SuperCDMS SNOLAB Gen2 and Beyond

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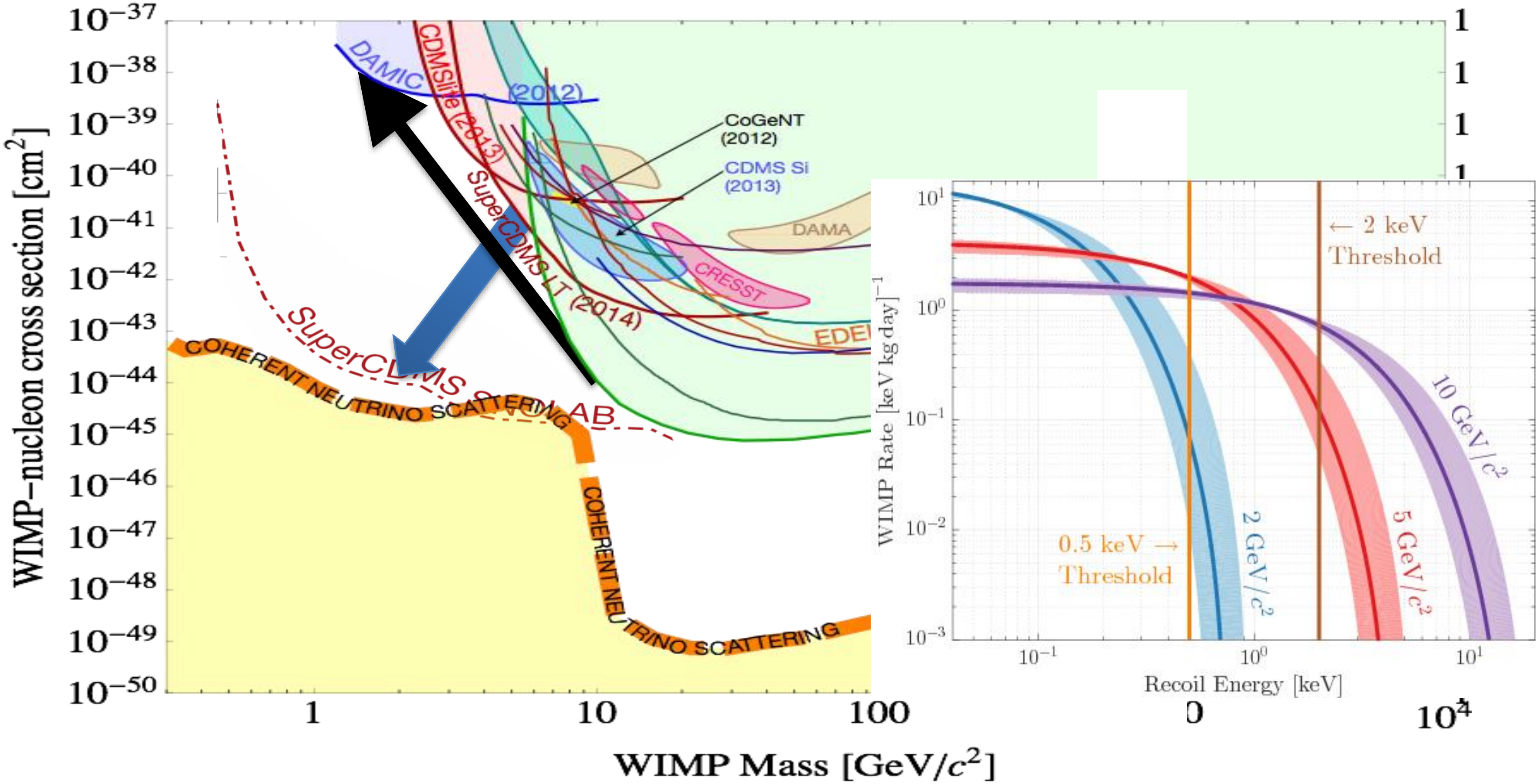
G2 Landscape: SuperCDMS Low-mass Search



- SuperCDMS SNOLAB focuses on low mass DM region
  - Over 1000x better sensitivity compared to SuperCDMS soudan
  - Driven by improvements in detector design, better background control, more exposure, and lower thresholds

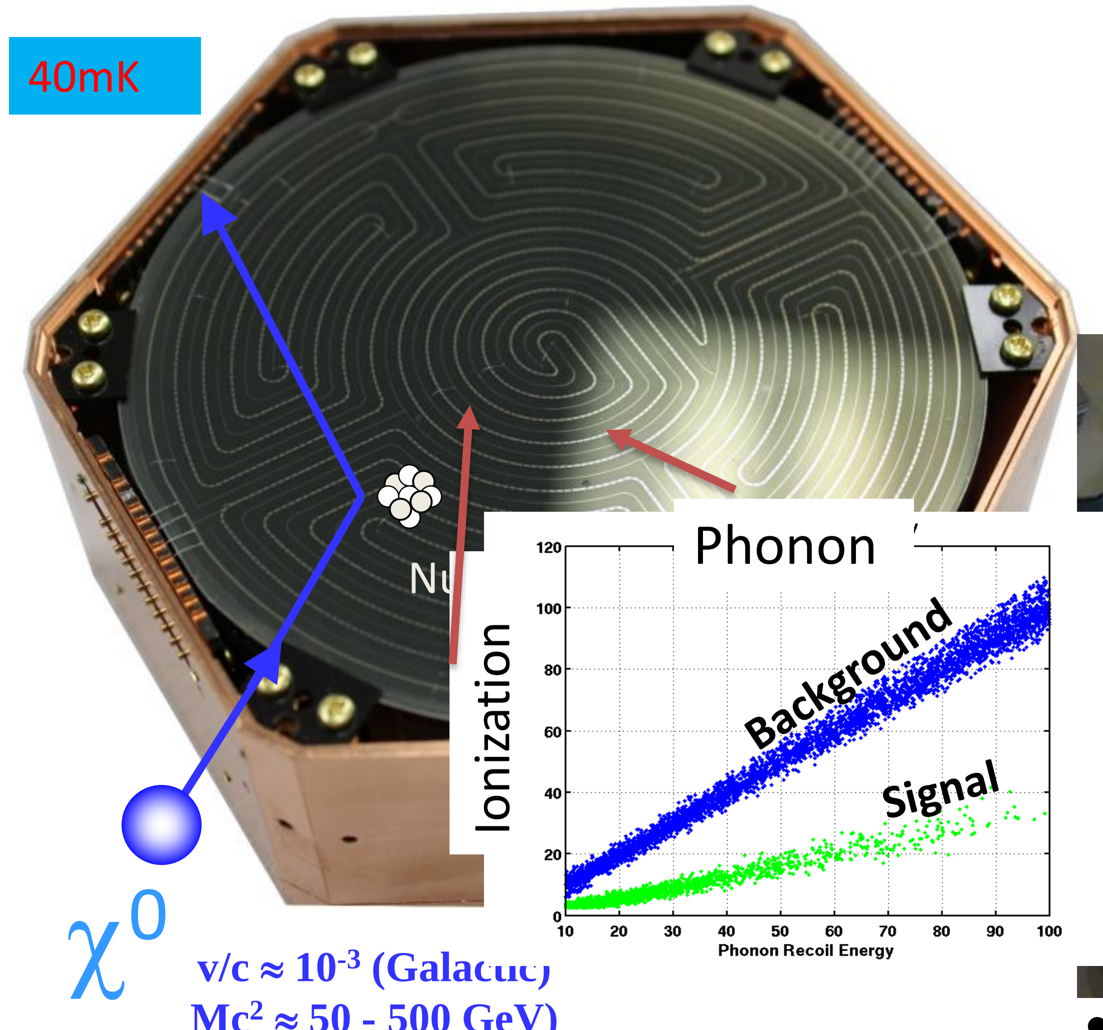
Caltech C2N NIST Pacific Northwest NATIONAL LABORATORY SLAC SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

SNOLAB UBC Cal UF UNIVERSITY OF SOUTH DAKOTA

NSF DAE ATOMS IN THE SERVICE OF THE NATION Emmy Noether-Programm DFG Deutsche Forschungsgemeinschaft

Cryogenic Dark Matter Search: The Big Picture

Cryogenically cooled Ge/Si detectors with photo-lithographically patterned Transition Edge Sensors for excellent energy and position resolution

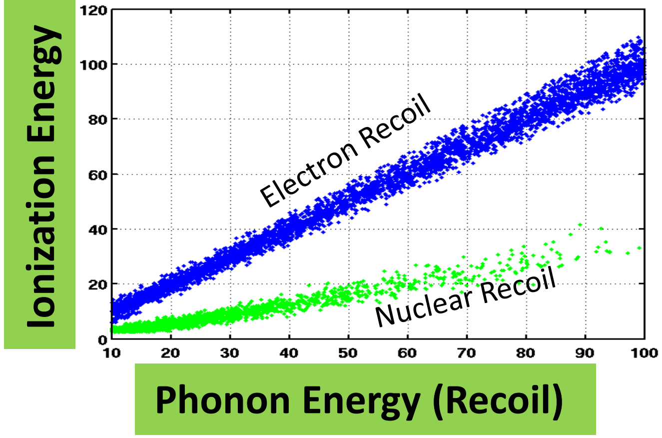


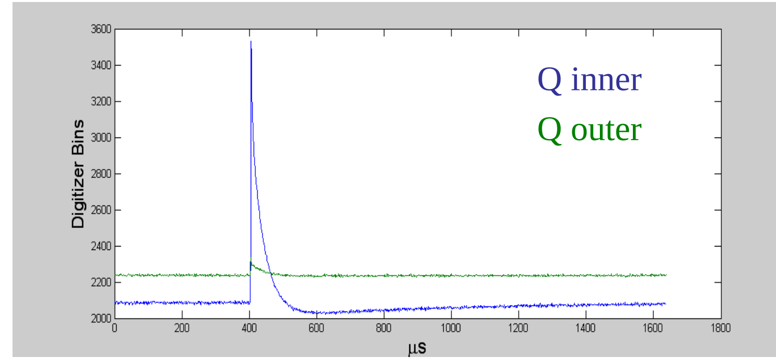
X-Y-Z Position from Phonon Pulse Timing

Demonstrated two decades of leading WIMP search limits with excellent low-background performance

- Passive Shielding (Pb, poly, *depth*)
- Active Shielding (muon veto shield)

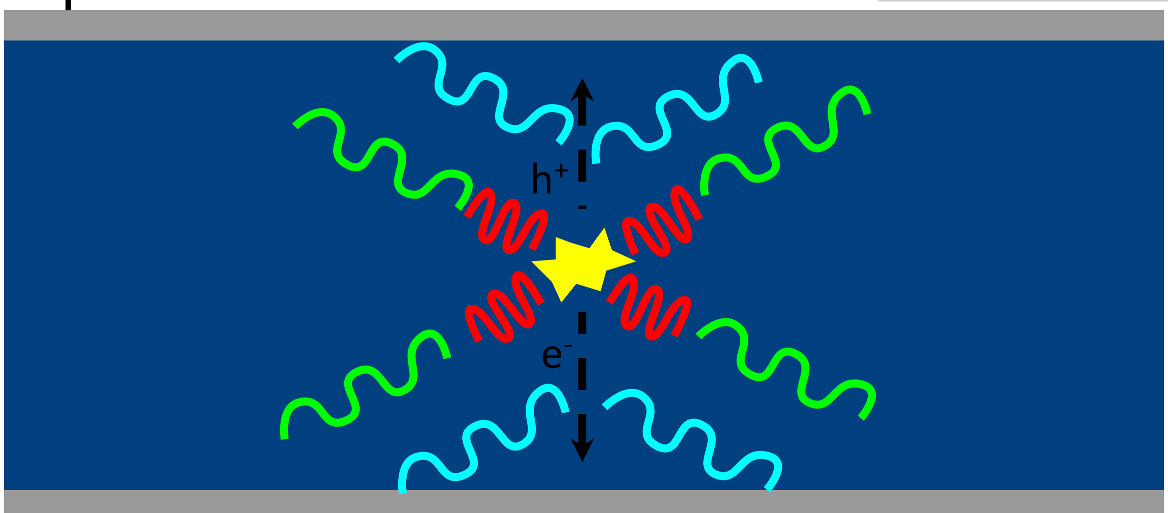
Anatomy of an event

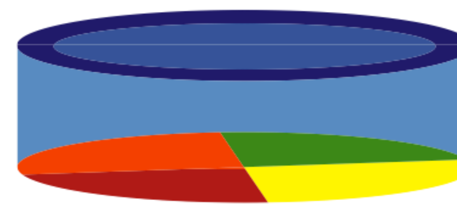




Hot charge carriers (3eV/pair)

-3V





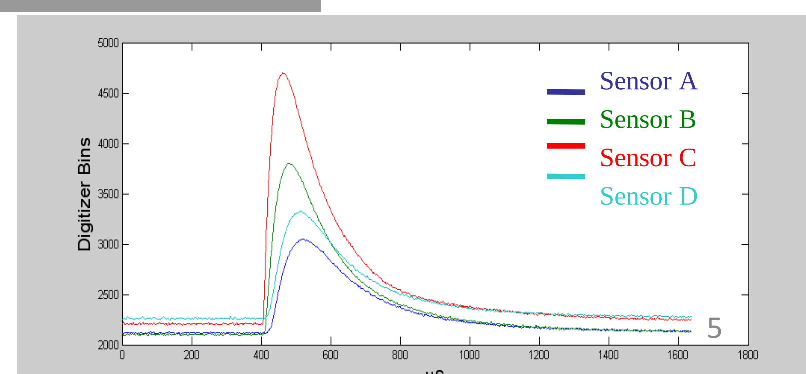
0V

Quasi-diffusive THz phonons

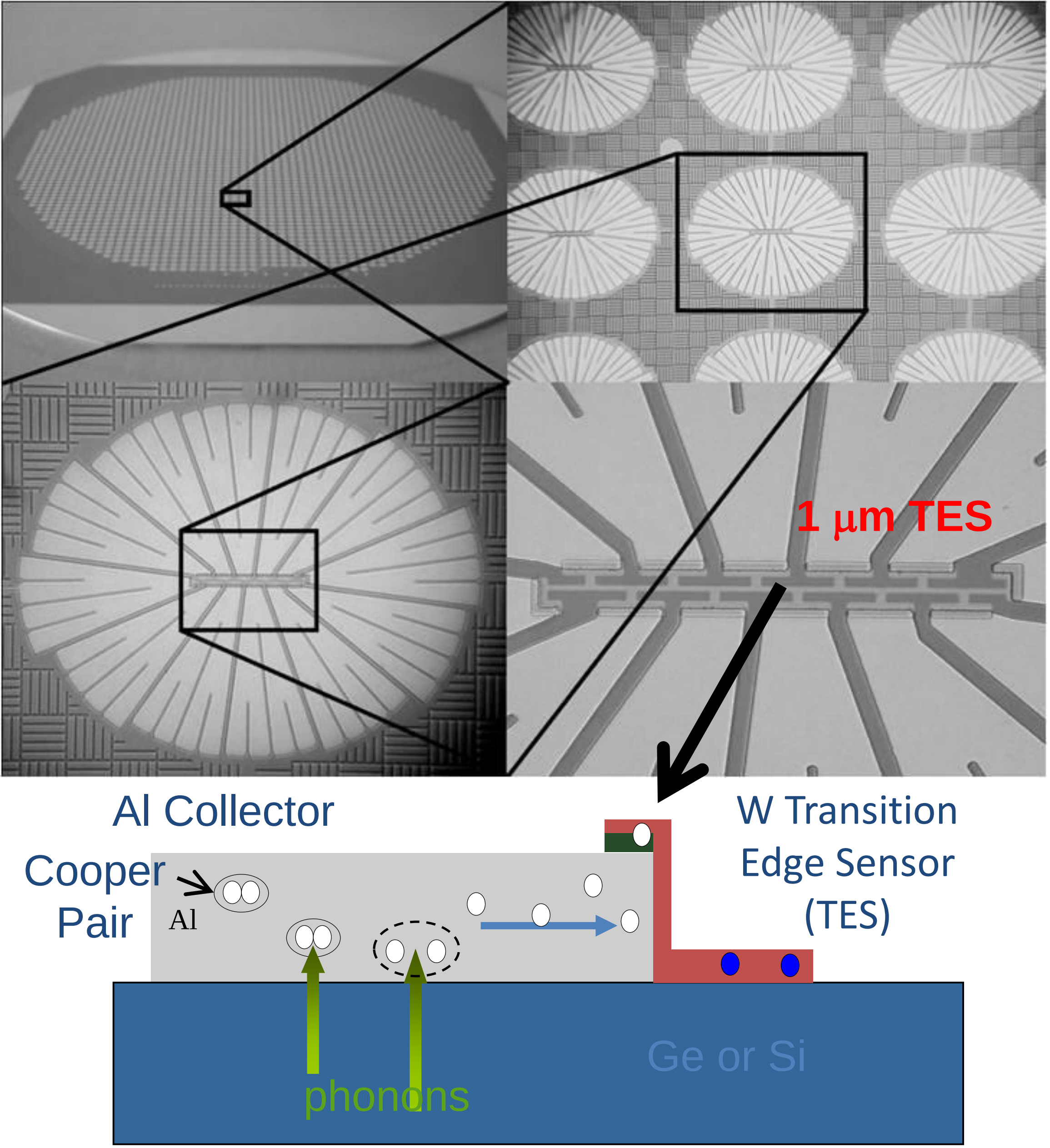
Ballistic Neganov-Luke phonons

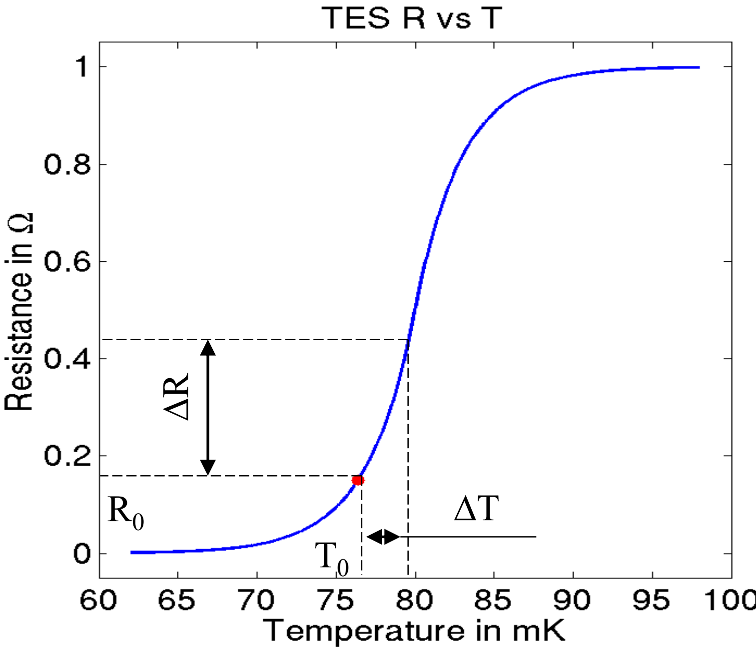
Ballistic low-frequency phonons

Total Phonons = Direct Phonons + Luke Phonons

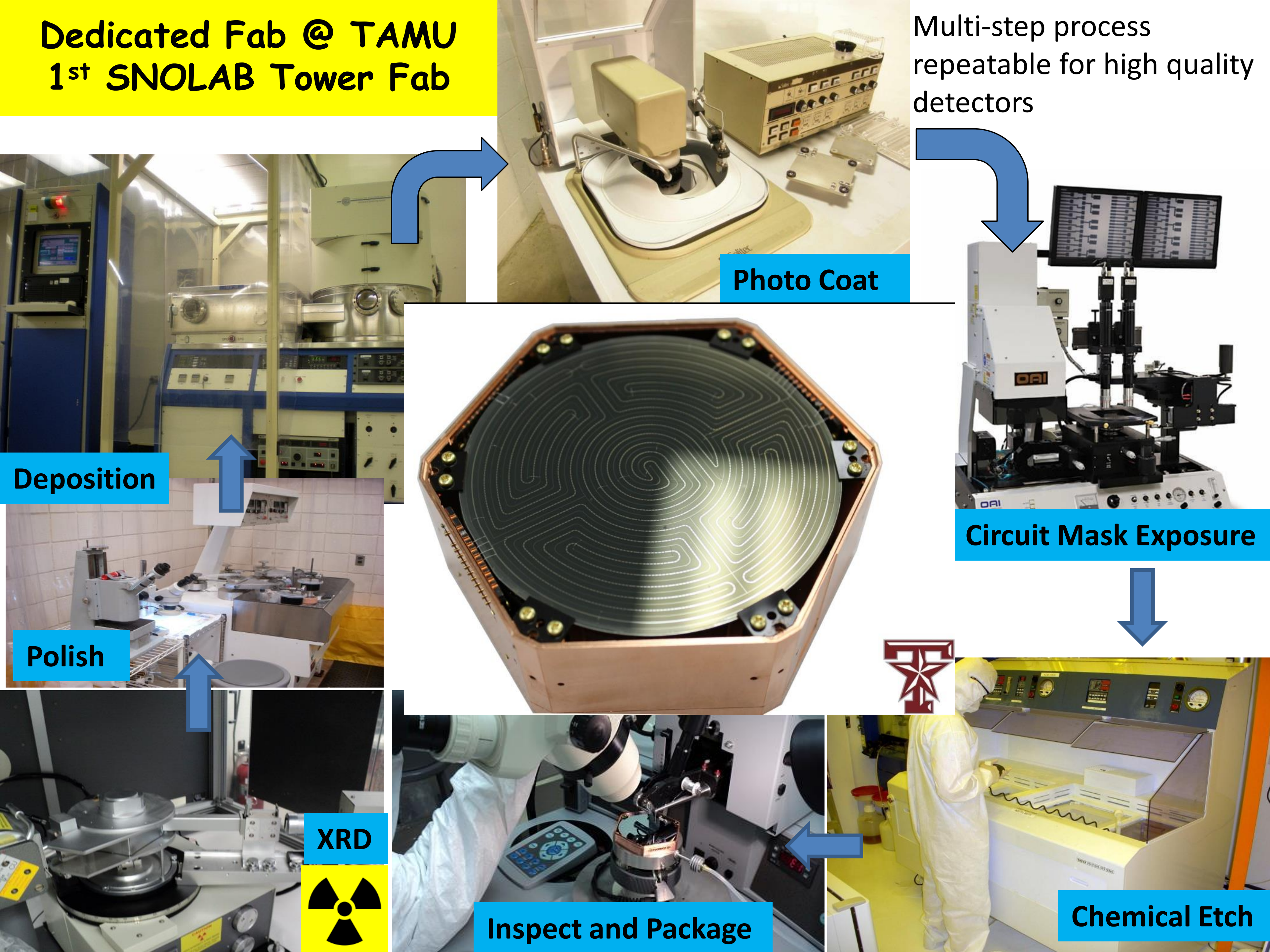


Phonon Sensors





Phonons are collected by superconducting Al fins (Δ=~meV), creating quasi particles that are then trapped by the W Transition Edge Sensors (TES), held in equilibrium between Normal and Super Conducting temp. SQUIDs measure small change in current through sharp ΔR/ΔT

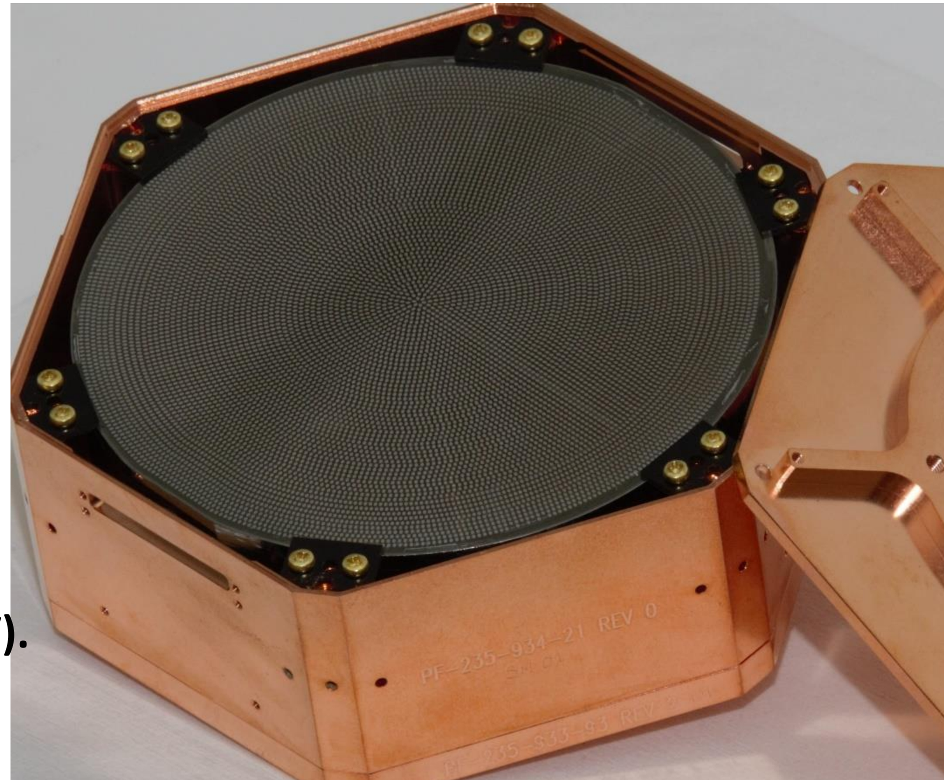

Dedicated Fab @ TAMU
1st SNOLAB Tower Fab
Multi-step process repeatable for high quality detectors
Photo Coat
Circuit Mask Exposure
Chemical Etch
Inspect and Package
XRD
Polish
Deposition

Detector Technologies – iZIP and HV

iZIP Detector with ionization and phonon sensors for ER/NR discrimination (>keV)

First SNOLAB Ge iZIP (fabricated at TAMU)

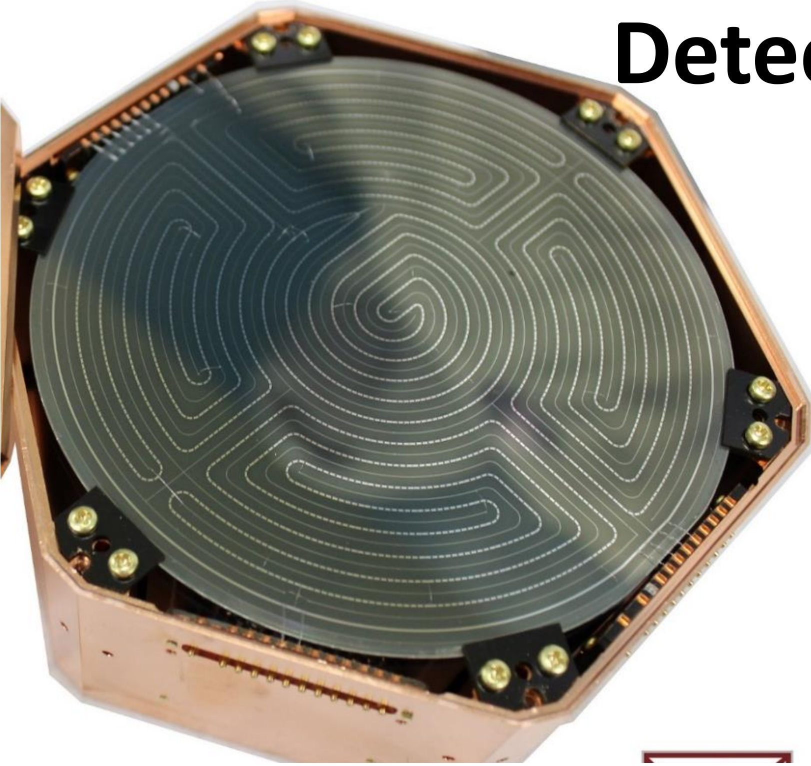
https://arxiv.org/pdf/1610.00006.pdf



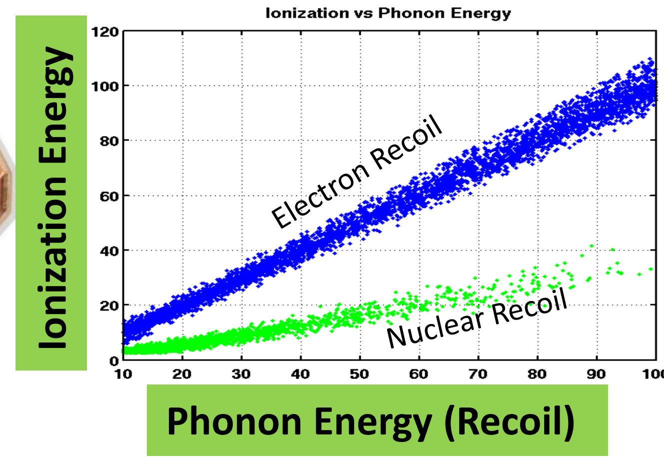
High Voltage Detector with NTL gain. Give up discrimination in favor of low threshold (~100eV).

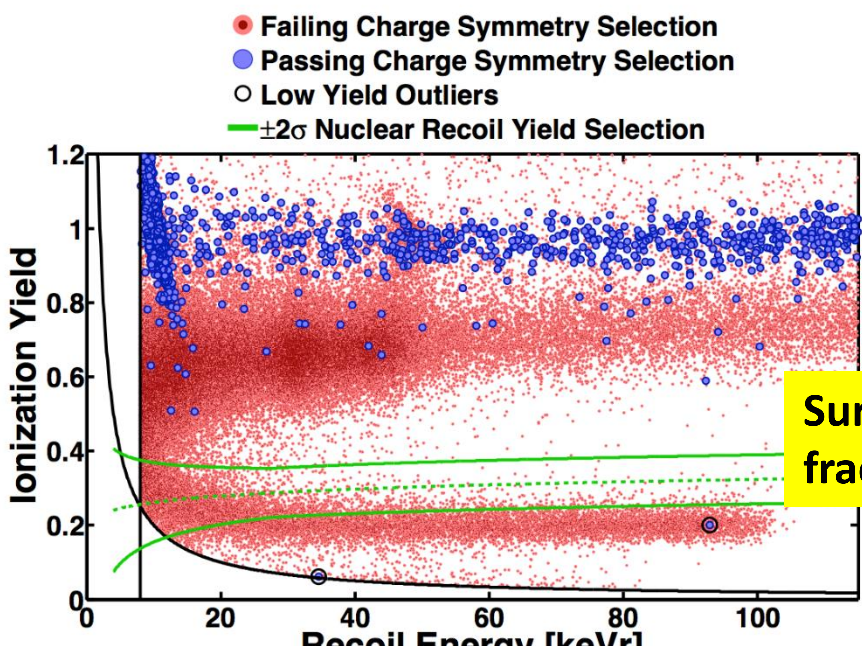
First SNOLAB Si HV (fabricated at TAMU)

Detector Technologies - iZIP

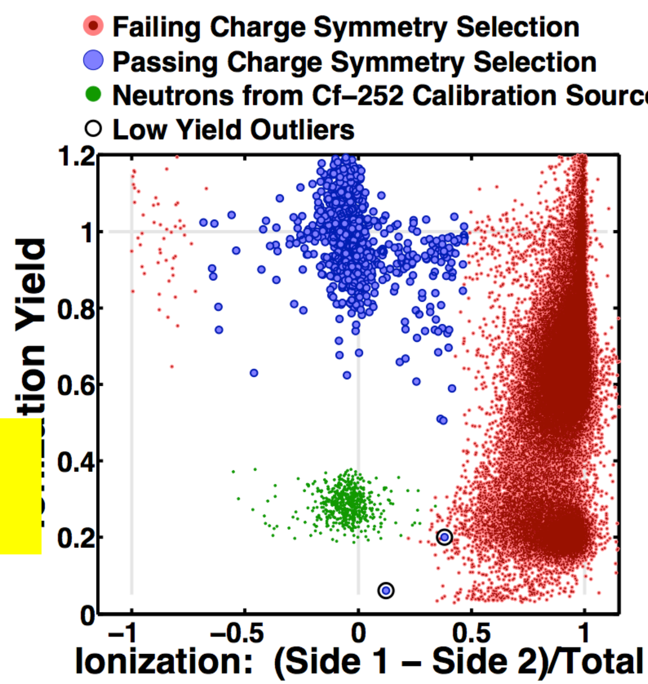


Simultaneous measurement of ionization and phonon for ER/NR discrimination (>keV)

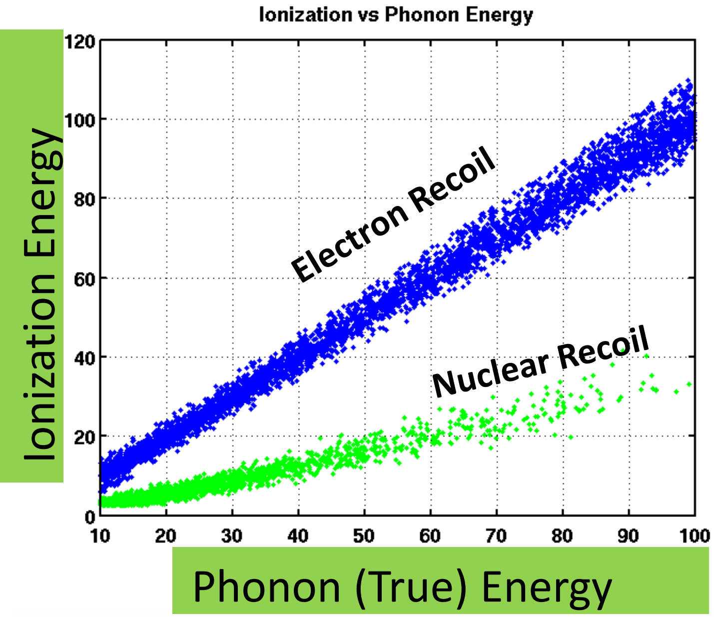




Surface event leakage fraction <1.7×10^{-5}



Detector Technologies – High Voltage (HV)

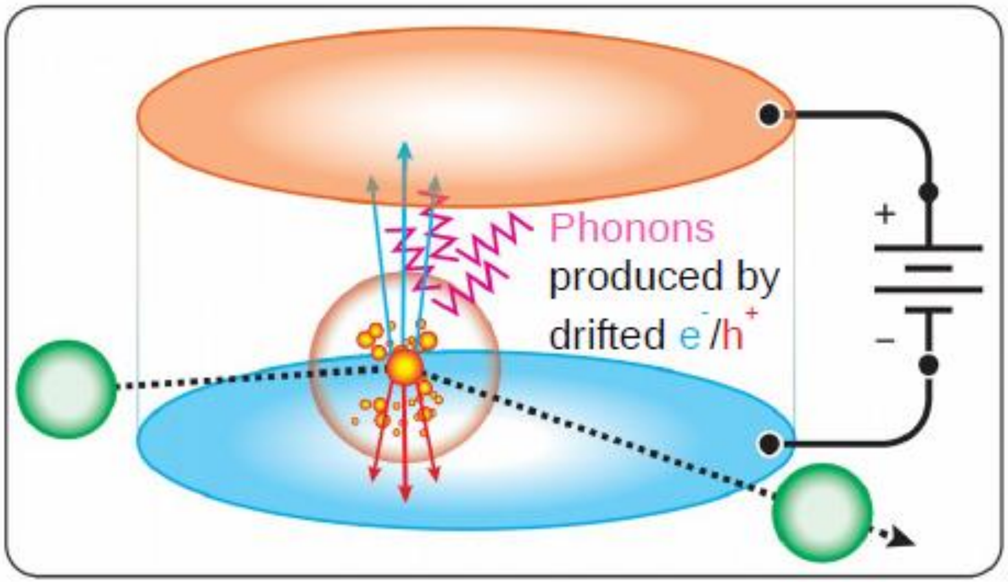


Ionization efficiency small (~1/5) at low energies

To detect low WIMP nuclear recoil, challenge is to measure the much lower ionization signal

Use Luke-Neganov amplification: Drifting electron across high voltage would produce lots of phonons

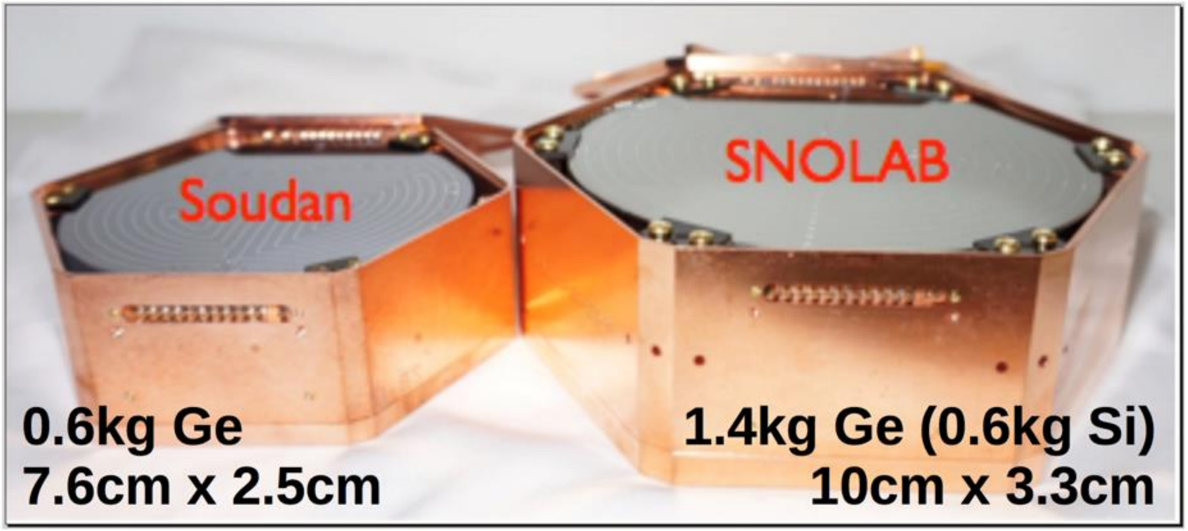
Phonon-based charge amplification through Voltage has already been used by CDMSLite up to 25V/cm.
9 eVee baseline resolution achieved for ~kg-scale



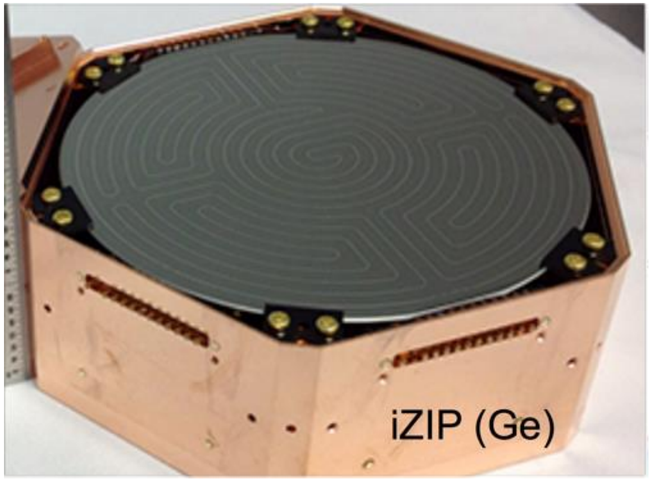
- **Luke**-Neganov Gain

$$E_{tot} = E_r + E_{luke}$$
$$= E_r + n_{eh} e V_b$$
$$= E_r \left(1 + \frac{eV_b}{\epsilon_{eh}}\right)$$

Improved Detectors



- Bigger
- Larger voltage bias
- More position information
- Lower Tc for better phonon resolution
- Resolution approaching level of single electon-hole pair (for HV)

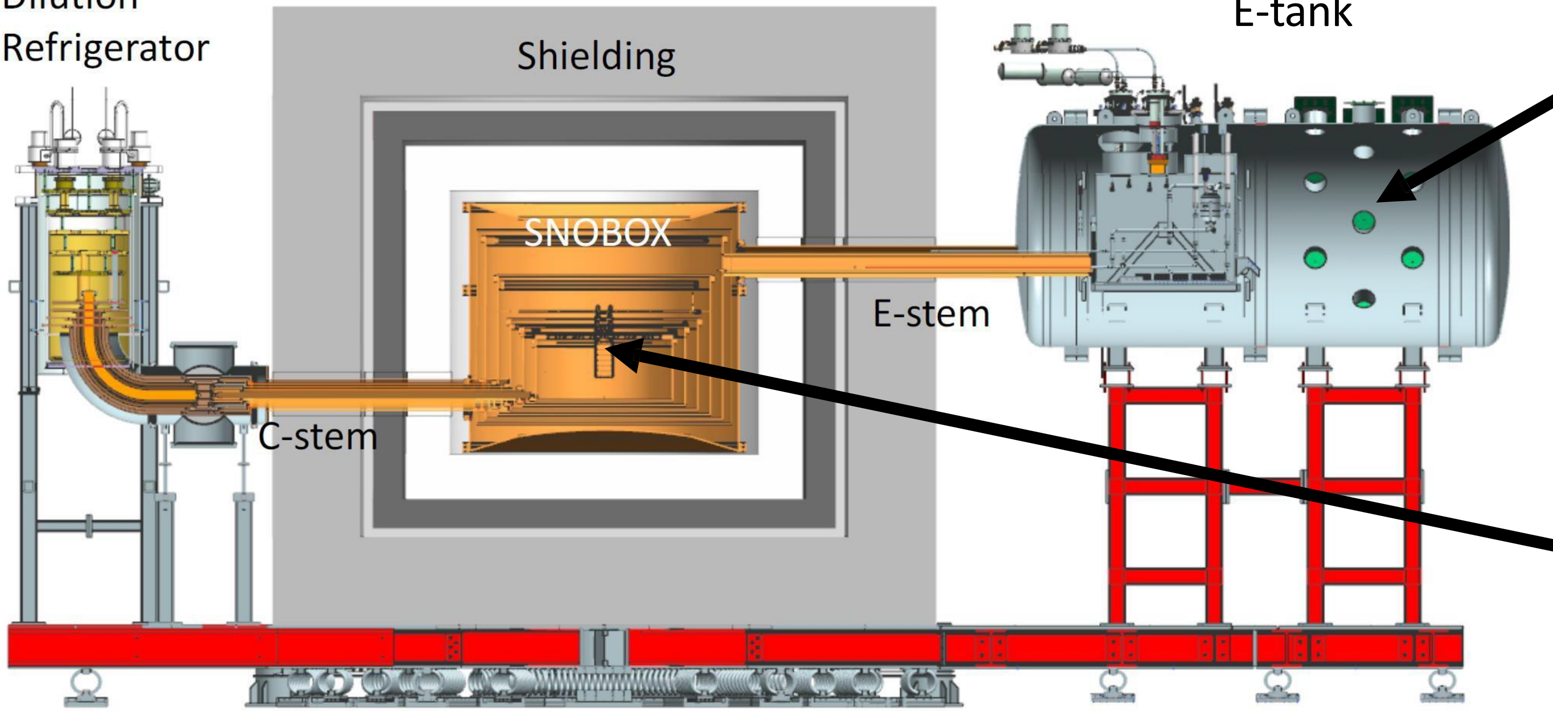


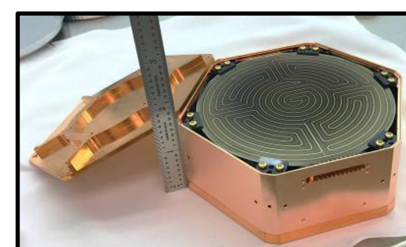
	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure (kg·yr)	56	4.8	44	9.6
Phonon resolution (eV)	50	25	10	5
Ionization resolution (eV)	100	110	–	–
Voltage Bias (V)	6	8	100	100

Expected threshold as per SuperCDMS SNOLAB sensitivity
<200 eVnr in iZIP and <40 eVnr in HV detectors

https://arxiv.org/pdf/1610.00006.pdf

SuperCDMS experiment design





C-Stem (cold) is stem for heat conduction to a dilution refrigerator

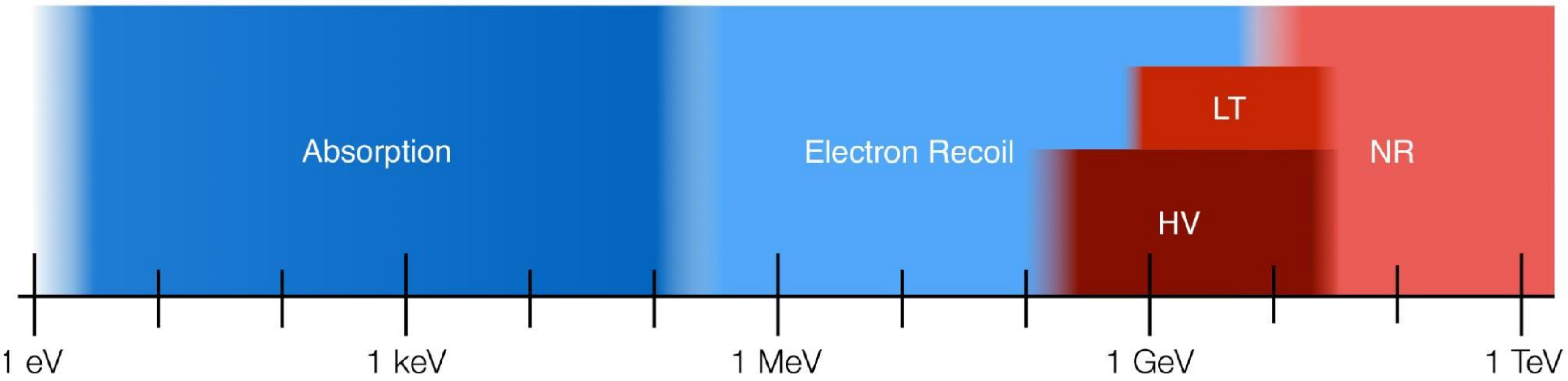
Shielding:
- Cu cans
- Inner neutron shield
- Pb gamma shield
- Outer neutron shield

E-tank is the vacuum bulkhead where the detector readout boards (DCRCs) connect

E-Stem (electronic) carries signals out from the detectors

SuperCDMS: A broadband DM search

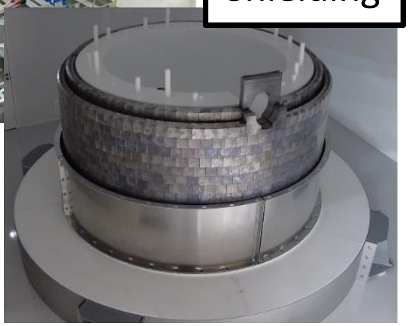
Traditional Nuclear Recoil	iZIP, Background free	>5 GeV
Low Threshold Nuclear Recoil	iZIP, limited discrimination	>1 GeV
HV mode	HV, no discrimination	0.3 - 10 GeV
Electron recoil	HV, no discrimination	0.5 MeV - 10 GeV
Absorption (Dark Photons, ALPs)	HV, no discrimination	1 eV - 500 keV

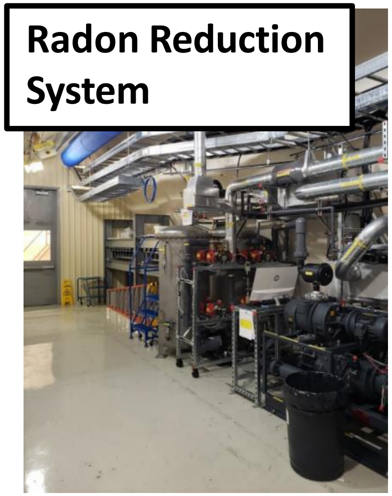


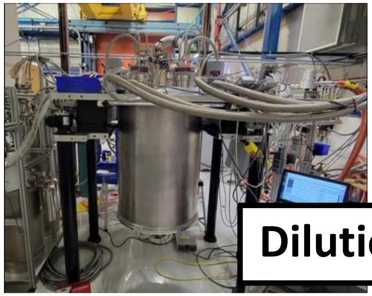
SuperCDMS installation in progress

Component deliveries to SNOLAB by the construction project

Plan	Status
Seismic Platform	Installed
3T Gantry Crane	Installed
Radon Reduction System	Installed
Cleanroom	Installed
DAQ	Installed
Computing	Offsite, data transferred to SLAC and others
Calibration	Preparing to ship
Readout Electronics	Complete
Dilution Refrigerator	Received from vendor
Shielding	Received from vendor
Detector Towers	Scheduling The Work
SNOBOX	In Development





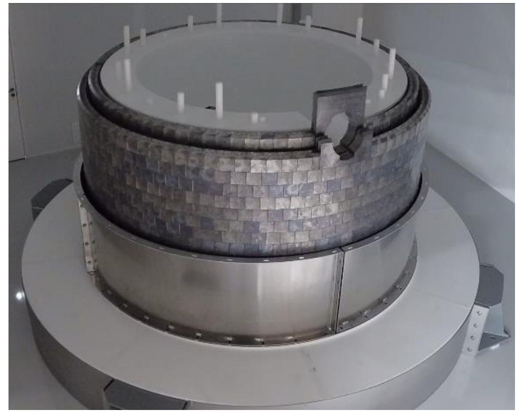


Plan is to start commissioning run in 2023!

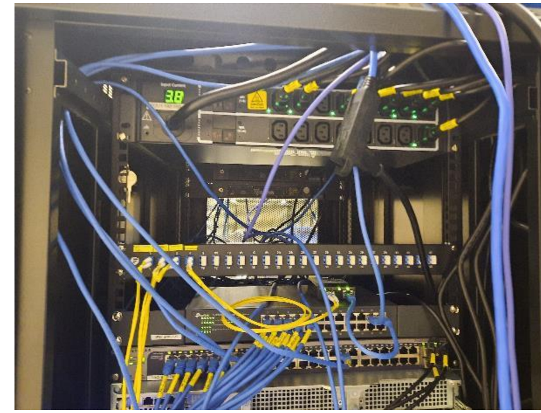
SuperCDMS installation in progress

Seismic platform

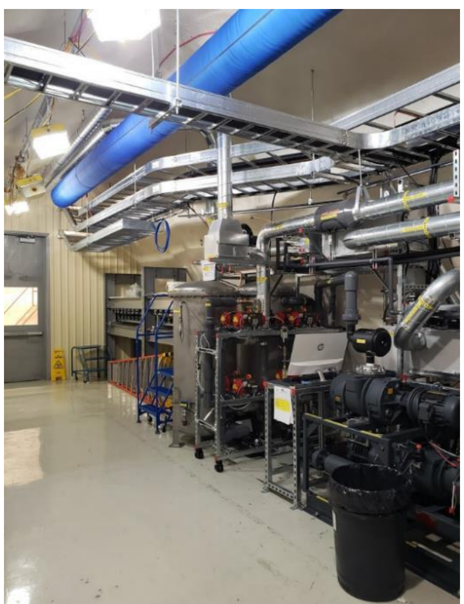
Inner lead and polyethylene shield



Hardware

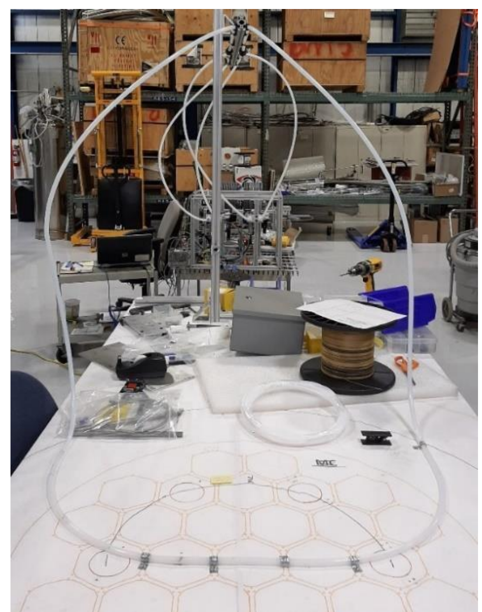


Radon filter system



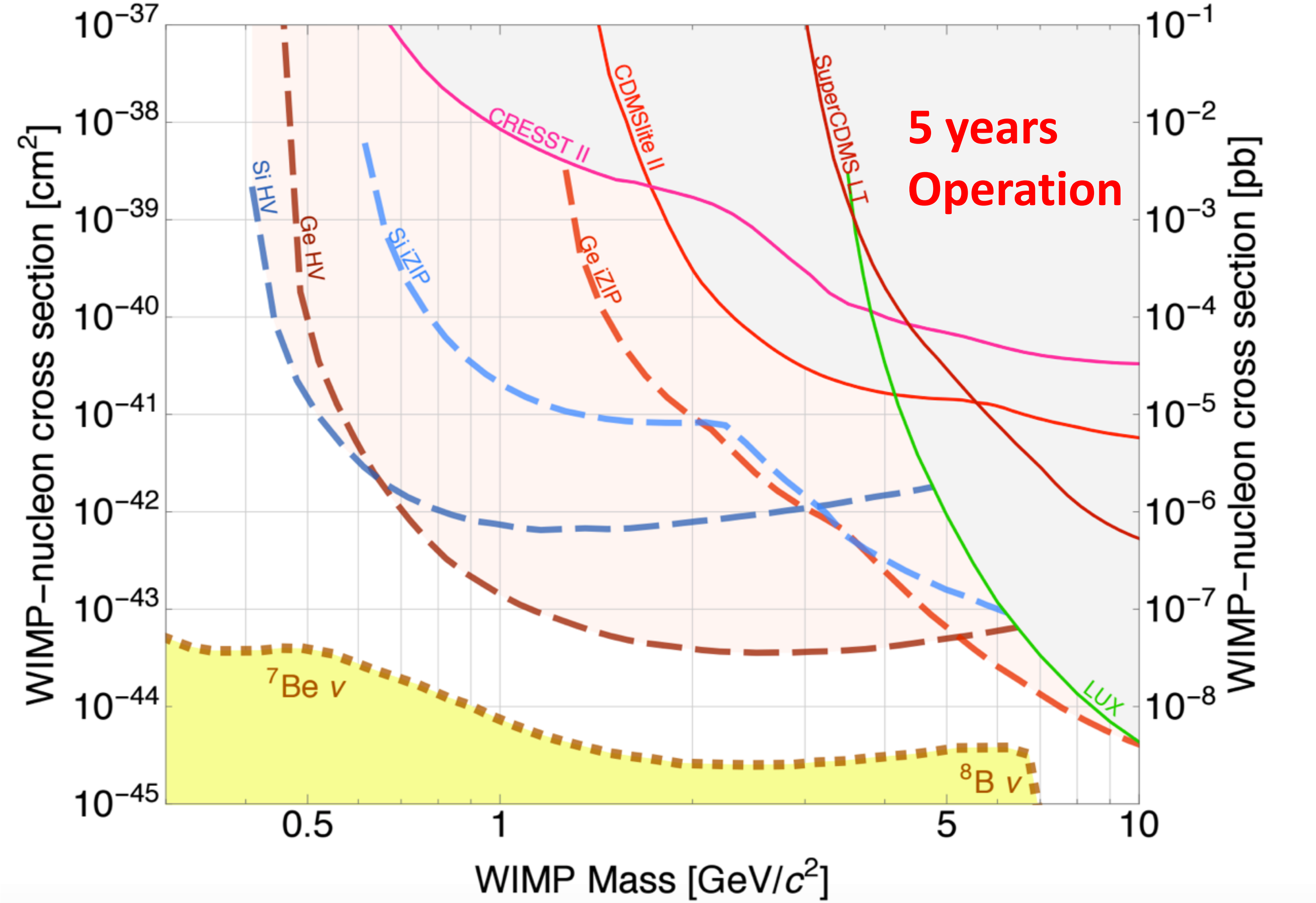
Chilled waterloop

Calibration system



Plan is to start commissioning run in 2023!

Projected Sensitivity

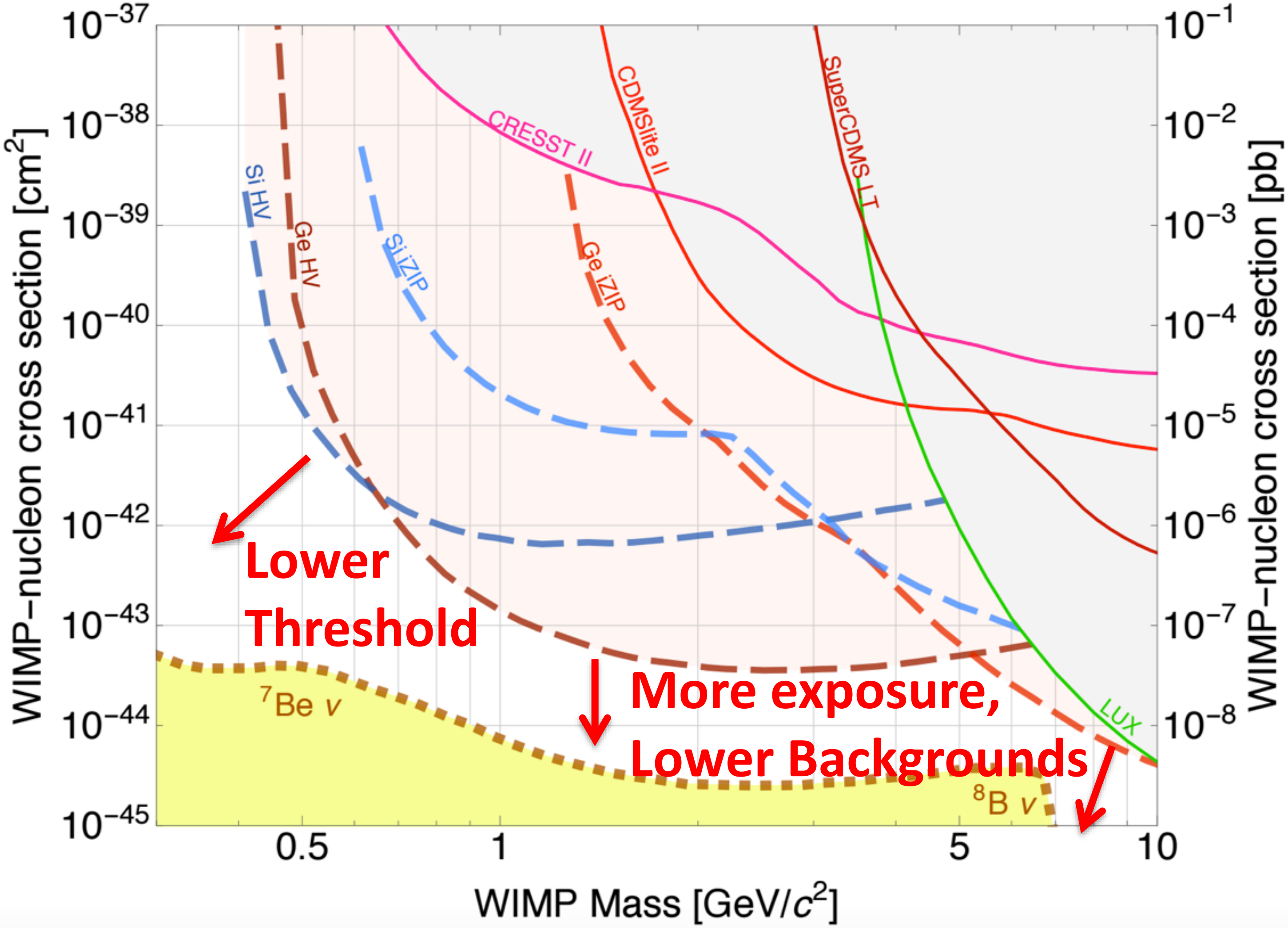


arXiv:1610.00006

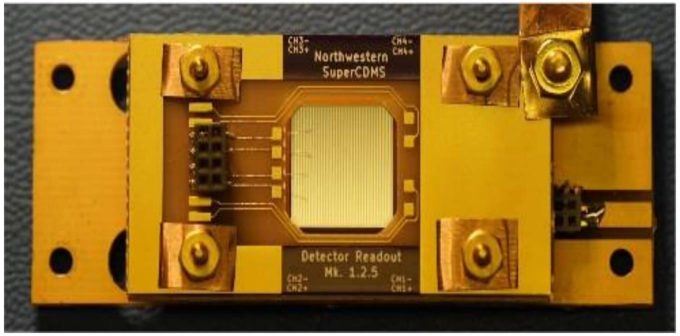
Limits obtained with conservative optimum interval **method**, no background subtraction

Future SNOLAB Upgrades

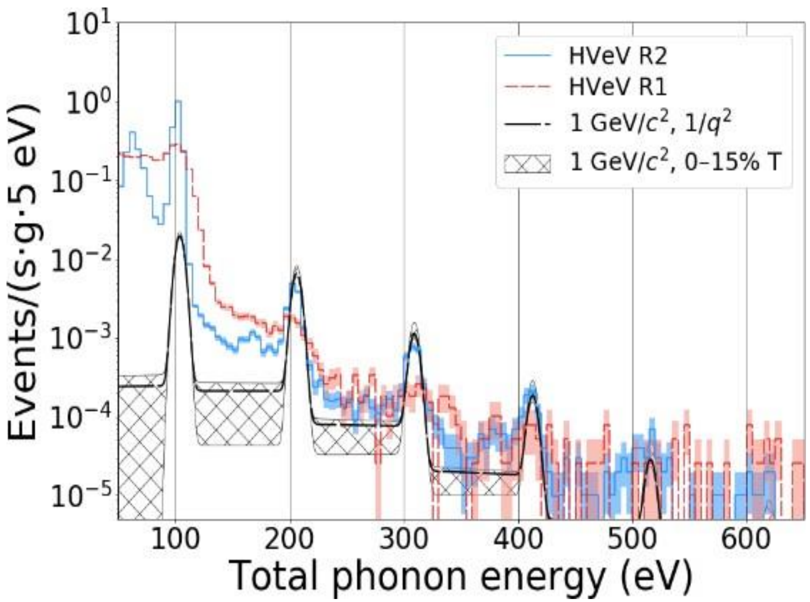
Let's reach the solar neutrino floor!

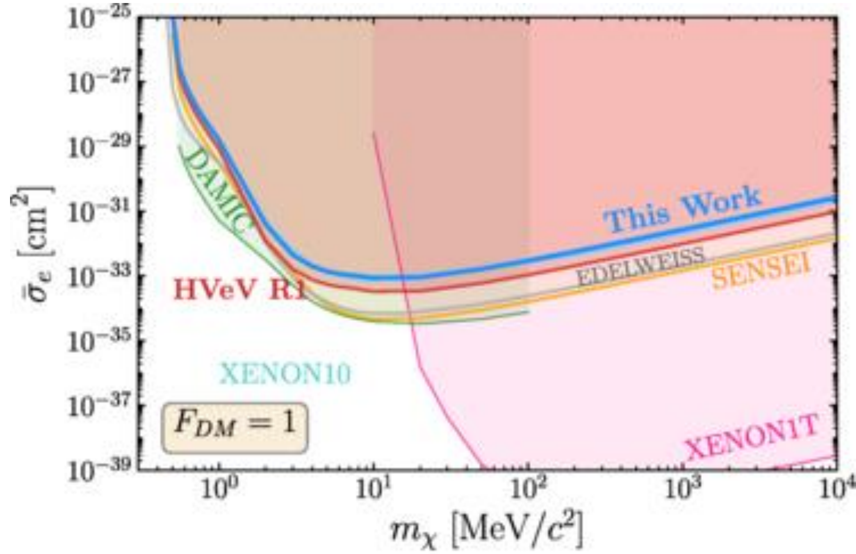


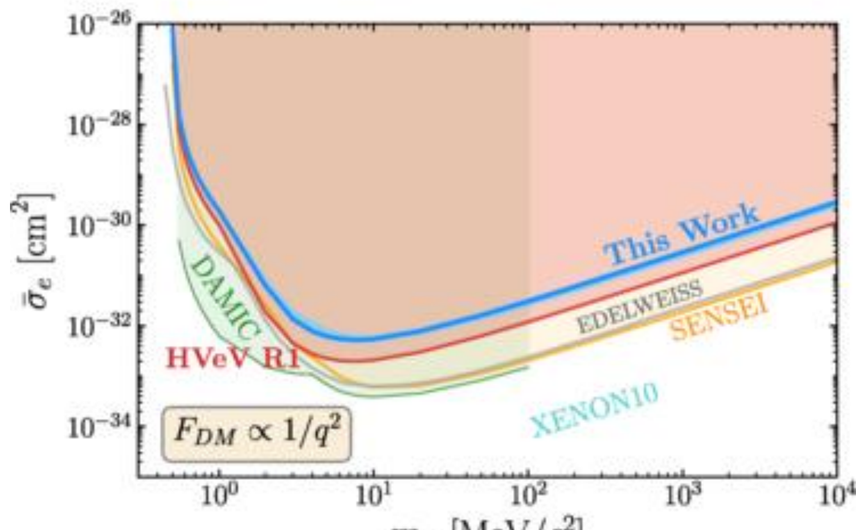
Single-e sensitive HVeV Detector (gram -scale)



Single-e sensitivity has been demonstrated at gram-scale ($1cm^2$x4mm) Si detector. Run 1 at Stanford and Run 2 at Northwestern provided world leading low-mass sensitivity





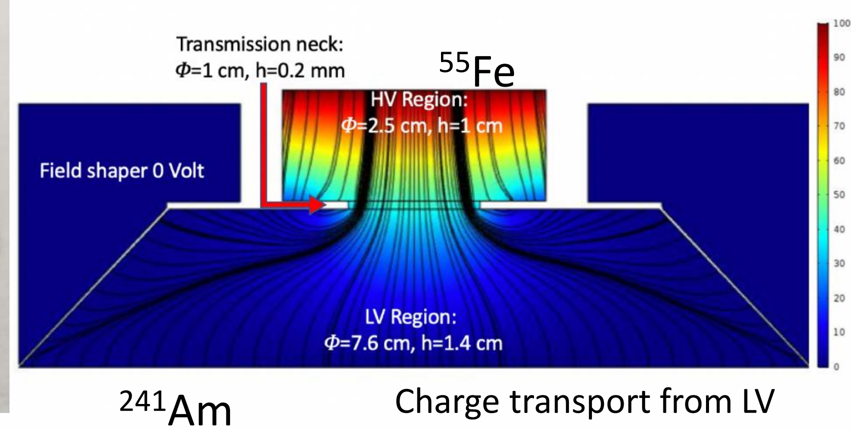


See Schmidt talk on energy calibration with HVeV

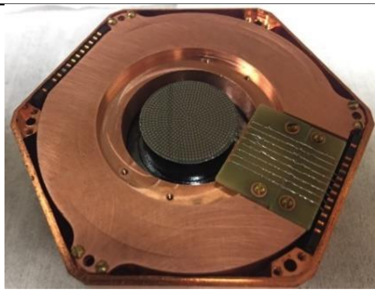
Phys. Rev. D 102, 091101(R)

Hybrid HV Detector

Main idea: Monolithic detector with a LV and a HV side – LV to measure primary phonons like iZIP and HV to measure NTL phonons. Do it without significant NTL pollution from HV to LV. **~100gm**



Charge transport from LV region to HV almost 100%

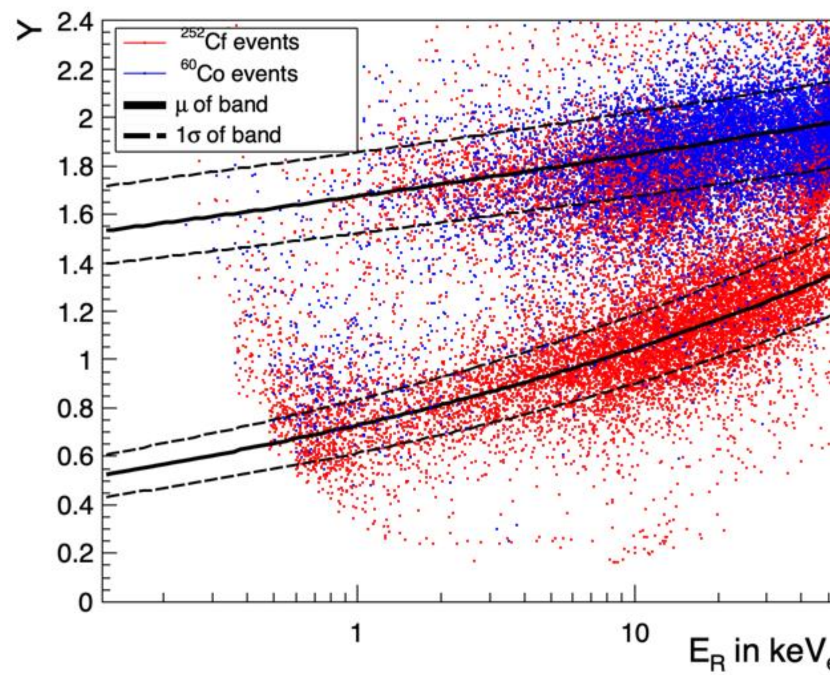


$$P_{HV} = \alpha[(1-\eta_{HL})E_R LV_{HV}/4 + \eta_{LH} E_R (1 + LV_{LV}/4)]$$

$$P_{LV} = \beta[\eta_{HL} E_R LV_{HV}/4 + (1-\eta_{LH}) E_R (1 + LV_{LV}/4)]$$

$$\text{Discrimination}: D = \frac{P_{HV}}{P_{LV}}$$

Discrimination improves at low energies due to the Lindhard suppression of NR ionization. Funded by DOE for DM and CEνNS searches



Phonon-mediated High-voltage Detector with Background Rejection for Low-mass Dark Matter and Reactor Coherent Neutrino Scattering Experiments:
https://inspirehep.net/literature/1802528

Detector R&D for G2+

Exiting new detector technology being developed by the collaboration for low-energy detection. Reduced charge leakage, reduced Tc (σ scales as Tc^3) and improved design pushes the frontier for both HV detectors as well as 0V phonon detectors.

record low noise TES

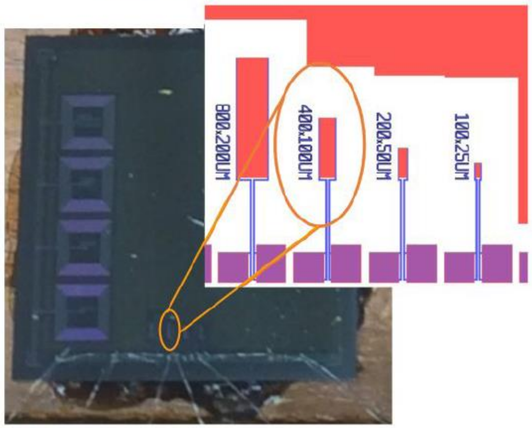
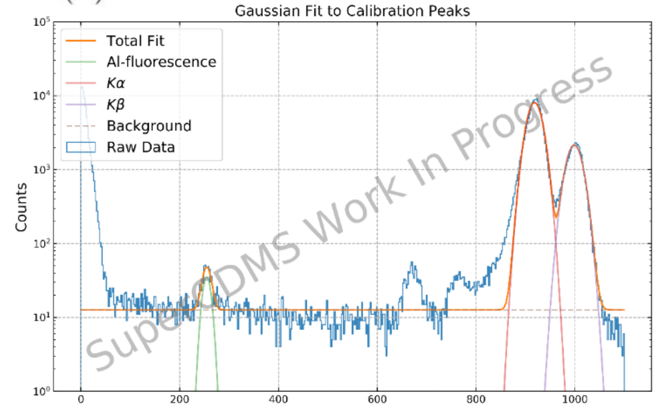


Figure 7: Simple small volume R&D TES test structures that have been fabricated by Texas A&M and tested by U C Berkeley. The 40mK 100umx400umx40nm thick TES has achieved a measured sensor resolution of 40meV and the requisite environmental noise isolation needed for requirement

TES	T_c [mK]	Volume [μm $\times \mu$m $\times$ nm]	σ_E [meV]	$\frac{\sigma_E}{\sqrt{V}}\left[\frac{\text{meV}}{\sqrt{\mu\text{m}^3}}\right]$
W [2]	125	25×25×35	120	25.7
Ti [3]	50 100	6×0.4×56	47 47	128.2
MoCu [4]	110.6	100×100×200	295.4	6.6
TiAu [5]	106	10×10×90	48	16
TiAu [6]	90	50×50×81	~23*	1.6
W	40	100×400×40	40	1.0

record resolution athermal phonon detector

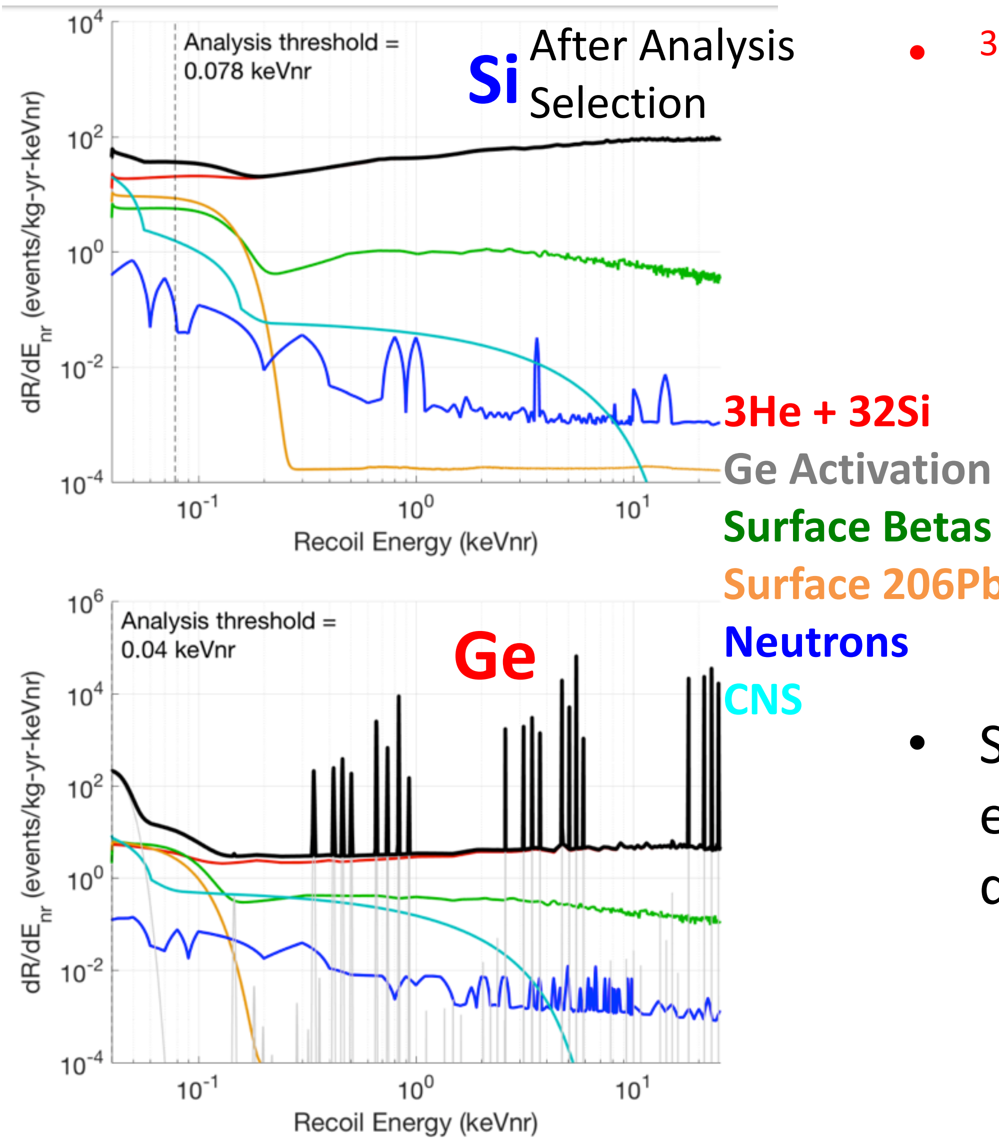
Figure 2: Photo of prototype athermal phonon detector on thick silicon wafer of similar characteristics to our baseline, but larger area. This demonstrator was fabricated at Texas A&M and achieved a 3.9 eV resolution (σ) over its 45 cm^2 collection area.



Summary

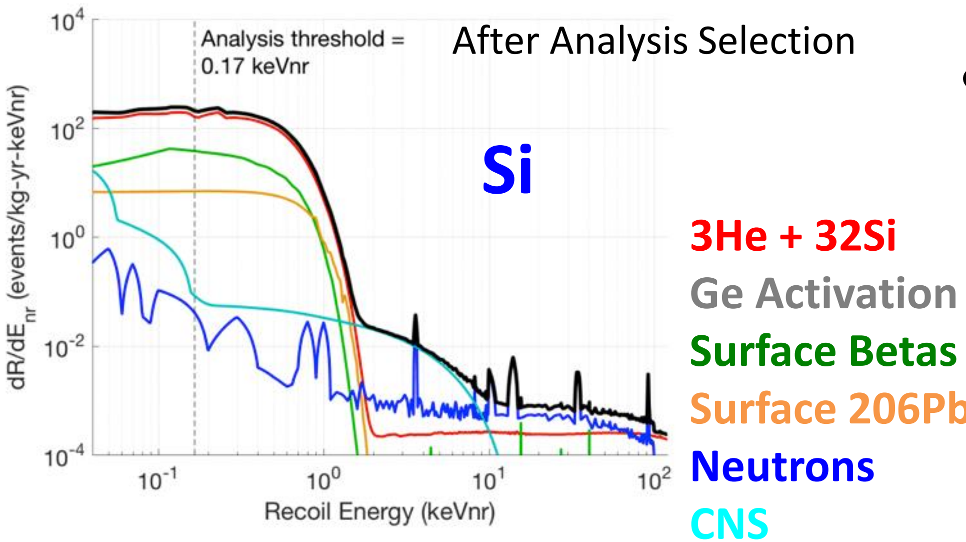
- SuperCDMS SNOLAB G2 making progress
- 4-tower initial payload for 5 years (2023-2028)
  - 25 kg Ge, 3.6 kg Si
  - iZIP (higher threshold, with ER/NR discrimination) and HV (low threshold, no discrimination) detectors
- Future improvements and payload increase with aim to reach neutrino floor
- Very active detector R&D program to push threshold down to single-electron sensitivity beyond the gram-scale HVeV detectors and maintain electron recoil-nuclear recoil discrimination below KeV by new technologies like the Hybrid detector.

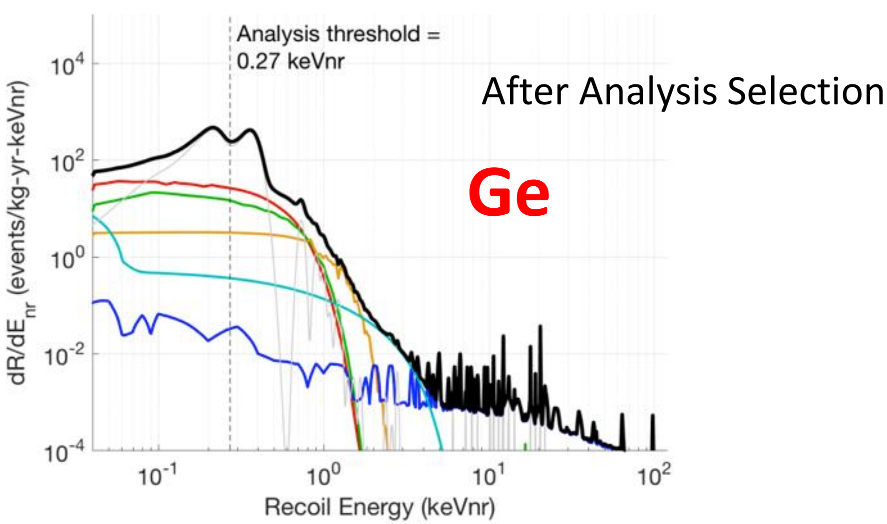
Expected Backgrounds in High Voltage Detectors



- ^{32}Si and ^{3}H limiting backgrounds
  - β-decay in detector bulk
  - ^{3}H produced cosmogenically in Ge and Si, builds up over time ($T_{1/2}$ = 12.3 years)
  - ^{32}Si produced cosmogenically from argon in atmosphere, seeps into natural Si and ends up in crystals
- Some control by limiting surface exposure of components and detectors

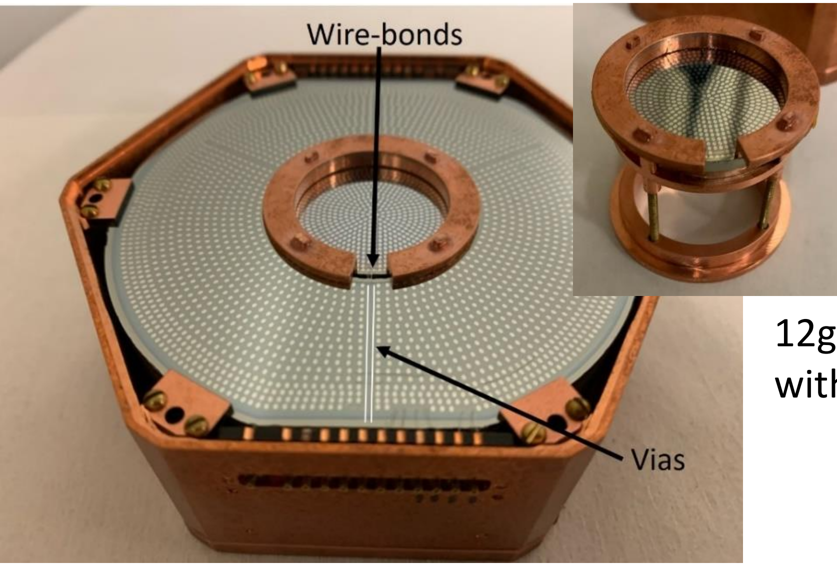
Expected Backgrounds in iZIP Detectors



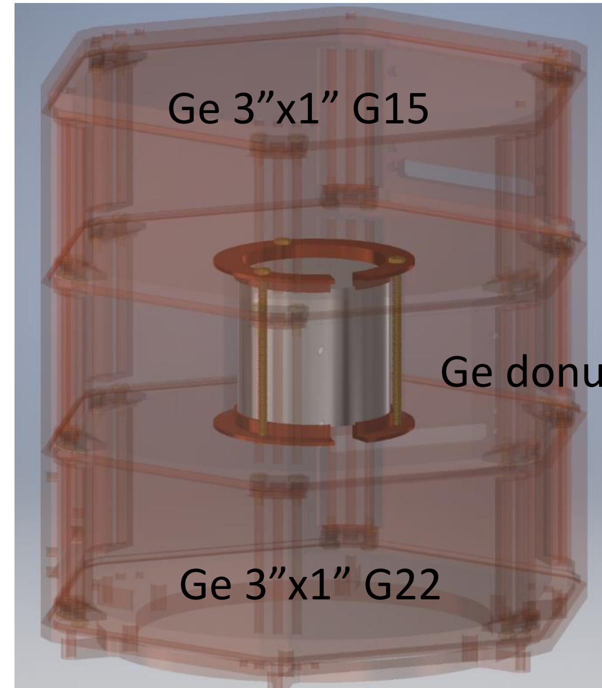


- Other backgrounds controlled to be < ^{3}H and ^{32}Si levels by:
  - 6000 m.w.e
  - Better screening of materials
  - Shielding design improvements
  - Better Radon mitigation (both in lab and during fabrication)

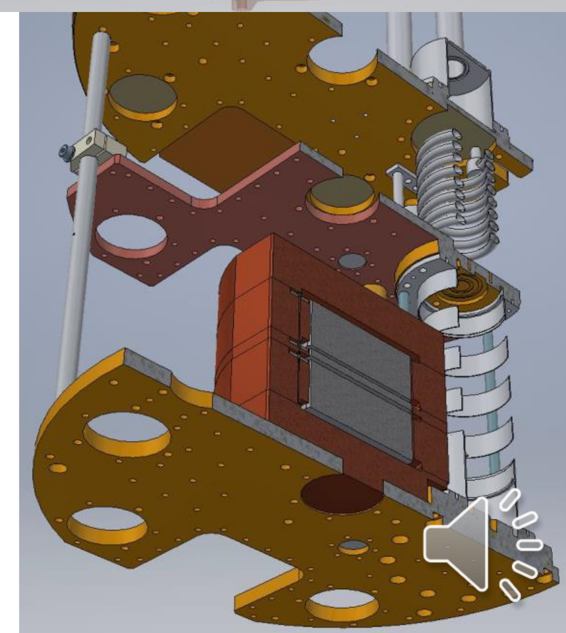
Low-Threshold Ge Detector inside Fully Hermetic Ge Shielding



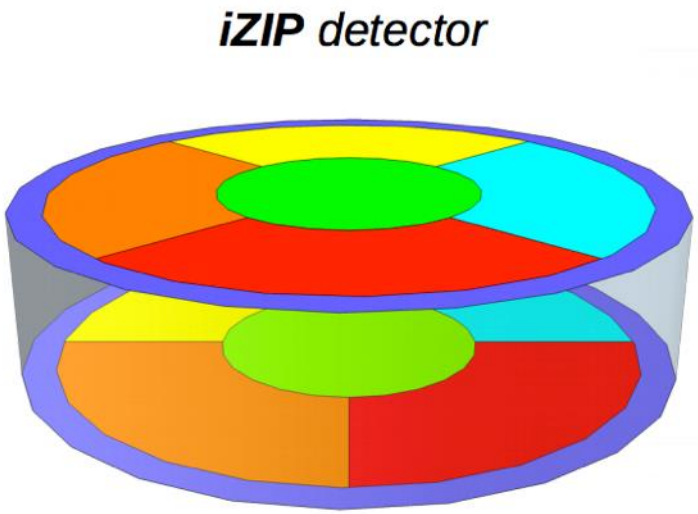
12gm Ge coin. Next runs with~30-75 gm Ge coins

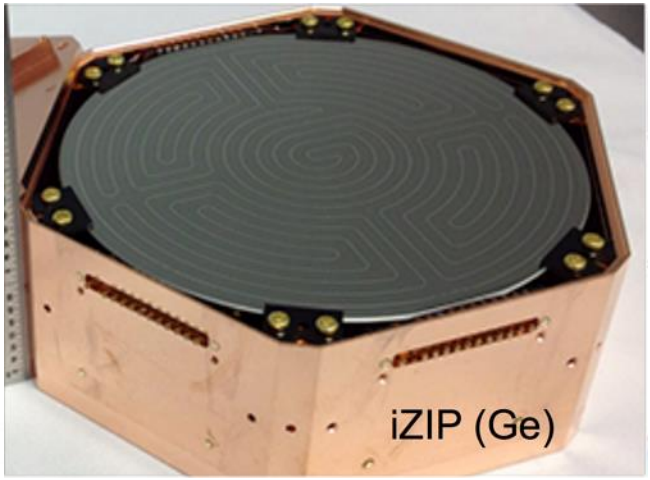


650 gm upper and lower detectors along with the donut veto (1" thick annulus) provide excellent hermetic active shielding/veto



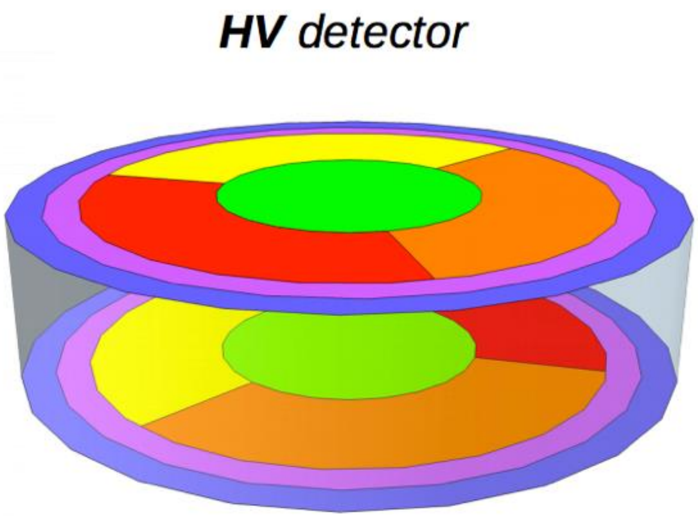
Detector Improvements





10 Ge, **2** Si
iZIP detectors

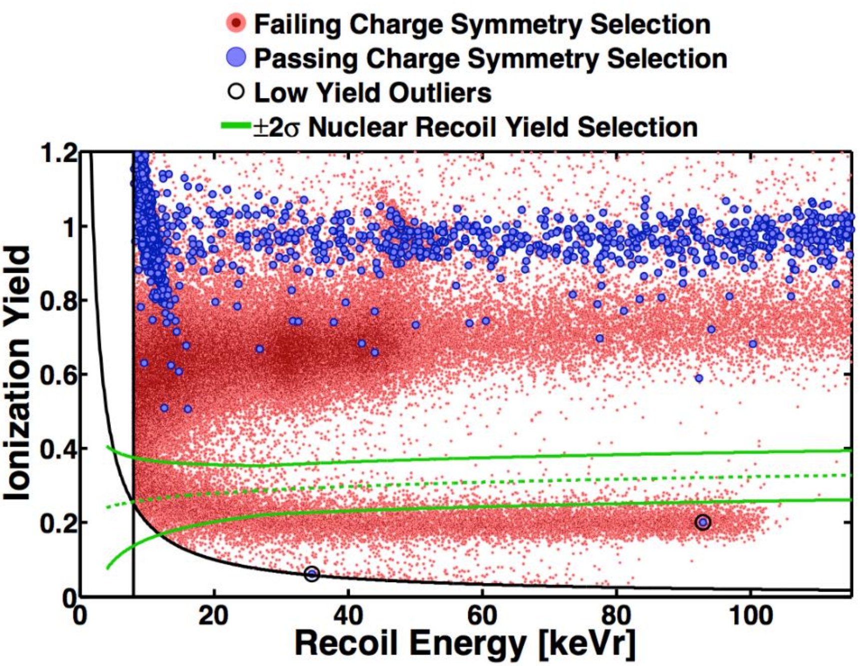
- Full background discrimination down to ~ 1keV



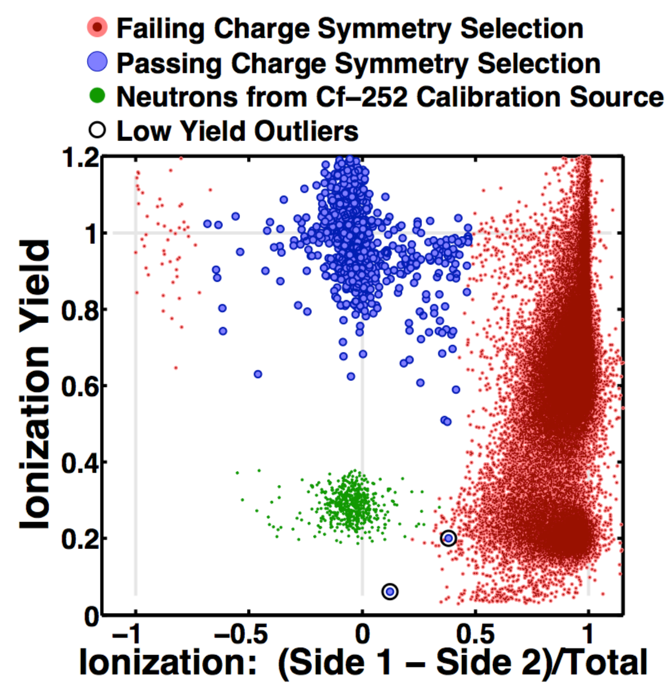
8 Ge, **4** Si **HV** detectors

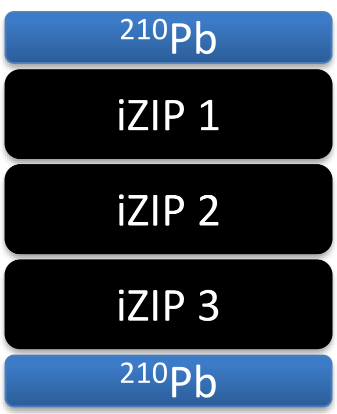
- Better resolution (5 eV in Ge, 10 eV in Si), lower threshold

SuperCDMS-Soudan iZIP Performance



- ^{210}Pb sources installed for SuperCDMS-Soudan
  - Limiting background for CDMS-II
- Surface event leakage fraction $<1.7 \times 10^{-5}$ (90% C.L.)





The traditional yield-based discrimination, combined with the new iZIP surface event identification results in excellent fiducial volume definitions and dark matter sensitivity.

arXiv:1305.2405; Appl. Phys. Lett. 103, 164105 (2013)