Searching for Nuclear Recoils from Dark Matter with SuperCDMS

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Lake Louise Winter Institute 2019

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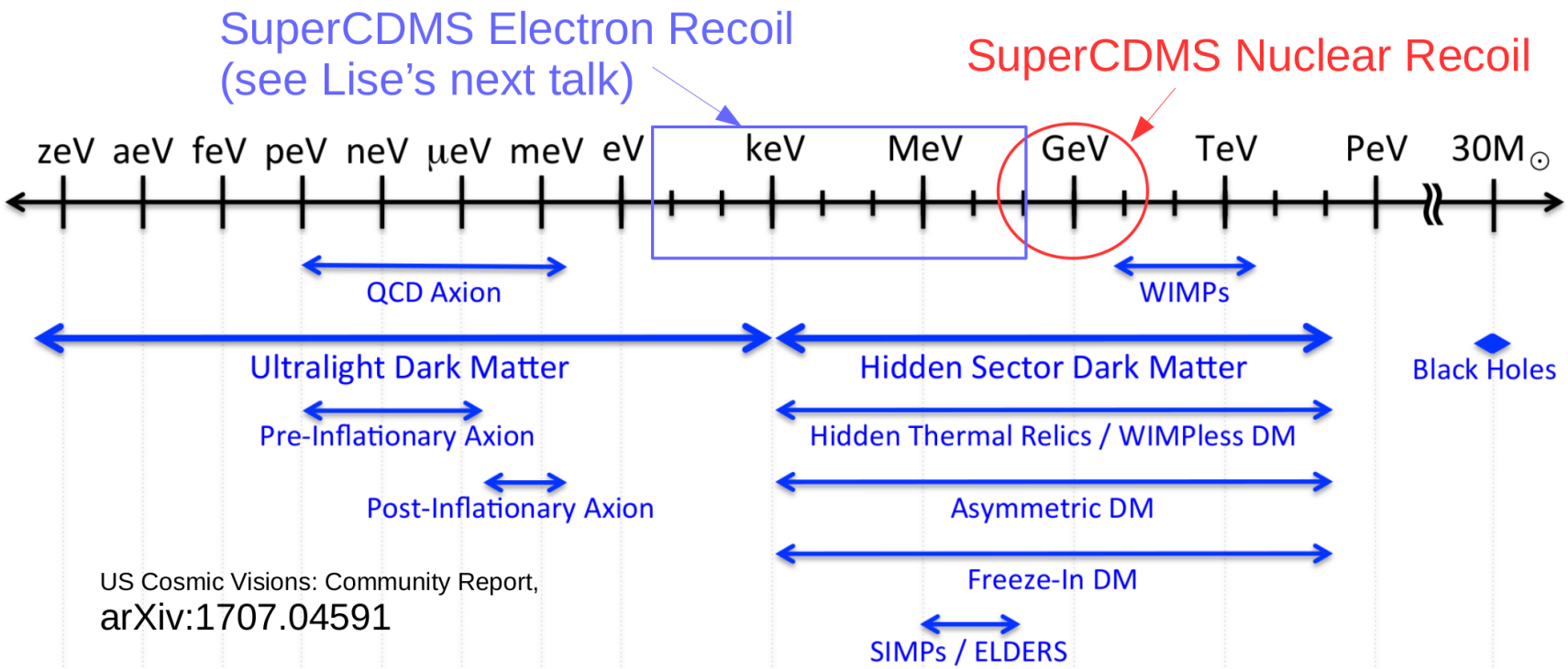
Which is your favourite dark matter candidate?

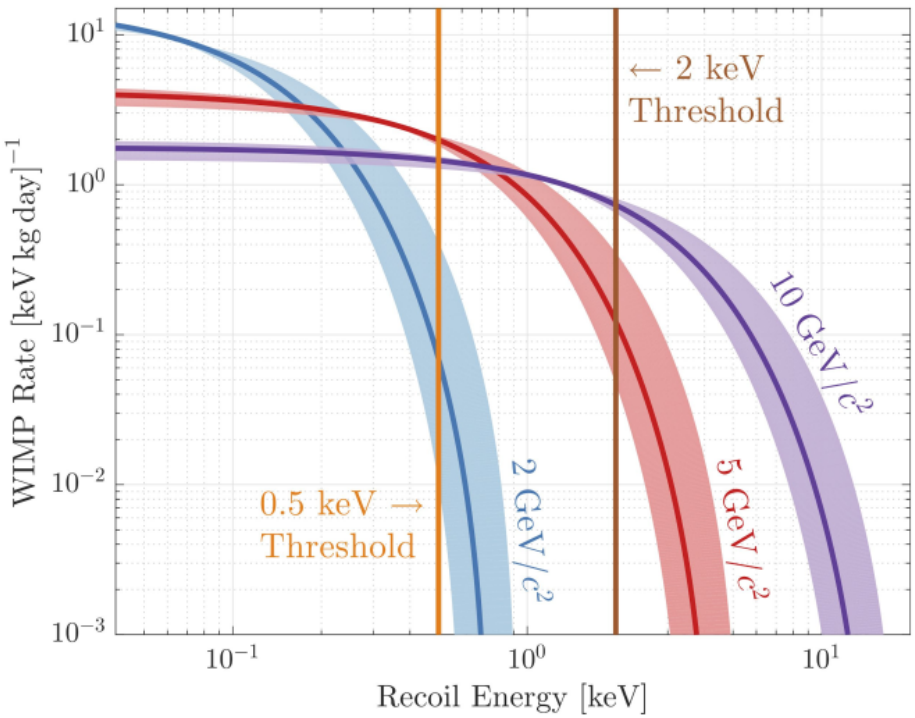


Amongst these many scenarios, SuperCDMS looks for scattering interactions of **low-mass** ($< 10\,\mathrm{GeV}/c^2$) dark matter particles with standard model particles.

Toward lower masses..

SuperCDMS detector technology

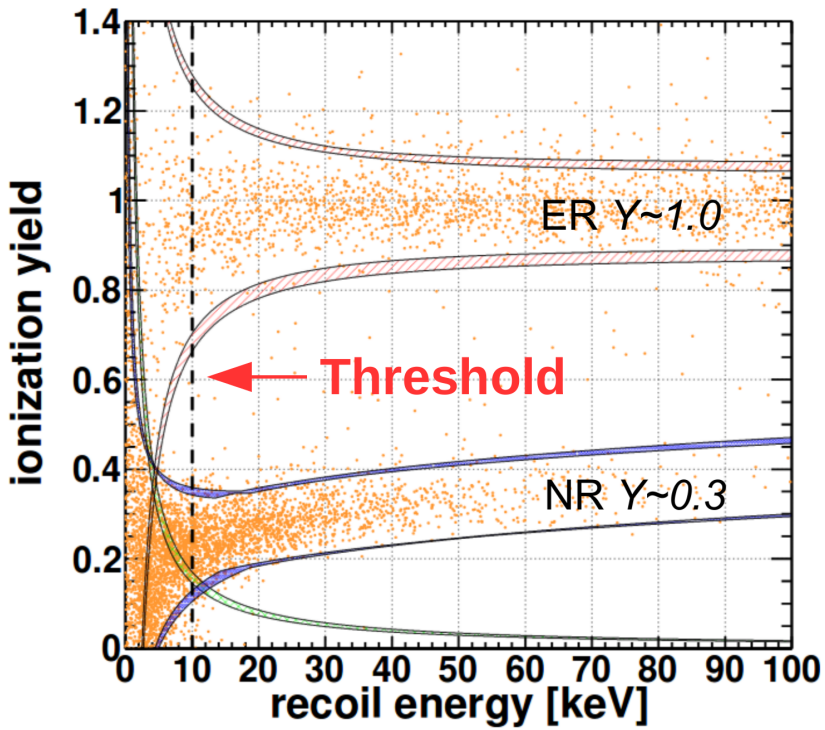
- High-purity mK cryogenic Ge and Si crystals
- Phonons measured via transition edge sensors
- Ionization measured via interleaved electrodes



Energy threshold key to extend the search to lower masses

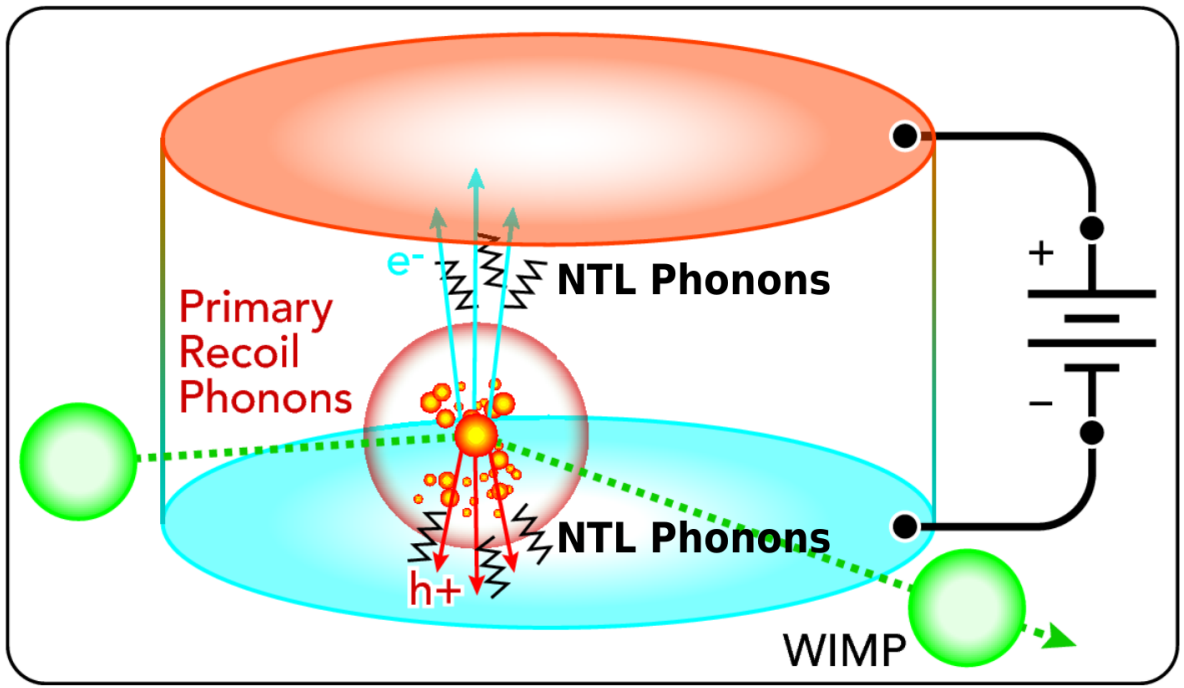
SuperCDMS detectors: Interleaved Z-sensitive Ionization Phonon (iZIP)

- $\Delta V < 10\,\mathrm{V}$ top to bottom
- Phonon and ionization signal measurements $\rightarrow$ allow for electron/nuclear recoil (ER/NR) discrimination
- Goal 100% nuclear recoil discrimination for NR DM search



Pushing for lower masses: CDMSlite operating mode

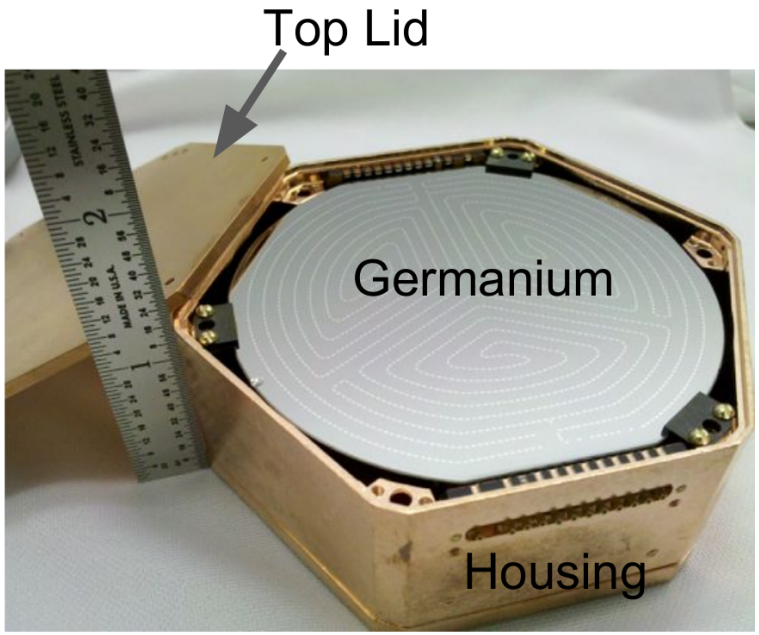
- Observed phonon energy $= E_{\mathrm{Recoil}} + E_{\mathrm{NTL}}$
- E_{NTL} energy from Neganov-Trofimov-Luke effect: phonons created by drifting charges
- **E_{NTL} proportional to ΔV ($E_{\mathrm{NTL}} = e\Delta V N_{e/h}$)**



$\Delta V \sim 100\,\mathrm{V}$: lower threshold but no ER/NR discrimination

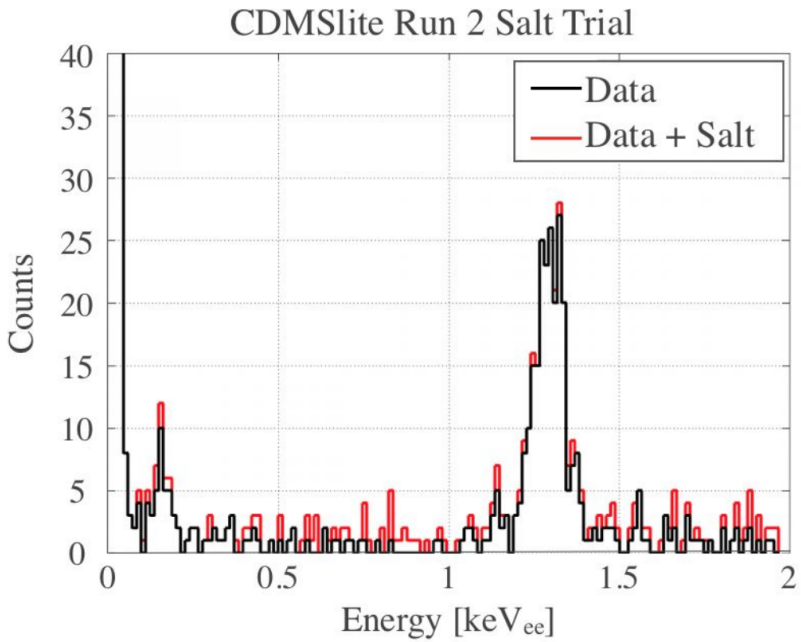
CDMSlite Run 3

arXiv:1808.09098



- Single iZIP detector in CDMSlite mode, $\Delta V = 75\,\mathrm{V}$
- From February to May 2015, total of **36 kg-day**
- Energy threshold of 70 eV

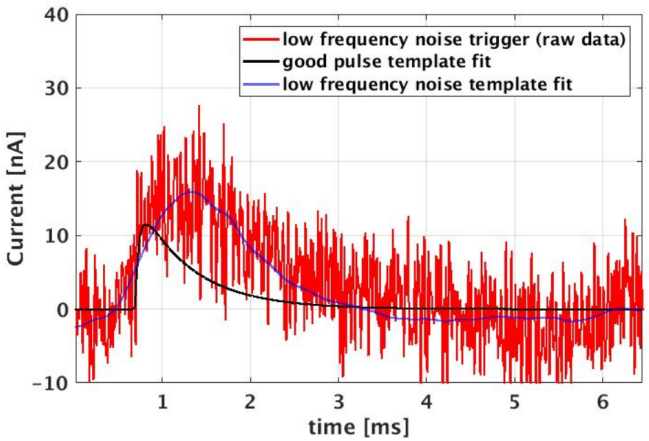
- First **blind analysis** with the CDMSlite detector
- Data salting: fraction of the DM-search events are replaced with artificial signal-like events

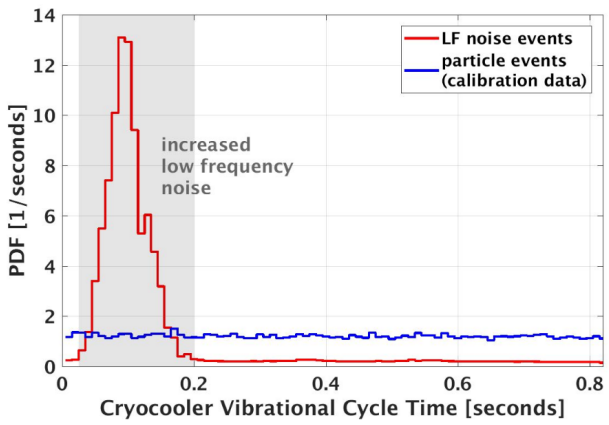


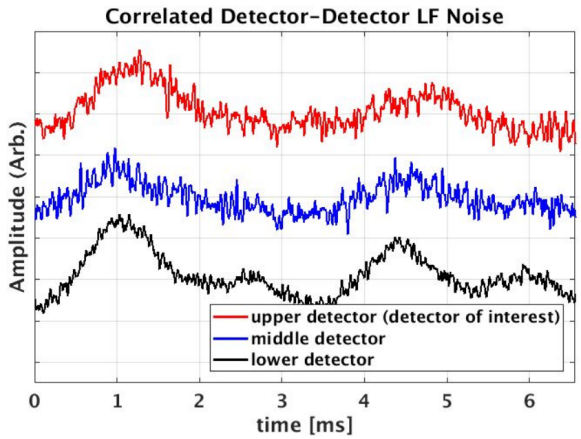
CDMSlite Run 3 ingredients to boost sensitivity

Efficient discrimination of instrumental backgrounds

- Low-frequency noise (LF) from cryostat vibrations
- Three handles combined in two uncorrelated BDTs:
  1. Pulse shape discrimination
  2. Time variable correlated with the cryostat vibration
  3. Detector-detector data correlations







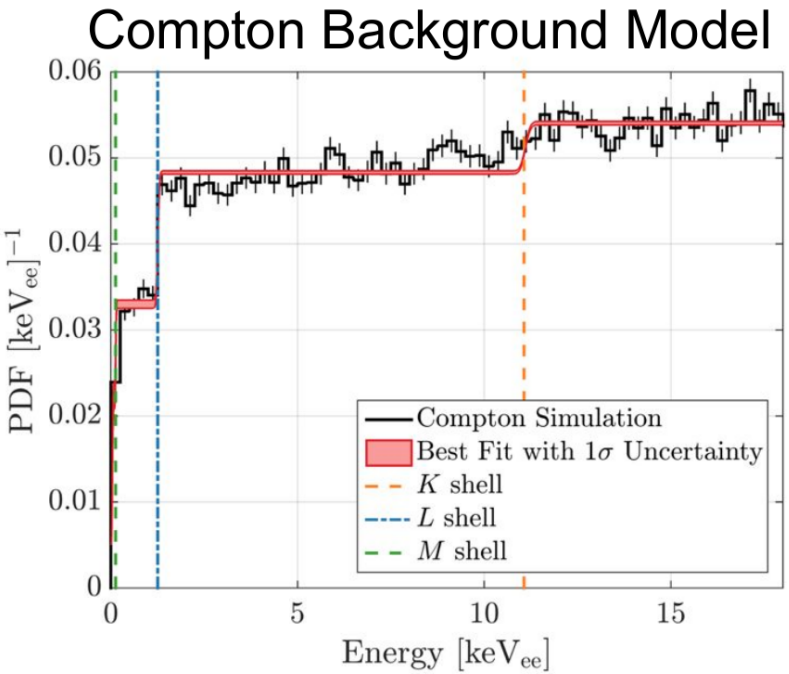
0.4 ± 0.1 **LF noise event leaking past cuts**

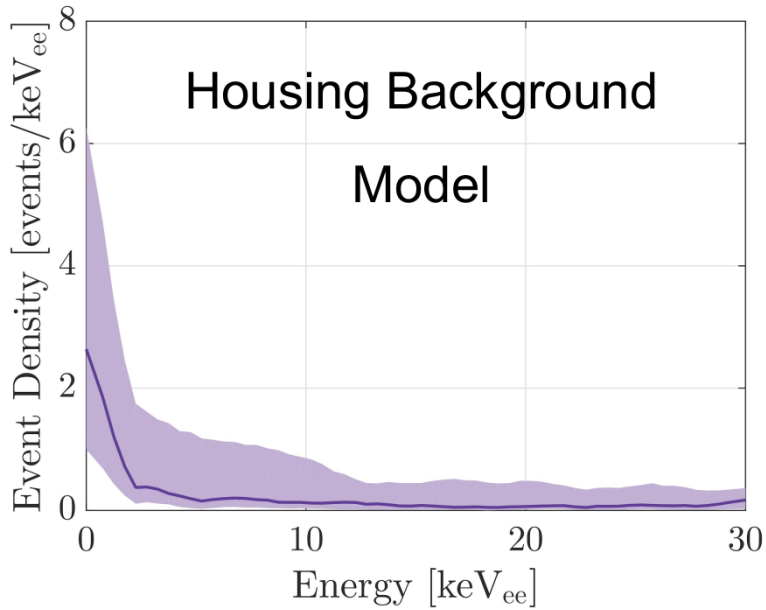
CDMSlite Run 3 ingredients to boost sensitivity

Backgrounds modeling

- ^{71}Ge peaks
- Cosmogenics, specifically Tritium
- Compton scattering
- Decay products from ^{210}Pb contamination

Modeled using Monte Carlo simulations and data-driven fits



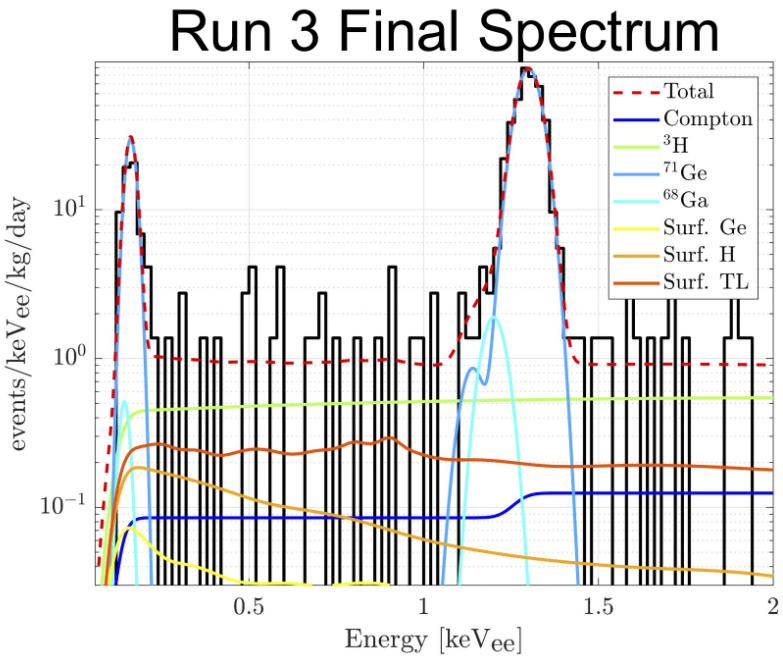


CDMSlite Run 3 ingredients to boost sensitivity

Profile likelihood analysis

- CDMSlite Run 2 analysis set the limit treating all the events as signal candidates (▸ optimum interval method)
- Background models allow profile likelihood WIMP limit
  - Allow for discovery claim
  - Naturally incorporates systematic uncertainties

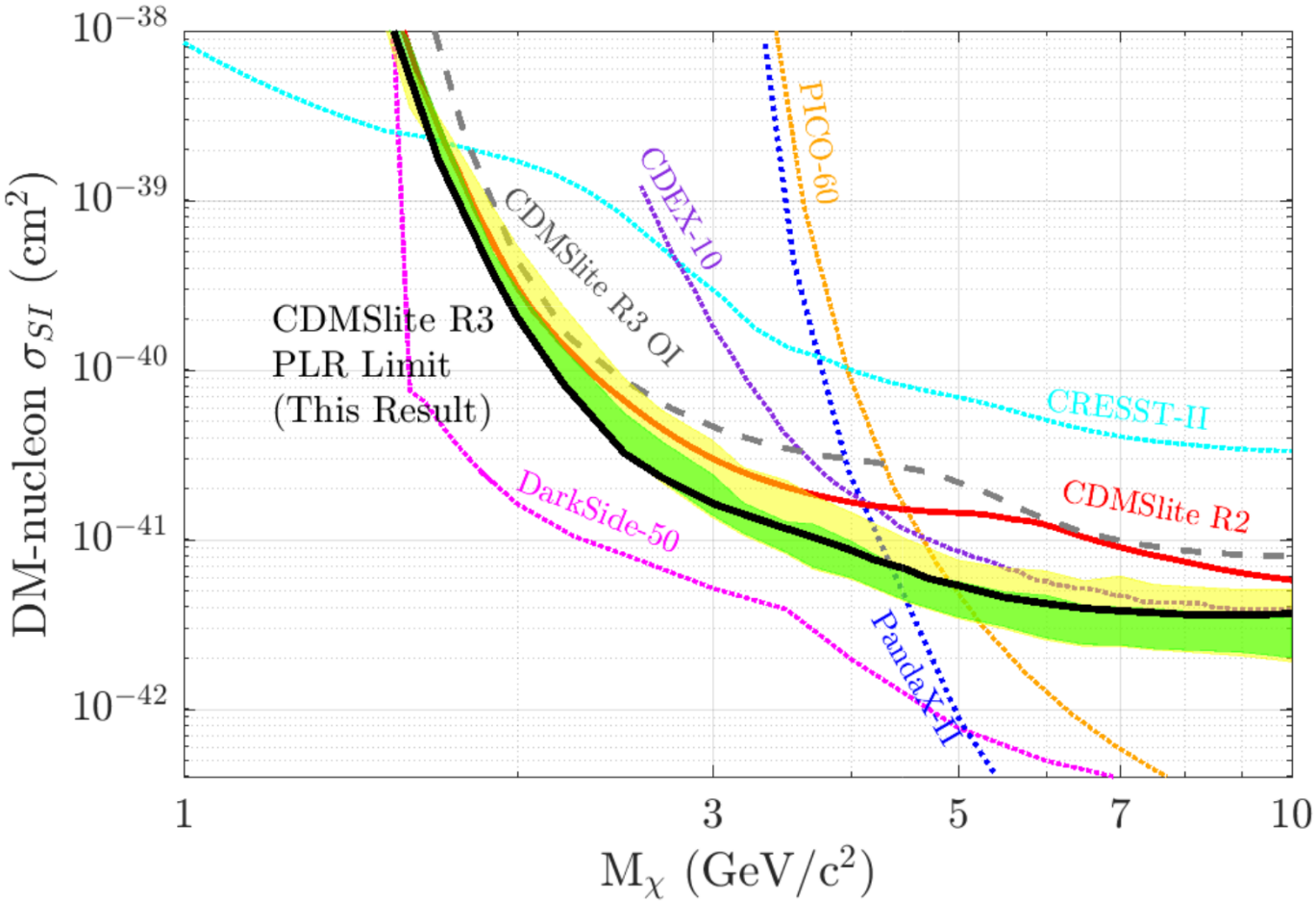
- Nuisance parameters include uncertainties on efficiency, detector resolution and ionization yield
- P-value of 0.988 that data are consistent with background model



CDMSlite Run 3 result

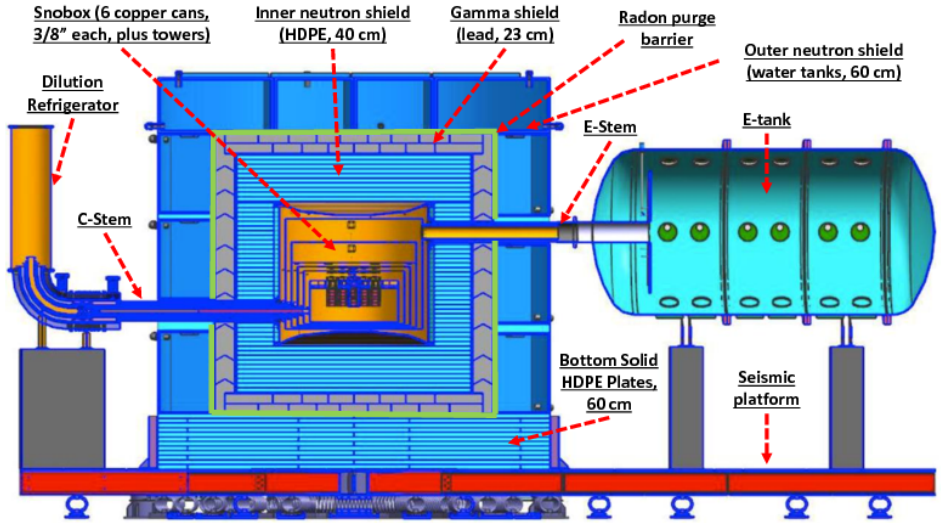
arXiv:1808.09098

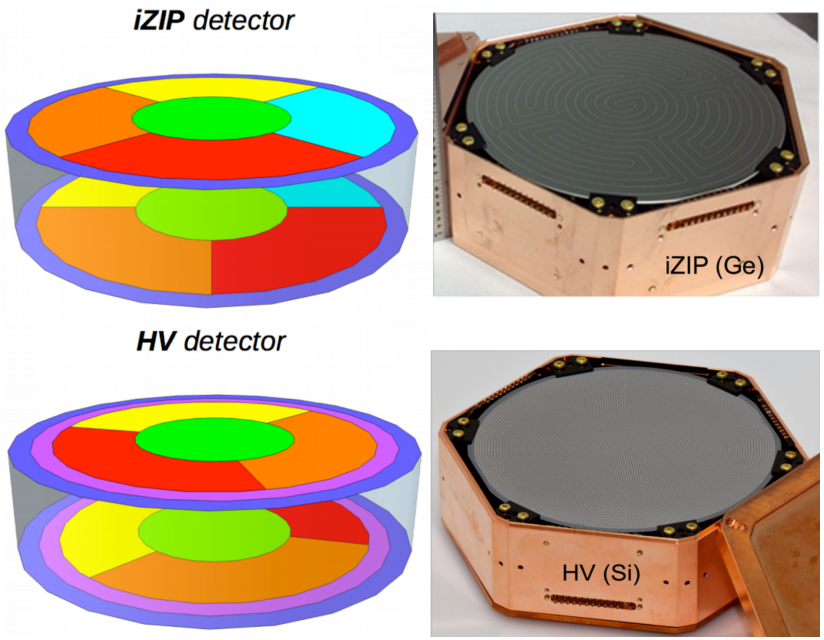
- Limit set using CL_S method
- ≈ 2.5 improvement over CDMSlite Run 2 at 5 GeV, which had about double the exposure PRD 97,022002



Looking forward.. SuperCDMS SNOLAB

- Background reduction from Soudan (2090 mwe) to SNOLAB (6010 mwe) and improved low-activity shielding
- Lower operating temperature for less noise and better resolution





- Bigger (more fiducial volume) higher purity (less radioactive impurities) Ge and Si crystals
- 12 iZIP detectors with full ER/NR discrimination down to ~ 1 keV
- 12 HV detectors with 10 eV in Ge and 5 eV in Si resolution for lower threshold

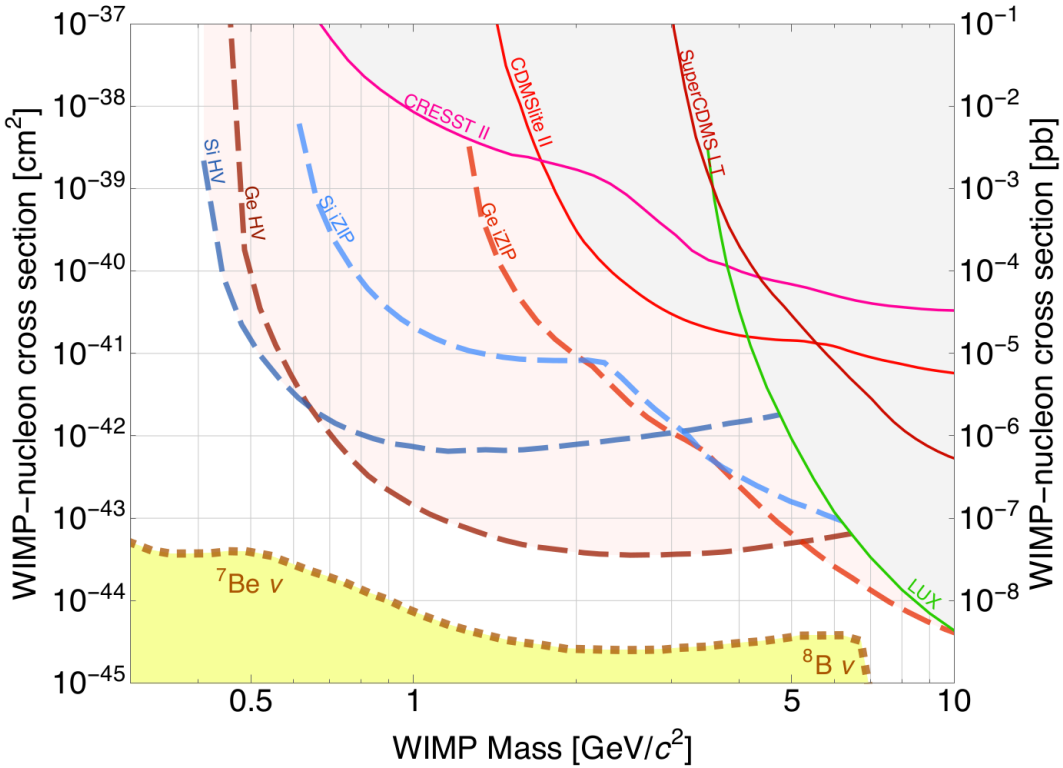
Start data taking in 2020

SuperCDMS SNOLAB goal

arXiv:1610.00006

	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

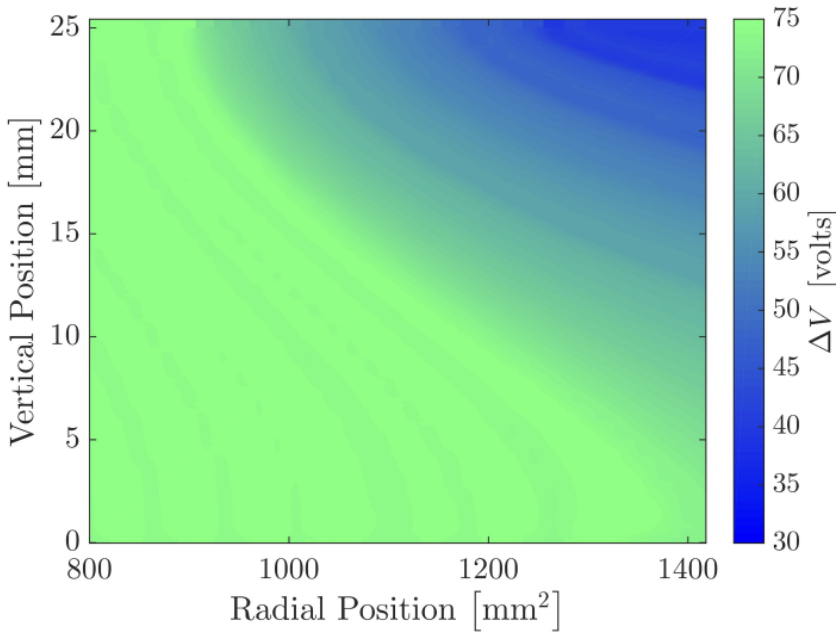
Conservative projected sensitivity.
As shown in CDMSlite Run 3 analysis, backgrounds modeling and likelihood analysis are the way to get the most from our data.
True especially for HV detectors

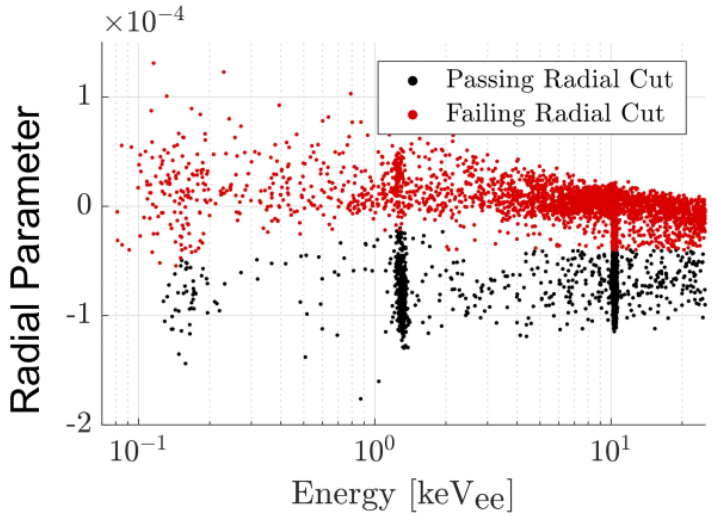


Backup

Run 3 fiducial volume cut

- Events at high radius receive reduced NTL amplification, are reconstructed at lower energy. Must remove for likelihood fit
- Design cut to remove radial regions where reduced NTL events fall



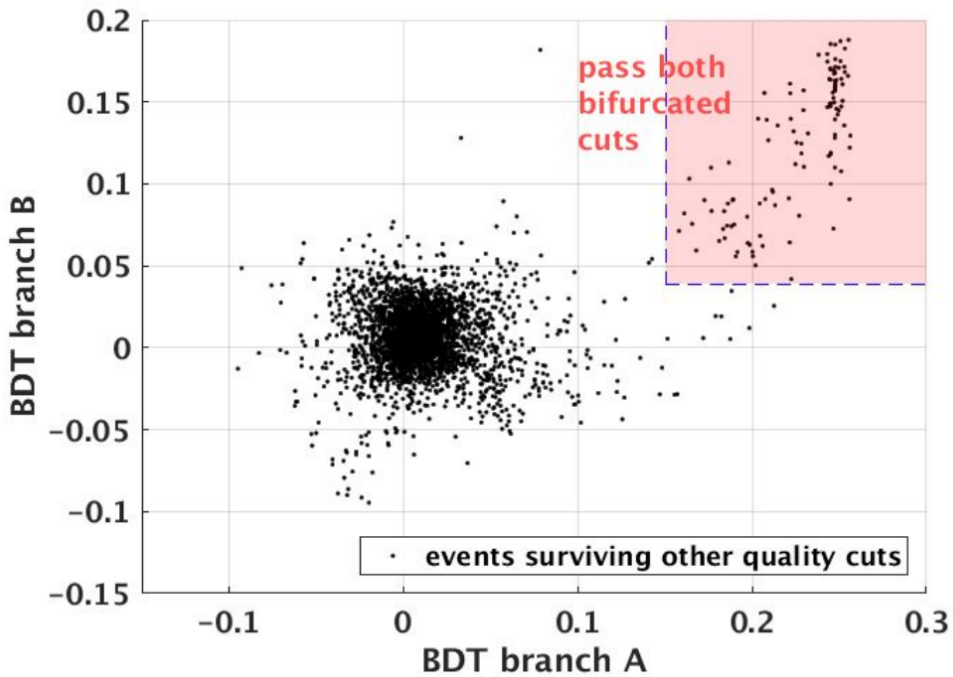


Bifurcated analysis setup

Two uncorrelated BDT variables are formed using the three different handles on discriminating LF noise

- Branch A : primarily pulse shape discrimination information
- Branch B : primarily cryostat vibration and detector-detector correlation information

Bifurcated analysis to get the noise event leaking past cuts



SNOLAB backgrounds

- Dominant background: in-crystal ^{3}H, ^{32}Si, ^{68}Ge
- Line-of-sight contamination from ^{210}Pb
- Material and cavern contamination: ^{40}K, ^{60}Co

"Singles" Background Rates (counts/kg/keV/year)	Electron Recoil				Nuclear Recoil ($\times 10^{-6}$)	
	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.