The Future of CDMS

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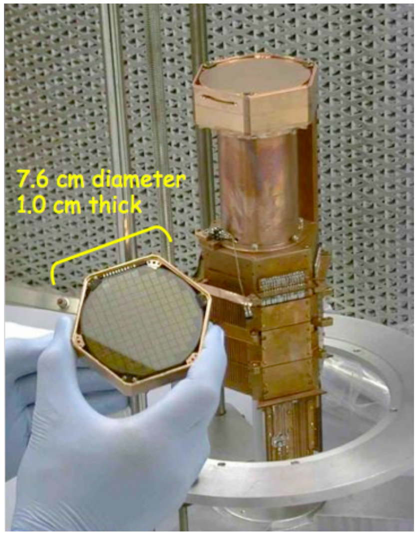
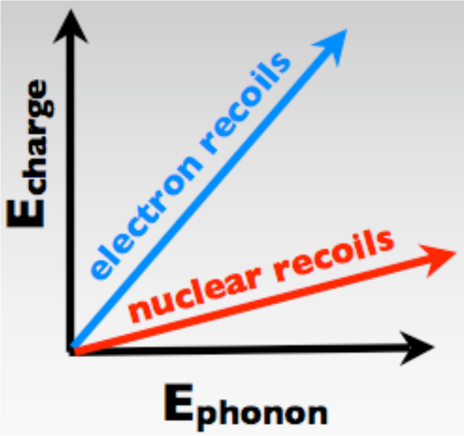
CDMS Overview (I)

- CDMS = Cryogenic Dark Matter Search
- Half a mile underground at the Soudan Underground Lab in northern Minnesota
- Attempts direct detection of WIMPs through elastic scattering on nuclei in Ge crystals
- Detectors continuously cooled in dilution refrigerator to maintain operational temperature for superconducting phonon sensors

CDMS Overview (II)

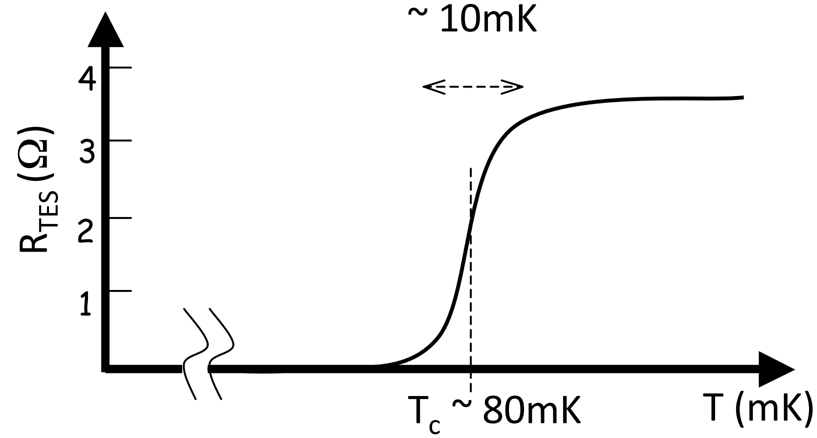
- Solid Ge "ZIP" detectors measure ionization and phonon signals from particle interactions
- Basic strategy:
  1. Discriminate *electron recoils* (γ, β background) from *nuclear recoils* (WIMP signal, n^0 background)
  2. Remove neutron background

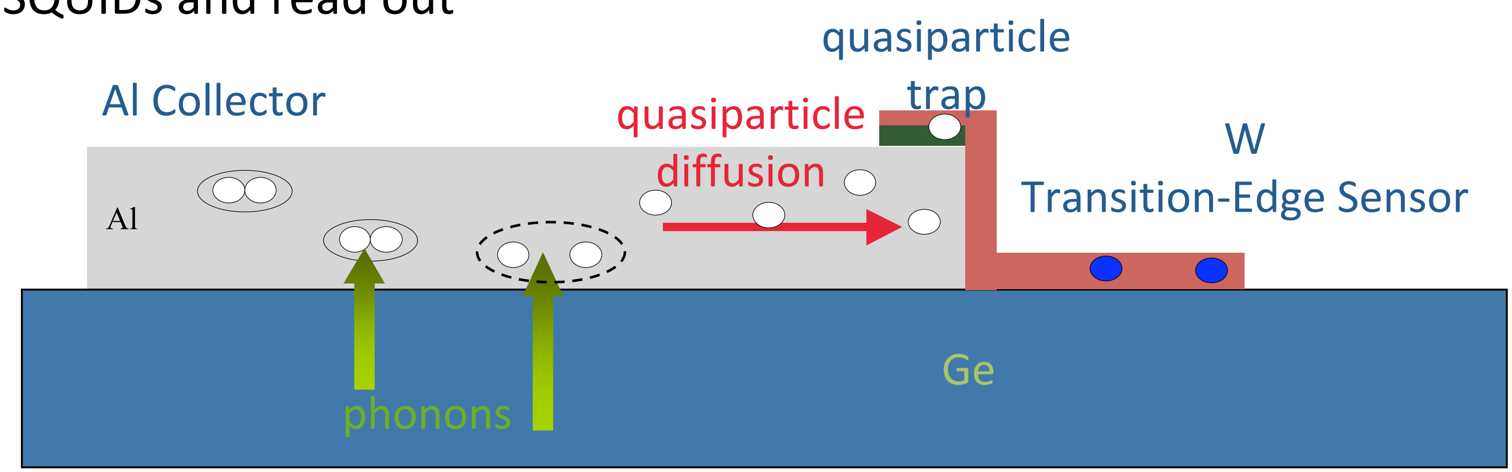




Detector Basics

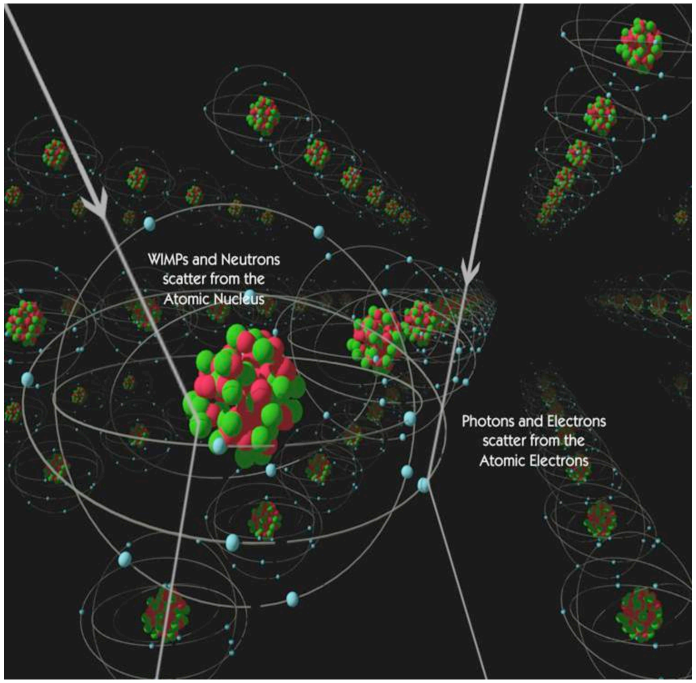
- Ionization:
  - Electron-hole pairs from interaction separated by applied E field, and collected at opposing electrodes
- Phonons:
  - collected by Al, causing diffusion into superconducting tungsten TES, driving it normal
  - Change in R_{TES} amplified by SQUIDs and read out

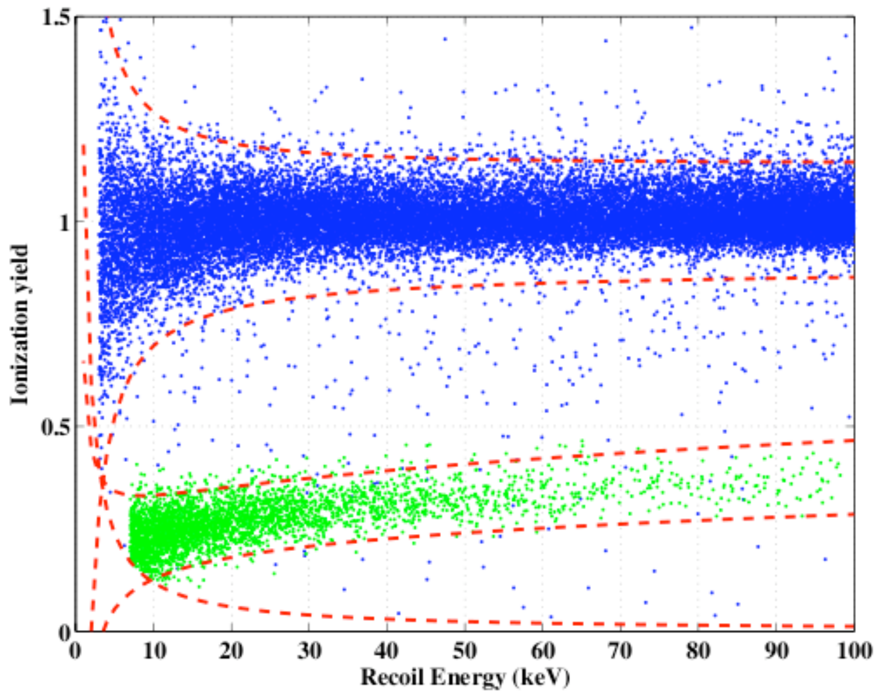




Ionization Yield

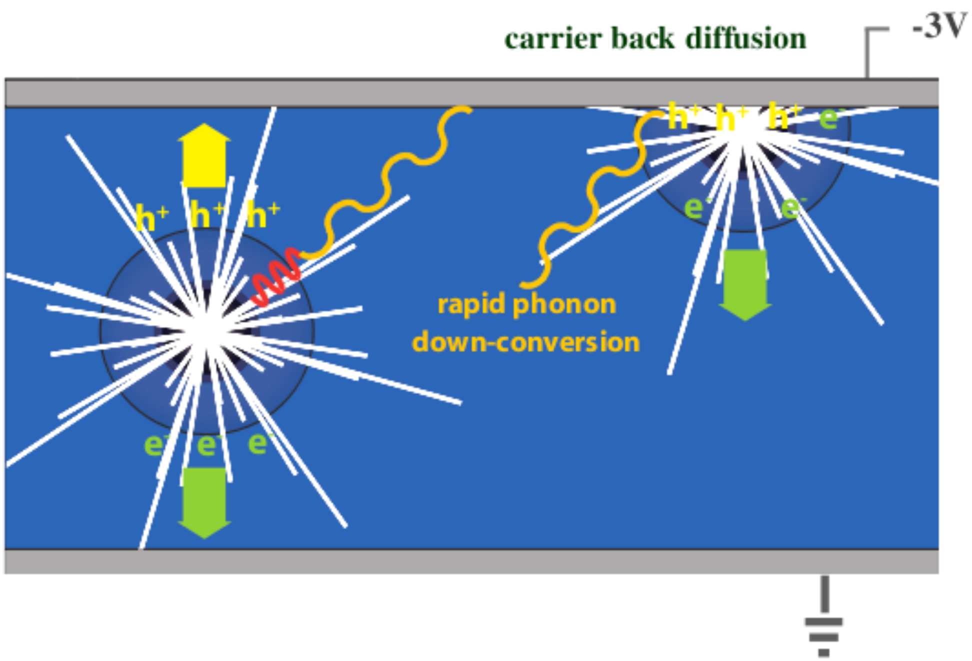
- Ratio of ionization to phonon energy is greater for electron recoils than for nuclear recoils
- Allows us to reject most e^-,γ backgrounds to $1:10^4$ level for CDMS-II ZIPs

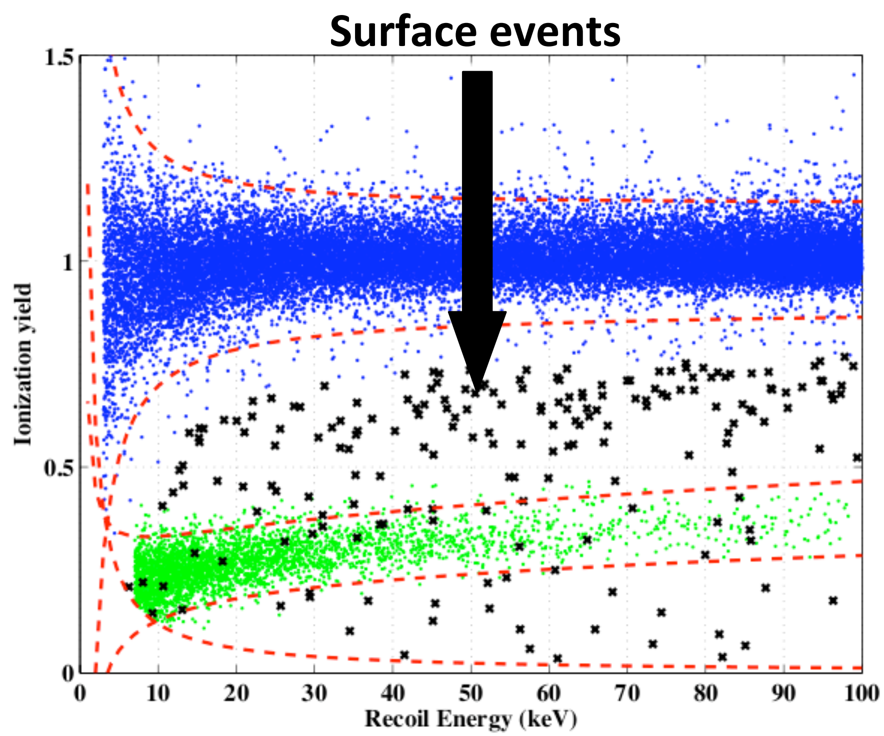




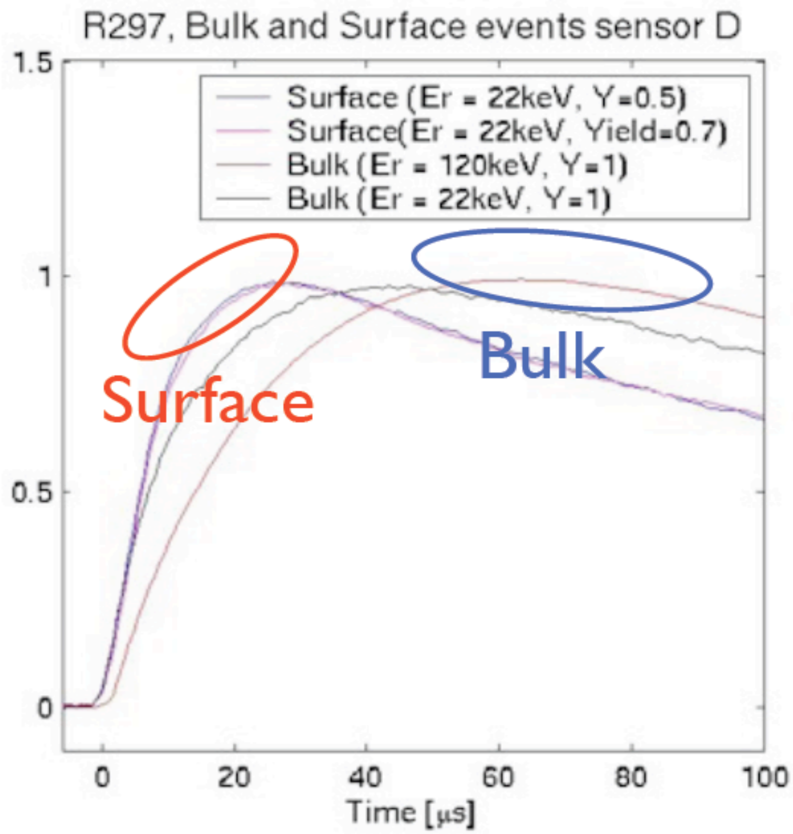
Surface Events

- Incomplete charge collection for events on outer 10-µm "dead layer"
- Suppressed ionization yield
- Phonon pulses show different timing properties



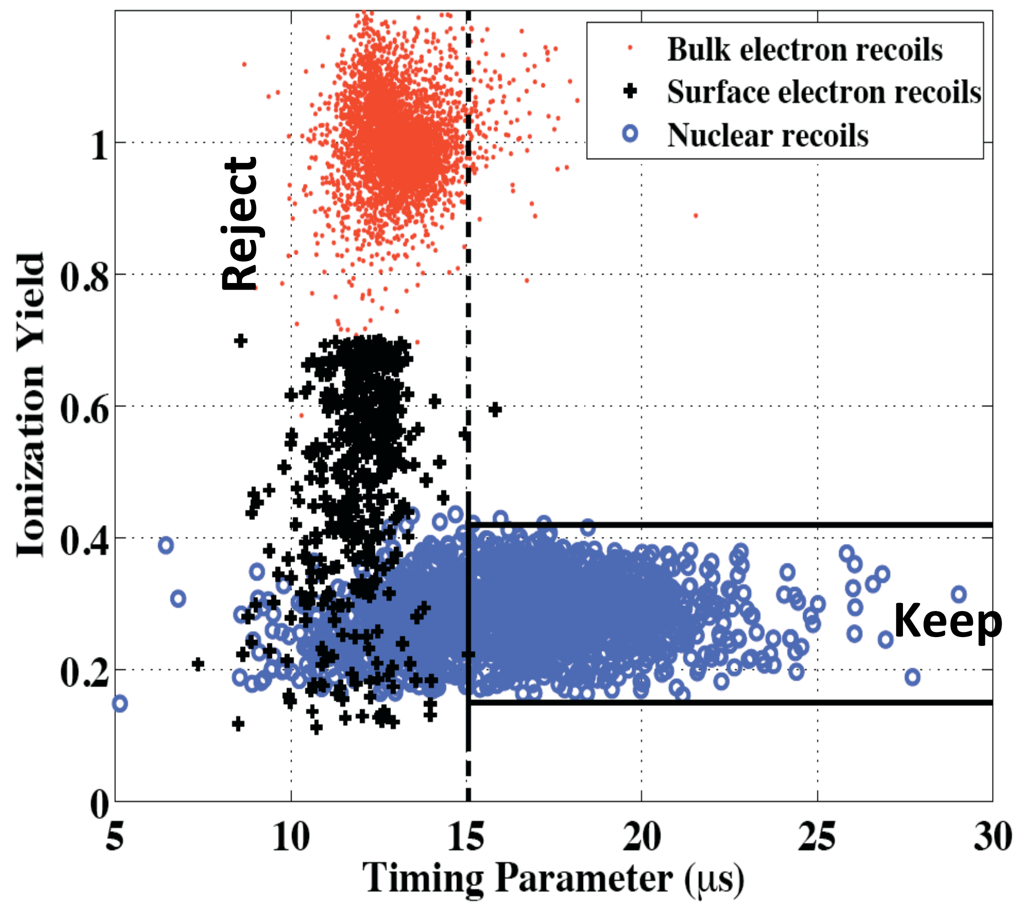


Surface-Event Rejection



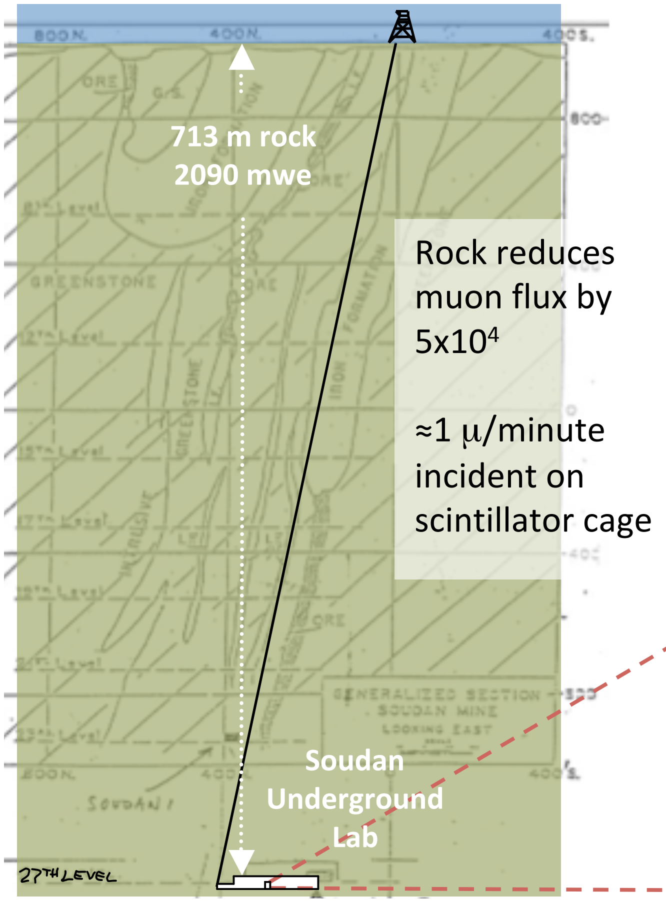
Phonon pulse-shape contains information on interaction depth

Calibration Data

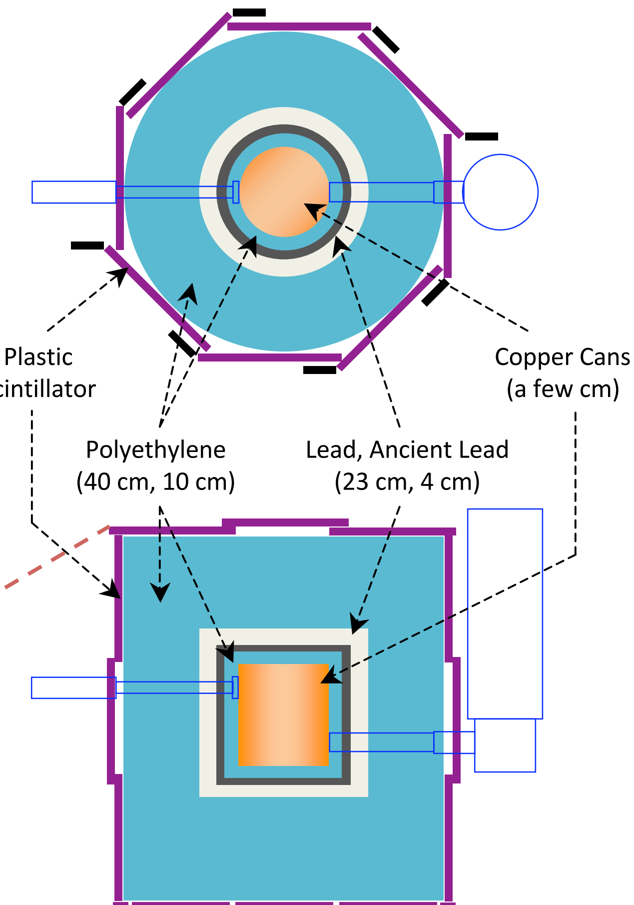


Rejection power of 1:350 for surface events on CDMS-II ZIPs

n^0 Background: Shielding and Tagging



(M. Fritts)



Scintillator veto cage: muon-tagging efficiency >99.9%

Polyethylene shields against external radiogenic neutrons

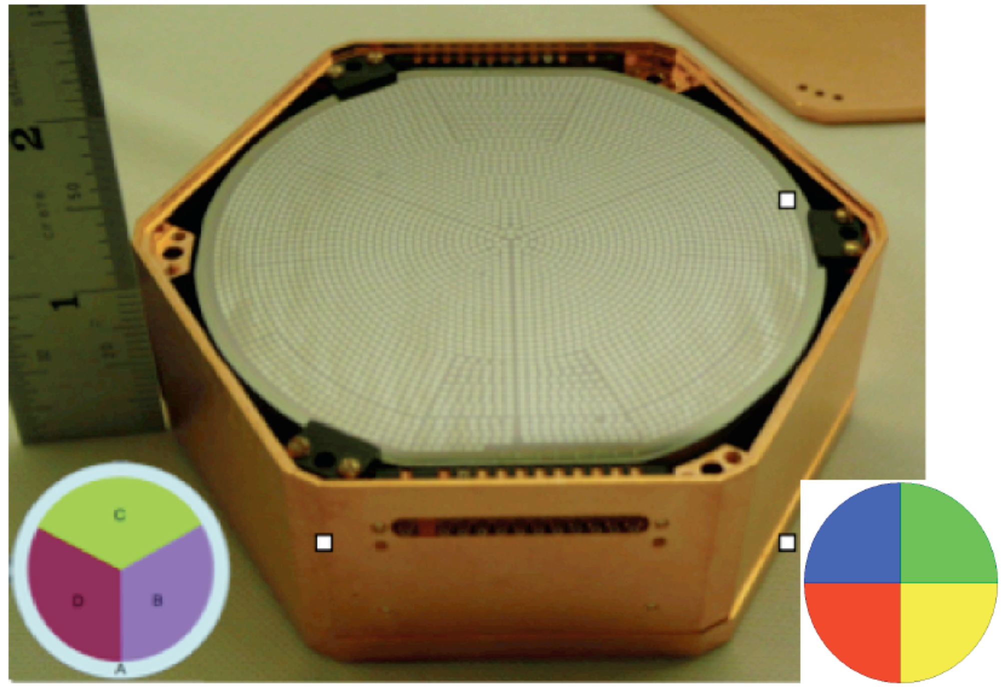
Cosmogenic background estimated to be 0.04 events for last run; similar for radiogenic

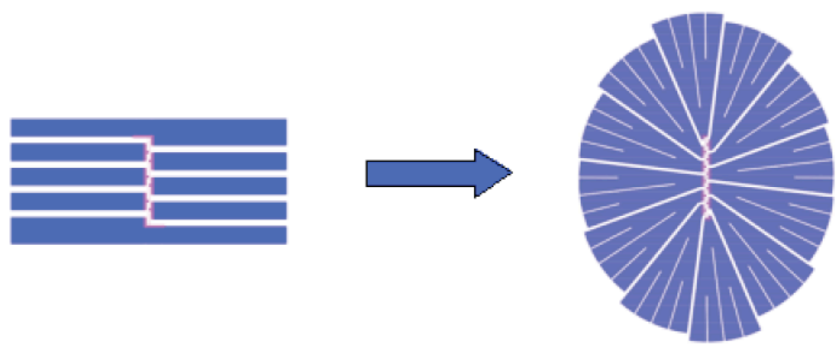
Scaling Up

- Ge-based technology is one of several candidates for ton-scale dark matter searches
  - competing with liquid Xe, liquid Ar, and others
- Increase exposure while limiting background
  - increased detector size, number
  - improved detector design, analysis techniques
  - improved handling: lower contamination (fewer β)
  - deeper site to limit neutron background (SNOLAB)

mZIP

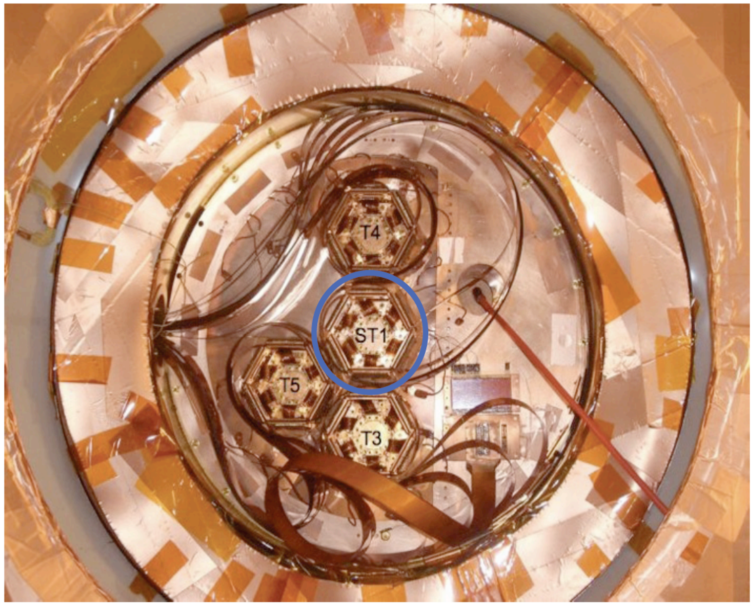
- Relatively minor design changes
- 1" thick, 2.5x suppression of surface events
- "Stadium" phonon sensor design:
  - Covers more surface area
  - Improves phonon collection
- "Mercedes"-like phonon sensor layout
  - Better phonon signal at the outer edge
  - Breaks degeneracies in position reconstruction
  - Improves phonon timing information

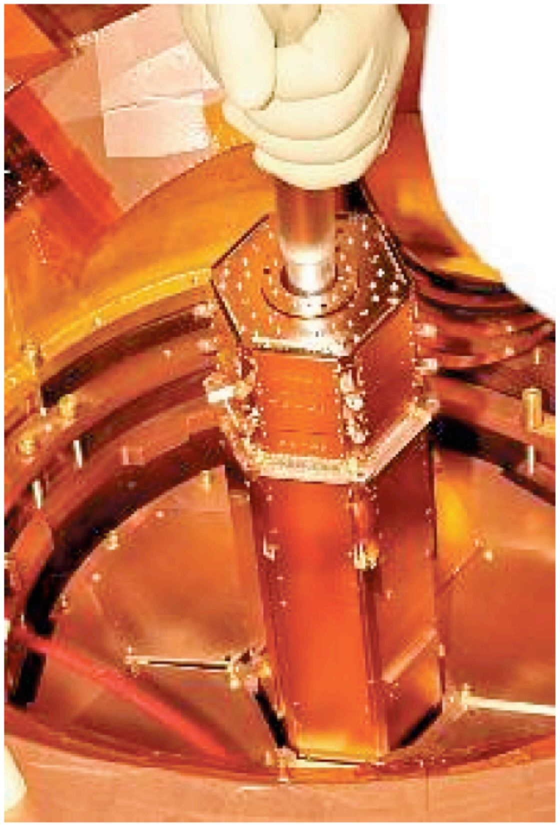




mZIP at Soudan

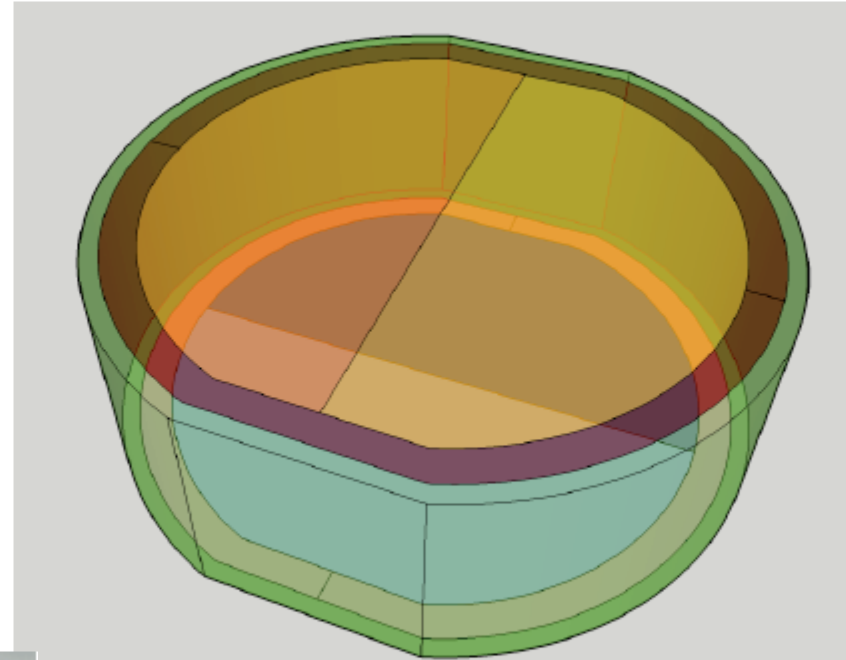
- SuperTower 1 installed at Soudan
  - Five 1” thick mZIPs + two endcap veto detectors
  - Took data fall/winter 2009-10
  - Data analysis ongoing

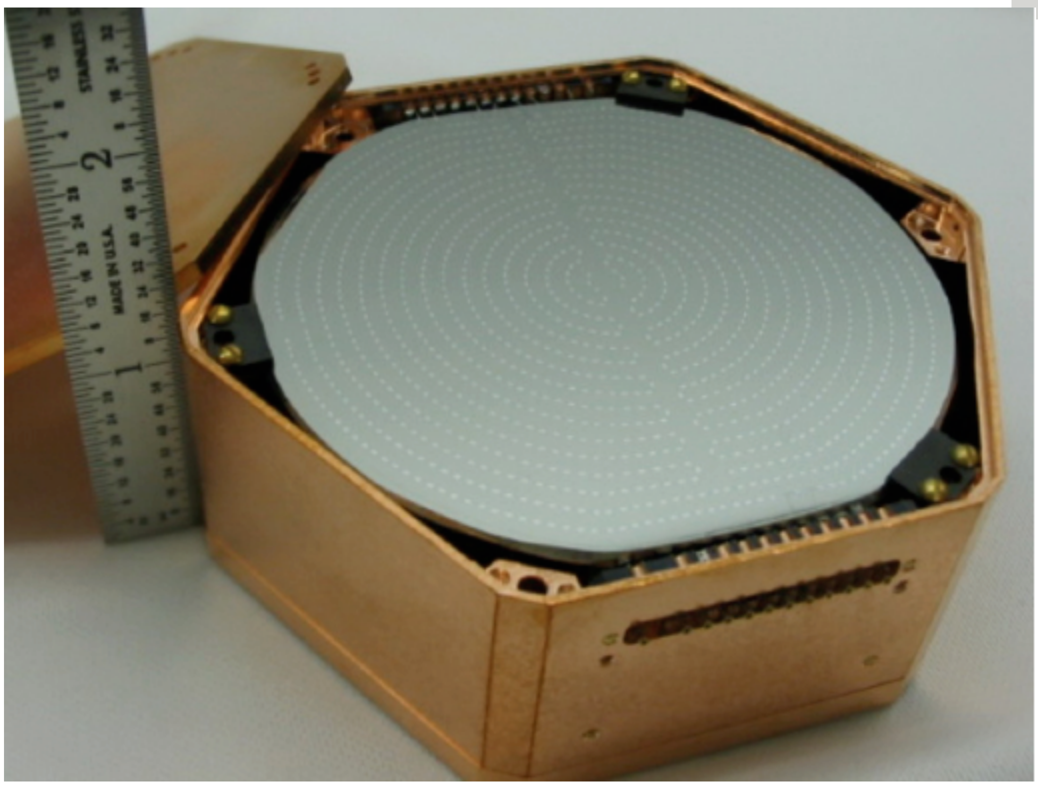


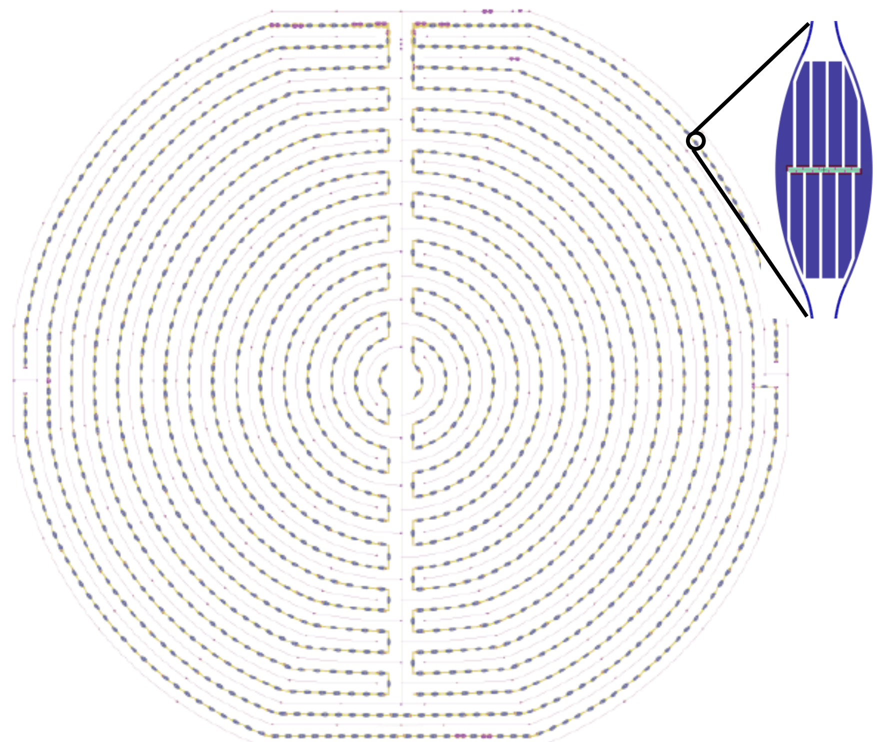


iZIP

- Major design change
- Still 3” x 1” (650 g Ge)
- Phonon sensors: on both sides for full 3D reconstruction
- Charge and phonon channels interleaved

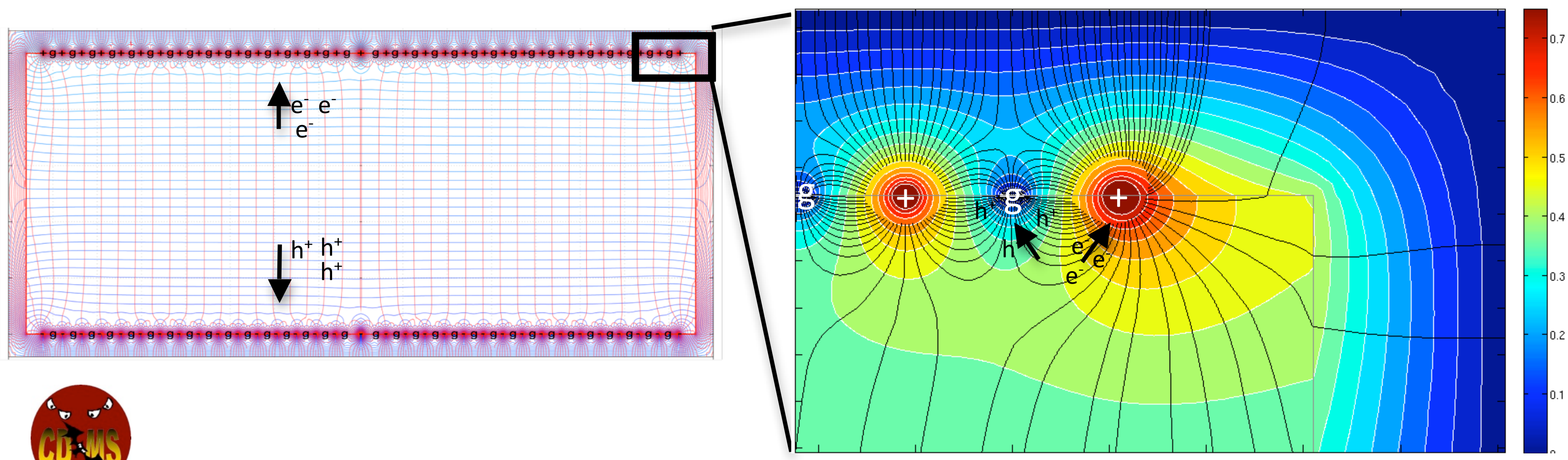




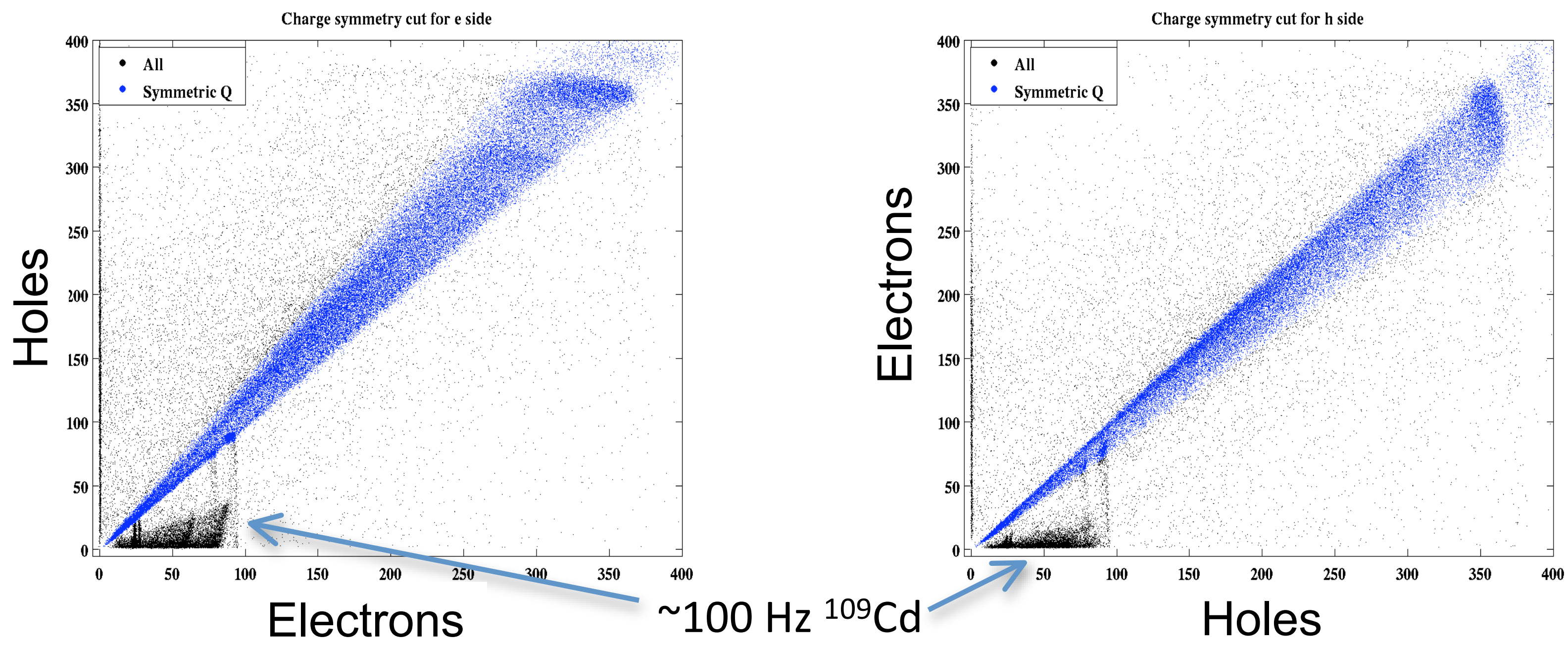


iZIP Charge Collection

- Charge lines alternating at ±2V/0V cause asymmetric e^-/h^+ collection for surface events
- Charge collection is symmetric for bulk events
- Vastly reduces dominant background

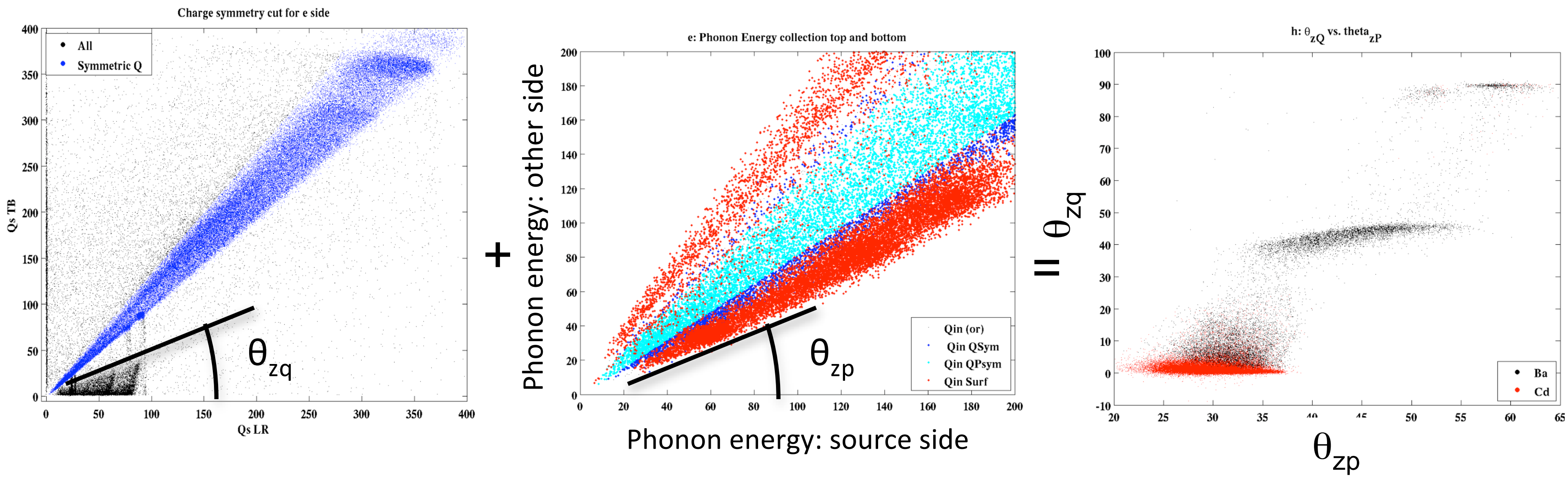


Charge Asymmetry



- With a ^{109}Cd source on the electron (+2V) side, hole collection is reduced for surface events – they go to the e^- side ground
- 90% efficient q-symmetry cut rejects surface events to <1:1000
- Bonus: 10x smaller leakage of low yield surface events into NR band even before this cut (stronger transverse E fields)

Reconstruction in Phonons



- Two additional parameters to combine with q-symm.
    1. Phonon energy partition (*shown, center*)
    2. Timing difference between rising edge of phonon pulses on upper/lower detector faces
- iZIP ER/NR discrimination power satisfies requirements of ton-scale experiment

From CDMS II to SuperCDMS to GEODM

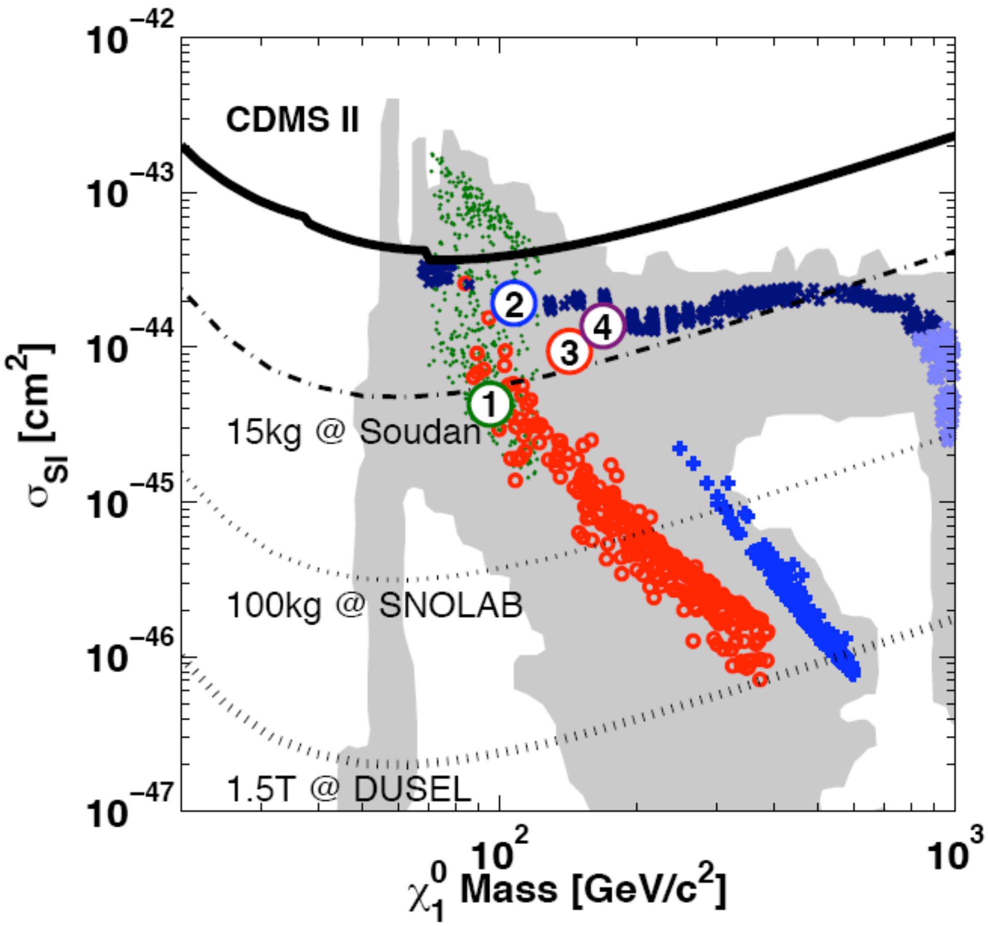
CDMS II
3” x 1cm ~ 0.25 kg/det
16 detectors = 4 kg
~2 yrs operation (last analysis)

SuperCDMS
3” x 1” ~ 0.64 kg/det

Soudan	SNOLAB
25 detectors = 15 kg	150 detectors = 100 kg
2 yrs ~ 10,000 kg-d	3 yrs ~ 100,000 kg-d

SuperCDMS SNOLAB and Ge-Observatory for Dark Matter (GEODM)
6” x 2” ~ 5.1 kg/det

SNOLAB	DUSEL
20 detectors = 100 kg	300 detectors = 1.5 ton
3 yrs ~ 100,000 kg-d	4 yrs ~ 1.5 Mkg-d



(V. Mandic)

Summary

- New iZIP detectors offer vastly improved performance
  - Charge symmetry
  - Reduced low yield surface events in NR band
  - Phonon energy partition
  - Improved phonon timing discrimination
- Combined with reduced neutron background at SNOLAB/DUSEL, Ge detectors should be competitive in ton-scale WIMP search

Backup: How Do We Get There?

- Current surface-event rejection efficiency: 3×10^{-3}.
- SuperCDMS-15 kg (Soudan):
  - x2 (cuts) x2.5 (1"thick) x1.6 (lower bkgd) $\Rightarrow$ 10x.
- SuperCDMS-100 kg (SNOLAB):
  - x2 (lower contamination) x2 (electrodes) x2 (phonon timing) x2 (phonon collection) $\Rightarrow$ 150x.
- GEODM 1.5 ton (Homestake-7400):
  - x2 (2" thick) x2 (lower contamination) x3 (detector improvements) $\Rightarrow$ 2000x.
- Bulk EM background (gammas): similar factors to above.
- Lower contamination (radon mitigation, material screening).
- Neutron background:
  - Deeper sites (SNOLAB, Homestake-7400).
  - Internal shielding (inside cryostat).
  - External moderator (water or poly).