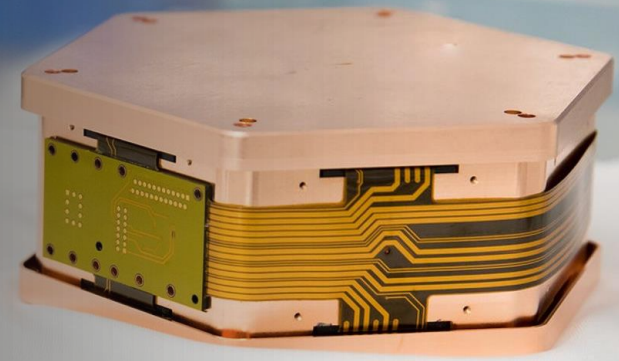
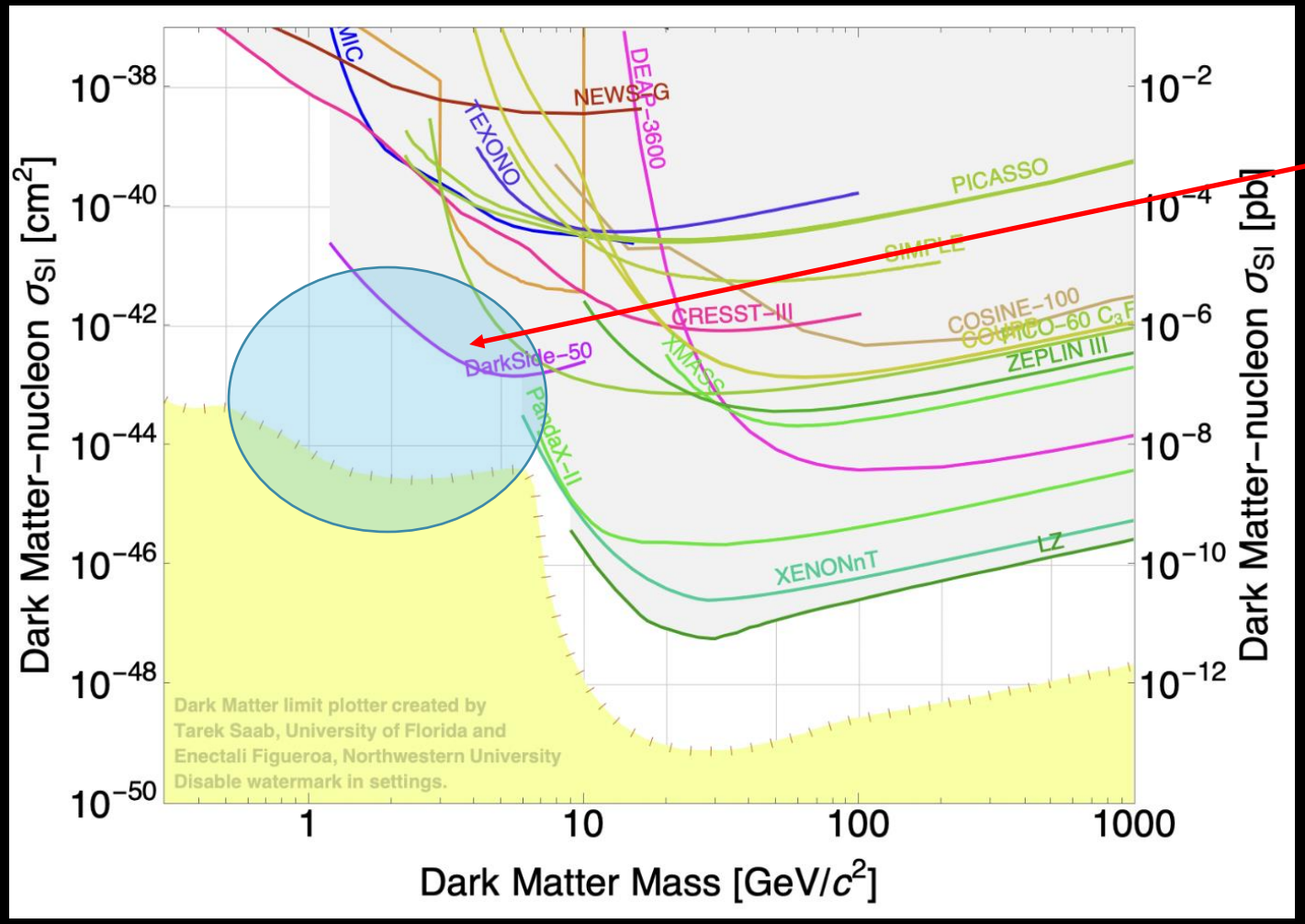
Status of **the SuperCDMS SNOLAB** Experiment

Yan Liu (UBC & TRIUMF)

Oct. 30th, 2023

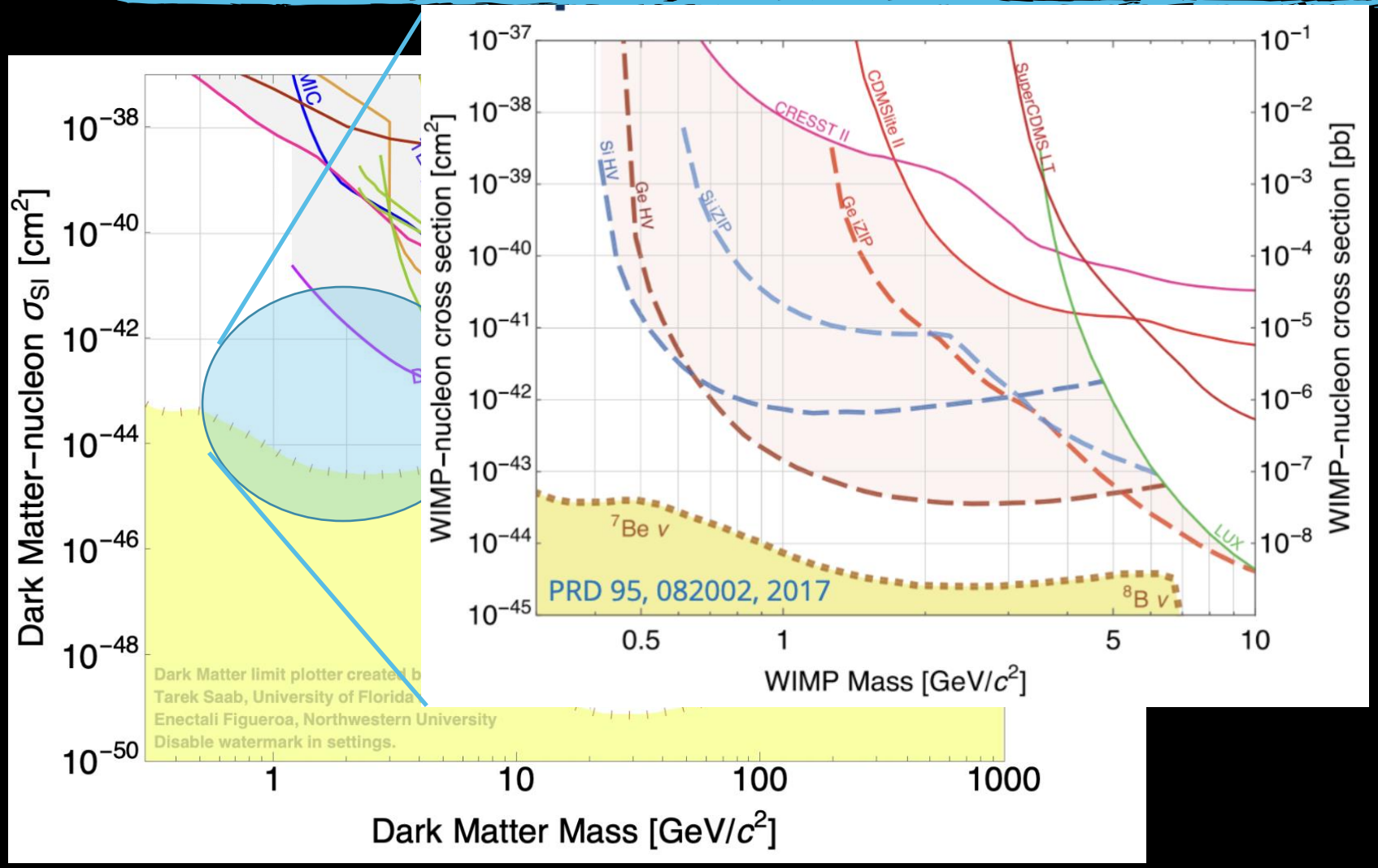


Direct detection of WIMPs



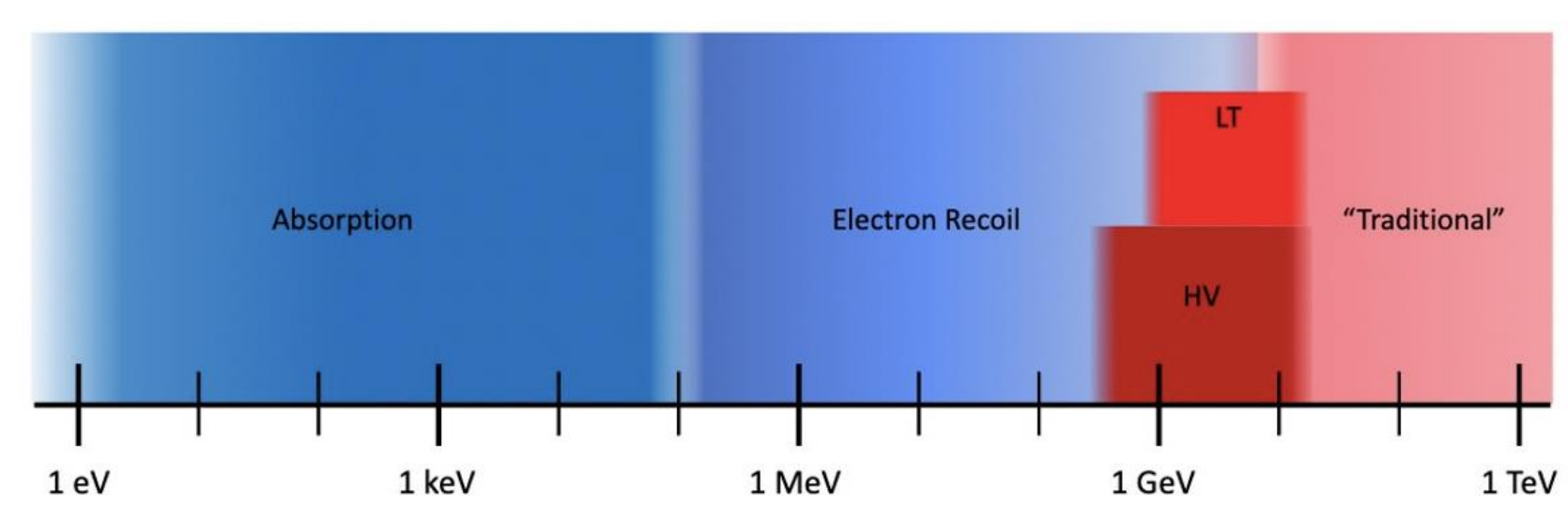
SuperCDMS SNOLAB focuses on low-mass (<10 GeV) WIMPs

SuperCDMS sensitivity



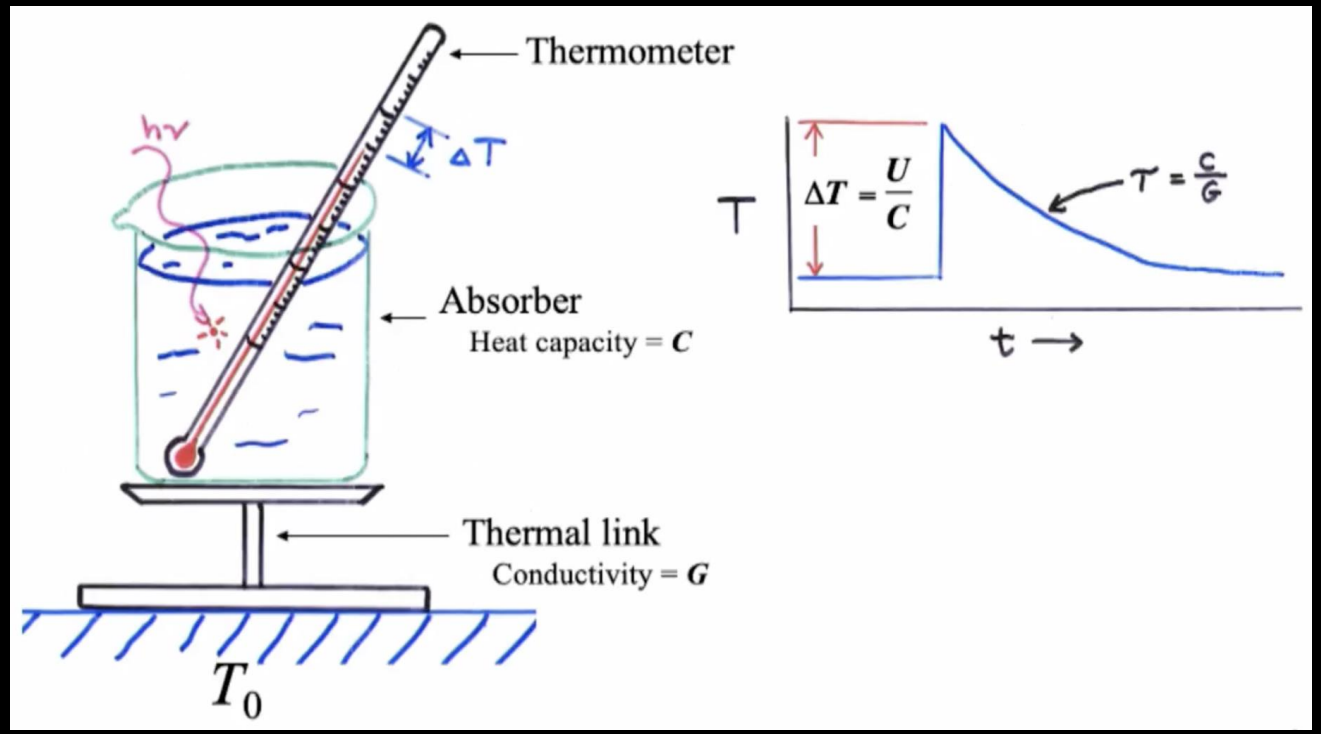
SuperCDMS SNOLAB focuses on low-mass (<10 GeV) WIMPs

SuperCDMS conducts a wide band search



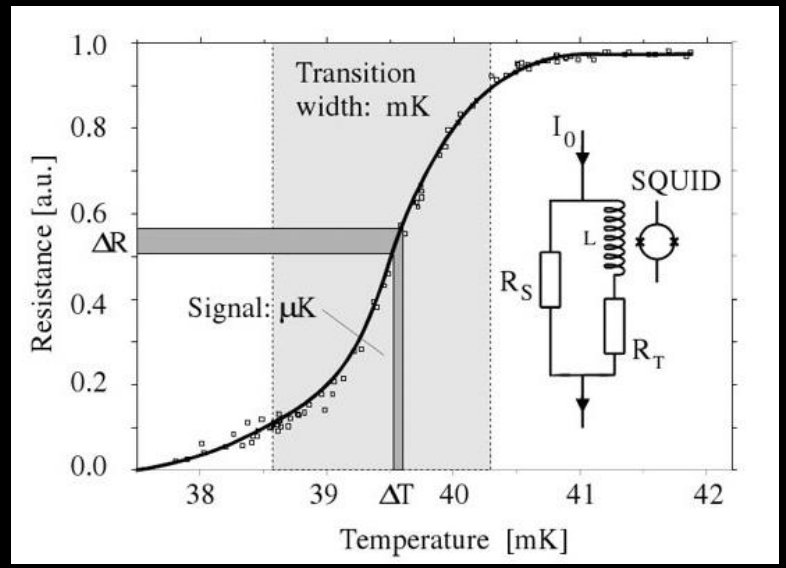
In addition to its primary objective, SuperCDMS SNOLAB will also be sensitive to other dark matter candidates, such as dark photon mediated dark matter via electron recoil, ALPs via absorption, etc.

SuperCDMS detector technology



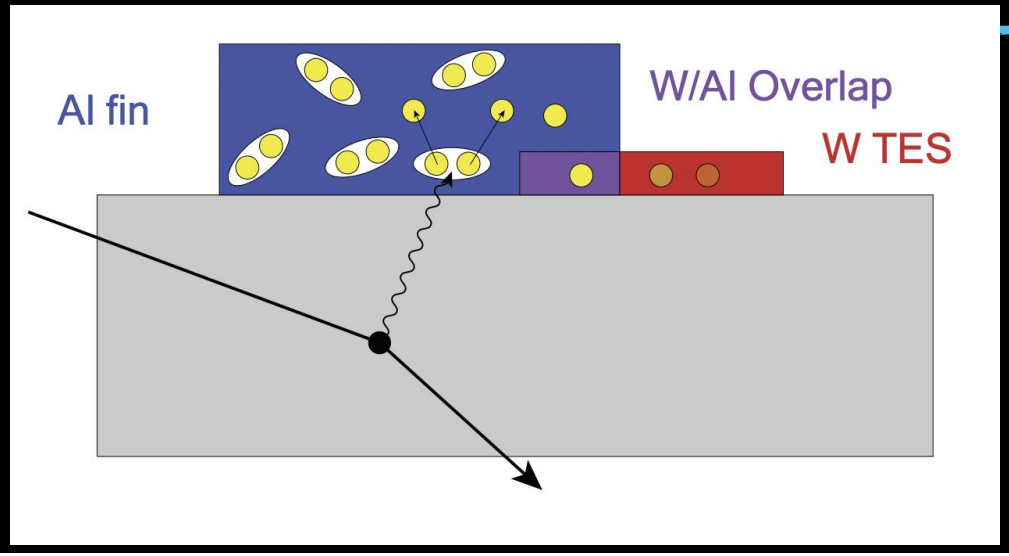
Basic components of a calorimeter

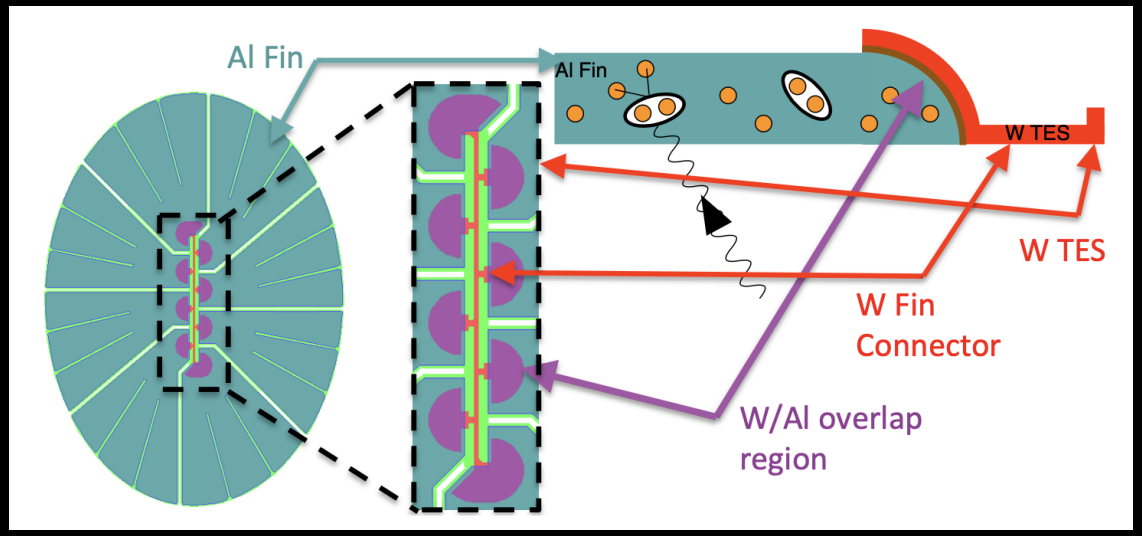
- Bath, thermal link, absorber, and a thermometer
- Transition Edge Sensor (TES)



Höhne, *et al.*, EDXRF 981998

Quasiparticle-trap-assisted Electrothermal-feedback Transition Edge Sensor





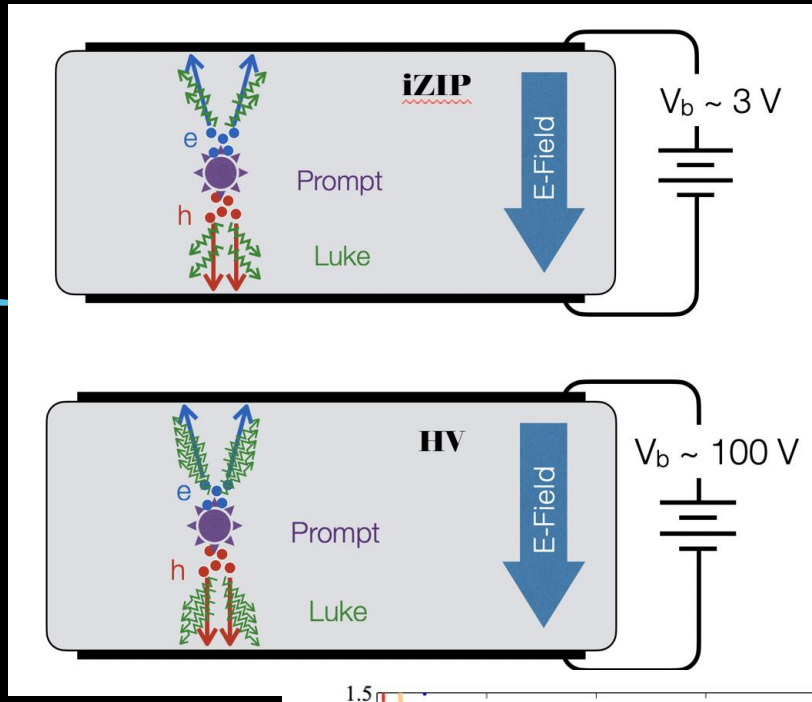
Watkins, PhD thesis, 2022

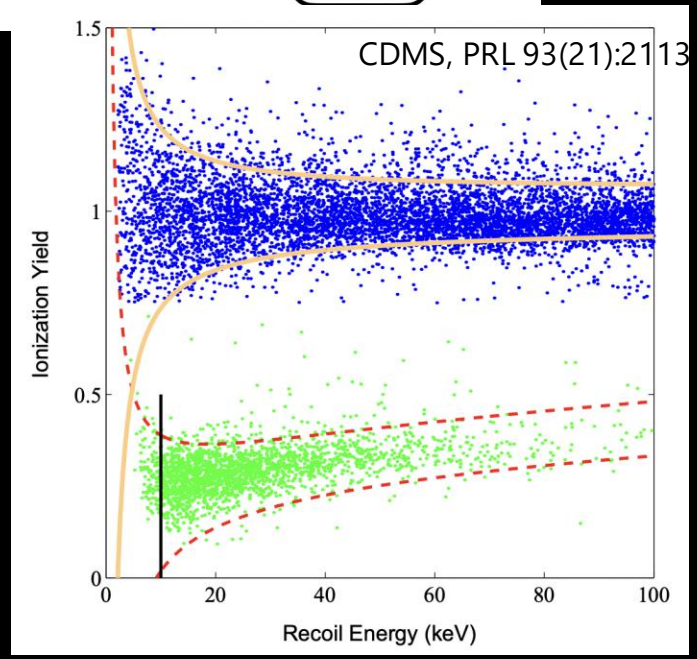
Collect athermal phonons using superconducting Al fins.

- Advantages
  - Larger coverage area
    - Bigger detector size
  - Faster pulses
  - Lower critical temperature Tc

Detector designs

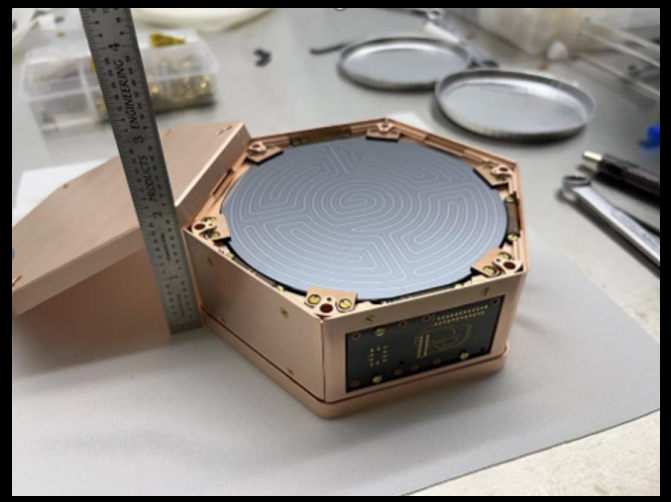
- iZIP: background reduction
  - Measure the charge signal in addition to phonons
  - Ionization-yield based discrimination
- HV: low threshold
  - Increased bias voltage (NTL effect)
  - Necessitates position-based background discrimination

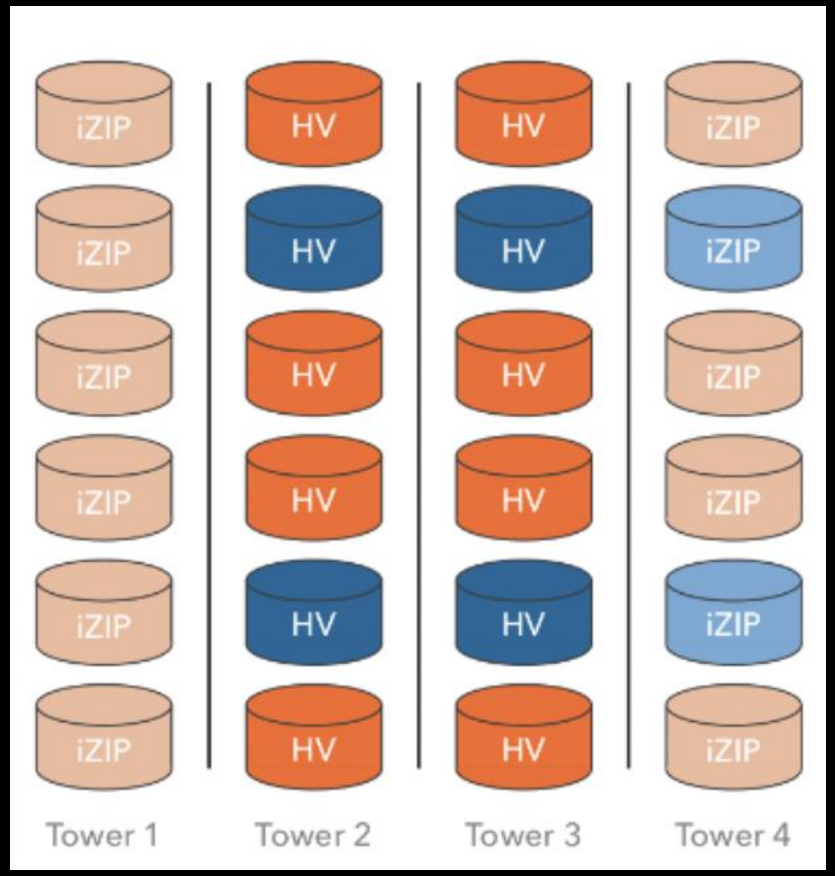




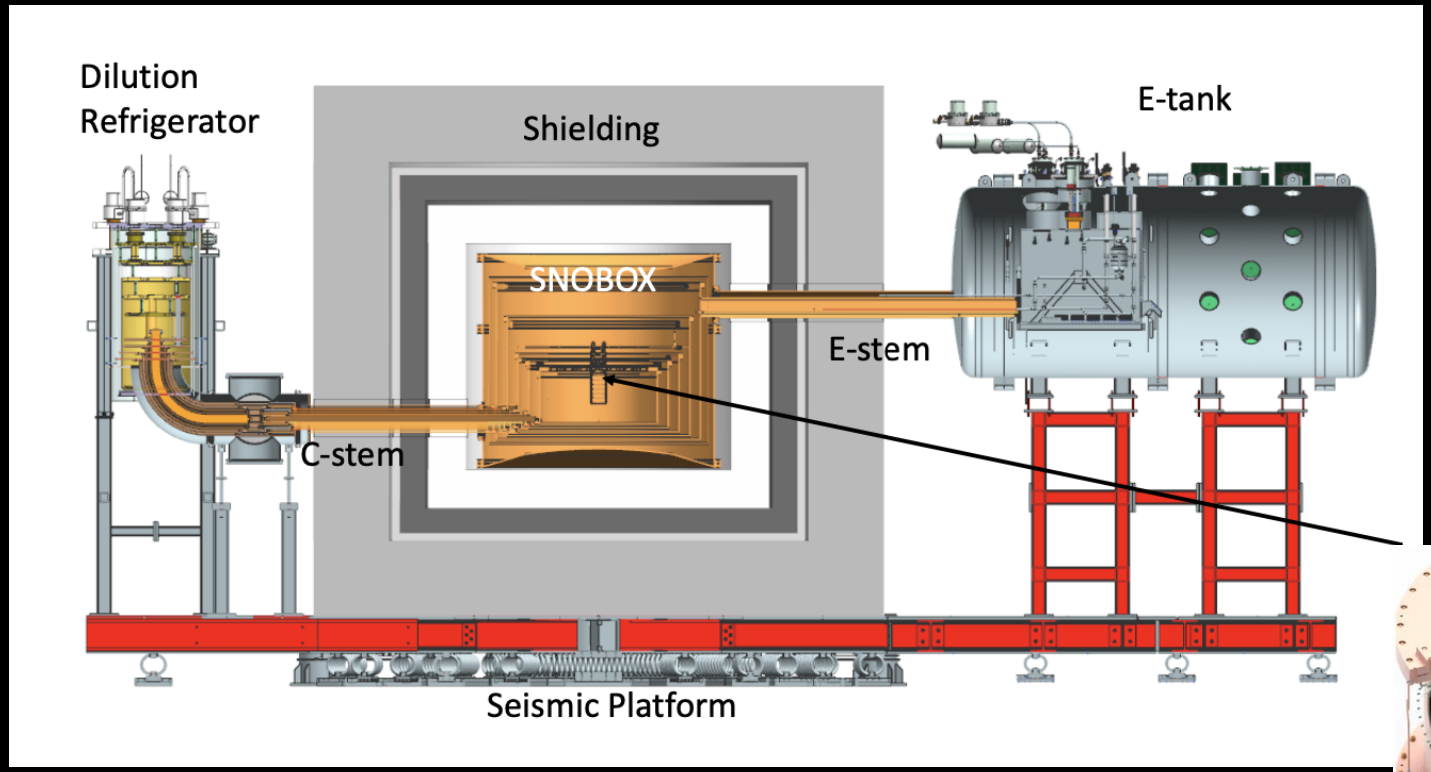
The SuperCDMS SNOLAB experiment

- Payload:
  - 4 towers, 24 detectors
    - 10 Ge iZIP; 2 Si iZIP
    - 8 Ge HV; 4 Si HV
- All towers passed preliminary testing at SLAC in 2022
  - Tc: Ge = ~60 mK; Si = ~ 40 mK





The SuperCDMS SNOLAB experiment



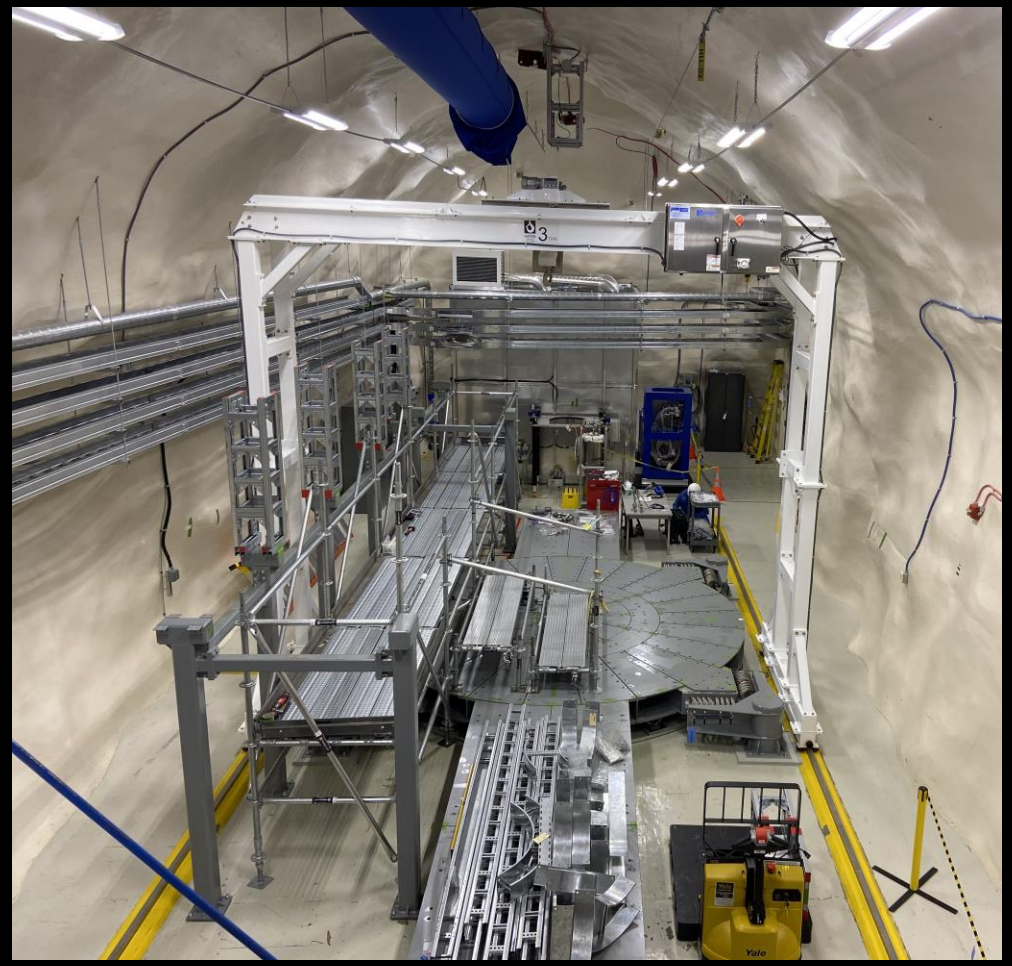
- Towers are hosted in nested cans of different thermal stages, called SNOBOX
- SNOBOX is serviced by a dilution refrigerator and E-tank

SuperCDMS SNOLAB status and schedule

- DAQ installation finished Nov. 2021
- Two towers arrived underground at SNOLAB May 2023
- Standalone commissioning of the dilution fridge completed July 2023
- Shield base (HDPE + Pb) installed July 2023

SuperCDMS SNOLAB status and schedule

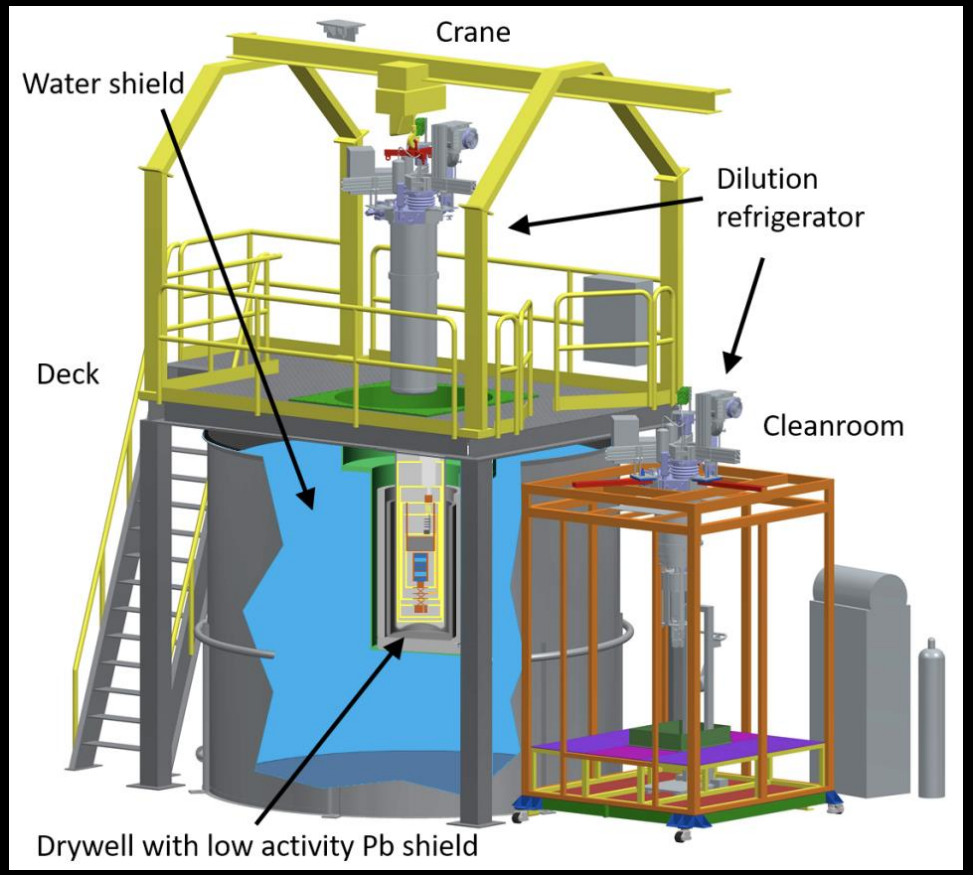
- SNOBOX and E-tank currently being tested at SLAC, and are scheduled to arrive at SNOLAB early next year



Subsystems are coming together, we expect the experiment to start commissioning in 2025!

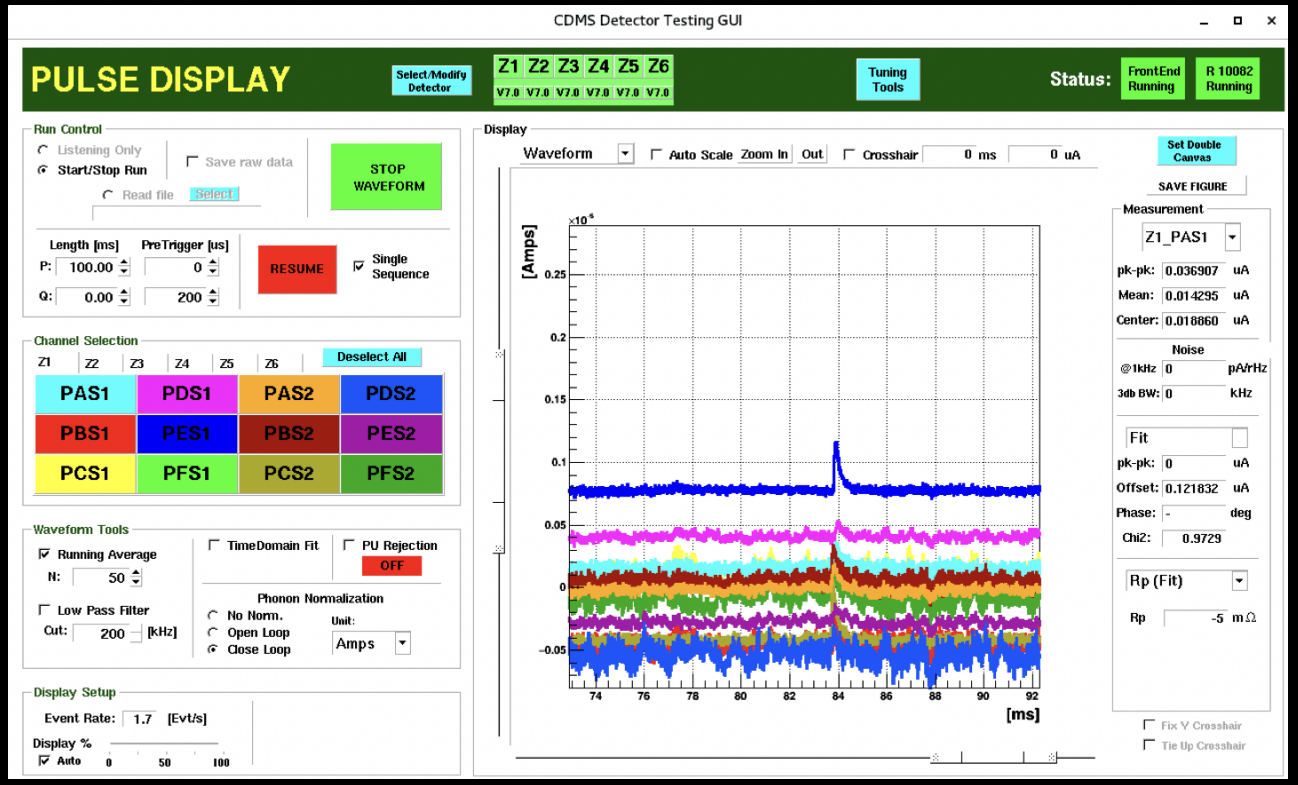
Cryogenic Underground TEst facility

- CUTE is a unique deep underground, low background cryogenic test facility located at SNOLAB.
- Background level < 10 DRU
  - Water tank
  - Lead shield
  - Class-300 clean room
- Capable of deploying different cryogenic devices with quick turnaround time
  - Cooldown time ~3 days



Cryogenic Underground TEst facility

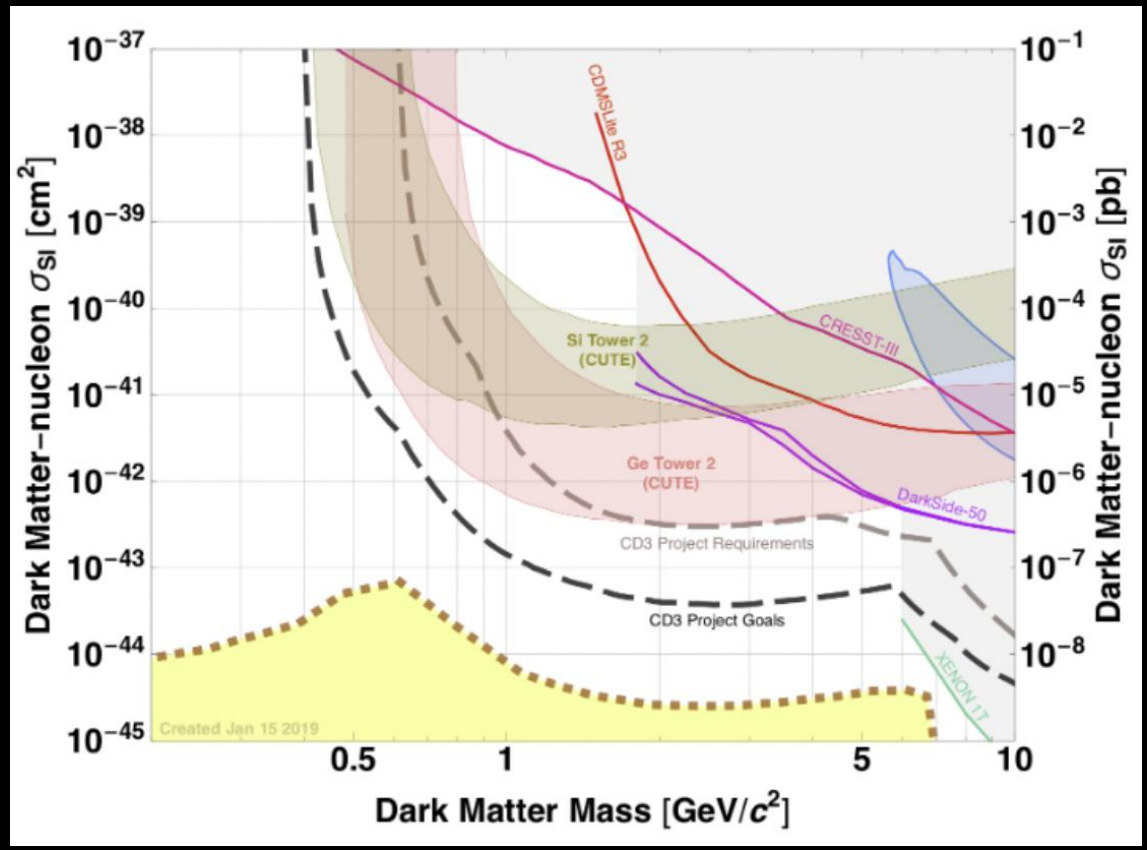
- As of last week (Oct. 24), one SuperCDMS HV tower is being deployed and tested at CUTE!
  - Stringent procedure was followed to keep the tower radon exposure low (~2 Bq/cm^3) during tower transport and installation.
  - All detectors went superconducting right after fridge reached base temperature (<15 mK).
- First glimpses of the capability of these new detectors.



Pulses are averaged to hide noise information :-)

Cryogenic Underground TEst facility

- For the next few months, we will be characterizing the detector performance, carrying out detector calibration, and doing background studies.
- Exciting opportunity for science
  - Expect to improve current best limit at 1GeV WIMPs by ~2 orders of magnitude*.
  - * charge leakage rate was not taken into account in the sensitivity projection – need to measure it in-situ.
  - Will independently (re)test recent DAMIC excess.



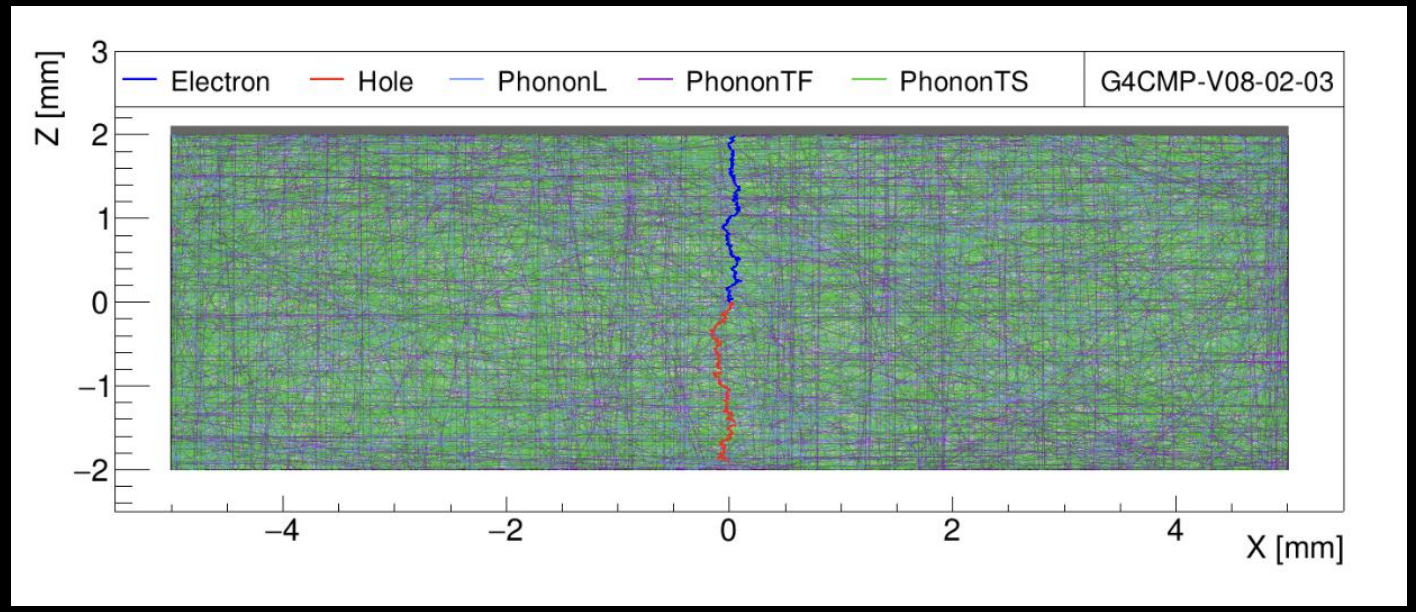
SuperCDMS science planning report, 2019

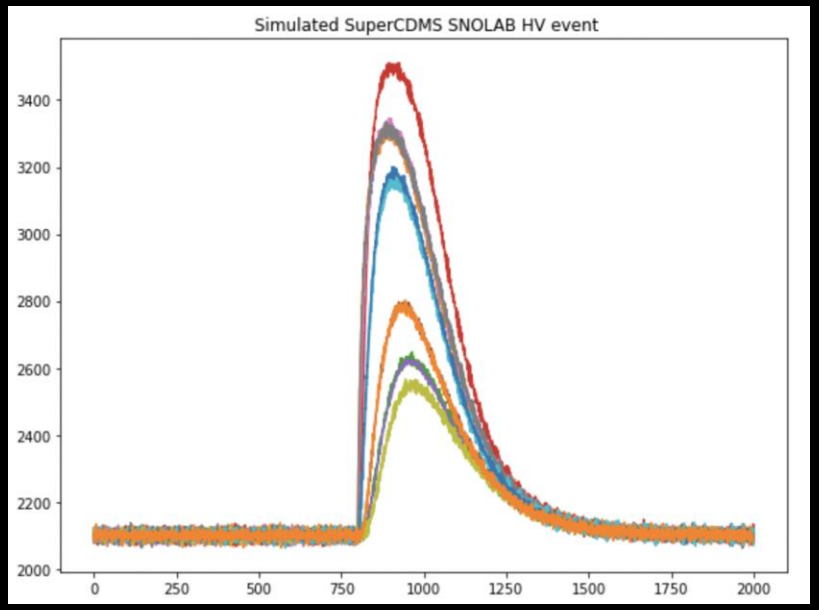
Analysis preparation: NxM optimal filter

- We devised a new optimal filter algorithm that can improve the detector energy resolution significantly.
  - Fit all(12) channels simultaneously with multiple templates.
  - Takes into account correlated noise between channels, and accommodates pulse shape variation.
  - Preliminary studies on CDMSlite data suggest significant improvement on energy resolution is possible.
  - Also expect improved position reconstruction.

Analysis Preparation: Simulation

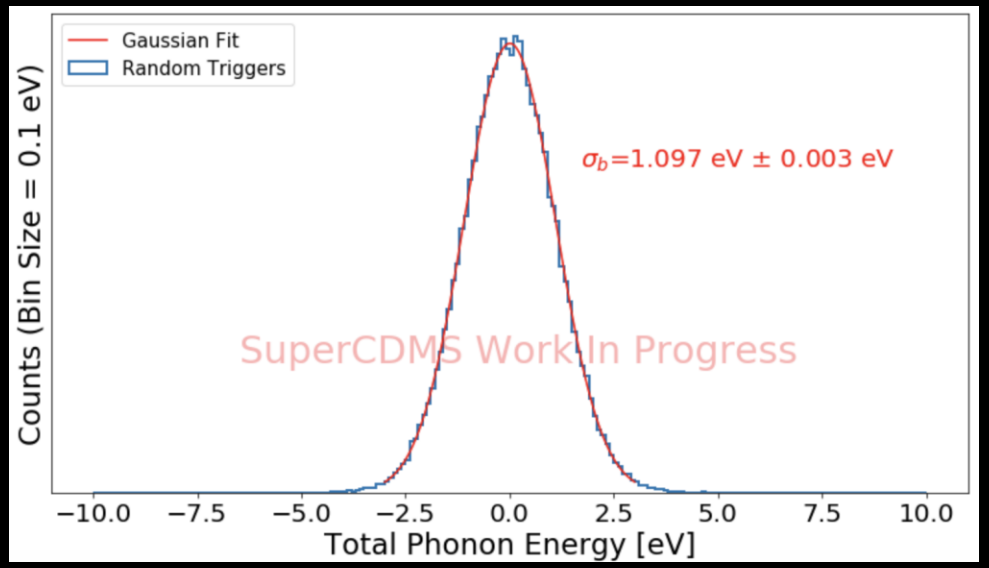
- Simulation: Fully GEANT-4 Based, detector response model derived from first principles.
  - First simulated HV dataset generated June 2023.



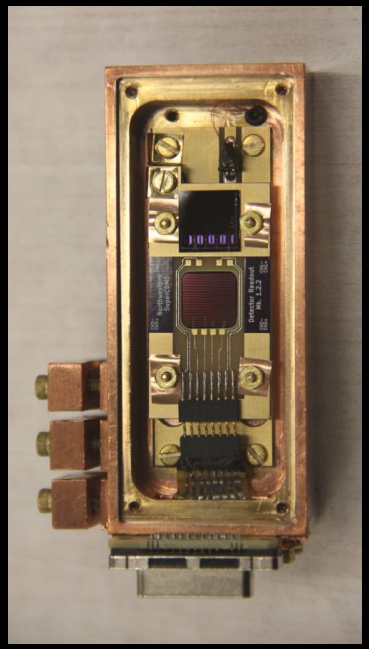


SuperCDMS detector R&D

- HVeV (High Voltage eV scale):
  - Operated at NEXUS, superb sensitivity to electron recoil signals.
  - Newest version of HVeV was able to achieve ~1 eV resolution (best in the field!).
- Plan to deploy multiple HVeV detectors at CUTE to further investigate background early next year!



Energy spectrum of random triggered events



Conclusion

- Direct detection of Dark Matter is one of the most promising probes to investigate Beyond the Standard Model physics.
- SuperCDMS SNOLAB's main objective is to search for low-mass WIMPs.
- The experiment expects to start commissioning in 2025.
- One HV tower is currently being tested at CUTE to better characterize the detector performance. Exciting science potential will be explored!

Thank you!


Francisco Ponce
Matt Wilson
Hanno Meyer zu Theen...
Mouli
Varchaswi Kashyap
Ruslan Podviianiuk
Sagar Sharma
Tina Cartaro
Richard Schnee
Kent May
Steven Pellin
Huanbo Sun
David MacFarlane
Rob Cameron
Vijay Iyer
David Santiago Pedreros
Sasha (A. Zaytsev)
sudipta (he/him/his)
Qubit & Quark
Silvia Scorza
Sukee (S. Dharani)
Wolfgang Rau
Belina von Krosigk (she...
Lauren Hsu
Kelsey, Michael H
Arts
science
UNIVERSITY OF TORONTO
SUPER
CDMS
Cryogenic Dark Matter Search

Back-up Slides

SuperCDMS SNOLAB

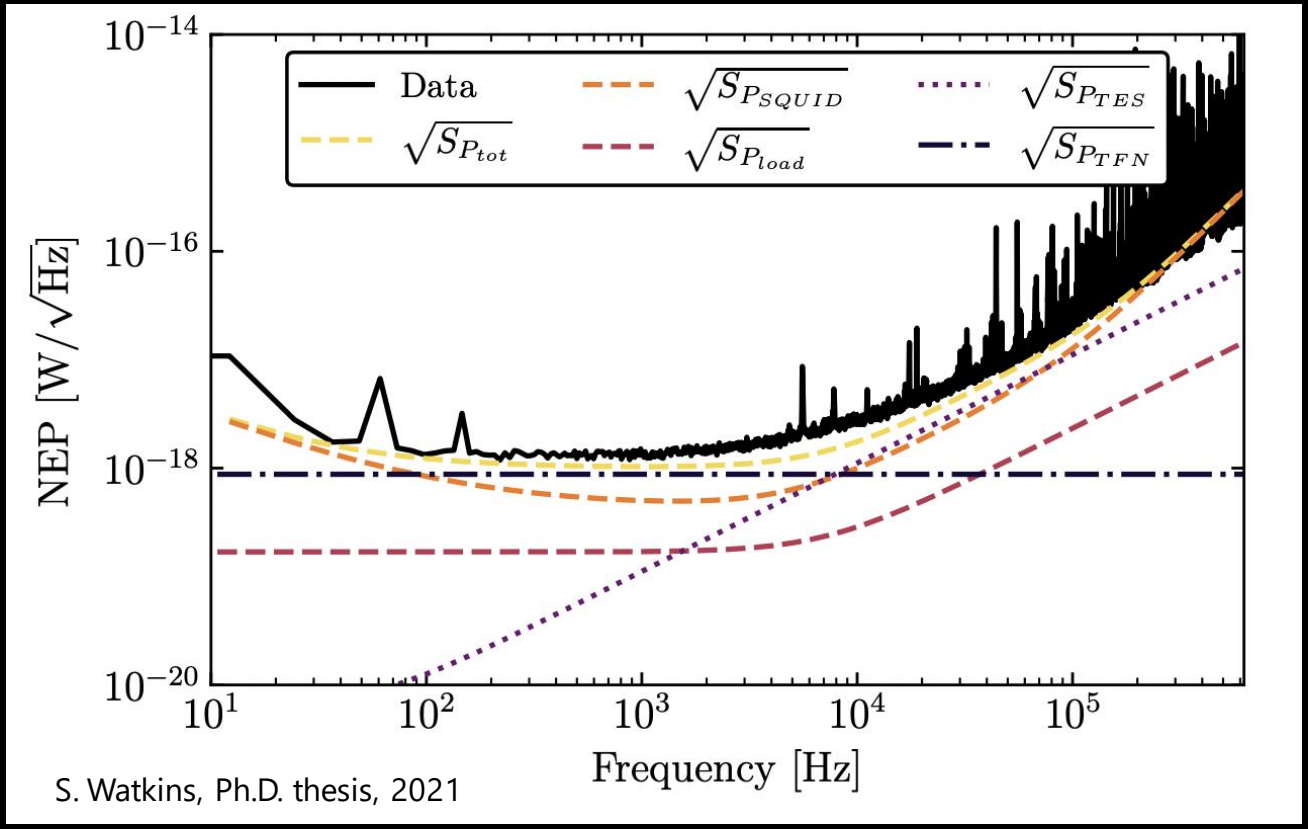
	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure (kg·yr)	56	4.8	44	9.6
Phonon resolution (eV)	50	25	10	5
Ionization resolution (eV)	100	110	–	–
Voltage Bias (V)	6	8	100	100

- Two target materials; Two configurations
- Total 24 detectors, 100kg yr exposure
- Each Ge (Si) detector weigh 1.39 kg (0.61 kg)
- Each HV detector has 12 phonon channels (iZIP detector has additionally 4 charge channels)

Future Upgrade

- Detector size:
- Phonon energy resolution
  - Single electron-hole pair resolution would enable possible NR/ER discrimination
- Ionization energy resolution
- Ionization collection non-idealities
  - Leakage current, impact ionization, charge trapping

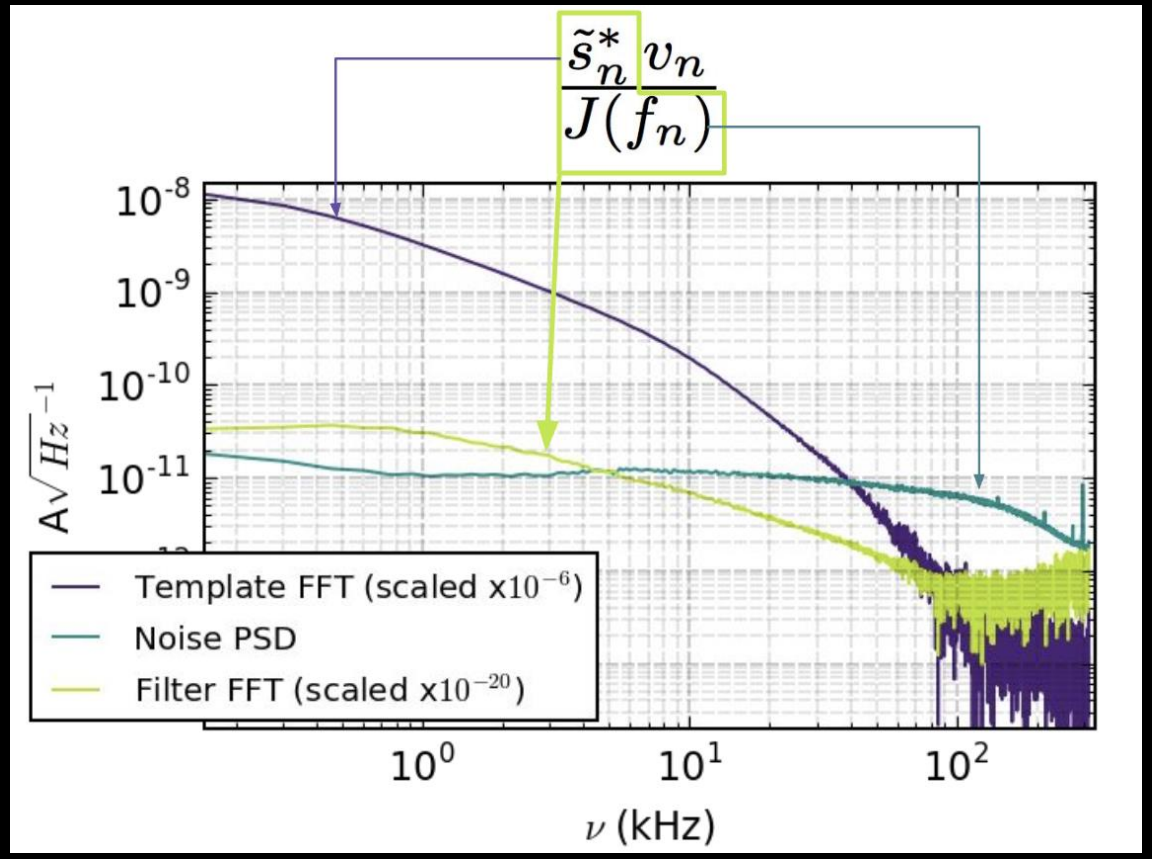
Noise Modelling

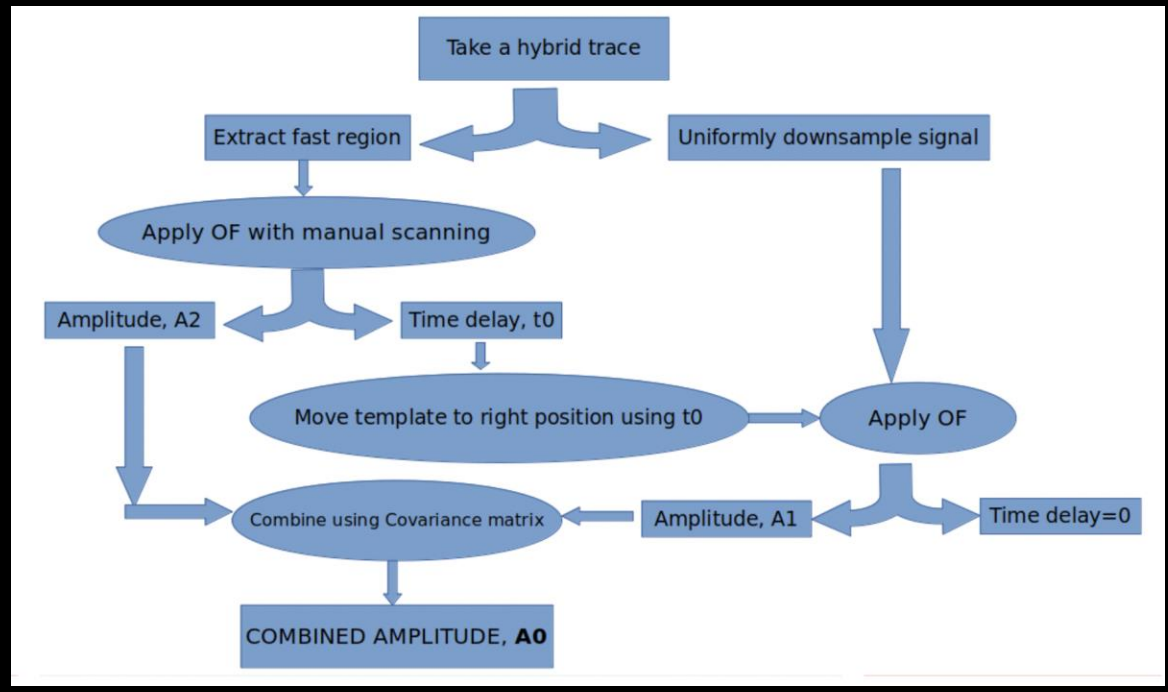


S. Watkins, Ph.D. thesis, 2021

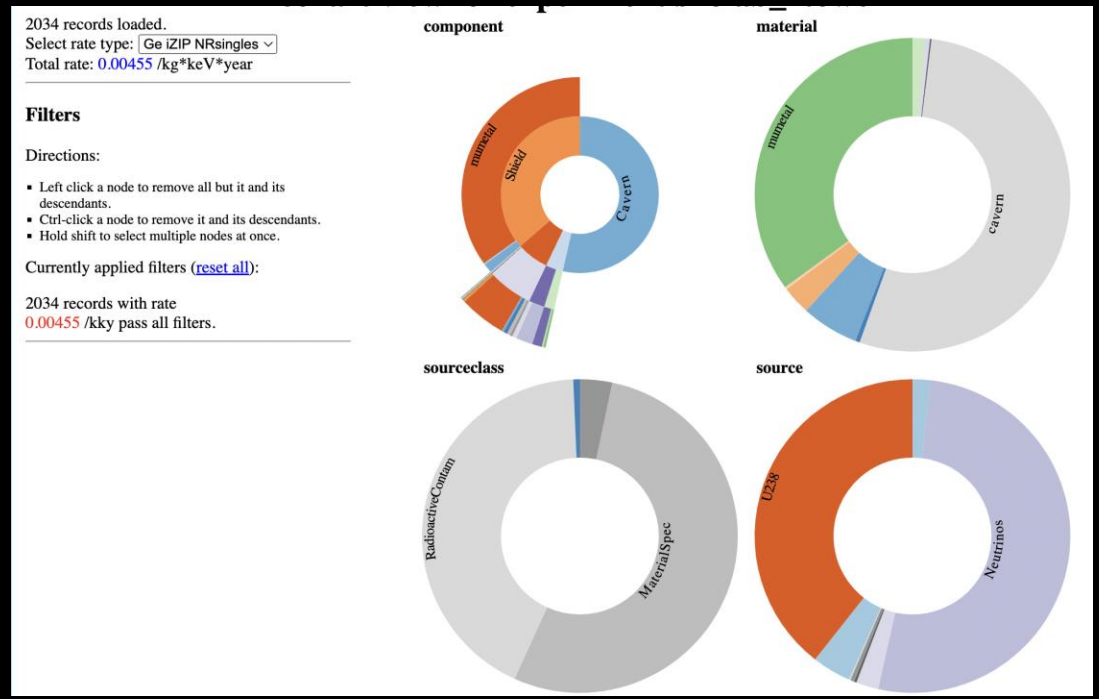
Transition noise of a TES chip

Optimal Filter





Background Model (Ge)



Background Model (Si)

2034 records loaded.
Select rate type: Si HV ERsingles
Total rate: 380 /kg*keV*year

Filters

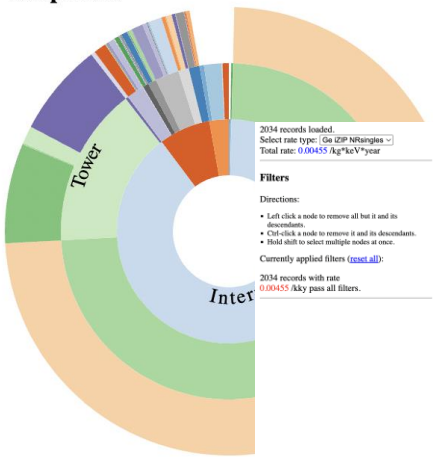
Directions:

- Left click a node to remove all but it and its descendants.
- Ctrl-click a node to remove it and its descendants.
- Hold shift to select multiple nodes at once.

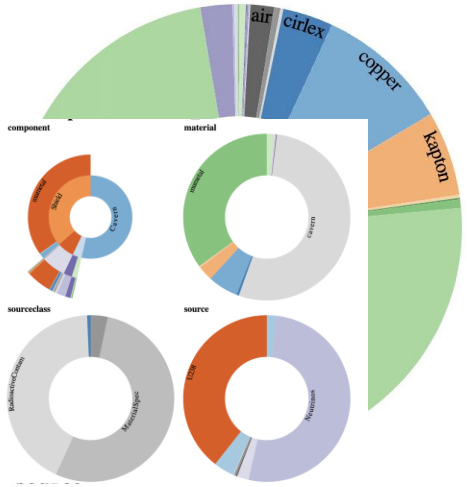
Currently applied filters (reset all):

2034 records with rate
380 /kky pass all filters.

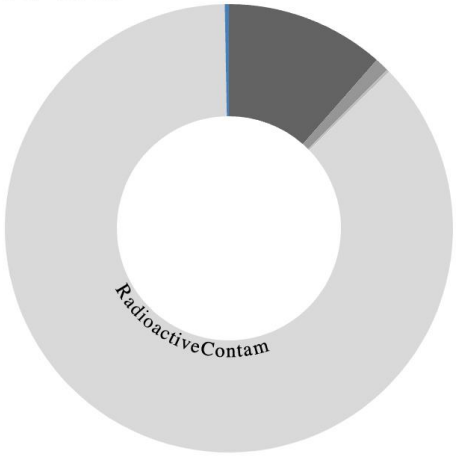
component

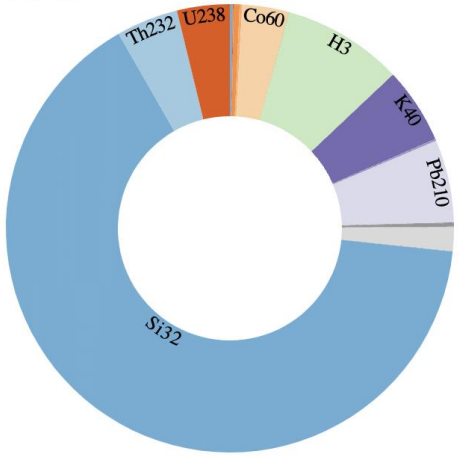


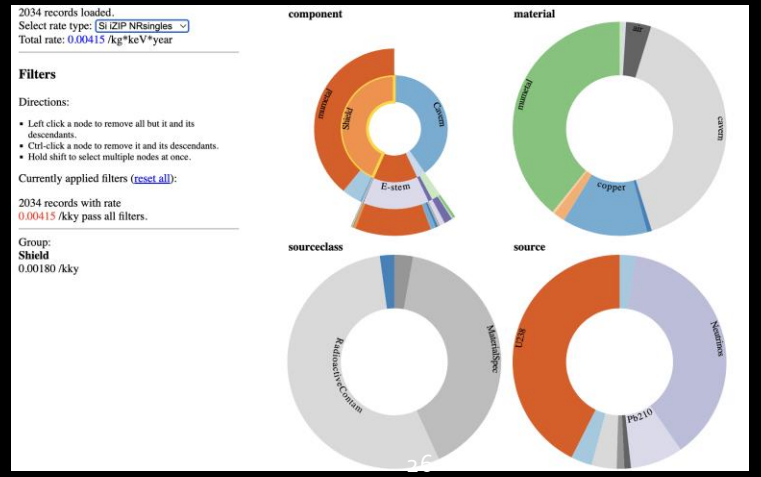
material



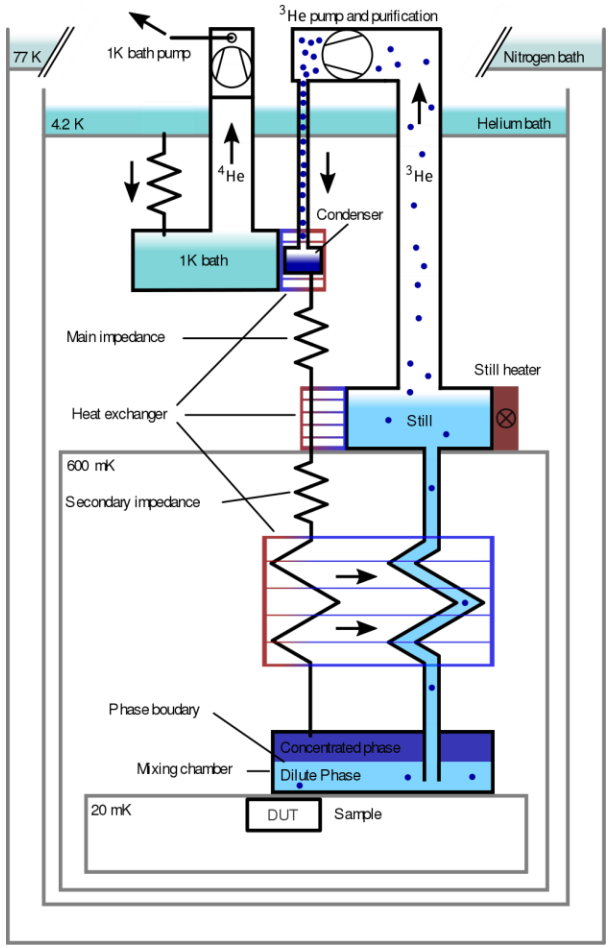
sourceclass

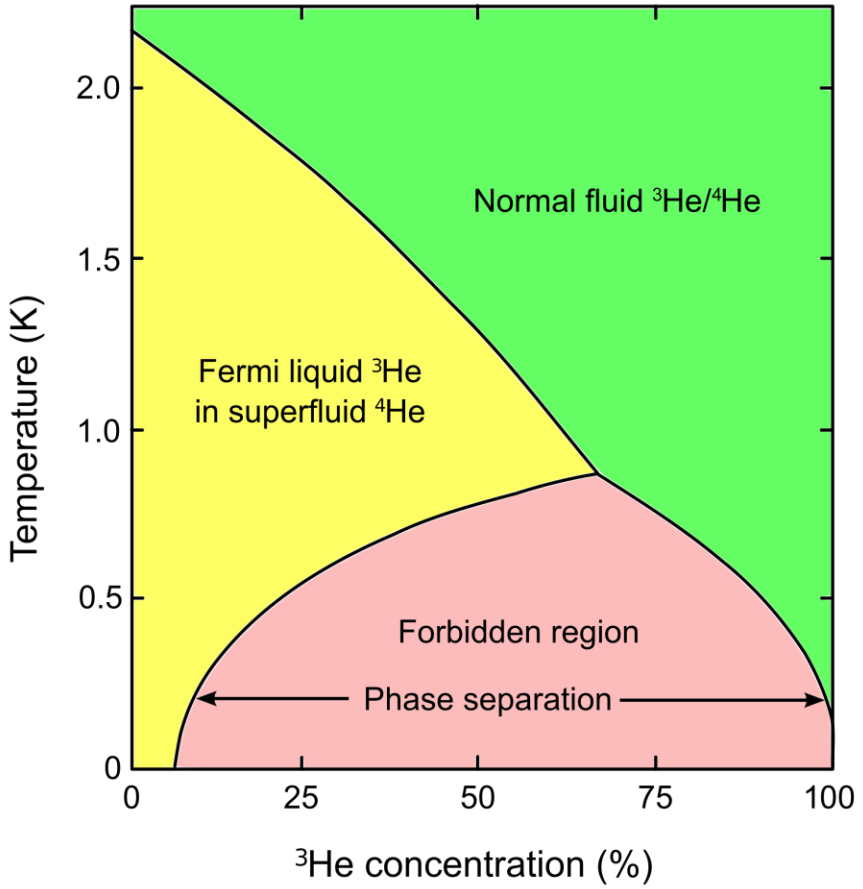




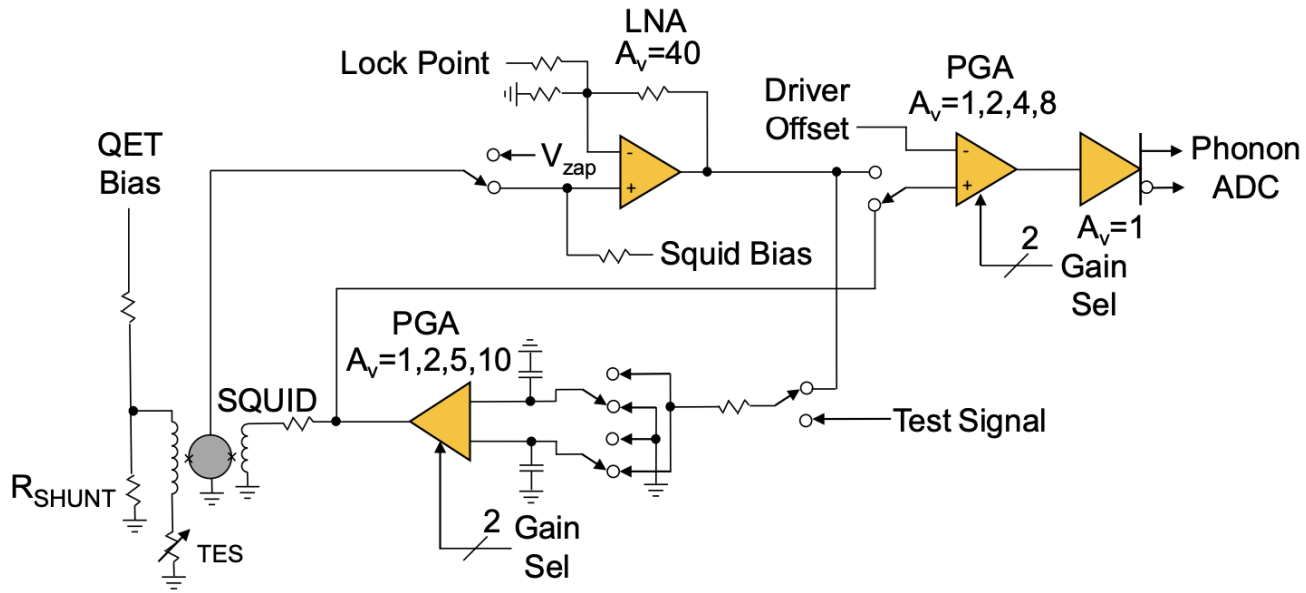


Dilution Refrigerator





Readout diagram

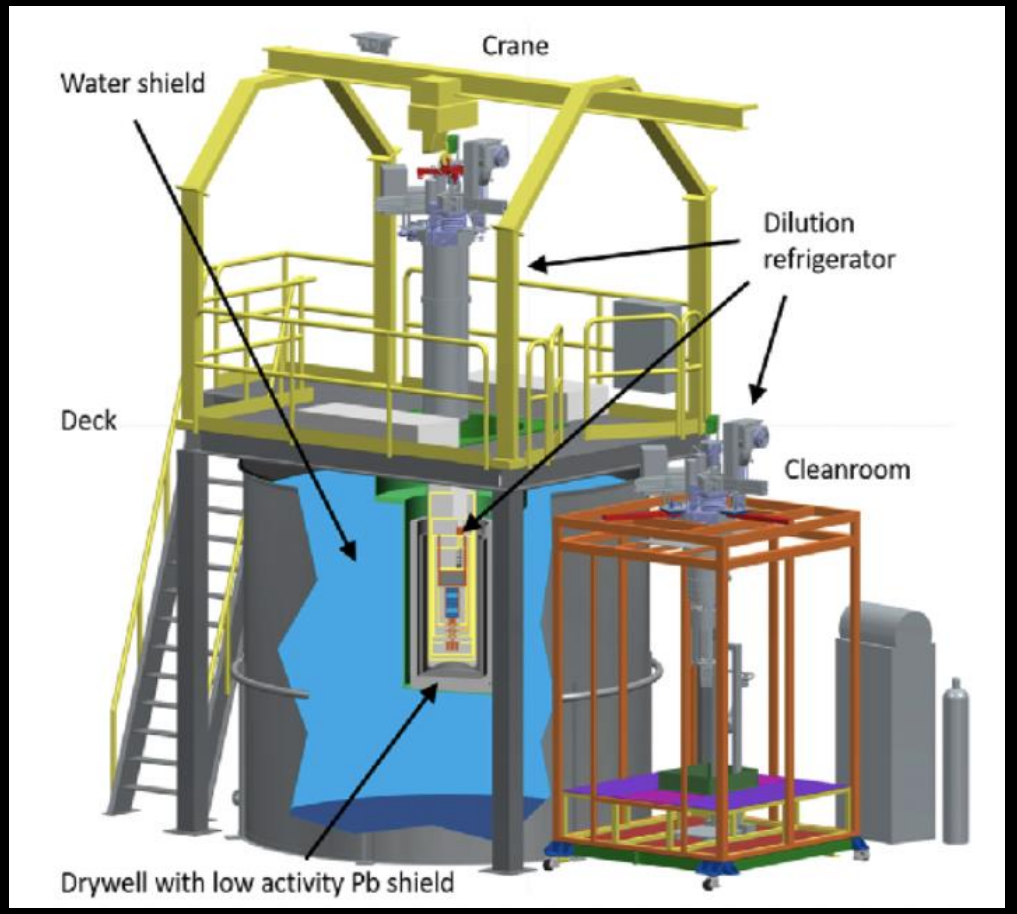


Reduced Feature Set Phonon Channel Block Diagram

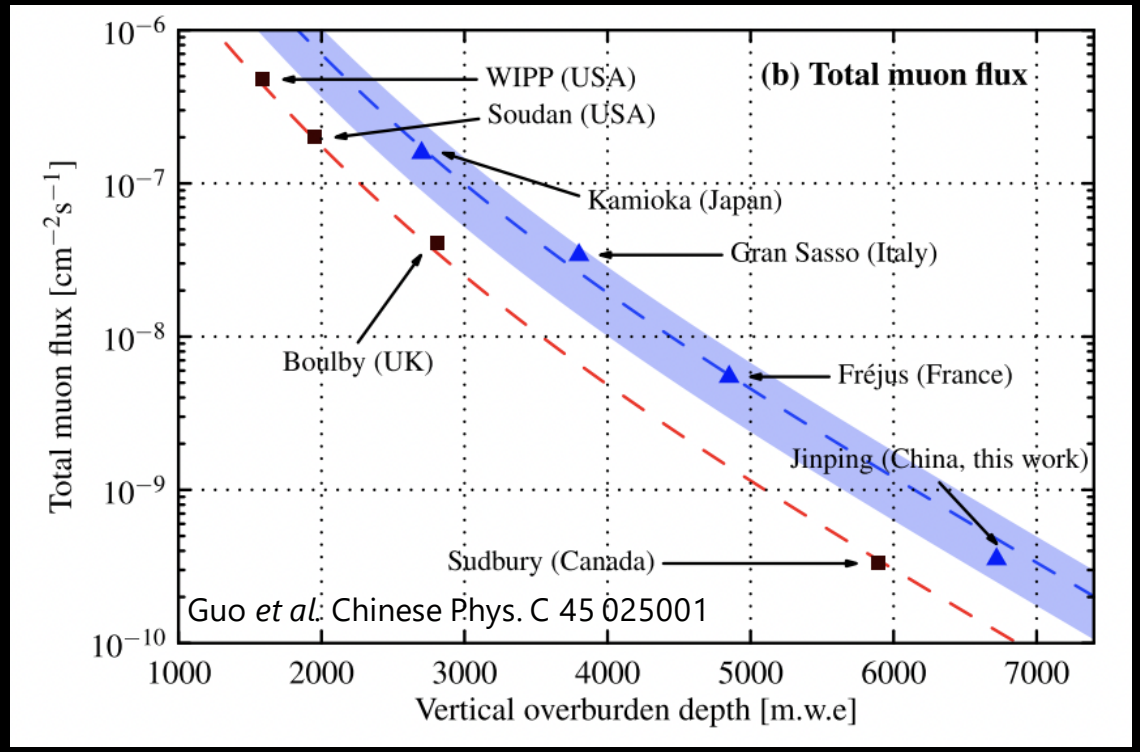
Package Count: LNA : ½ ADA 4897 ADC Driver : ½ ADA4940 or THS4532
PGA : 1 AD8250,1 AD8251 Switches: 2.5 ADG1636
DACs : ½ AD5668 ADCs: ¼ LTC2170 DAC Amps: 1 OPA4209

Rev C Package Count: LNA : 1 ADC Driver : 2 VGA : 1/2 DACs : 5/8 ADCs: 1
PGA : 1 Feedback Amp: 1 Switches: 3 DAC Amps: 1.25

CUTE


Crane
Water shield
Dilution
refrigerator
Deck
Cleanroom
Drywell with low activity Pb shield

SNOLAB


(b) Total muon flux
WIPP (USA)
Soudan (USA)
Kamioka (Japan)
Gran Sasso (Italy)
Boulby (UK)
Fréjus (France)
Jinping (China, this work)
Sudbury (Canada)
Guo *et al.* Chinese Phys. C 45 025001
Total muon flux [cm^{-2}s^{-1}]
Vertical overburden depth [m.w.e]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1000
2000
3000
4000
5000
6000
7000

DAMIC Excess