# Status and prospects of SuperCDMS SNOLAB

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MultiDark Multimessenger Approach for Dark Matter Detection

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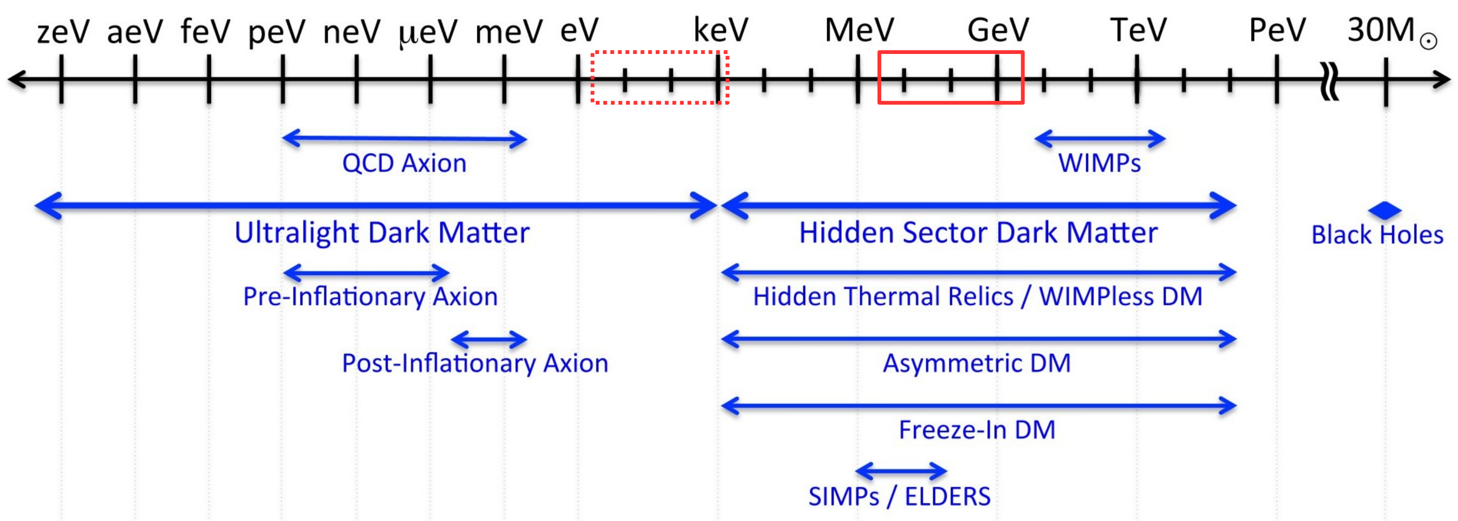
# Introduction

Direct detection experiments have strongly constrained the WIMP hypothesis, motivating the search for dark matter in regimes beyond the GeV scale

Sub-GeV dark matter: allowed in several models that explain the amount of DM in the universe by assuming new interactions (hidden sector freeze-out, freeze-in, etc)

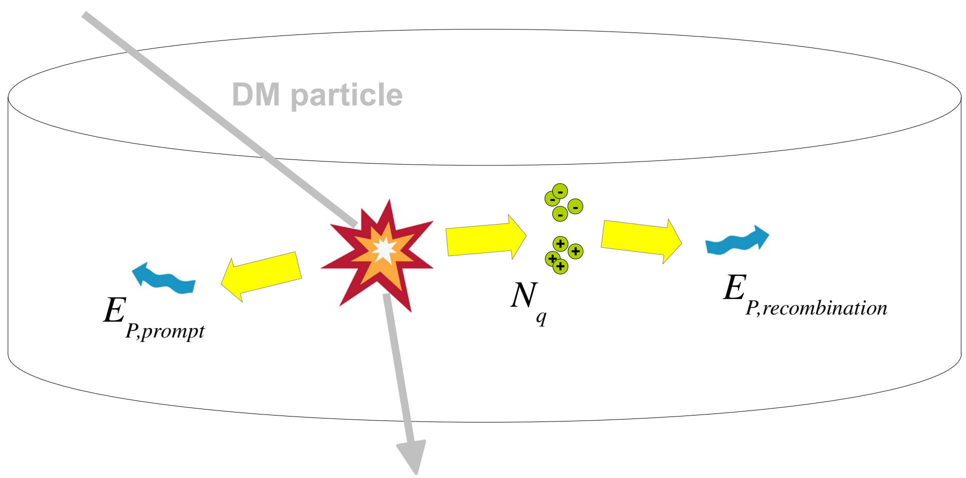


# Detector physics

Semiconductor monocrystals (Si, Ge) at cryogenic temperatures (~50 mK)

Effect of recoiling particle (atomic nucleus or electron) after DM interaction:

- Fraction of deposited energy produces electron-hole pairs (charge, $N_q$)
- Eventually, all deposited energy goes into athermal phonons ($E_P$): quanta of lattice vibrations, related to sound and temperature




Ionization yield, quantifies fraction of deposited energy producing charge

Depends on recoiling particle: ~1 for electrons, < 0.3 for nuclei (< 10 keV)

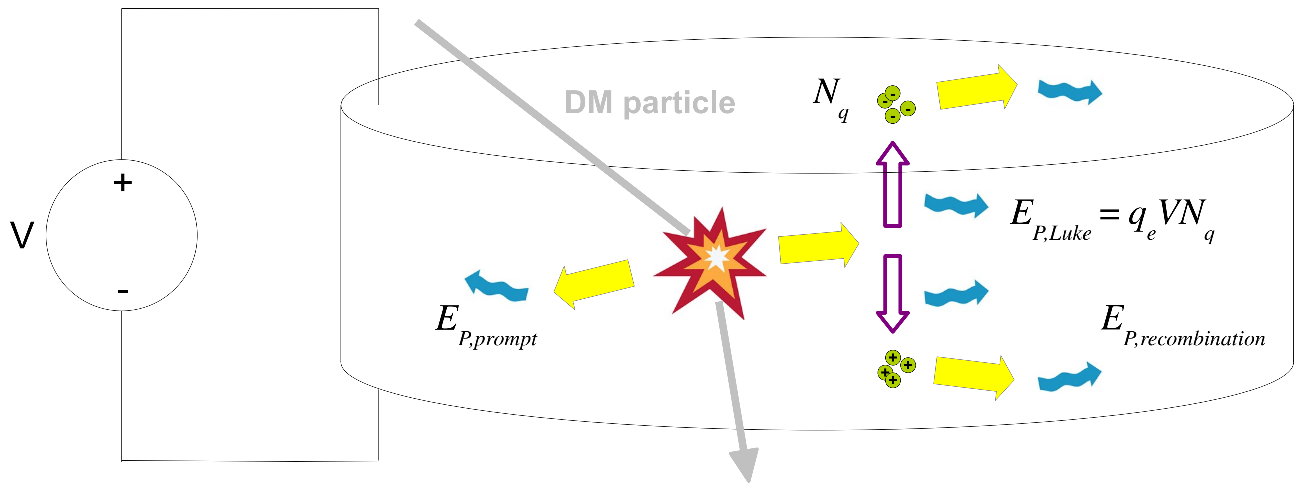
$$N_q = Y \frac{E_R}{\epsilon}$$

$$E_P = E_{P,prompt} + E_{P,recombination} = E_R$$

| ε(Si) | ε(Ge) |
|---|---|
| 3.6 eV | 2.9 eV |

# Detector physics

Neganov-Trofimov-Luke (NTL) effect: if electric field applied, charge produces additional (athermal) phonons while drifting




Additional phonons from charge carriers

$$N_q = Y \frac{E_R}{\epsilon}$$

$$E_P = E_R + q_e V N_q = E_R \left(1 + Y \frac{q_e V}{\epsilon}\right)$$

# SuperCDMS detectors

Two detector approaches:

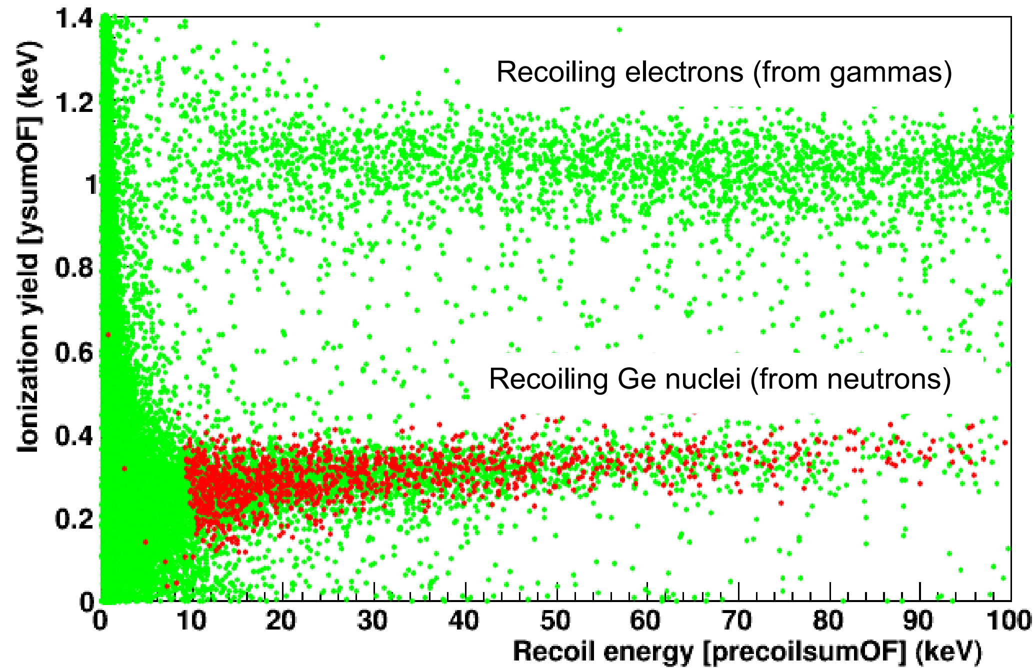
- IZIP: measures both charge ($N_q$) and phonon energy ($E_P$), to obtain recoil energy ($E_R$) and ionization yield ($Y$) ⇒ Discriminates between nuclear and electron recoil
- HV: applies high voltage in order to measure amplified NTL phonons (indirect measurement of $N_q$), ⇒ Effectively decreases the energy threshold

**iZIP**

$$N_q = Y \frac{E_R}{\epsilon}$$

$$E_P = E_R + q_e V N_q = E_R\left(1 + Y \frac{q_e V}{\epsilon}\right)$$

**$^{252}$Cf calibration data (neutrons+gammas)**



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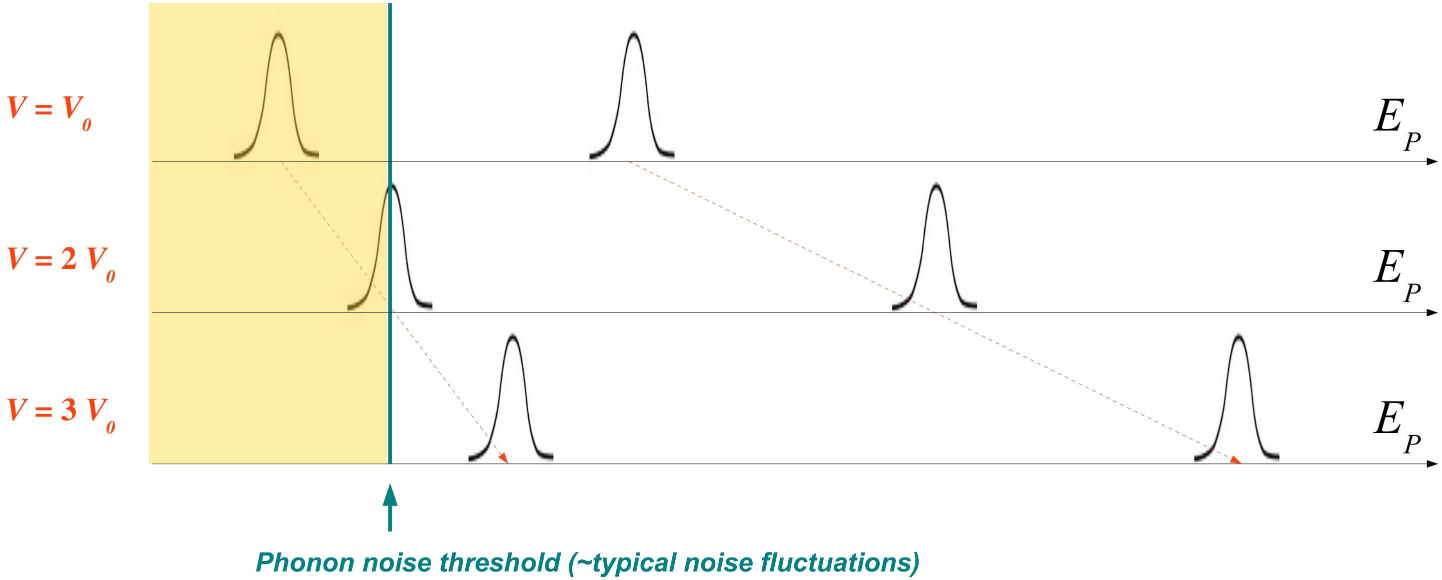
**HV** $$E_P = E_R + q_e V N_q = E_R\left(1 + Y\frac{q_e V}{\epsilon}\right) = g(V) E_R$$

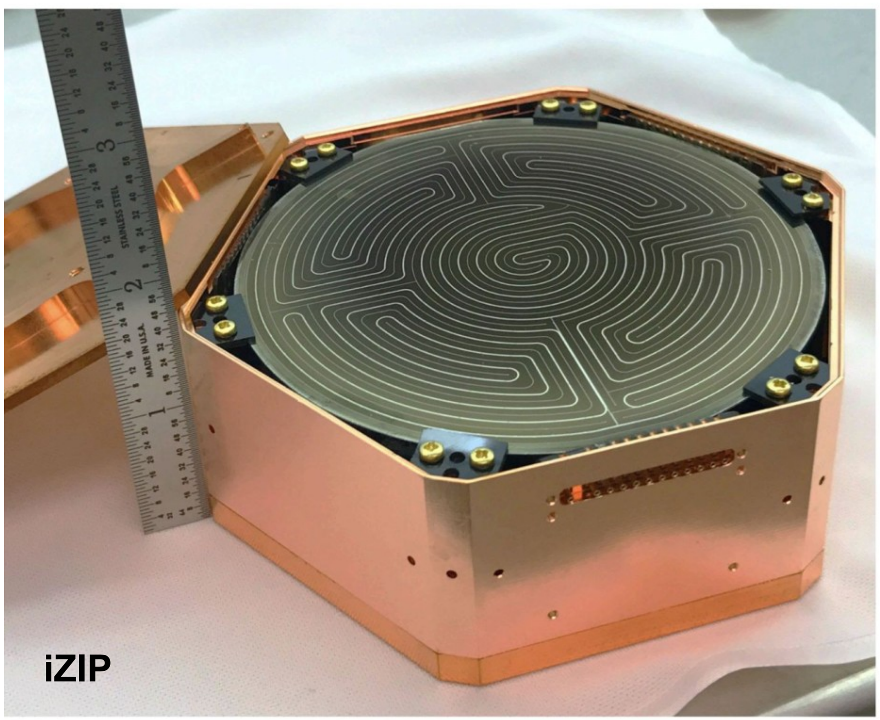


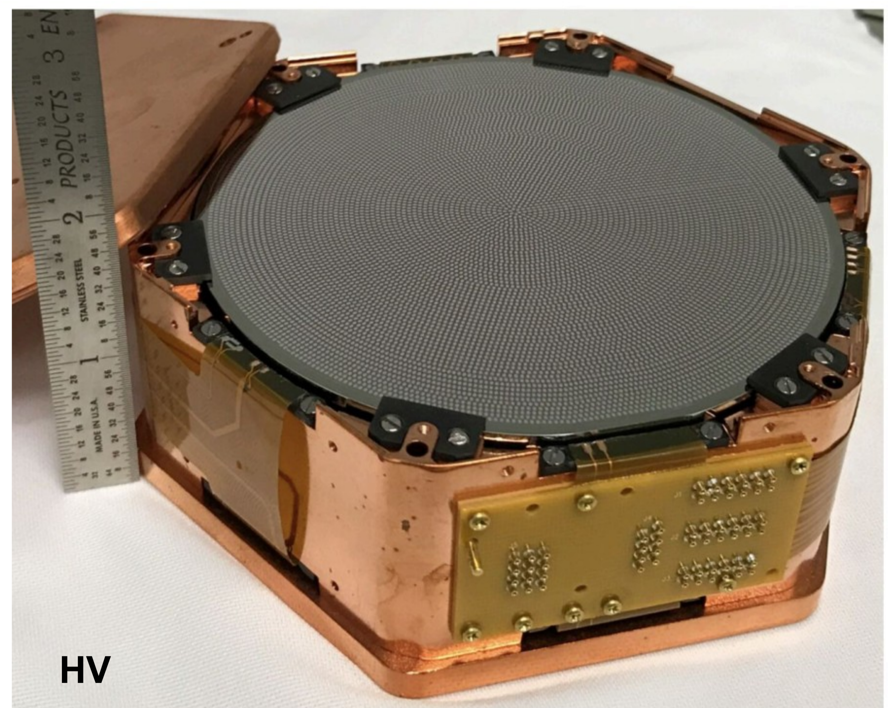
# SuperCDMS detectors

Monocrystalline semiconductor cylinders, instrumented on top and bottom surfaces in order to build a vertical electric field, and measure:

- Charge (iZIP detectors only), from current induced on electrodes due to drifting
- Phonon energy (both iZIP and HV detectors), using transition-edge sensors (TES)

Charge and phonon sensors arranged in channels to have position sensitivity



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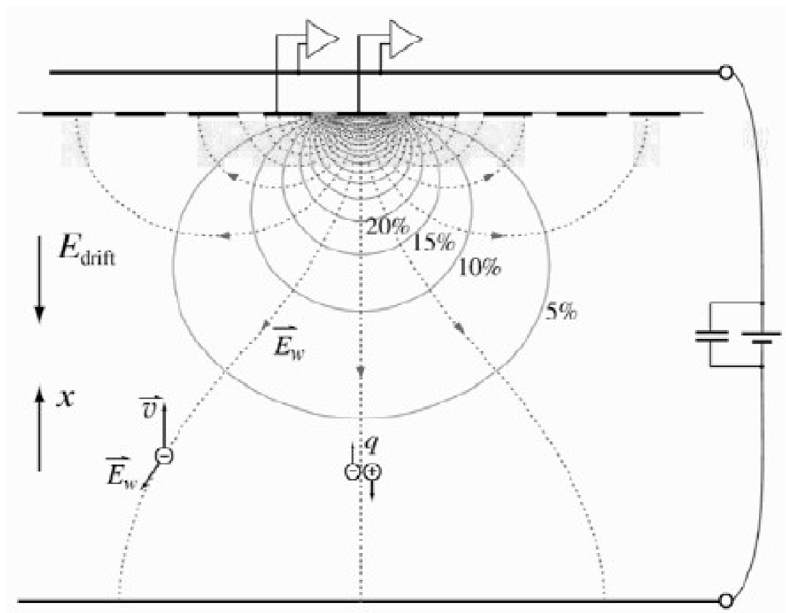

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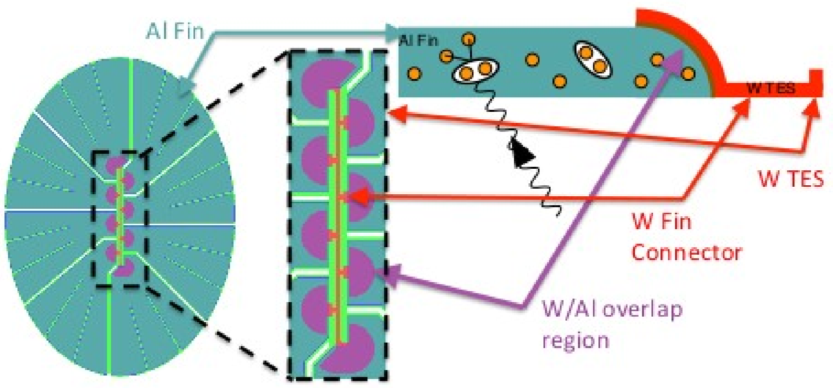
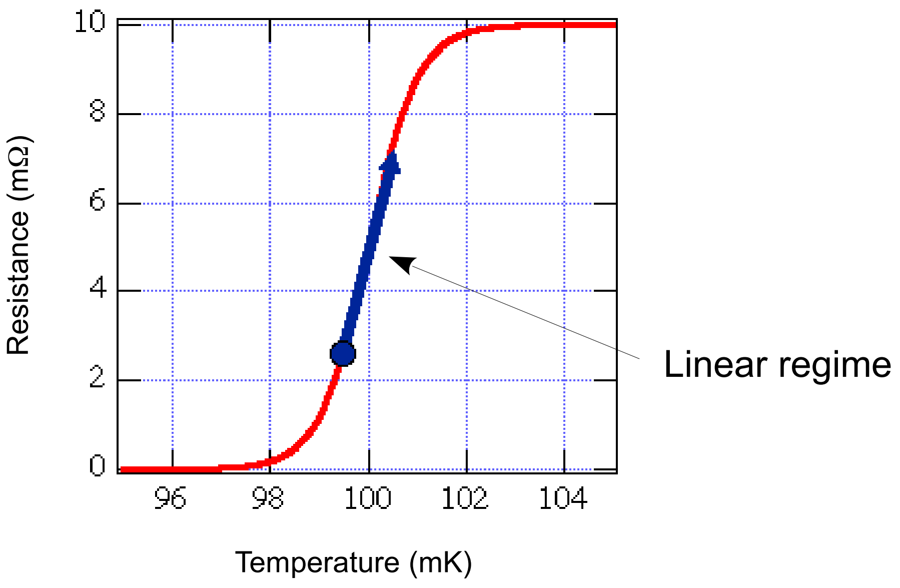



Al fin+TES



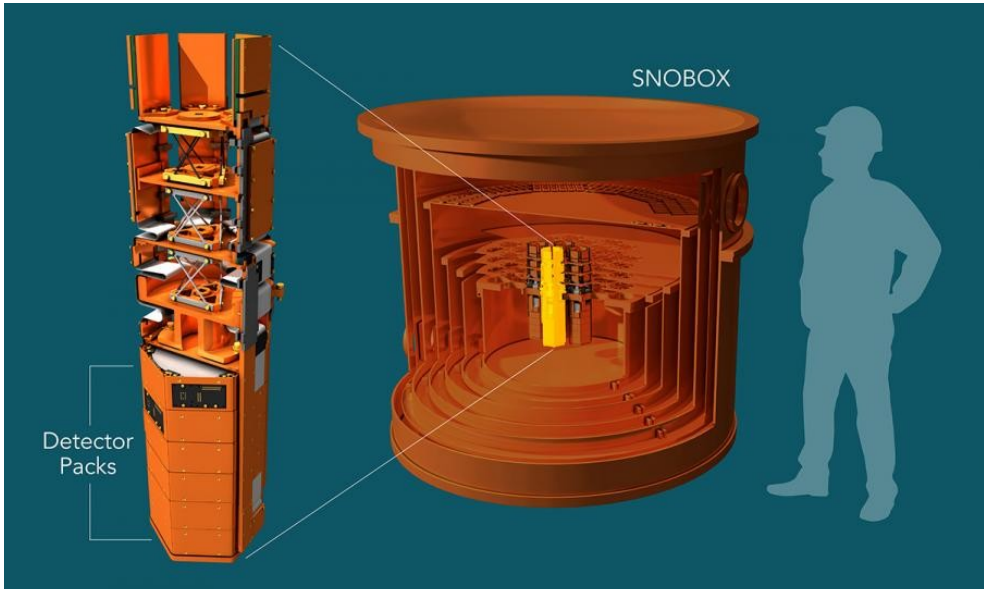
# The SuperCDMS SNOLAB experiment

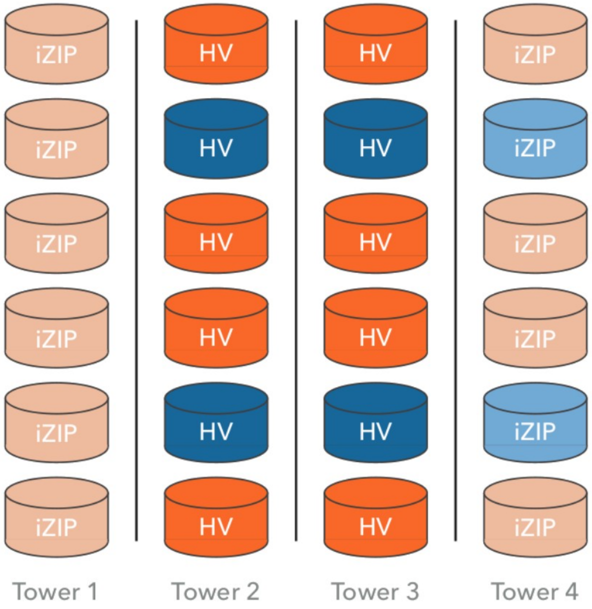
4 arrays (towers) of Si and Ge detectors (0.6 and 1.4 kg respectively)

Cryogenics: cryocooler+dilution refrigerator

Shielding: high-density polyethylene+Pb

Experiment site: SNOLAB, Canada (6000 m. w. e. overburden)



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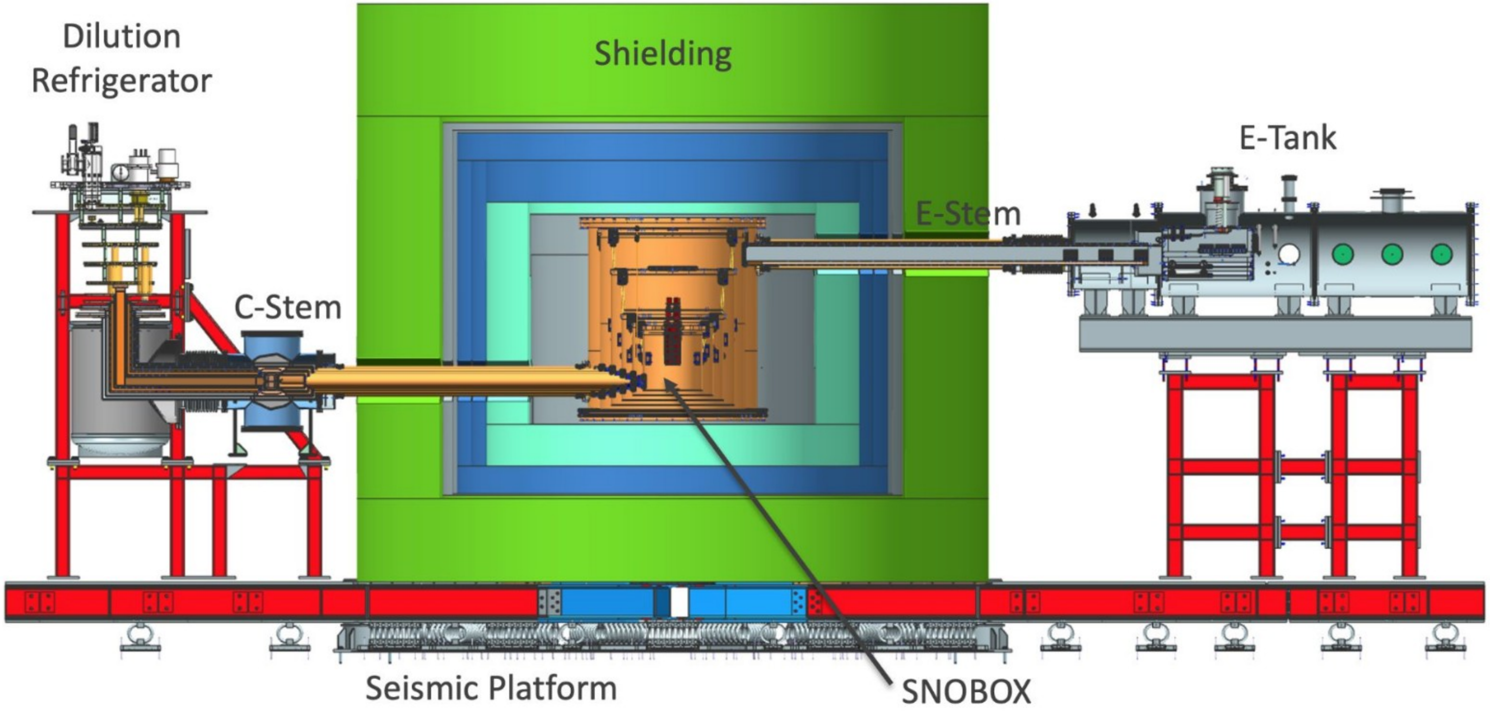


# Current status

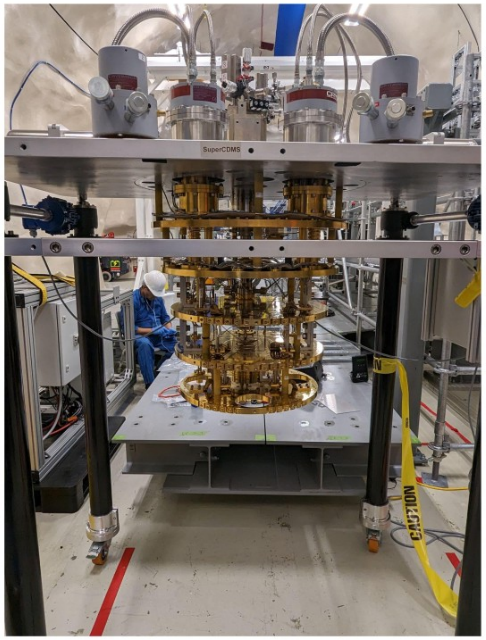
Base shielding completed

Dilution refrigerator already underground, reached 10 mK earlier this year

2 towers arrived at SNOLAB in May, other 2 expected later this year

Planning to test first tower at CUTE in November, opportunity for early science

Commissioning scheduled for late 2024



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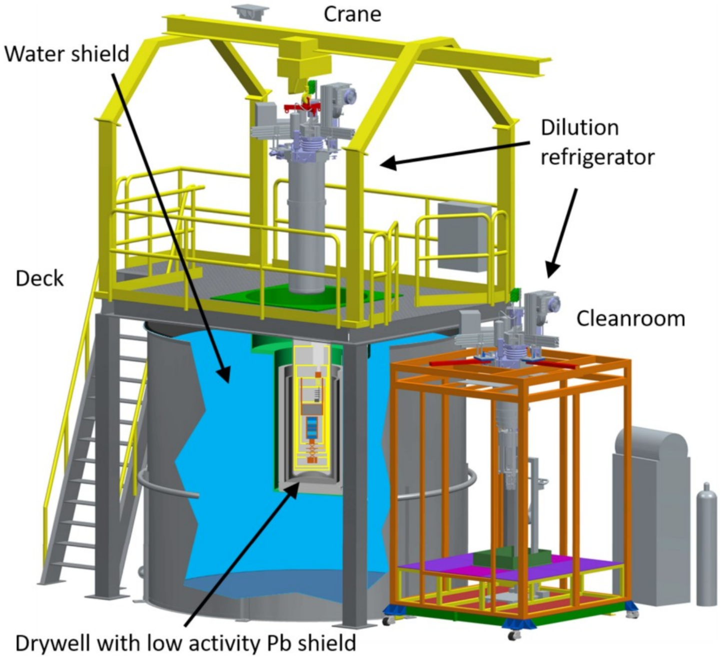
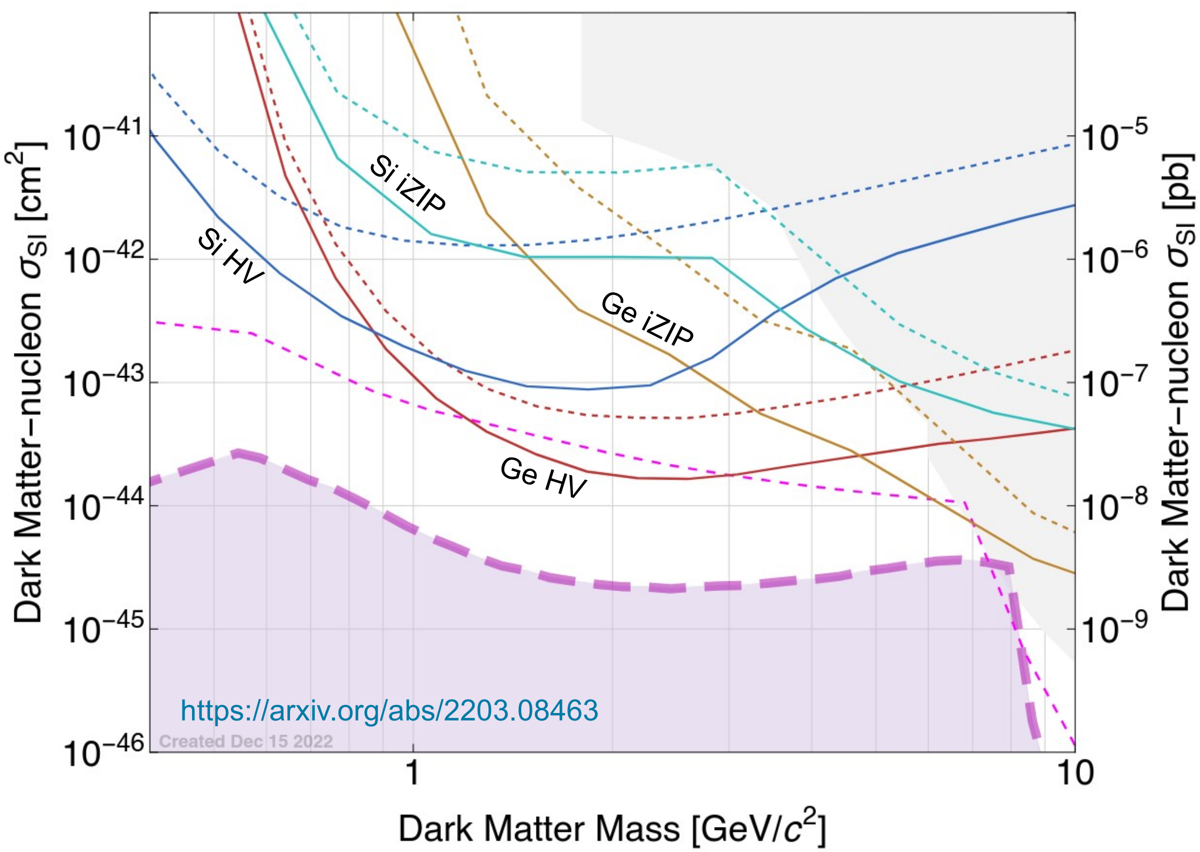



CUTE

# Projected sensitivity – nuclear recoils

SuperCDMS SNOLAB will be sensitive to dark matter down to ~400 MeV, well into the sub-GeV regime, and will approach the neutrino floor

Potential to further constrain the sub-GeV regime with future upgrades



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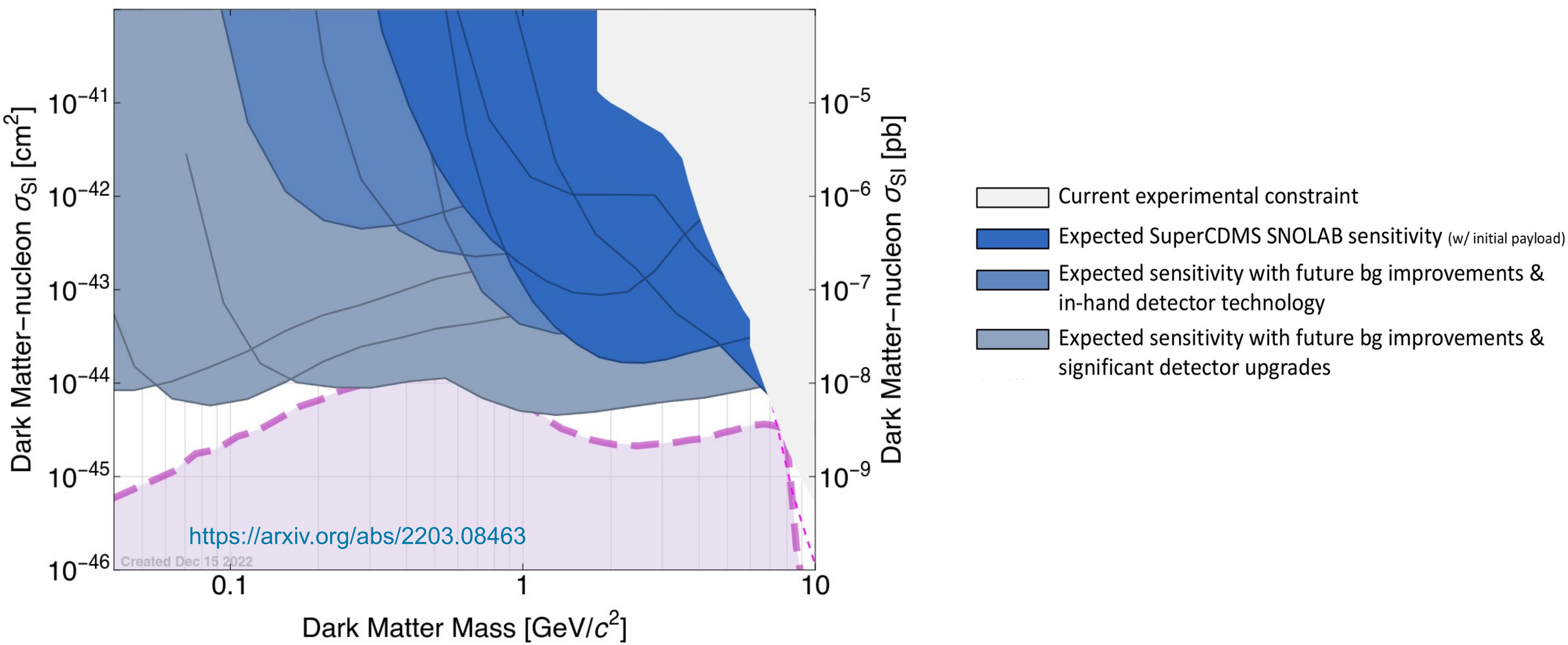
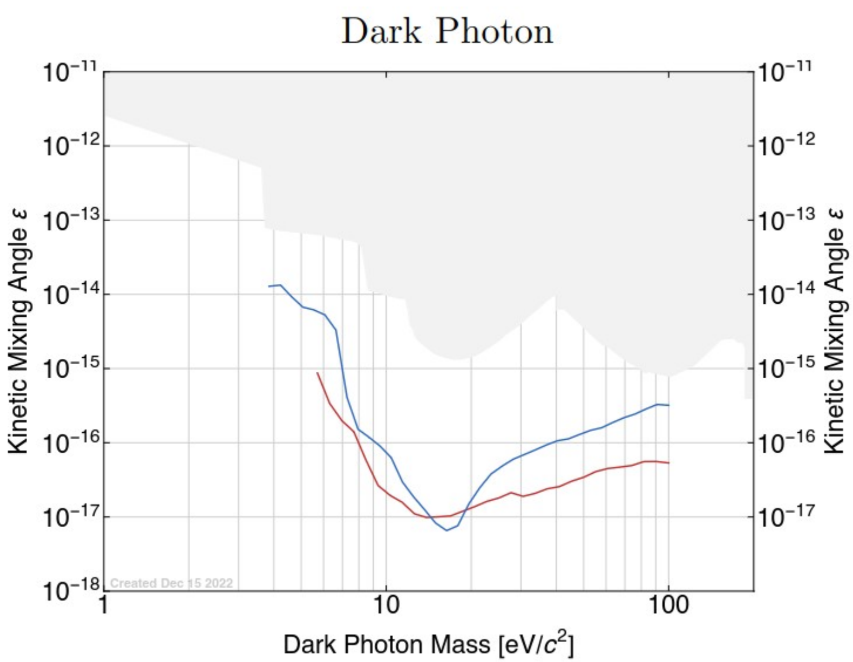
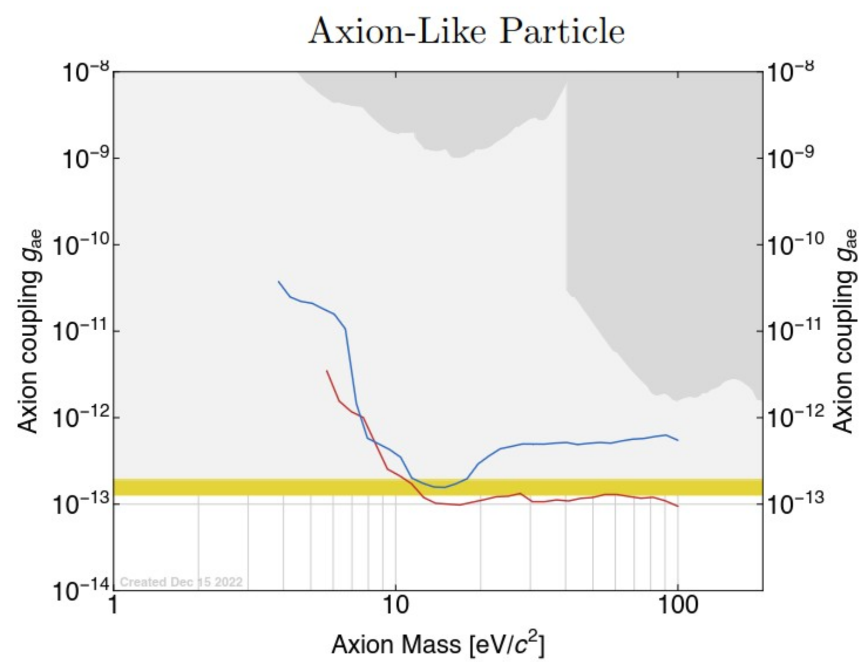


# Projected sensitivity – electron recoils

SuperCDMS SNOLAB will be also competitive to search for:

- Dark photon dark matter
- Axion-like particle dark matter
- Light dark matter mediated by dark photons




https://arxiv.org/abs/2203.08463

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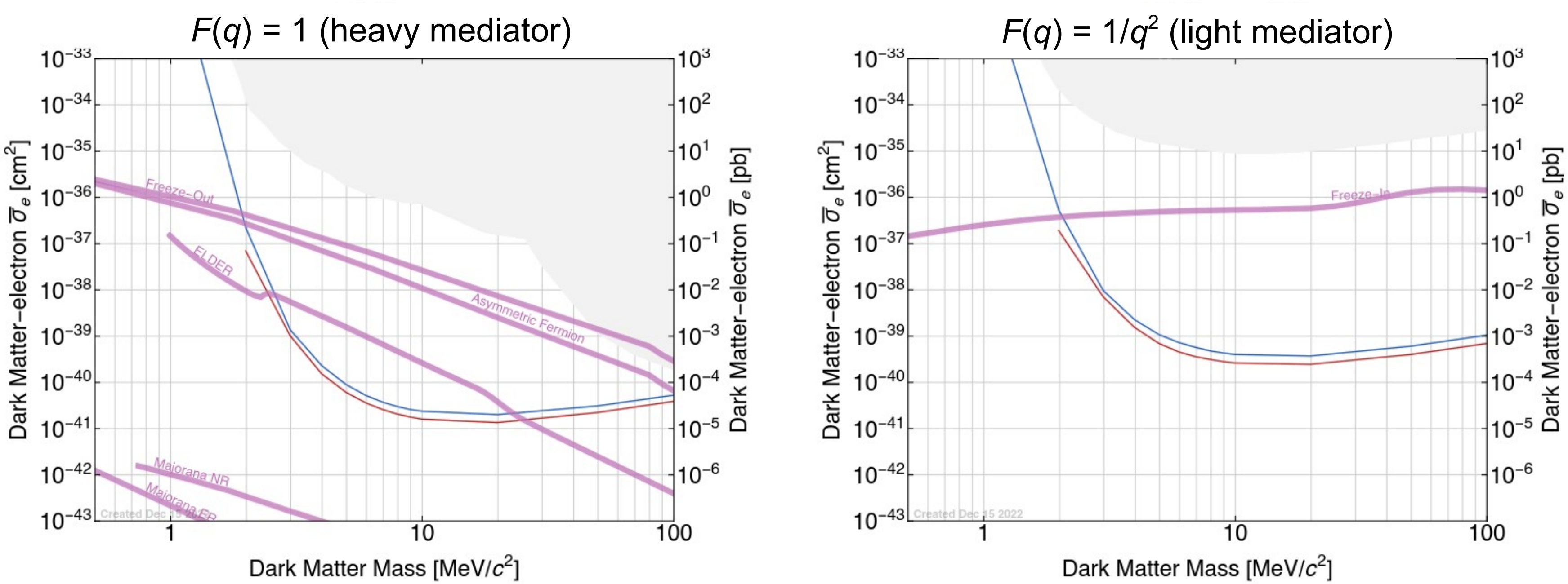


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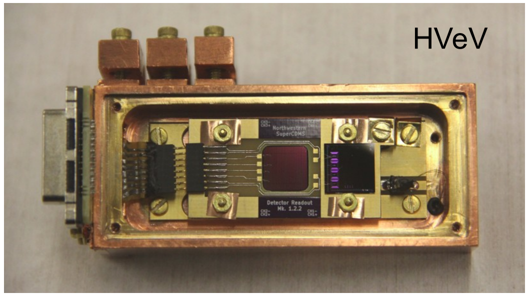
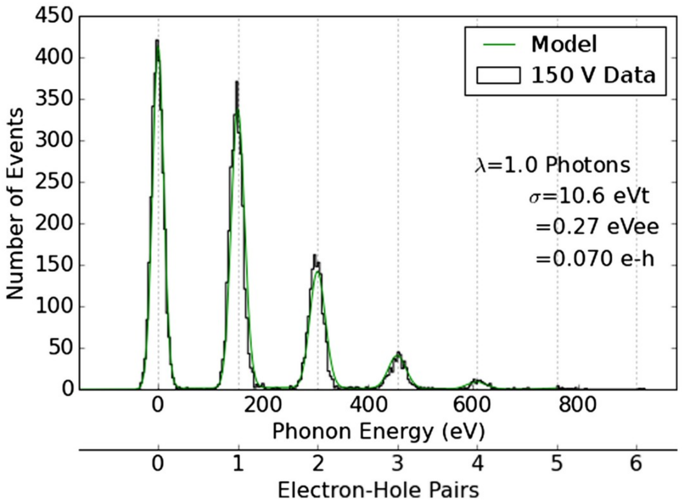
# Detector R&D

SuperCDMS is also conducting R&D to achieve sensitivity to lower energy recoils:

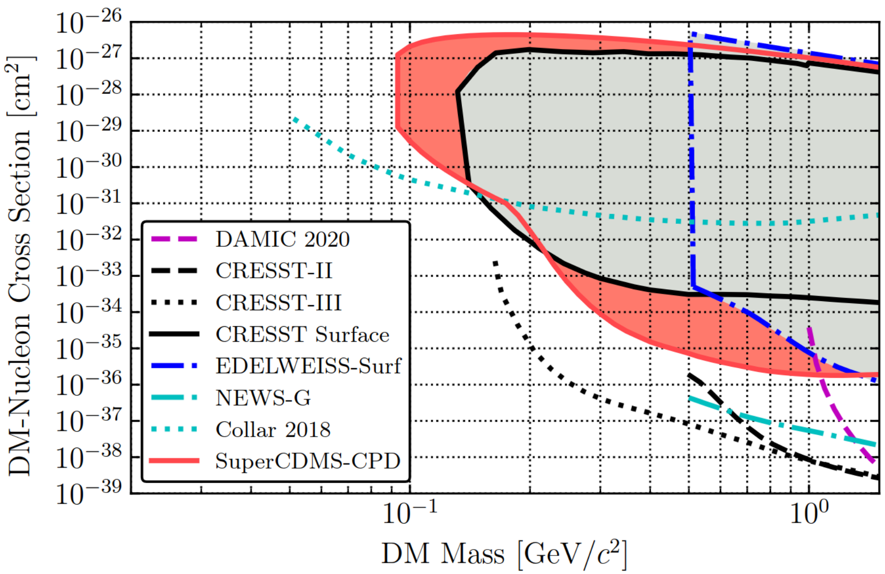
- HVeV: gram-scale Si, able to detect single ionization electrons through NTL effect
- Cryogenic photo-detector (CDP): 10 g Si, high-sensitivity phonon detector ($\sigma_E$ ~ 4 eV)




Phys. Rev. Lett 121, 051301 (2018)

DM exclusion limits from CPD




Phys. Rev. Lett. 127, 061801 (2021)

# Conclusions

SuperCDMS SNOLAB aims to search for sub-GeV dark matter, using semiconductor targets instrumented with phonon and charge sensors

Two detector approaches: iZIP (discrimination between nuclear and electron recoils), HV (decreased energy threshold)

Base shielding completed, dilution refrigerator and 2 towers already in SNOLAB

Commissioning scheduled for late 2024

Will be sensitive to dark matter down to ~400 MeV, and competitive to search for dark photons, axion-like particles, etc

Conducting R&D to achieve sensitivity to lower energy recoils: HVeV, CPD

# Backup slides

# Detector physics

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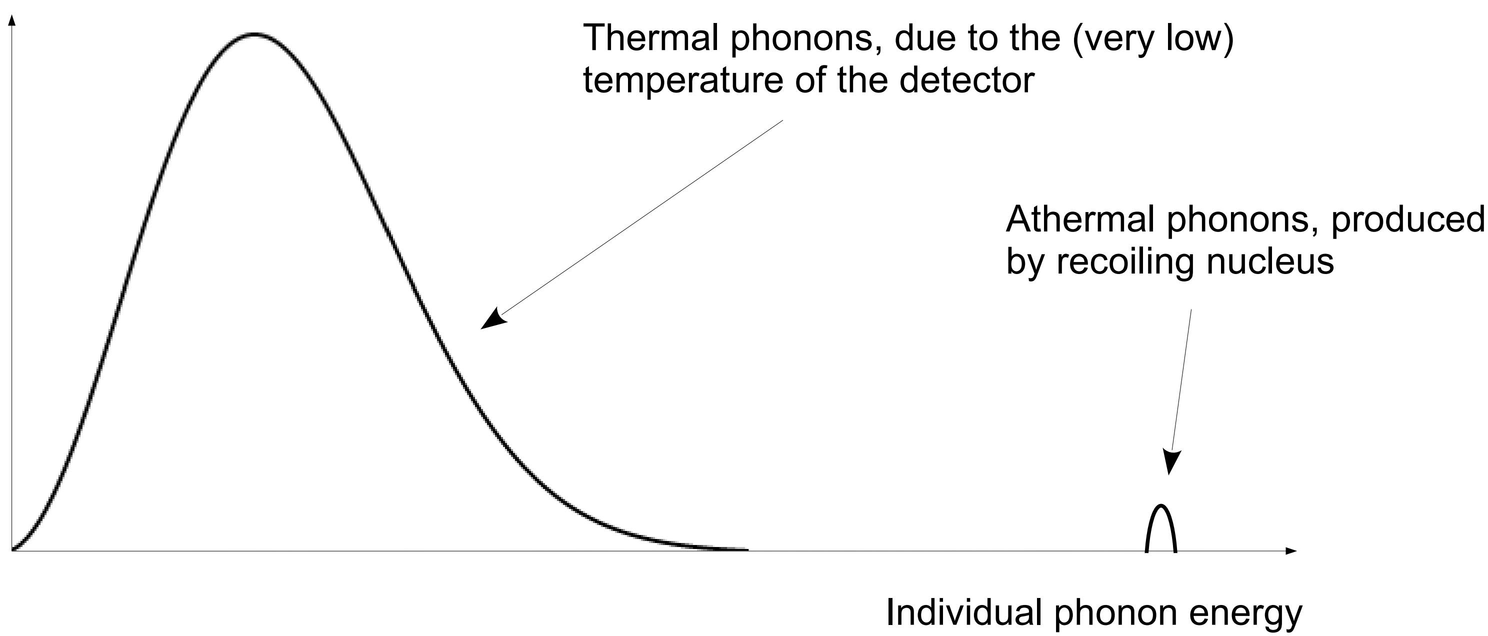

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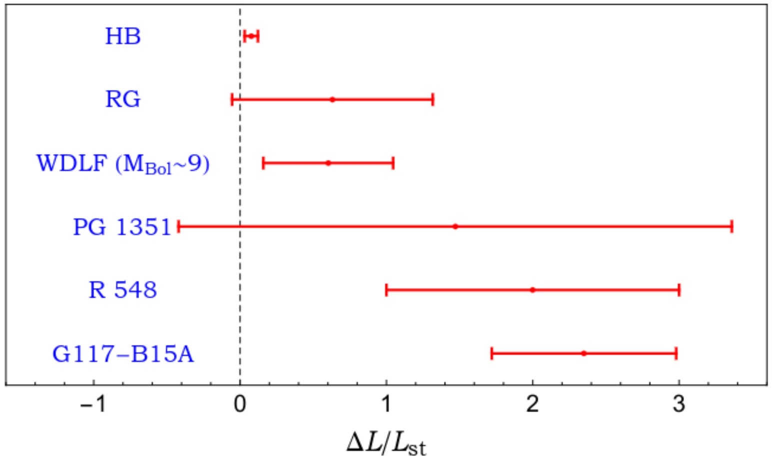


https://arxiv.org/abs/1512.08108

**Figure 1**. Missing energy loss, $\Delta L$, normalized over a reference luminosity, $L_{\rm st}$, for different stellar systems. The plot includes only stars for which an analysis with confidence levels was provided: the three white dwarf variables G117-B15A [4], R548 [6] and PG 1351+489 [7]; an example from the central region of the WDLF ($M_{\rm Bol} \sim 9$) [8, 9]; red giants [11, 12]; and HB stars [13]. For RG and HB stars, the reference luminosity is taken to be the core average energy loss. The errors are derived from the $1\,\sigma$ uncertainties provided in the original literature.