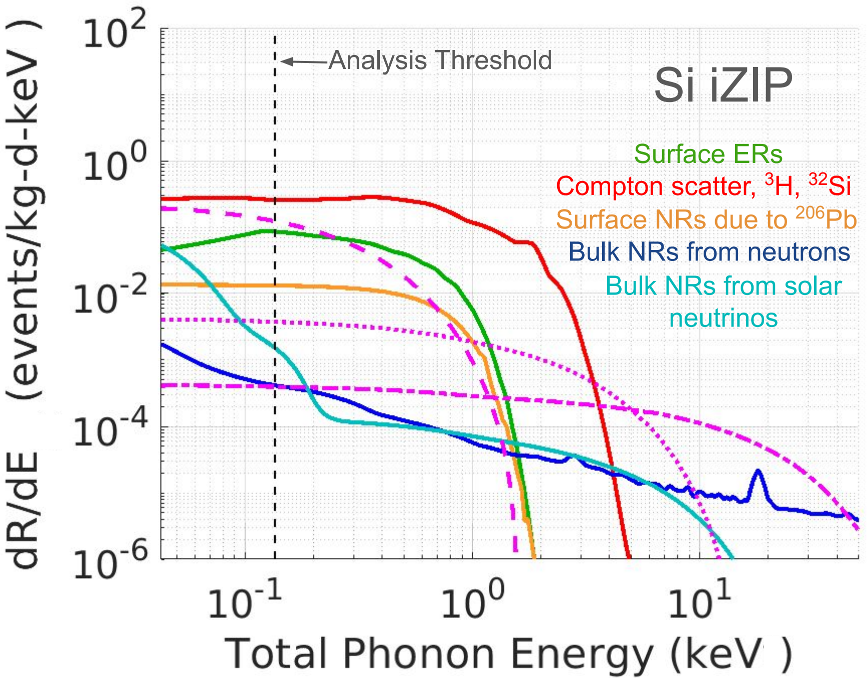
- 2 km underground.
- Cleanroom (class 2000).
- Large lab (~5000 m^2)
- Muon flux from cosmic rays reduced by a factor of 100 compared to Soudan mine.
- Large support staff(>100)
- Availability of surface facilities.

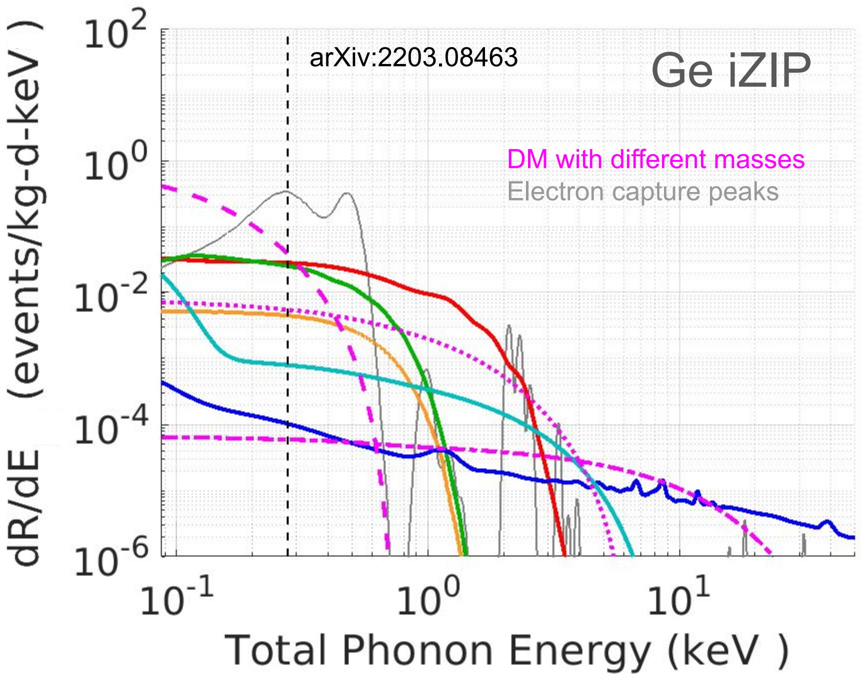
Shielding setup



Backgrounds

- Detector internal contamination:
  - ^{3}H (in both Ge and Si detectors)
  - ^{32}Si (in Si detectors)
- Material internal contamination or activation:
  - ^{60}Co, ^{40}K, ^{238}U, ^{232}Th
- Prompt interstitial Radon





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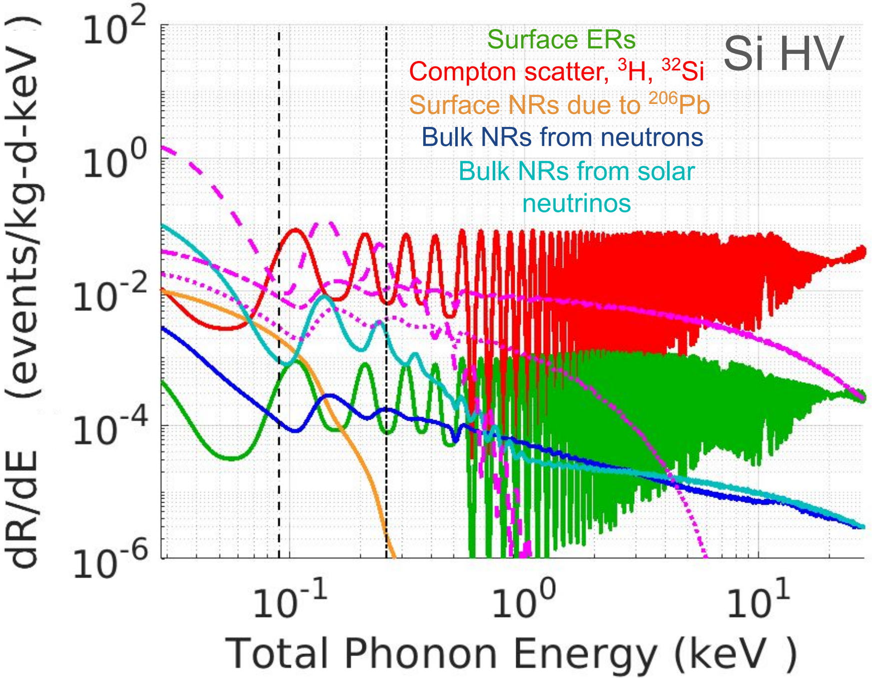
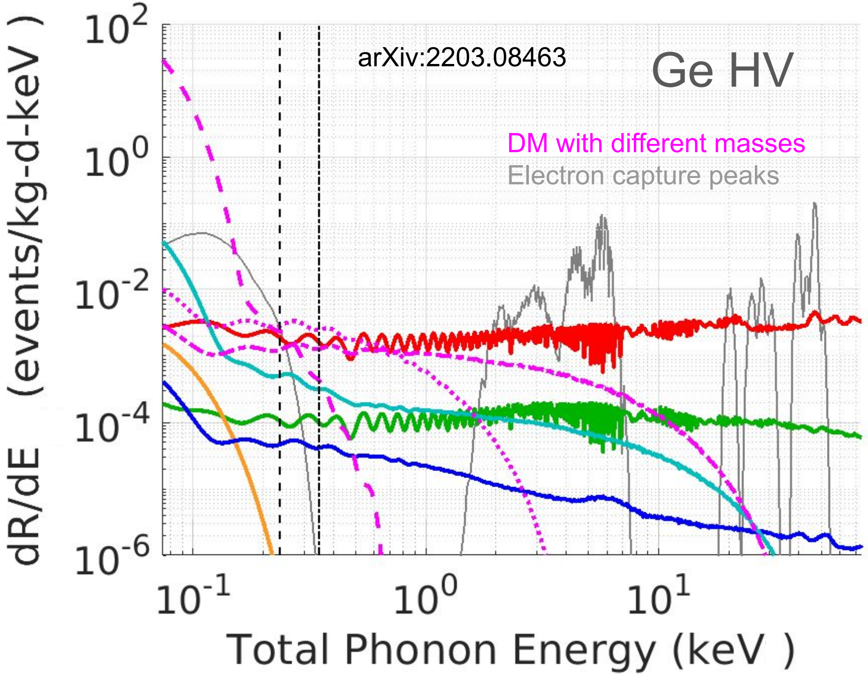
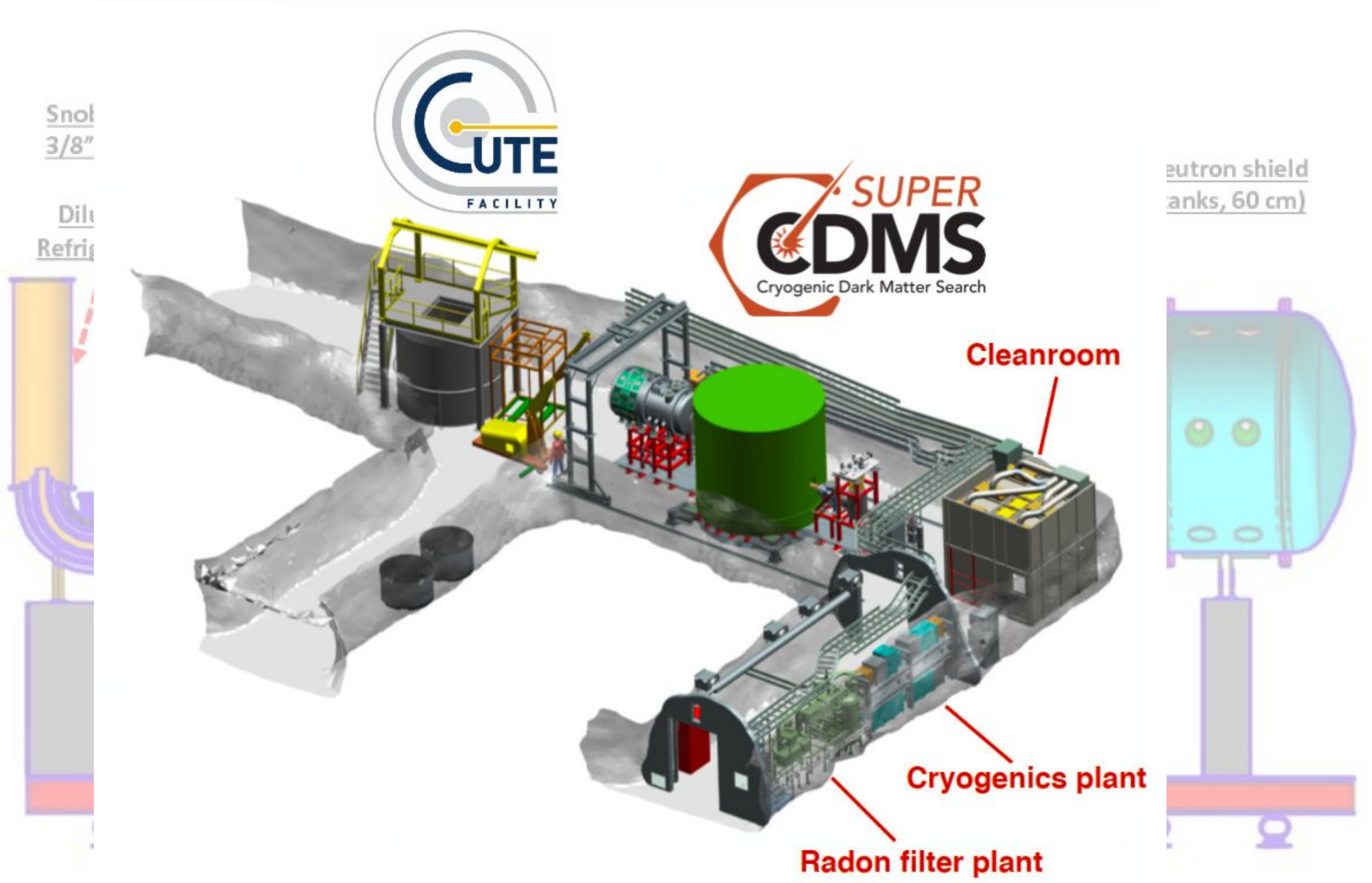




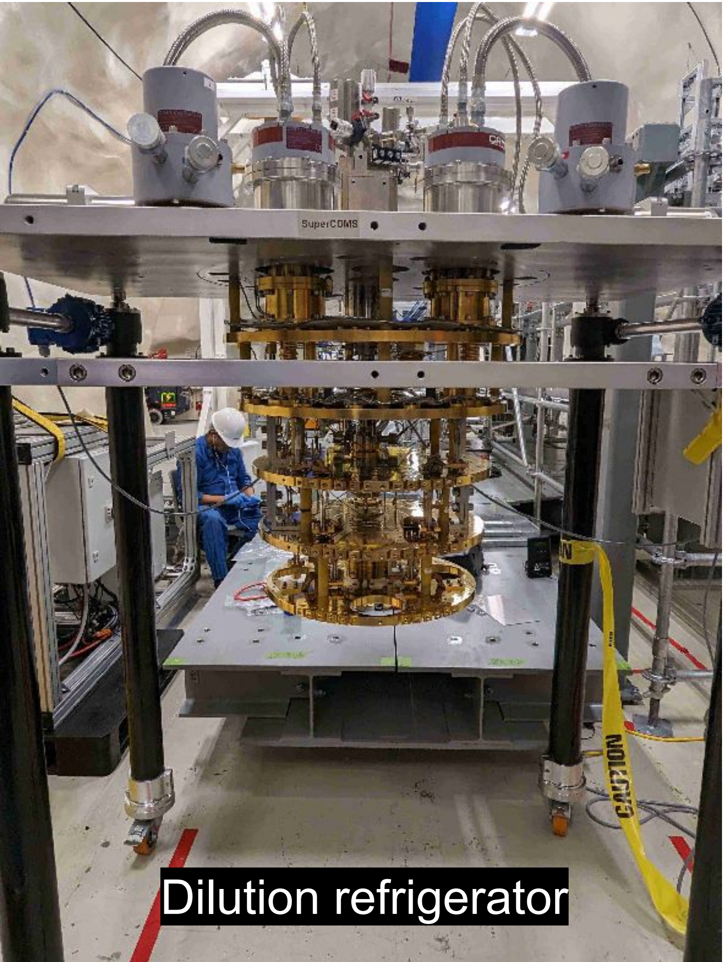
Challenge 3

Commissioning and operations

Experiment setup

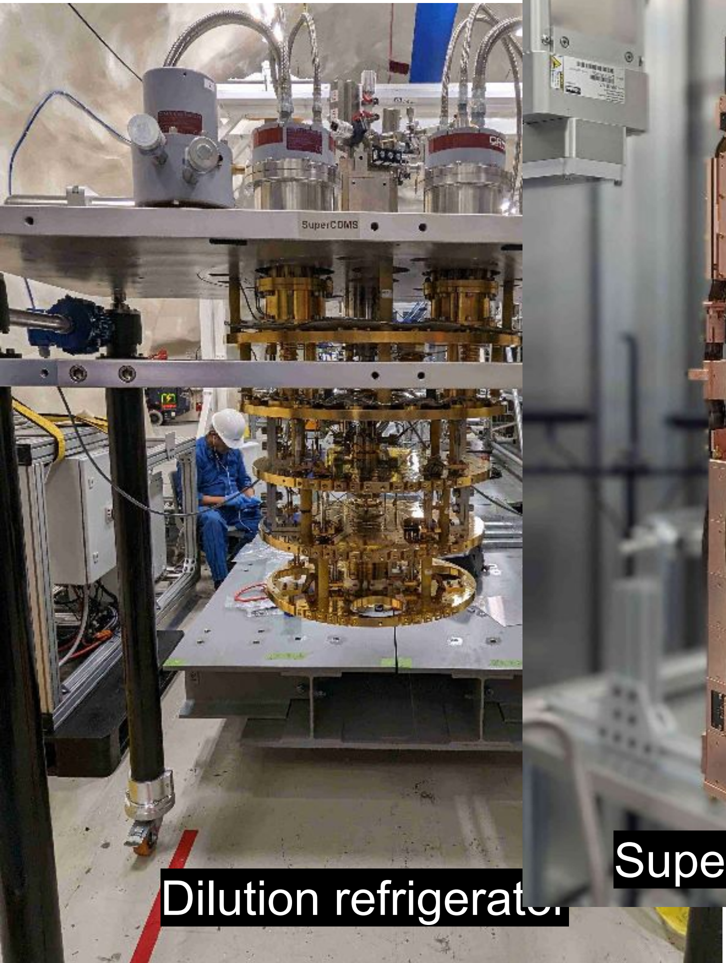


Current Status

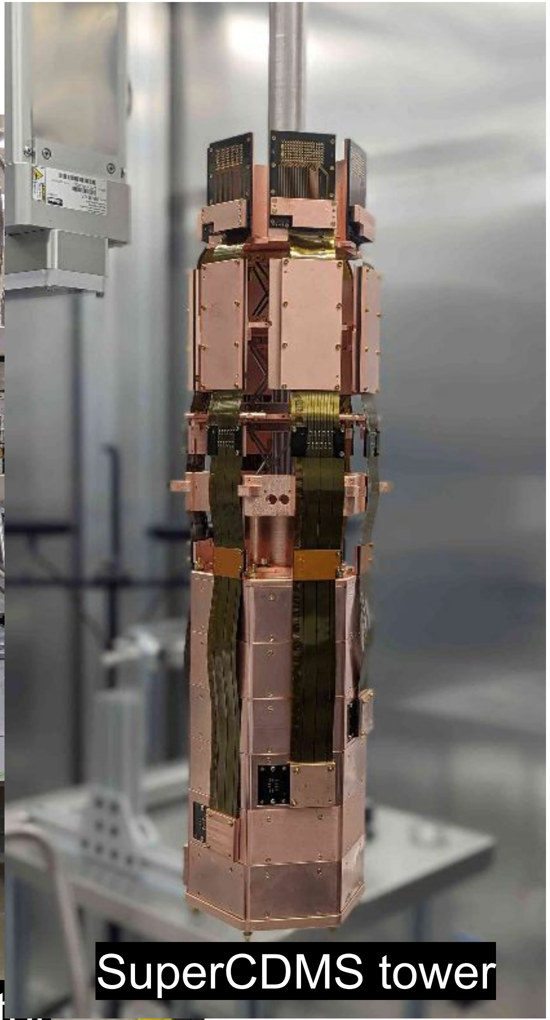


Dilution refrigerator

Current Status

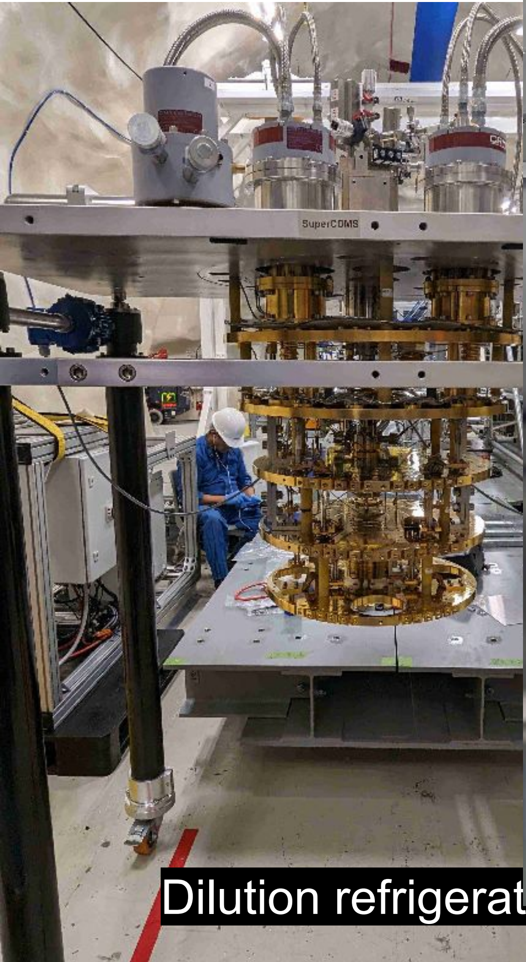


Dilution refrigerator



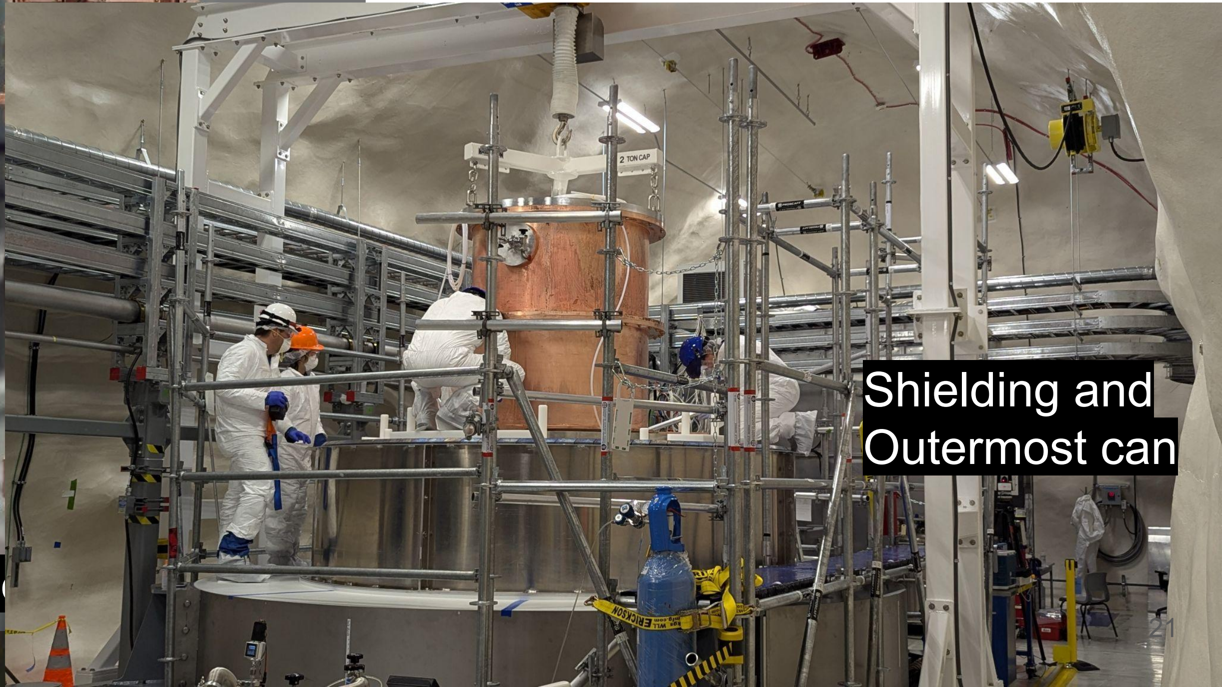
SuperCDMS tower

Current Status



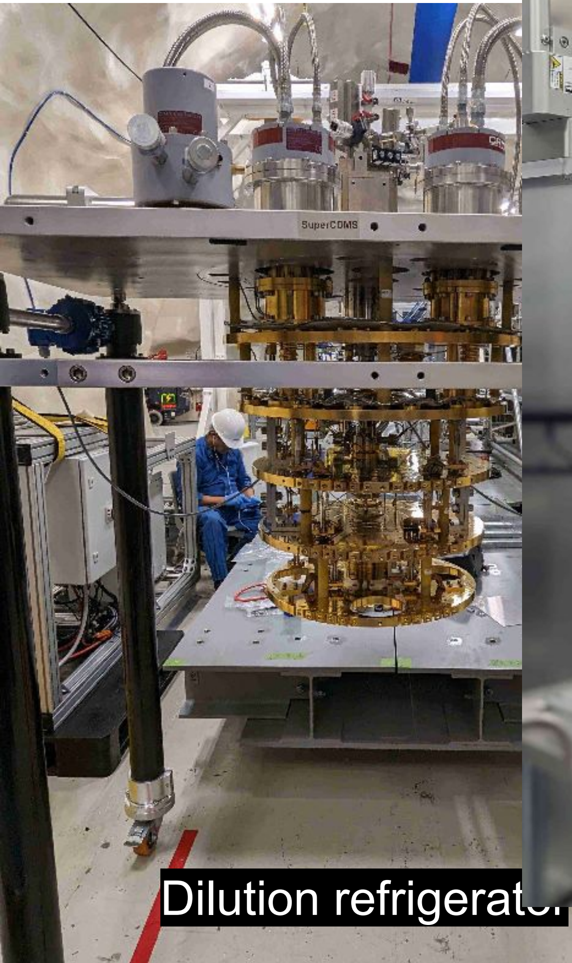
Dilution refrigerat

Sup



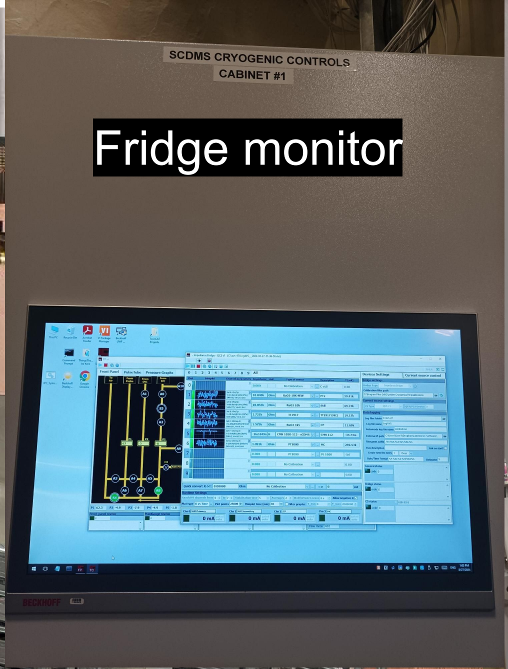
Shielding and
Outermost can

Current Status



Dilution refrigerat

Sup

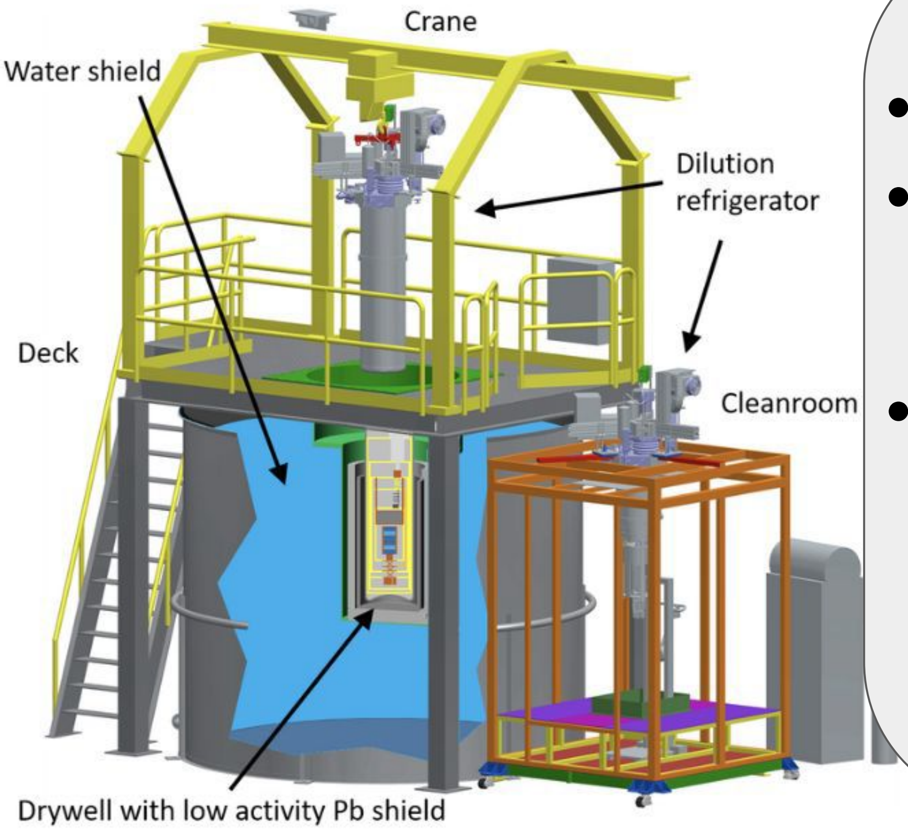


Fridge monitor

Cryogenic controls

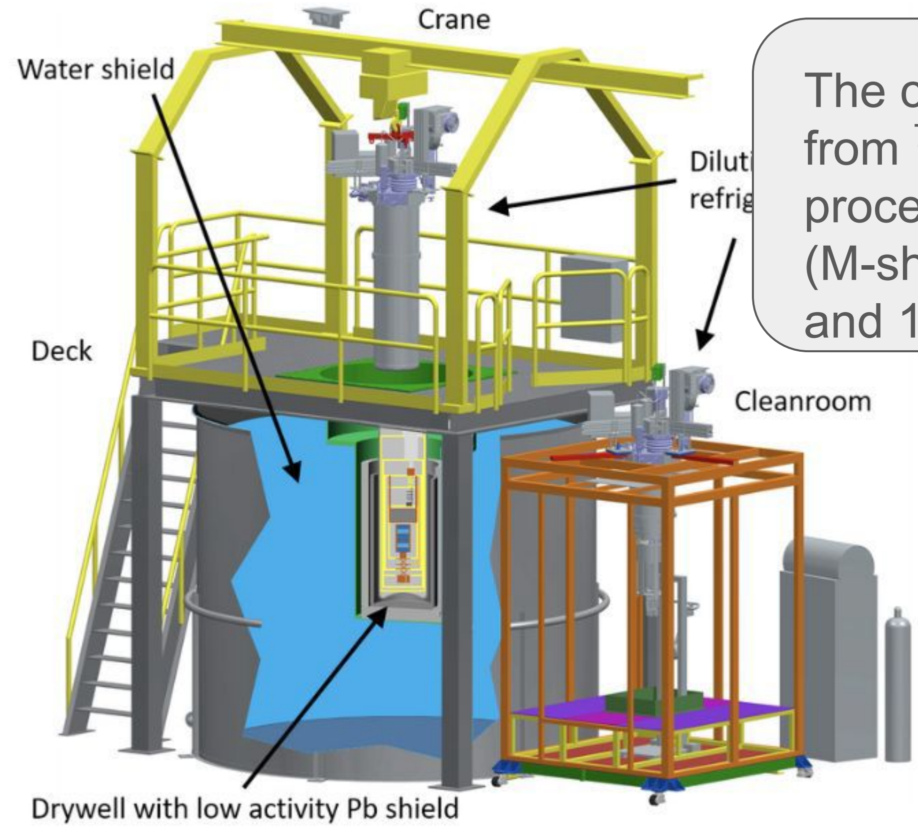
Outermost can

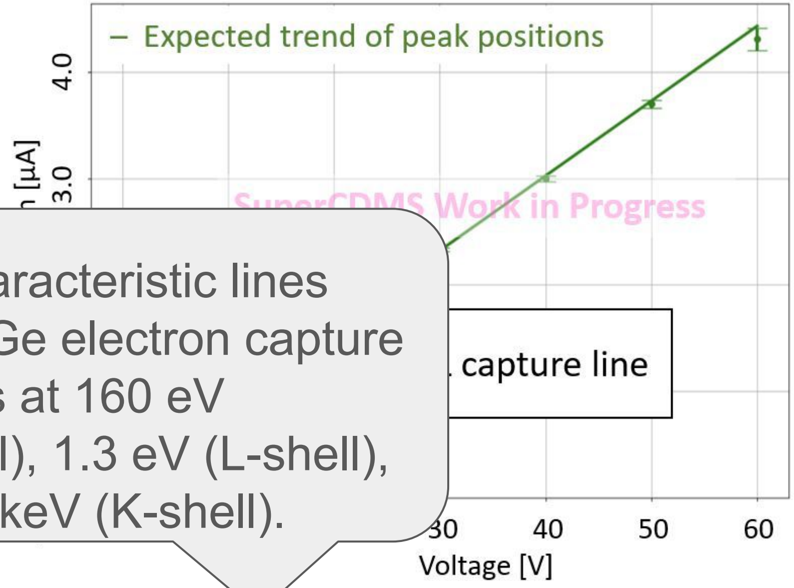
Testing at Cryogenic Underground TEst Facility



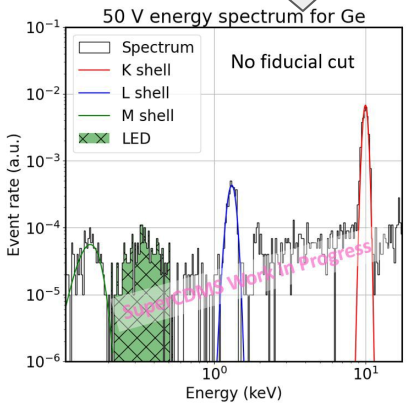
- October 23, 2023 - March 13, 2024.
- A tower of 6 HV detectors:
  - 2 Silicon and 4 Germanium.
  - Operated at a max voltage of 100 V.
- ~151 days covering 4 thermal cycles.
  - ~2 months of calibration data.
  - ~2 weeks of low background data.
  - Several weeks on sensor performance testing, HV testing, developing detector conditioning protocols.

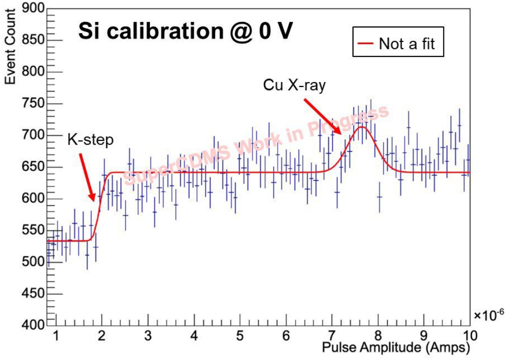
Testing at CUTE





The characteristic lines from ^{71}Ge electron capture process at 160 eV (M-shell), 1.3 eV (L-shell), and 10 keV (K-shell).





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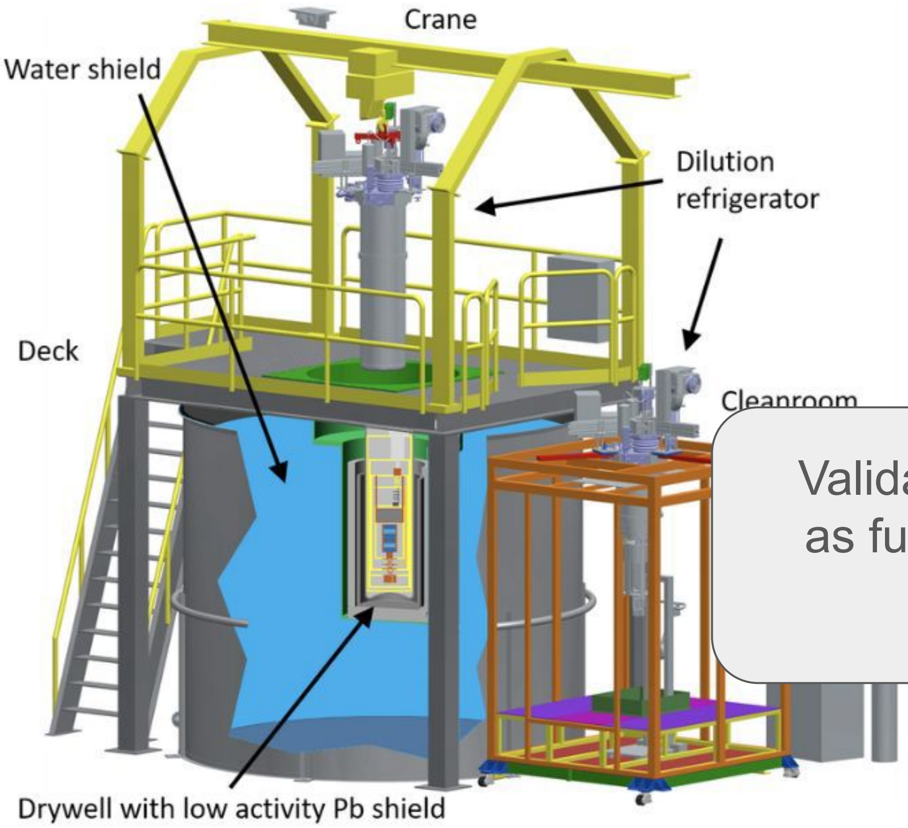
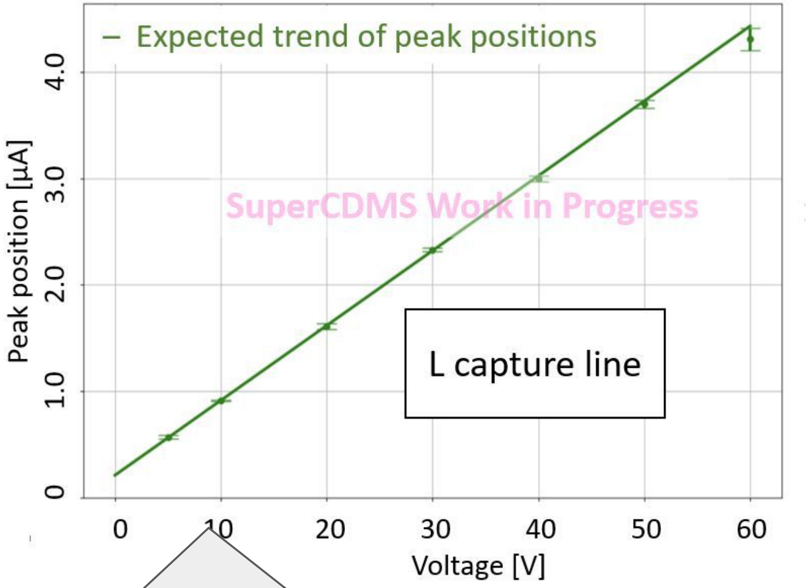
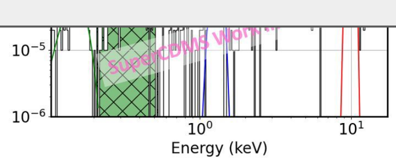
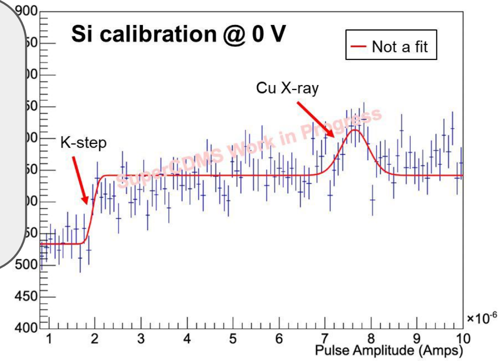




Validation of NTL gain as function of applied voltage





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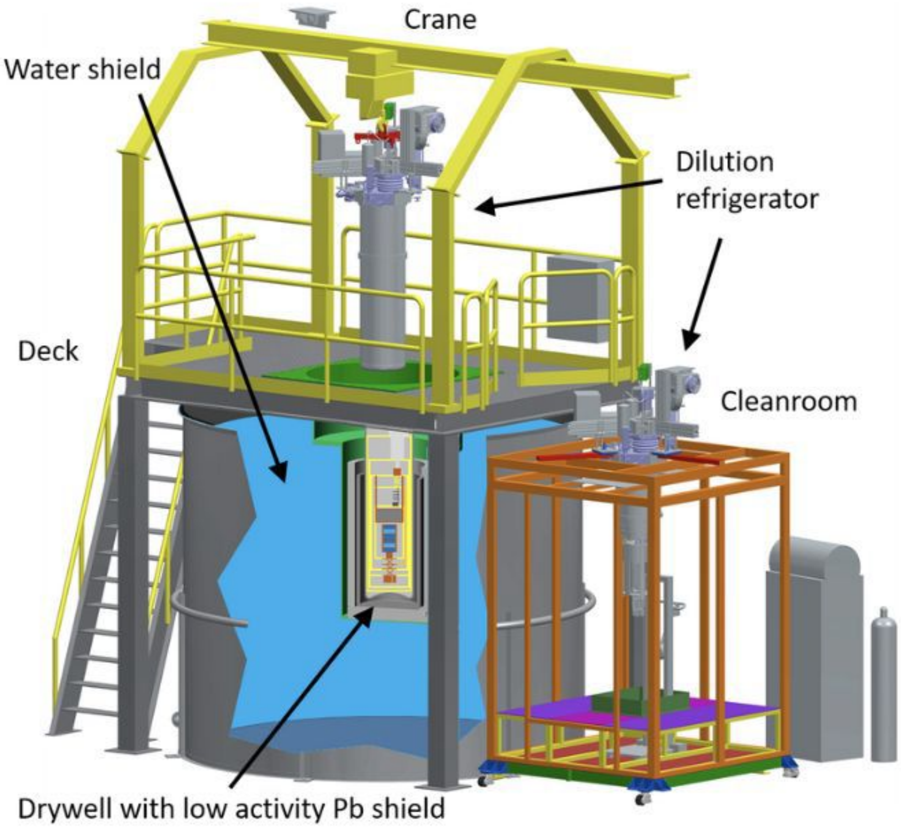
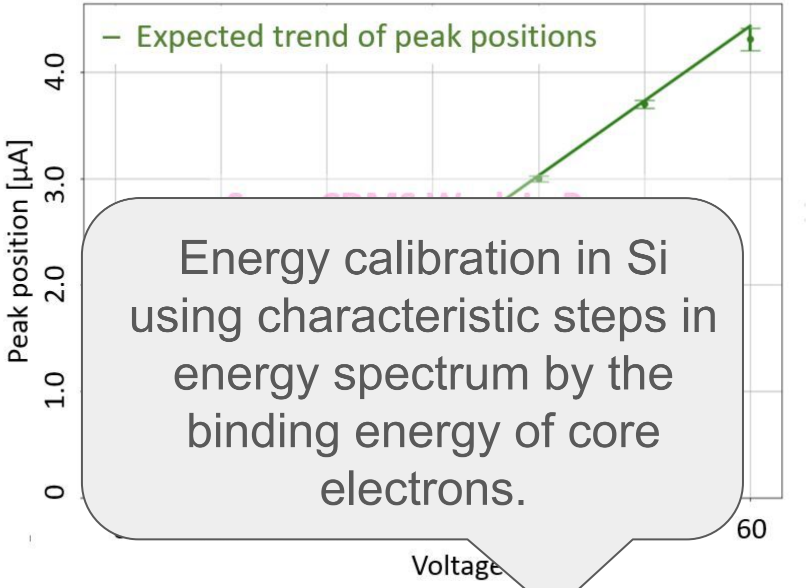
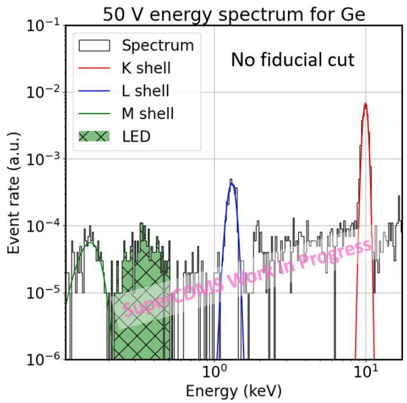
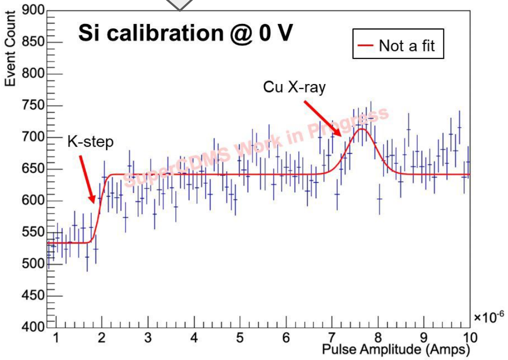




Energy calibration in Si using characteristic steps in energy spectrum by the binding energy of core electrons.





Summary

- SuperCDMS experiment is aimed at sub-GeV dark matter searches.
- The experiment is currently being built at SNOLAB.
- HV tower tests at CUTE validate the expectations from the detectors.
- Expect to finish building the experiment and start a science run by 2026.

Outlook

- SuperCDMS has a detector R&D program:
  - Gram-scale, single electron resolution detectors.
- Novel directions explored by collaborators like building Diamond, SiC detectors.
- Optimize signal, backgrounds modeling and simulations of detector response.
- Continue to improve our understanding of crystal properties like ionization yield.

SUPER CDMS
Cryogenic Dark Matter Search

Back up