Backgrounds and Shielding for SuperCDMS SNOLAB

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On behalf of the SuperCDMS Collaboration
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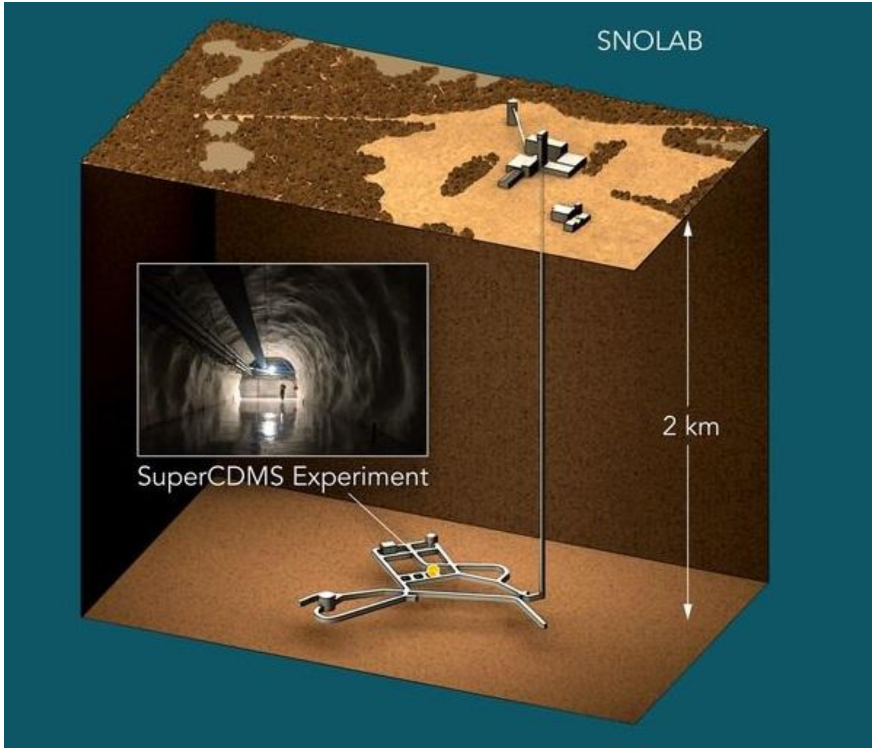
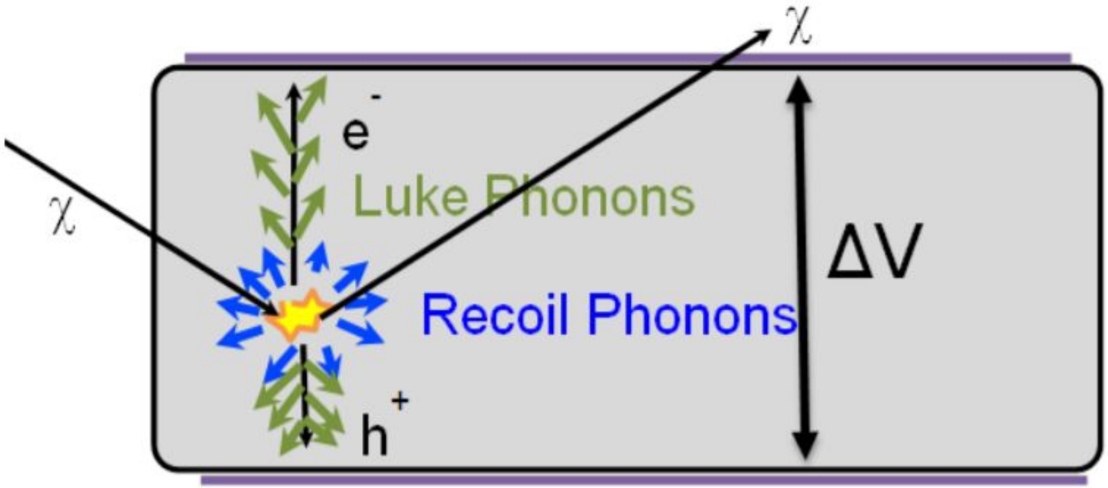
SUPER CDMS
Cryogenic Dark Matter Search

SuperCDMS @ SNOLAB

- Direct detection search for low mass (<10 GeV) WIMP dark matter
- Uses cryogenic Ge and Si detectors. Sensitive to energy depositions via athermal phonons and ionization
- Located at SNOLAB near Sudbury, Ontario. 2 km overburden shields cosmic rays
- Currently under construction. Initial payload of ~20 kg



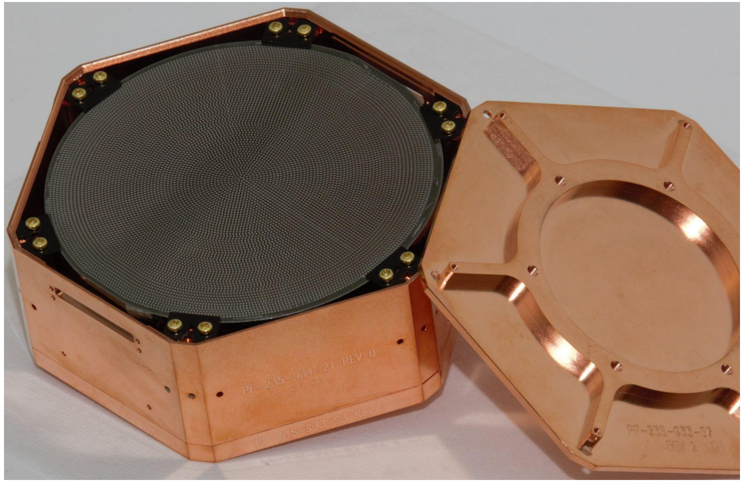
CDMS Detector Principles



$$E_P = E_R + E_{NTL} = E_R + \frac{eV}{\epsilon} E_Q$$

- Interleaved Z-sensitive Ionization and Phonon (iZIP) detectors measure number of electron-hole pairs and phonon energy
- Phonons produced by initial recoil and drifting eh-pairs (NTL effect)
- Particle interactions classified as nuclear recoils (NR) or electron recoils (ER)
- NRs produce less ionization, identify interaction by charge to phonon ratio.
- NR backgrounds mimic WIMP signal

CDMS Detectors



- Can also run detectors in high voltage (HV) mode.
- Amplify signal through NTL-effect. Lose event-by-event ER/NR discrimination. ER background can mimic WIMP
- Still sensitive to NR backgrounds, but expect ERs to domindate

Detector Type	Bias	Threshold	ER/NR Discrimination?	Critical Background
iZip	~4V	O(100eV)	Yes	NR
HV	~100V	O(10eV)	No	ER

Overview of Backgrounds

Cosmic Rays

- High energy muons and secondary neutrons
- Mitigated by SNOLAB overburden

Cavern Environment

- Primordial U, Th, K in cavern rock
- Mitigated by shielding

Material Contamination

- Trace U, Th, K and cosmogenic activation in material near the detectors
- Mitigate by assay and selecting radiopure materials

Detector Activation

- Cosmogenic ^{3}H, ^{32}Si in detectors
- Mitigate by tracking and limiting exposure above ground

Miscellaneous

- ^{222}Rn, dust accumulation
- Mitigate with cleanliness protocols, LN$_2$ shield purge

Coherent Neutrino Scattering

- Contributes to NR background below 50 keV

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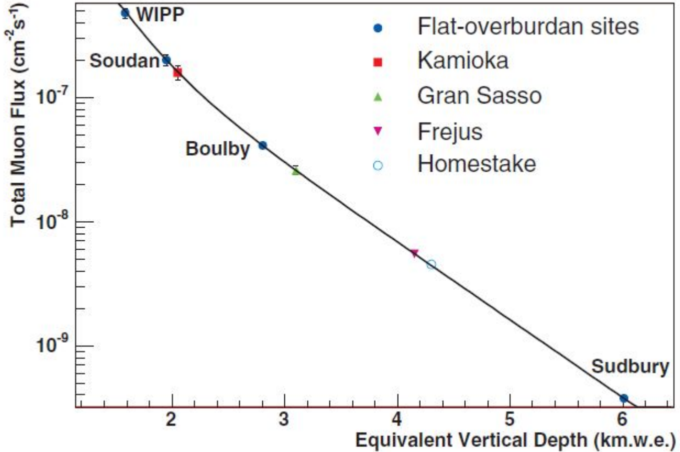
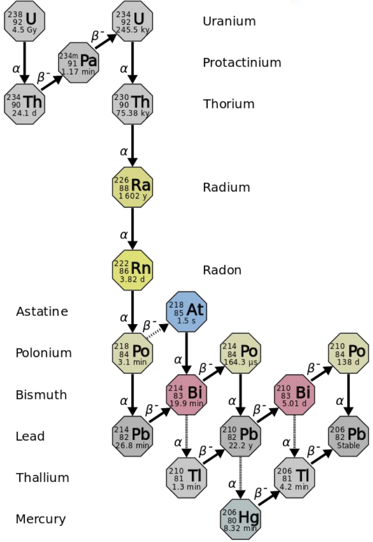
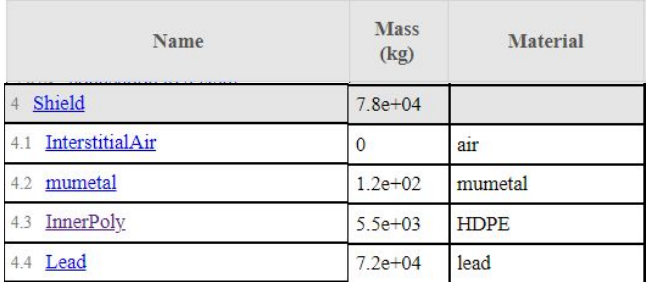




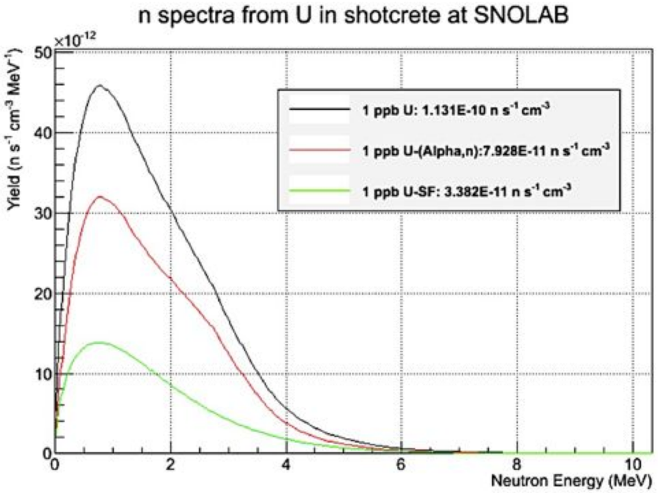
Estimating the Background



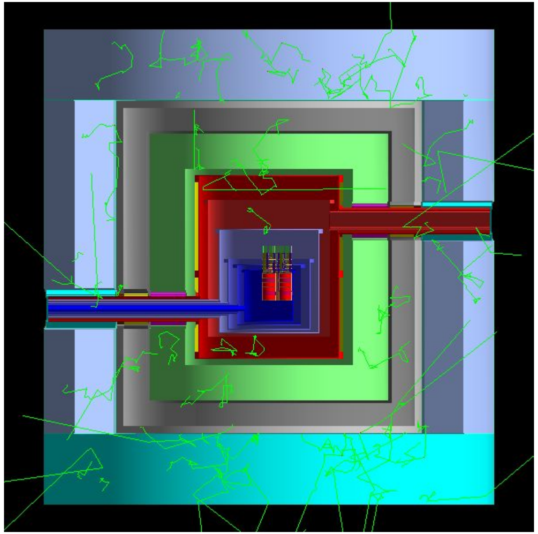
Name	Mass (kg)	Material
4 Shield	7.8e+04	
4.1 InterstitialAir	0	air
4.2 mumetal	1.2e+02	mumetal
4.3 InnerPoly	5.5e+03	HDPE
4.4 Lead	7.2e+04	lead

U238	Th232	K40
< 0.67 mBq/kg	< 0.45 mBq/kg	4 mBq/kg
0.098 mBq/kg	0.095 mBq/kg	0.8 mBq/kg
0.66 mBq/kg	0.5 mBq/kg	7 mBq/kg

Background= (Bill of Materials) X (Component Specifications) X (Geant4 Simulation)

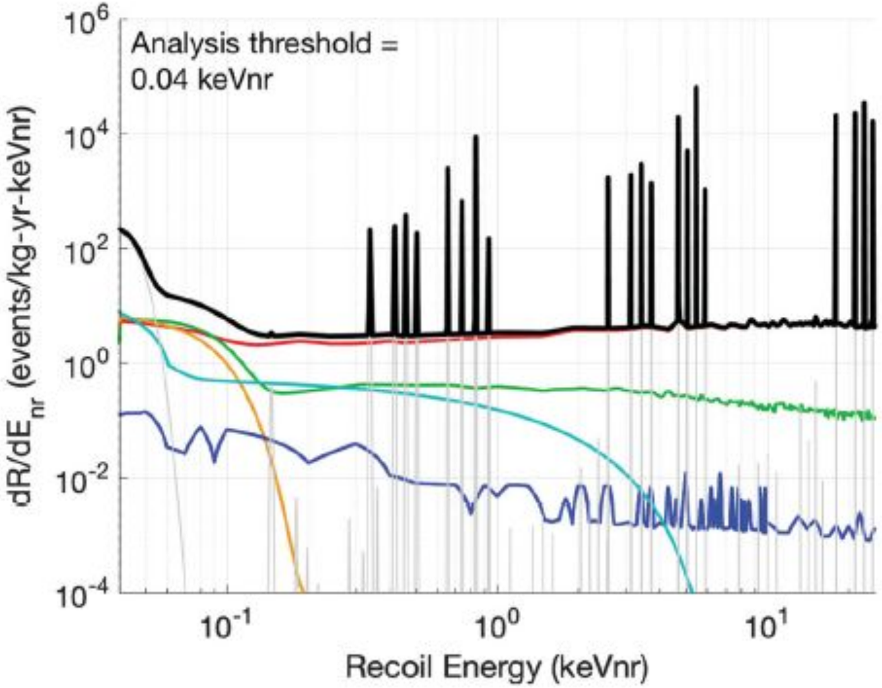


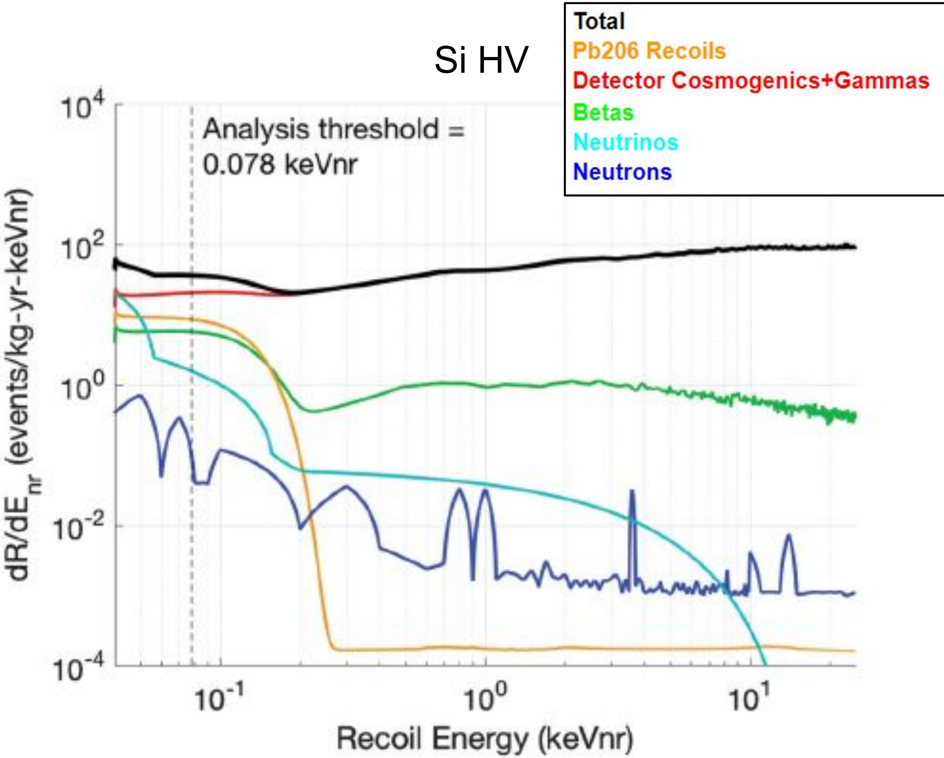
n spectra from U in shotcrete at SNOLAB



Simulation propagates decays from rock bulk -> shield -> detectors

Simulated Spectra


Ge HV


Si HV

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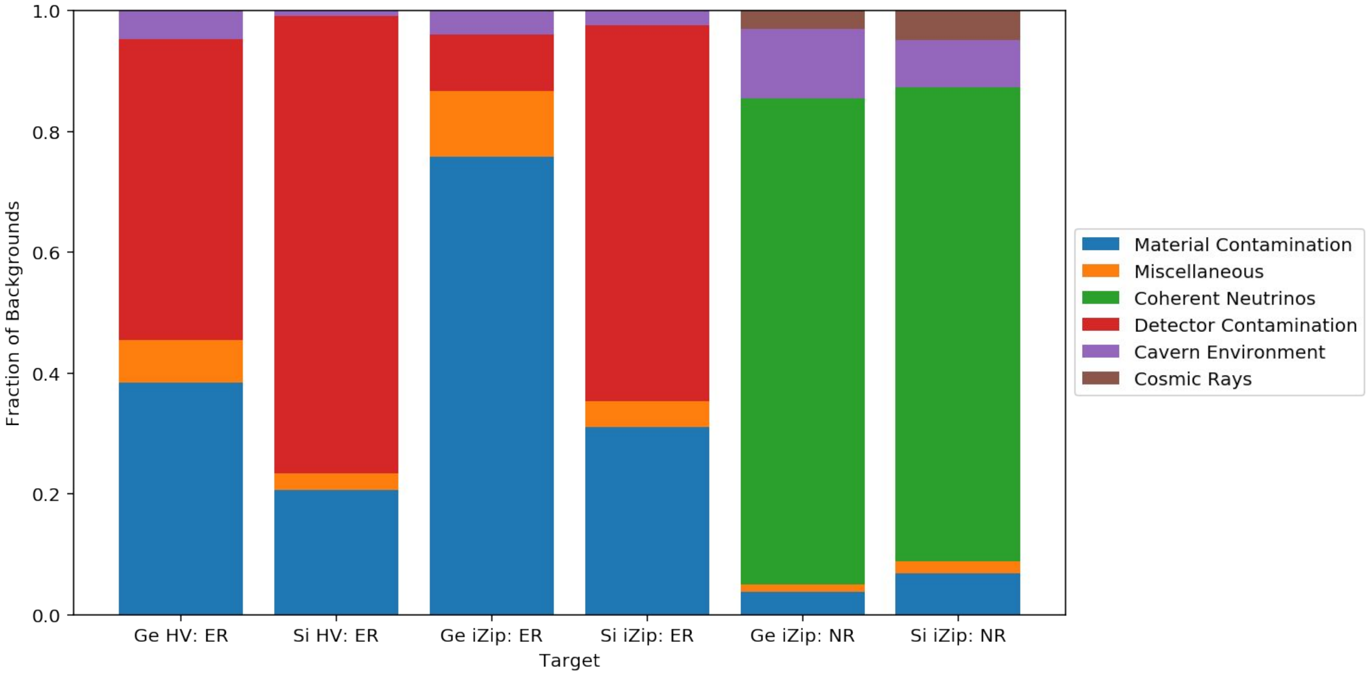
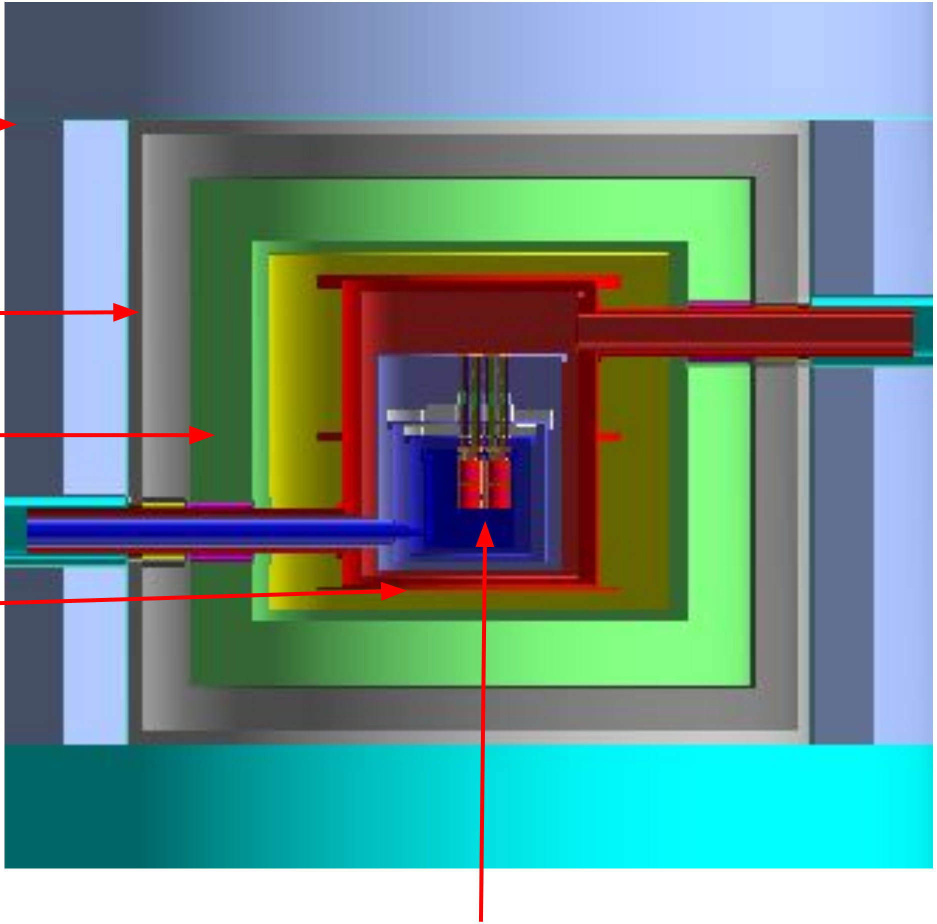
Complementary Targets - Complementary Backgrounds

- Nuclear recoils (NR) are dominated by CNS
- Electron recoils (ER) limited by β’s from ^{3}H, ^{32}Si



Benchmark for shield:
Ensure that background from cavern environment is <10% of the detector internal background

Design of Shield



Outer neutron shield
- 60 cm of water in stainless steel tanks
  + high density polyethylene base
- Reduces MeV neutrons from cavern wall by 10^6

Gamma shield
- 23 cm lead. Inner layer is cleaner
- Reduces MeV gammas from cavern wall by 10^5

Inner neutron shield
- 40 cm high density polyethylene
- Reduces GeV neutrons induced by muons in cavern or shield by 100

Cryostat
- Shielding is secondary function, but few cm Cu provides modest gamma reduction

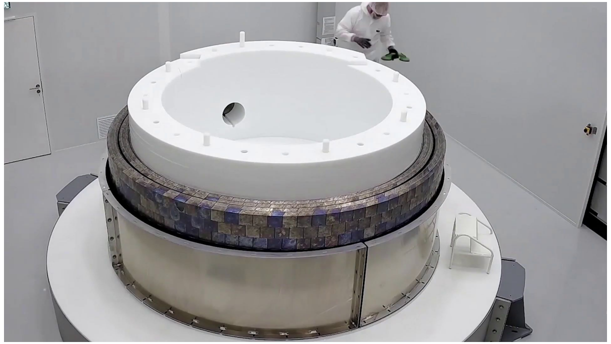
Layered design provides complimentary shielding from environmental neutrons and gammas

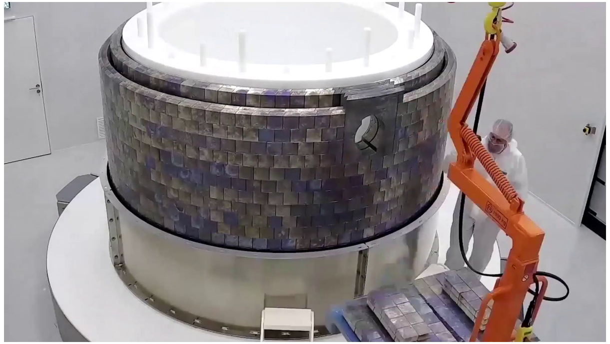
Stems connect exterior components (fridge and electronics) to the detectors - vulnerable to backgrounds.

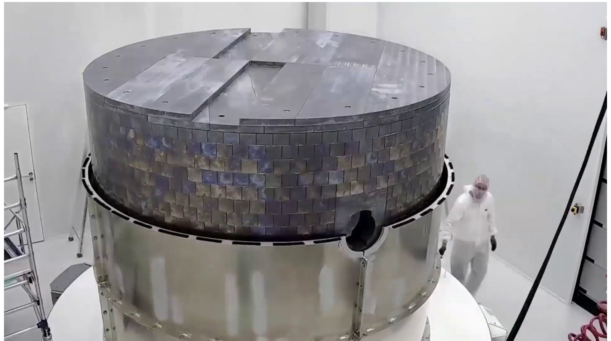
Detectors

Building the Shield

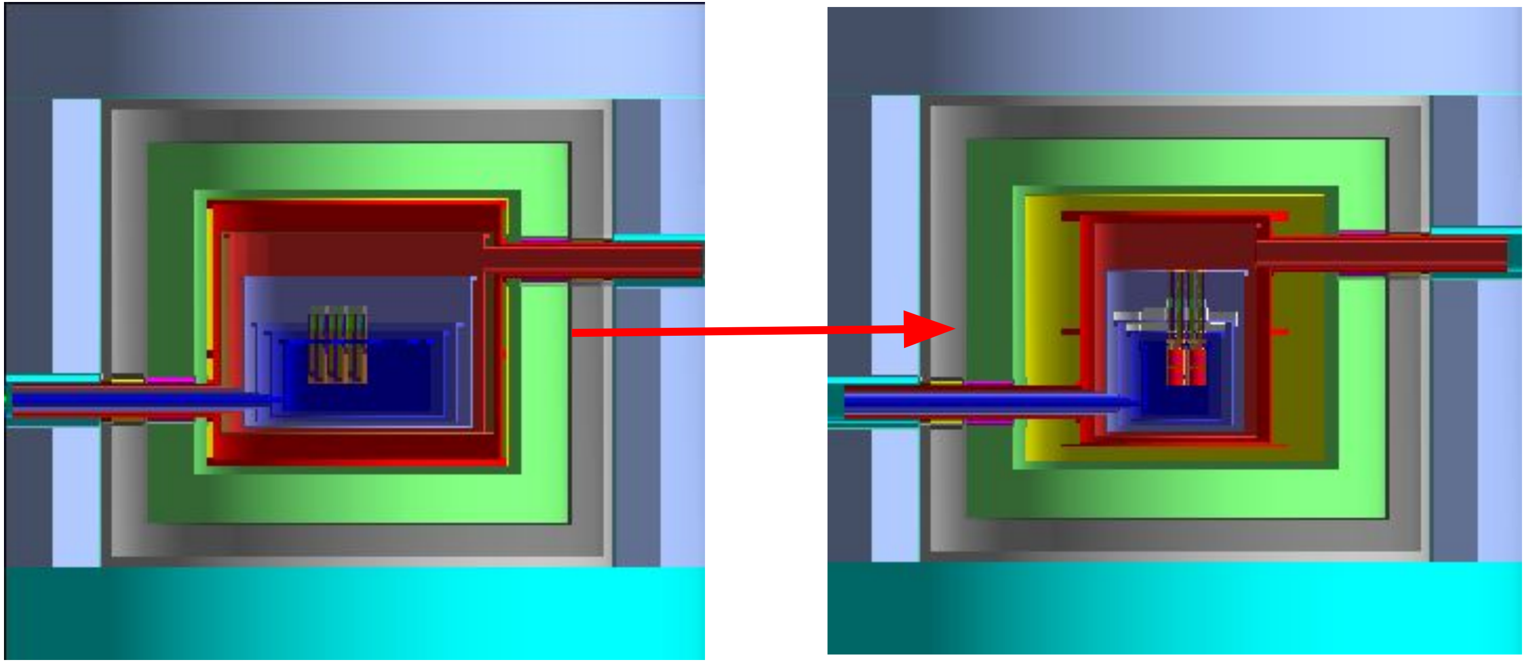
- Shield designed by Lemer Pax (France)
- Inner shield (lead+poly) also fabricated by Lemer Pax
- Water tank fabricated by SAS (Canada)







Shrinking the Cryostat



- Final bid for cryostat came in 3 years behind schedule, needed to settle for a smaller one.
- Total Cu mass and radius reduced ~2x
- No change to initial SuperCDMS payload! Smaller cryostat still accommodates four towers

What happens from a backgrounds perspective?

The cryostat is a source of backgrounds

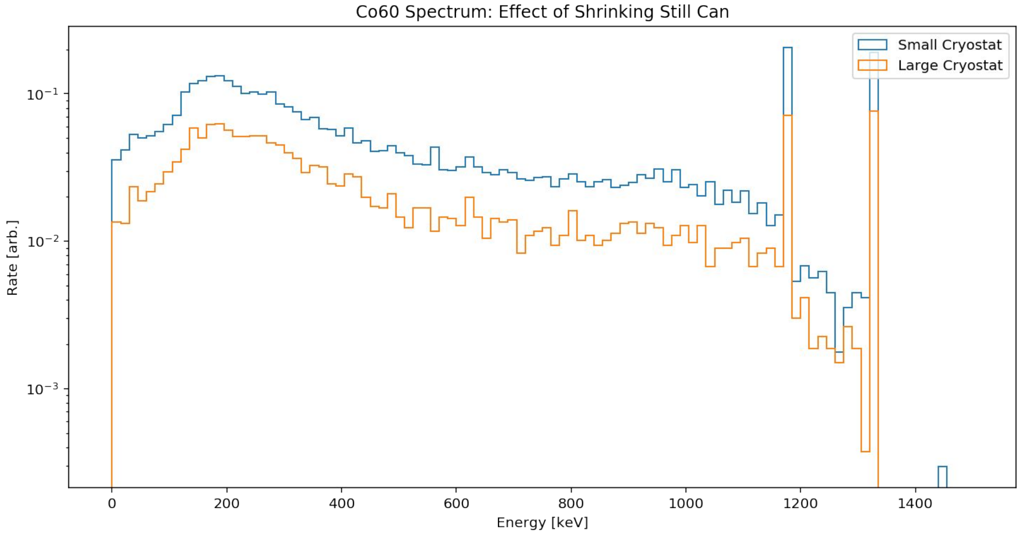
- Cosmogenic ^{60}Co, ^{210}Pb contamination
- Reducing Cu mass means there's less source, but it's closer to the detectors

The cryostat shields from backgrounds

- Blocks gammas from shield and cryostat

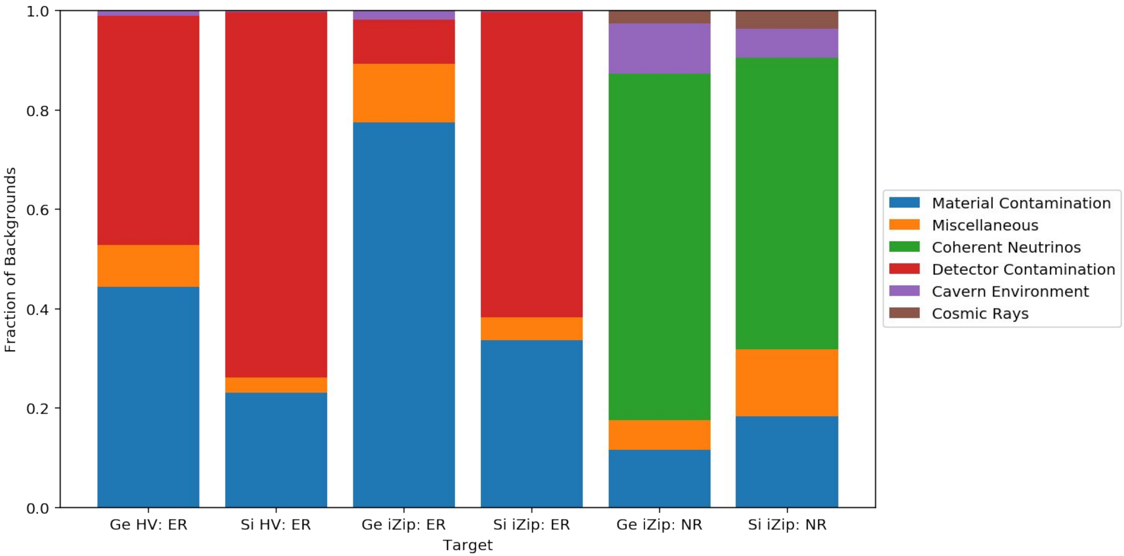
Changes placement of detectors

- Environmental backgrounds penetrate predominantly through the stems



Revisit simulation to confirm whether the net background increases. If it does, how does our target of (reducible backgrounds)/(irreducible backgrounds) look?

- Small increase in background from material contamination (~10%)
- Small decrease in environmental backgrounds (~20%)
- Small overall increase in background, but desired ratio of environmental to cosmogenic is mostly unaffected
- Shrinking the cryostat doesn’t have dramatic effect on backgrounds



Conclusions

- The dominant ER backgrounds for SuperCDMS at SNOLAB are ^{3}H β's in Ge, ^{32}Si in Si. Coherent neutrino scattering dominates NR background.
    - Uncertainty on ^{32}Si? arXiv:1506.02562 vs arXiv:2011.12922
- SuperCDMS has designed and built an integrated shield. Simulations demonstrate that the shield blocks the environmental background such that it is ~10% of the dominant background.
- Practical considerations forced SuperCDMS to shrink the cryostat. This did not change the initial payload, and simulations indicate that the effect on the total background is small.

Questions

Backup Slides

Hermetic Shield Study

Perform simulations with varying shield thickness to determine optimum shielding vs background