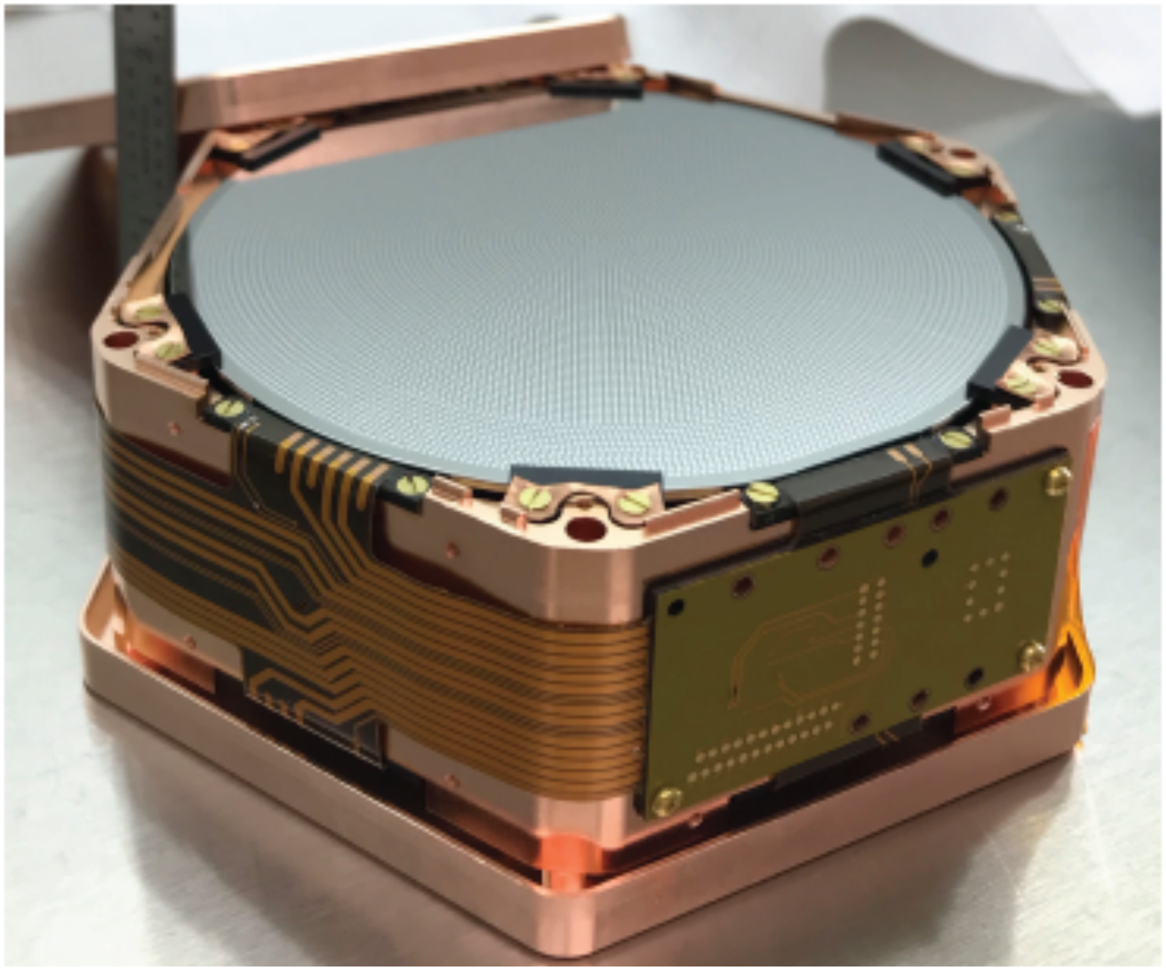
Status and Expected Sensitivity of SuperCDMS SNOLAB

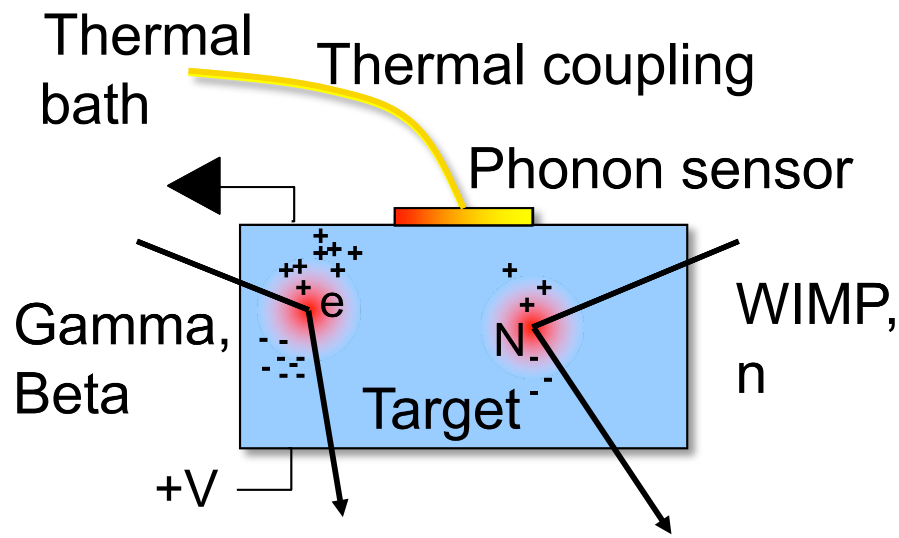


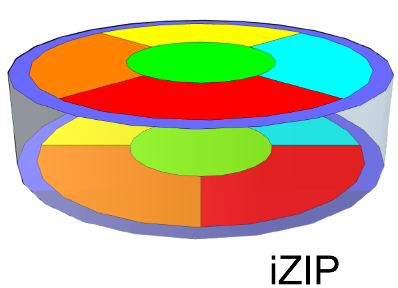
Richard Schnee

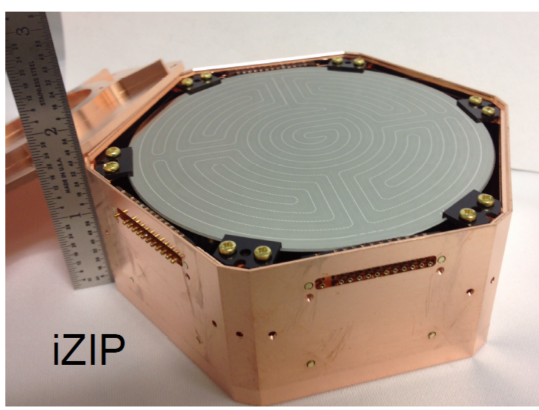
South Dakota School of Mines & Technology

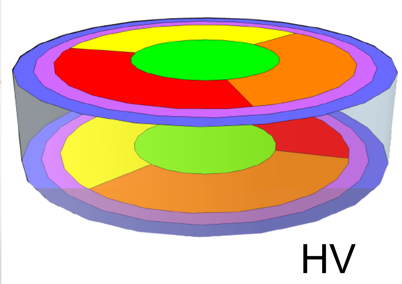
SuperCDMS Detector Technology

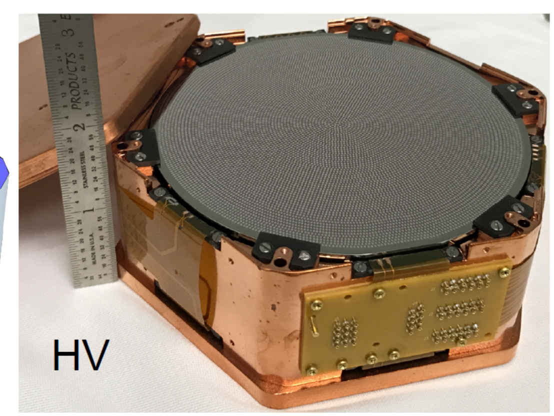
- High-purity Ge and Si crystals operated at 10's of mK.
- Sensors patterned on crystal surfaces measure phonons and ionization from particle interaction.
- Multiple channels give position information, with outer guard rings allowing rejection of high-radius events.
- 2 types: iZIP (better rejection) and High Voltage (lower threshold)



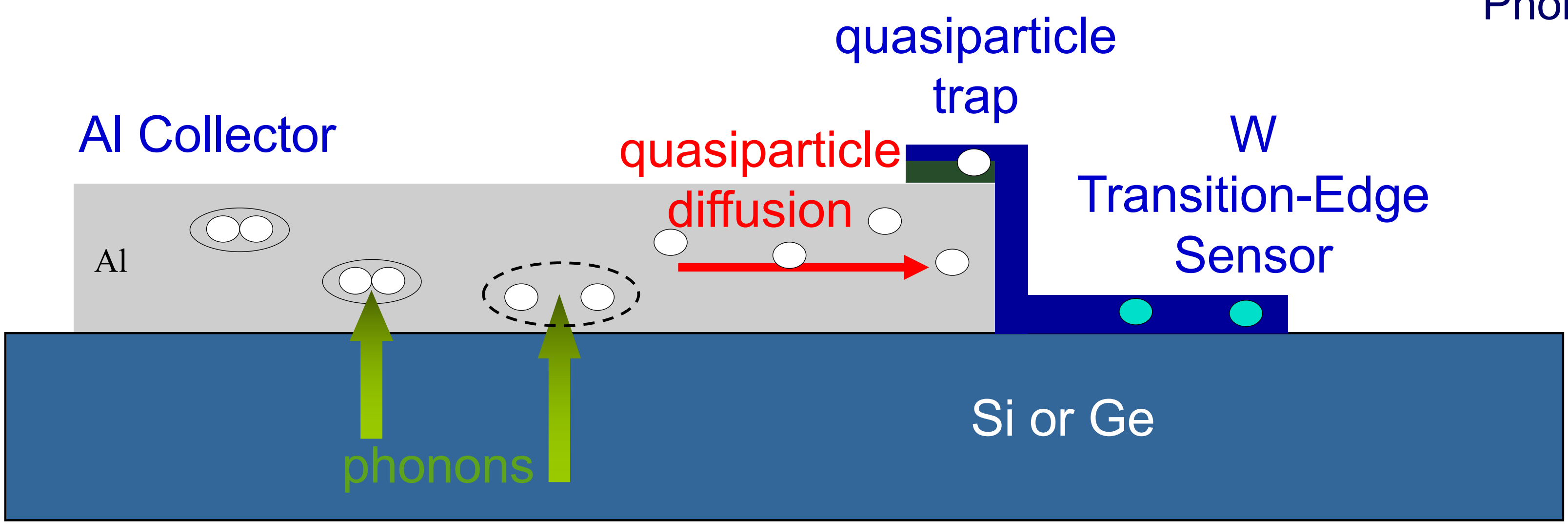


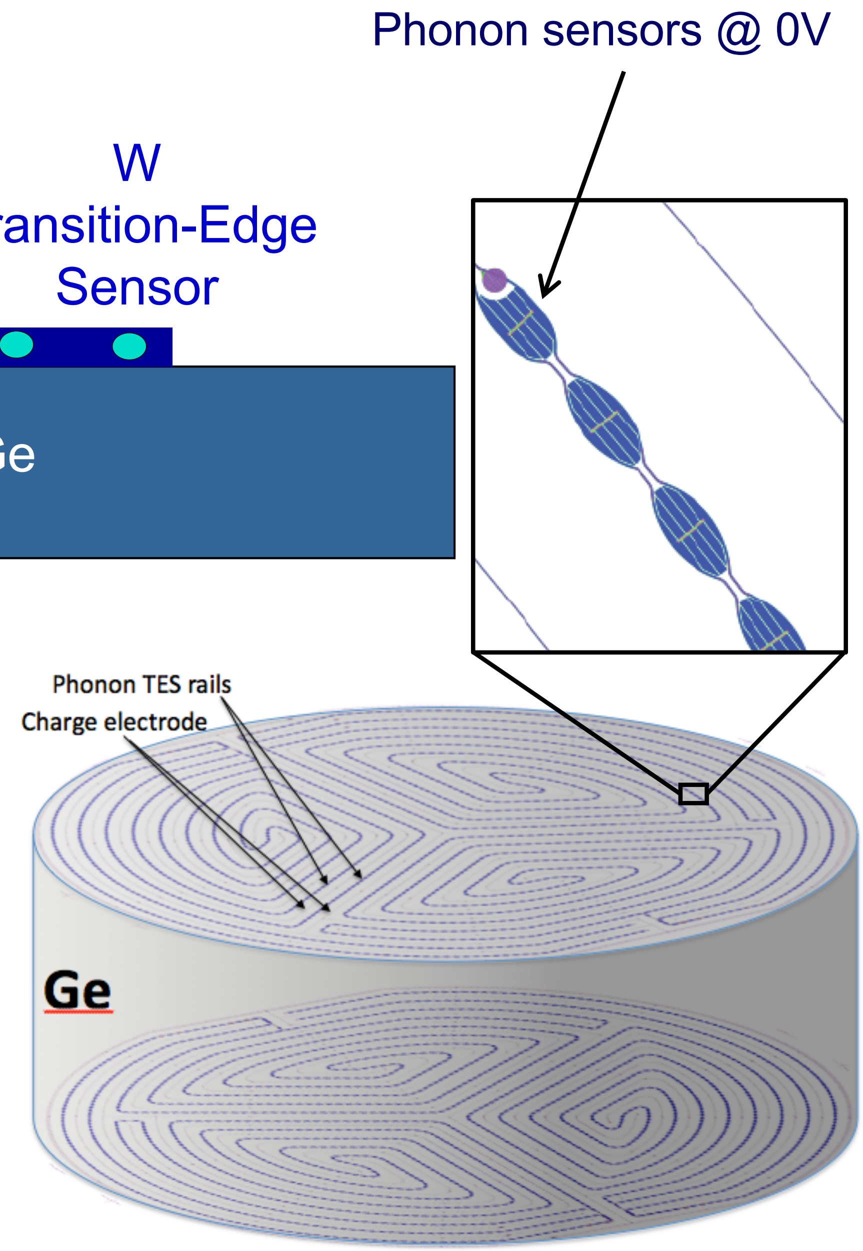




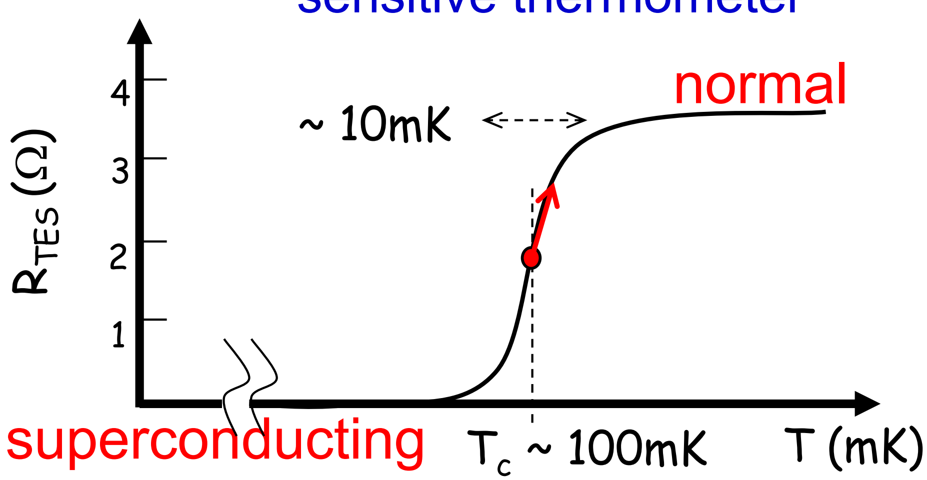


Phonon Sensor Technology

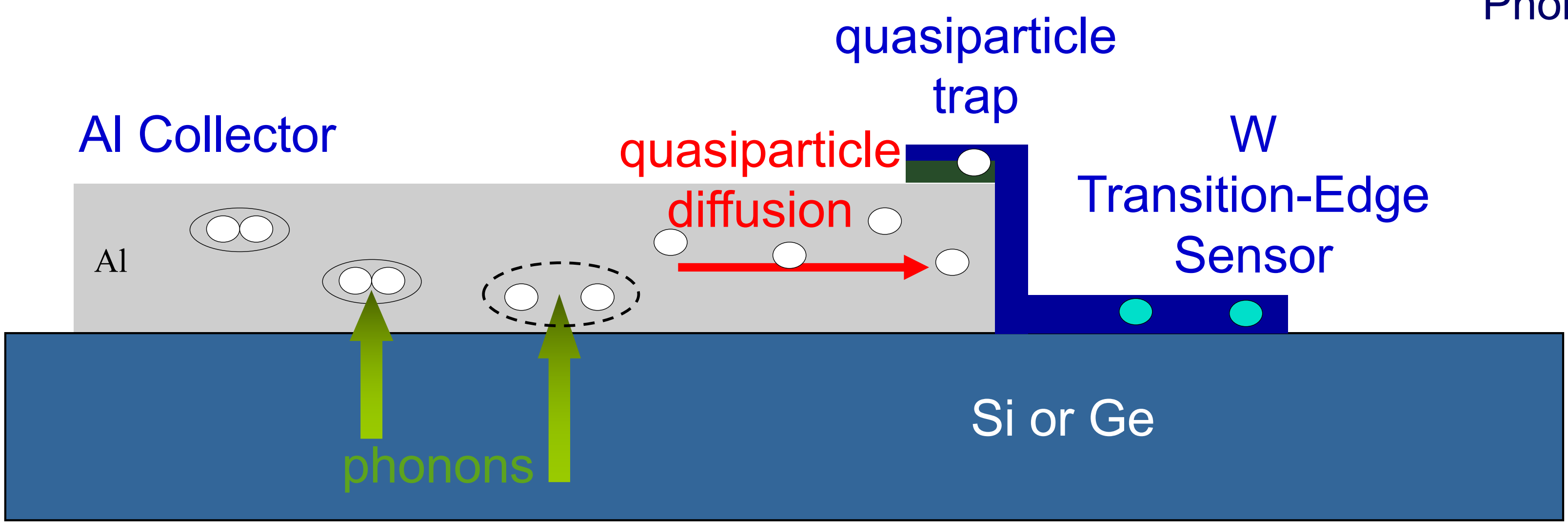


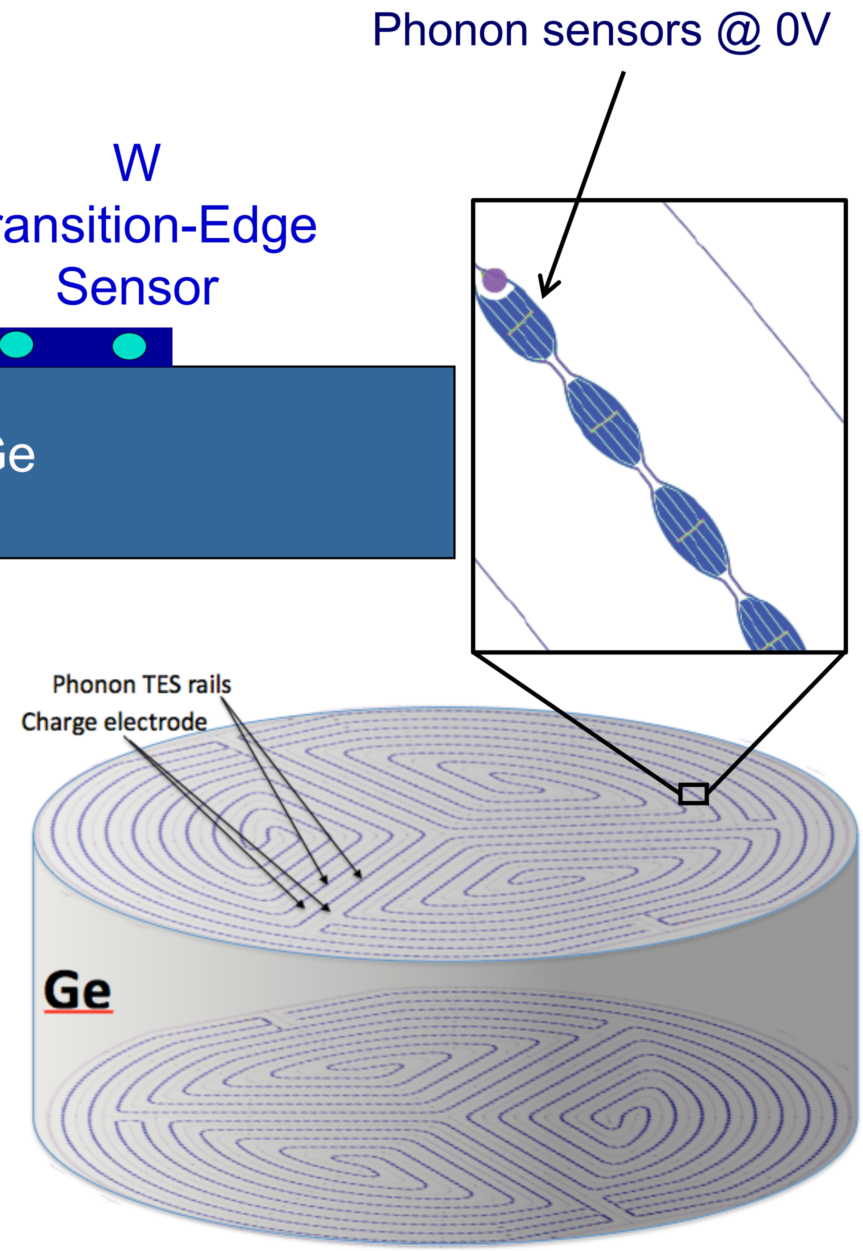


W Transition-Edge Sensor: sensitive thermometer



Phonon Sensor Technology





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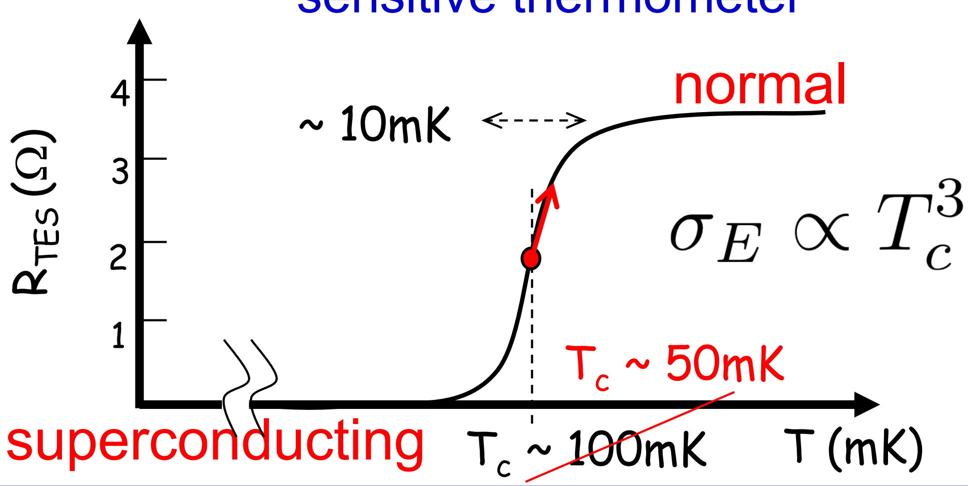
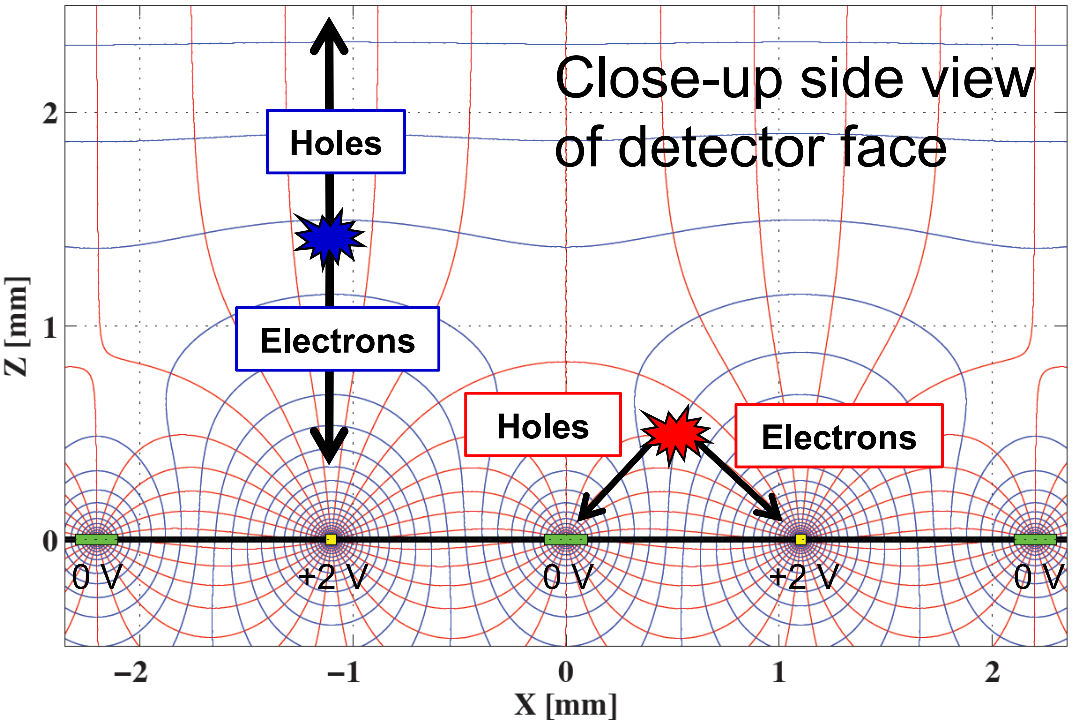
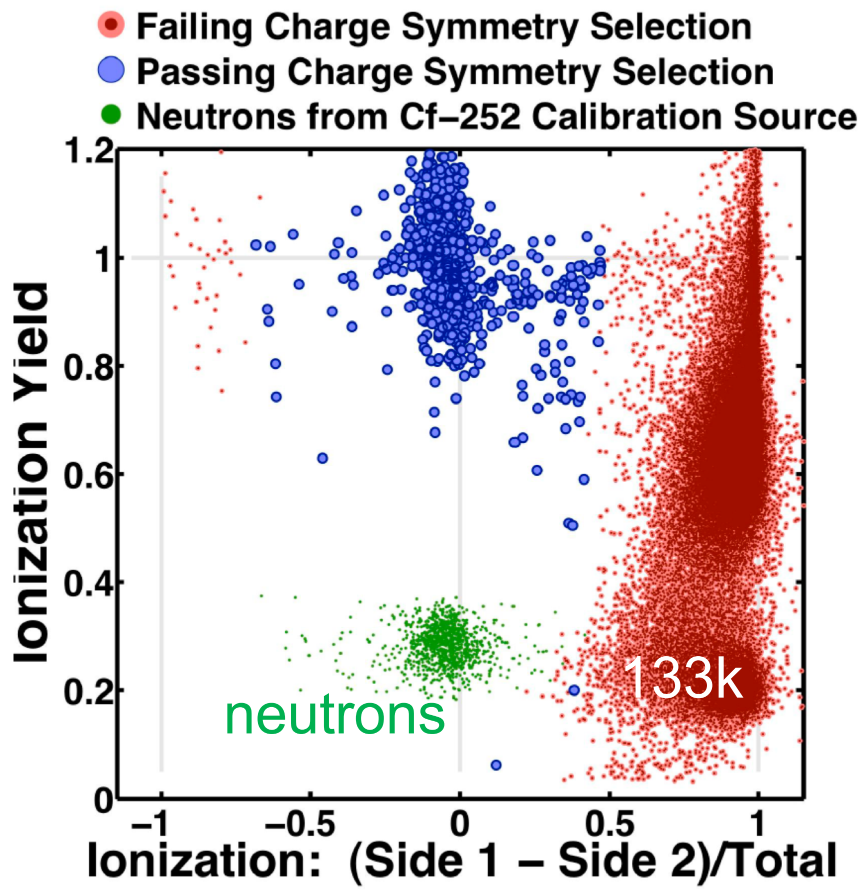


SuperCDMS iZIP Detectors

- Interleaved Z-sensitive Ionization & Phonon sensors
- ~10^6:1 rejection of electron-recoil backgrounds ≳ 2 keV.
  - **Nuclear recoils** produce less ionization than **bulk electron recoils** do
  - **Surface events** rejected by side-asymmetric ionization signal
- Ionization electrodes at ±2V, phonon sensors at 0 V.

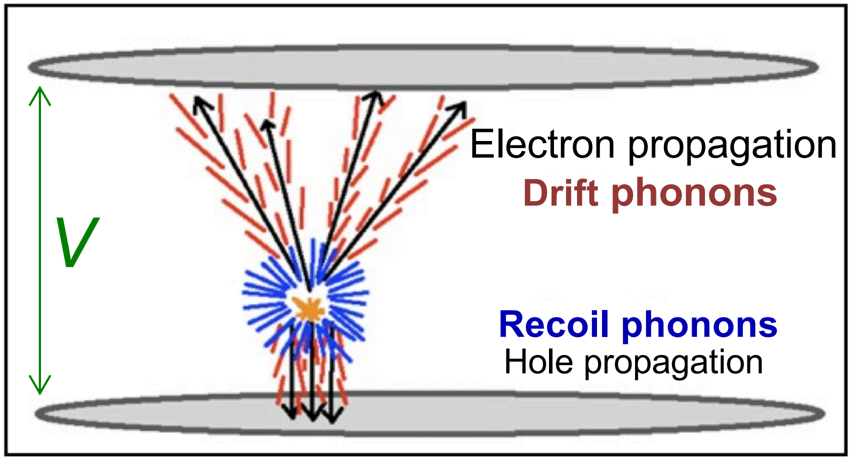




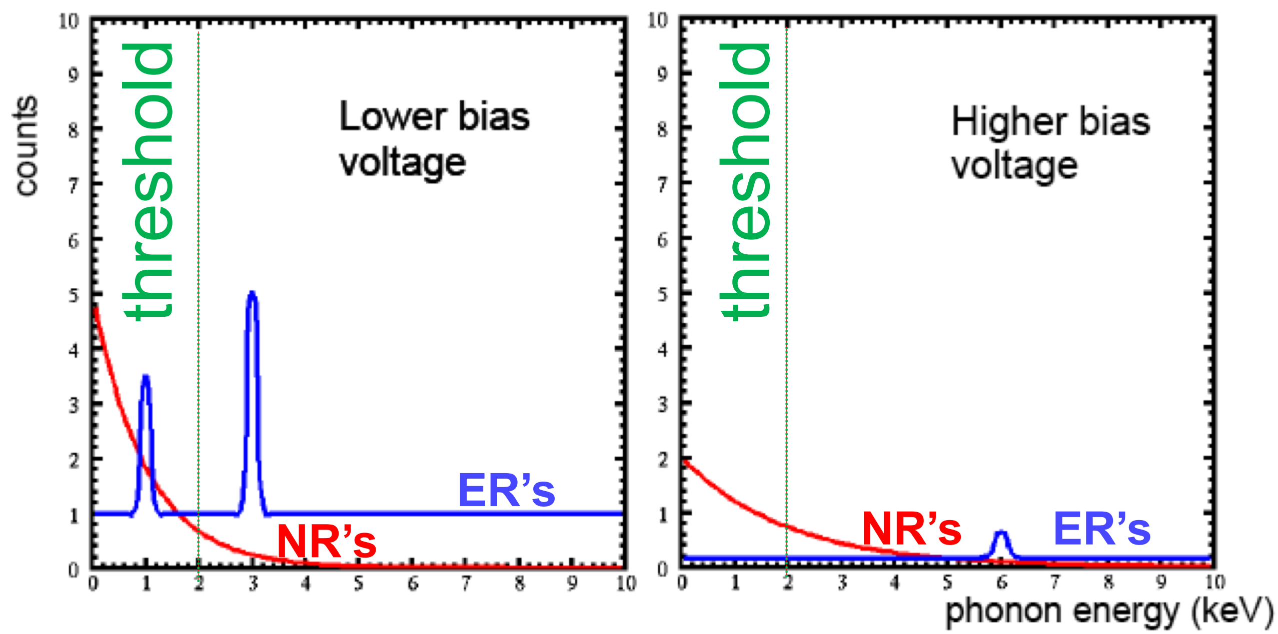
Appl.Phys. Lett., 103, 164105 (2013) [1305.2405]

SuperCDMS High Voltage Detectors

- Drifting N_e electron–hole pairs across a potential V generates $N_e V$ electron volts of phonons.
- For detector at high voltage (say 80 V), these phonons drown out the primary phonons.
  - Significantly lowers energy threshold.
  - No electron/nuclear recoil discrimination based on phonons vs. ionization.
  - Stretches electron-recoil energy scale, effectively reducing background rate.



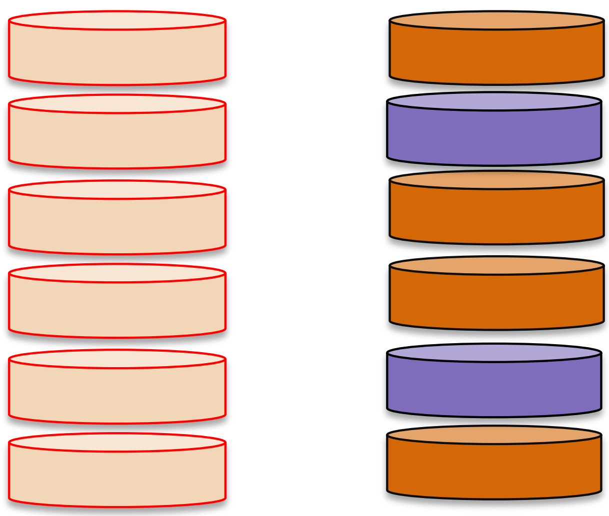
Neganov and Trofimov, Otkryt. Izobret., ***146****, 215 (1985)*
Luke, J. Appl. Phys., 64, 6858 (1988), Luke et al., Nucl. Inst. Meth. Phys. Res. A, ***289****, 406 (1990)*



Complementarity of Detectors

	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

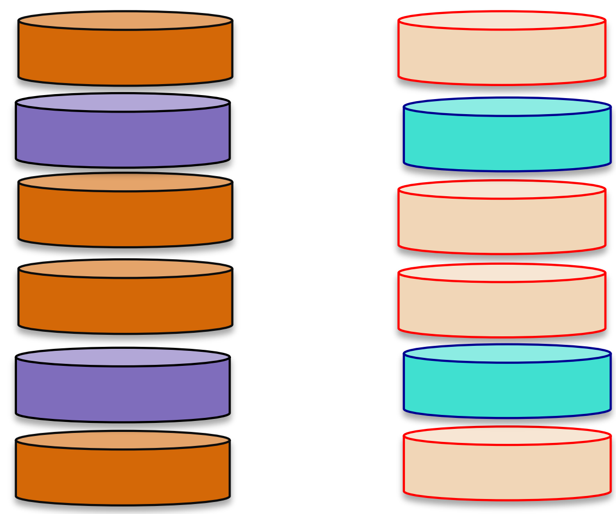
"Pre-production" towers
to be tested March 2019



Tower 1 (iZIP) Tower 2 (HV)

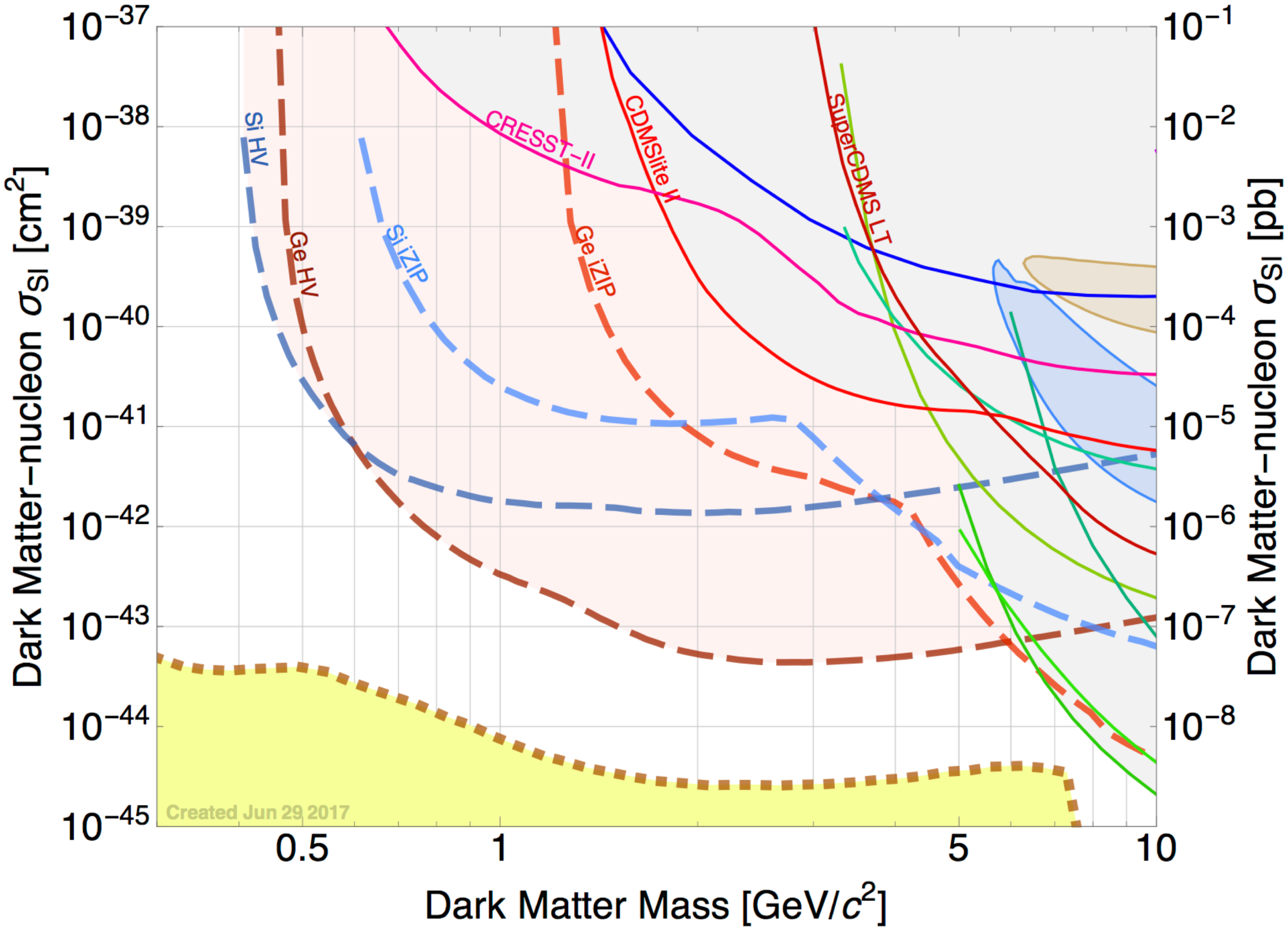
Towers 3 & 4 fabricated together to have same backgrounds.

Twin "Production" towers
to be tested November 2019



Tower 3 (HV) Tower 4 (iZIP)

Complementarity of Detectors

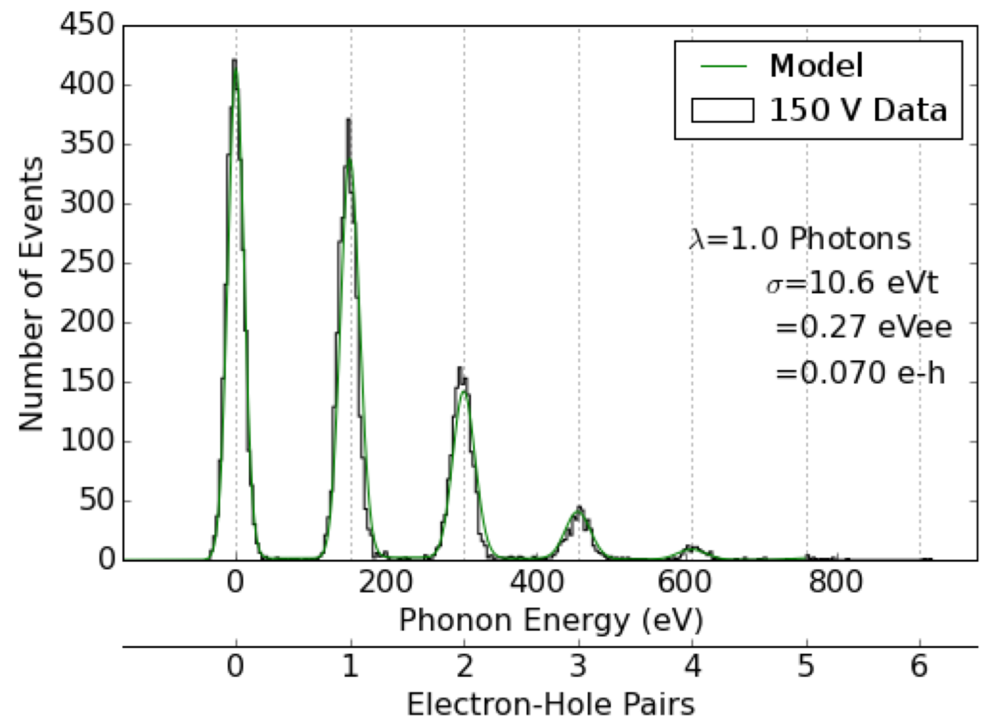


SuperCDMS Detectors: The Next Generation

- SuperCDMS SNOLAB driven primarily by improvement of phonon energy resolution

	Soudan	SNOLAB goal
Phonon resolution, eVt	~250	HV:10, iZIP:50
HV Bias Voltage, V	70	100
iZIP Charge res., eVee	~400	160
HV Threshold, eVnr	300	40

- 1 cm^2 x 4 nm Si test device with 160 V bias demonstrated single e/h pair measurement with <10% resolution (*Appl. Phys. Lett.* ***112****, 043501 [1710.09335], [1804.10697]*) [see N. Kurinsky talk Tuesday 15:00]
    - Results in excellent sensitivity for dark photon searches [see B. von Krosigk talk Friday 14:00].



SuperCDMS SNOLAB Background Reductions

- Second big improvement in SuperCDMS SNOLAB is >20x lower bulk and surface ER backgrounds, and ~5x lower neutron backgrounds, driven by
  - SNOLAB: 6800 feet underground with class 2000 environment
  - More complete materials screening
  - Improved shield
  - Reduced cosmogenic activation of detectors
  - Reduction of radon daughters on surfaces by combination of specialized cleaning, radon exposure reduction, and assays

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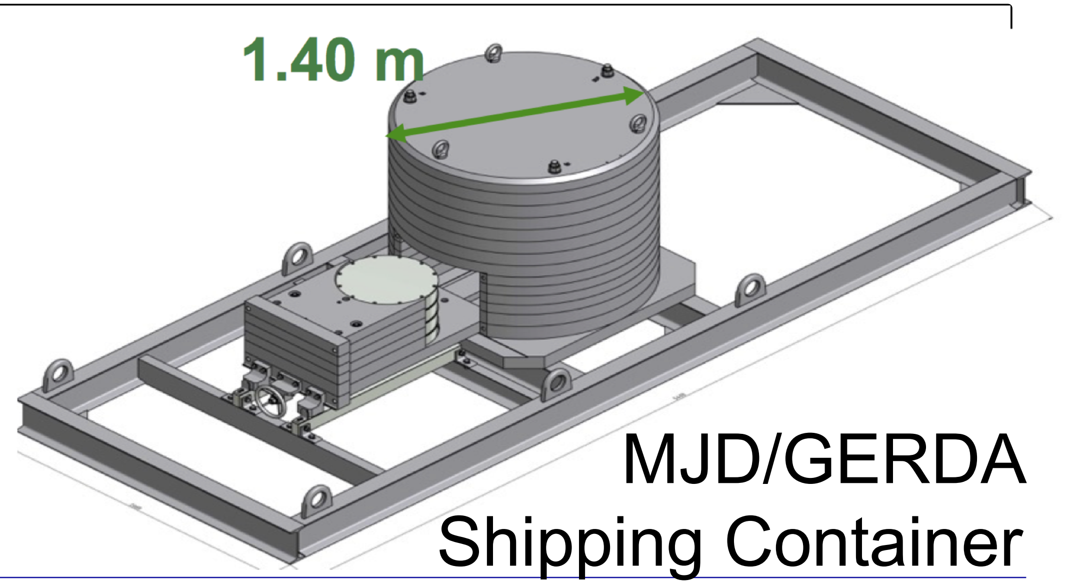

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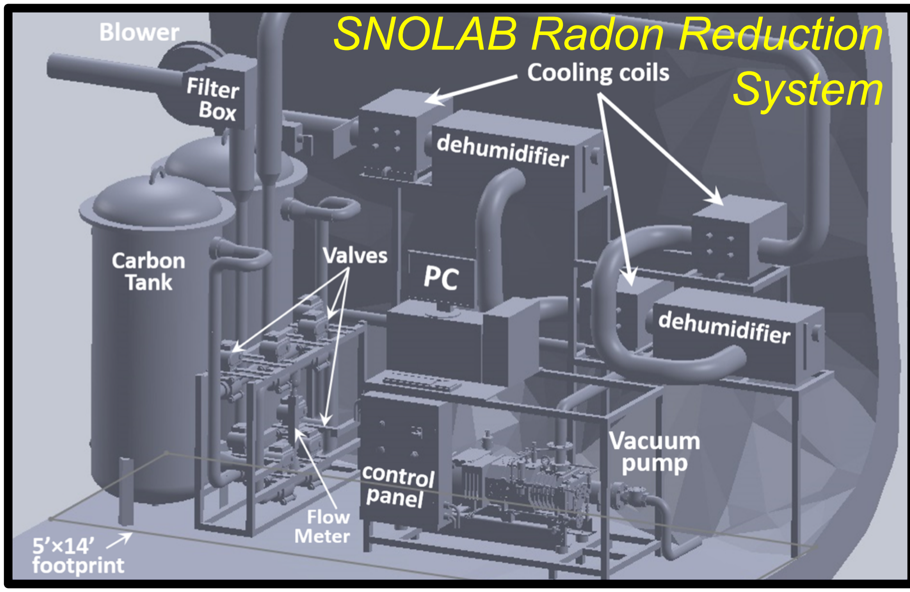
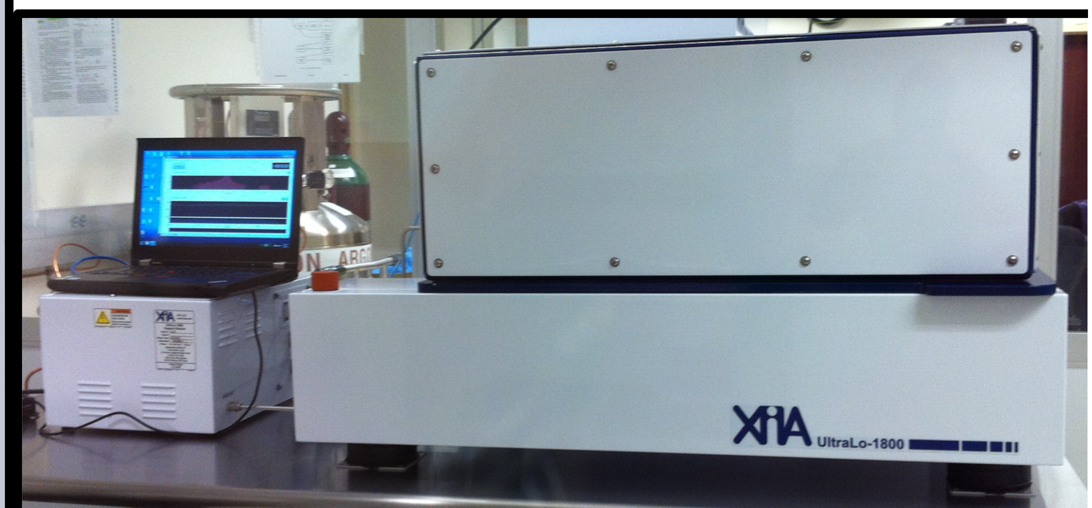
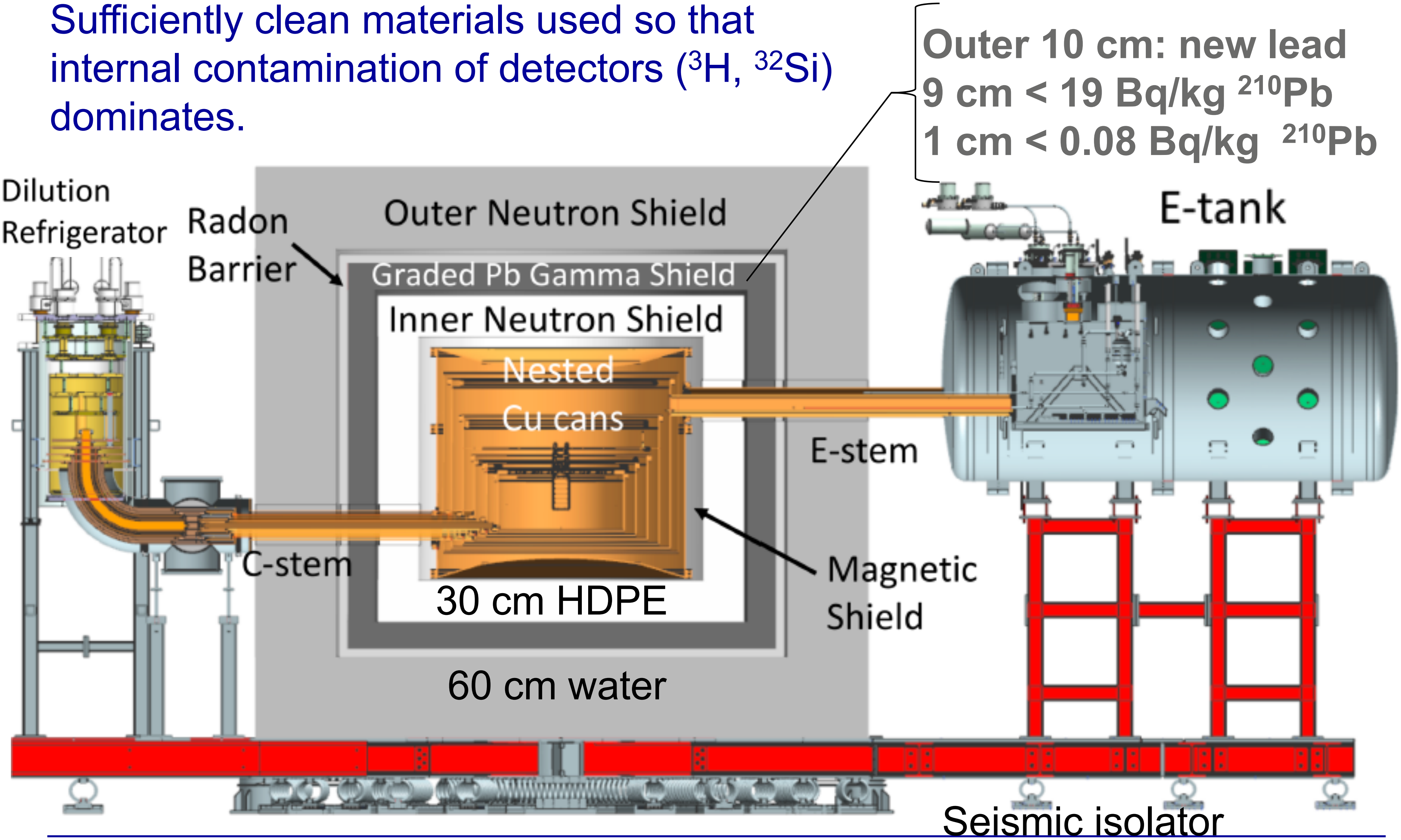




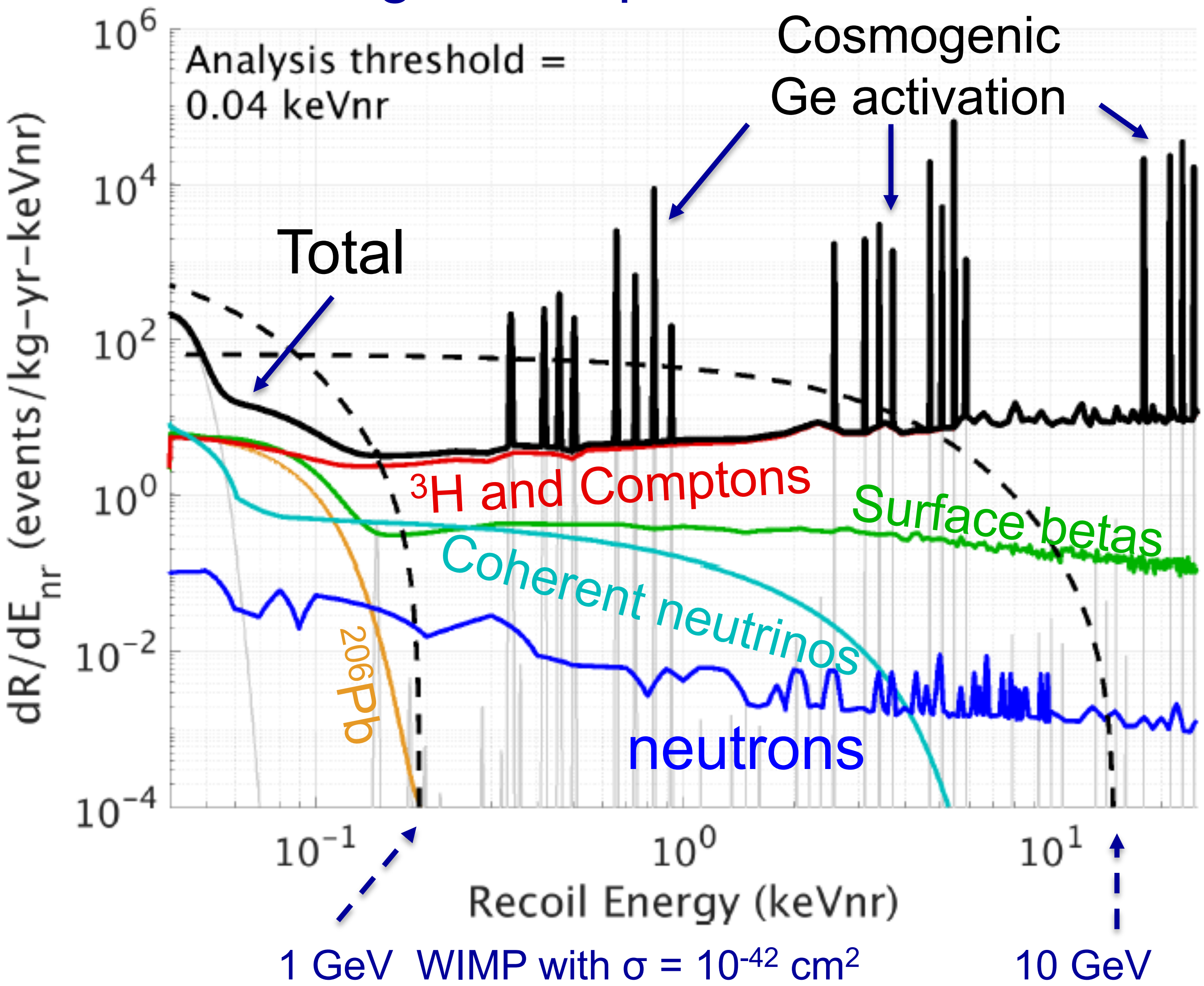
SuperCDMS SNOLAB Shielding and Infrastructure

Graded shield reduces environmental γ by 10^6.
Sufficiently clean materials used so that internal contamination of detectors (^3H, ^{32}Si) dominates.



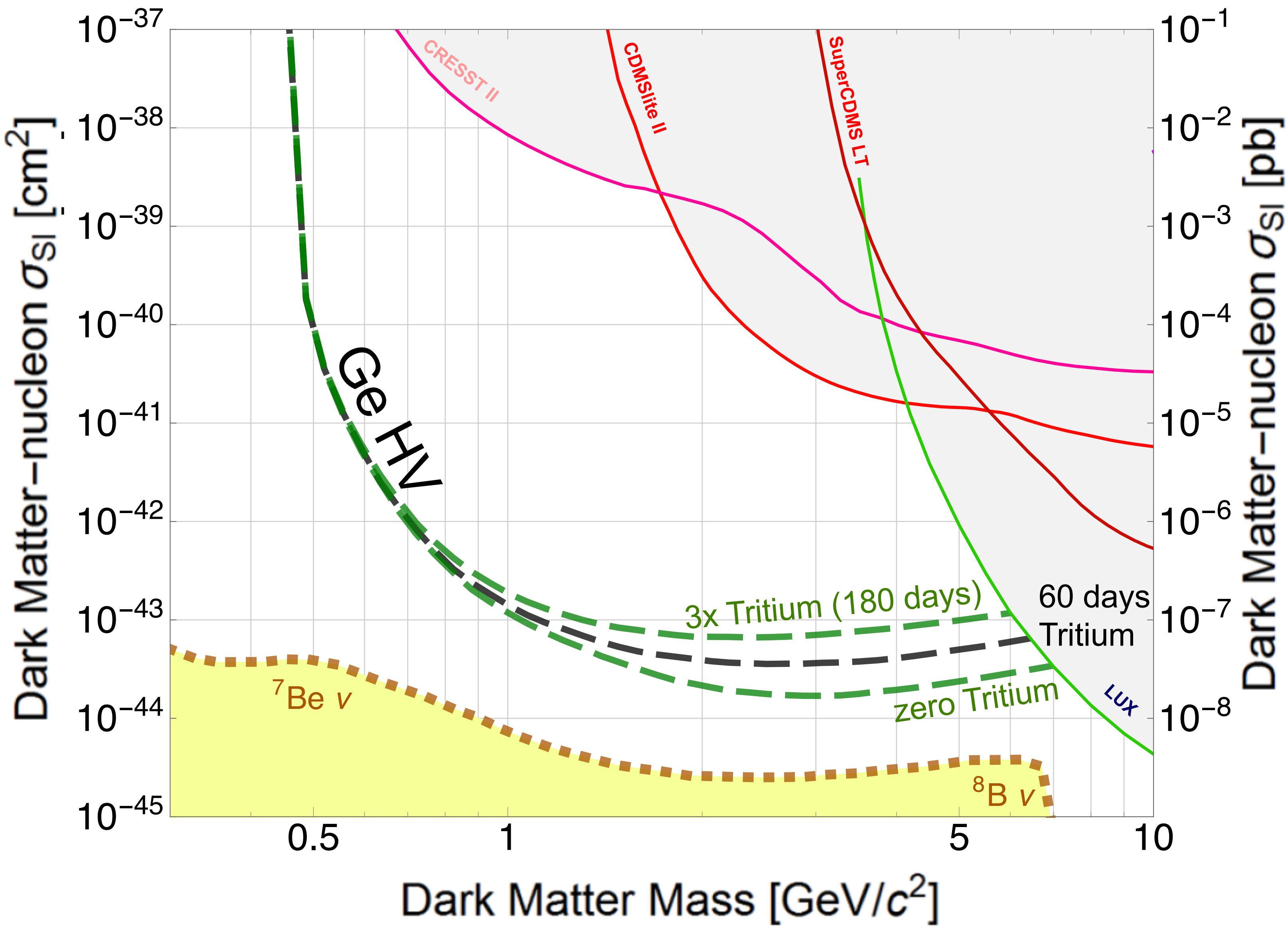
SuperCDMS SNOLAB Backgrounds

Predicted background spectrum in Ge HV detectors after cuts



- Dominated by ^{3}He and Comptons for all but the lowest energies.
- Dominated by surface betas and surface ^{206}Pb radon daughters at low energy
  - Lose discrimination of events on sidewall at low energy

Tritium: Sensitivity vs. Exposure Time



SuperCDMS Tritium Backgrounds in Ge

- Minimize cosmic-ray exposure of Tower 2-4 Ge detectors

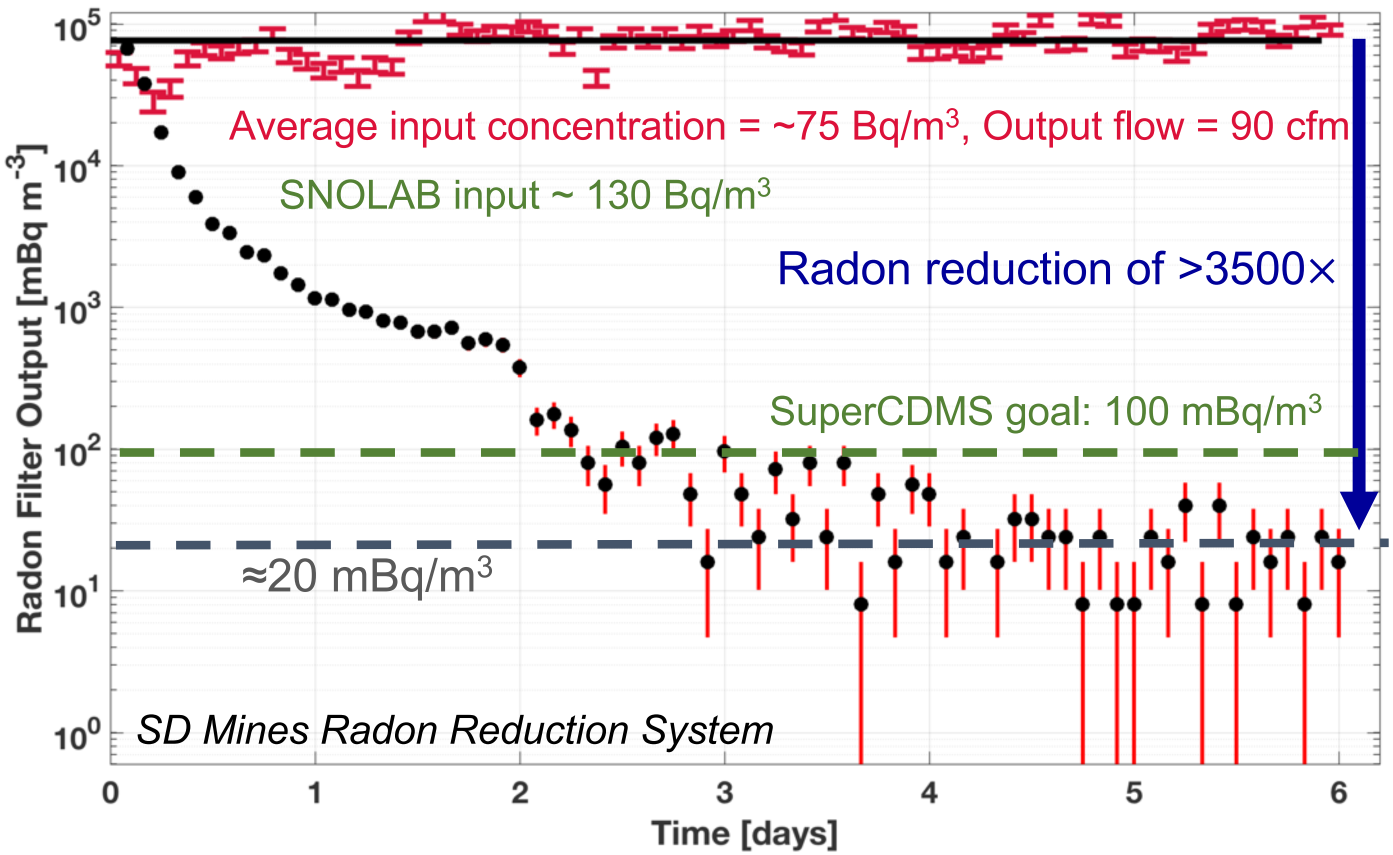
  (^{32}Si dominates in Si)
  - Store and prepare crystals underground
  - Shield crystal transport
  - Shorten testing at surface
- Expect to meet goal of <60 days exposure
- Exposure much smaller than previous detectors
  - ~1000 days common

Stage	Activity	Days
Boules & cut crystals	Production Storage Shipment	5 **0** **<2**
Prepare crystals	Align/shape/polish	**0**
Fabrication	Lithography	8
Mounting	Put in housing ~~300 mK test~~ Tower assembly	3 **0** 2
Tower testing	Functional test	**7**
Shipment	SNOLAB delivery	7
Total Exposure		34

- Predict backgrounds assuming 90 tritium atoms/kg/day in Ge
  - Conservative, based on SuperCDMS **arXiv:1806.07043**, and EDELWEISS-III **arXiv:1607.04560**.

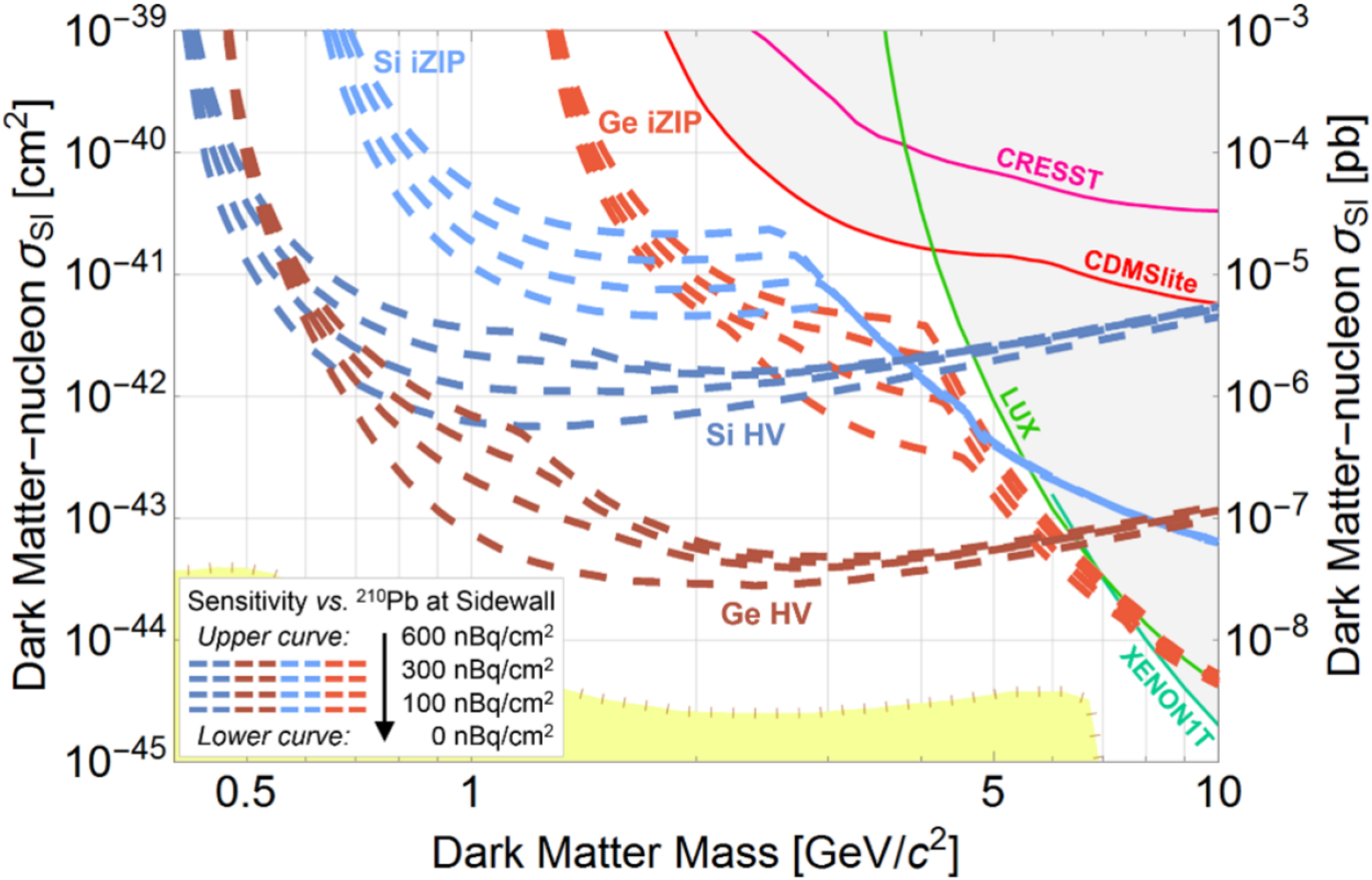
SuperCDMS Radon Daughter Backgrounds

- Similar analysis performed to estimate radon exposure.
  - Move of Ge crystal polishing underground (to reduce tritium activation) will increase radon exposure (to 45 nBq/cm^2 ^{210}Pb).
  - Other leading exposure during sensor fabrication (27 nBq/cm^2).
  - Installation at SNOLAB would dominate, so installing low-radon cleanroom:



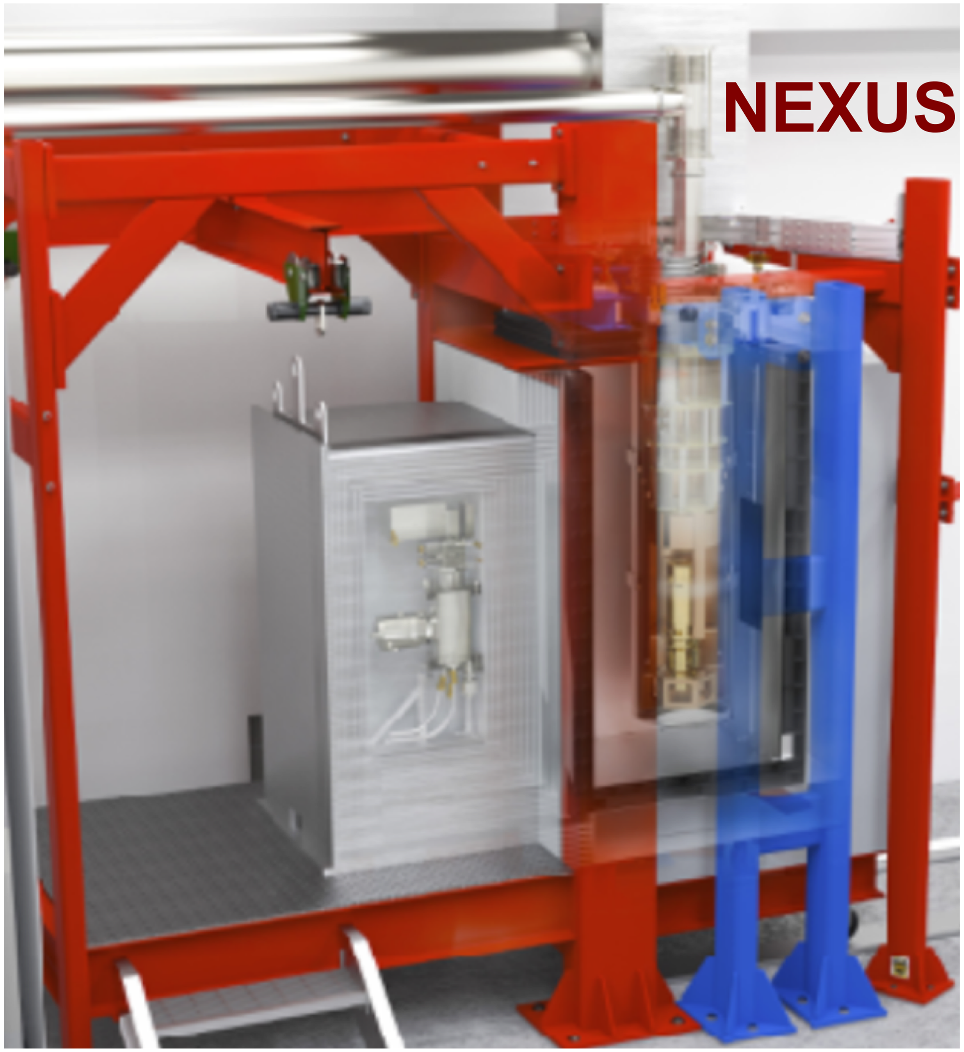
- Results in radon daughter background only slightly higher than ^{3}H + Comptons at lowest energies.

Sensitivity vs. ^{210}Pb Contamination



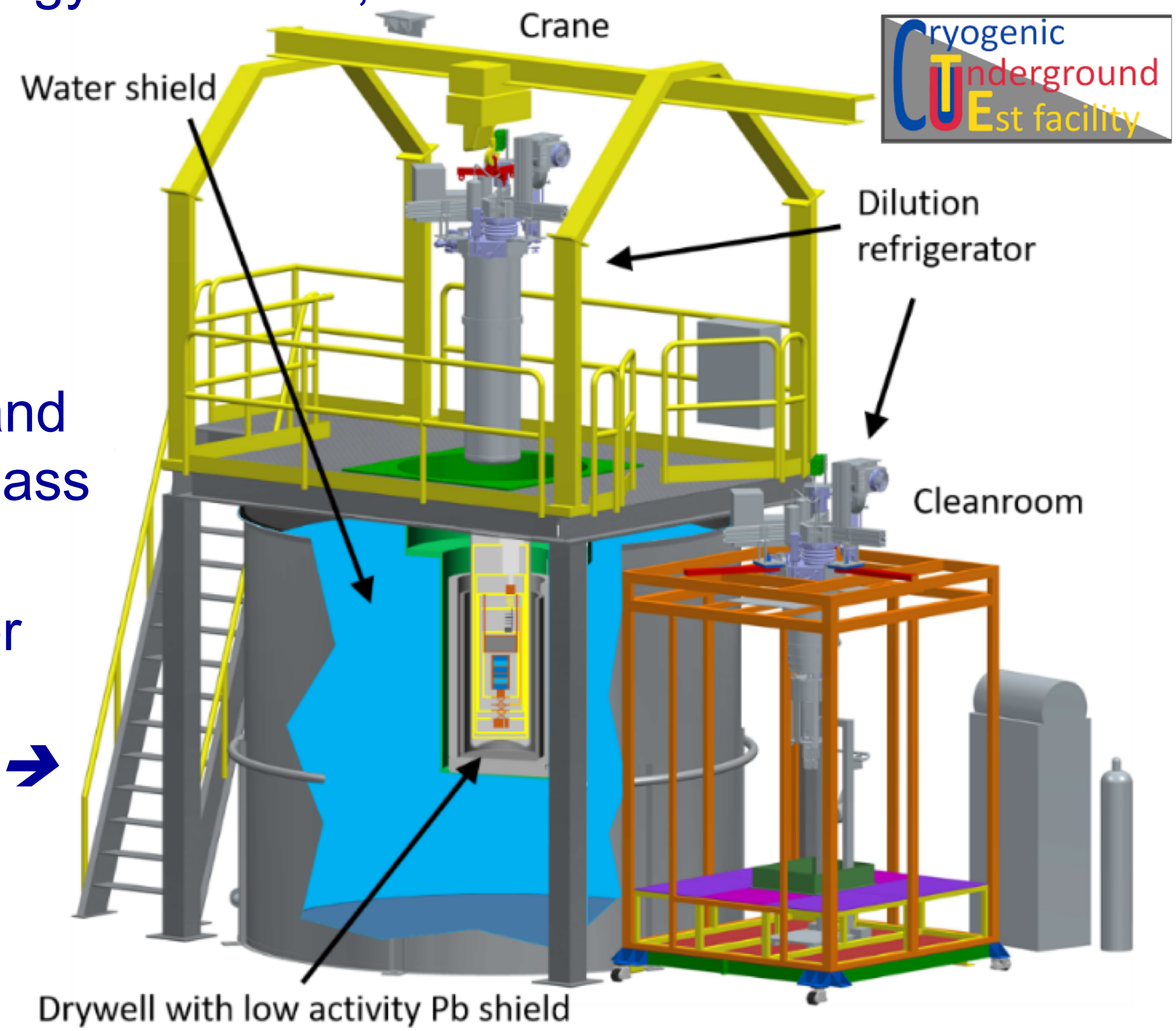
SuperCDMS Calibrations

- Need to understand nuclear recoil ionization yield at low energies [See A. Robinson talk Wednesday 8:30 am].
  - Plan measurements at Test Facilities 2018-2020.
    - *Neutron beams at U. Montreal and the TUNL facility*
    - *DD generator at NUMI underground hall at FNAL* **"NEXUS"**
    - *Thompson scattering, photon emission after n capture*
  - Also periodic measurements *in situ.*

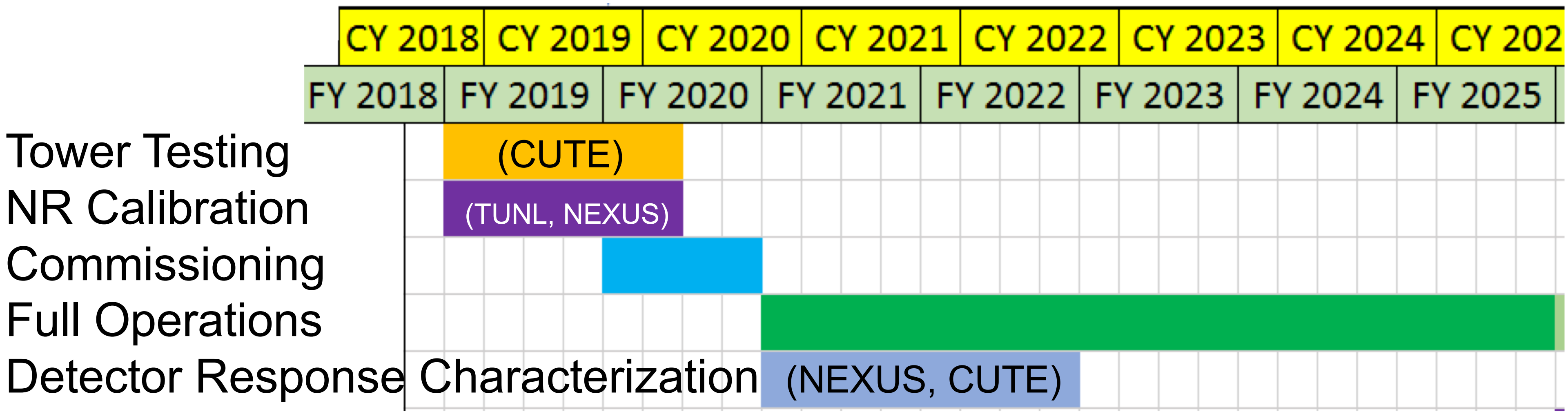


SuperCDMS Detector Testing

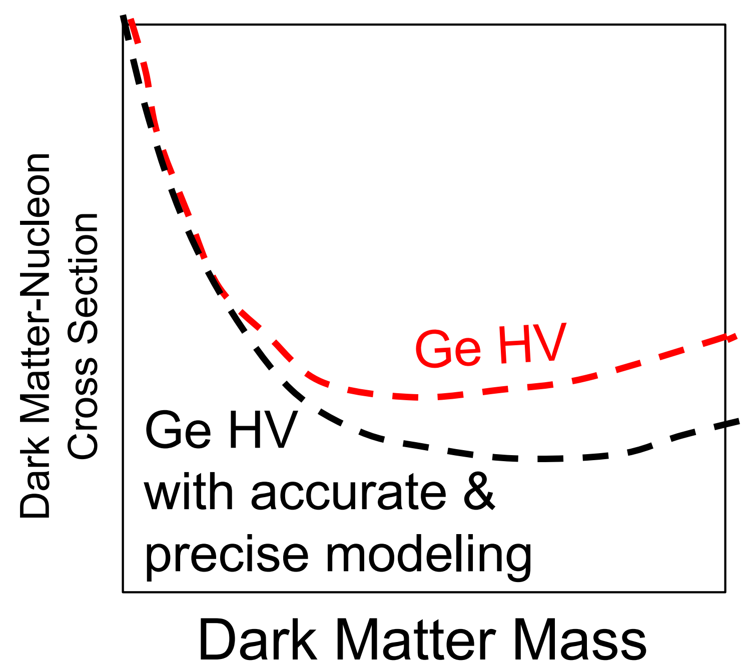
- Underground testing is crucial to evaluating detector performance [See T. Aramaki talk Monday 14:20].
  - Characterize noise, energy resolution, and discrimination without activating detectors.
  - Confirm full detector functionality after transport, before installation.
  - Validate backgrounds and possibly get new low-mass science results.
  - All this will enable faster commissioning of SuperCDMS SNOLAB ➔ *Test Towers in a co-located cryogenic test facility* ➔ **CUTE**



SuperCDMS Schedule



- Characterization of detector response at Test Facilities in parallel with Operations will allow understanding of backgrounds needed to maximize sensitivity reach.



Conclusions

- SuperCDMS SNOLAB has unique advantages for a low-mass dark matter search experiment.
  - Excellent energy resolution and threshold
  - Multiple targets and technologies maximize information
- Sensitivity $<10^{-43}$ cm^2 for 1-10 GeV/c^2 dark matter masses, coverage to 0.4 GeV/c^2 .
- Actively working to minimize dominant backgrounds of cosmogenic activation and radon daughters.
- Passed CD3 review this year, which authorized beginning construction.
- Beginning detector testing and calibrations.
- Underground installation starts next year, completed by 2020.

Thank you!

California Inst. of Tech.	CNRS-LPN*	Durham University	FNAL	NISER	NIST*
Northwestern	PNNL	Queen's University	Santa Clara University	SLAC	South Dakota SM&T
SMU	SNOLAB	Stanford University	Texas A&M University	TRIUMF	U. British Columbia
	U. California, Berkeley	U. Colorado Denver	U. Evansville	U. Florida	
* Associate members	U. Montréal	U. Minnesota	U. South Dakota	U. Toronto	