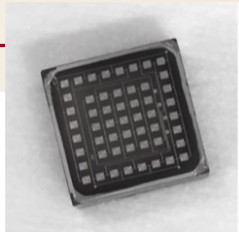
SuperCDMS Experimental Program

Noah Kurinsky
Staff Scientist, SLAC
SNOWMASS 2022
July 23, 2022

BOLD PEOPLE. VISIONARY SCIENCE. REAL IMPACT.

Athermal Phonon Sensors (SuperCDMS HVeV)



In any recoil event, all energy eventually returns to the phonon system

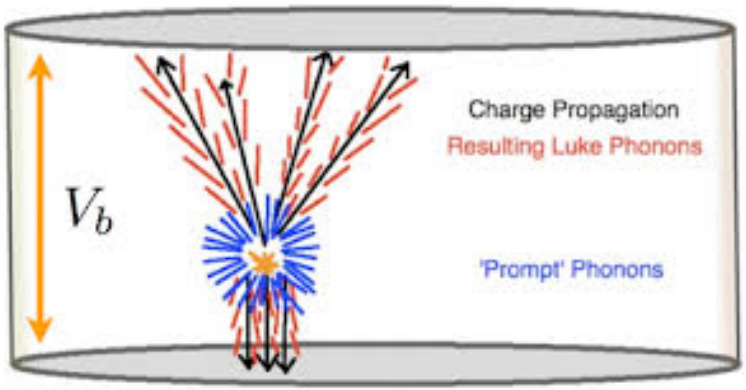
- Prompt phonons produced by interaction with nuclei
- Indirect-gap phonons produced by charge carriers reaching band minima
- Recombination phonons produced when charge carriers drop back below the band-gap

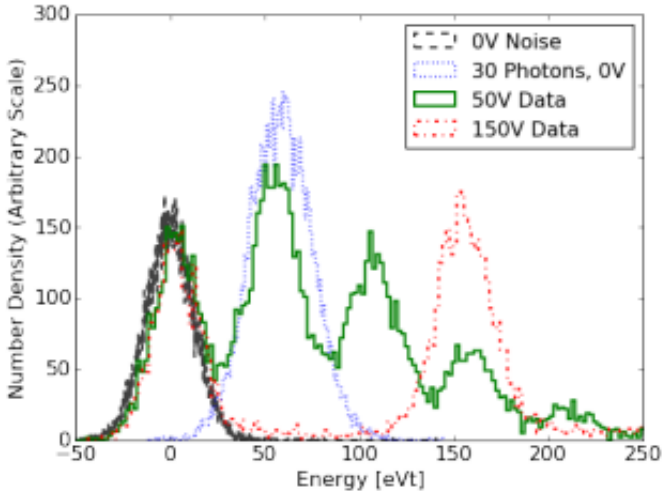
Phonons are also produced when charges are drifted in an electric field; makes sense by energy conservation alone

Total phonon energy is initial recoil energy plus Luke phonon energy, as shown at right

$$E_{phonon} = E_{recoil} + V * n_{eh}$$
$$= E_{recoil}\left[1 + V * \left(\frac{y(E_{recoil})}{\varepsilon_{eh}}\right)\right]$$

Athermal phonons collected in superconducting aluminum fins and channeled into Tungsten TES, effectively decoupling crystal heat capacity from calorimeter (TES) heat capacity





Romani et. al. 2017 (https://arxiv.org/abs/1710.09335)

Optimal Readout and Triggering

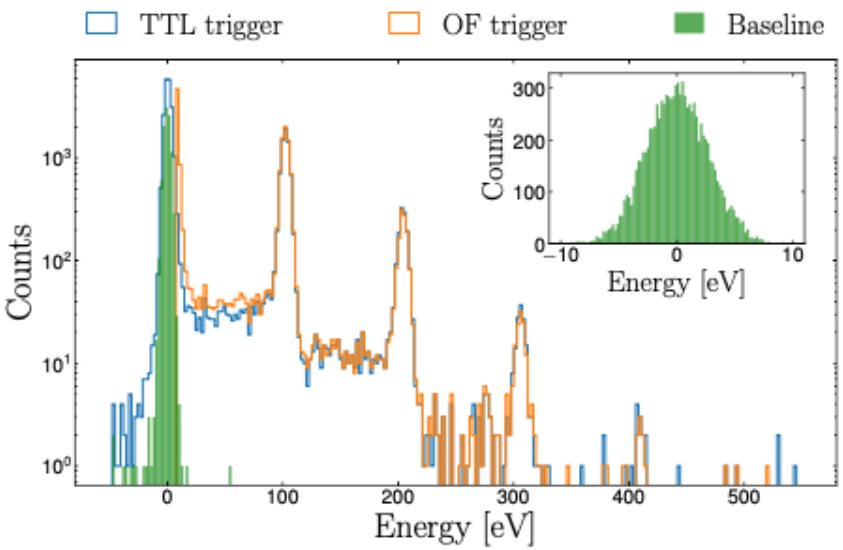
Best performance is by HVeV (gram-scale Si) detector; has repeatedly achieved 2.5 eV resolution, and <10 eV threshold, with the TES-based SuperCDMS sensors.

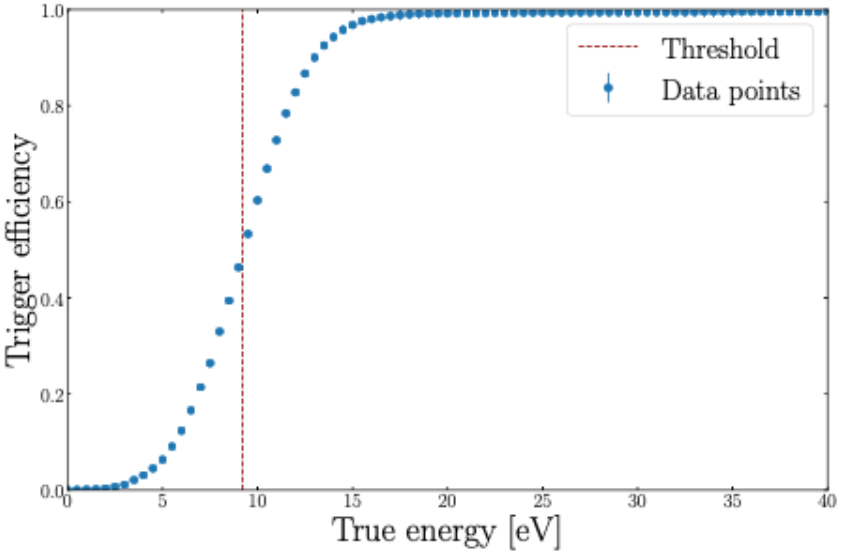
- This detector was run as a DM detector at Northwestern and NEXUS, and in the TUNL neutron beam

Run in continuous readout mode for trigger-free operation, triggering done offline

- Optimal filter trigger and processing with time-shifting and pileup rejection

Achieves >30% energy efficiency, implying that the intrinsic resolution of the TES arrays are less than 1eV



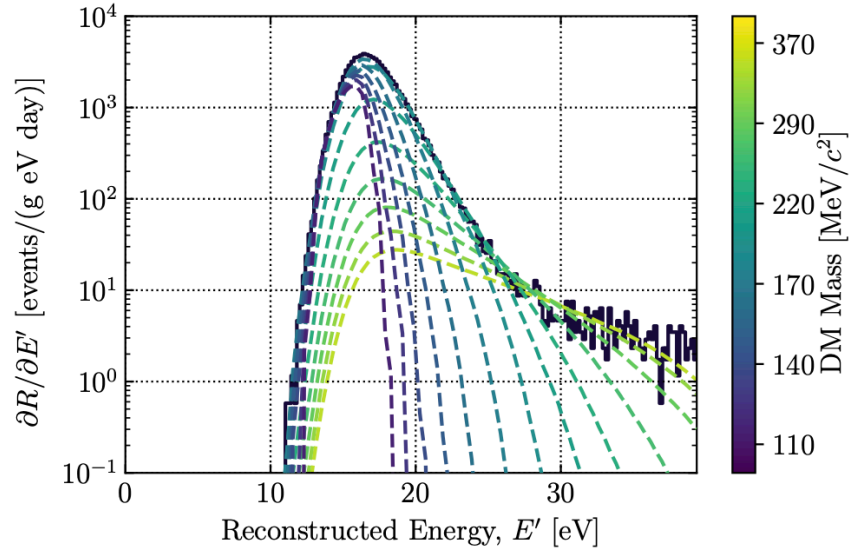


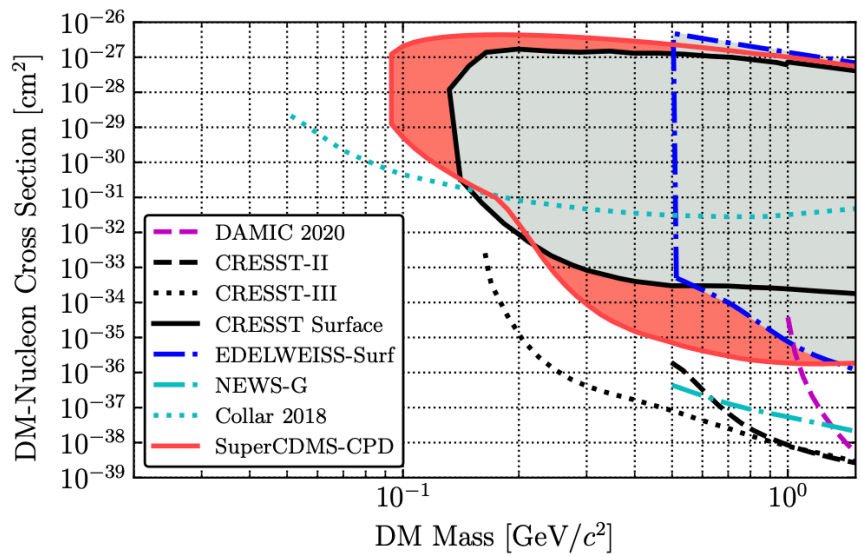
Ren et al (ArXiv:2012.12430)

SuperCDMS CPD

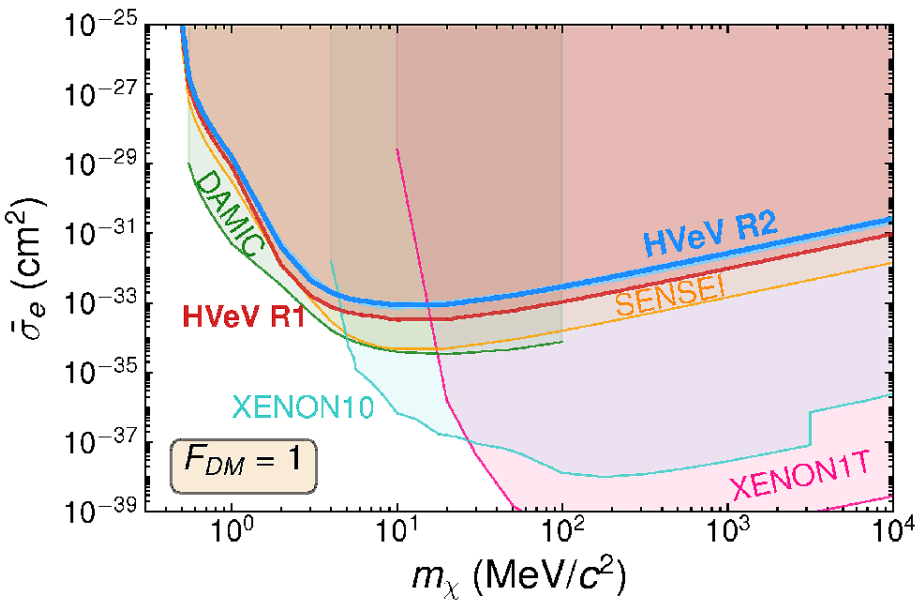
https://arxiv.org/abs/2007.14289

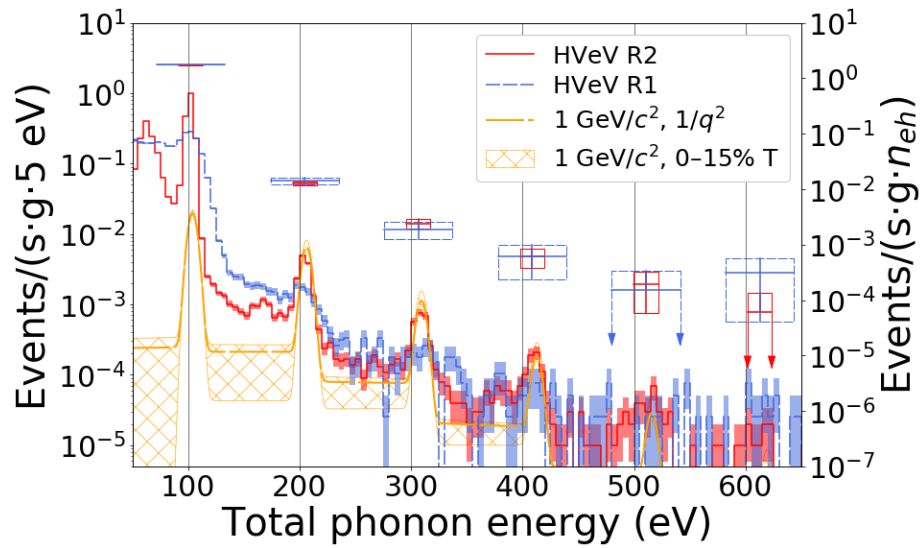
- 10g detector with 4eV resolution
  - Single TES channel
  - Designed for photon detection
- Surface limit set at SLAC with copper shield, subsequent runs at CUTE (SNOLAB test facility)
  - Publication forthcoming on CUTE data
- One of the first detectors to begin to see low-energy phonon-only backgrounds in cryogenic phonon detectors
  - Results from CPD very important for comparison to other low-energy excesses discussed at EXCESS workshops





HVeV Run 2

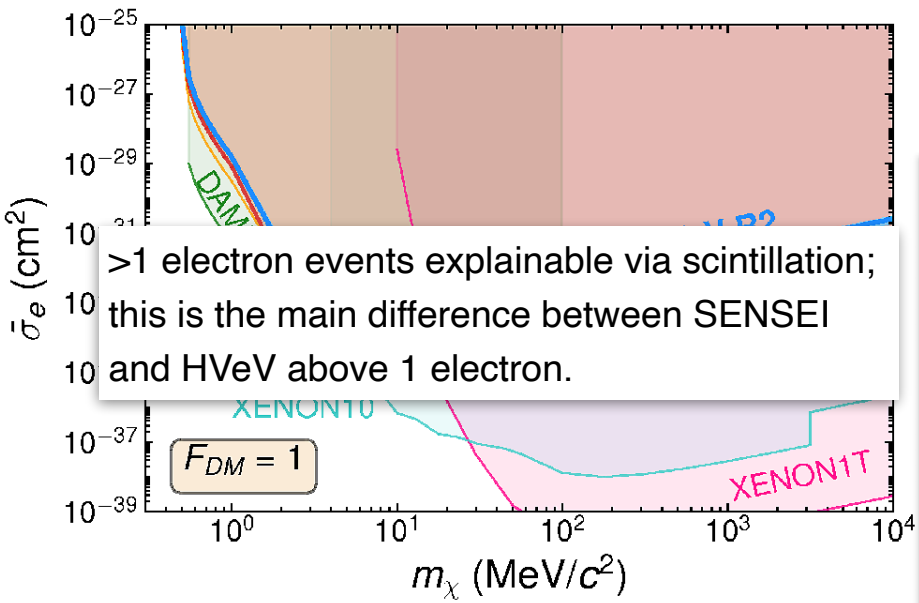




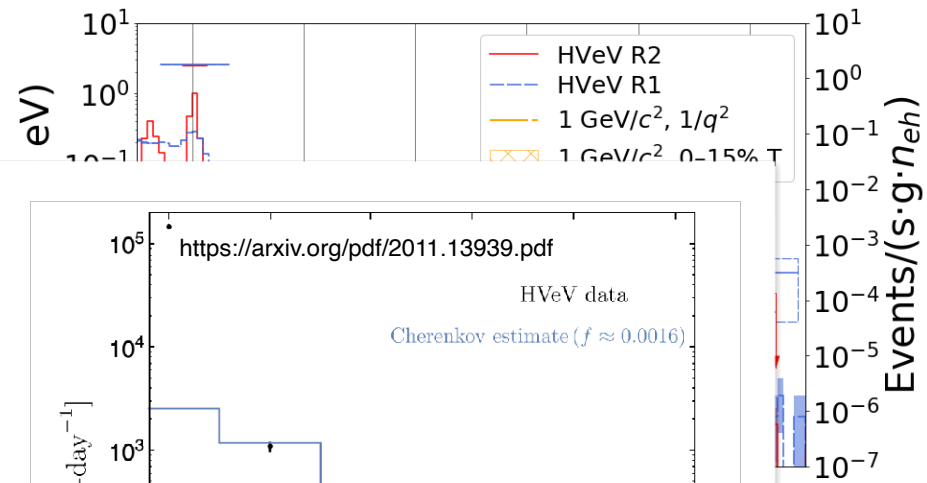
HVeV second run taken with 3 eV resolution detector over the course of 3 weeks:

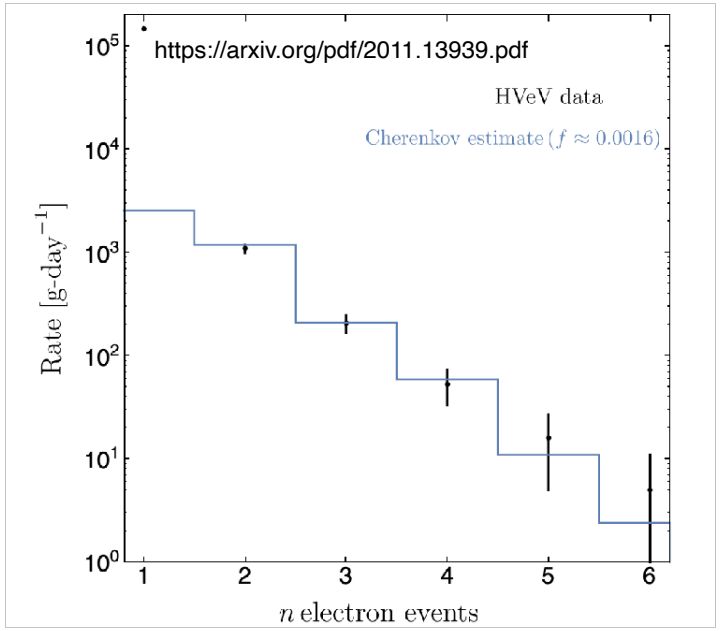
- 60V and 100V spectra show identical backgrounds; signal seen not voltage dependent
- Different prototype, run in a different lab, in a different state
- 0V data acquired with ~10 eV threshold, results still being analyzed
- Rates in *every charge bin* consistent with Run 1…that was completely unexpected

HVeV Run 2



>1 electron events explainable via scintillation; this is the main difference between SENSEI and HVeV above 1 electron.





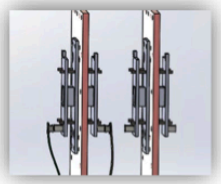
HVeV second run taken with 3 eV resolution

- 60V and 100V spectra show identical ba
  dependent
- Different prototype, run in a different lab, in a different state
- 0V data acquired with ~10 eV threshold, results still being analyzed
- Rates in *every charge bin* consistent with Run 1…that was completely unexpected

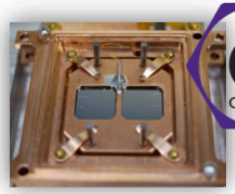
Progress in HVeV Backgrounds

SLAC

- Burst events detection and study
- Hypothesis: originated by SiO_2 in the detector holder (PCB)

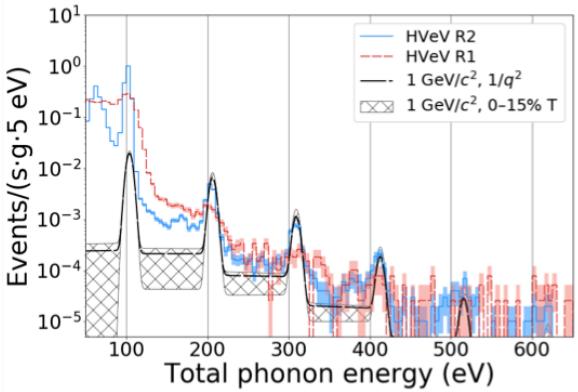


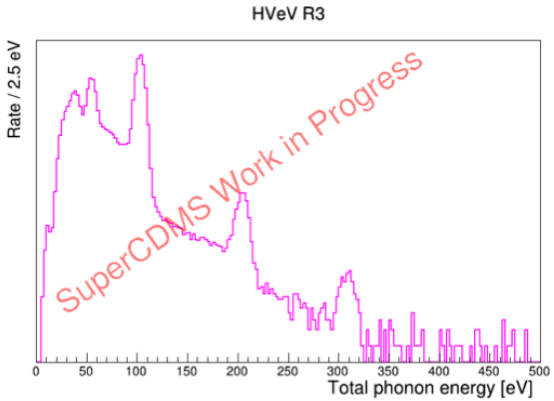
- Coincidence measurement
- Confirmed external origin of this background and its reduction with coincidence cut

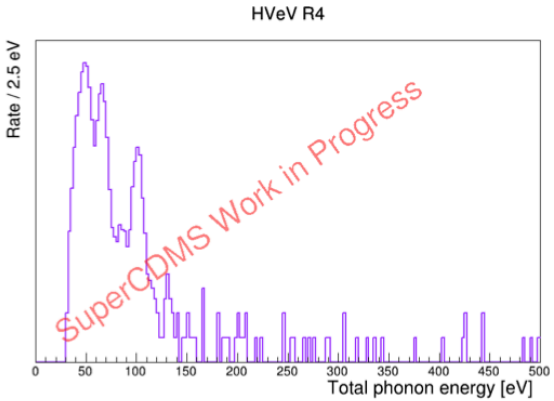


- Removed PCB from the detector holder
- Elimination of the quantized background above 1 eh peak

HVeV R2 → HVeV R3 → HVeV R4







Northwestern 21

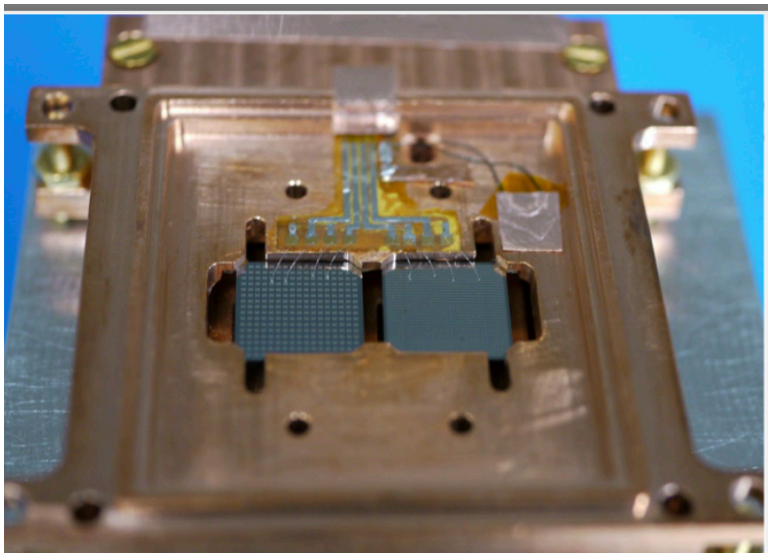
https://indico.cern.ch/event/1117540/contributions/4907094/attachments/2480975/4259027/20220716_excess_SuperCDMS_Novati_final.pdf

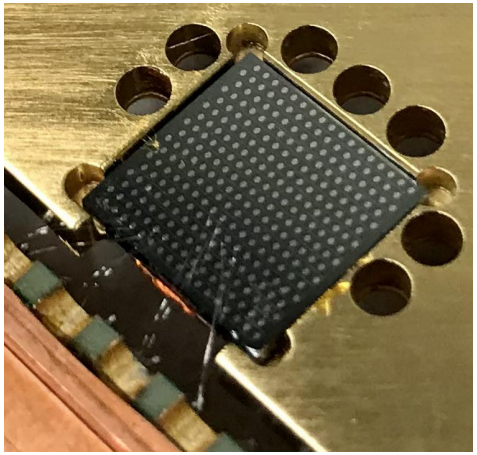
SuperCDMS R&D Publications

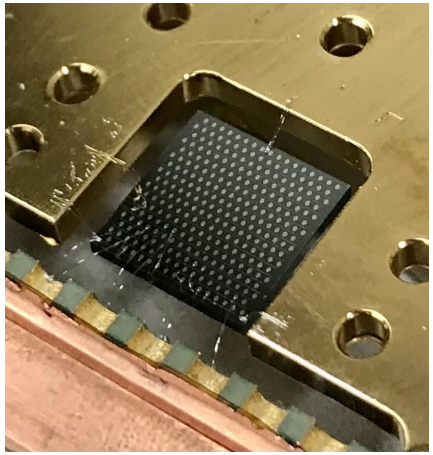
- Recent device papers:
  - HVeV: https://arxiv.org/abs/2012.12430
  - CPD: https://arxiv.org/abs/2009.14302
  - TES Characterization: https://arxiv.org/abs/2004.10257

- Recent Science Results
  - HVeV Run 1: https://arxiv.org/abs/1804.10697
  - HVeV Run 2: https://arxiv.org/abs/2005.14067
  - 0VeV (HVeV at 0V): https://arxiv.org/abs/2204.08038
    - Identification of scintillation events, comparison of backgrounds at 0V, 60V, and 100V
  - CPD: https://arxiv.org/abs/2007.14289

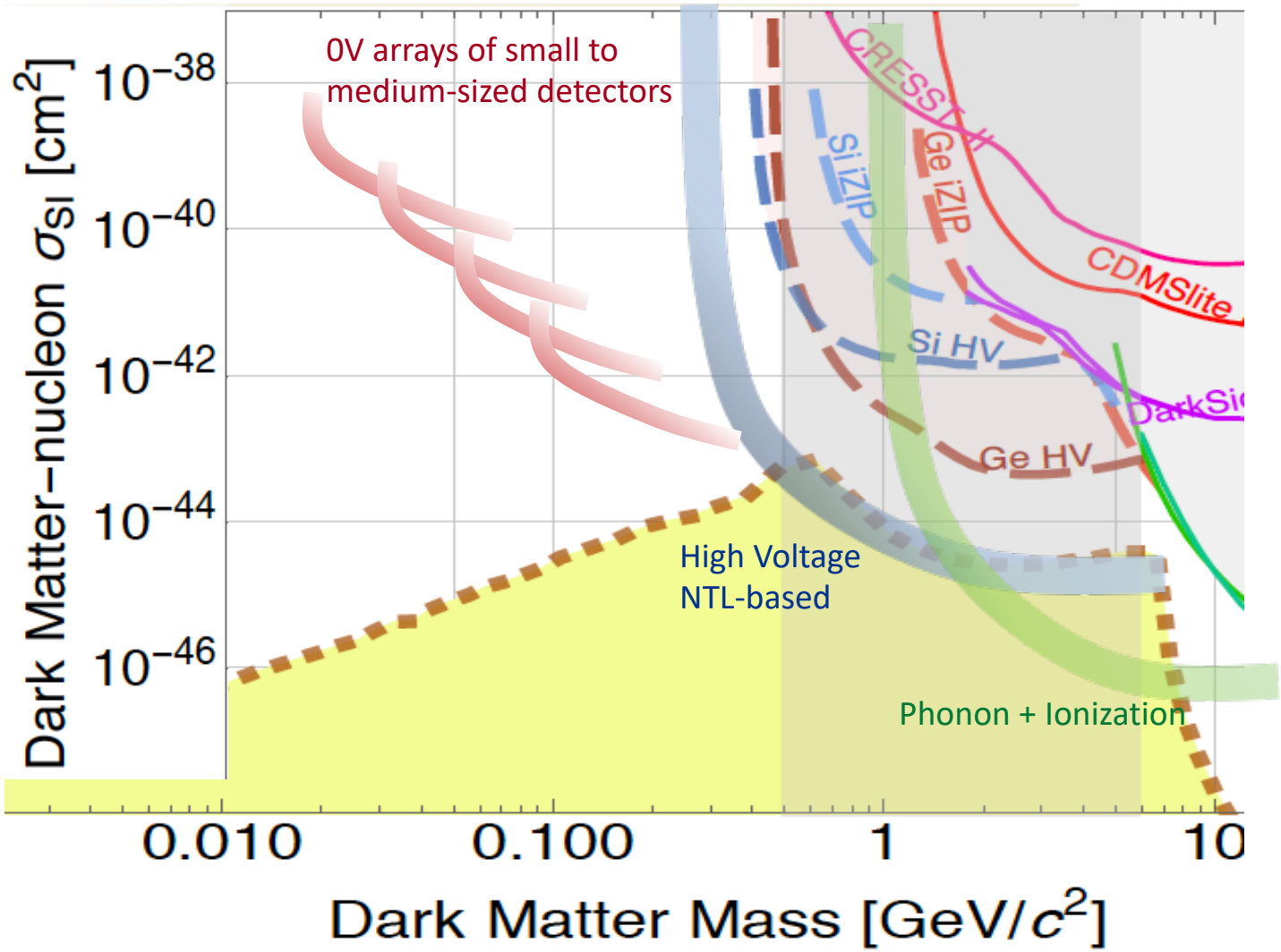
- Coming this year:
  - HVeV Run 3 (multiples cuts)
  - HVeV Run 4 (ultra-low leakage)
  - CPD at CUTE (underground phonon-only backgrounds)
  - Stress-induced backgrounds in Cryogenic Crystals
    - Subset of SuperCDMS/SPICE authors



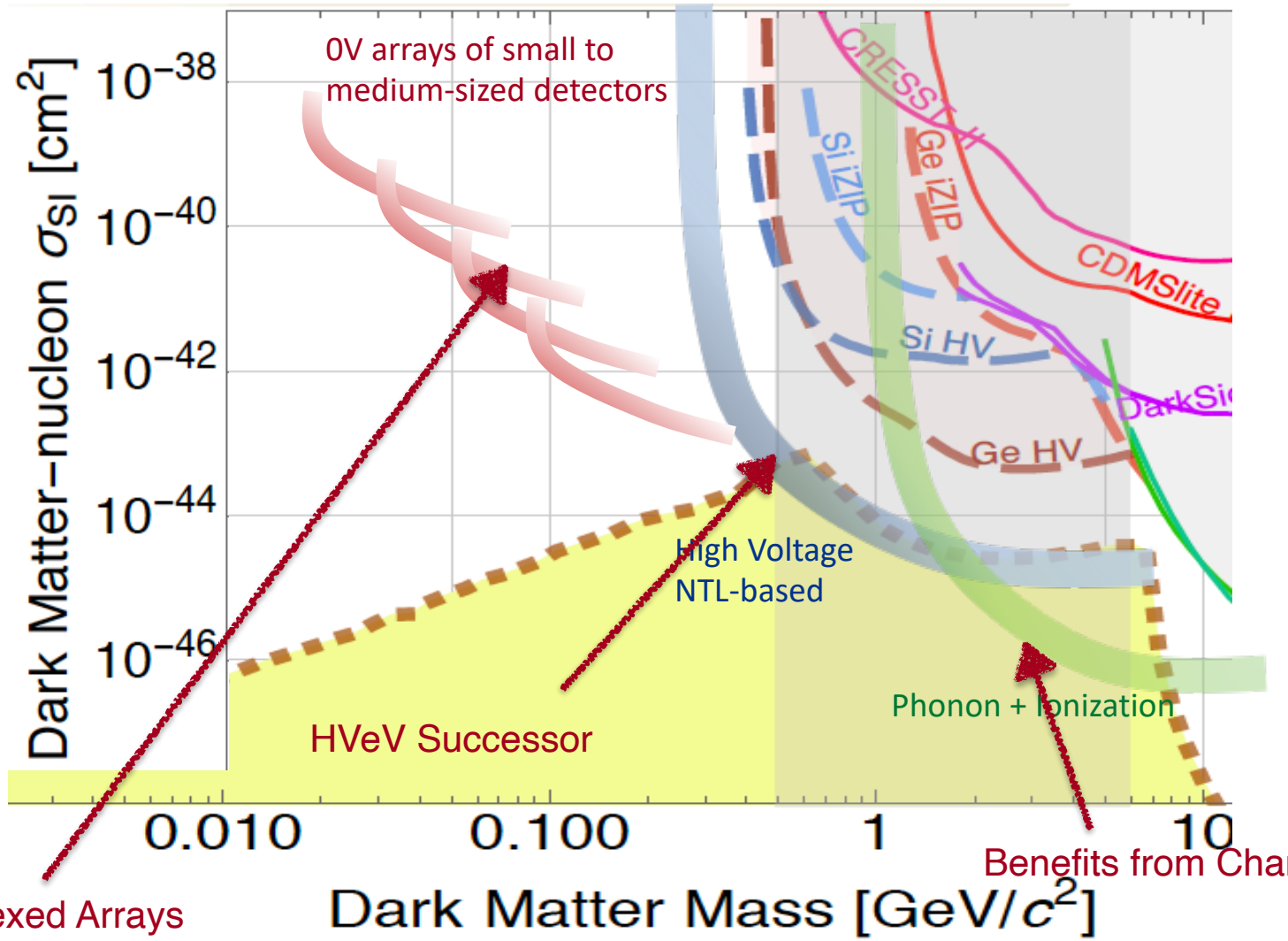




These are Upgrade Paths for SuperCDMS SNOLAB!



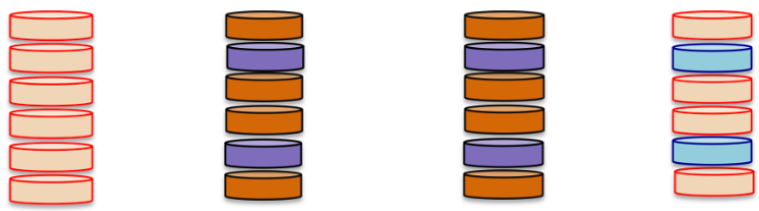
These are Upgrade Paths for SuperCDMS SNOLAB!



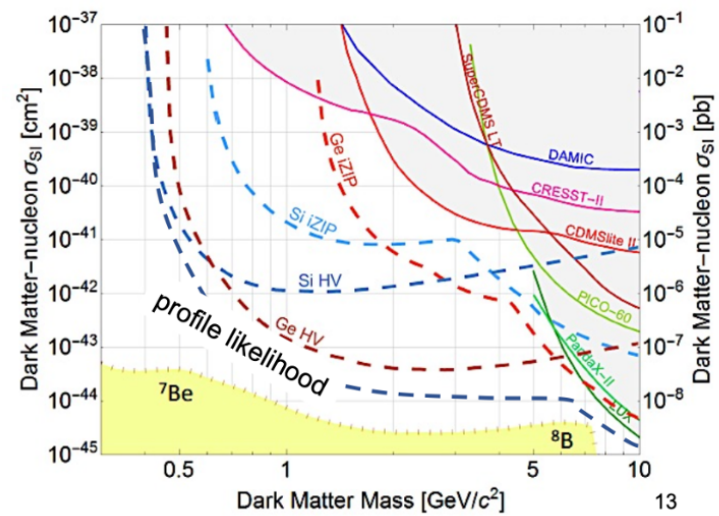
SuperCDMS Science Payload

Mode	Germanium	Silicon
HV	Lowest threshold for low mass DM Larger exposure, no ^{32}Si bkgd	Lowest threshold for low mass DM Sensitive to lowest DM masses
iZIP	Nuclear Recoil Discrimination Understand Ge Backgrounds Sensitive to ^{8}B ν-scatter	Nuclear Recoil Discrimination Understand Si Backgrounds Sensitive to ^{8}B ν-scatter

	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure [kg·yr]	45	3.9	36	7.8
Phonon resolution [eV]	33	19	34	13
Ionization resolution [eV_{ee}]	160	180	–	–
Voltage Bias ($V_+ - V_-$) [V]	6	8	100	100



Tower 1 (iZIP) | Tower 2 (HV) | Tower 3 (HV) | Tower 4 (iZIP)



Project Goals assume Optimum Interval, no prior knowledge of backgrounds. To reach full potential, a profile likelihood analysis will use iZIP background data in the fit.

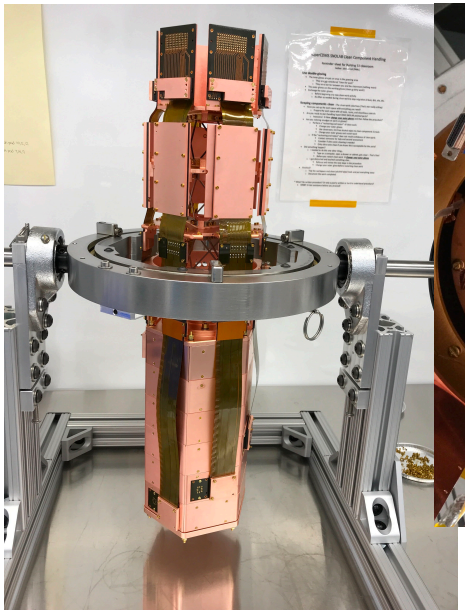
SuperCDMS Construction Progress

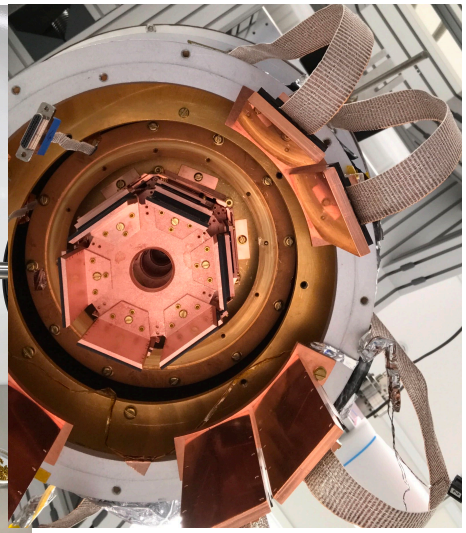
- First two SuperCDMS SNOLAB detector towers have been assembled and tested - yield is excellent and towers are meeting all expectations so far!

- Final two towers will be finished by the end of August - Tower 3 being stacked this month, Tower 4 packaging underway.

- Underground facility partially build
  - Shield is underground at SNOLAB
  - Radon mitigation facility online
  - Cryostat being tested at Fermilab and will be shipped out soon

- On track for taking world's most sensitive sub-GeV dark matter exposure for NRDM





Conclusions

- SuperCDMS has a robust R&D program producing low-mass dark matter science results which will inform first SuperCDMS SNOLAB results
  - Our test facilities allow for quick turn-around with smaller detectors
  - CUTE will run a SuperCDMS SNOLAB tower while the SNOLAB cryostat is commissioned
  - We are well setup to produce a number of novel detector payloads for a SuperCDMS SNOLAB upgrade targeted at keV-MeV mass dark matter

- There will be numerous challenges for meV-eV scale backgrounds that we are excited to collaborate with the community to further understand
  - EXCESS workshops are helping to elucidate the nature of the phonon-only backgrounds seen in Si, Ge, and CaWO4 detectors
  - SENSEI/HVeV collaboration has been incredibly fruitful
  - We look forward to building more collaboration for future SNOLAB payloads