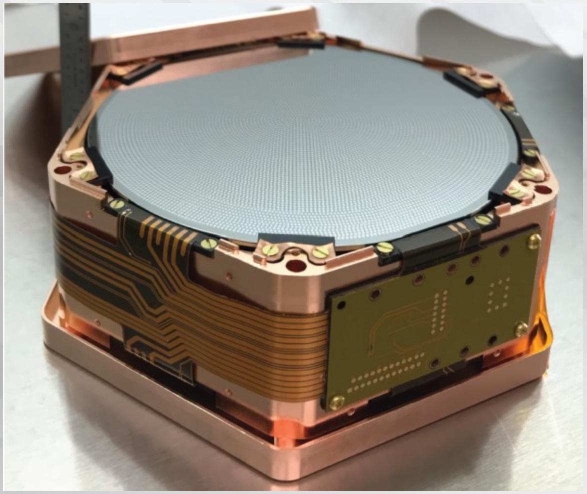

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Prospects for Low Mass WIMP Searches with SuperCDMS

BEN LOER, SUPERCDMS COLLABORATION

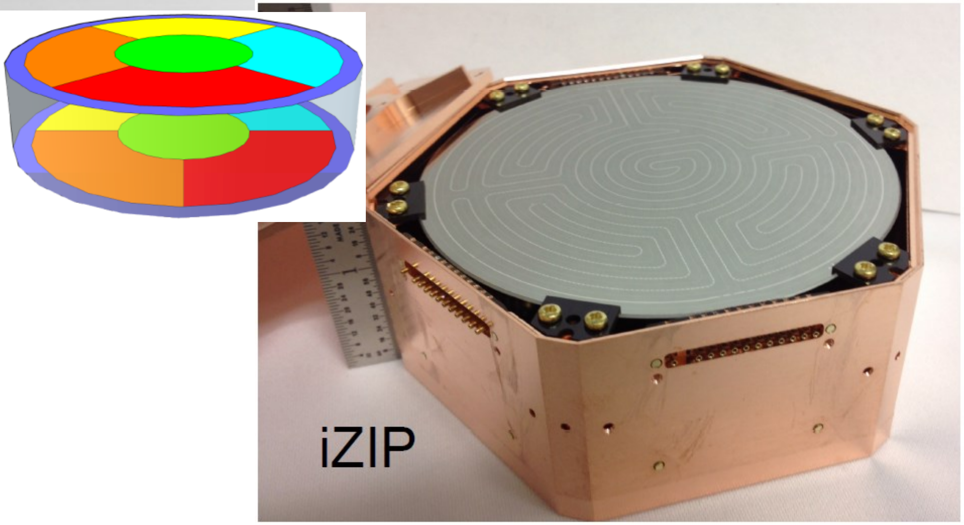
Pacific Northwest National Laboratory

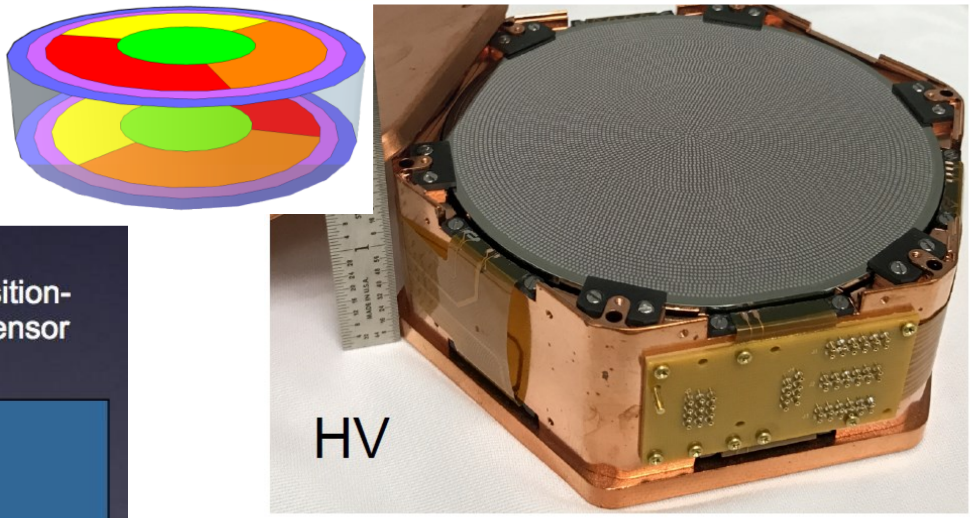
UCLA Dark Matter 2018

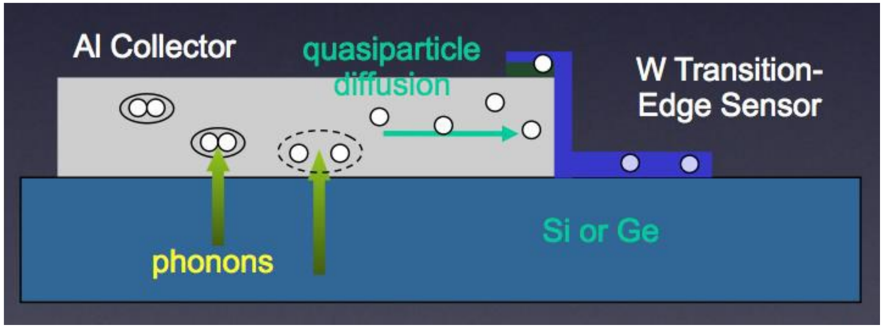
U.S. DEPARTMENT OF ENERGY

SuperCDMS Detector Technologies

- Ultra-pure ~kg Ge and Si crystals
- Operate at 10's of mK
- Measure athermal phonon signal via transition edge sensor
- Multiple channels give position info
- Outer "guard" rings fiducialize high radius events







SuperCDMS Detector Technologies

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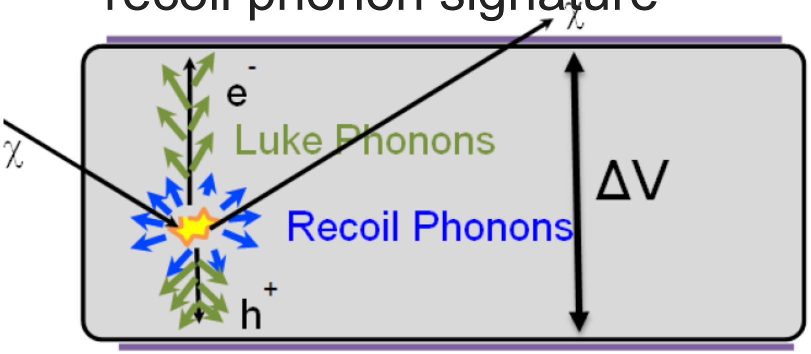
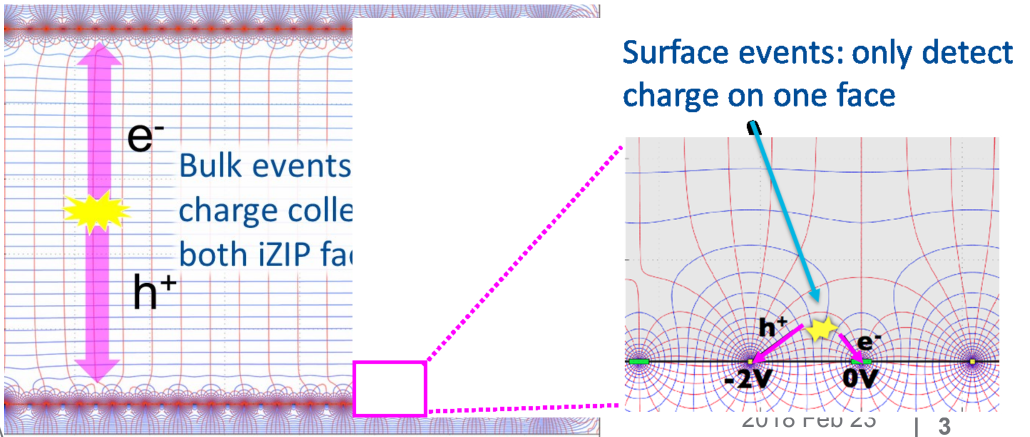
High Voltage (CDMSlite)

- Free e/h ionization from interaction gains energy from large potential (~100 V)
- Emits Luke-Neganov phonons from scattering on lattice
- Analogous to electroluminescence gain (S2 production) in TPC
- Luke phonons drown out intrinsic recoil phonon signature



iZIPs: *i*nterleaved *Z*-sensitive *I*onization and *P*honon detectors

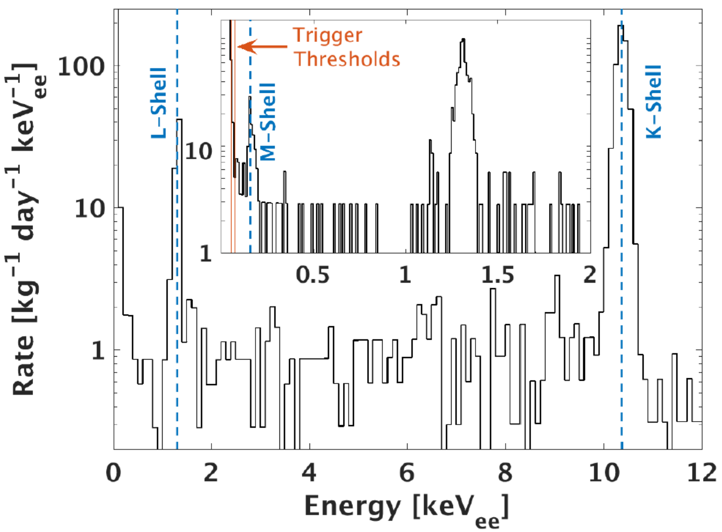
- Simultaneously measure charge (ionization) and phonons (energy)
  - Reject main electron-recoil backgrounds (works like S2/S1)
- Reject face events via asymmetric charge signal from interleaved electrodes



SuperCDMS Detector Technologies

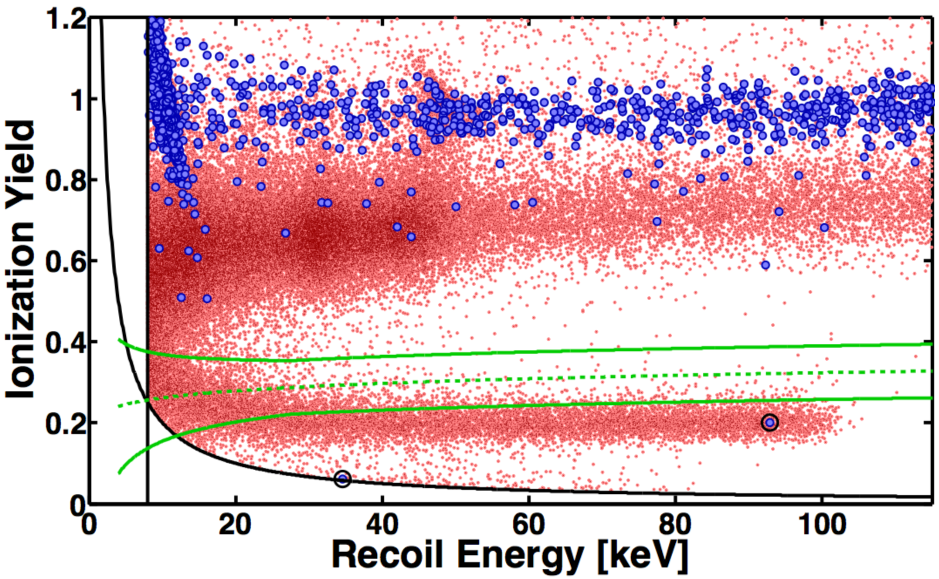
High Voltage => Low Threshold

- Ultra high resolution indirect charge measurement
  - Measured 17 eVee at 160 eVee
- No yield or detector face discrimination



iZIPs => Low Background

- High resolution phonon and charge readout
- All surface and ER backgrounds above few keV removed



(Super)CDMS at Soudan

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2006-08: CDMS-II Five Tower Phase
2009: CDMS-II Ge Results

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2016: Move on to greener pastures

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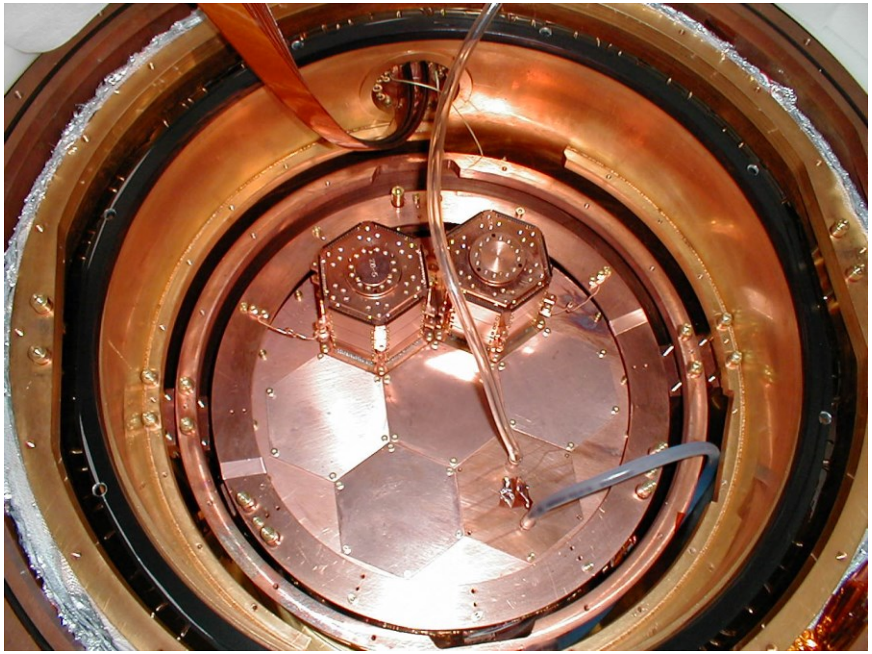

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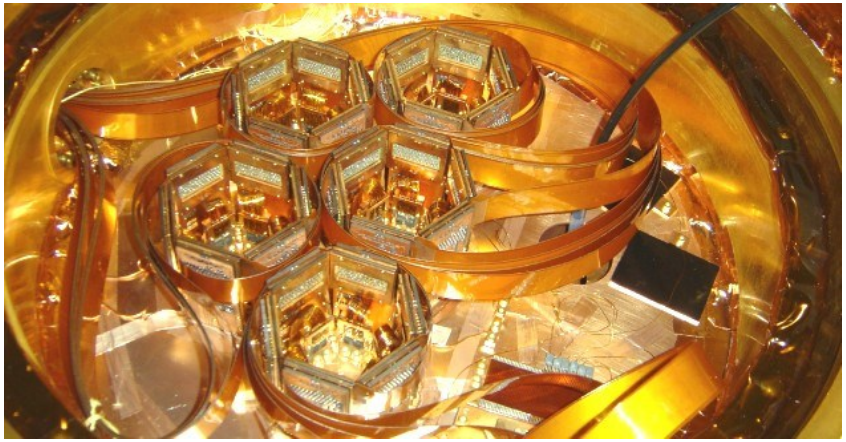

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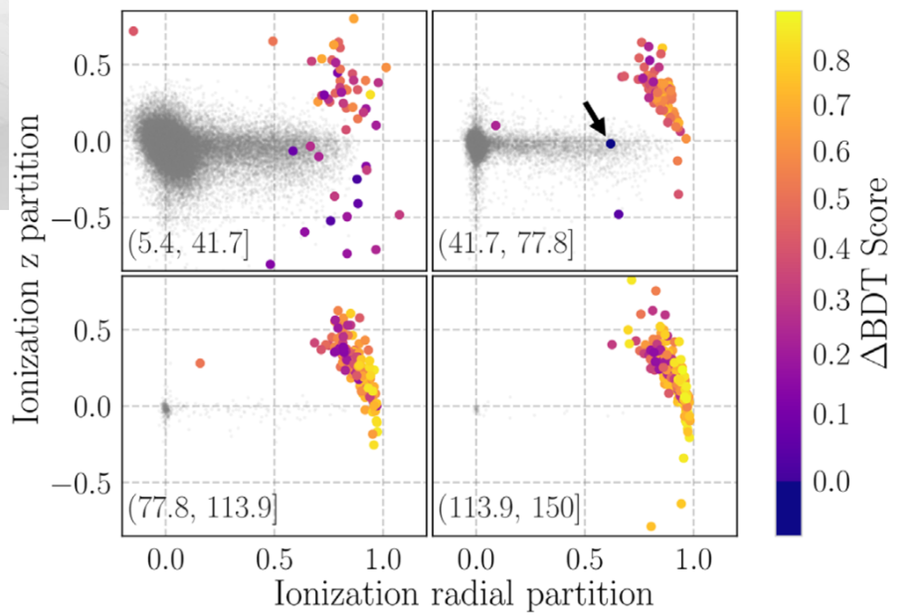
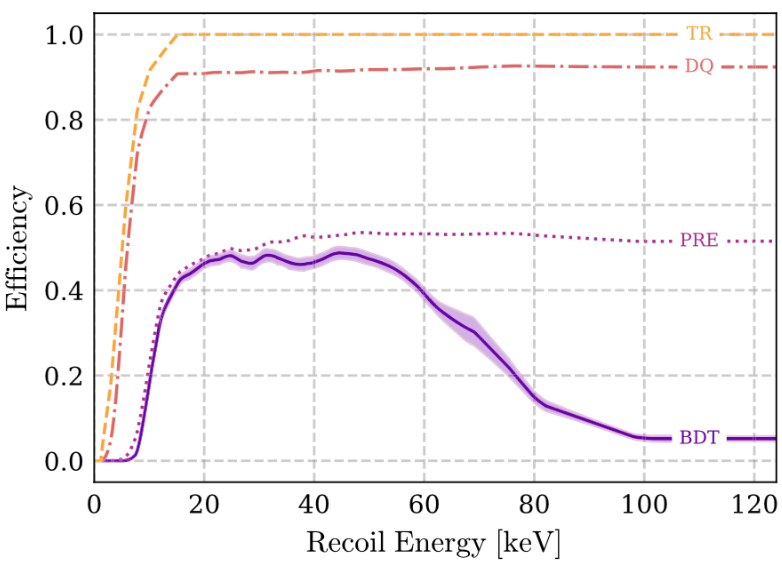
2016: Move on to greener pastures
(but new results still coming!)

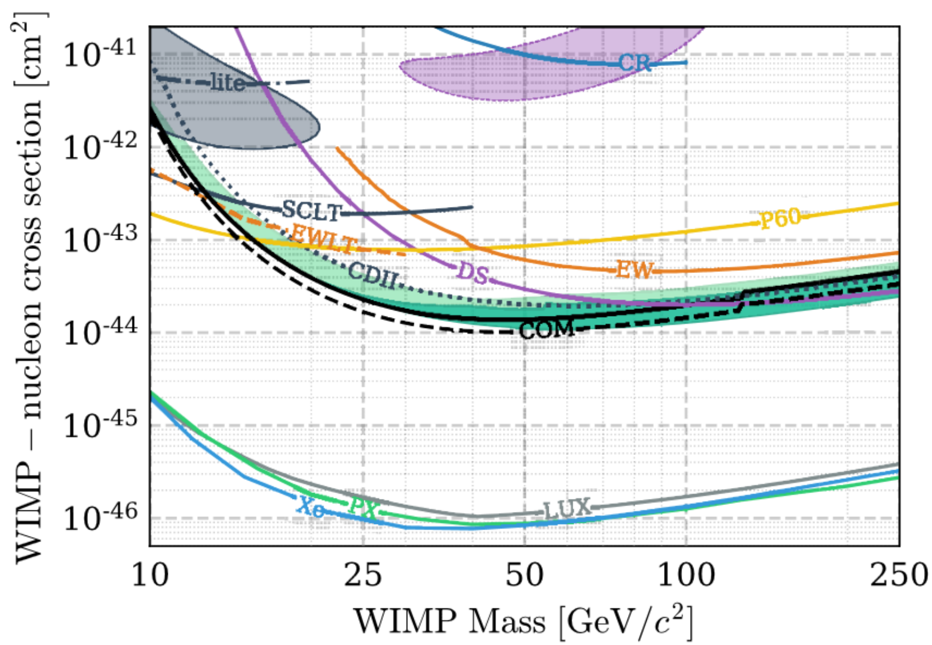
Improving technology; lower threshold and WIMP mass

SuperCDMS Soudan
"High Threshold" Analysis

- Majority of SuperCDMS dataset
- 2 calendar years, ~1700 kg*days
- Few keV threshold
- BDT background discriminant
- Observed 1 event, 0.33 expected
- PRL published last week

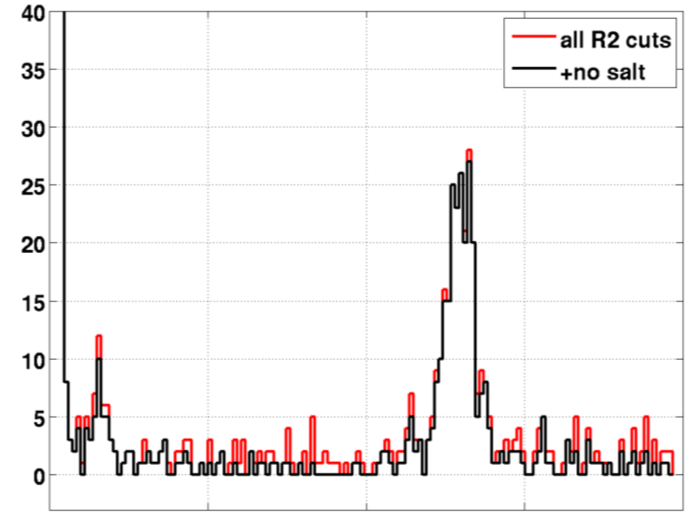


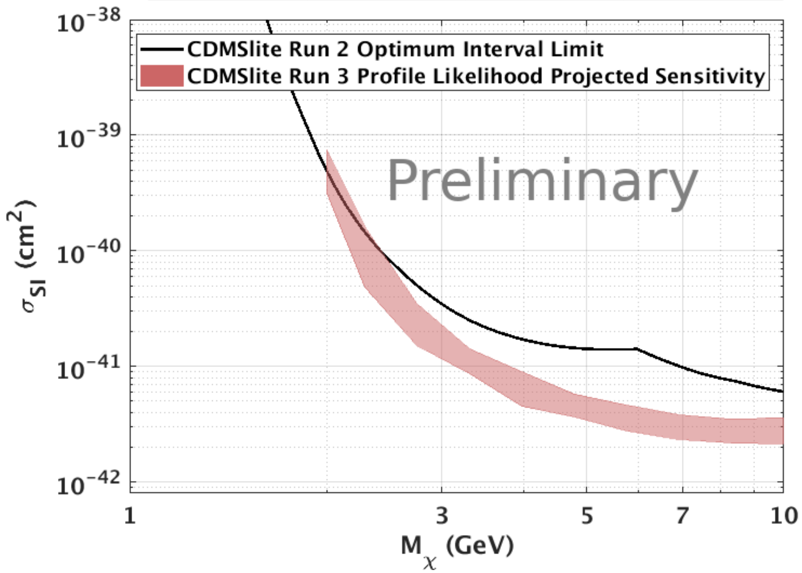




CDMSlite Run 3

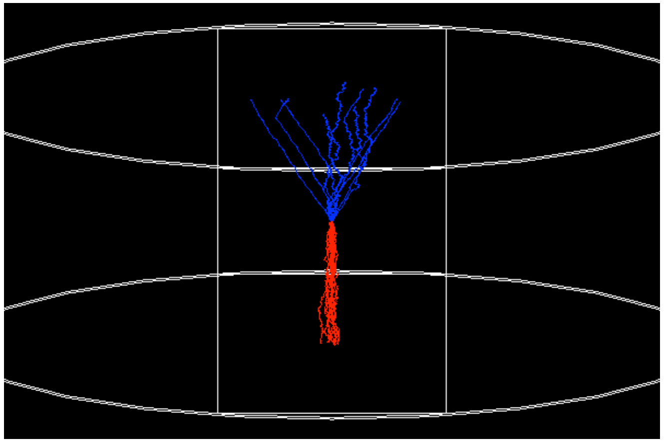
- Different detector, similar threshold, livetime
- Focus on improving analysis techniques
- Data blinded by “salting” fake signal-like events into data
- Improving detector response and background modeling
- Likelihood estimate allows some background rejection
- Expect factor ~3 improvement over previous results



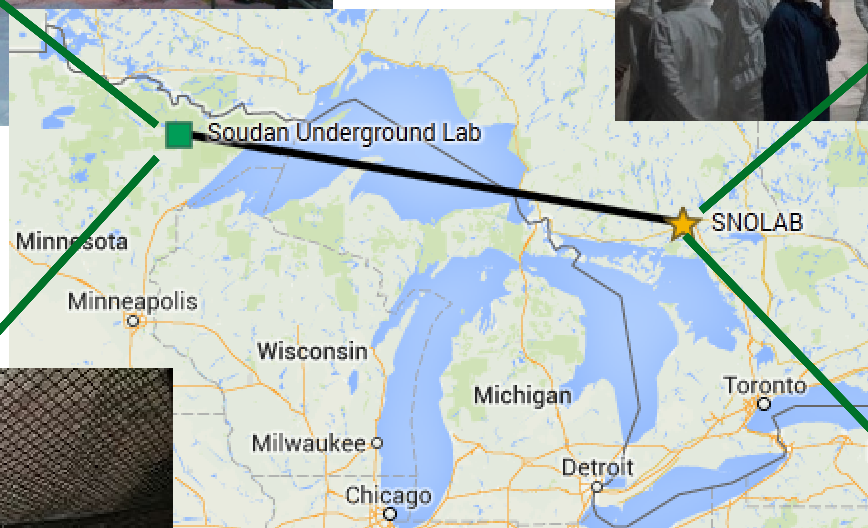


Other new results on the way

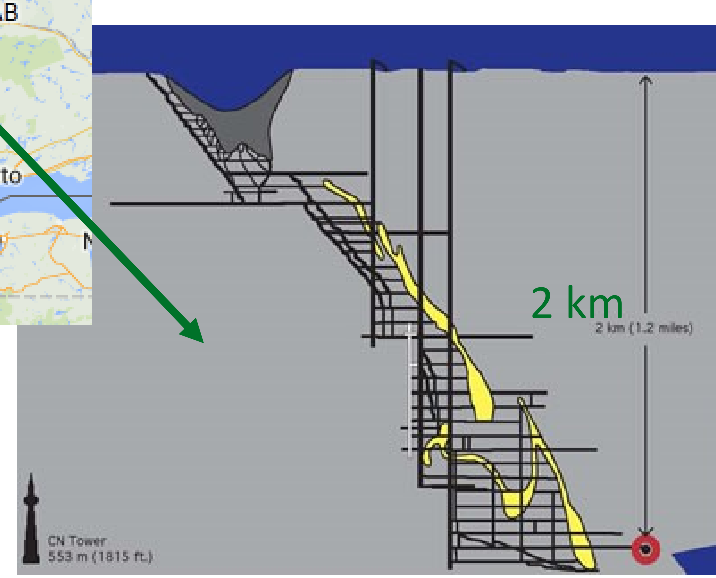
- Nuclear recoil energy scale from CDMS-II Si detectors
- Photoneutron nuclear recoil calibration with SuperCDMS (Ge) detectors
- Improved low-threshold SuperCDMS iZIP data analysis
- Fractionally charged particles
- Dark matter electron recoils
- Ongoing improvements to G4CMP: Geant4 add-on package for phonon and charge propagation in crystals



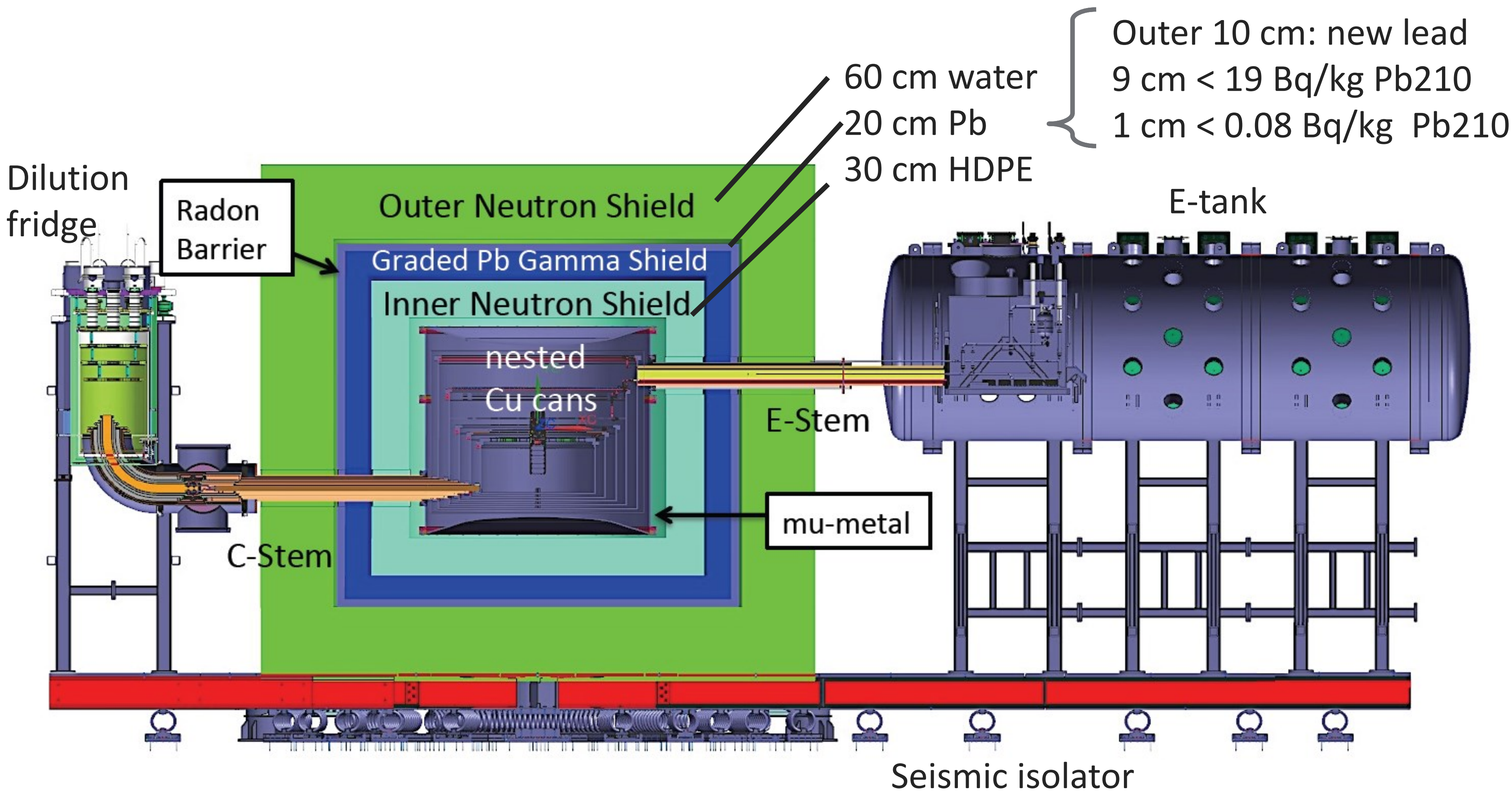
Moving down (and south) to SNOLAB



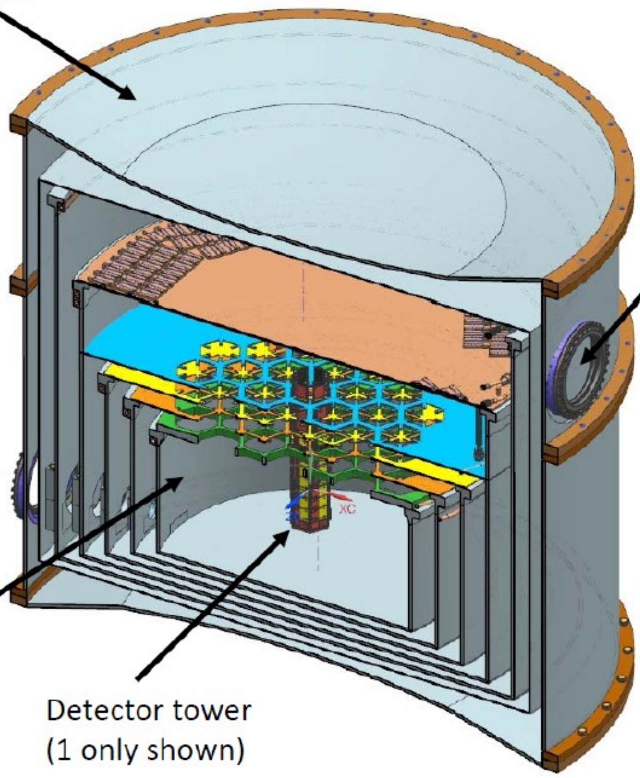
>100x reduction in muon flux at SNOLAB compared to Soudan



SuperCDMS SNOLAB
Shielding and Infrastructure

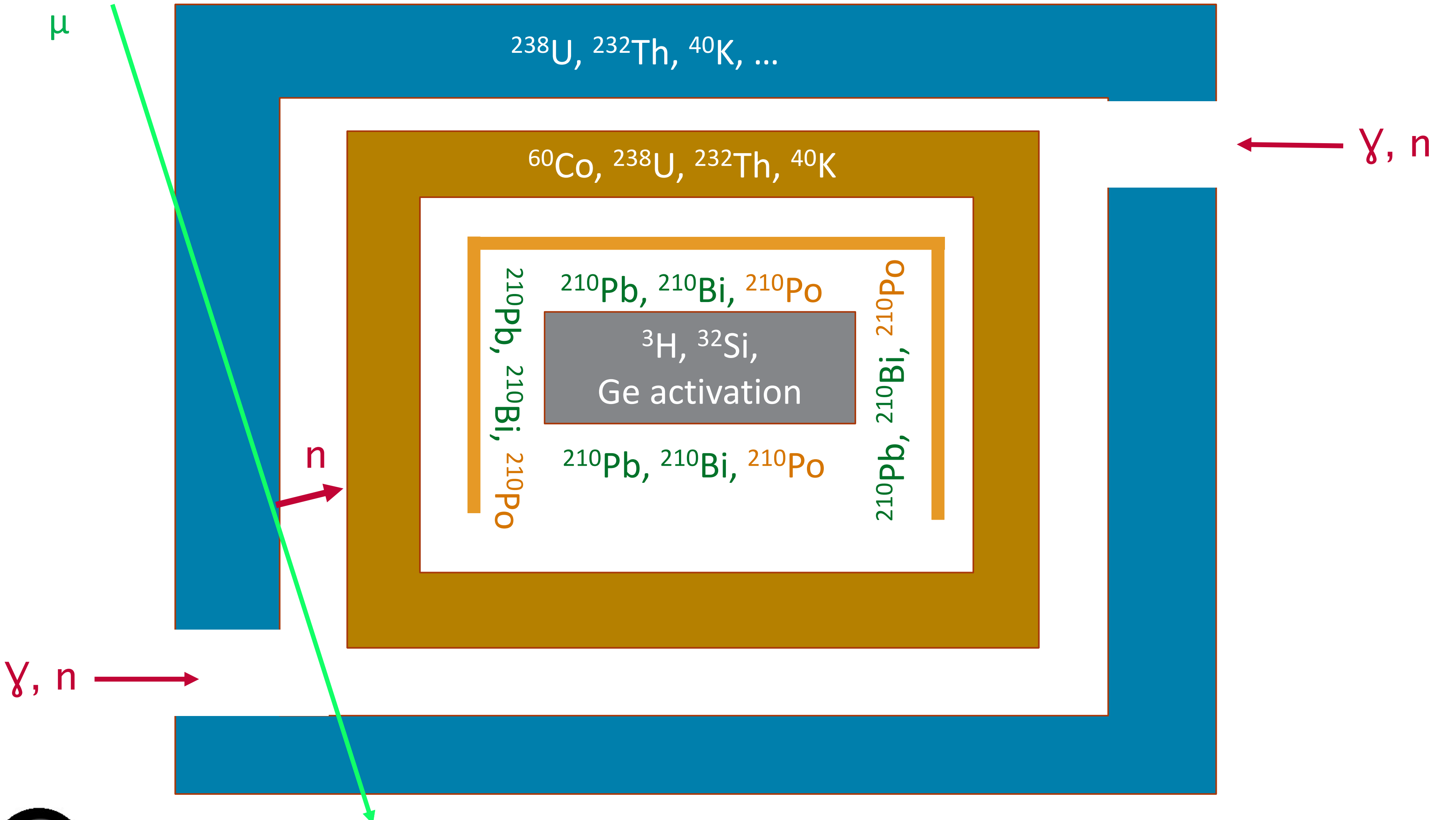


SuperCDMS SNOLAB Cryostat



- 4 tower initial payload
  - 2 HV (4 Ge, 2 Si each)
  - 2 iZIP (6 Ge in 1, 4/2 Ge/Si other)
- Fridge, cryostat capable of 31 towers, nominal 15 mK

Background Categories



SuperCDMS SNOLAB Detector Performance Goals

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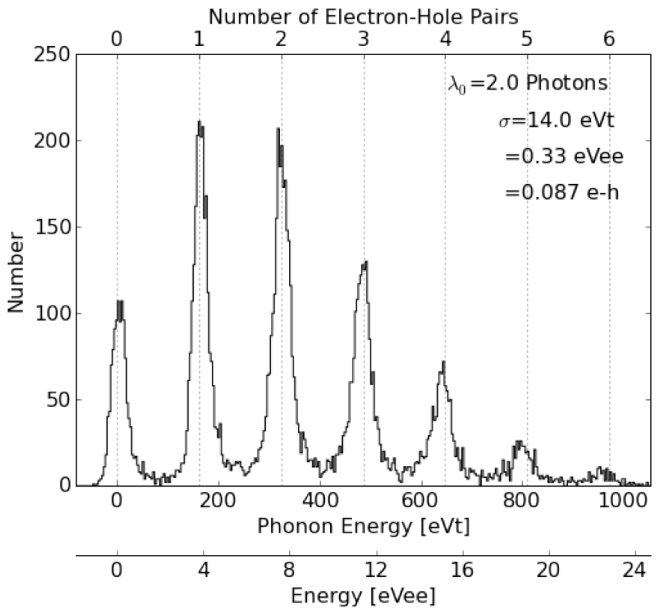
	Soudan	SNOLAB
Phonon resolution, eVt	~250	10 HV, 50 iZIP
HV Bias Voltage, V	70	100
iZIP Charge resolution, eVee	~400	160
HV Threshold, eVnr	300	40



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

1 cm^2 x 4 nm Si test device with 160V bias demonstrating single e/h pair measurement with <10% resolution

See R. Calkins' talk for more details

SuperCDMS SNOLAB Backgrounds

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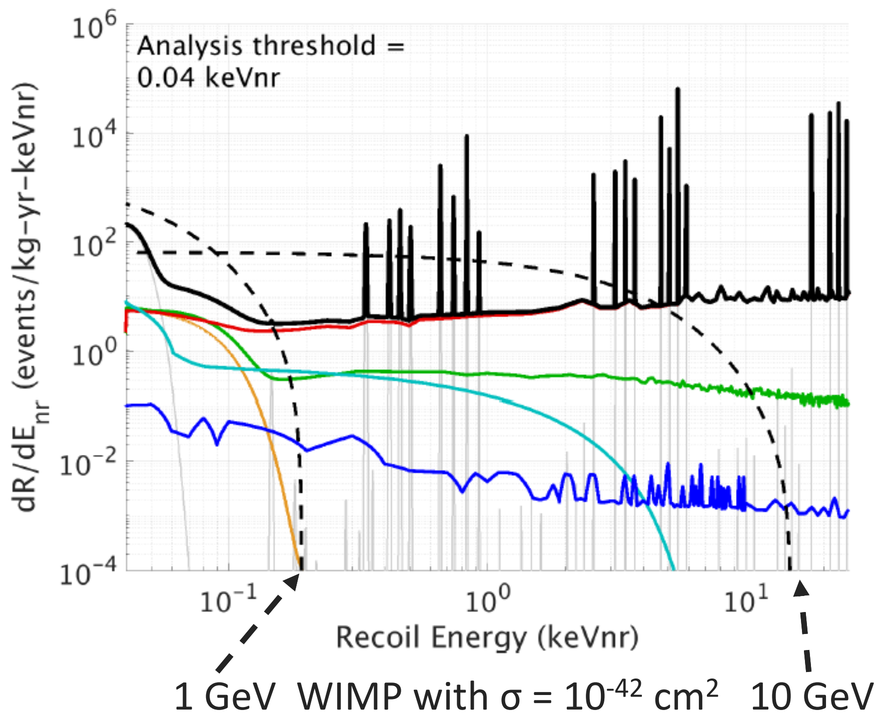
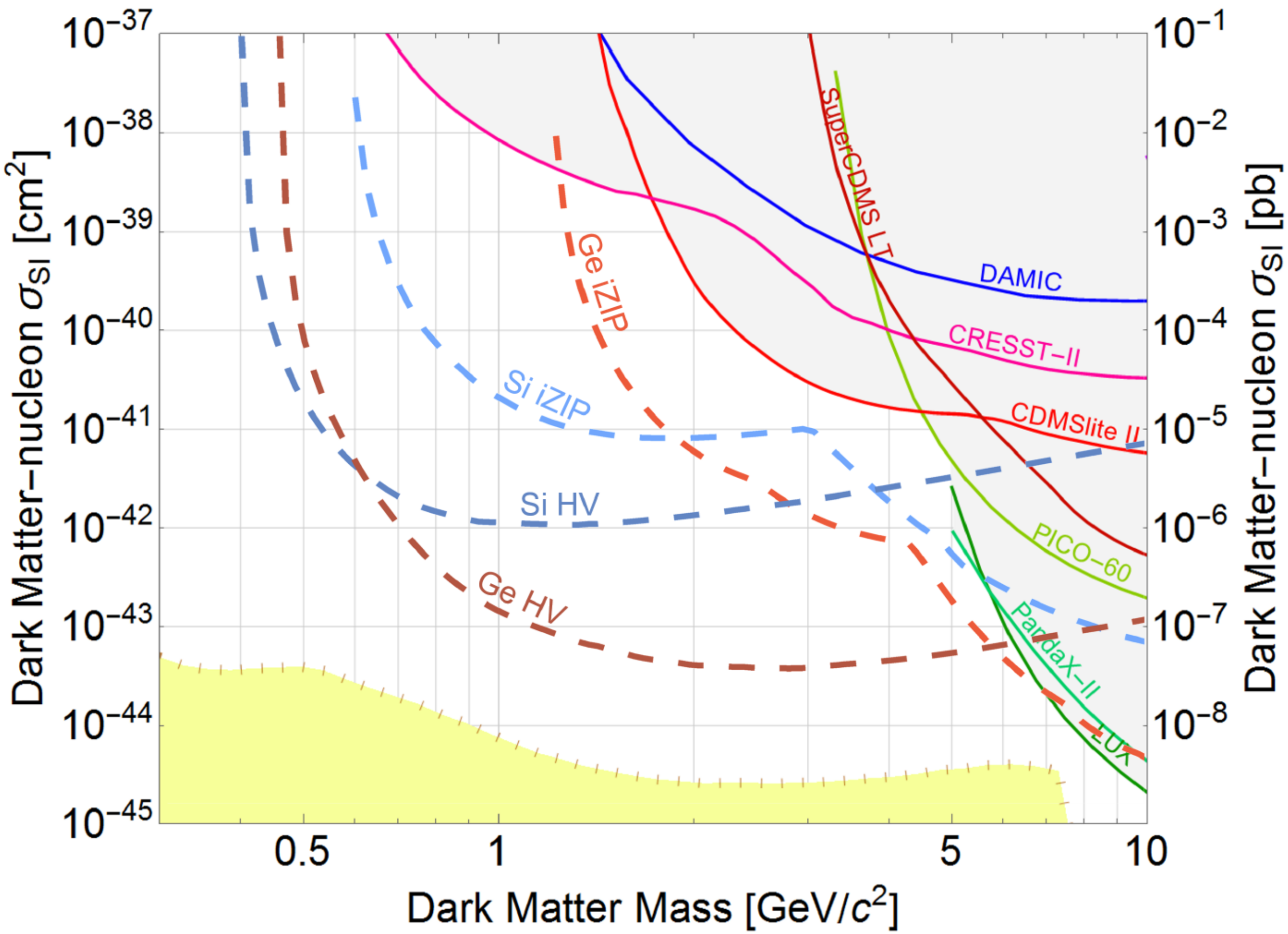
Predicted background spectrum in Ge HV Detectors after fiducial cuts



Total
^{3}H and Comptons
Ge activation
Surface betas
Surface ^{206}Pb
neutrons
Coherent neutrinos

SuperCDMS SNOLAB Projected Sensitivity



Conclusions

- CDMS has departed Soudan after over 15 years of great science
- Data analysis is ongoing with multiple new results coming soon
- SuperCDMS SNOLAB will be the world-leading low mass WIMP search experiment
- Sensitivity $<10^{-43}$ cm^2 for 1-10 GeV WIMP masses, coverage to 0.4 GeV
- Passed CD3 review last month to begin construction
- Underground installation starts next year, completed by 2020

Thank you!

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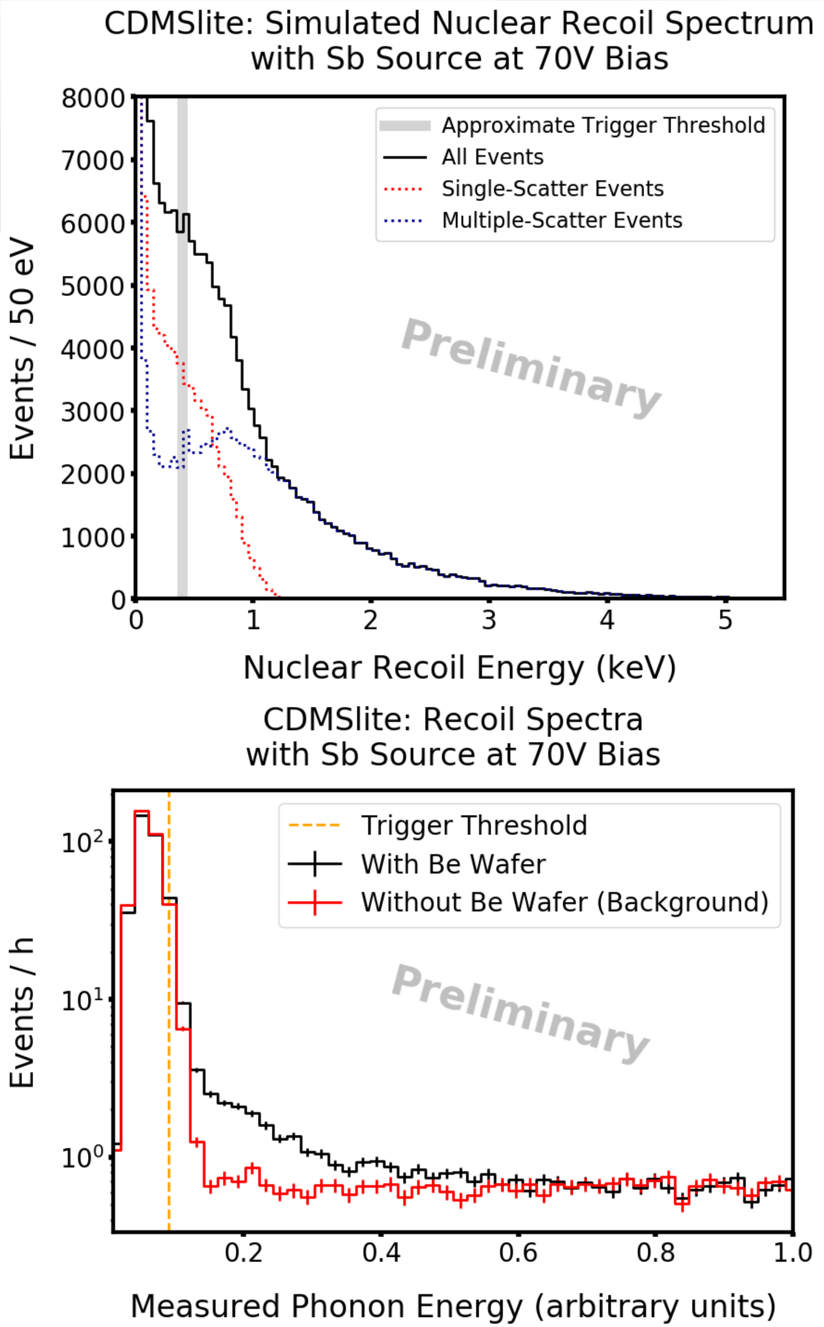
CNRS-LPN*
Durham University
FNAL
NISER
NIST*
Northwestern
PNNL
Queen's University
Santa Clara University
SLAC
South Dakota SM&T
SMU
SNOLAB
Stanford University
Texas A&M University
TRIUMF
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Montréal
U. Minnesota
U.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

* Associate members

Backup

Photoneutron calibration

- Monoenergetic neutrons from (gamma,n) process
- Ideally produces sharp edge in recoil spectrum to calibrate neutron response
- Distorted by degraded energy and multiple scattering
- Must subtract high gamma flux



G4CMP: Geant4 add-on framework for phonons and charge-carrier physics

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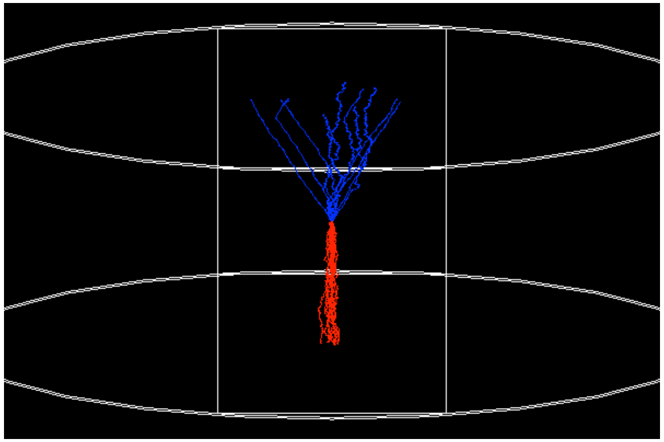
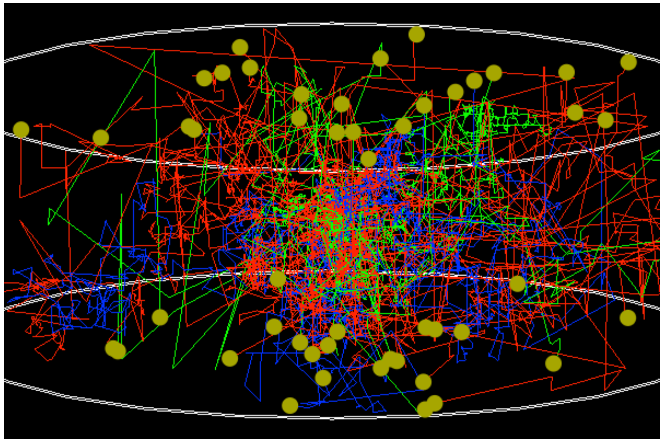
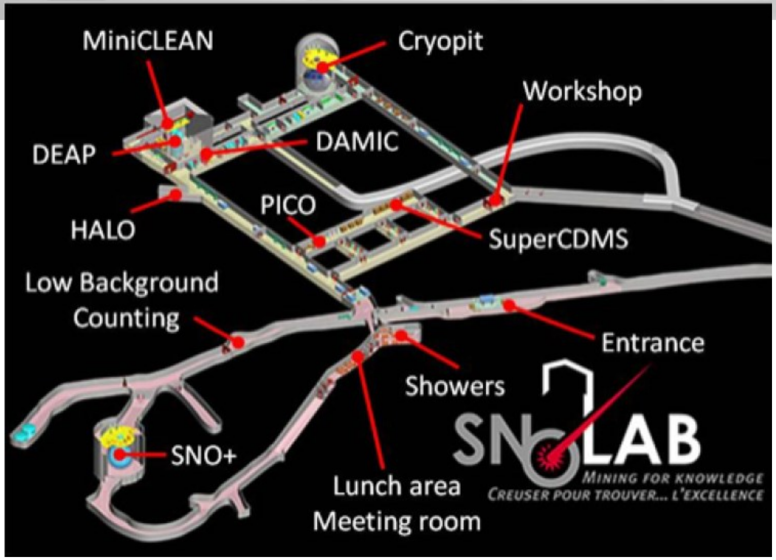
- Library of tools on top of Geant4
  - Available on Github since 2015
  - https://github.com/kelseymh/G4CMP
- Material properties for Ge, Si
  - Users can add new materials
- Charge transport in valleys
- Acoustic phonon transport
- Surface interactions, detection

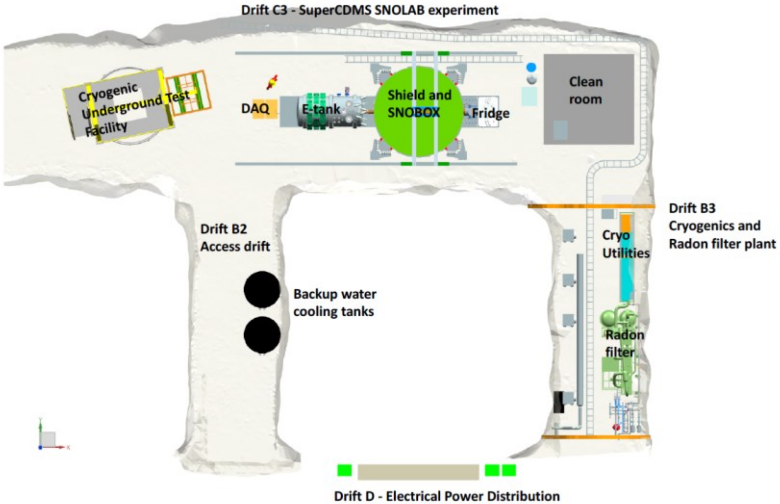


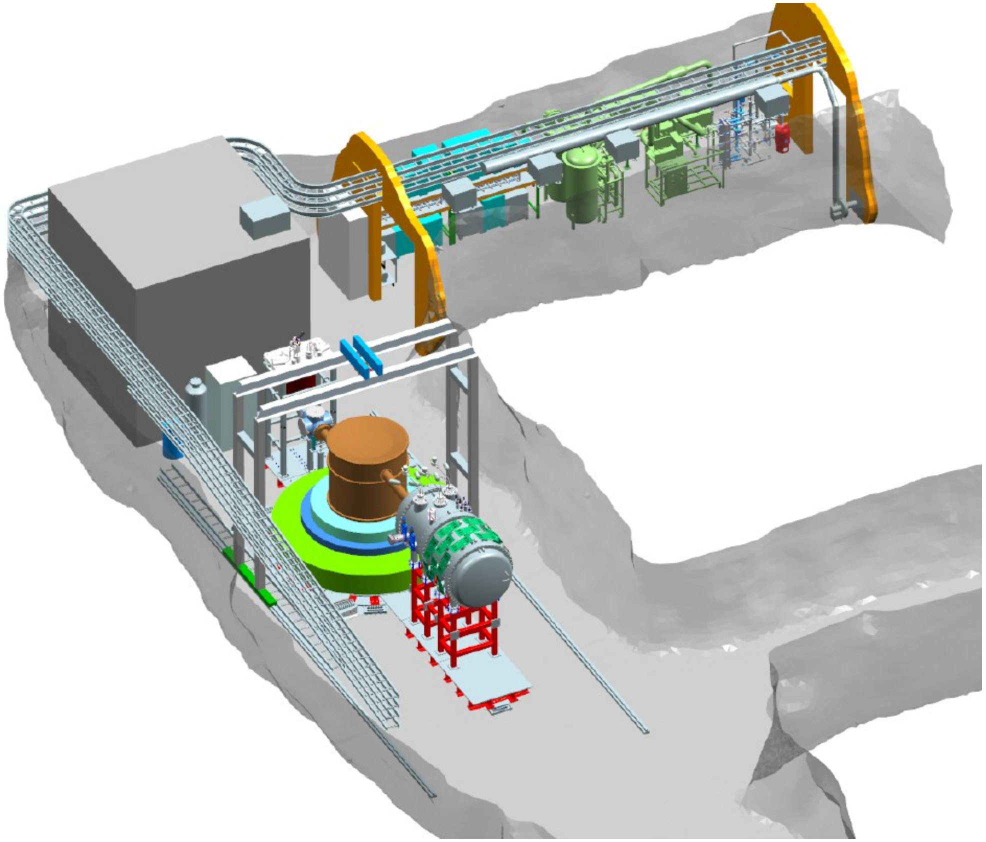


SuperCDMS

Moving to SNOLAB







SuperCDMS SNOLAB Backgrounds

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Predicted rates in counts / kg*keVr*year

Category	Ge HV ERsingles	Si HV ERsingles	Ge iZIP ERsingles	Si iZIP ERsingles	Ge iZIP NRsingles ($x10^{-6}$)	Si iZIP NRsingles ($x10^{-6}$)
-Total	48.	360.	50.	400.	3200.	2300.
Coherent Neutrinos					2300.	1600.
-Detector Internal Contamination	24.	280.	4.7	250.	0	0
Tritium	24.	33.	4.7	6.6	0	0
Silicon-32	0	250.	0	250.	0	0
Other						
-Material Internal Contamination	17.	66.	36.	120.	370.	460.
+Housing and Towers	6.5	34.	19.	65.	51.	66.
+Readout Cables	0.31	0.46	0.39	0.80	11.	15.
+SNOBOX Cans	4.0	13.	6.5	22.	68.	75.
Kevlar Ropes	2.1	5.1	2.7	8.3	3.6	4.0
+Calibration	0.92	3.0	1.2	3.6	0.05	0.05
+Shield Materials	3.5	10.	5.3	17.	240.	300.
Bulk Pb-210 in Lead	0.07	0	0.22	0.75		
-Material Internal Activation	2.3	8.4	3.9	13.		
Housing and Towers	0.64	2.5	1.0	4.1		
+SNOBOX	1.5	5.6	2.8	8.9		
Shield	0.07	0.28	0.14	0.41		
Other						
+Non-line-of-sight Surfaces	1.6	5.0	2.9	9.3	35.	41.
Prompt Interstitial Radon	0.61	1.8	0.87	2.7		
+Cavern Environment	2.3	3.5	2.0	9.6	330.	160.
Cosmic Ray Flux	0.00	0.00	0.00	0.00	85.	99.

- HV dominated by ^{3}H and ^{32}Si
- iZIPs dominated by neutrinos, then neutrons
- iZIPs expect <1 events above 2 keV

Detector Internal Contamination

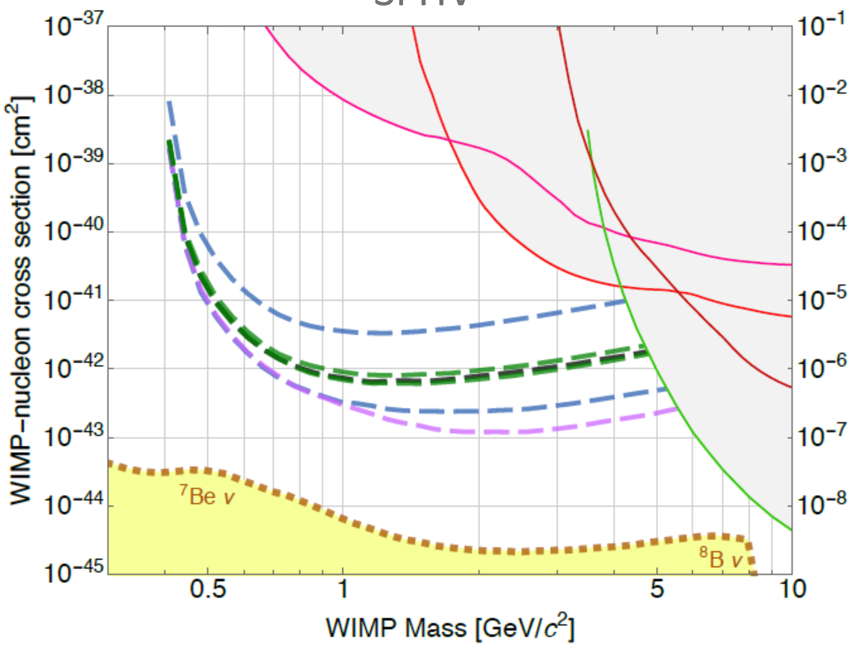
Material	Isotope	Production Rate (atoms/kg/day)	Concentration (decays/kg/day) Towers 2-4	Tower 1
Ge	^{3}H	90	0.7	12
Si	^{3}H	125	1	-
Si	^{32}Si	–	80	80

Dust and radon daughter deposition

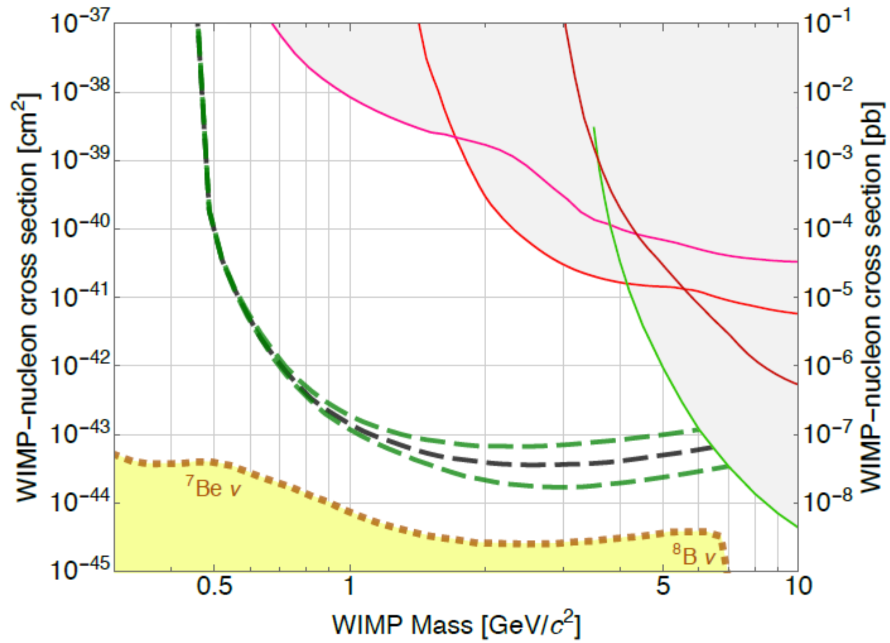
Region of dust accumulation	Surface Area (m^2)	^{210}Pb (μBq/cm^2)	Dust (μg/cm^2)
Detector faces (sidewalls)	0.4 (0.3)	0.025 (0.04)	
Detector housings inside (line-of-sight)	0.5	0.01	0.06
Housing outside and towers	4	10	0.5
Cryostat cans	100	10	1
Cryostat exterior and shield walls	80	10	10
Polyethylene interior surfaces	450	1	1

Sensitivity Variation with detector backgrounds

Si HV



Ge HV



Nominal

0 ^{3}H | 0 ^{32}Si | 0 ^{32}Si and 0 ^{3}H

10X ^{3}H | 10X ^{32}Si

Sensitivity Variation with ^{210}Pb level

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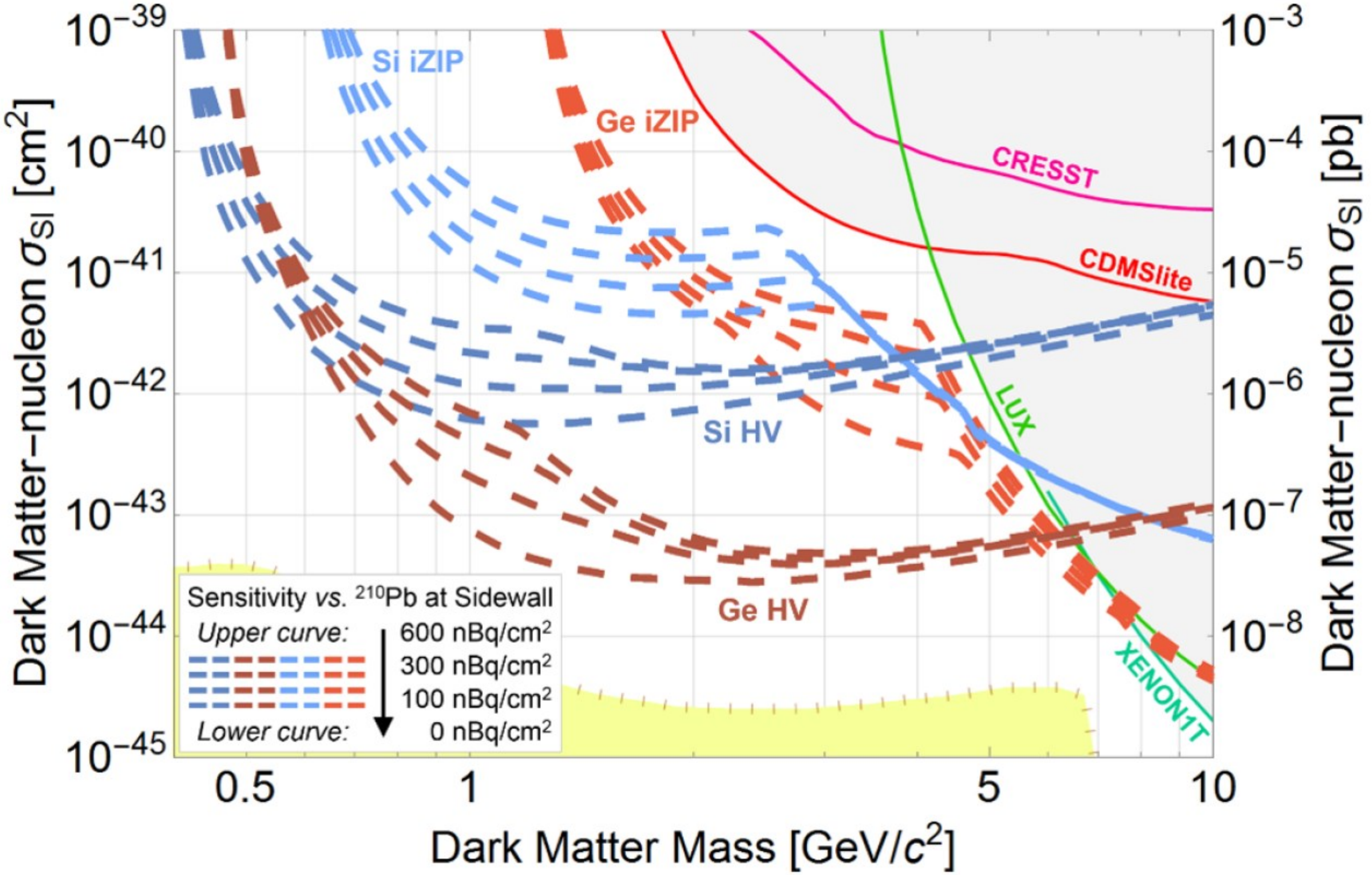
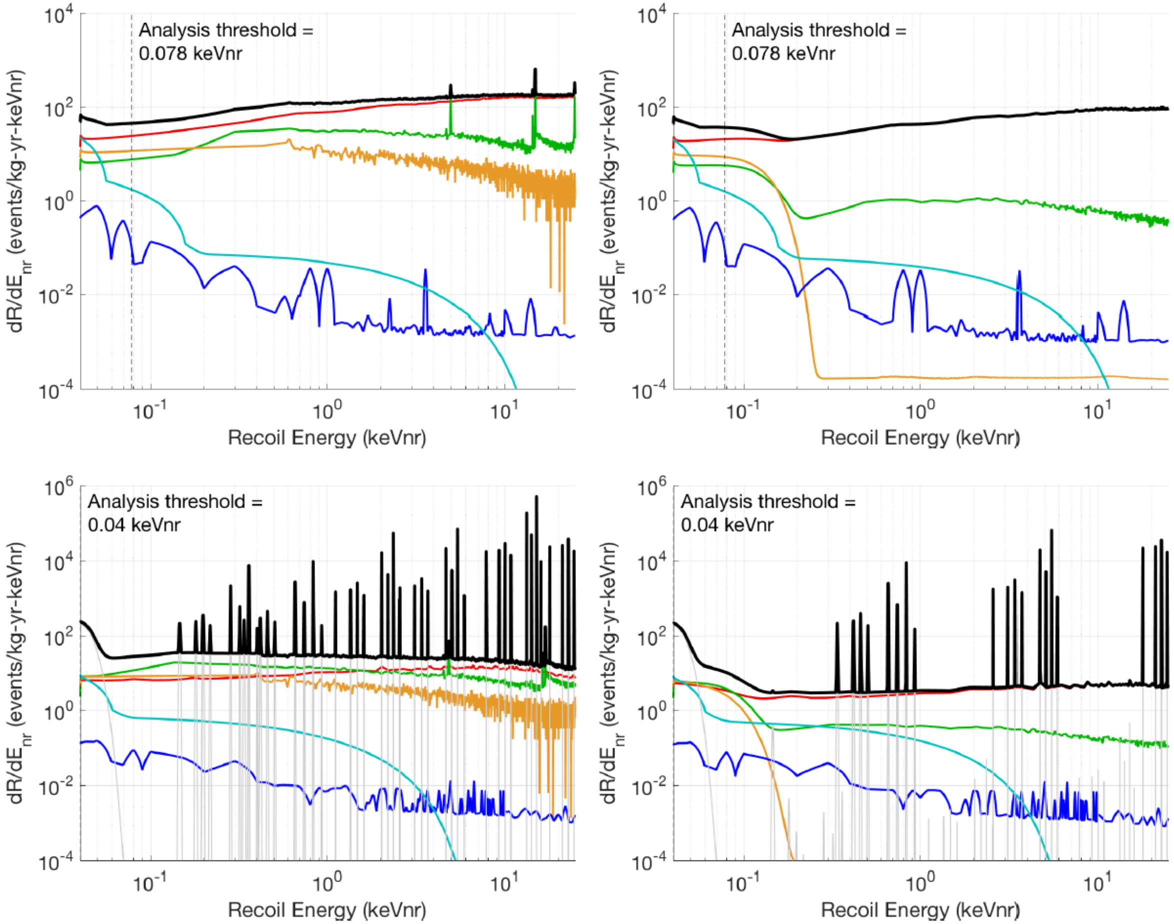


iZIP detector response



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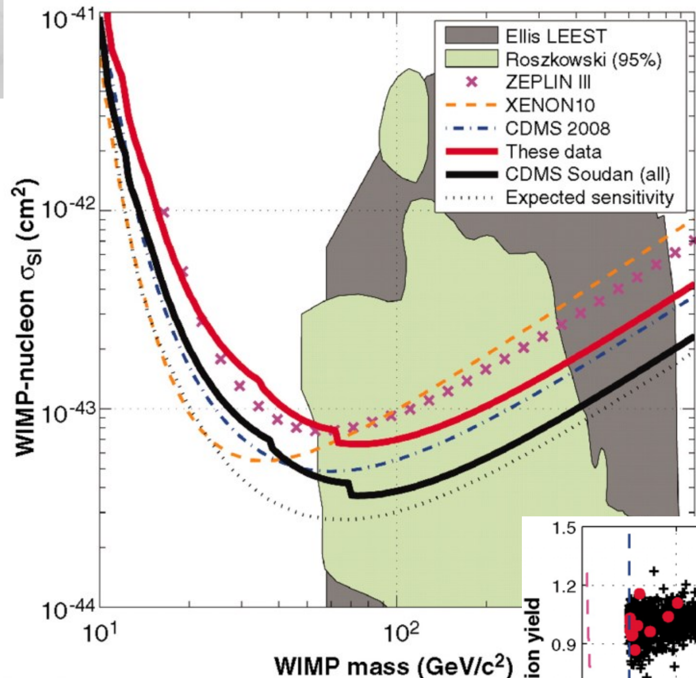

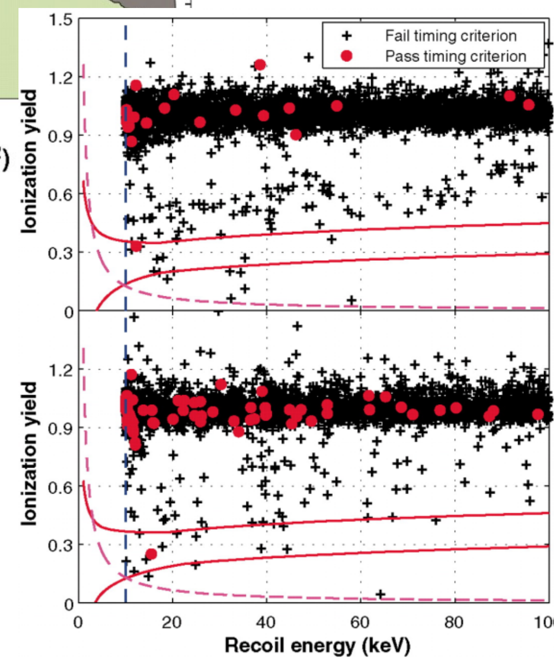

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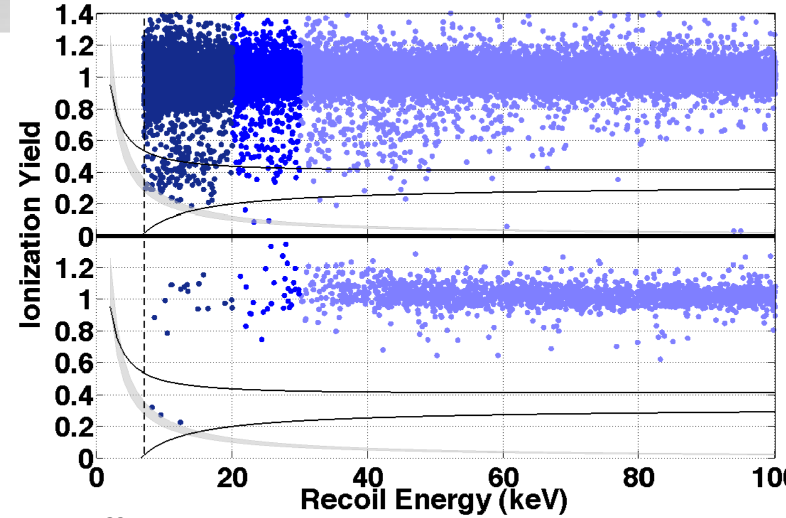

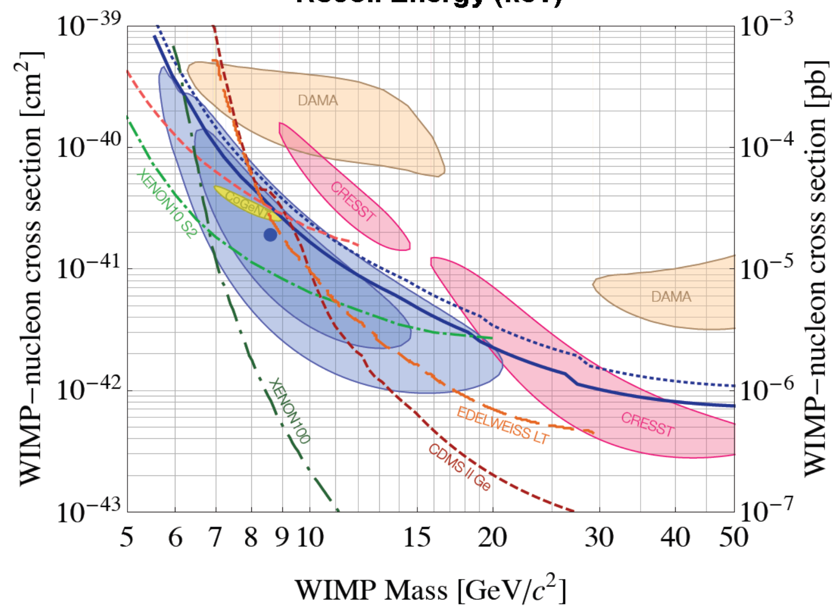

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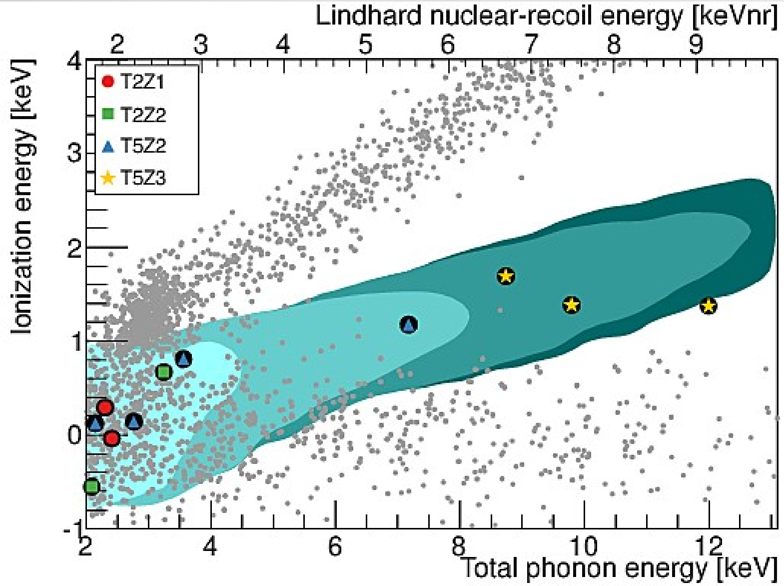

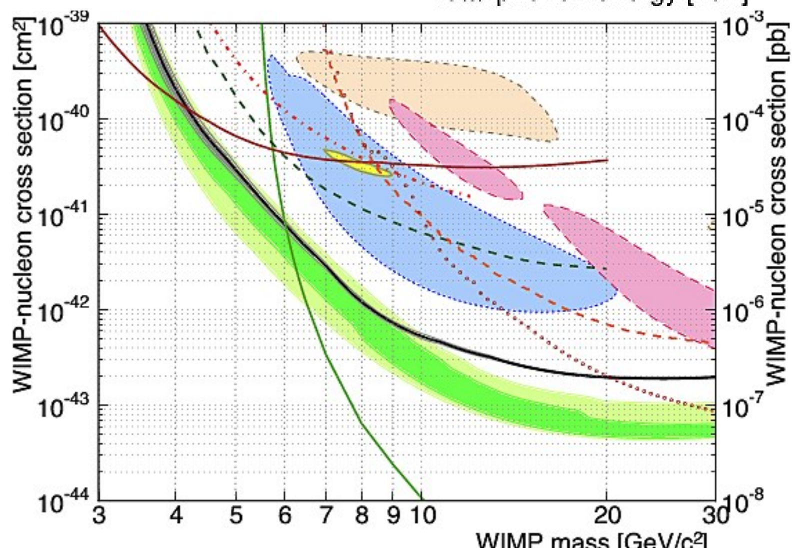

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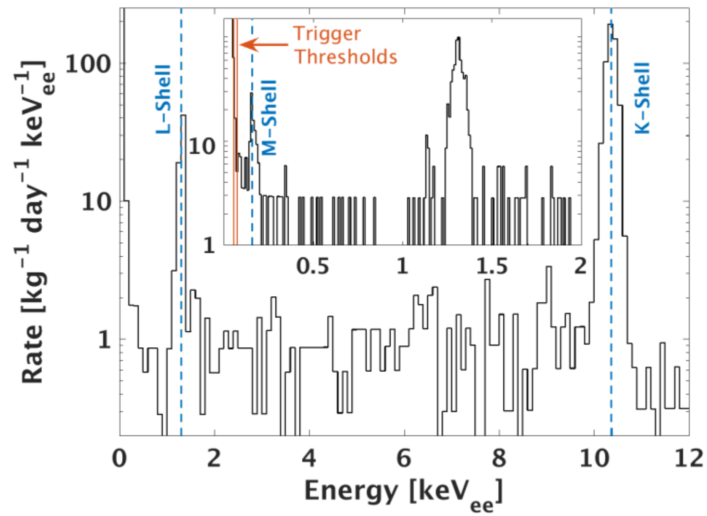
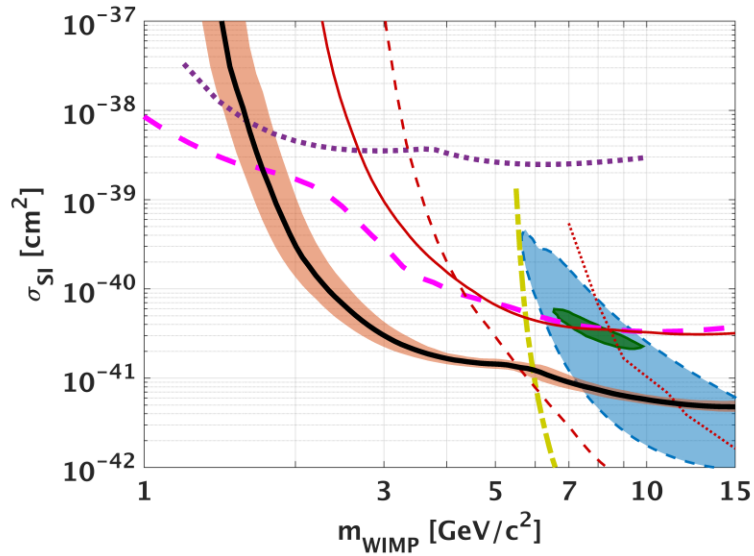
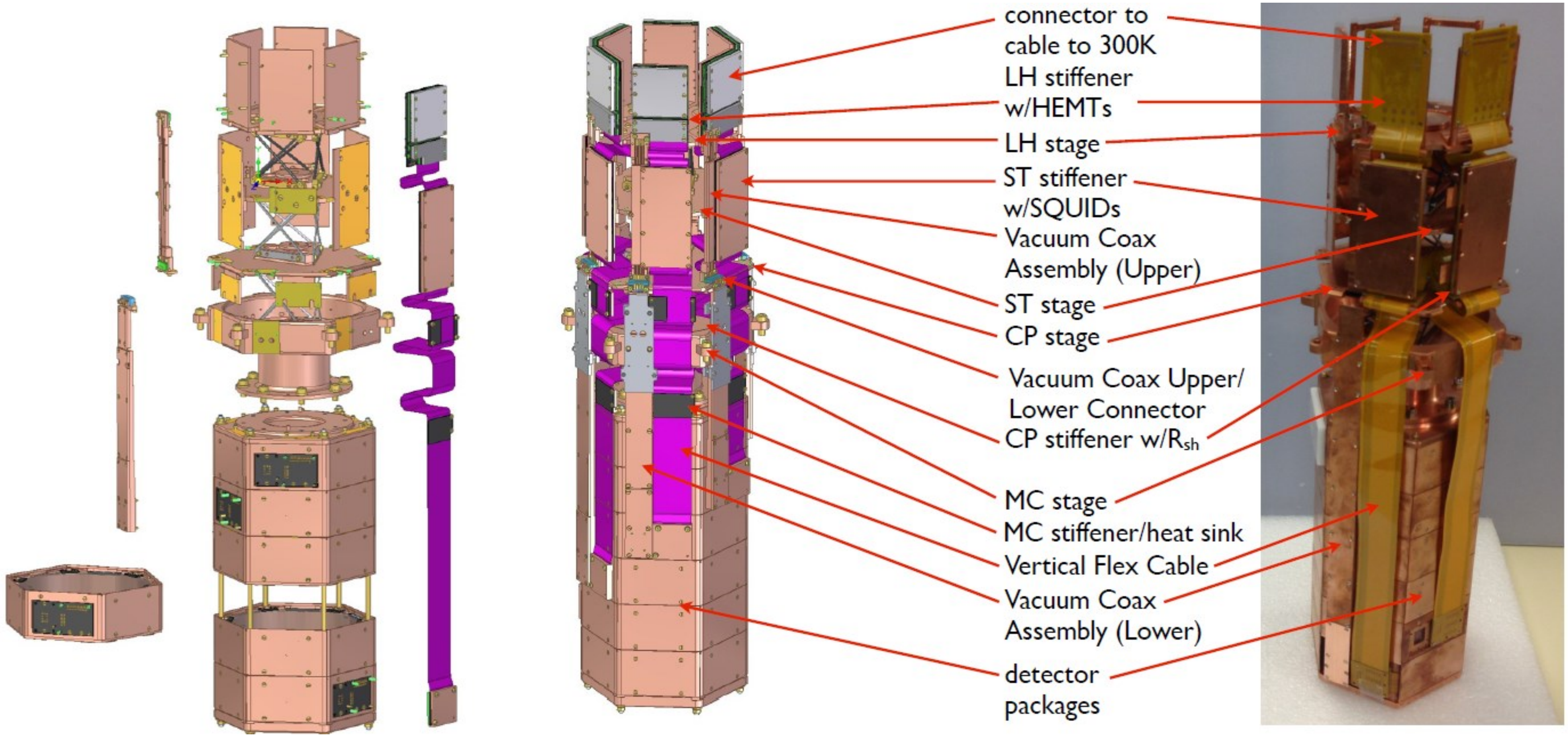
- 2016: Move on to greener pastures





SuperCDMS SNOLAB Towers



SuperCDMS SNOLAB Detector Performance Goals

	Soudan	Ge HV	Si HV	Ge iZIP	Si iZIP
Phonon resolution, eVt	~250	10	7	50	25
Bias Voltage, V	70	100	100	6	8
Charge resolution, eVee	~400	NA	NA	160	180
Threshold, eVt (eVnr)		100 (40)	100 (78)	350 (272)	175 (166)