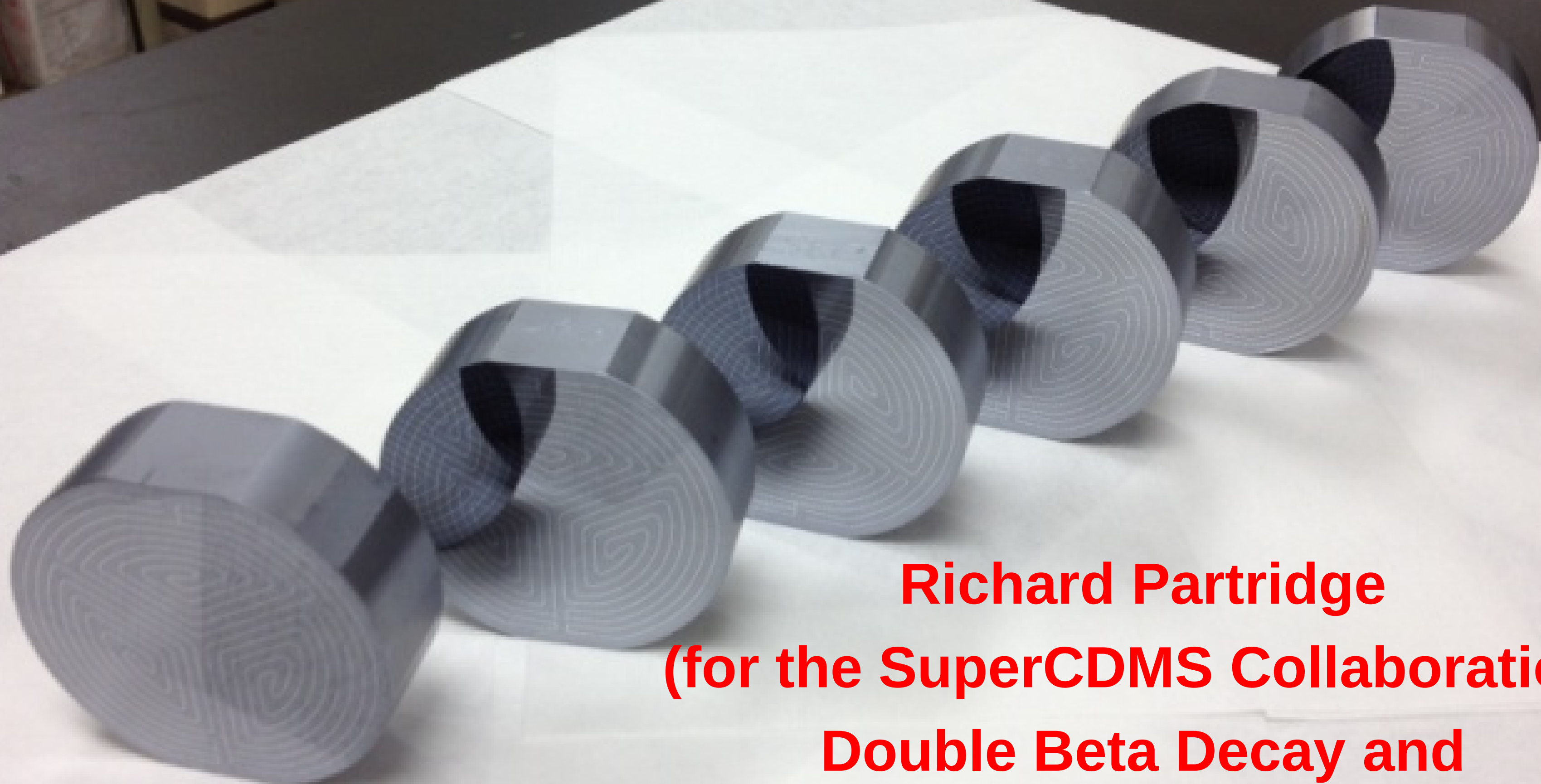
Searching for Dark Matter with SuperCDMS



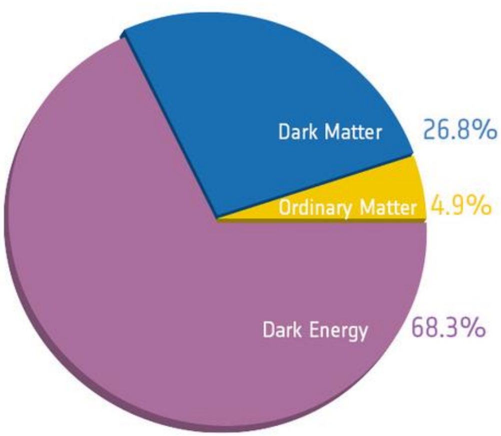
Richard Partridge
(for the SuperCDMS Collaboration)

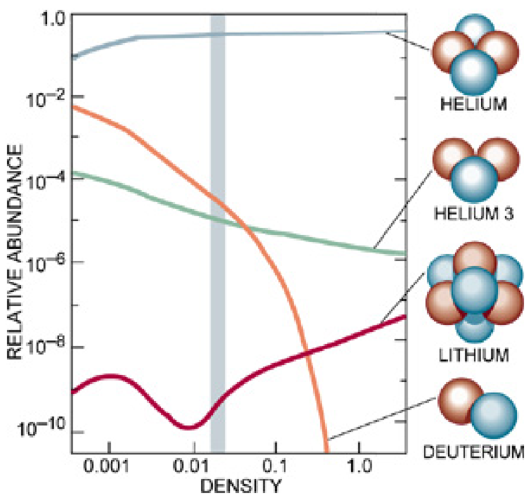
Double Beta Decay and Underground Science Workshop

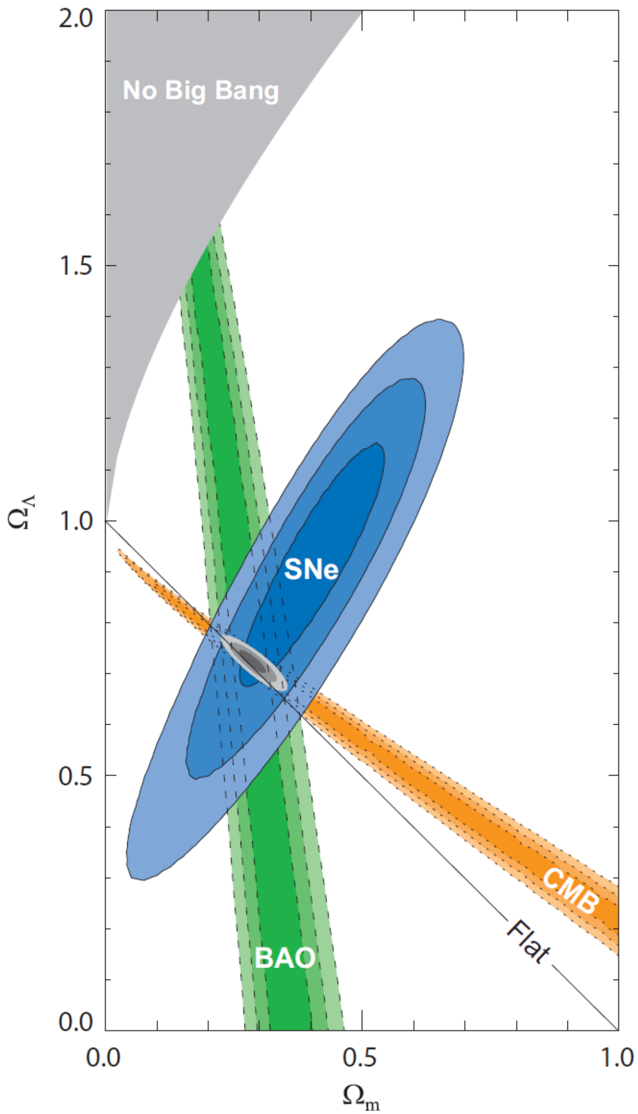
October 5 – 7, 2014

A Consistent Picture Has Emerged

- 27% of universe is dark matter
- We know a few things DM is not:
  - Non-baryonic, non-relativistic (cold)
  - Non-luminous, non-absorbing (dark)
  - Non-decaying, non-charged
- We know nothing about what DM is:
  - SUSY LSP? Asymmetric Dark Matter?
  - Axions? Dark Forces? Sterile neutrinos?







Challenge of Low Mass Dark Matter

- Focus of this talk is the search for low mass dark matter in SuperCDMS Soudan and SuperCDMS SNOLAB
  - Challenging kinematics for low-mass dark matter ($m_\chi << m_N$)!

$$E_r = m_\chi^2 \frac{m_N v_\chi^2}{\left(m_\chi + m_N\right)^2}\left(1 - \cos\theta^*\right)$$

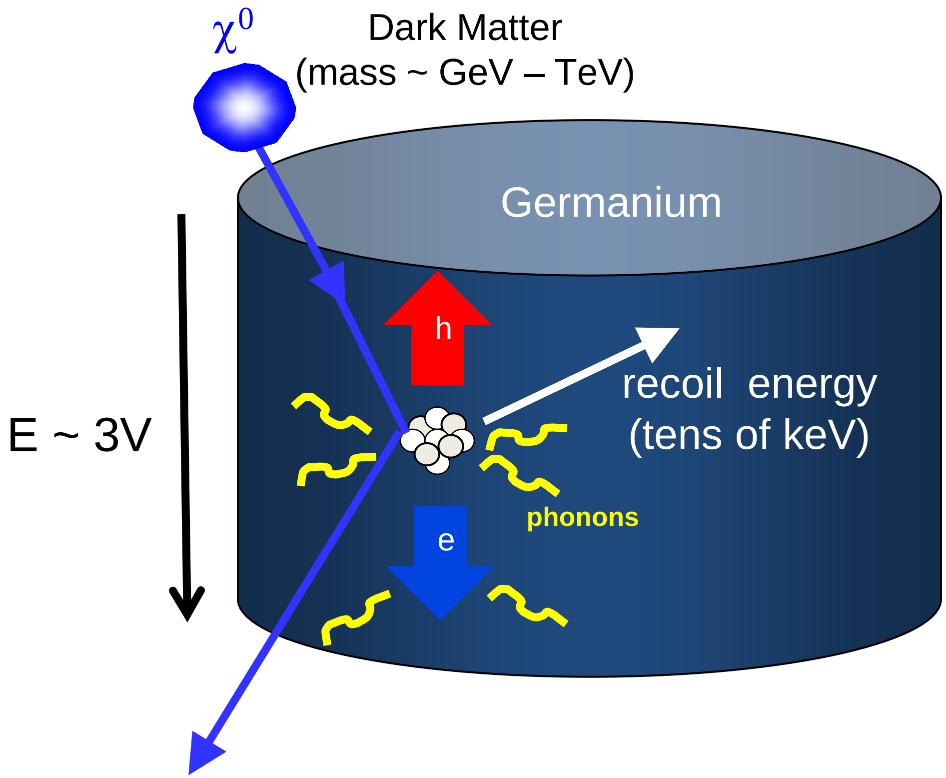
  - Low thresholds, light target nuclei are indicated
- So why bother with low mass dark matter?
  - There are interesting theoretical motivations for low mass dark matter
    - Personal favorite: Asymmetric dark matter, which connects the baryon asymmetry to a corresponding dark matter asymmetry, is natural to have light dark matter particles
  - Dark sector could be just as interesting as the SM
    - Even if we discover a 1 TeV SUSY LSP, that doesn't mean it is the only DM particle
  - Or dark sector could confound us with a very low mass DM particle
    - Critical to explore broad range of parameter space

The SuperCDMS Collaboration

California Inst. of Tech.
CNRS-LPN
FNAL
Mass. Inst. of Tech.
NIST Inst. of Tech.
PNNL
Queen's University
Santa Clara University
SLAC
Southern Methodist U.
South Dakota SM&T
Stanford University
Texas A&M University
U. Autónoma de Madrid
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Minnesota
U. South Dakota

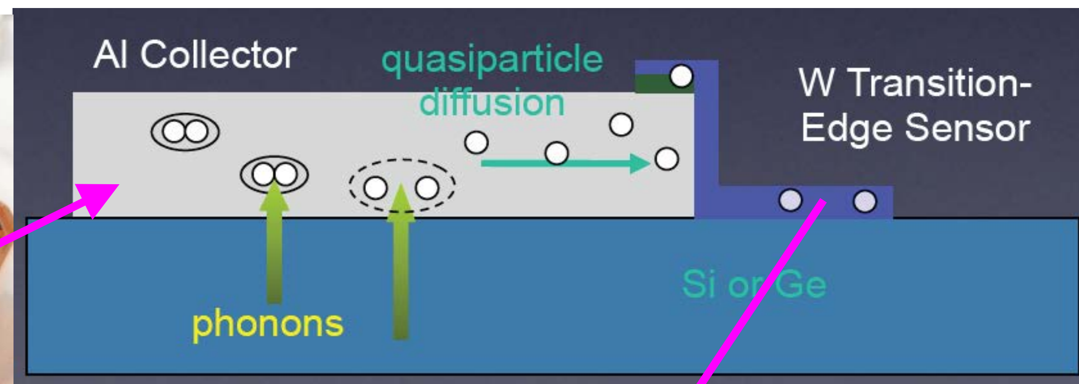
Searching for Dark Matter with CDMS

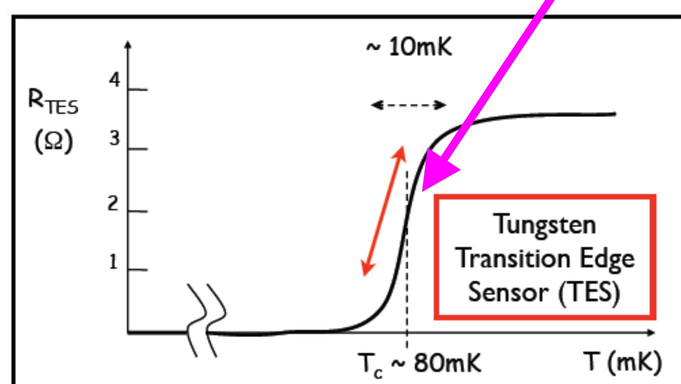
- CDMS has pioneered the technique of searching for dark matter in cryogenic Ge crystals that detect both ionization and phonon signals to achieve nearly “background free” sensitivity



SuperCDMS Technology

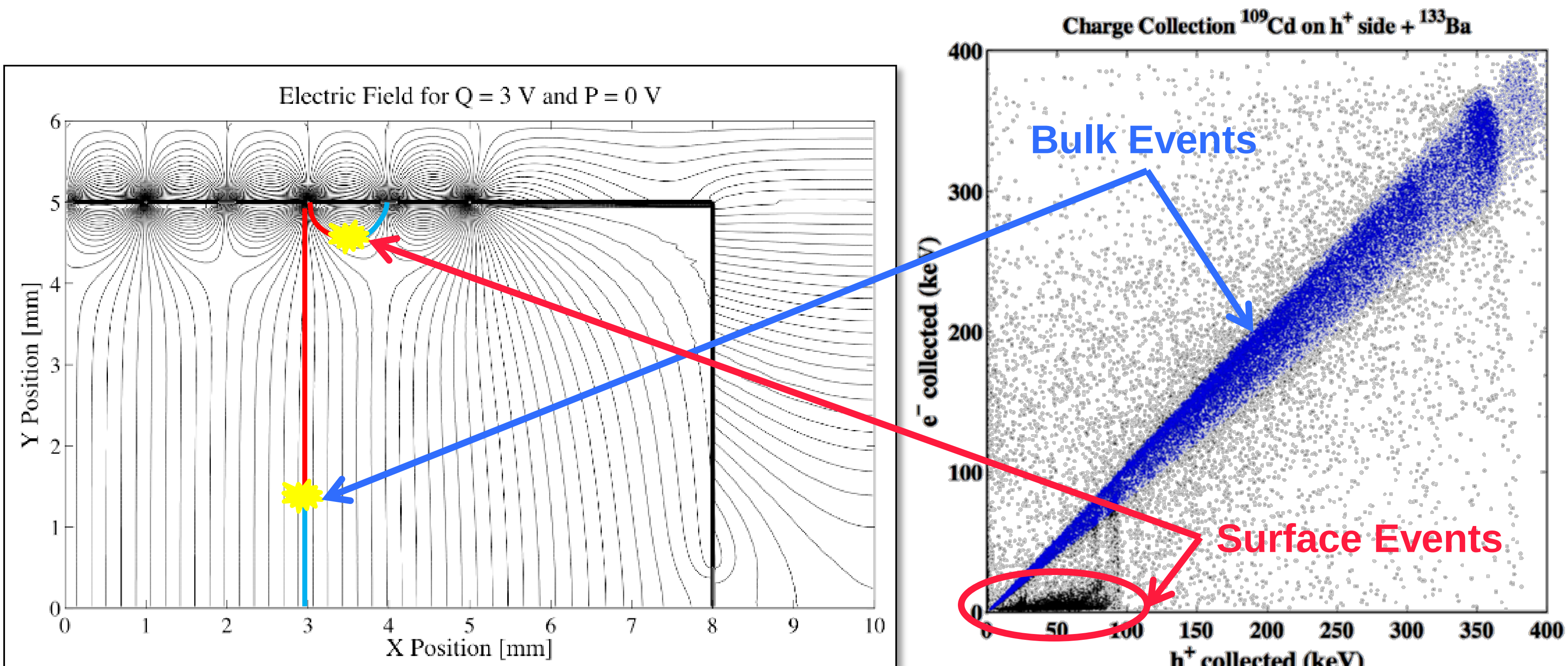
- Phonon and ionization electrodes are fabricated directly onto Ge crystal faces using photolithography
  - Phonons heat tungsten strips kept at transition between normal and superconducting state, producing change in resistance
  - Ionization signal helps distinguish electron recoils (highly ionizing - largely background) from nuclear recoils (dark matter signal)





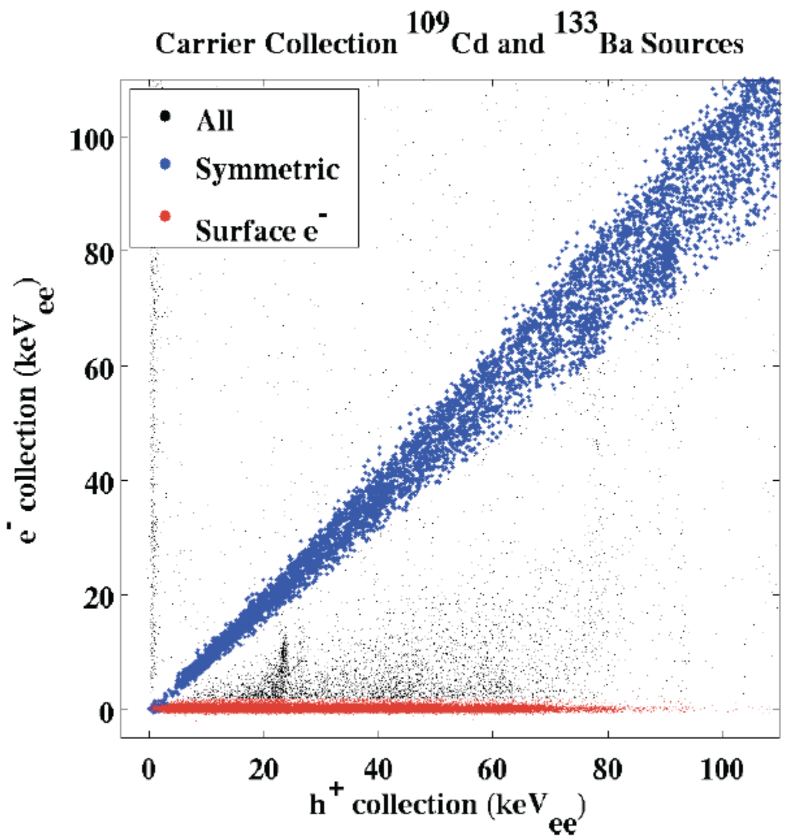
iZIP Electric Field Configuration

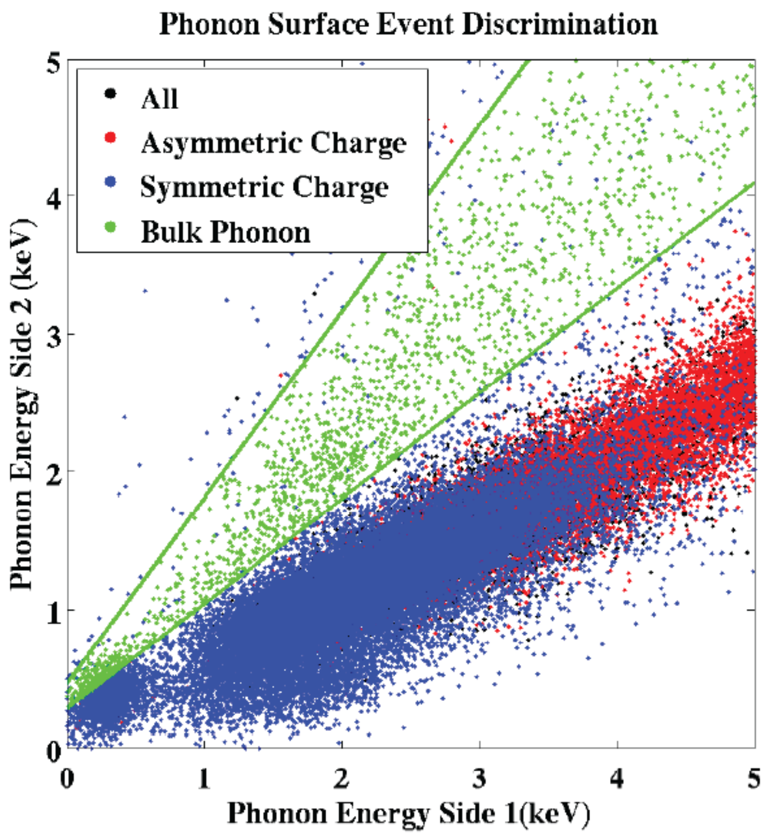
- Transverse surface field in addition to bulk drift field
  - Typical charge electrode bias is +2V (side 1) and -2V (side 2)
  - Phonon rails are set to ground potential on both sides
  - Surface events can be identified through their charge asymmetry



Surface Event Identification

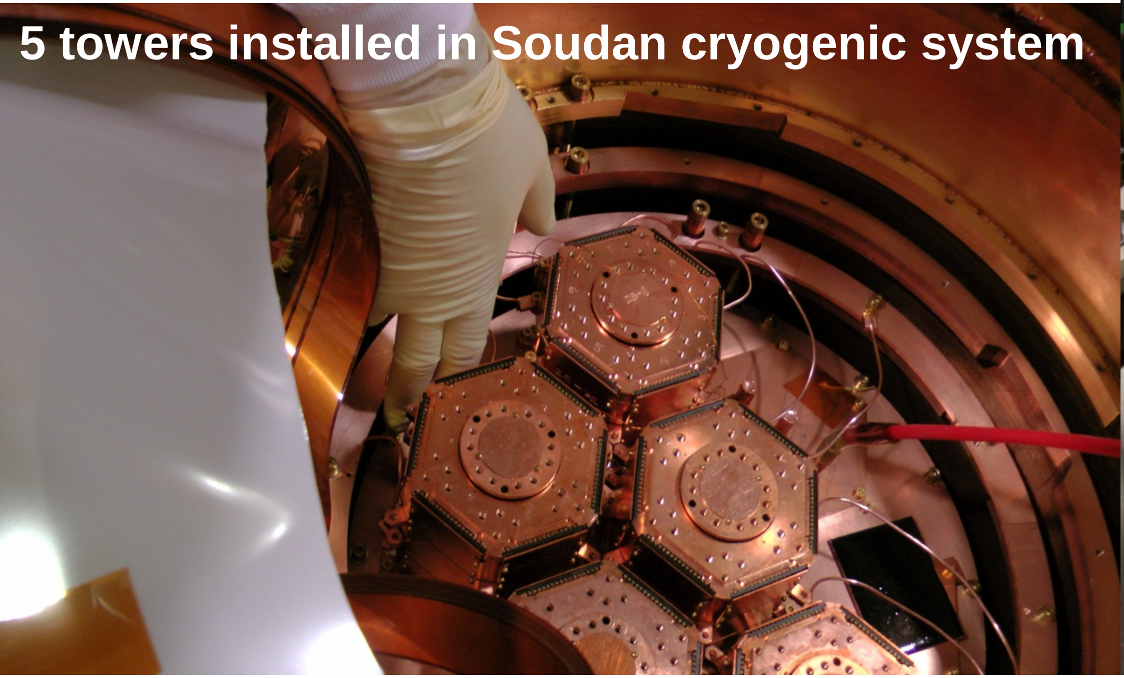
- Surface events exhibit top/bottom asymmetry in both charge and phonon measurements





15 iZIP Detectors Deployed at Soudan

- 5 Towers, each with 3 iZIPs
- ~9 kg of Ge target mass
- Cool down began late 2011
- Taking data since March 2012


5 towers installed in Soudan cryogenic system


Unpacking the first iZIP tower at Soudan

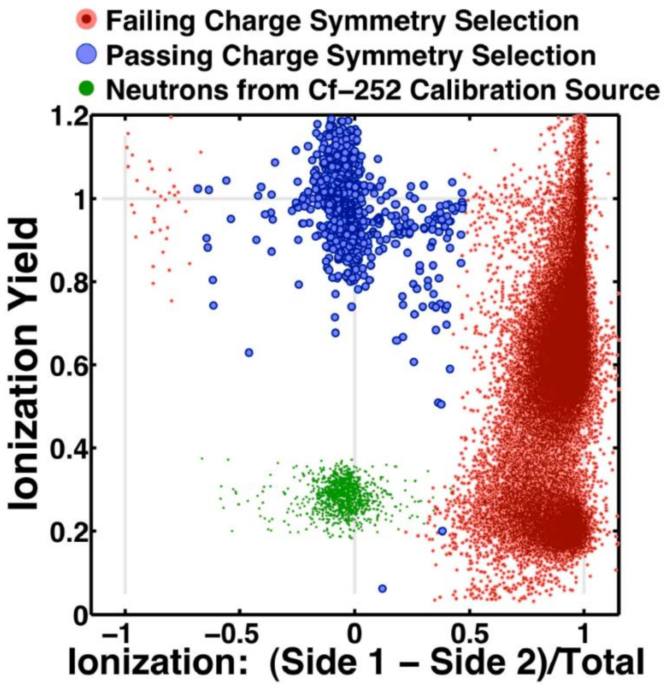
SuperCDMS Soudan Results

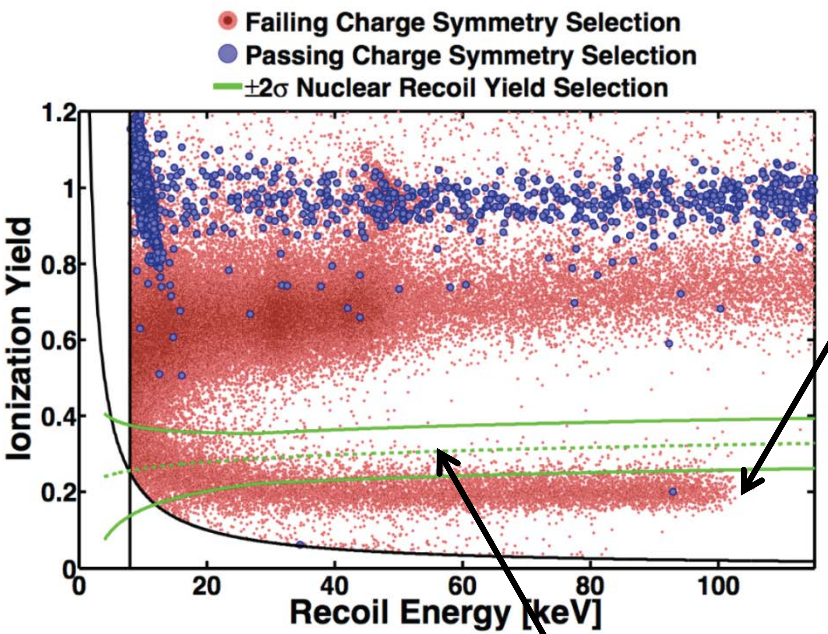
- “Demonstration of Surface Electron Rejection with Interleaved Germanium Detectors for Dark Matter Searches”
  - Demonstrates surface event rejection capability of iZIP detectors
  - R. Agnese *et al.*, Appl.Phys.Lett. **103,** 164105 (2013).
- Search for Low-Mass WIMPs with SuperCDMS
  - WIMP search with iZIP detectors, analysis optimized for light DM
  - R. Agnese *et al.*, Phys.Rev.Lett. **112**, 241302 (2014).
- “Search for Low-Mass Weakly Interacting Massive Particles Using Voltage-Assisted Calorimetric Ionization Detection in the SuperCDMS Experiment”
  - Very low threshold achieved at the expense of electron recoil rejection
  - R. Agnese *et al.*, Phys.Rev.Lett. **112**, 041302 (2014).

Testing iZIP Surface Event Rejection

- Si wafers exposed to radon adjacent to 2 Soudan iZIPs

$$Ionization\ Yield = \frac{Ionization\ (keV)}{Phonon\ Energy\ (keV)}$$



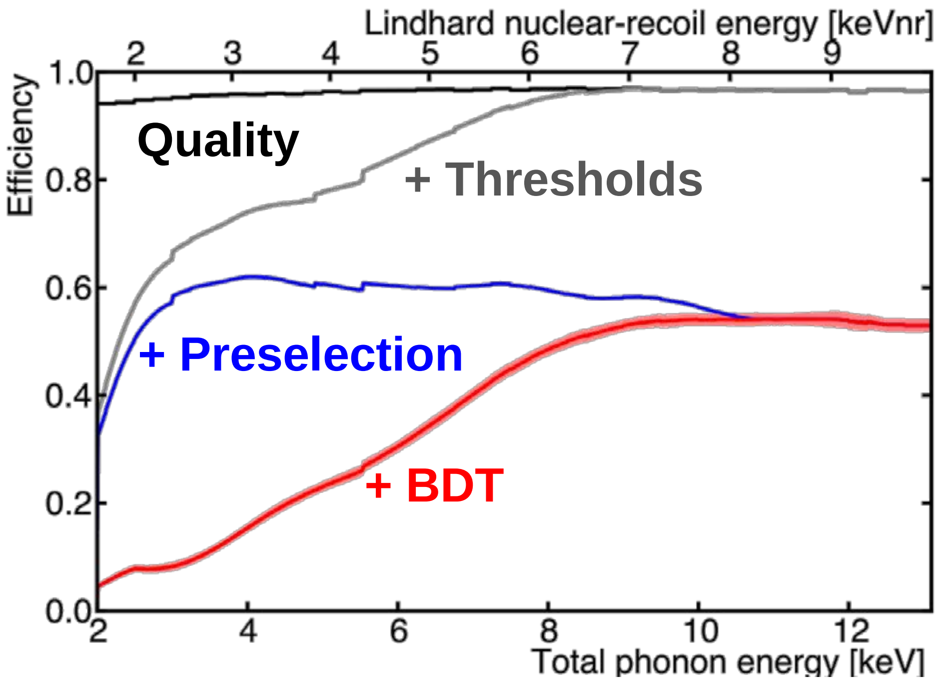


104 keV endpoint for ^{206}Po recoils

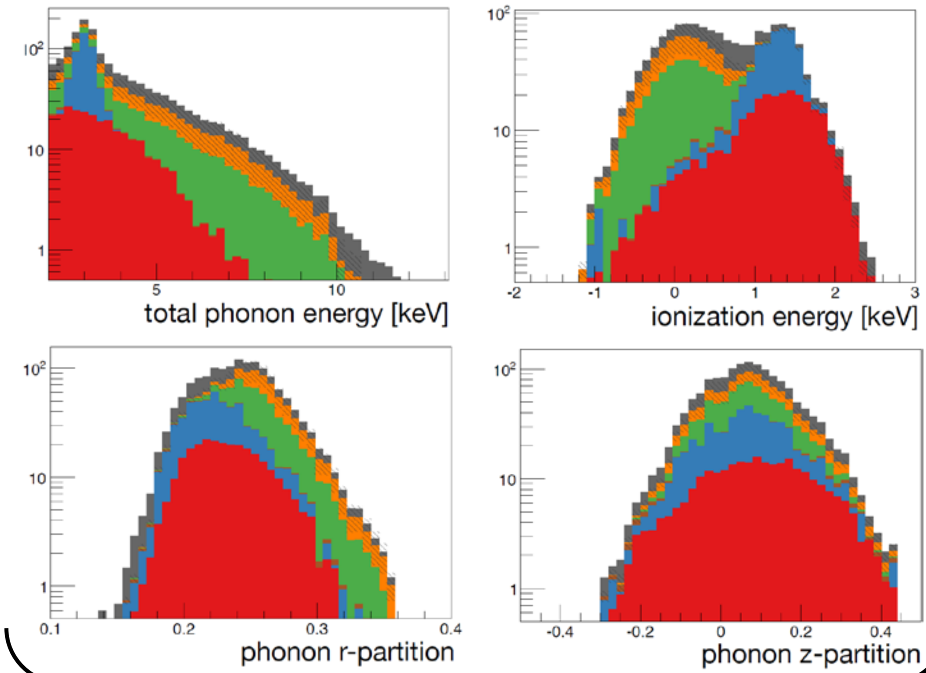
No symmetric (blue) events in nuclear recoil band for exposure equivalent to full SuperCDMS SNOLAB expt

SuperCDMS Low Threshold Analysis

- Analysis strategy:
  - Use the 7 detectors with lowest energy thresholds (1.6 – 5 keV_{nr})
  - Blind analysis of a 577 kg-day exposure
  - Optimize sensitivity for low-mass DM, allowing a small expected background at low energy where electron recoil rejection degrades
- Event Selection cuts:
  - Data quality
  - Analysis / trigger thresholds
  - Preselection cuts
    - Single detector hit, no muon veto
    - Ionization fiducial volume cuts
    - Consistent with nuclear recoil
  - Boosted Decision Tree
    - Phonon radial, z asymmetries
    - Phonon energy
    - Ionization energy
    - Tuned to accept DM, reject BG

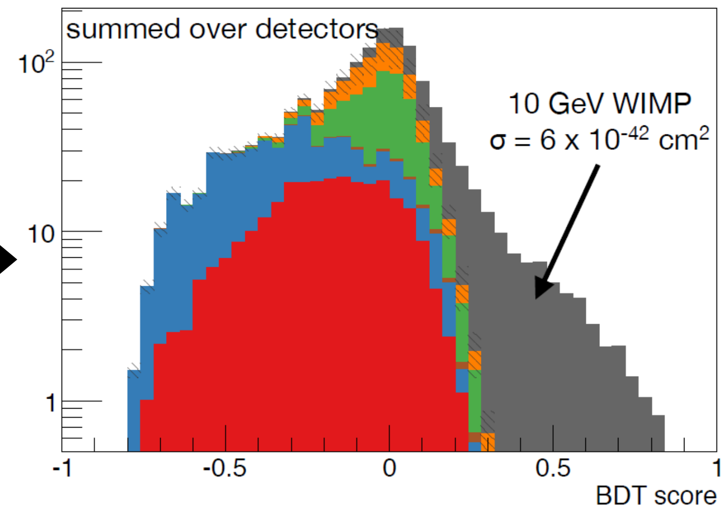


Boosted Decision Tree



Boosted Decision Tree Inputs

Boosted Decision Tree — Output



- Expected WIMP signal (10 GeV/c^2 shown here)
- Sidewall ^{206}Pb recoils
- Sidewall β's & X-rays
- Face β's & X-rays

→ ^{210}Pb-sourced (Sidewall ^{206}Pb recoils; Sidewall β's & X-rays; Face β's & X-rays)

- 1.1–1.3 keV L-shell activation lines
- External gammas ("Comptons")

Train BDT with:

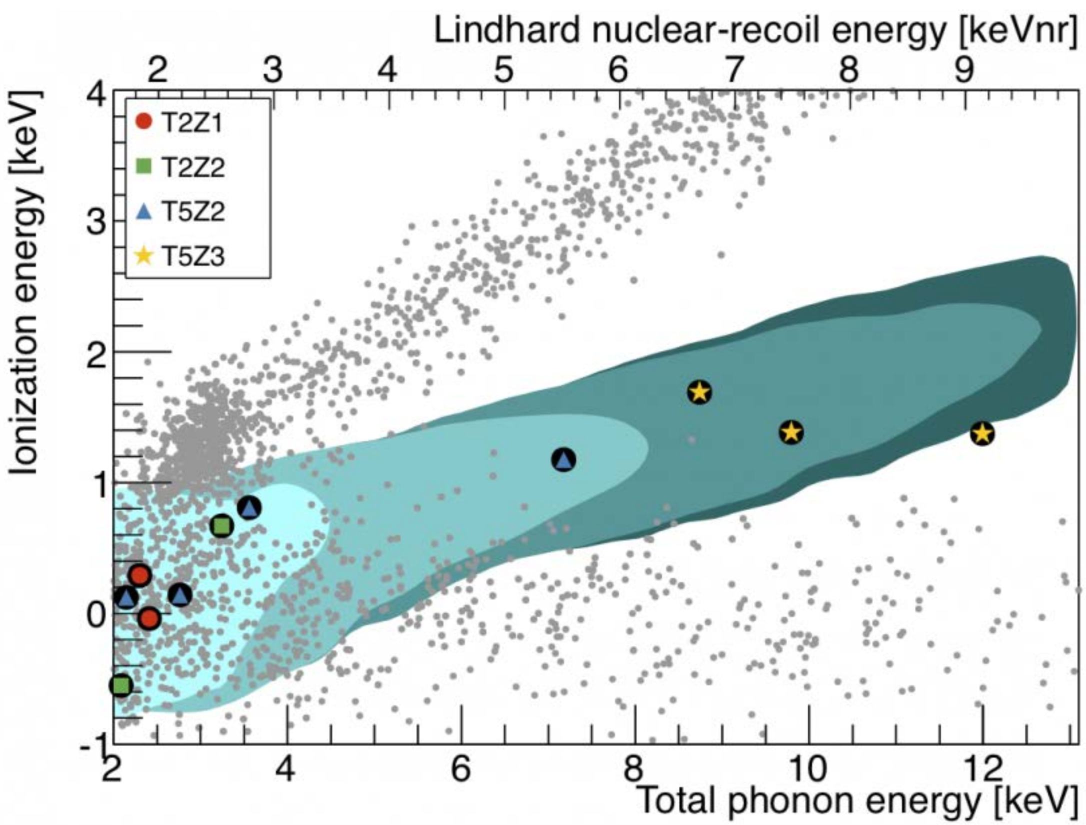
- Background: rescaled high-energy events
- Signal: ^{252}Cf NRs reweighted to expected energy spectra for 5, 7, 10 & 15 GeV/c^2 DM

Separate BDTs for each of 4 DM masses

Cuts on BDT scores optimized to give the best expected 90% CL upper limit

Accept events that pass any of the 4 BDTs

11 Events Survive Cuts



11 candidate events pass all cuts!
($6.1\ ^{+1.1}_{-0.8}$ expected)

3 with unexpectedly high energies
(all in detector T5Z3 that has a chassis short in the ionization guard electrode)

95% confidence contours for expected signal from 5, 7, **10** & **15** GeV/c^2 WIMPs

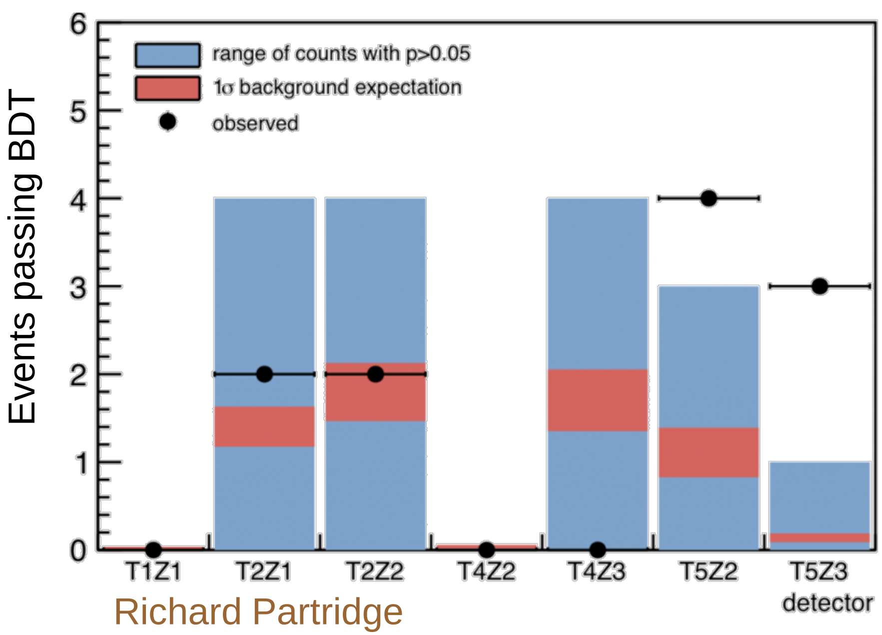
Comparison With Expected Background

Overall, 11 candidate events are consistent w/ background expectation & most individual detectors agree w/ model

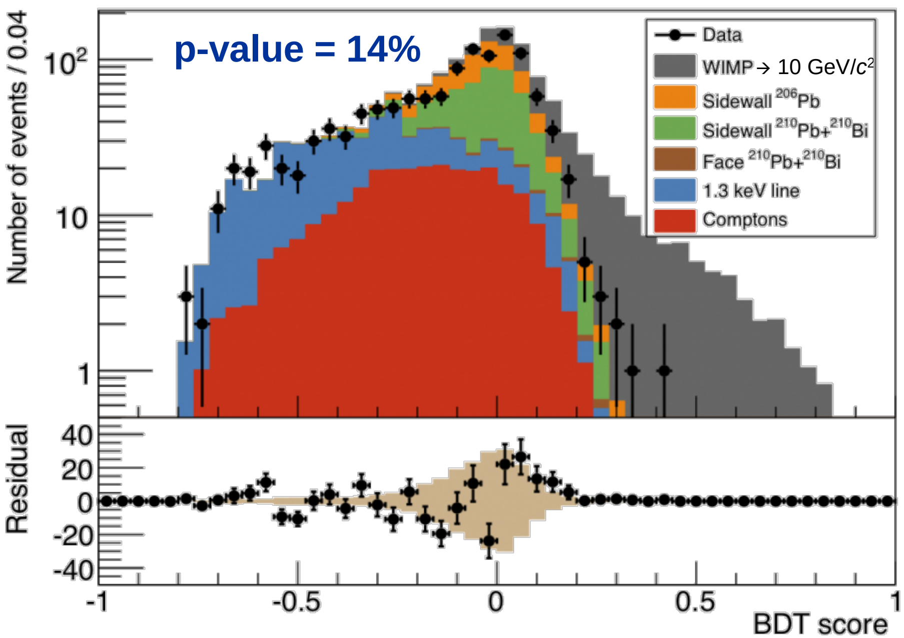
Altered electric field on T5Z3 may have affected background-model performance → *further investigation in progress*

Average thresholds (keV_{nr}):

4.6 1.5 1.8 4.7 1.7 2.0 1.7



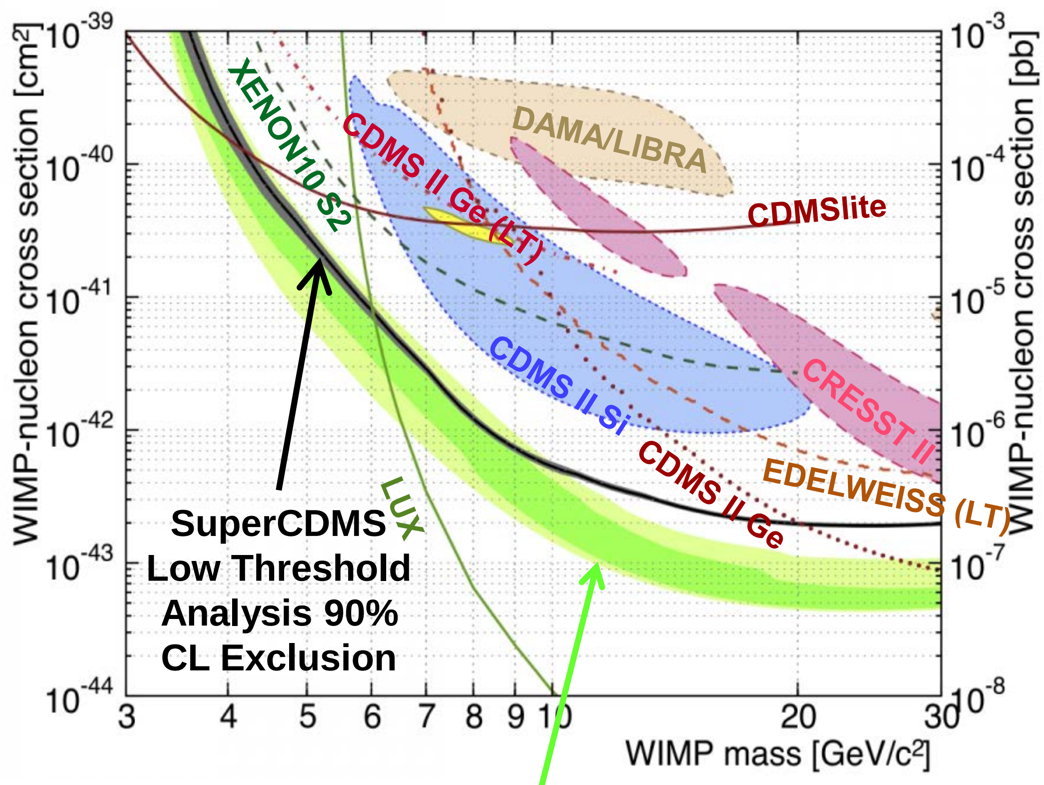
Quality + Thresholds + Preselection



Background model agrees well with events observed in preselection region
→ p-values = 8–26% for 4 WIMP masses

Low Threshold DM Exclusion Limit

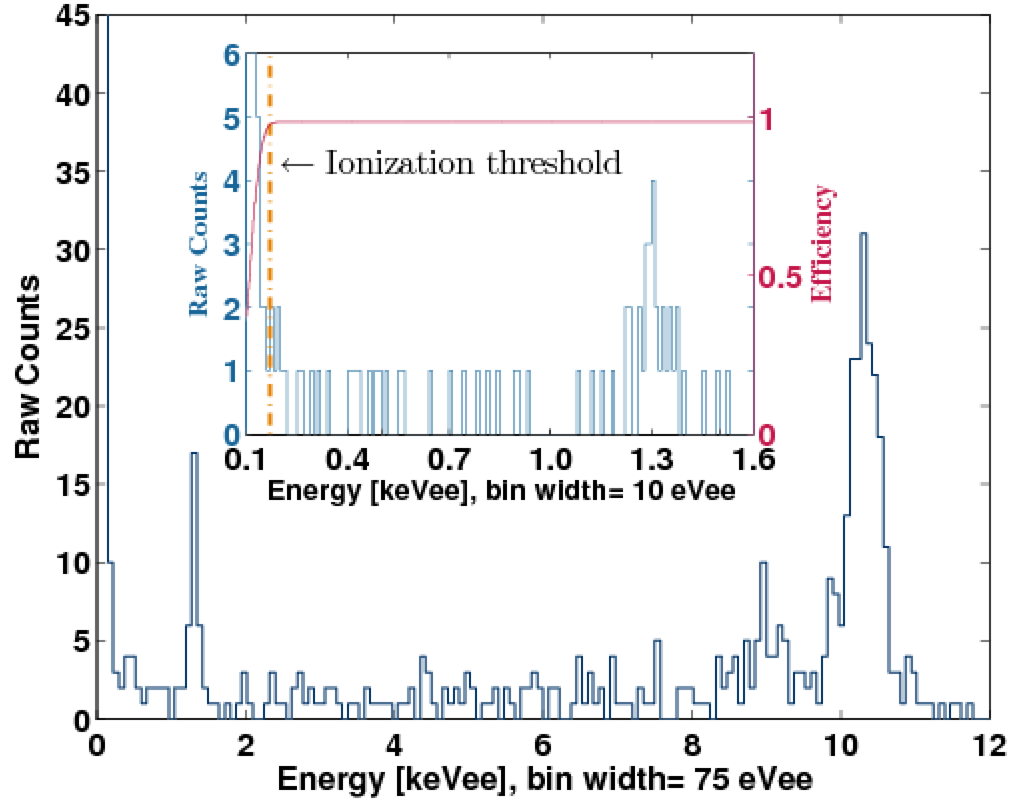
- New regions of DM parameter space excluded
  - No background subtraction – all observed events assumed to be from DM interactions in calculating exclusion limit
  - Assume spin independent coupling, Maxwellian velocity distribution
- Strong tension with DM interpretation of COGENT
  - Model independent result - both expts use Ge target
- Tension with DM interpretation of CDMS II Si, CRESST, and DAMA/LIBRA
  - Model dependent result due to assumptions on DM coupling, velocity distribution



Expected sensitivity from background model (68%, 95% CL)

CDMS-Lite

- CDMS-Lite mode allows ultra-low thresholds to be achieved
  - Apply ~70 V bias voltage across the detector
  - Ionization charge *q* produces $q\Delta V$ of "Luke Phonon" energy
  - Increase in phonon signal allows 180 eV_{ee} threshold
  - Lose ionization yield rejection
  - Flat Compton background is stretched out / reduced in amplitude
  - Unique sensitivity to very low WIMP masses

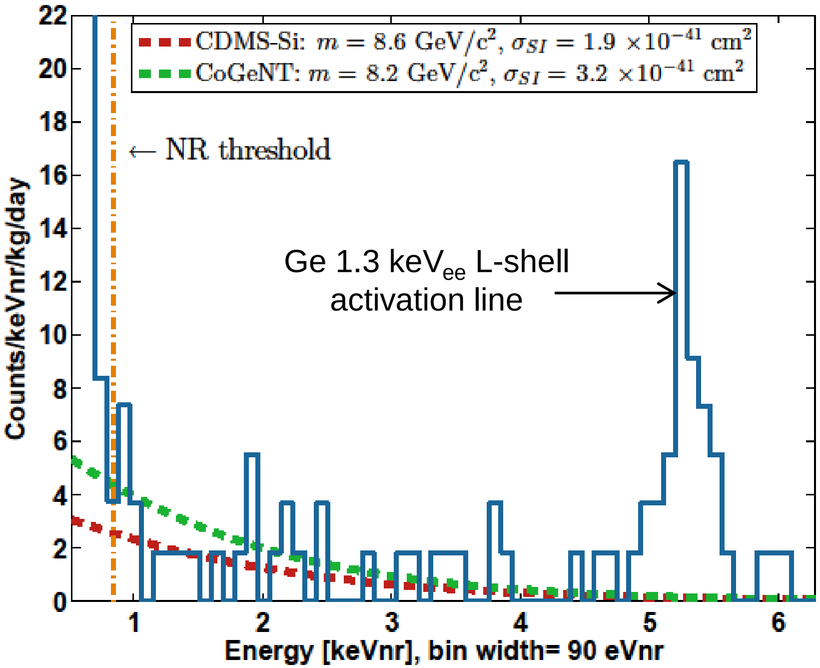


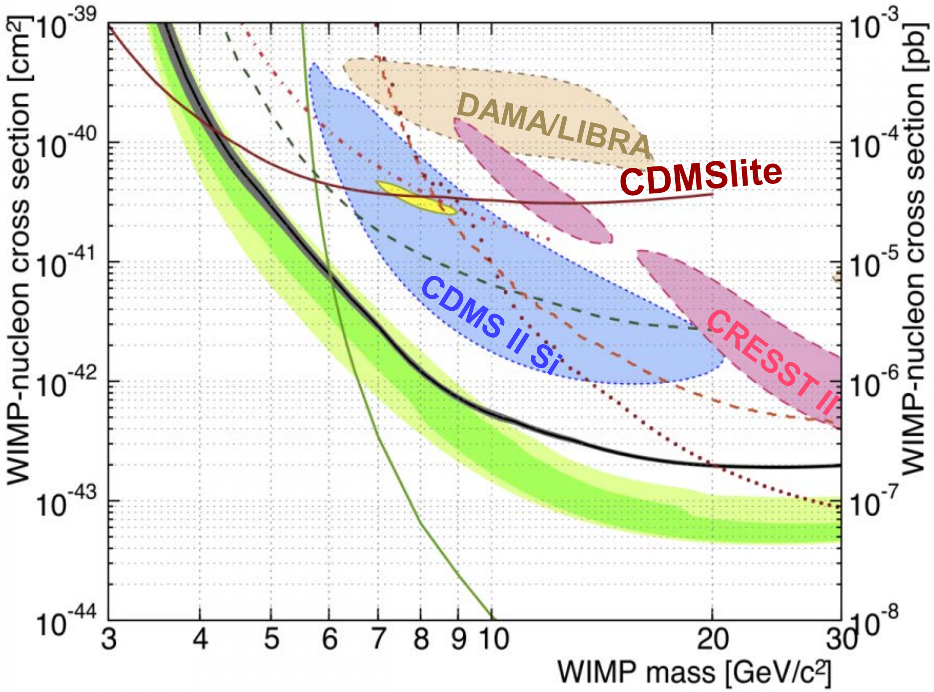
CDMS-Lite:

$E_{phonon} = E_{recoil} * (1 + Yield * \Delta V / 3eV)$

CDMS-Lite Run 1 Result

- Run 1: 10 day exposure with a single detector (5.9 kg-days)
  - Improves on low-threshold exclusion limit for DM mass below 4.5 GeV
- Run 2: 6 month run (same detector, improved electronics)
  - Analysis of Run 2 data in progress

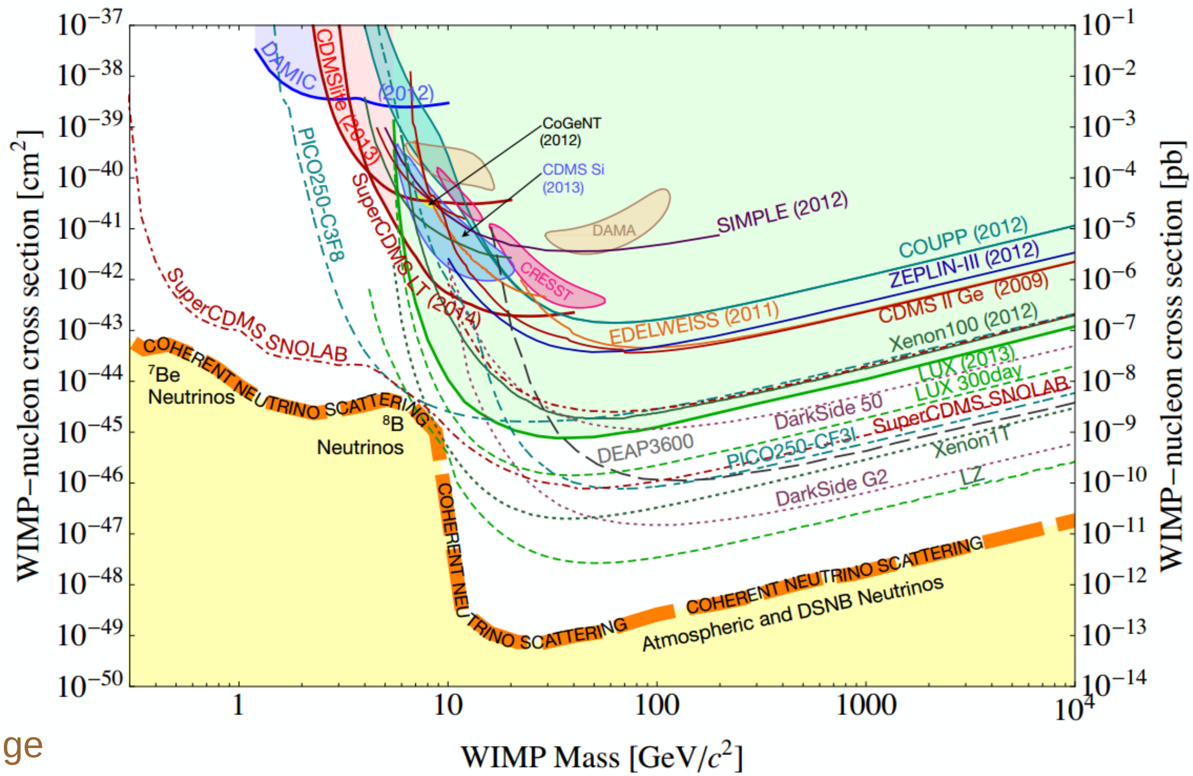




Use Lindhard model to calculate energy in keV$_{nr}$ assuming events are nuclear recoils

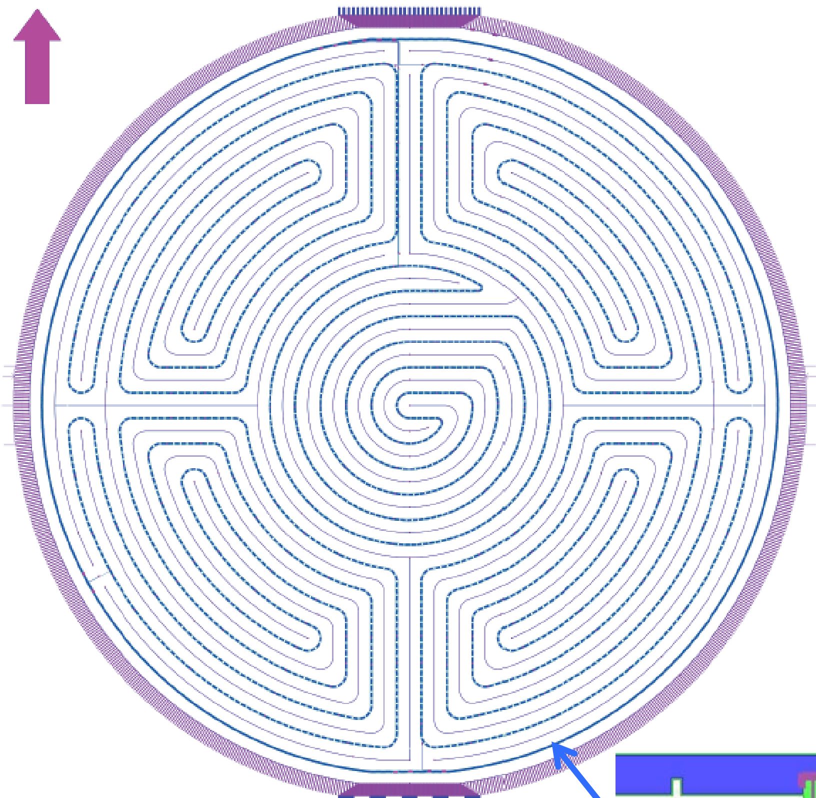
SuperCDMS SNOLAB

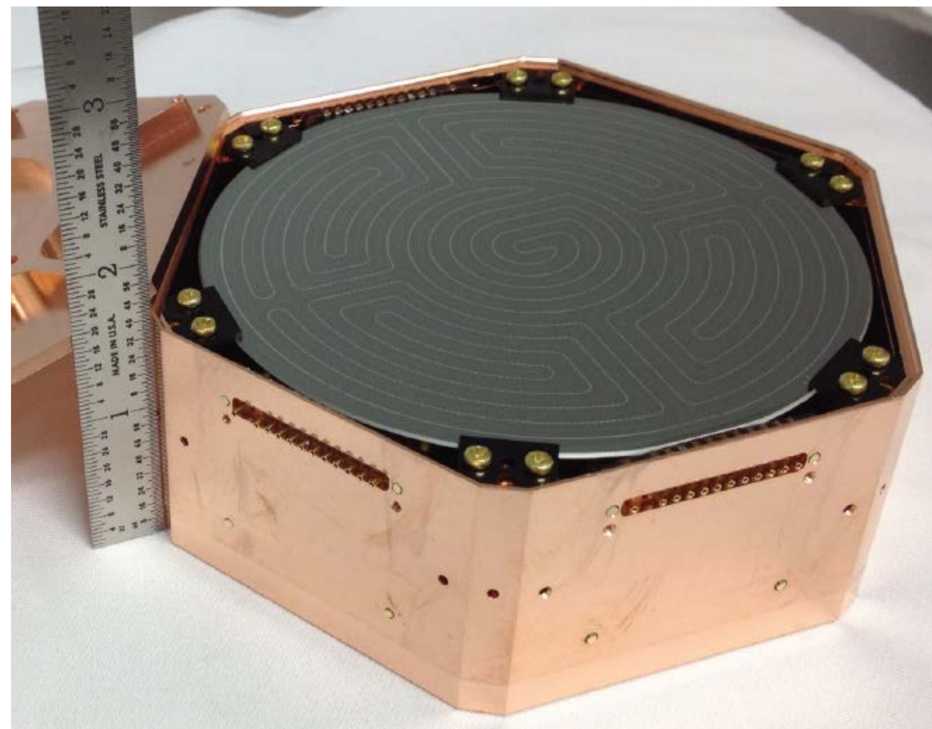
- Selected by NSF / DOE to be a 2nd generation DM expt
  - Mixed payload of ~50 kg of silicon and germanium crystals
    - iZIP detectors provide nearly background-free performance for DM masses >4 GeV
    - CDMS-Lite detectors extend sensitivity to DM masses of ~0.3 GeV
  - Expect to observe coherent scattering of ^{8}B solar neutrinos (~6/year)
    - Neutrino interactions ultimately limit sensitivity of DM searches

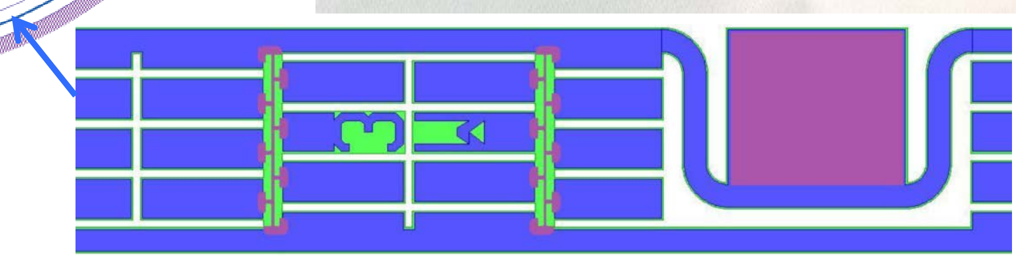


SNOLAB iZIP Detectors

- 100 mm diameter, x2.3 larger mass than current detectors
  - 6 phonon channels / side, 2 ionization channels per side
  - Fiducial region can be defined using ionization or phonon measurements

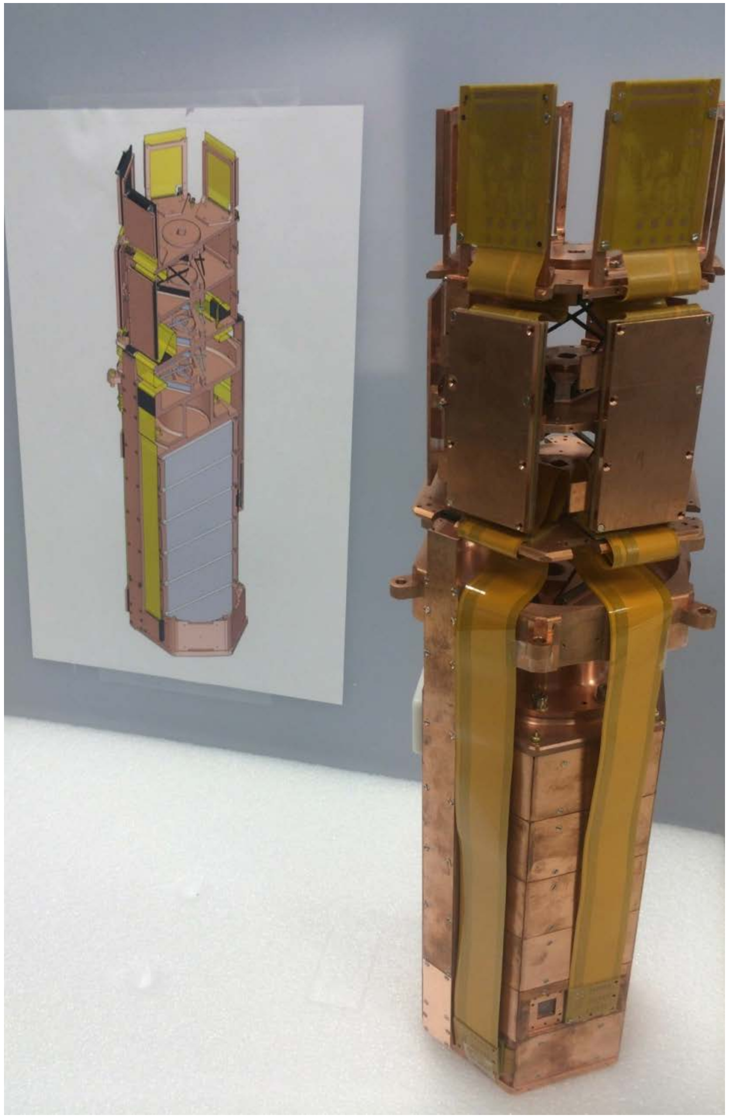






SNOLAB Detector Towers

- New SNOLAB detector towers
  - Tower provides mechanical support, cryogenic electronics, wiring, and thermal isolation
    - Detectors cooled to ~40 mK
    - 100 mK, 600 mK, and 4 K stages provide thermal isolation, cool cryogenic electronics
  - 6 detectors/tower
  - HEMTs at 4 K amplify charge signal
    - Goal is ~100 eV charge noise
  - SQUIDs at 600 mK for phonon readout
    - Goal is ~50 eV phonon noise for iZIP
    - Goal is ~10 eV phonon noise for CDMS-Lite
  - Superconducting flex circuits provide low-inductance phonon readout
  - Vacuum coax for charge readout
  - Engineering tower fabricated to validate tower design



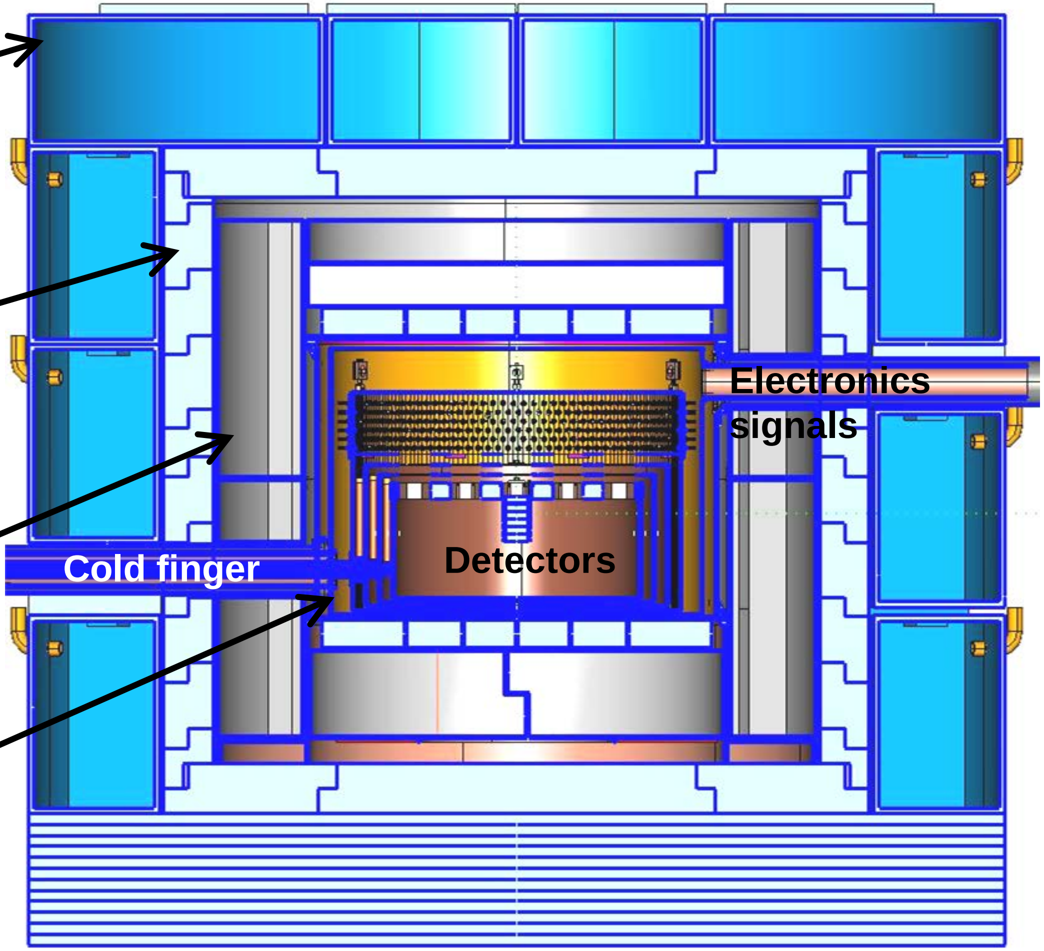
SNOLAB Shielding

Outer shielding (n, γ):
60 cm water or polyethylene

Inner passive shielding (γ):
23 cm lead with radon purge

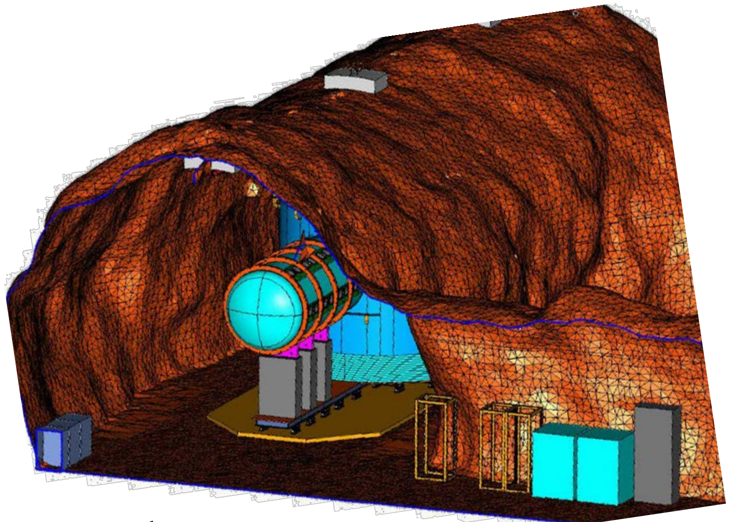
Active shielding (n):
40 cm doped scintillator

Nested cryostat (γ):
1/2–3/8" low-activity copper
Capacity for 400 kg of detectors

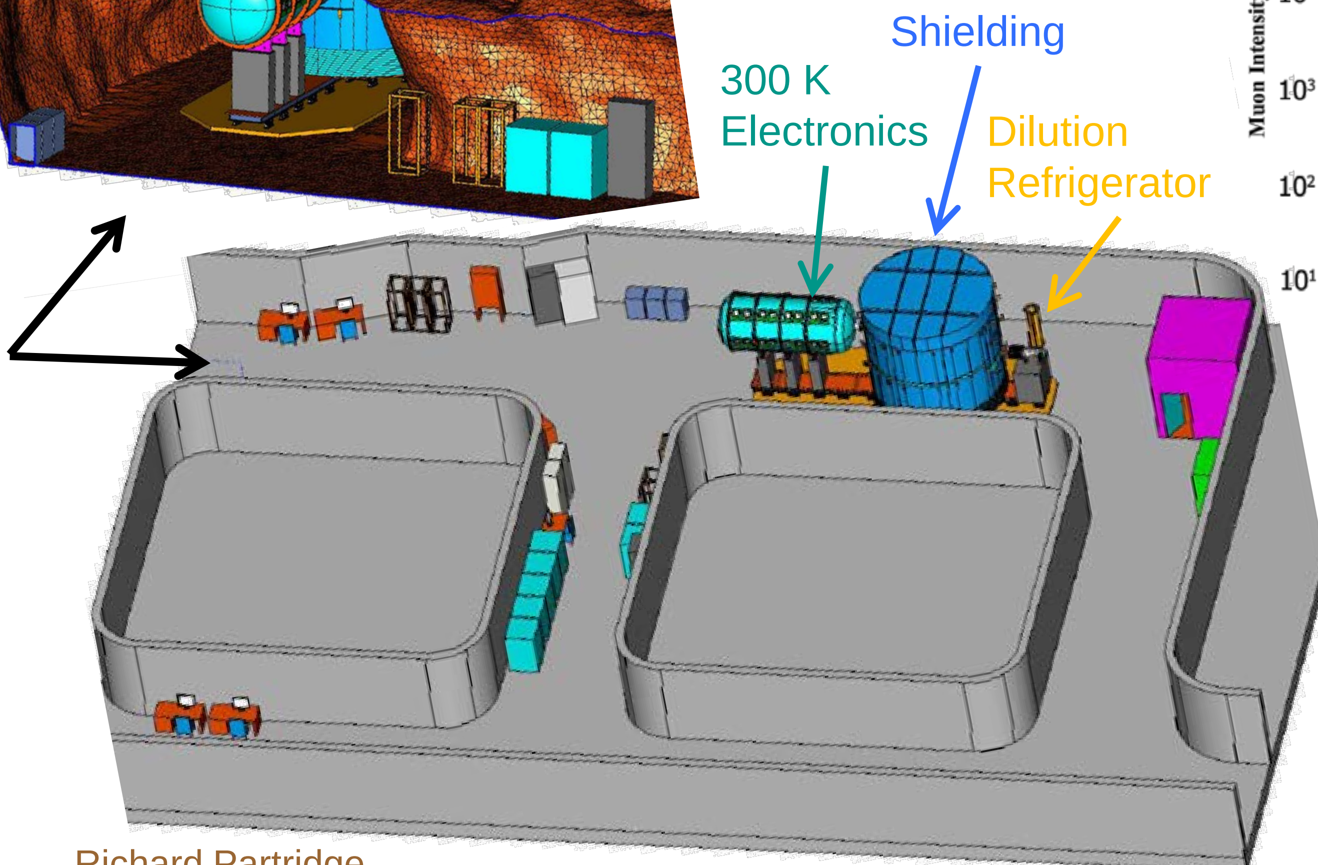


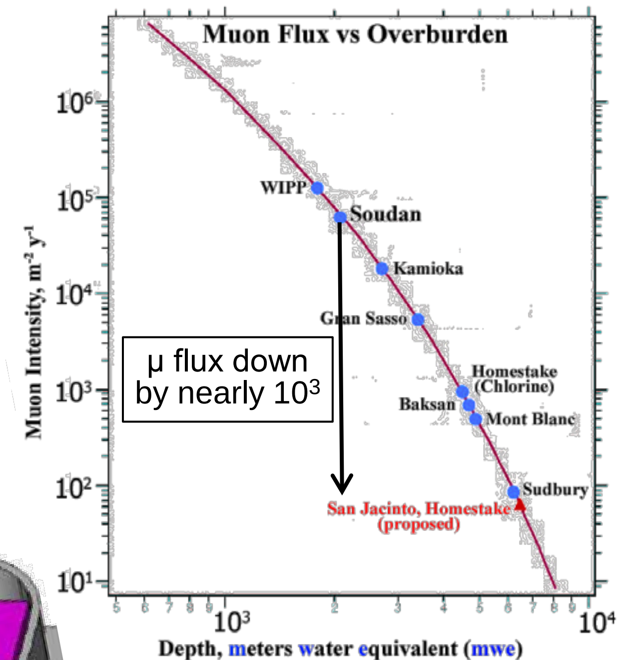
Assumed bulk contaminant levels no lower than measured by other experiments for easily available radiopure materials

SuperCDMS SNOLAB Layout



Experiment planned for SNOLAB Ladder Lab





Conclusions

- SuperCDMS Soudan results demonstrate:
  - Robust background rejection capabilities of the iZIP detectors
  - Sensitive searches for low-mass dark matter in low-threshold and CDMS-Lite modes of operation
    - Results are in tension with DM interpretation of COGENT signal (model dependent)
    - Also in tension with other low-mass excesses for spin independent coupling and Maxwell halo model
- SuperCDMS SNOLAB approved as a 2nd generation dark matter search
  - Focus on the low-mass region with DM masses of ~0.3 – 10 GeV
  - Deploying both iZIP and CDMS-Lite detectors, Si and Ge targets
  - Expect to observe coherent neutrino scattering of 8B solar neutrinos
  - Goal is to push to neutrino floor for low-mass dark matter
  - Building cryogenic infrastructure capable of hosting x7 larger payload
    - Ongoing discussions with EURECA collaboration to deploy additional payload
    - Provides upgrade path to follow up on any signals from noble liquid experiments