SuperCDMS SNOLAB

Andrew Kubik

on behalf of the SuperCDMS Collaboration

SUSY2019

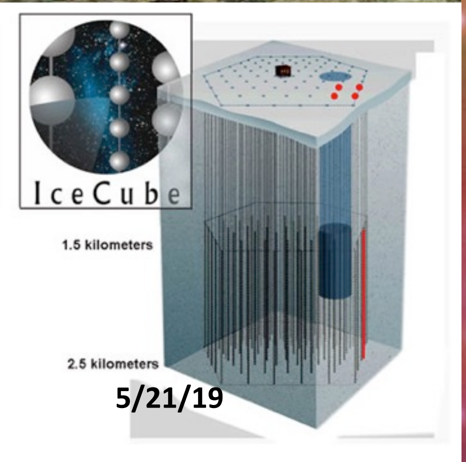
May 21, 2019

SuperCDMS


AMS-02


FERMI, Pamela, ATTIC


HESS, VERITAS, Magic



Annihilation in Cosmos

LHC

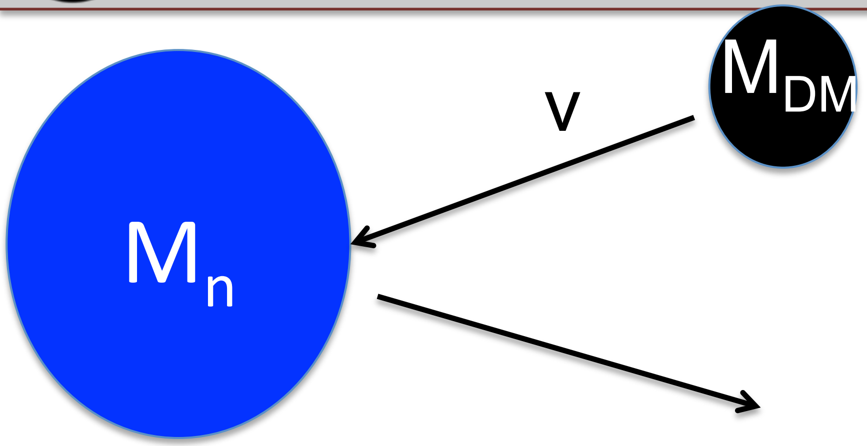
Production in Colliders

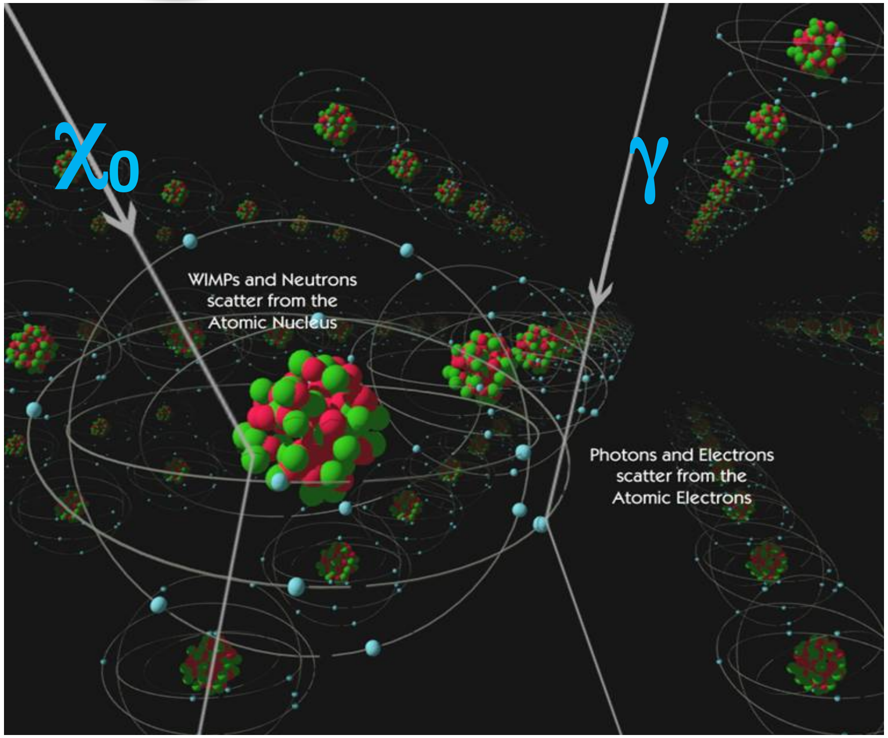
Direct Detection


SuperCDMS

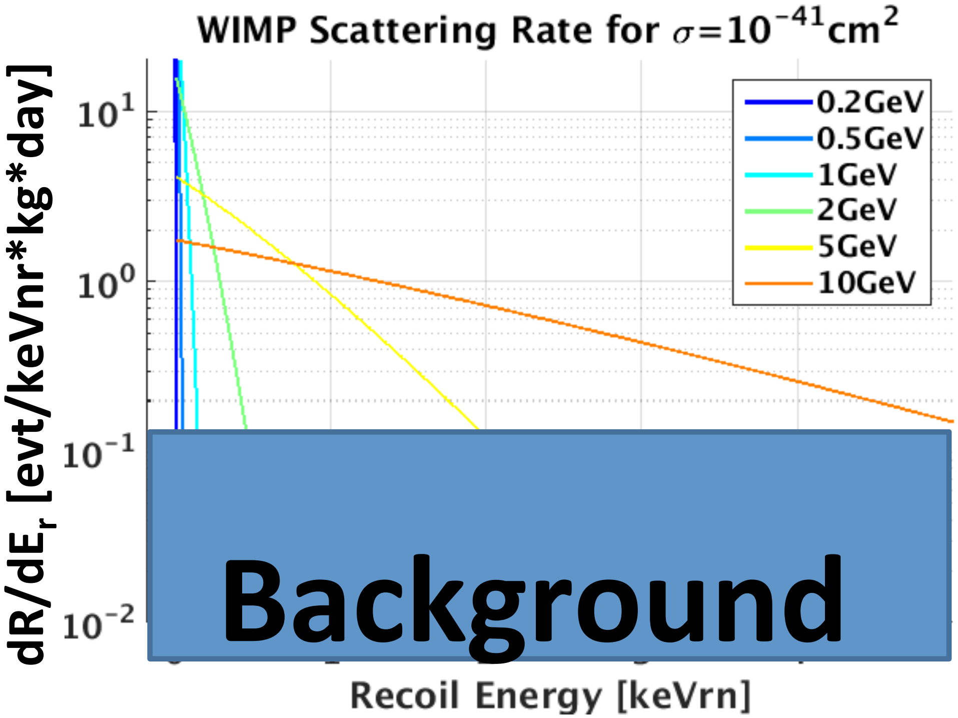

LUX

Direct Detection



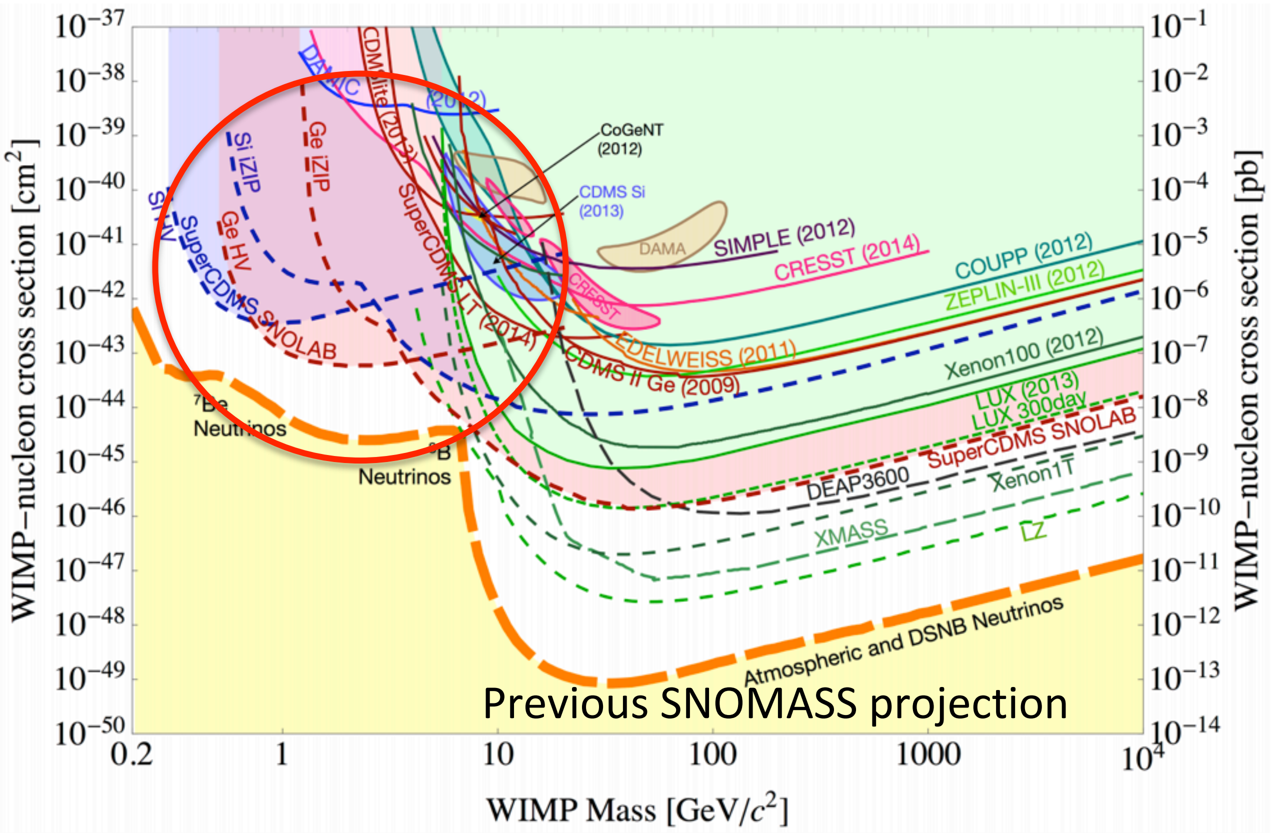


$$\Delta E = \frac{\Delta P^2}{2M_n} \lesssim \frac{2M_{DM}^2 v^2}{M_N}$$



- Start with a small signal and relatively huge radioactive background
- Reduce and Reject background
- Lower threshold

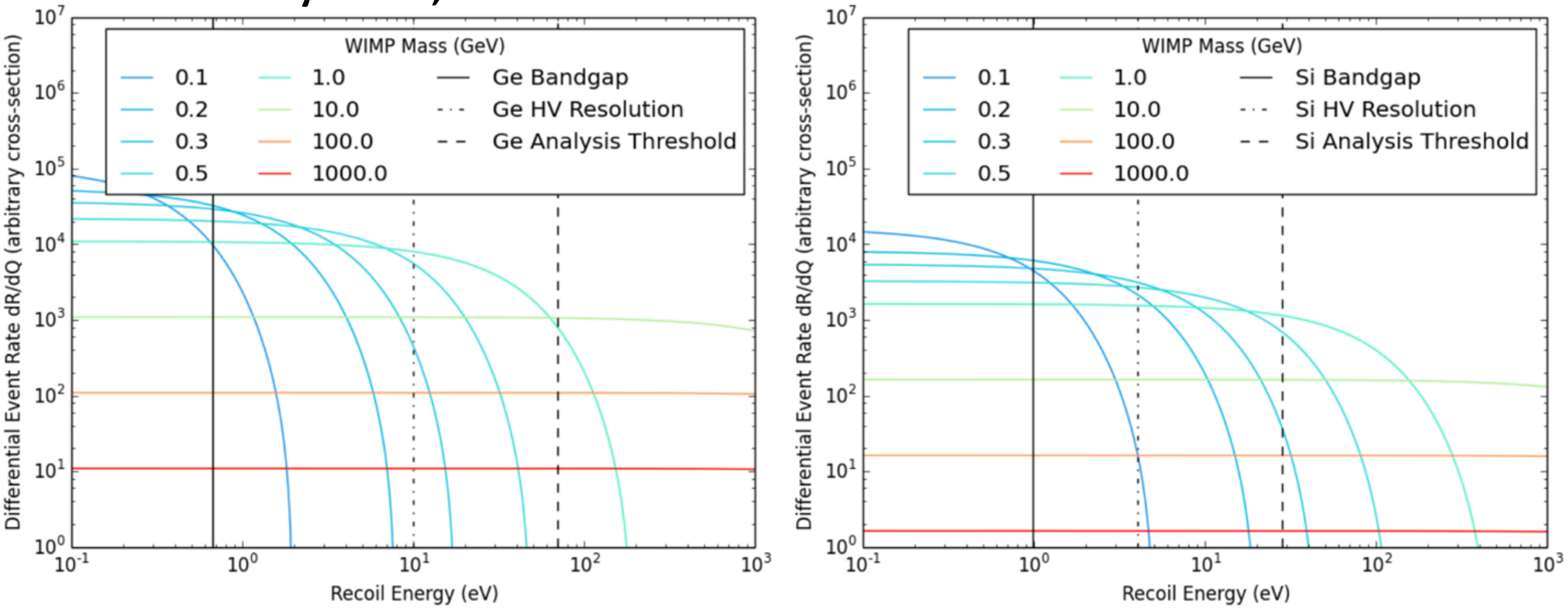
- **Low Mass DM models**
  - Not just WIMPS and not just nuclear recoils!
  - Asymmetric Dark Matter
  - Dark Sector
  - Many more …



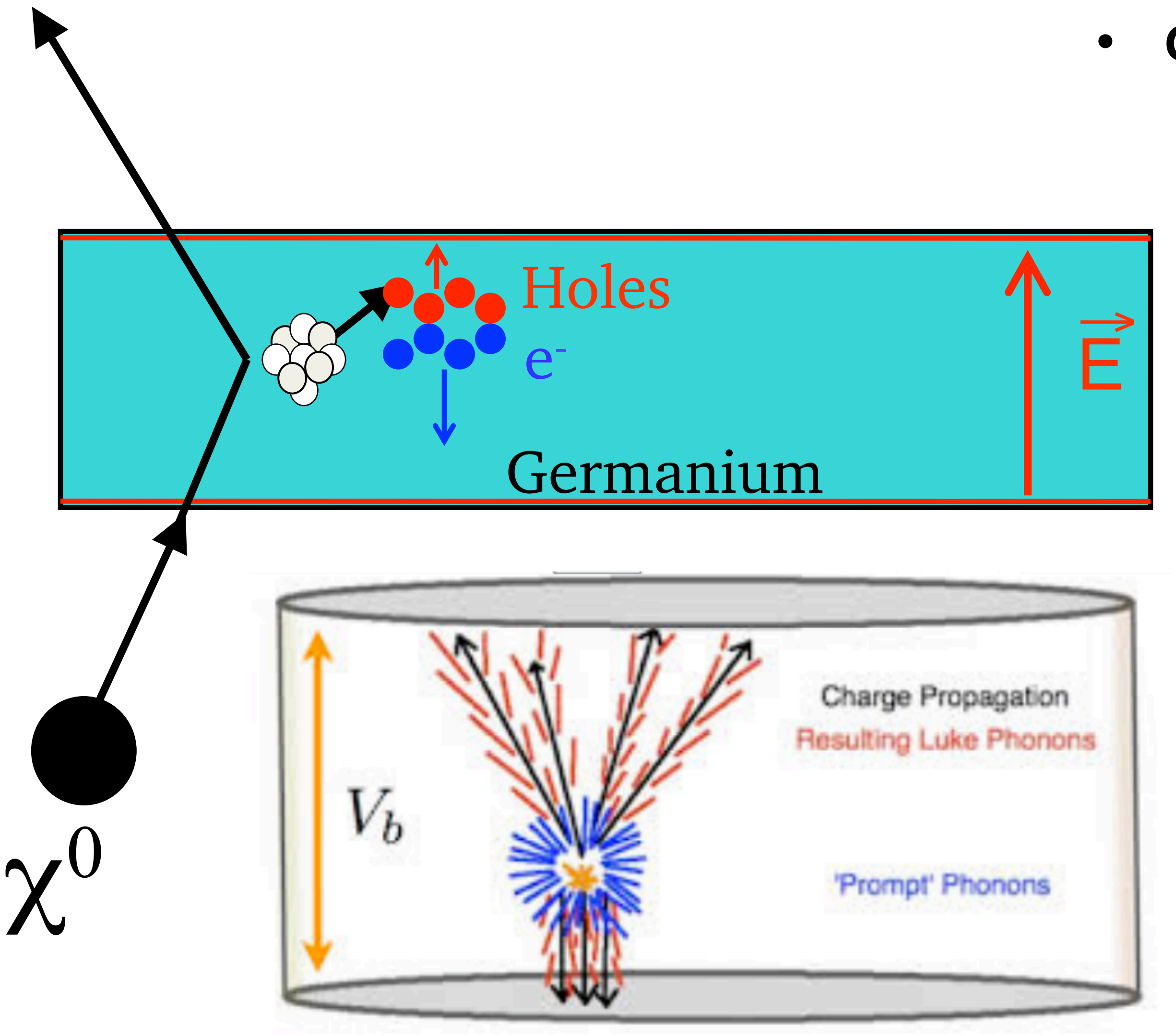
Previous SNOMASS projection

- **SuperCDMS SNOLAB focuses on low mass DM region**
  - Over three orders of magnitude better sensitivity
  - Driven by improvements in detector design, better background control, more exposure, and lower thresholds

Kurinsky et. al. , arXiv:1611.04083

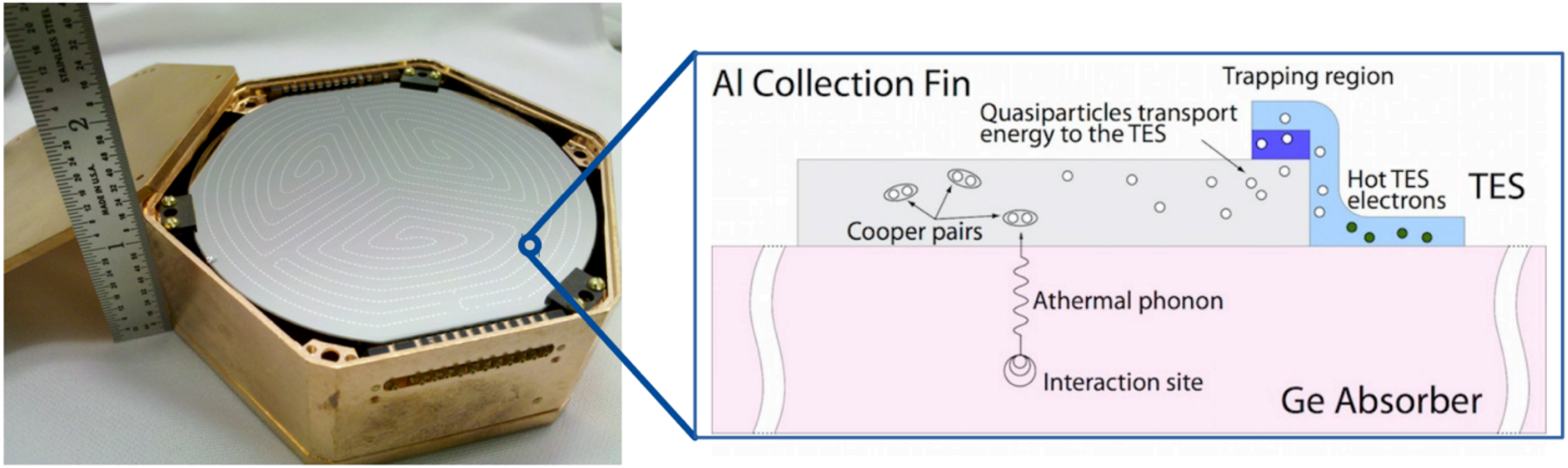


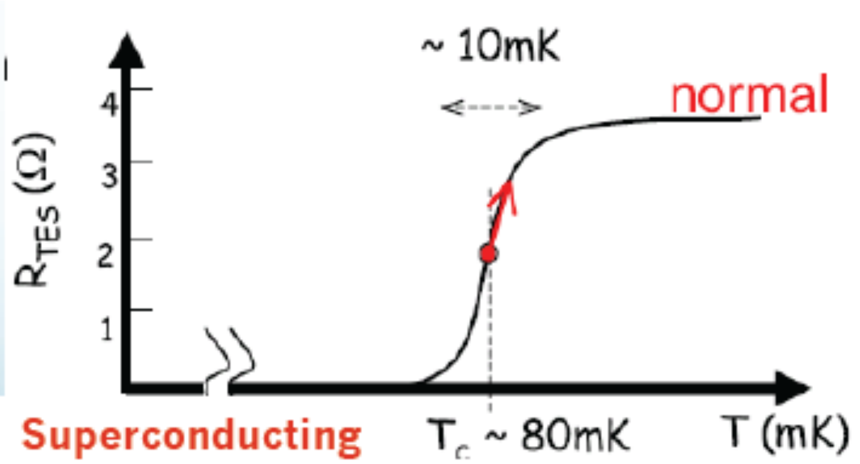
- Light DM searches require very low energy thresholds
  - – Example, rate vs. recoil energy for very light WIMPs



- **General Idea:**
  - Cryogenically cooled **Ge** or **Si** crystal
  - DM recoils off nucleus in target, creating athermal phonons and liberating electron hole pairs
  - Phonons read out using Transition Edge Sensor array
  - Electrons/holes drifted to surfaces by applied Voltage bias

Phonons

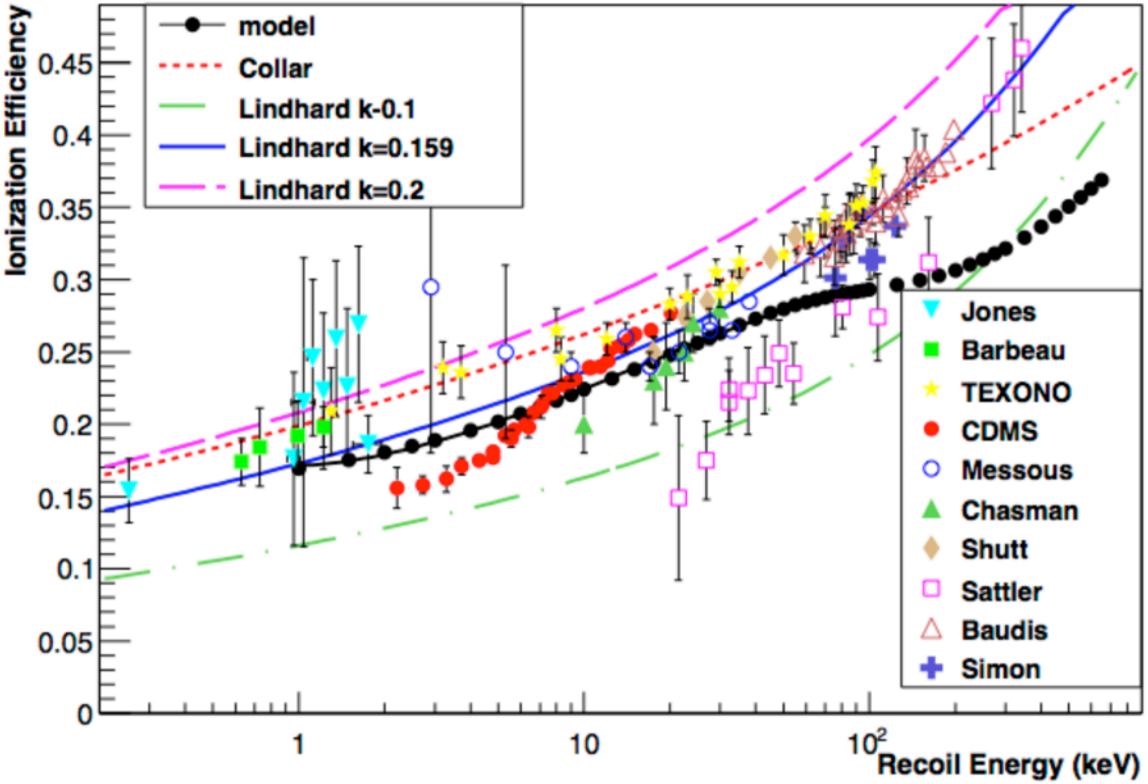




- Athermal phonons are collected in Al fins on surface, breaking Cooper pairs to create quasi-particles

- QPs travel to tungsten TES bringing heat which quickly alters the resistance, supplying the signal

$$\begin{aligned} E_{total} &= E_{recoil} + E_{luke} \\ &= E_{recoil} + Qe\Delta V \\ &= E_{recoil}\left(1 + \frac{\boxed{Y}e\Delta V}{< E_{eh} >}\right) \end{aligned}$$



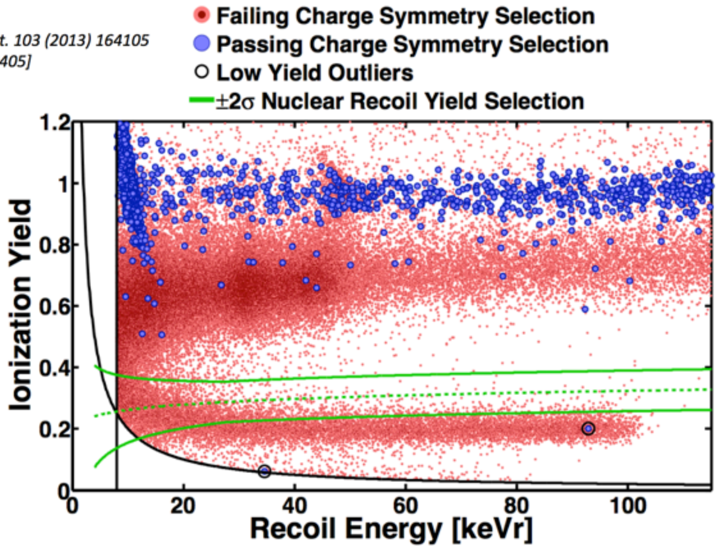
- **Electron recoils create electron-hole pairs**
  - 1 eh pair per ~2.9 eV in Ge, ~3.6 eV in Si

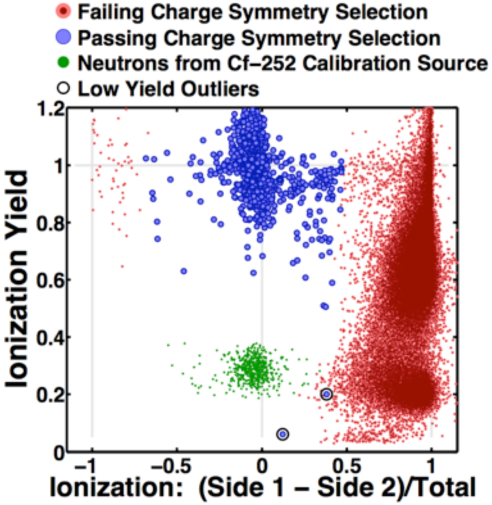
- **Nuclear recoils not so easy**
  - Use Lindhard scaling law to predict ionization as function of recoil energy
  - Ionization is **LESS** than that for equivalent electron recoil

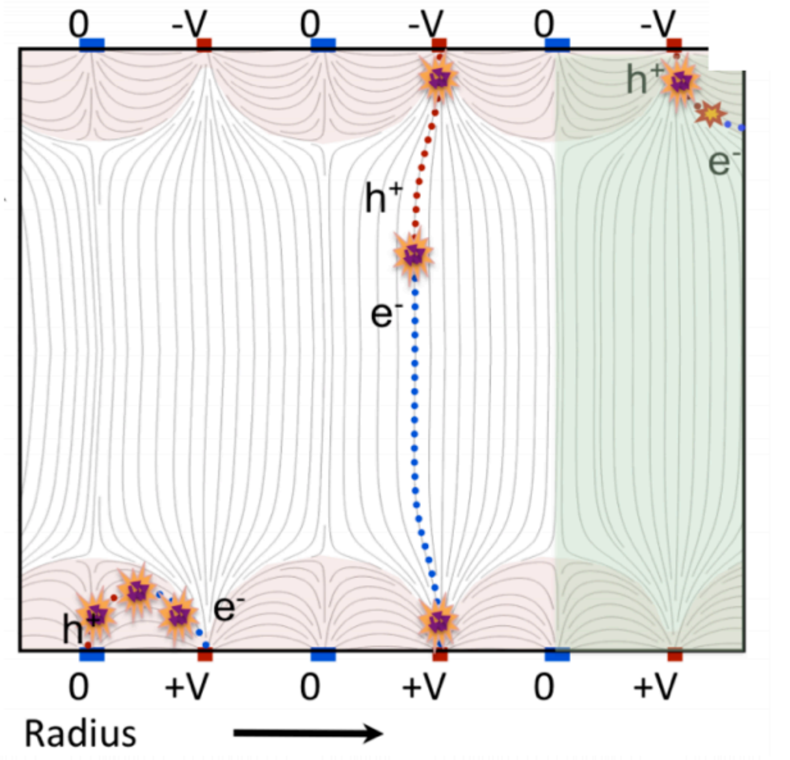
- **Can exploit difference in ionization yield to discriminate electron and nuclear recoils**

iZIP

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







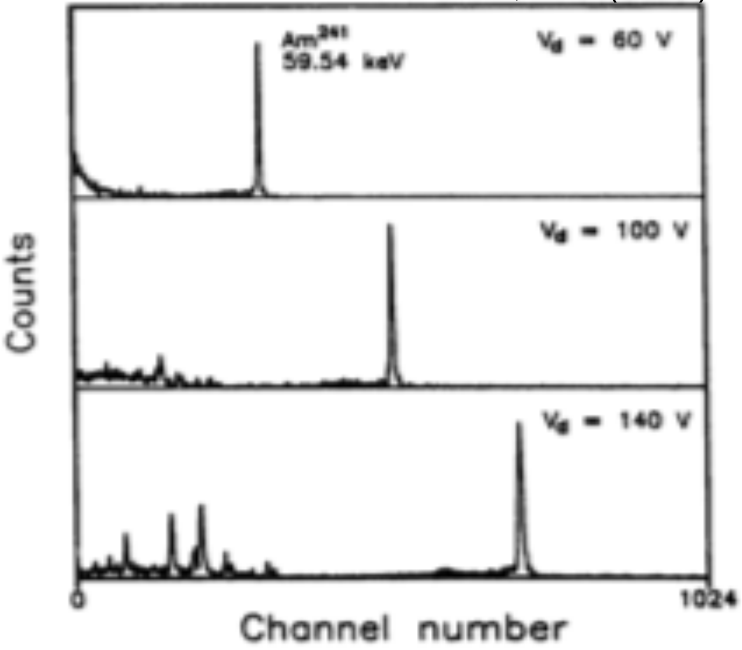
- Exploit ionization yield differences in electron and nuclear recoils to discriminate
- Interweaved electrodes create trapping field near surface to discriminate surface and bulk events

HV Detectors

$$
\begin{aligned}
E_{total} &= E_{recoil} + E_{luke} \\
&= E_{recoil} + Qe\Delta V \\
&= E_{recoil}\left(1 + \frac{Ye\boxed{\Delta V}}{< E_{eh} >}\right)
\end{aligned}
$$

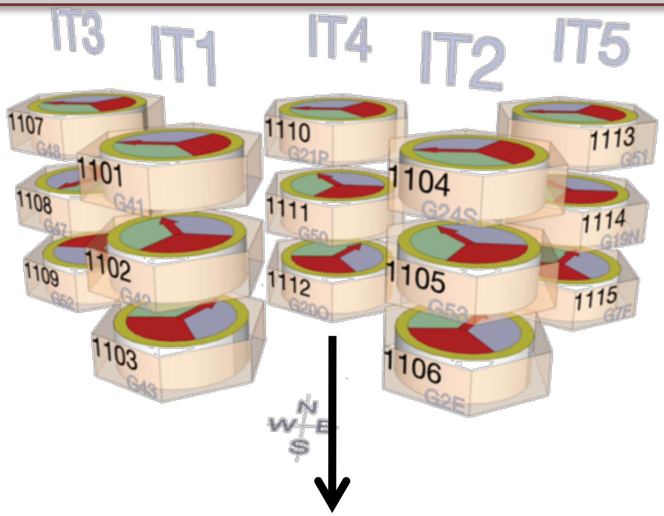
- In iZIP detectors, discrimination only good down to ~ 1 keV, limited by ionization measurement noise
- As charge carriers traverse crystal, they create secondary (Luke) phonons
- The higher the field, the more Luke phonons created
- Increase the bias, measure the phonons. Basically a charge amplifier (which doesn't amplify the noise!)

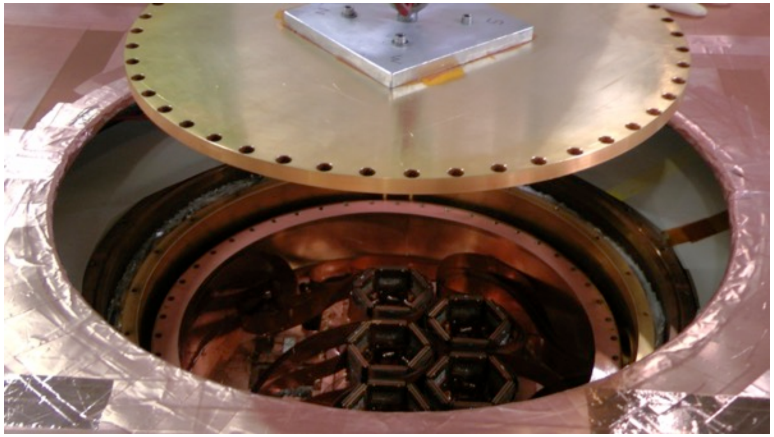
P.N. Luke et al. NIM A289, 405 (1990)



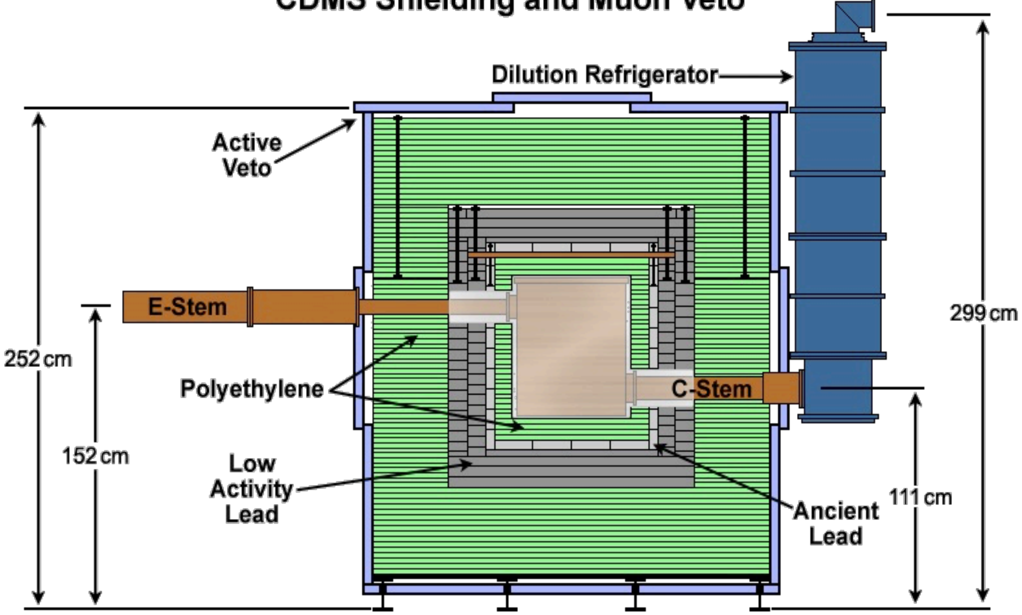
SuperCDMS Soudan

- 15 Ge iZIP detectors (9 kg)
- HV mode: CDMSlite (using iZIP detectors)
- Operational until late 2015

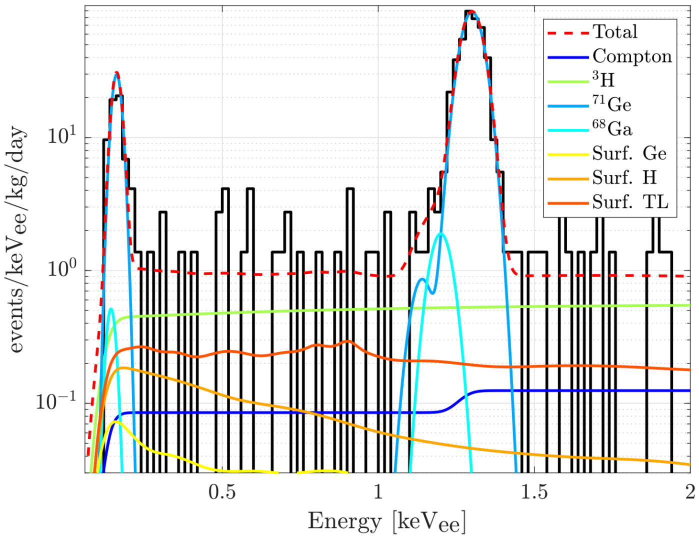




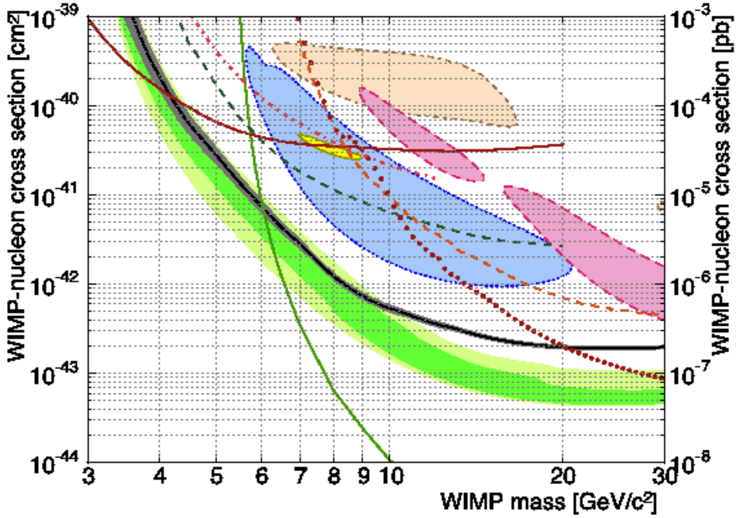
CDMS Shielding and Muon Veto



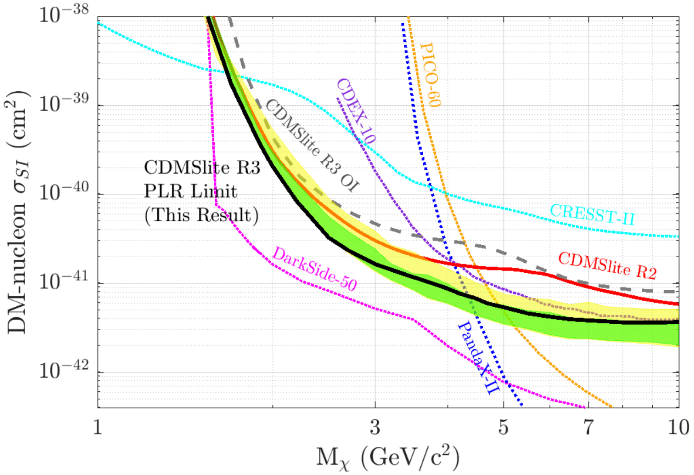
Soudan Results



Phys. Rev. D 99, 062001 (2019))

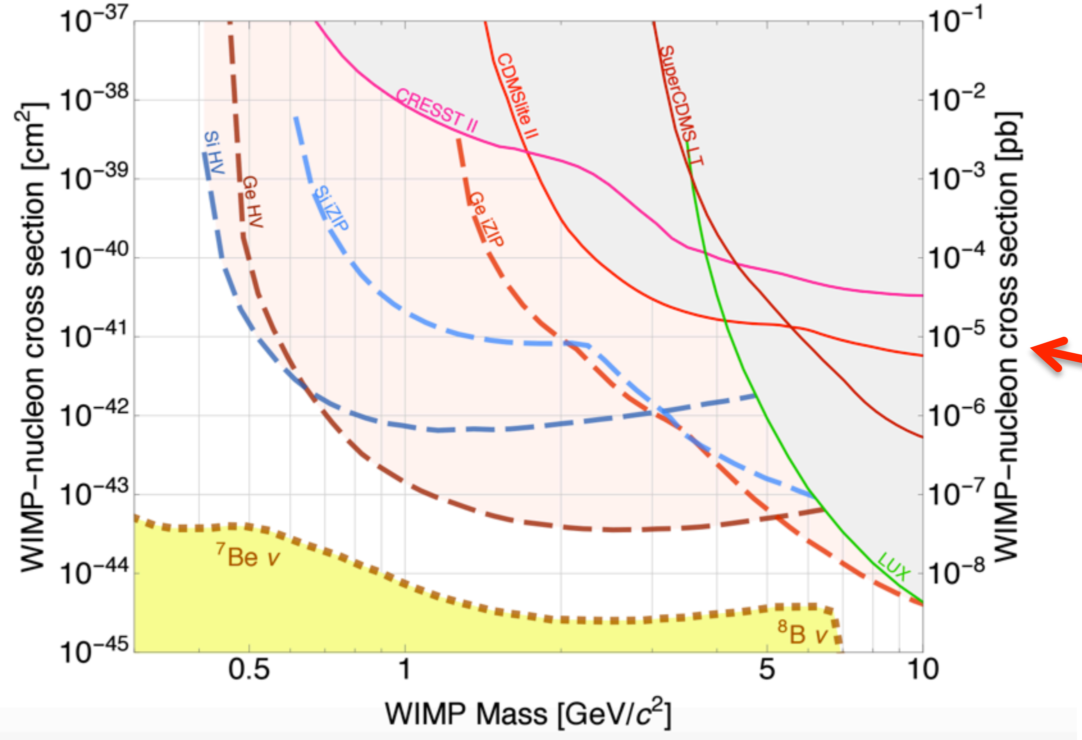


Low Threshold Analysis
Phys.Rev.Lett. 112 (2014) no.24



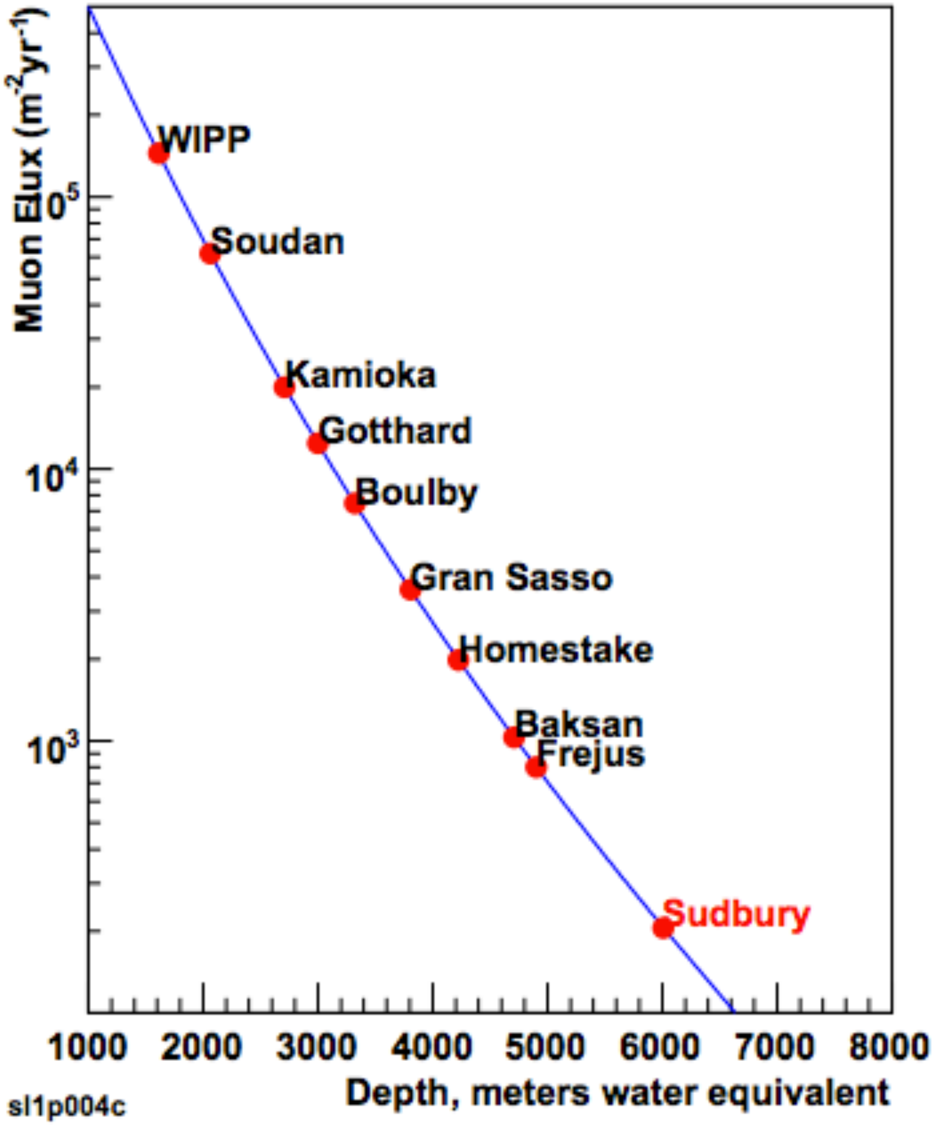
- Many great results from SuperCDMS Soudan
- Recently CDMSlite analysis pushed low mass WIMP limits to uncharted territory

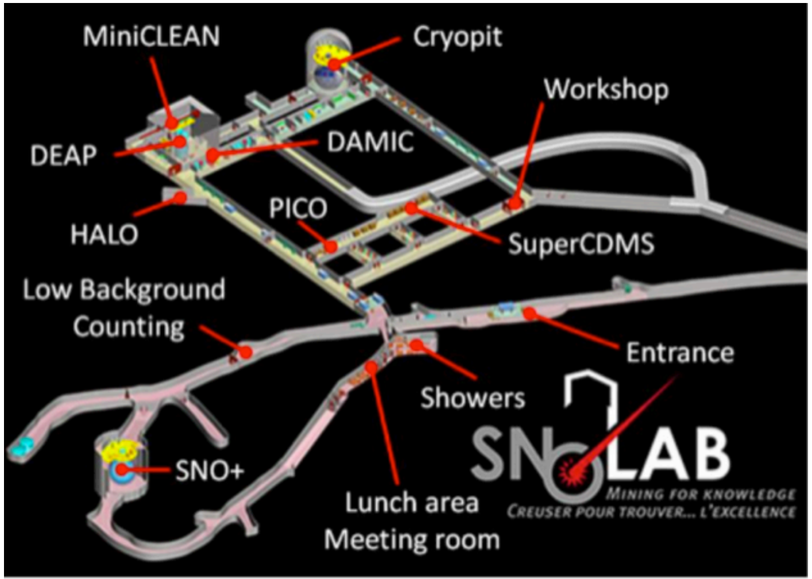
SuperCDMS SNOLAB



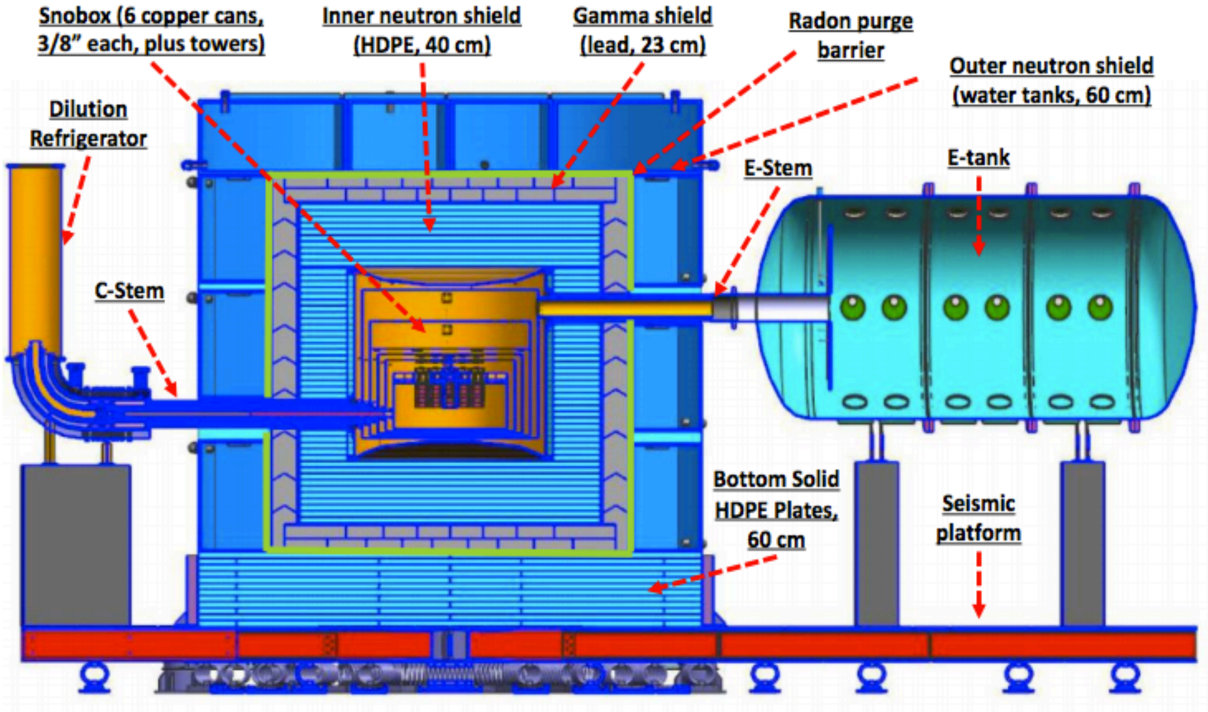
- **What's next?**
  - SuperCDMS SNOLAB will focus on pushing harder into the low mass search region
  - Show the punch line first (Sensitivity projection)
  - How do we plan to get there?

Background Improvements

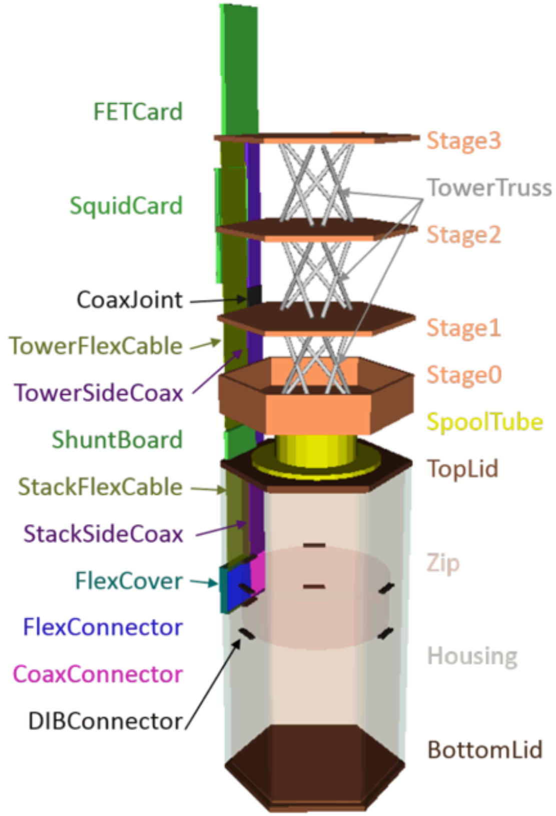




Shielding and Simulation

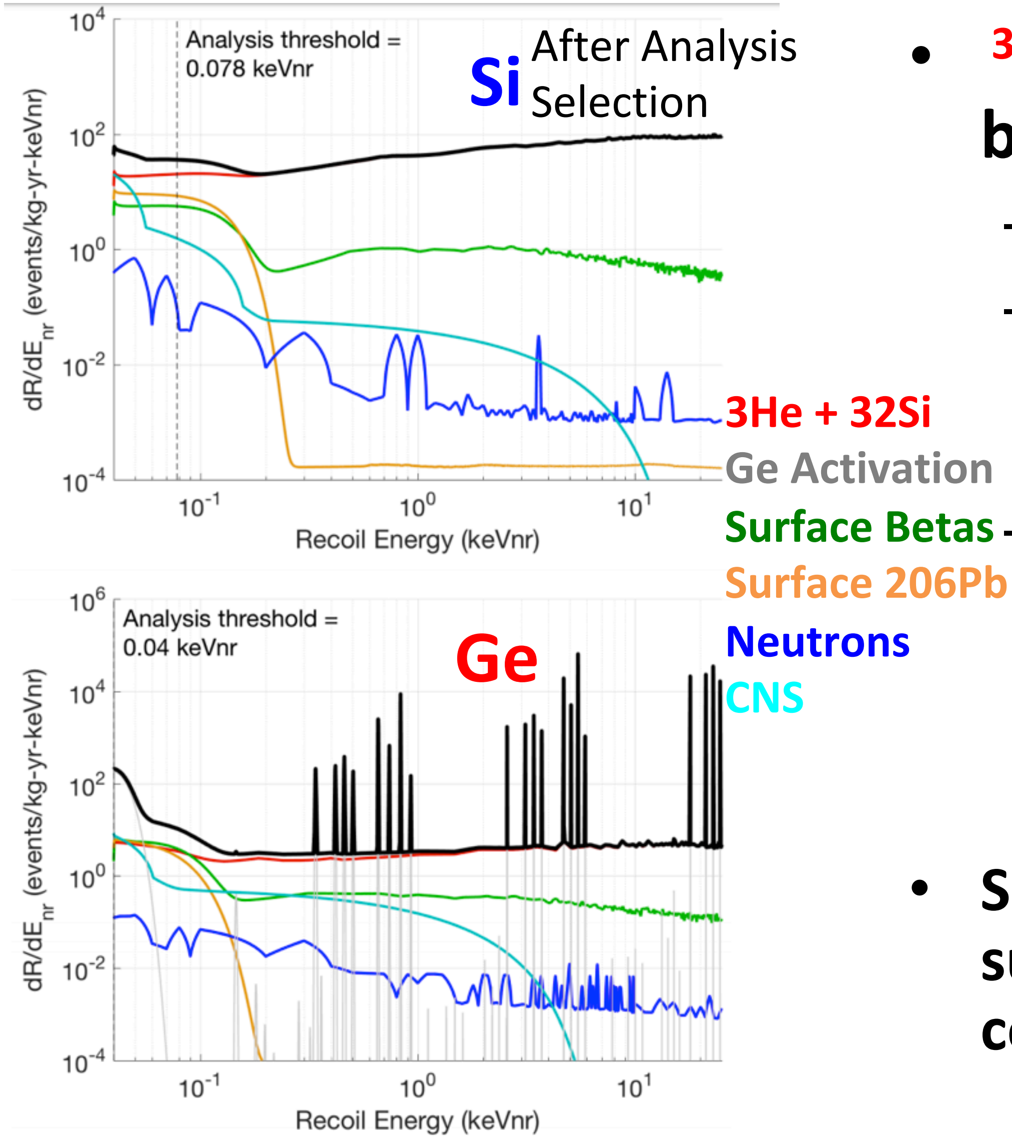


SNOLAB shielding design



Detailed simulation of detector tower components.

HV Backgrounds

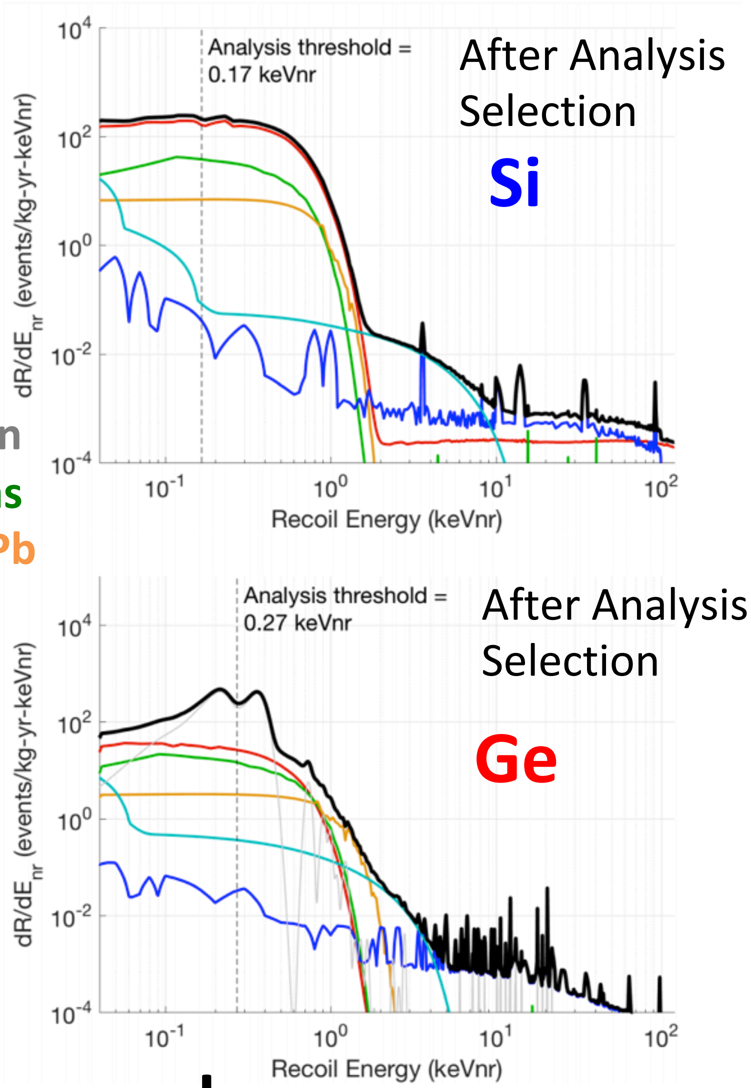


- **^{32}Si and ^{3}H limiting backgrounds**
  - β-decay in detector bulk
  - ^{3}H produced cosmogenically in Ge and Si, builds up over time (τ = 12.3 years)
  - ^{32}Si produced cosmogenically from argon in atmosphere, seeps into natural Si and ends up in crystals
- **Some control by limiting surface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

Improved Environmental Backgrounds

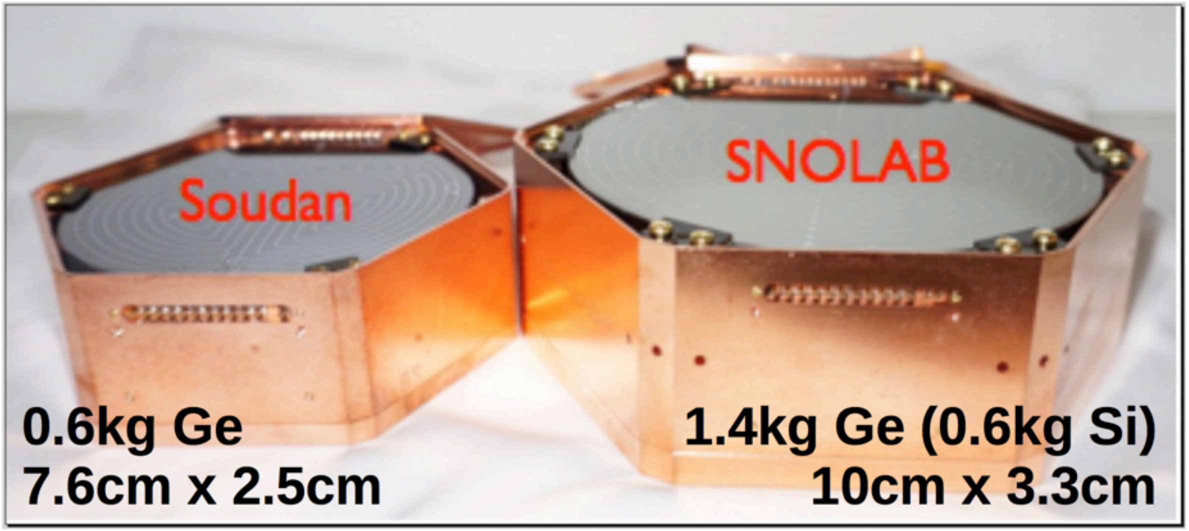
- **Other backgrounds controlled to be < ^{3}H and ^{32}Si levels by:**
  - 6000 M.W.E.
  - Better screening of materials
  - Shielding design improvements
  - Better radon mitigation (both in lab and during fabrication) and surface radon removal

3He + 32Si
Ge Activation
Surface Betas
Surface 206Pb
Neutrons
CNS

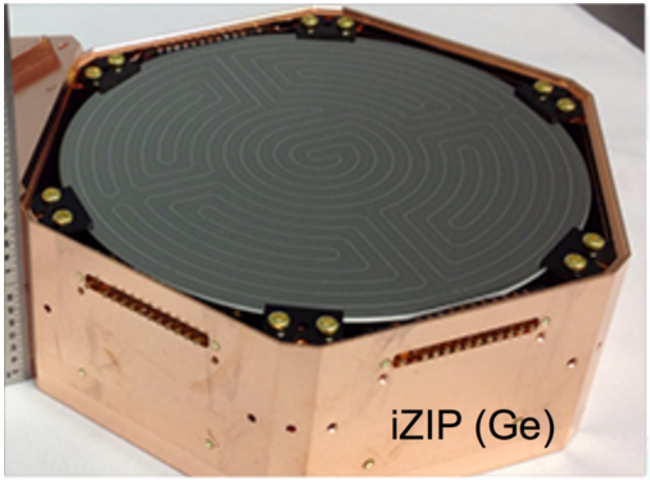


iZIP Backgrounds

Improved Detectors



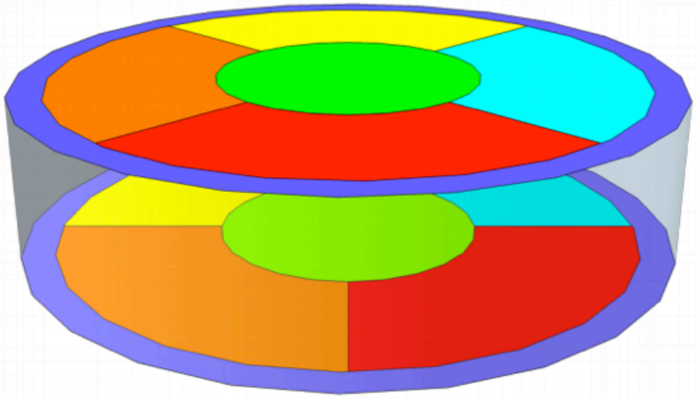
- Bigger (more fiducial volume in proportion to surface area)
- Larger voltage bias
- Faster phonon pulses, more position information
- Lower T_c (better noise and resolution)
- Resolution approaching level of single electron-hole pair (for HV)

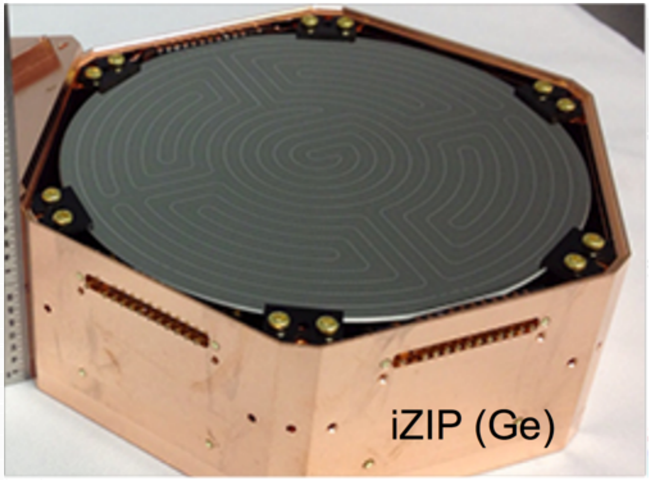


	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure (kg·yr)	56	4.8	44	9.6
Phonon resolution (eV)	50	25	10	5
Ionization resolution (eV)	100	110	–	–
Voltage Bias (V)	6	8	100	100

Detector Improvements

iZIP detector

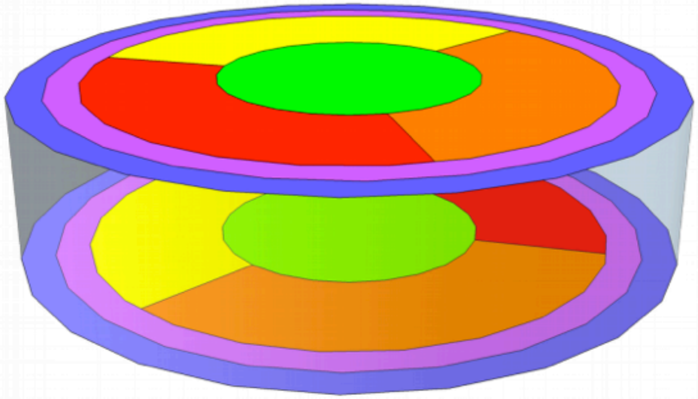


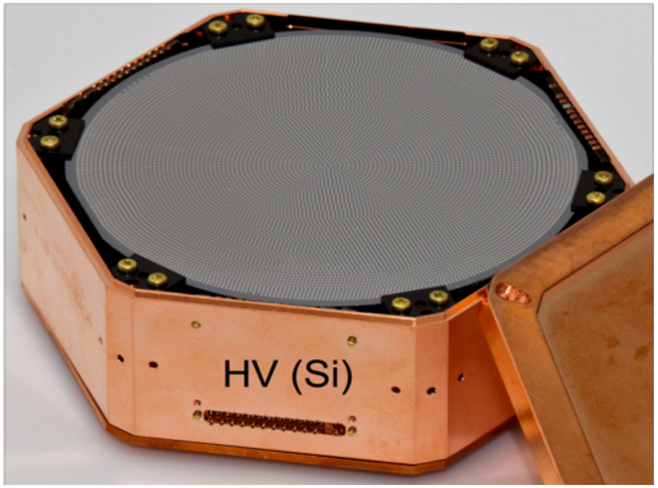


10 Ge, **2** Si **iZIP** detectors

- Full background discrimination down to ~ 1keV

HV detector

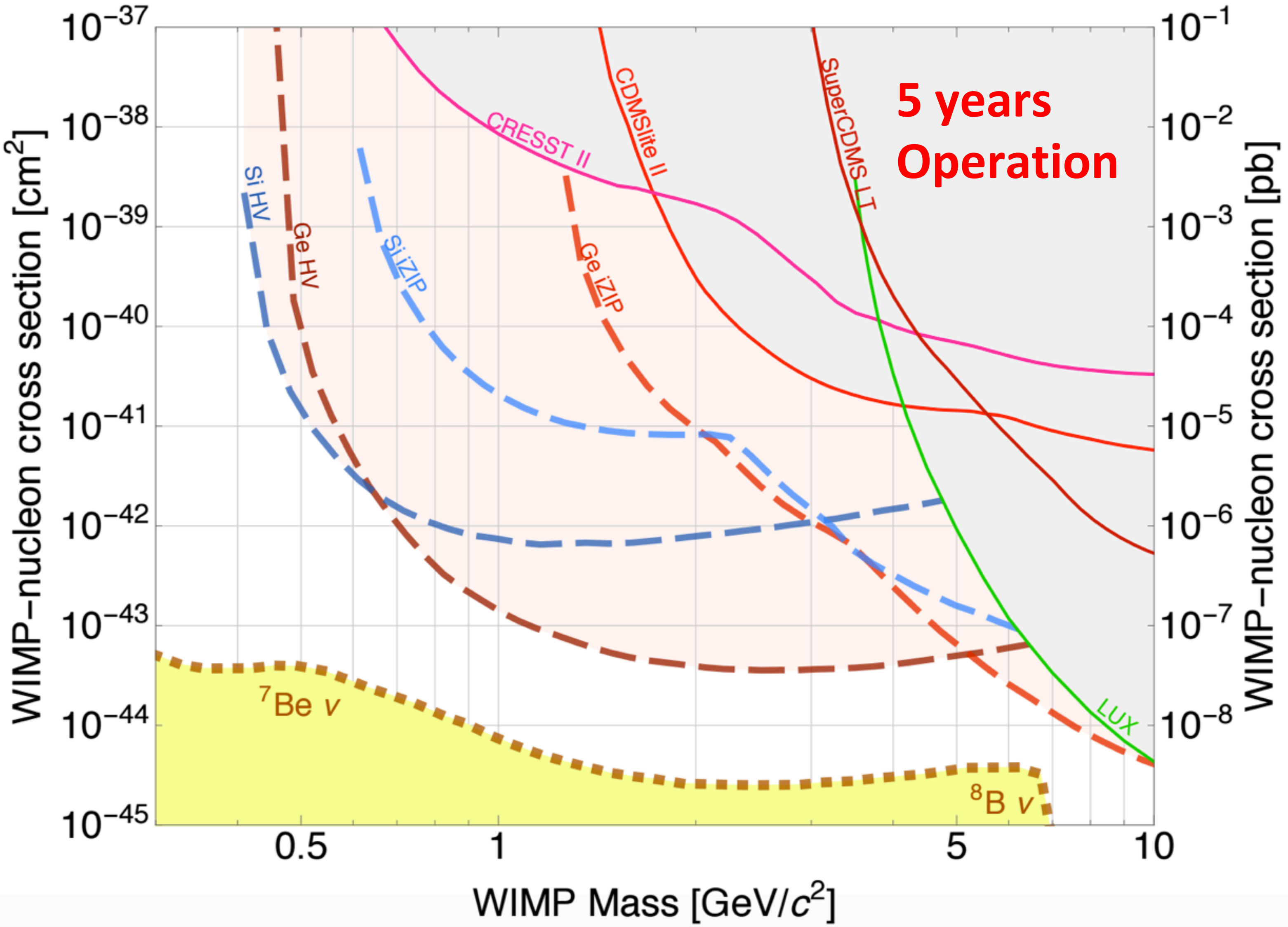




8 Ge, **4** Si **HV** detectors

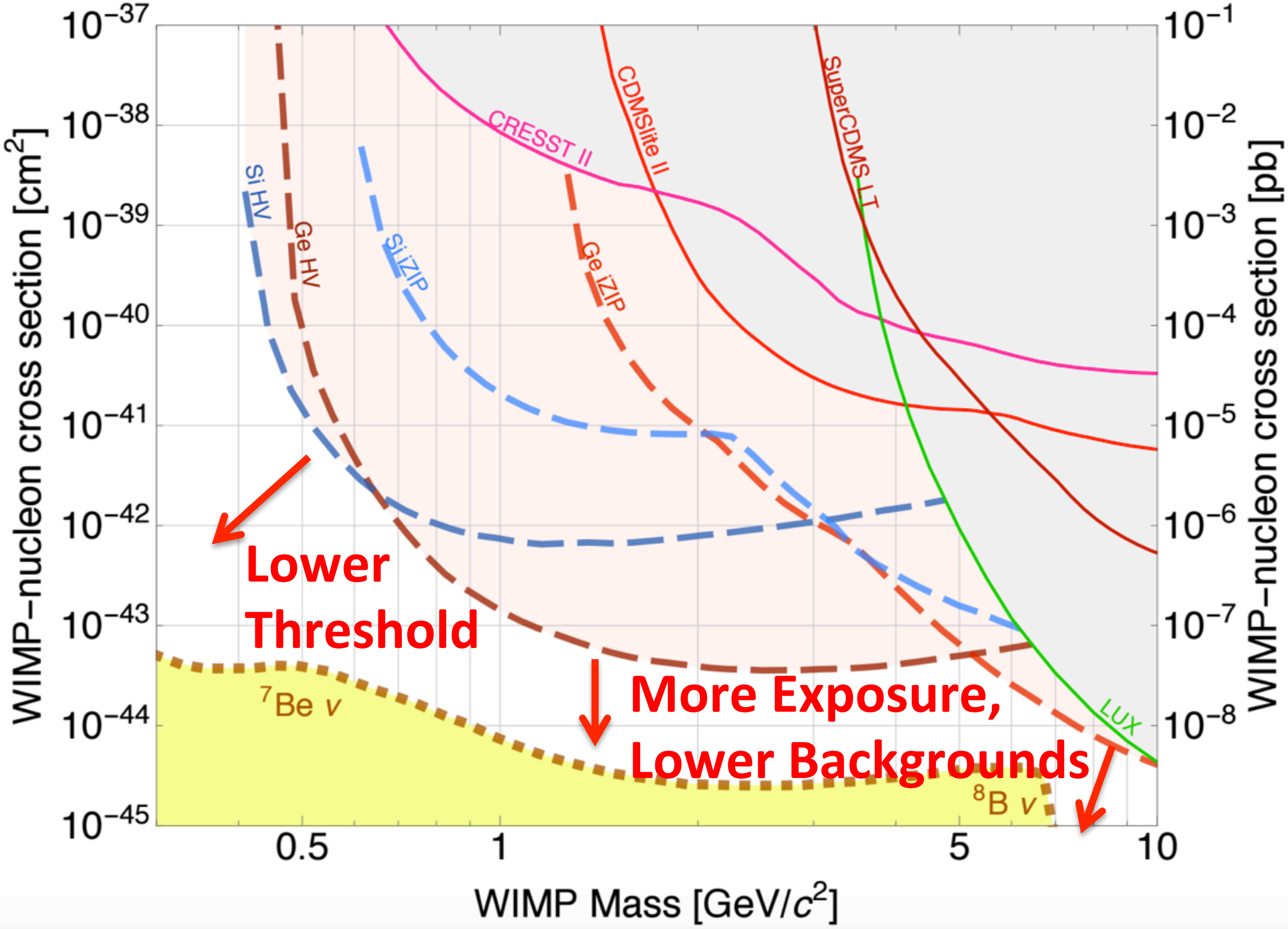
- Better resolution (5 eV in Ge, 10 eV in Si), lower threshold

Projected Sensitivity



Future SNOLAB Upgrades

Let’s reach the solar neutrino floor!

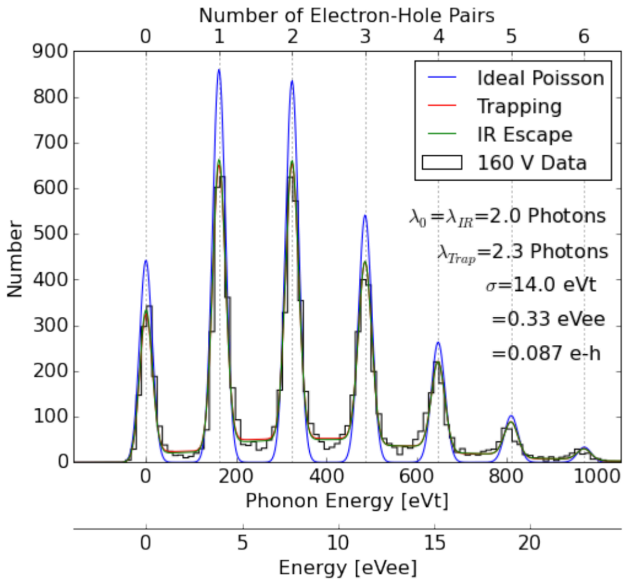


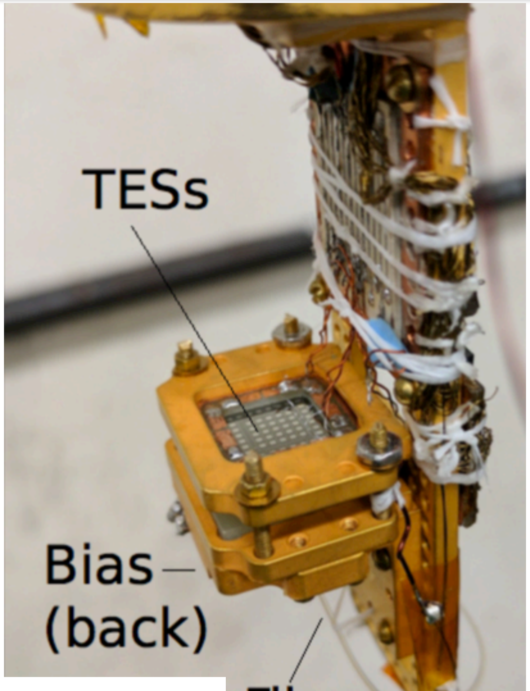
Lower Threshold

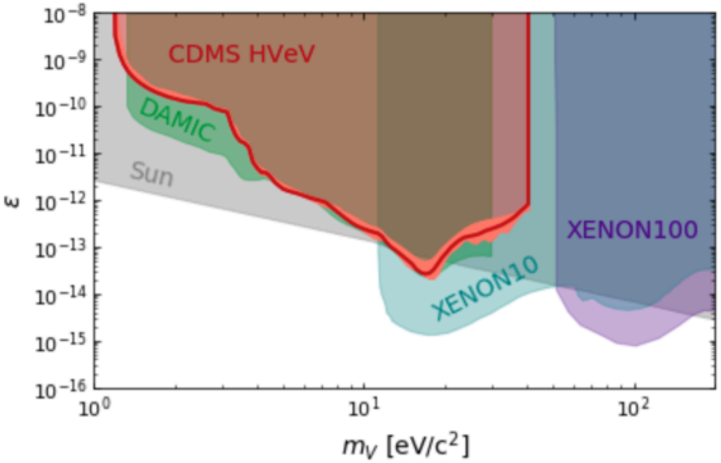
More Exposure, Lower Backgrounds

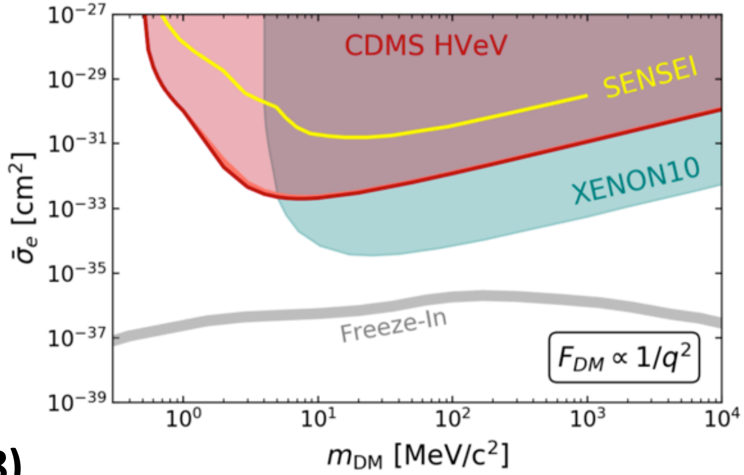
HVeV Detector

- Prototype ultra-low threshold phonon detector
- 1 cm^2 **Si**, ~1 gram
- First science run: 11.7 gram-hours
- First phonon detector to measure single e$^-$h$^+$ pairs









Appl. Phys. Lett. 112, 043501 (2018)

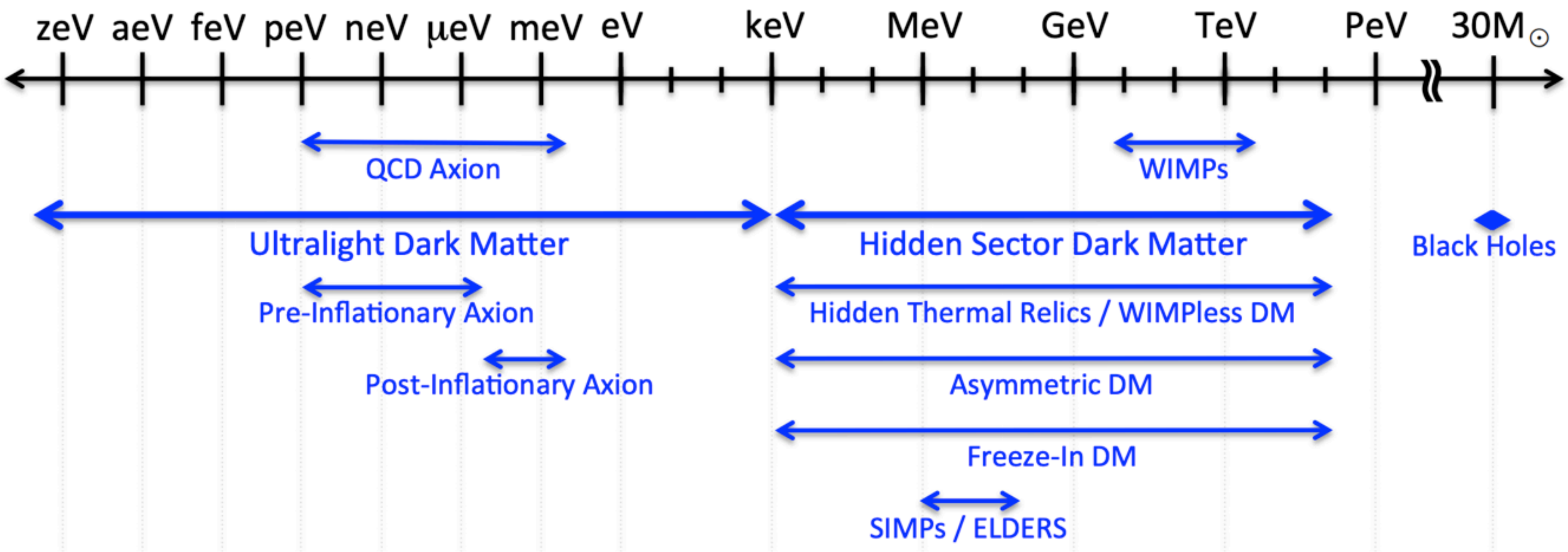
The Future

- Much work already towards reaching the neutrino floor:
- **More detectors**
  - SNOLAB cryostat designed to hold up to 15 detector towers
  - Design flexible to hold other detector designs
- **Lower and better understood backgrounds**
  - ER/NR discrimination in HV detectors at lowest recoil energy around single electron-hole pair resolution
  - Improvements in physics modeling of low energy backgrounds
- **Better calibrations**
  - Nuclear recoil calibrations with photo-neutron source, thermal neutron capture recoils, mono-energetic neutron beam (TUNL)
  - understand Ionization yield down to lowest energy recoils
- **Lower thresholds**
  - Detector improvements allowing much higher voltage bias, more signal amplification, single electron/hole counting

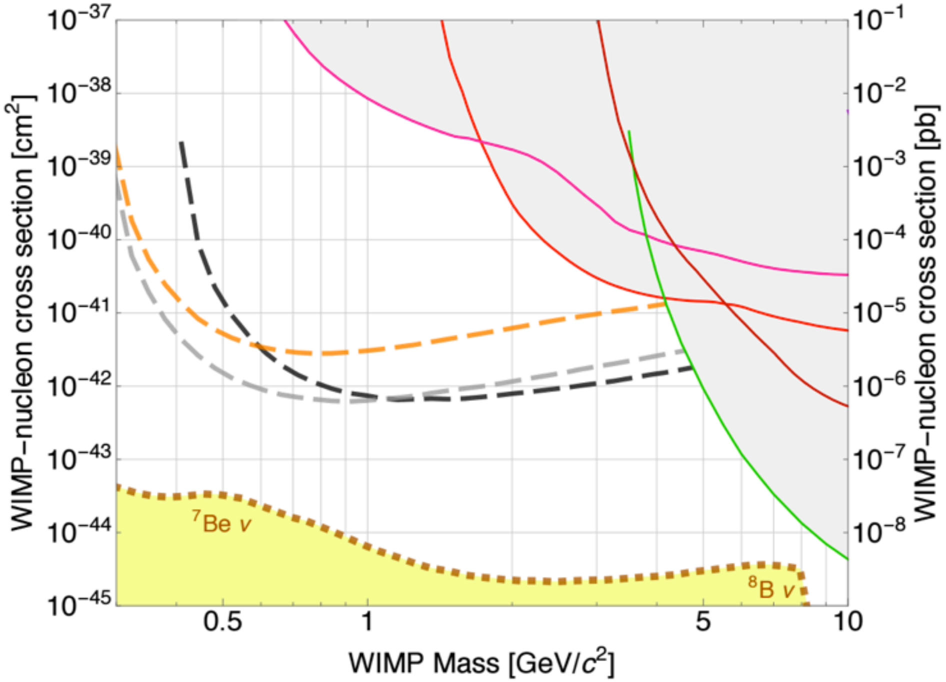
Summary

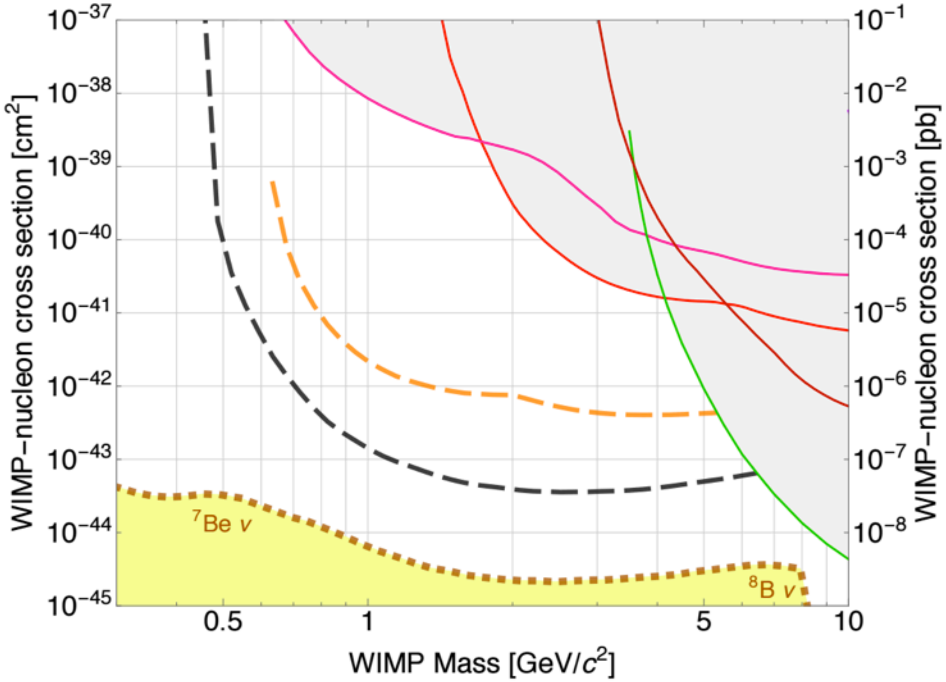
- SuperCDMS SNOLAB is gearing up
- 4-tower initial payload for 5 years (2020-2024)
  - 25 kg Ge, 3.6 kg Si
  - iZIP (full discrimination) and HV (low threshold) detectors
  - Sensitivity projections have been released
- Prototype small (gram scale) detectors have reached single e^-h^+ sensitivity
- Future improvements with aim to reach neutrino floor

BACKUP

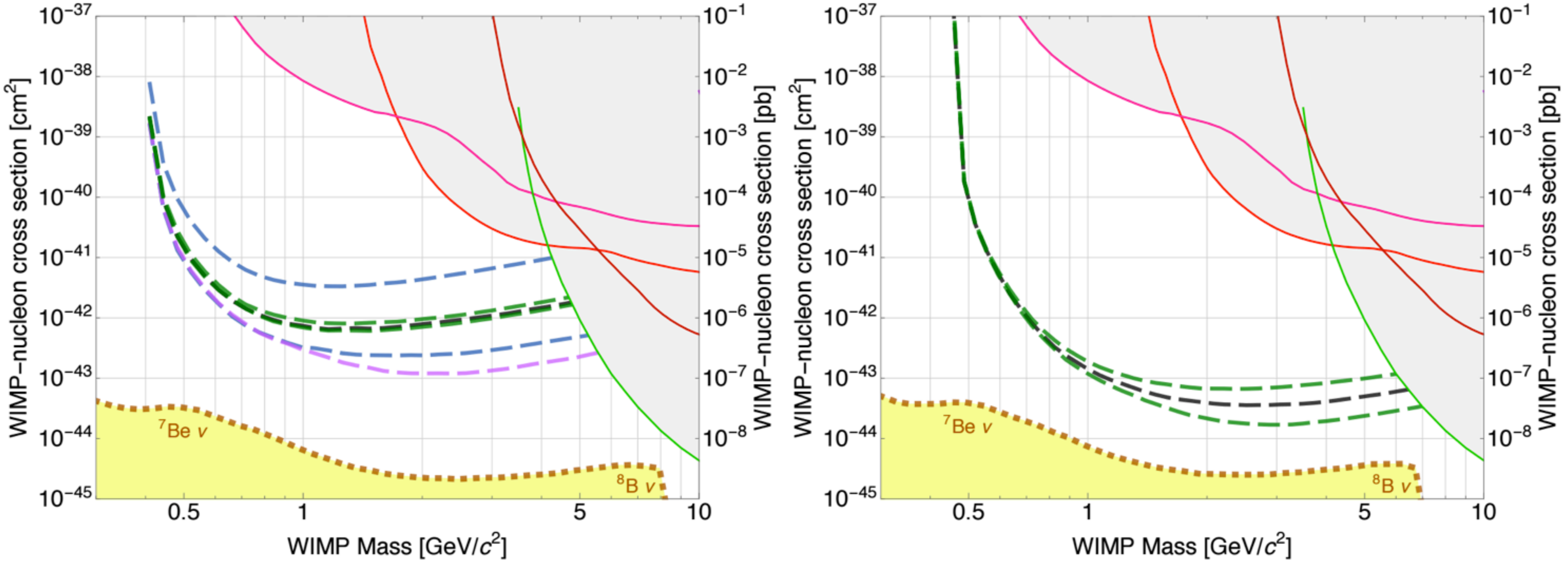


US Cosmic Visions: arXiv:1707.04591





- Orange = zero bias voltage operation
- Gray = Using standard Lindhard model for ionization yield in Si



- Green = varying ^{3}H x3
- Blue = varying ^{32}Si x10 (up) to 0 (down)
- Purple = both ^{32}Si and ^{3}H at x0

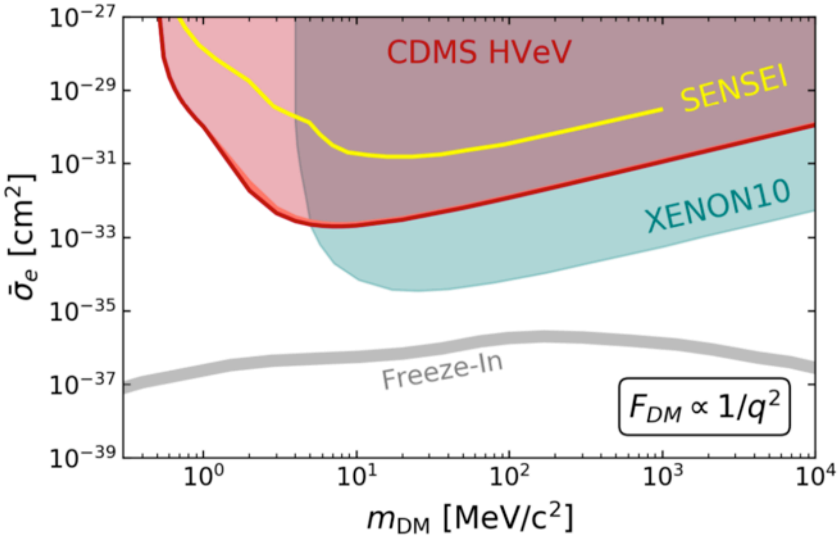
		Production Rate (atoms/kg/day)	Concentration (decays/kg/day)	
Material	Isotope		HV	iZIP
Ge	^{3}H	80	0.7	1.5
Si	^{3}H	125	1	2
Si	^{32}Si	–	80	80

Detector	$7\sigma_{Ph}$ (eV)	$e\Delta V$ (eV)	Analysis threshold (eV) E_{Ph}	Analysis threshold (eV) E_{nr}
Si HV	35	100	100	78
Ge HV	70	100	100	40
Si iZIP	175	8	175	166
Ge iZIP	350	6	350	272

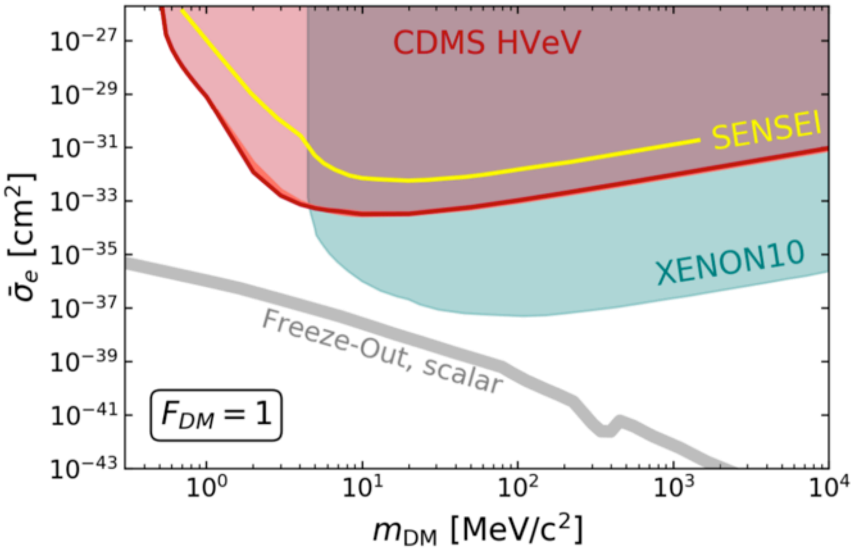
“Singles” Background Rates	Electron Recoil				Nuclear Recoil ($\times 10^{-6}$)	
(counts/kg/keV/year)	Ge HV	Si HV	Ge iZIP	Si iZIP	Ge iZIP	Si iZIP
Coherent Neutrinos					2300.	1600.
Detector-Bulk Contamination	21.	290.	8.5	260.		
Material Activation	1.0	2.5	1.9	15.		
Non-Line-of-Sight Surfaces	0.00	0.03	0.01	0.07	–	–
Bulk Material Contamination	5.4	14.	12.	88.	440.	660.
Cavern Environment	–	–	–	–	510.	530.
Cosmogenic Neutrons					73.	77.
Total	27.	300.	22.	370.	3300.	2900.

$$\sigma_E^2 = \frac{2nKk_bT_c^{n+1}}{\varepsilon^2}\left(\tau_{pulse} + \frac{2}{n}\tau_{TES}\right) \xrightarrow{n=5,\tau_{pulse}>\tau_{TES}} \frac{10Kk_bT_c^6}{\varepsilon^2}\tau_{pulse}$$

- Phonon Energy Resolution



CDMS HVeV
SENSEI
XENON10
Freeze-In
$F_{DM} \propto 1/q^2$
$\bar{\sigma}_e$ [cm^2]
10^{-27}
10^{-29}
10^{-31}
10^{-33}
10^{-35}
10^{-37}
10^{-39}
10^0
10^1
10^2
10^3
10^4
m_{DM} [MeV/c^2]



CDMS HVeV
SENSEI
XENON10
Freeze-Out, scalar
$F_{DM} = 1$
$\bar{\sigma}_e$ [cm^2]
10^{-27}
10^{-29}
10^{-31}
10^{-33}
10^{-35}
10^{-37}
10^{-39}
10^{-41}
10^{-43}
10^0
10^1
10^2
10^3
10^4
m_{DM} [MeV/c^2]