# Future Electron Recoil Dark Matter Searches with SuperCDMS Cryogenic Detectors

SUPER CDMS
Cryogenic Dark Matter Search

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SuperCDMS Collaboration

Snowmass 2021 CF1 Meeting
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# The SuperCDMS Collaboration

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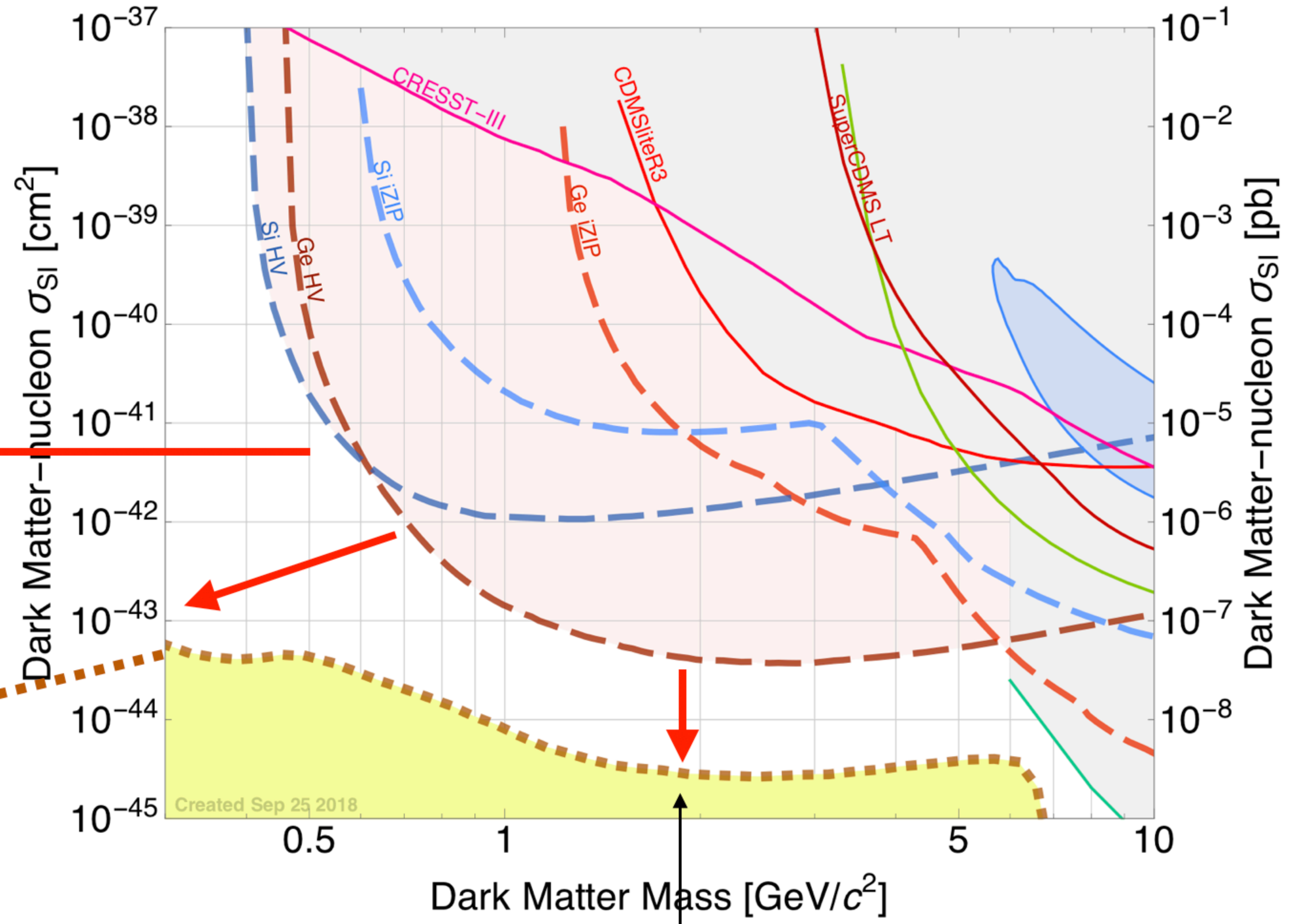
# Overview

- Although the SuperCDMS SNOLAB G2 Experiment was originally conceived to search for GeV scale dark matter:
  - It has the ability to probe significant regions of sub-GeV dark matter parameter space.
  - Fits in well with the current dark matter landscape which has evolved substantially since the G2 projects began.
- See S. Golwala's Aug. 21 CF1 presentation for detail re. the SuperCDMS SNOLAB program and facility.

# Potential Science Goals of Upgrade Program: Nuclear-Scattering DM

Will discuss electron-scattering DM, dark photon, and ALP constraints in future CF1 sessions; requires modified combination of detector and background improvements

decades of unexplored mass: improve phonon energy resolution; reach potentially to 0.05-0.1 GeV




solar ν floor ~ $M^2$

solar neutrino floor drops in cross section below 0.5 GeV

ancillary science: NSI with solar CEvNS, pp solar neutrinos, Bragg scattering of solar axions, millicharged LIPs

1 decade to the neutrino floor 0.5-5 GeV: Improve charge leakage, improve bgnds or use quantization-based ER/NR discrimination (HV) or extend electron recoil rejection to lower energies (iZIP)

Snowmas2021CF1 2020/08/21 6 SuperCDMS/Sunil Golwala

# Detectors & DM Mass Scales

- SuperCDMS Detectors able to conduct DM searched over a mass range spanning 1 eV to 1 TeV
  - Nuclear recoil DM sensitivity: $\mathcal{O}$(10 MeV) - $\mathcal{O}$(10 GeV)
  - Electron recoil DM: $\mathcal{O}$(.1 MeV) – $\mathcal{O}$(10 GeV)
  - DM Absorption: $\mathcal{O}$(1 eV) – $\mathcal{O}$(.5 MeV)

# HV Detector Technology

**Low Threshold → Low Mass DM**

- Drifting electrons/holes across a potential ($V_b$) generates a large number of phonons (Luke phonons).
  - Enables very low thresholds!

$$E_t = E_r + N_{eh} e V_b$$

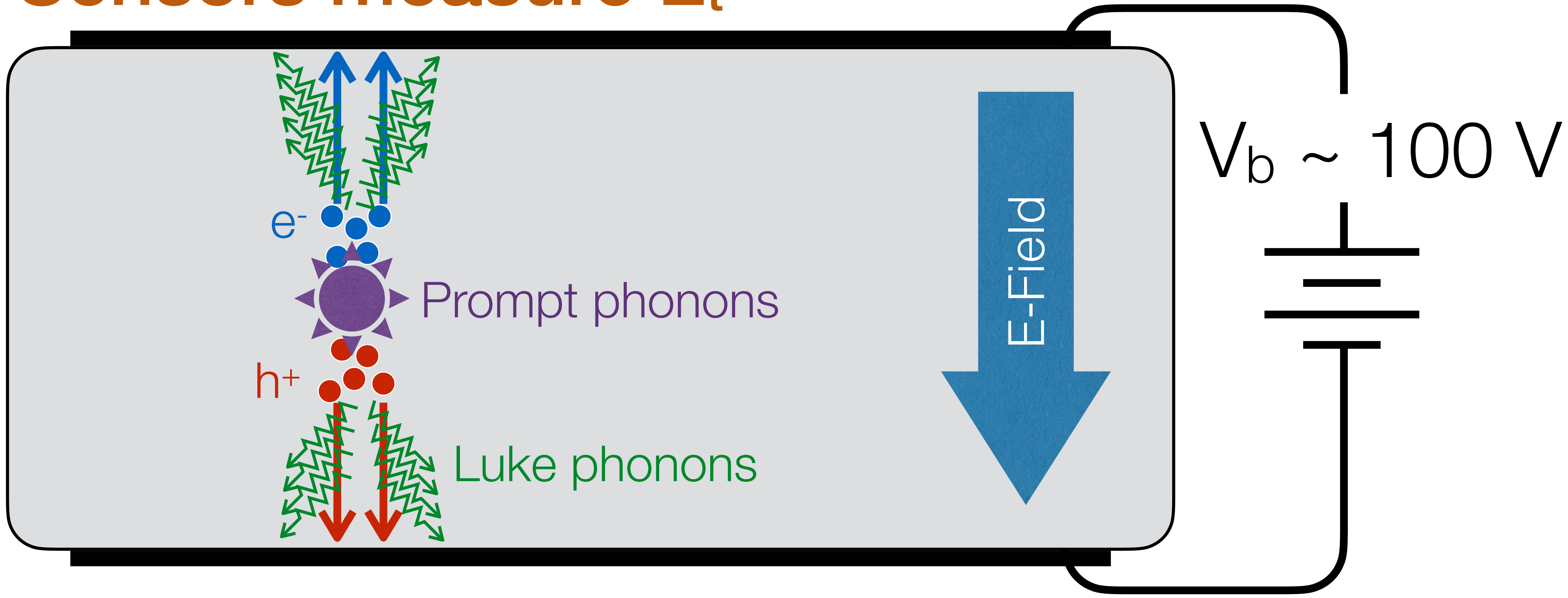
*total phonon energy* ($E_t$), *primary recoil energy* ($E_r$), *Luke phonon energy* ($N_{eh} e V_b$)

$$\sigma_{ER-eh} = \sigma_{Phonon}/V_b$$
$$\sigma_{ER-effective} = \sigma_{Phonon}/(V_b/\mathscr{E})$$

  - Retains ability to discriminate between NR/ER events if:

$$eV_b > \sigma_{Phonon}$$

**Sensors measure $E_t$**




- Signal amplification / lower threshold benefit from high $V_b$
- $V_b$ dependent charge leakage can be a significant background
- Technology challenge lies in keeping charge leakage under control for needed values of $V_b$

# 0V Detector Technology

**<u>Low Threshold → Low Mass DM</u>**

- Does not drift electrons/holes across the crystal. Measures recoil phonons.

$$E_t = E_r$$

*total phonon energy* → $E_t$

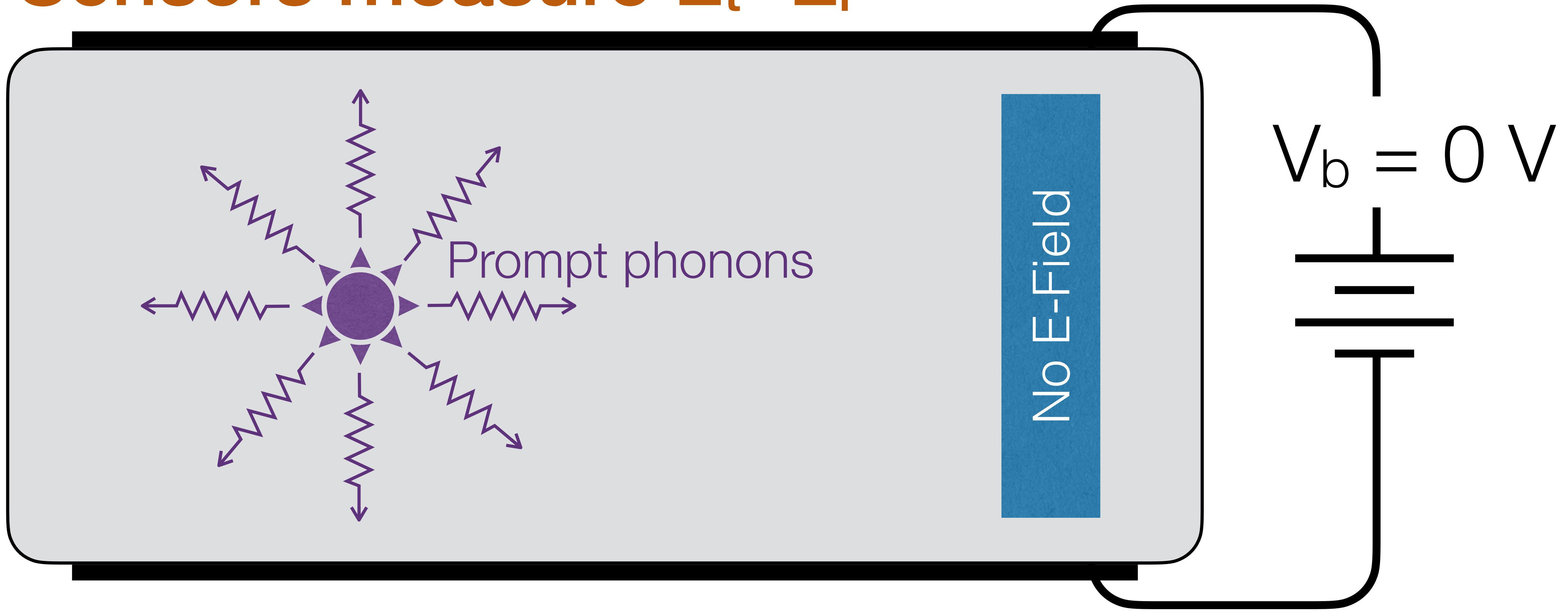
*primary recoil energy* → $E_r$

- Thresholds determined by $\sigma_{Ph}$

$$\sigma_{ER-eh} = \sigma_{Phonon}$$

$$\sigma_{ER-effective} = \sigma_{Phonon}$$

## Sensors measure $E_t$=$E_r$




- Measurement insensitive to details of NR or ER ionization yield
- Charge leakage background is non-existent
- Technology challenge lies in achieving needed phonon resolution while maintaining large detector masses

Background and technical challenges of HV and 0V detectors are orthogonal

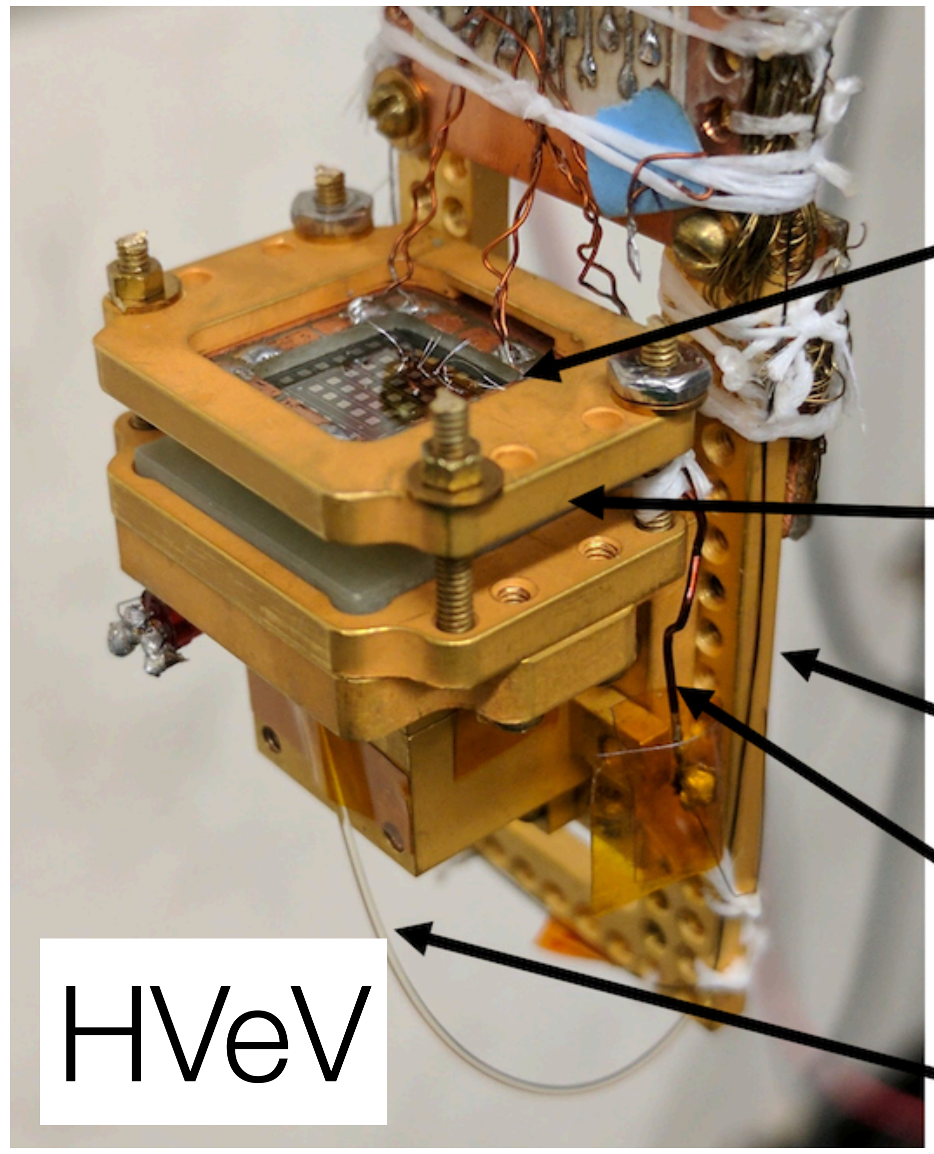
# ER Detection Energy Scales

| ERDM Mass [MeV] | Required Energy Threshold [eV] | HV $\sigma_{Ph}$ @ 100V | 0V $\sigma_{Ph}$ |
|---|---|---|---|
| **0.5** | 1 | 15 eV | 0.15 eV |
| **5** | 15 | 200 eV | 2 eV |
| **10** | 30 | 400 eV | 4 eV |

ERDM values presented for Si target

| ALP/DP Mass [eV] | Required Energy Threshold [eV] | $\sigma_{Ph}$ @ 100V | $\sigma_{Ph}$ @ 0V |
|---|---|---|---|
| **1** | 1 | 15 eV | 0.15 eV |
| **10** | 10 | 150 eV | 1.5 eV |
| **100** | 100 | 1500 eV | 15 eV |

# SuperCDMS HVeV & HV Detectors




https://doi.org/10.1063/1.5010699

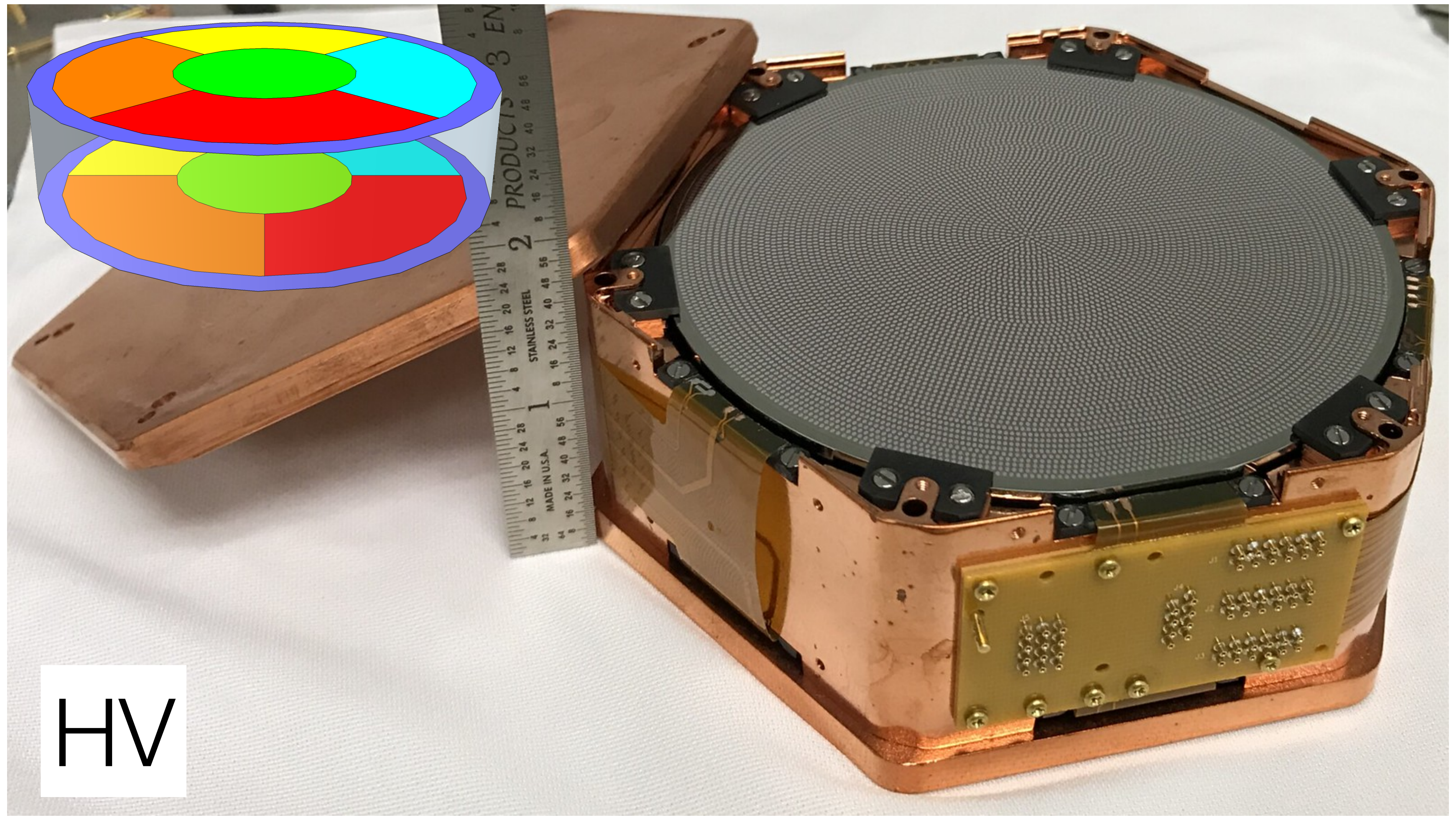
Si crystal/ phonon sensors

Crystal holder

Dilution refrigerator sample stage (30 mK)

Bias voltage line

Fiber optic



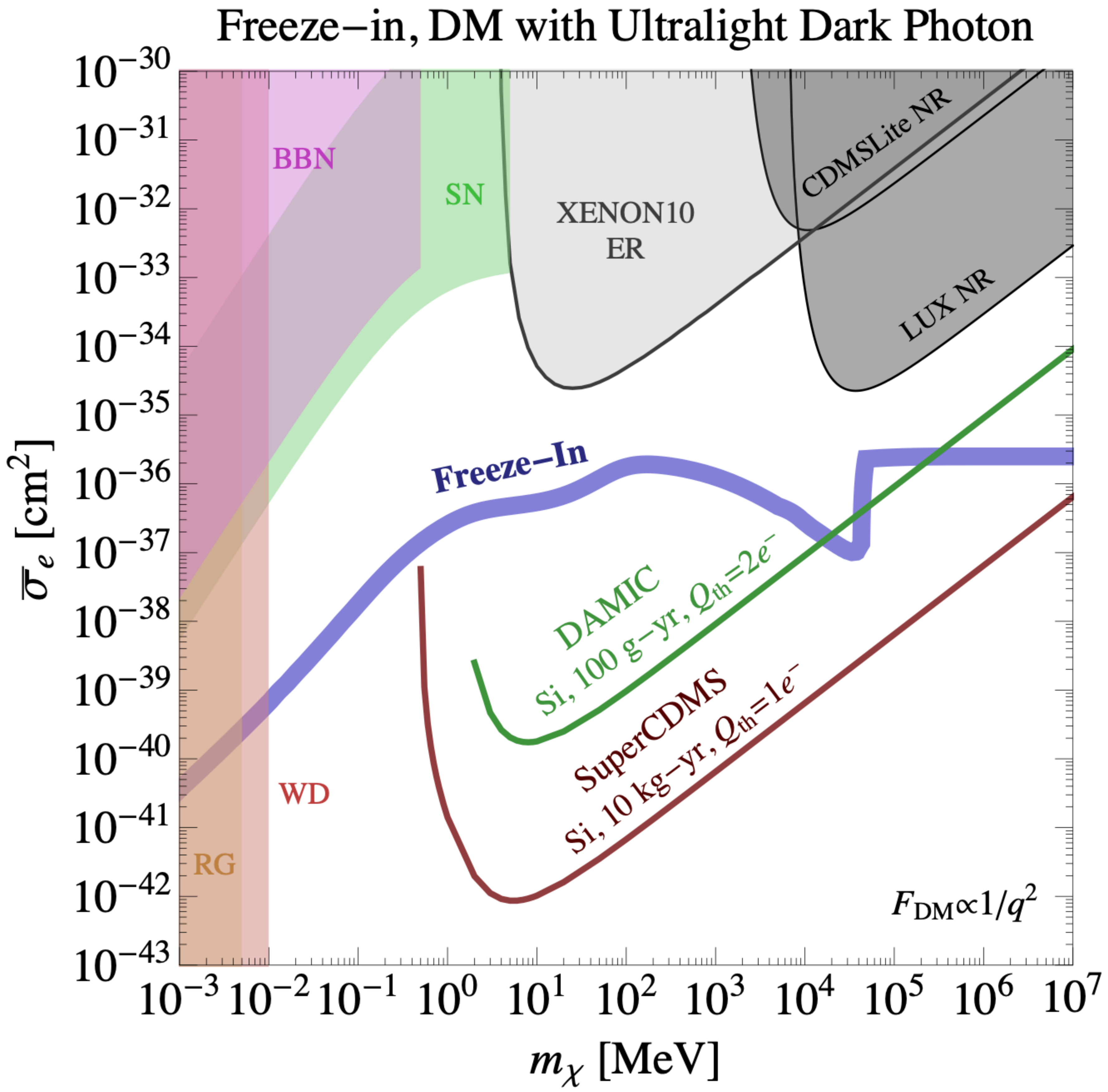

- R&D Detectors:
  - ⌀10mm x 4mm;
  - Si: 0.93 g
  - $\sigma_{Ph}$: 3 eV
    - $E_{th}$ ~ 21 eV
  - Single $e^-/h^+$ pair resolution: $\sigma_{eh}$ ~ 0.03 $e^-/h^+$.
  - Has sensitivity to a variety of sub-GeV DM models with gram*day exposures

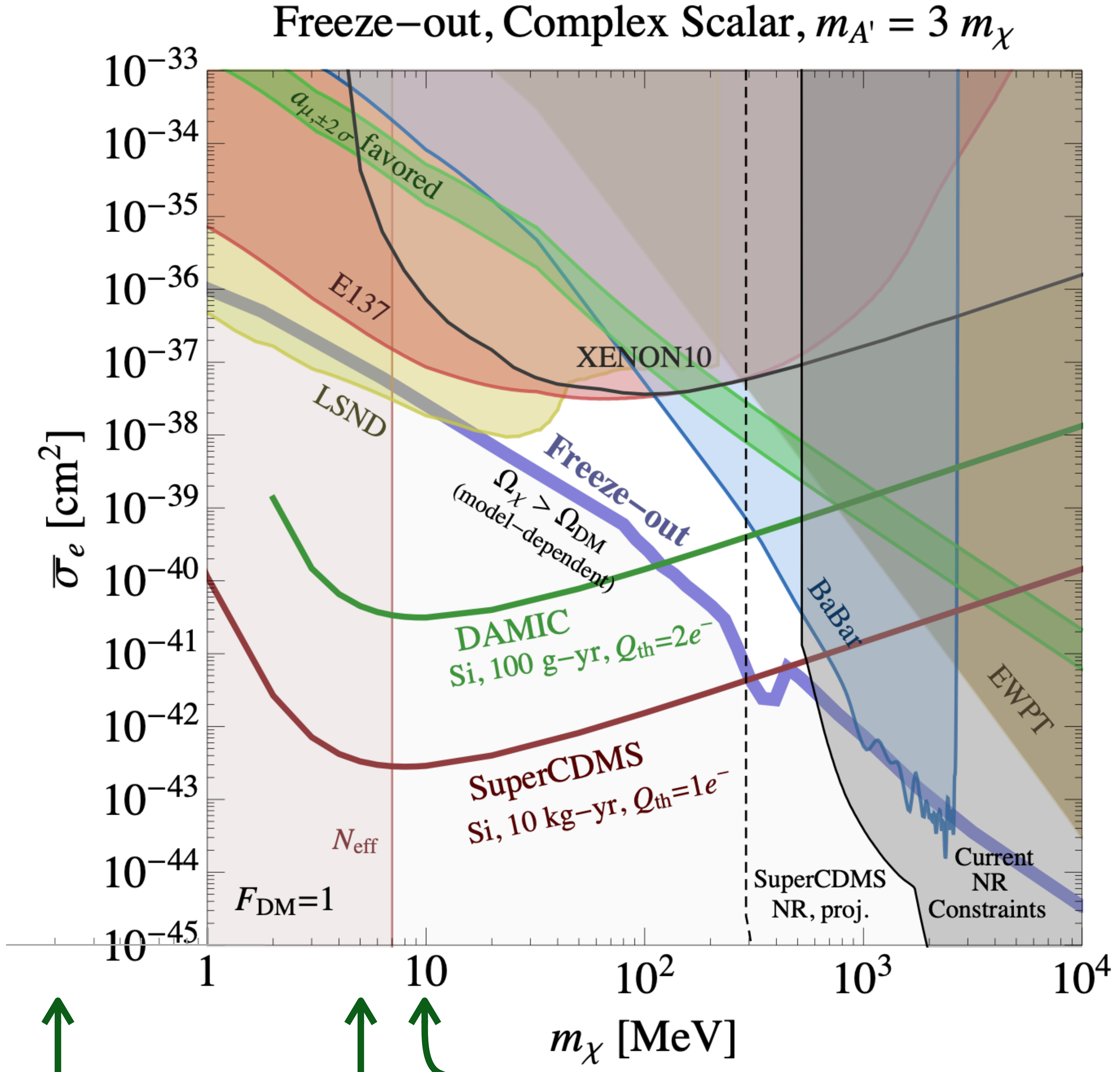
https://doi.org/10.1016/j.nima.2020.163757
arXiv:2005.14067

- Payload: 4 Si and 8 Ge detectors
  - ⌀100mm x 33mm;
  - Si: 0.6 kg, Ge: 1.4 kg
  - SNOLAB Goal $\sigma_{Ph}$: 7 eV (Si), 10 eV (Ge)
    - $E_{th}$ ~ 50 eV (Si), 70 (Ge)
  - Single $e^-/h^+$ pair resolution $\sigma_{eh}$ @100V bias: Si: ~ 0.07 $e^-/h^+$, Ge: ~ 0.1 $e^-/h^+$
  - Has sensitivity to various relic abundance DM models of sub-GeV DM with kg*year exposures

Better resolution ⟵ Tradeoff ⟶ Greater mass

# Large Exposure Sensitivity




**$Q_{th}$ = 1e-**
**$\sigma_{Ph}$ @ 0V = 0.15 eV**
**$\sigma_{Ph}$ @ 100V = 15 eV**

**$Q_{th}$ = 5e-**
**$\sigma_{Ph}$ @ 0V = 2 eV**
**$\sigma_{Ph}$ @ 100V = 200 eV**

**$Q_{th}$ = 10e-**
**$\sigma_{Ph}$ @ 0V = 4 eV**
**$\sigma_{Ph}$ @ 100V = 400 eV**

- Phonon resolution determines minimum accessible DM mass.
- SNOLAB HV detectors at SNOLAB in principle have sensitivity and exposure to reach ERDM relic models.
- Current great uncertainty is magnitude of leakage currents in the lowest $e^-/h^+$ bins
- R&D is needed to achieve
  - necessary thresholds shapes for 0V detectors and
  - control charge leakage for 100 V detectors

**arXiv:1509.01598**

# Detector R&D to Realize the Science Program

| Science Target | | Potential Detector R&D Topics — to be narrowed | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Improved Phonon Resolution | Different Substrate Size/ Geometry | Improved Charge Leakage | Improved Phonon Position Information | Improved Charge Noise | Different Targets | Active Veto of Photons | Active Veto of Betas |
| <0.5 GeV nuclear-scattering DM<br>Dark $\gamma$ via Optical Phonon | | ✓ | ✓ | | desirable | | ✓ | ✓ | desirable |
| Electron-scattering DM<br>Dark $\gamma$<br>ALPs | with NTL gain (HV) | for large substrates | | ✓ | | | | | |
| | 0V | ✓ | ✓ | | desirable | | desirable | ✓ | desirable |
| >0.5 GeV nuclear-scattering DM | Quantization via NTL gain (HV) | for large substrates | potentially | ✓ | | | | | |
| | ER rejection to lower energies (iZIP) | for large substrates | potentially | | | ✓ | | | desirable |
| | Phonon Position Information | ✓ | potentially | ✓ | ✓ | | | | |
| | Photon/ Phonon Discrimination | ✓ | potentially | | | | ✓ | | ✓ |

**Goals of R&D topics:**

- Phonon position information: Allows event fiducialization to reject sidewall leakage and surface backgrounds
- Different targets: Possibility of lower band-gap, sensitivity to direct phonon creation if reach $\mathcal{O}$(10 meV) resolution
- Active vetos: Reduction of backgrounds originating at the surfaces nearest the detectors

# Conclusions

- SuperCDMS detector technology being developed to search for electron recoil light dark matter, down to
  - $\mathcal{O}(1)$ eV via Dark Photon Absorption and Axion dark matter channels
  - $\mathcal{O}(1)$ MeV via Electron recoil channels and
- This complements nuclear recoil dark matter searches in
  - $\mathcal{O}(10)$ MeV via inelastic Nuclear recoil channels (Migdal, Bremsstrahlung)
  - $\mathcal{O}(1\text{-}100)$ GeV via elastic Nuclear recoil channels
    - Cryogenic detectors aiming to reach "neutrino floor" in the 1-10 GeV NR mass range


CDMS
... the end