Current and Future Dark Matter Searches with SuperCDMS

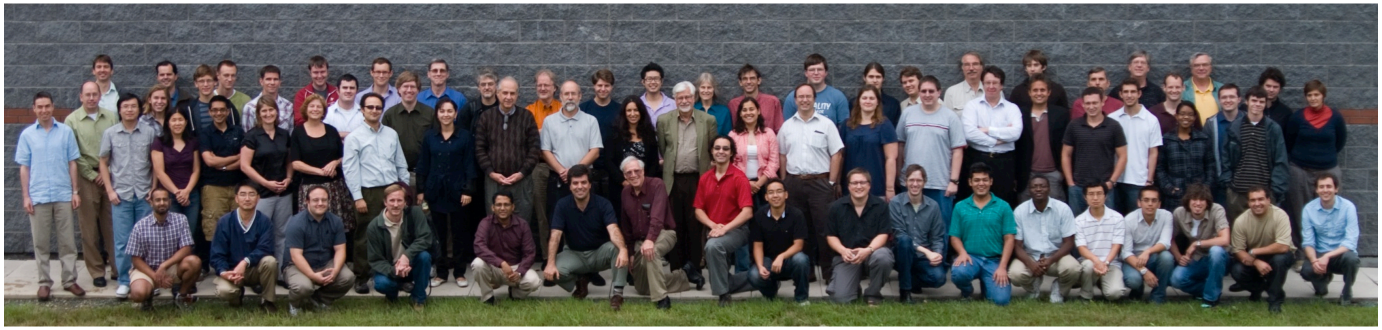
Oleg Kamaev

Queen's University

for the SuperCDMS collaboration

DPF-2011, August 9-13, Providence, RI

The SuperCDMS Collaboration



California Institute of Technology
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University of Minnesota
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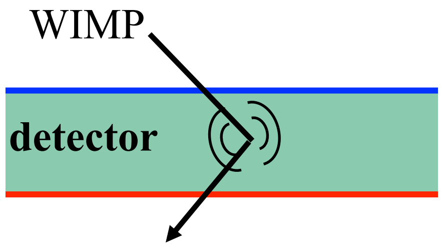
University of Zurich
S. Arrenberg, T. Bruch, L. Baudis, M. Tarka

CDMS: WIMP Detection Strategy

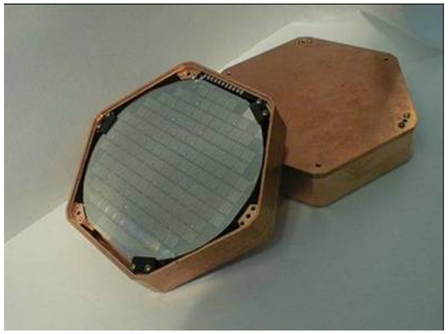
Direct Detection:

Search for WIMP signal via nuclear recoil elastic scattering in the detector.



State-of-the-art detector:

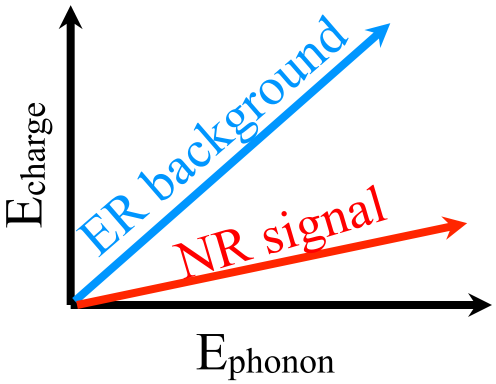
- Low temperature (< 50 mK) semiconductor detectors;
- Read out phonons from the recoil together with ionization signal.



Background Reduction and Rejection:

Goal = Maintain "<1 event expected background"

- Go deeper to reduce cosmogenic muons
- Active muon veto
- Shielding and material-purity
- Powerful background discrimination in the analysis

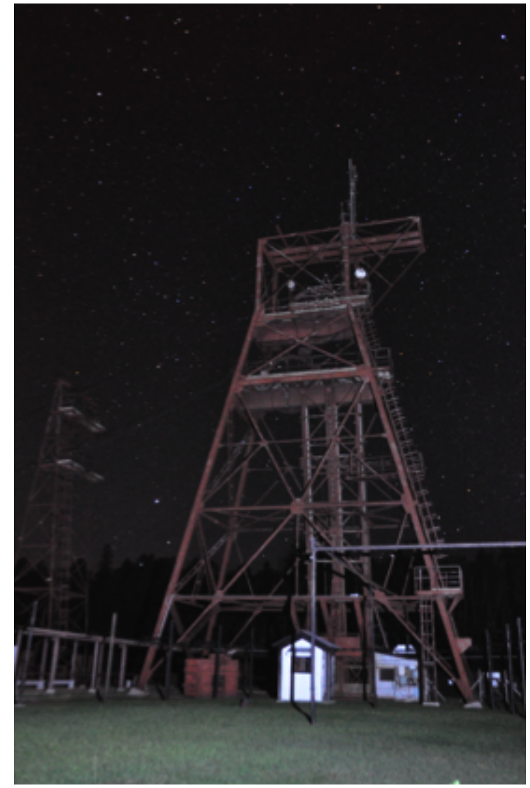


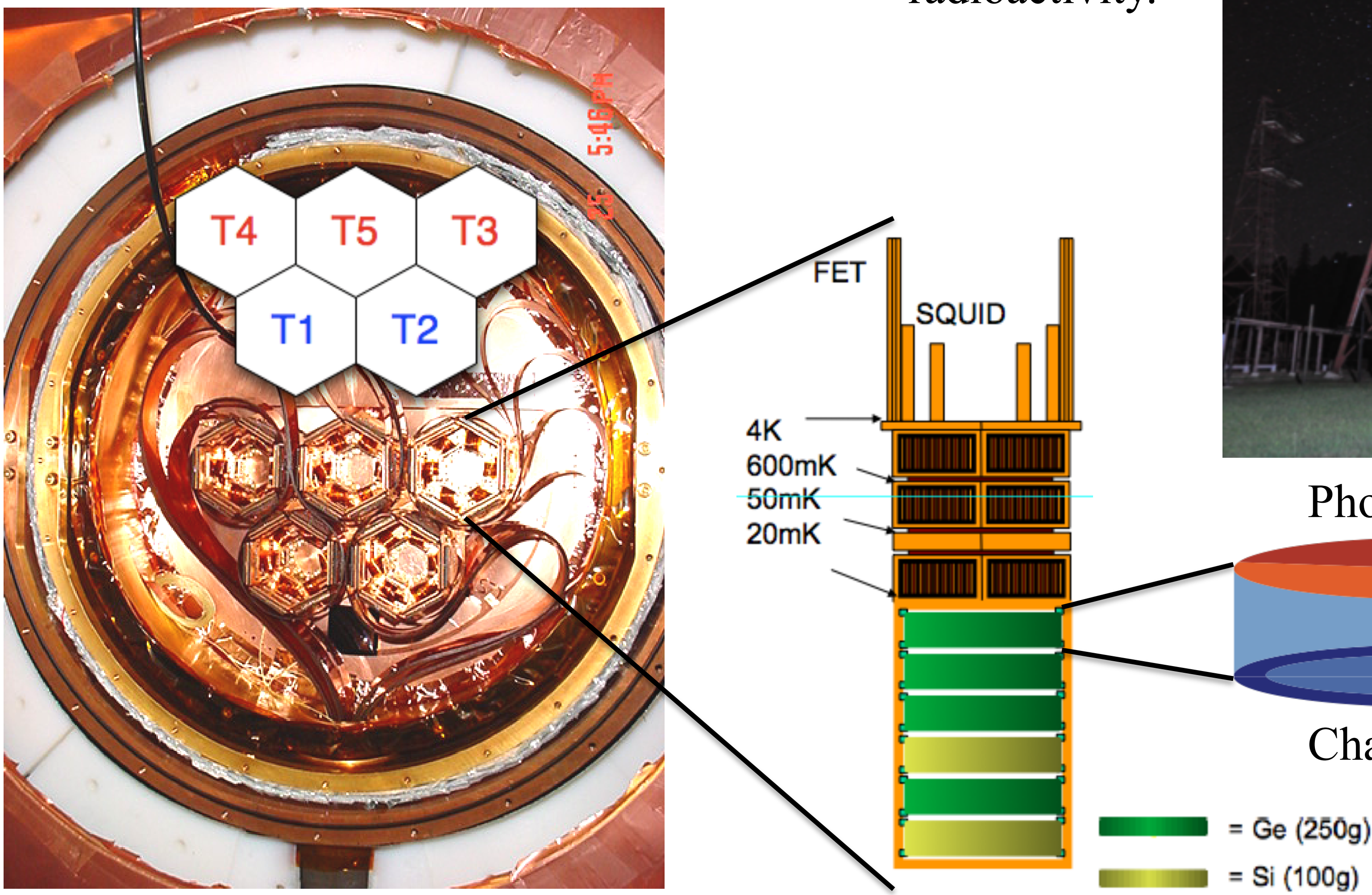
CDMS-II Experiment

- Soudan Underground Lab, USA (2090 m.w.e. depth)

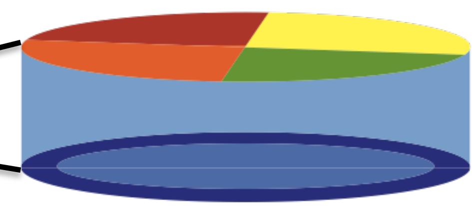
CDMS-II Experiment

- Soudan Underground Lab, USA (2090 m.w.e. depth)
- 5 Towers of 6 detectors (4.6 kg Ge, 1.1 kg Si)
- Active/passive shielding against muons and environmental radioactivity.





Phonon side

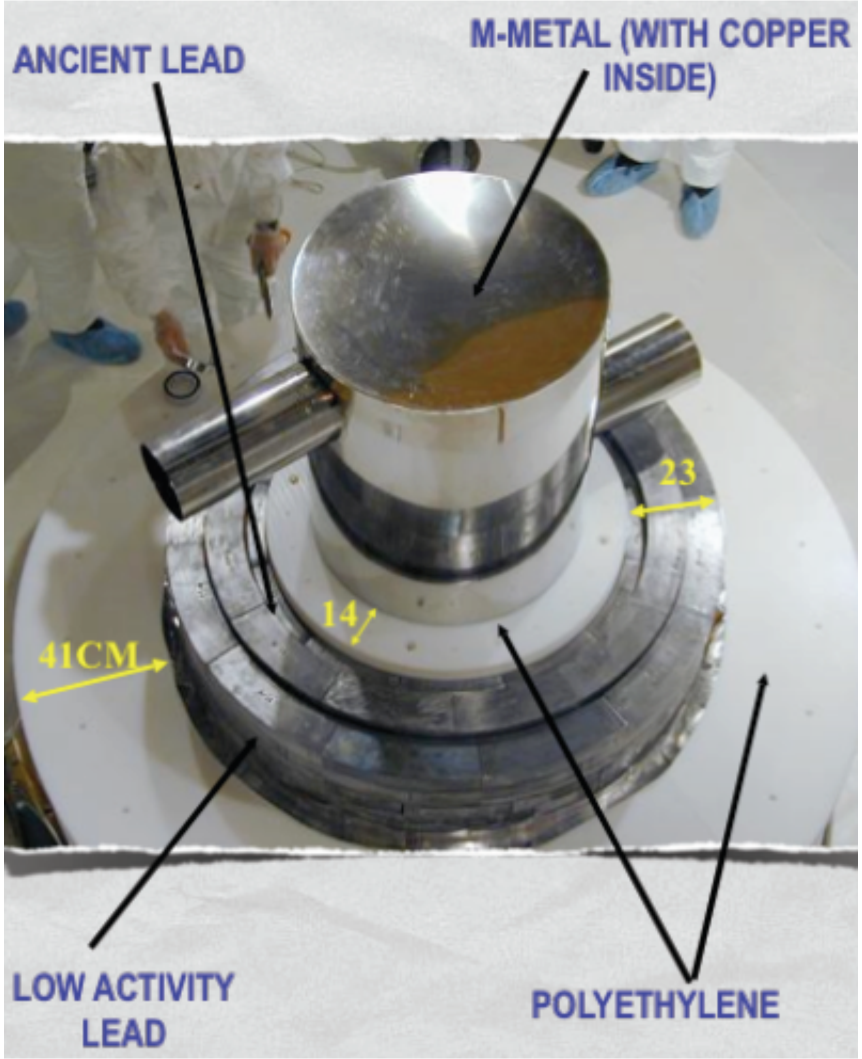


Charge side

CDMS Shielding

Passive shielding:

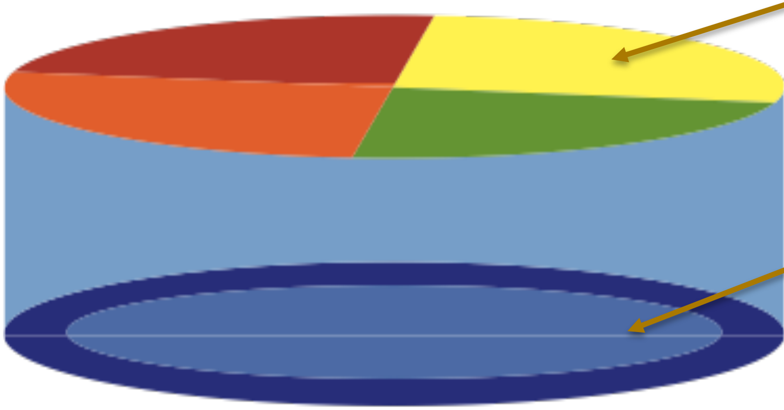
- Pb: shielding from γ's
- Polyethylene: moderate neutrons from fission and from (α,n) interactions from U/Th decays
- Copper: shielding from γ's.



Active shielding:

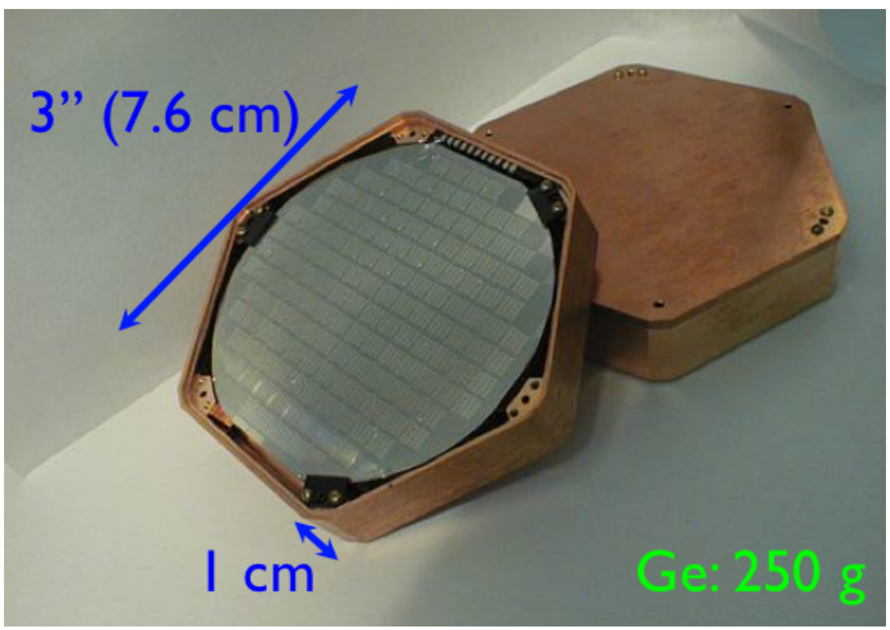
- Muon veto to reject events from cosmic rays.

Z-sensitive Ionization Phonon Detector (ZIP)

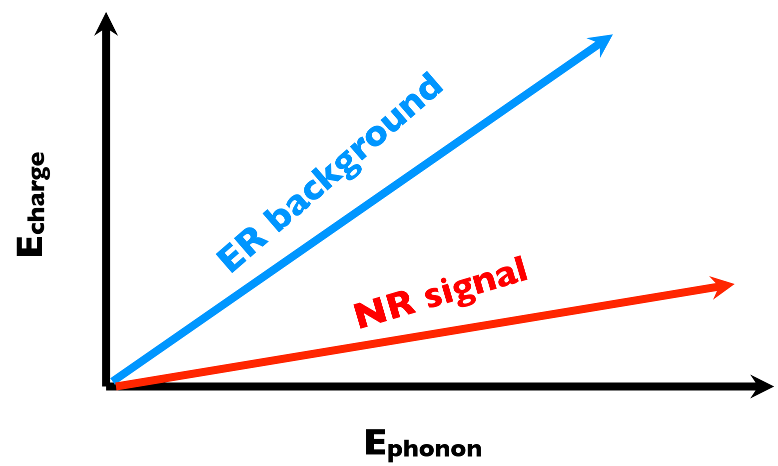


Phonon side:
- 4 quadrants of phonon sensors
- provide phonon energy and position info

Charge side:
- 2 concentric electrodes (inner and outer)
- provide ionization energy and veto

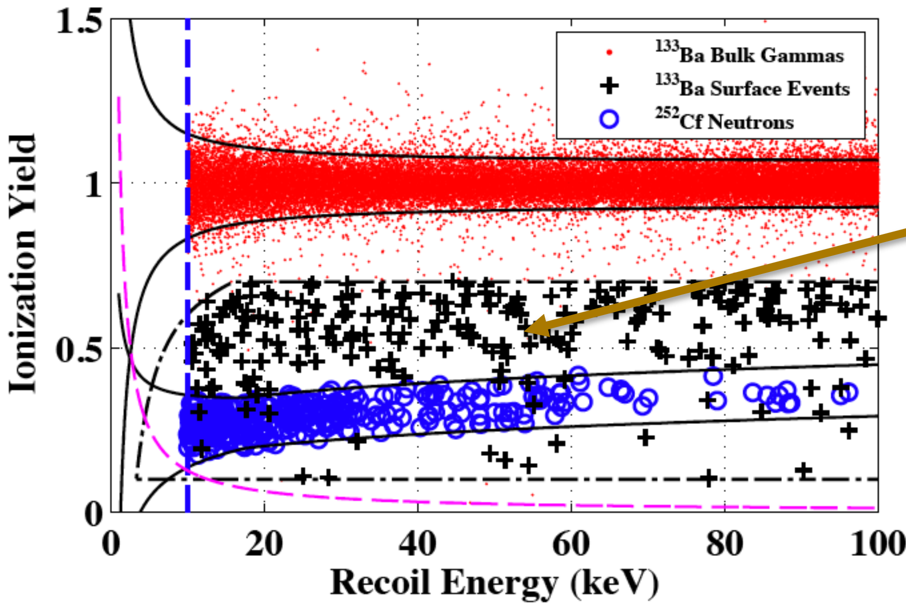


Nuclear/ Electron recoil discrimination:

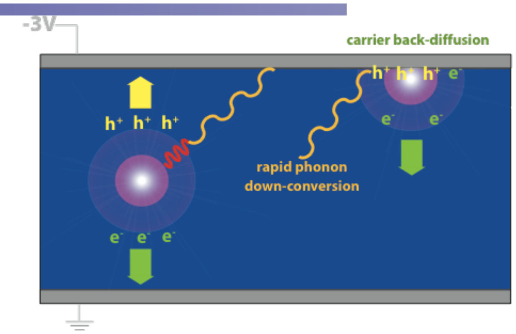


Signature of Nuclear Recoil: reduced ionization relative to phonon signal.

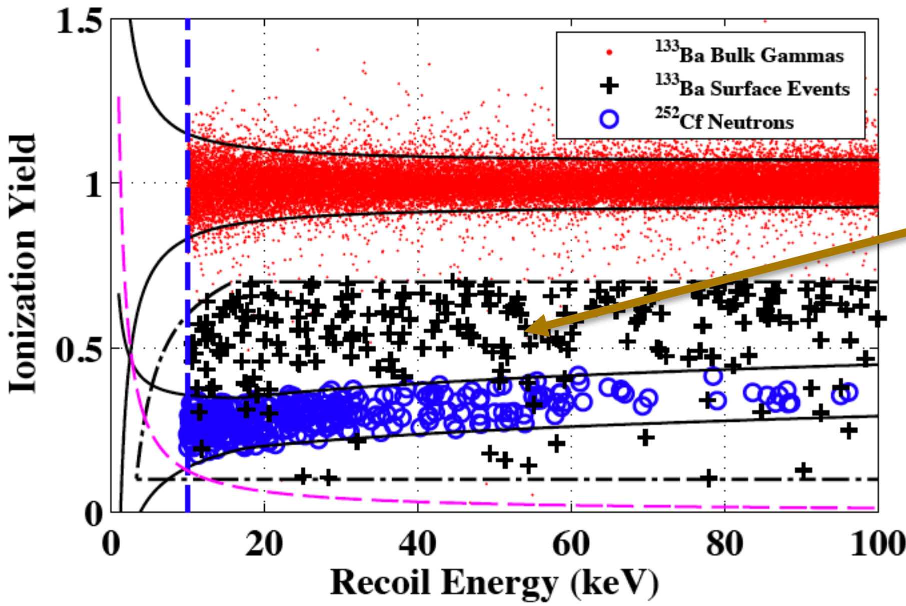
Surface Events Discrimination



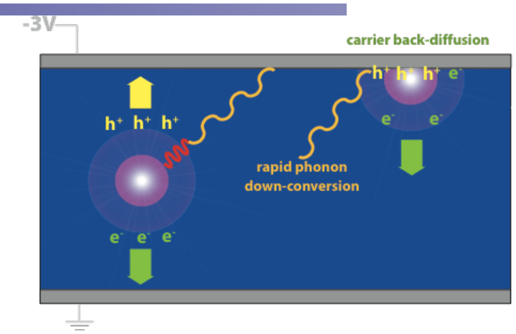
Low-yield ER surface events



Surface Events Discrimination



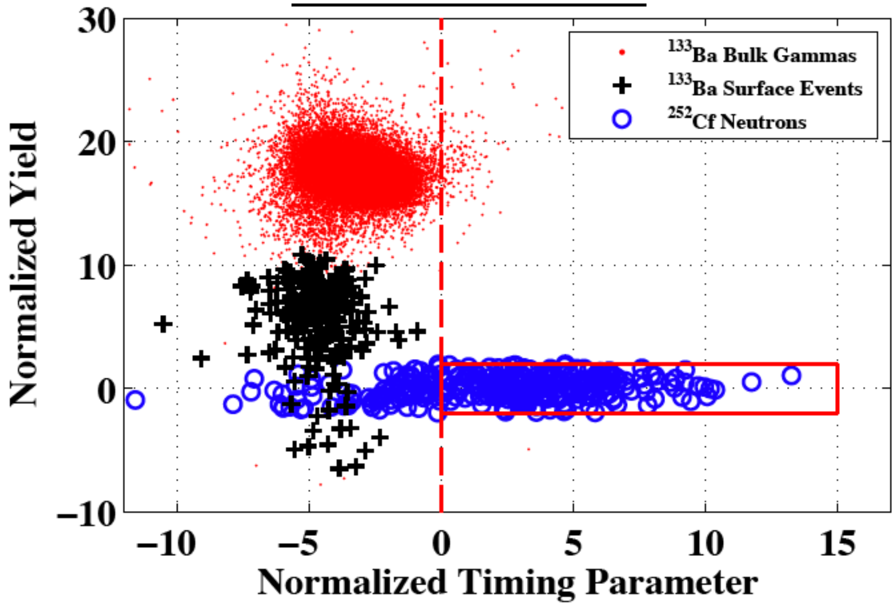
Low-yield ER surface events



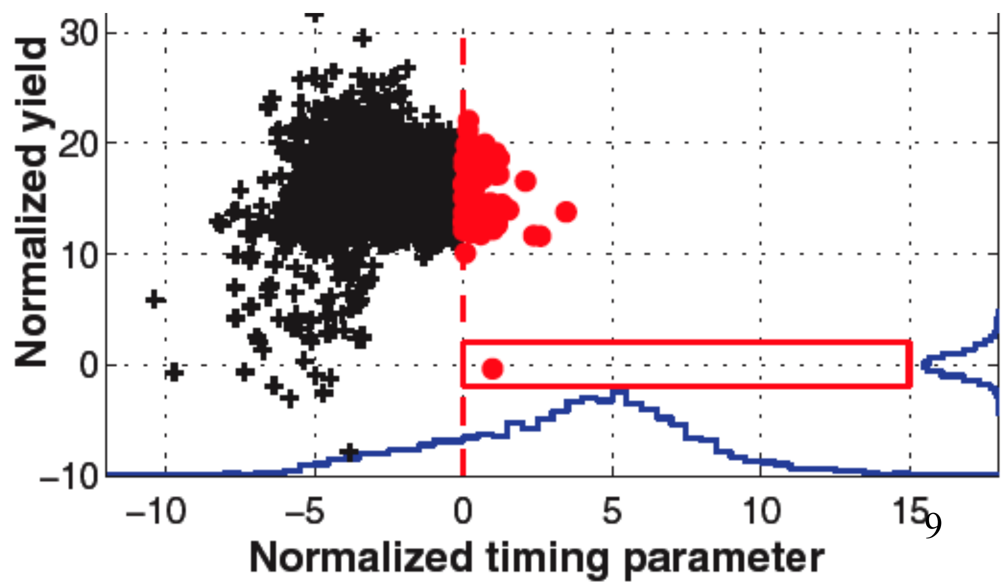
Introduce:

phonon timing parameter = *phonon pulse risetime + offset from ionization pulse*

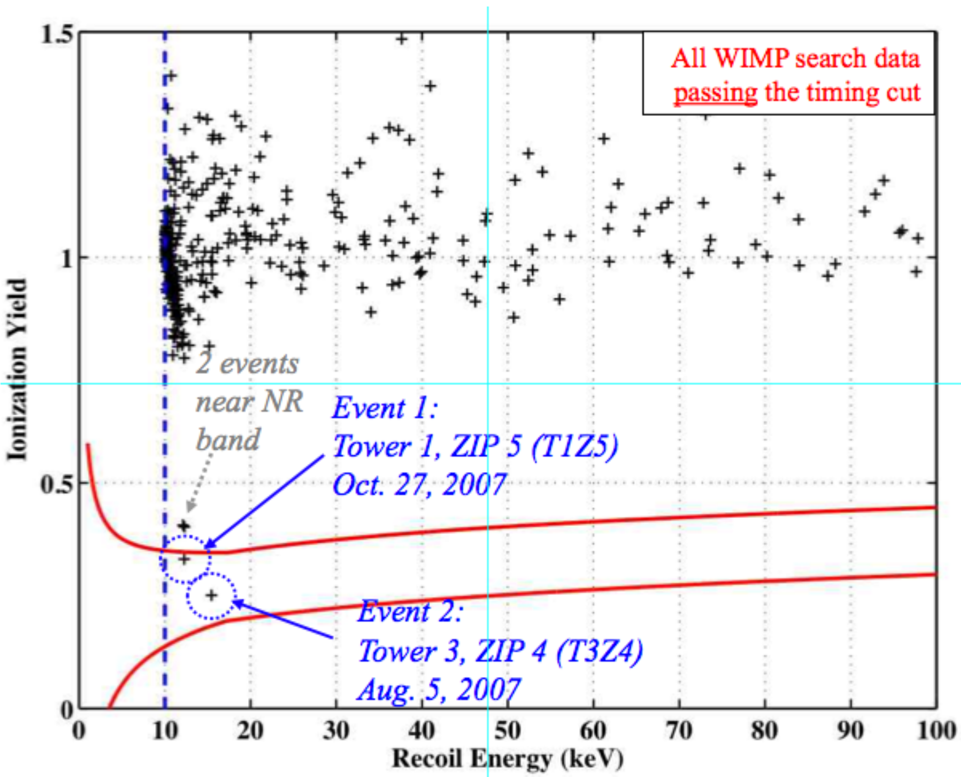
Calibration Data

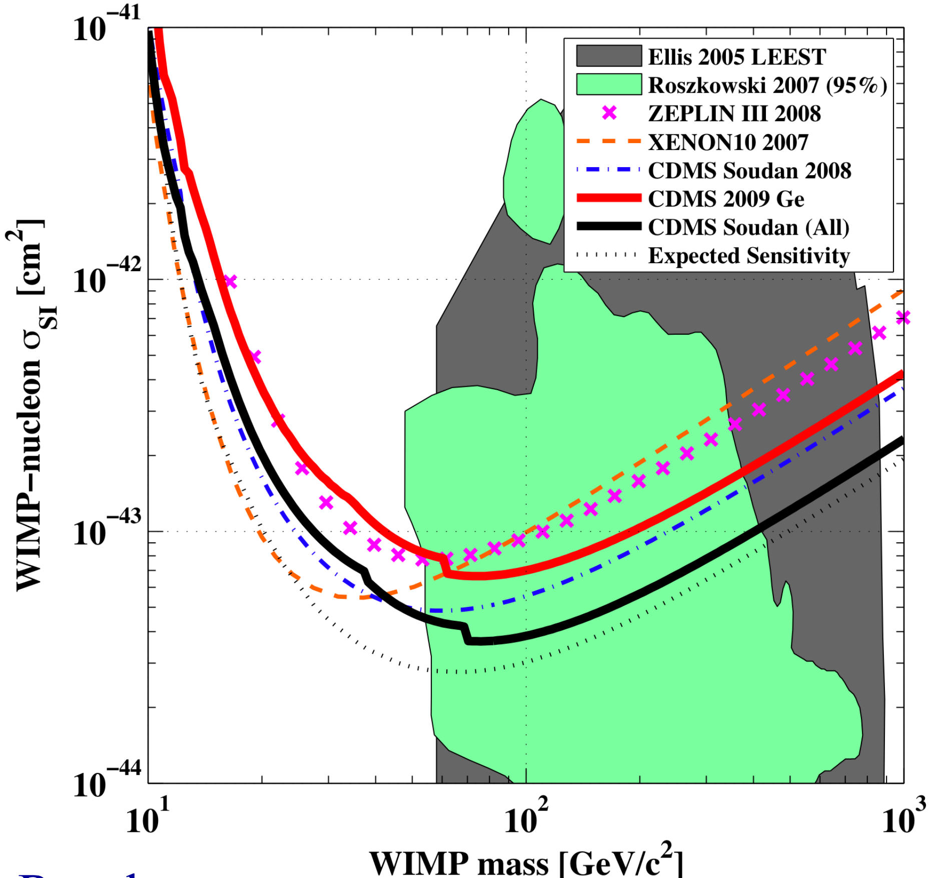


Low-background Data



CDMS-II Results





- spectrum-averaged exposure after all cuts is 194 kg-days
- 2 events in the NR band pass the timing cut

Result:

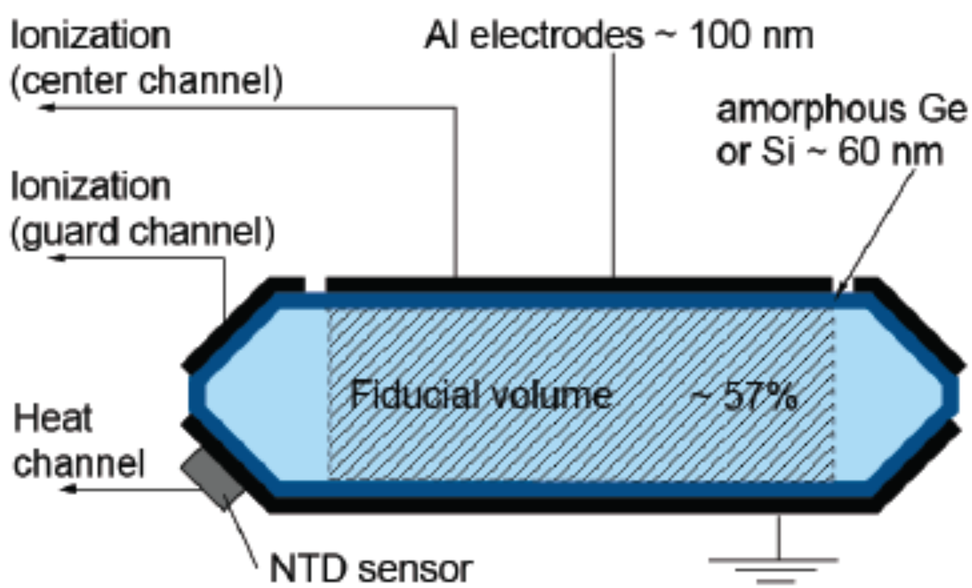
- 7.0×10^{-44} cm^2 @ 70 GeV/c^2
- 3.8×10^{-44} cm^2 @ 70 GeV/c^2 (combined with previous CDMS data)

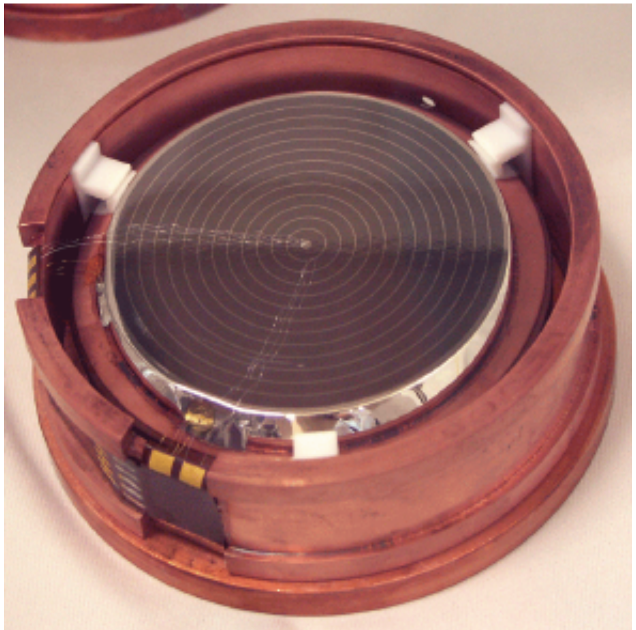
Science, vol. 327, p. 1619-1623 (2010)

CDMS + EDELWEISS Combined Result

EDELWEISS:

- Laboratoire Souterrain de Modane, France (4800 m.w.e. depth)
- 10x400 g Ge bolometers @ 20 mK
  - Ionization measurement
  - Heat measurement
- Threshold 20 keV
- Total exposure 384 kg-days (comparable to 379 kg-days of CDMS-II total)
- Observed 5 candidate events
- Expected background ~3 events



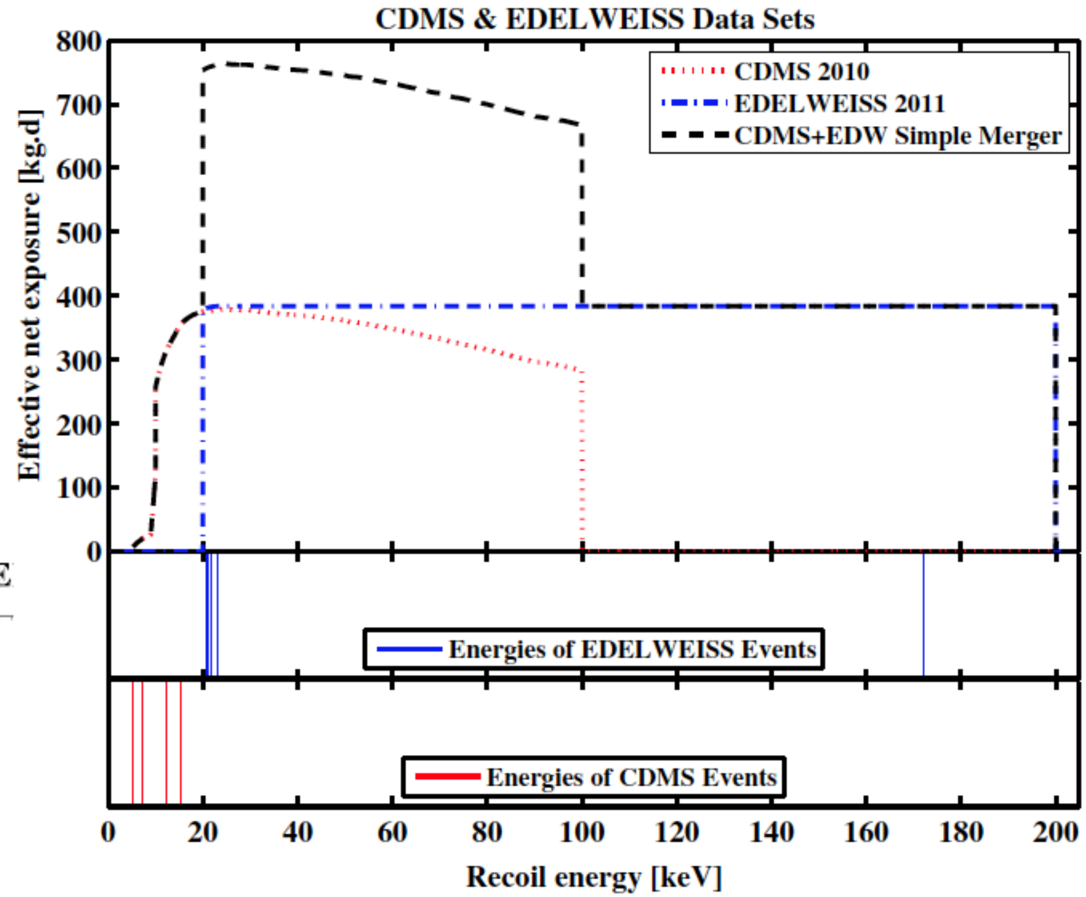


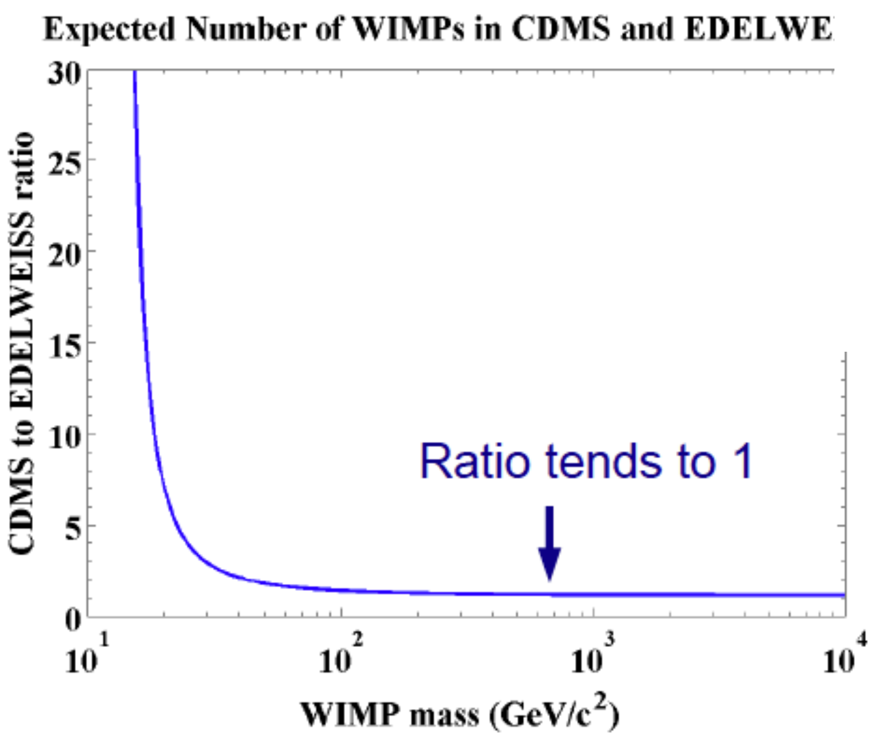
CDMS + EDELWEISS Combined Result

To combine limits:

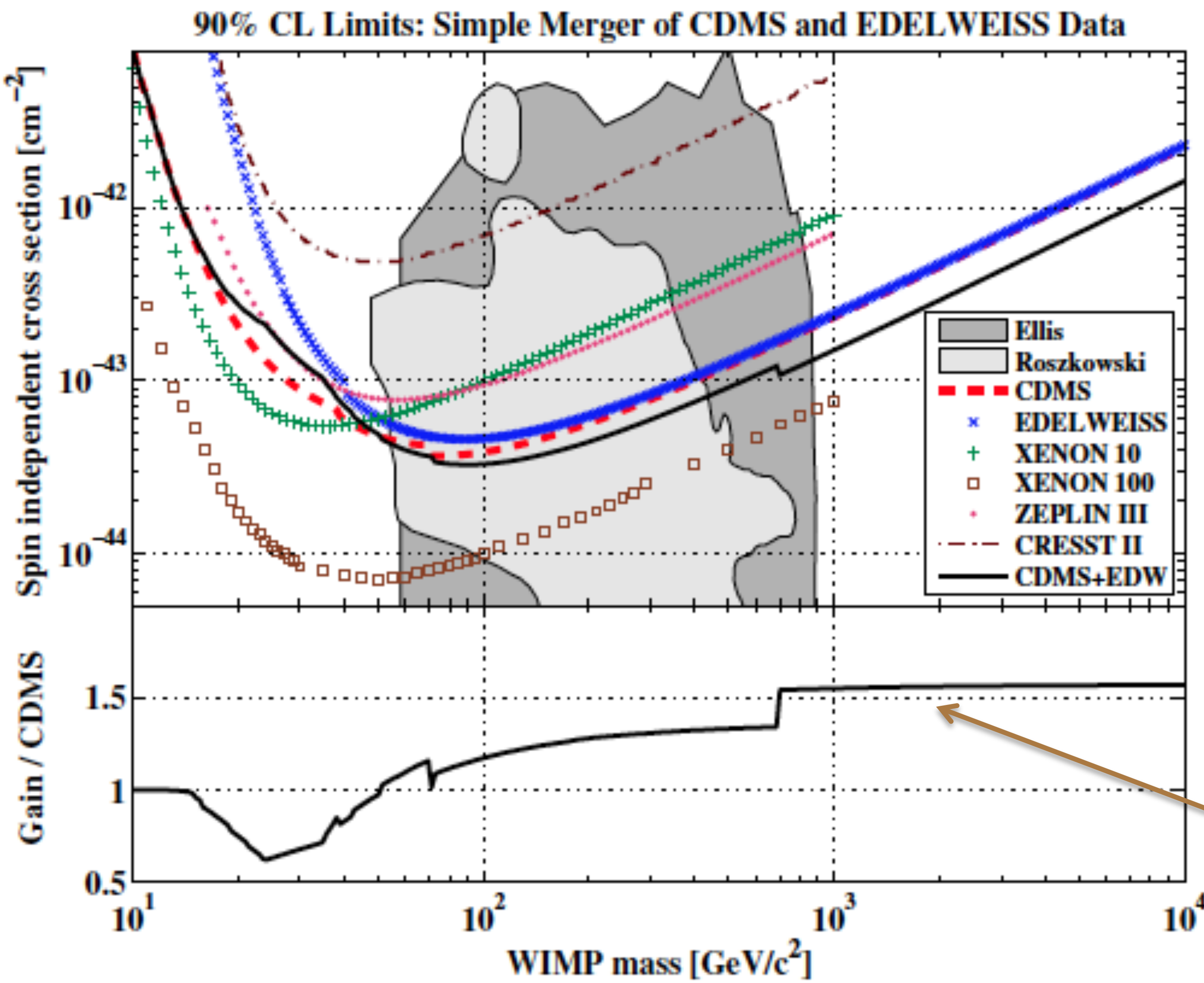
- Sum exposure-weighted efficiencies;
- Combine events regardless of experiment of origin;
- Calculate the limit.

Agreed on the method before exchanging data!





CDMS + EDELWEISS Combined Result

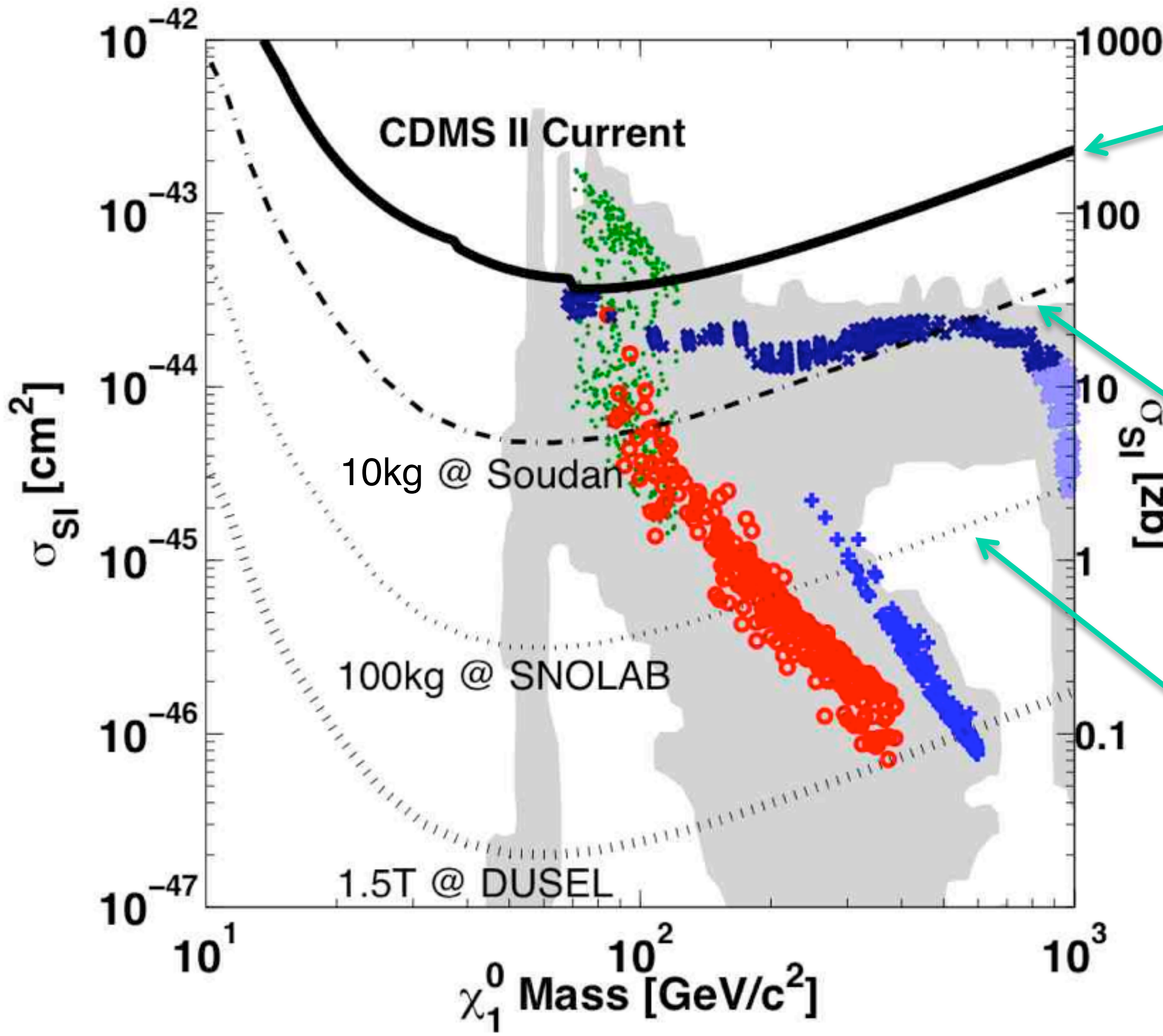


Strongest limit:
3.3×10^{-44} cm^2 for 90 GeV/c^2 WIMP

Improvement up to a factor 1.6 above 50 GeV/c^2

PRD 84, 011102(R) (2011)

CDMS, SuperCDMS, and beyond



- CDMS-II (completed)
  - 4 kg Ge for ~2 years
  - 3.8×10^{-44} cm^2

Current phase:

- SuperCDMS @ Soudan
  - 10 kg Ge for ~2 years
  - ~5×10^{-45} cm^2

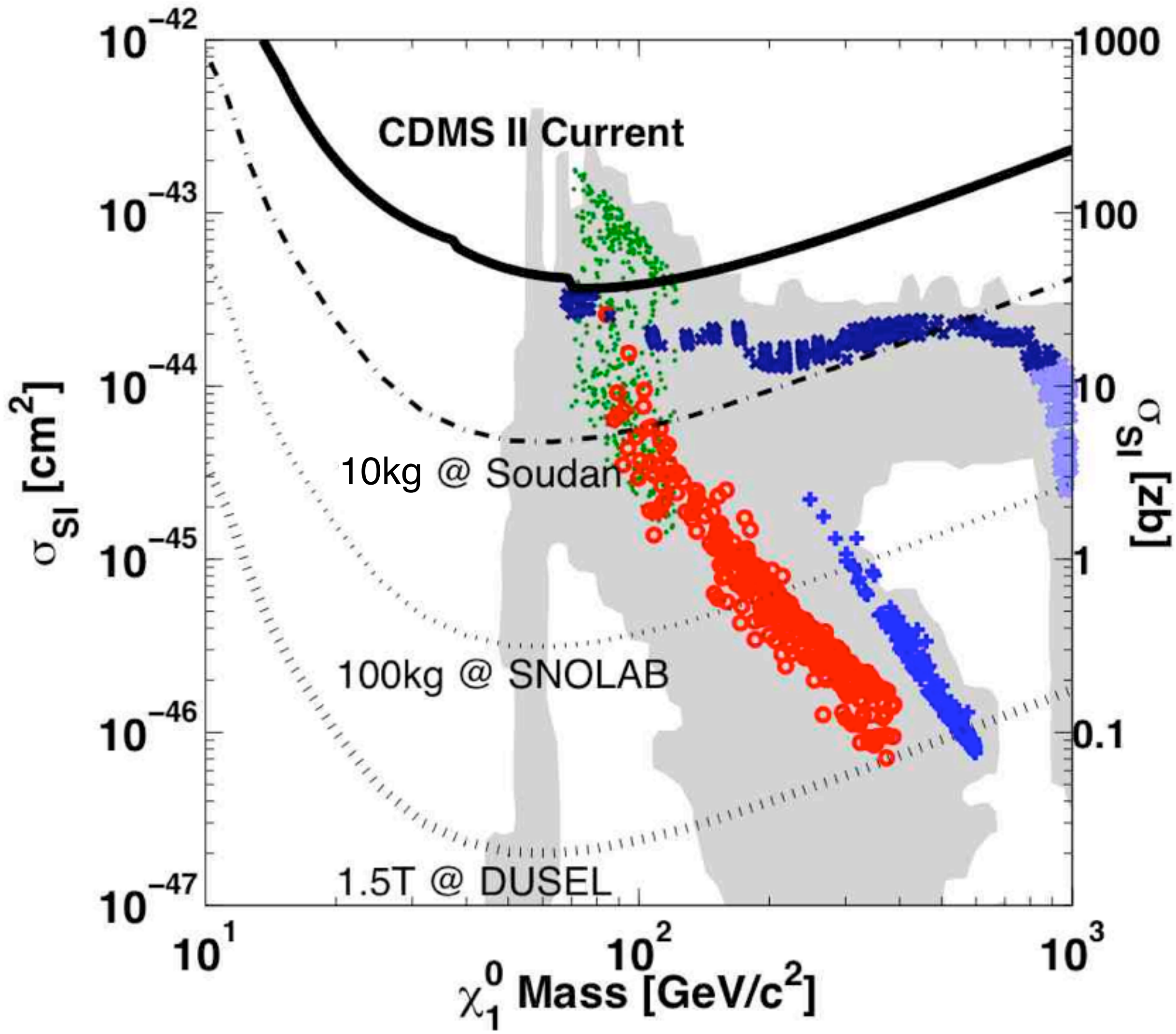
Future:

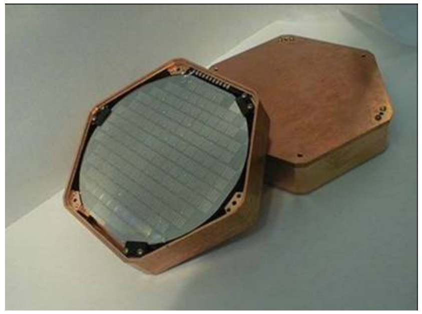
- SuperCDMS @ SNOLAB
  - 100 kg Ge for ~3 years
  - ~3×10^{-46} cm^2

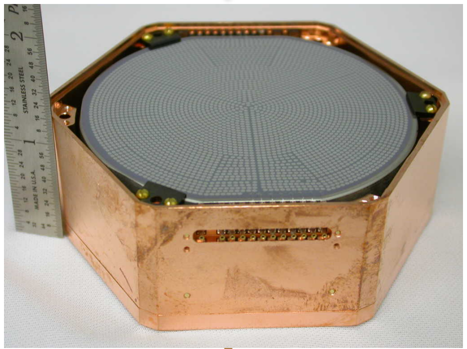
To reach the goals we need:

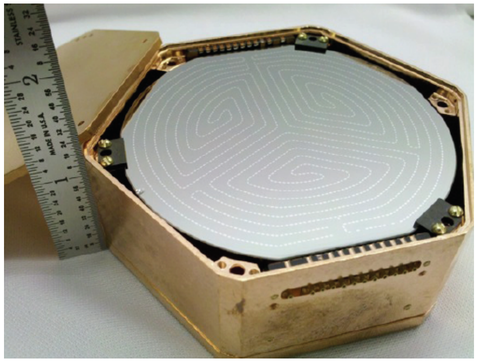
- increase mass
- decrease background leakage

CDMS, SuperCDMS, and beyond









To reach the goals we need:

- increase mass
- decrease background leakage

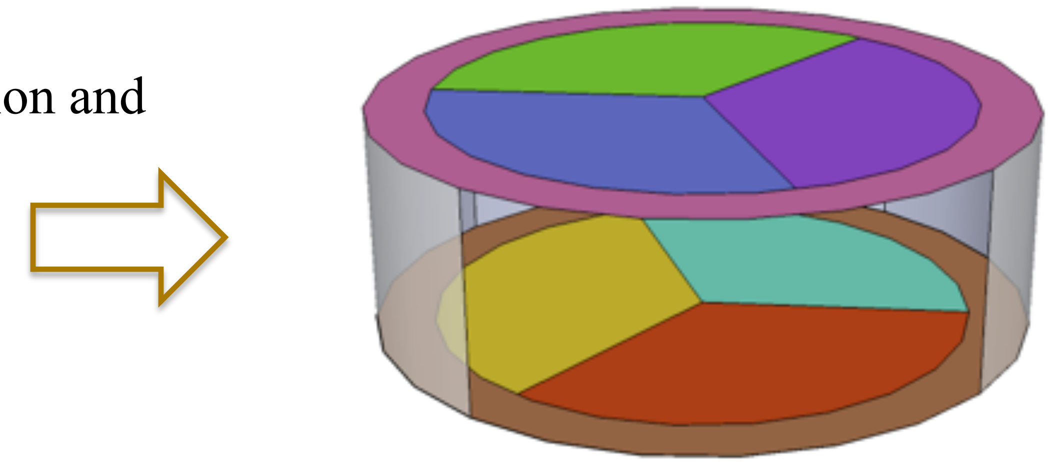
Redesign the detectors!

iZIP Detector

Redesigned detector:

interleaved **Z**-dependent **I**onization and **P**honon detector (**iZIP**):

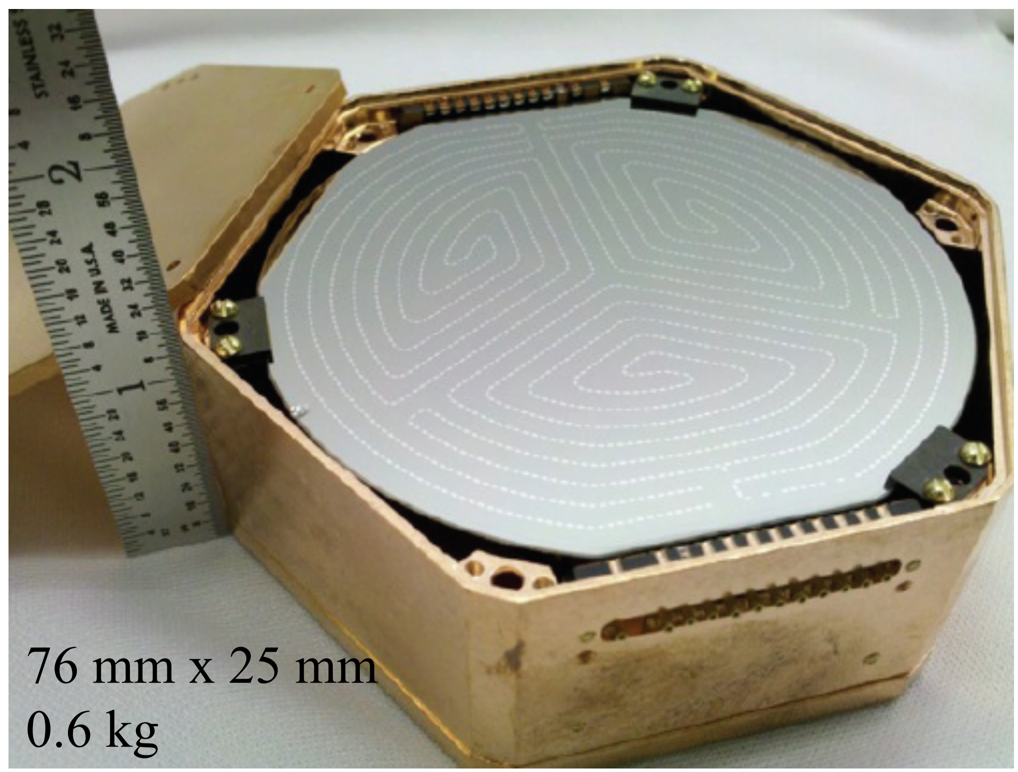
- 4 charge channels
- 8 phonon channels



Appears to meet needs of SuperCDMS @ SNOLAB.

iZIP improvements:

- ✓ Detectors are x2.5 thicker;
- ✓ Optimized phonon sensor layout;
- ✓ Modified phonon mask;
- ✓ Interleaved charge electrodes and phonon sensors on both sides of the detector.



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iZIP Detector

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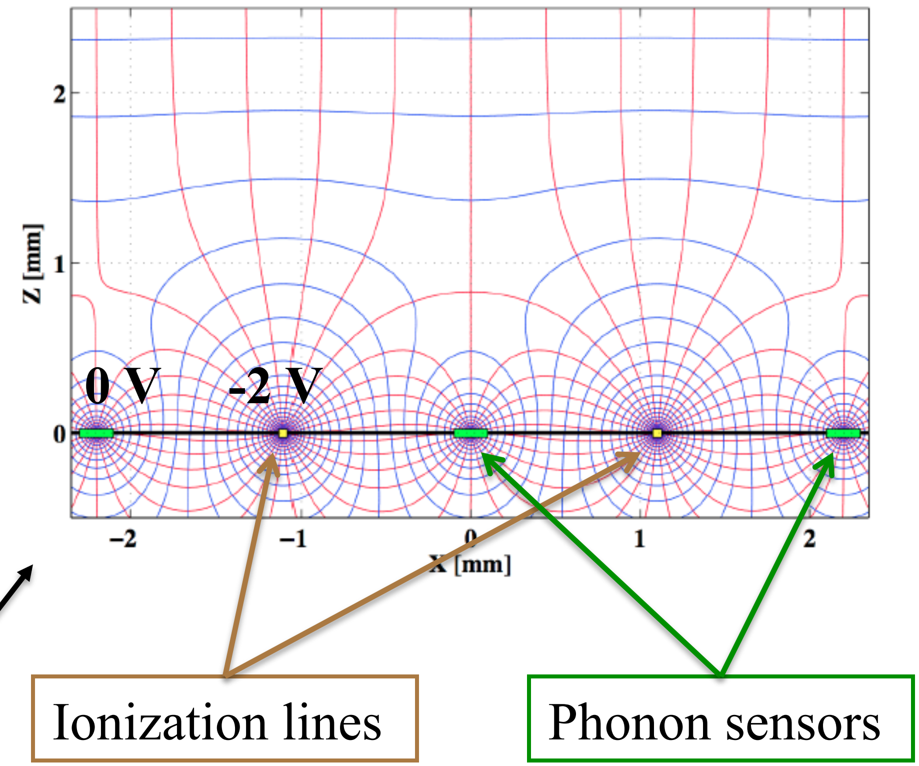
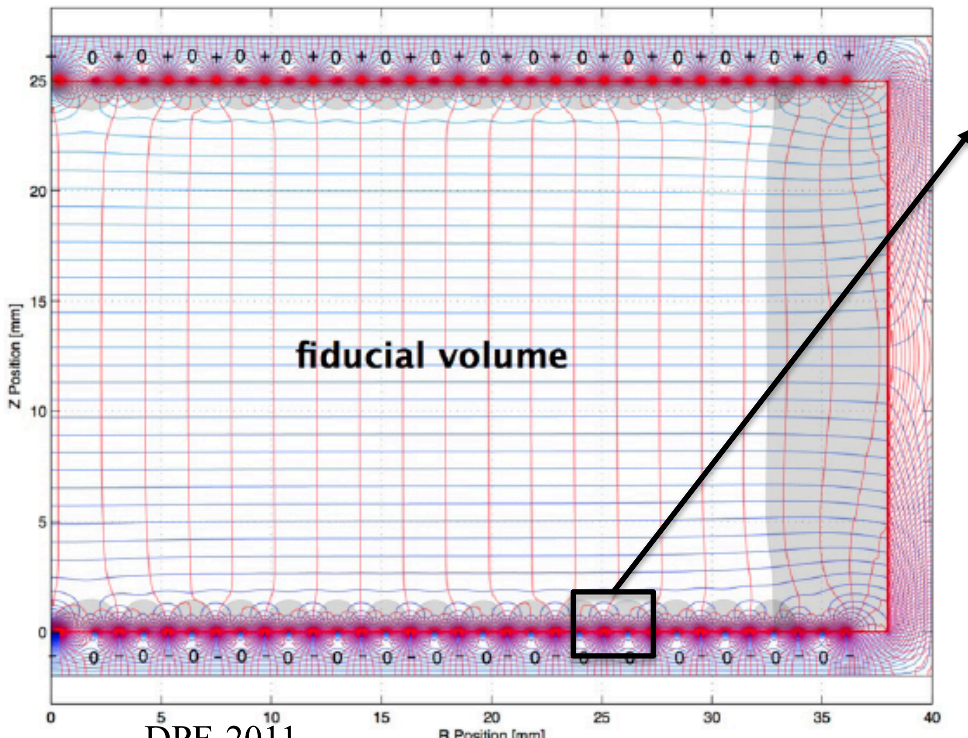
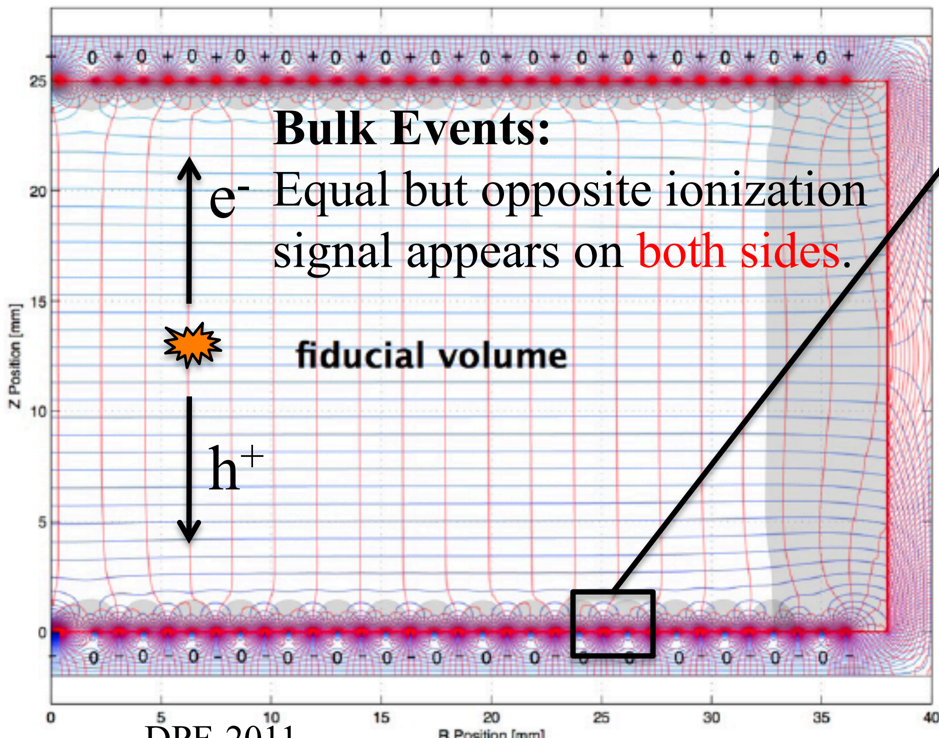


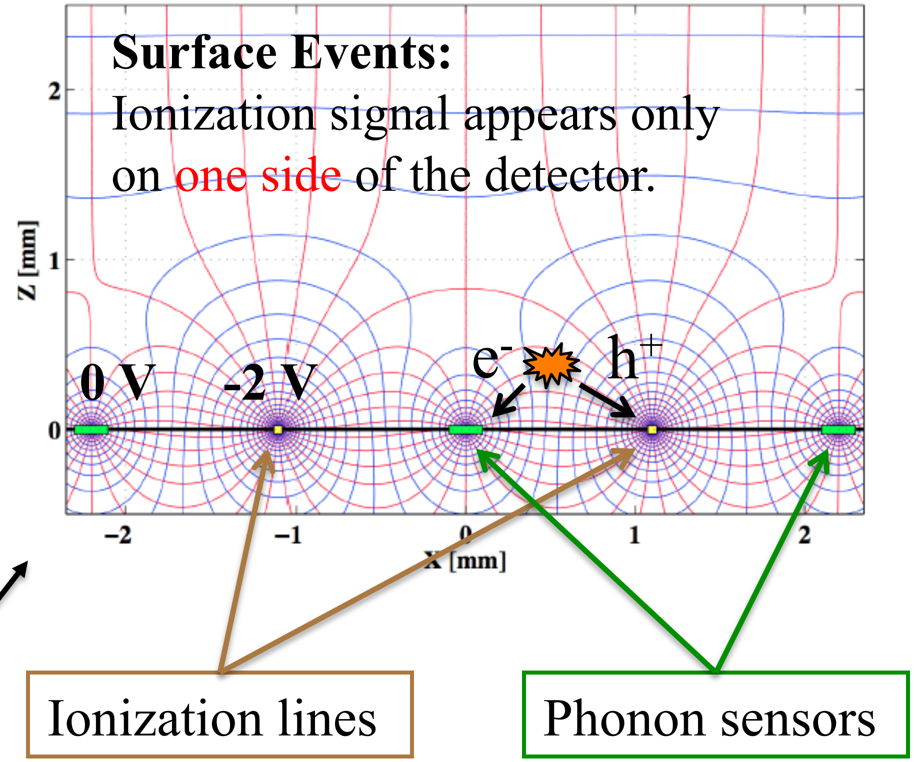


iZIP: Charge Discrimination

✓ Interleaved charge electrodes and phonon sensors on both sides of the detector:

Charge channels can be used to reject surface events.





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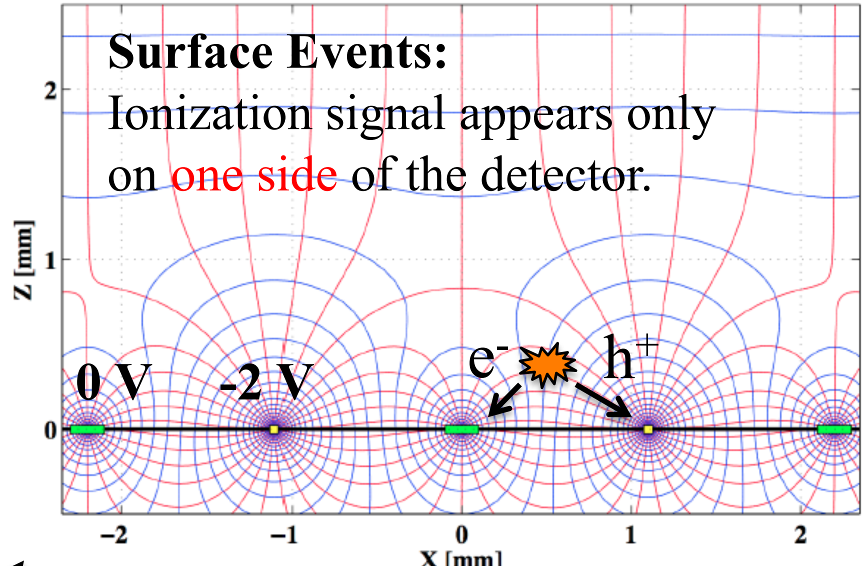
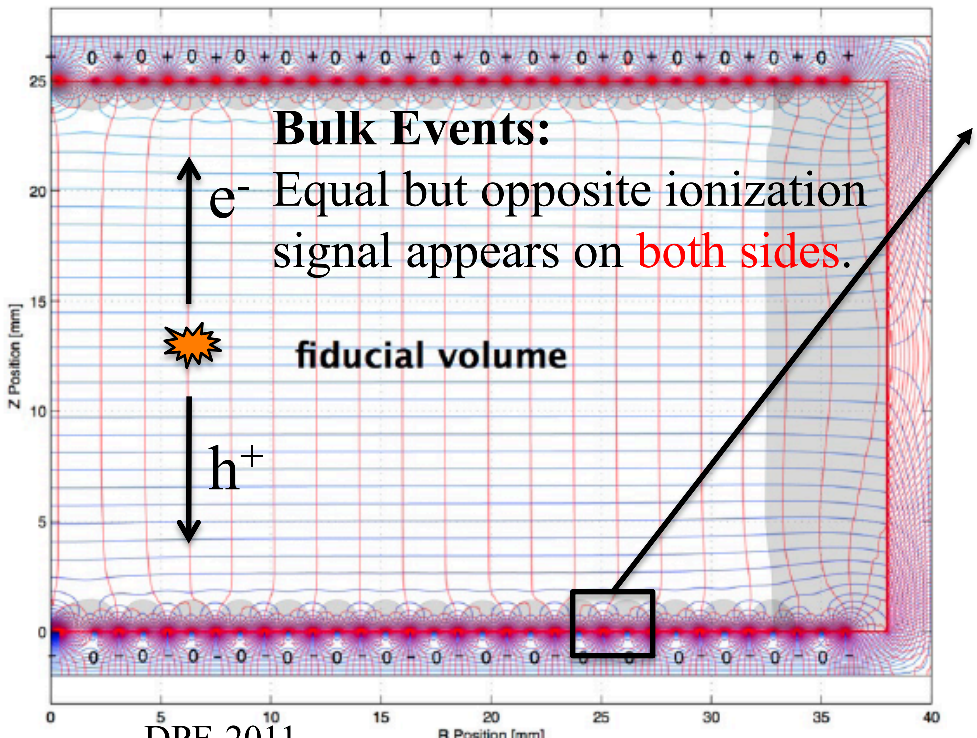
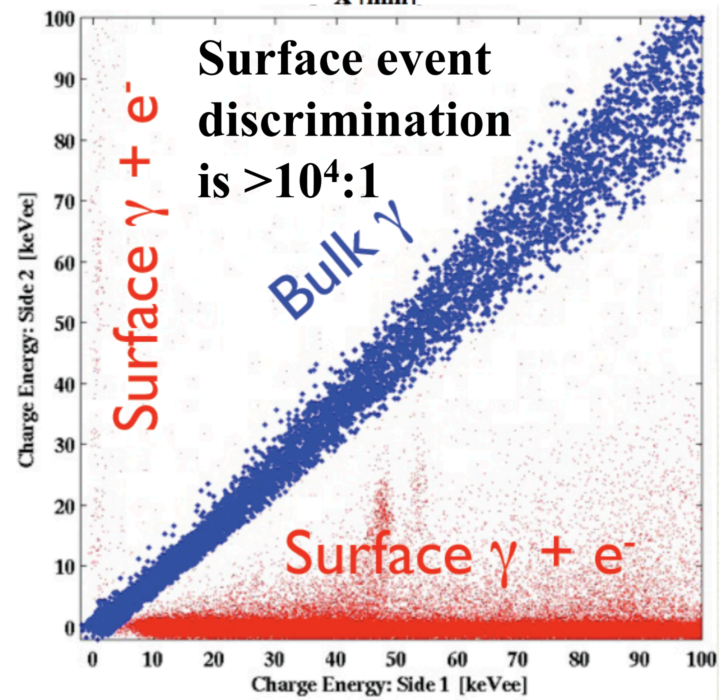
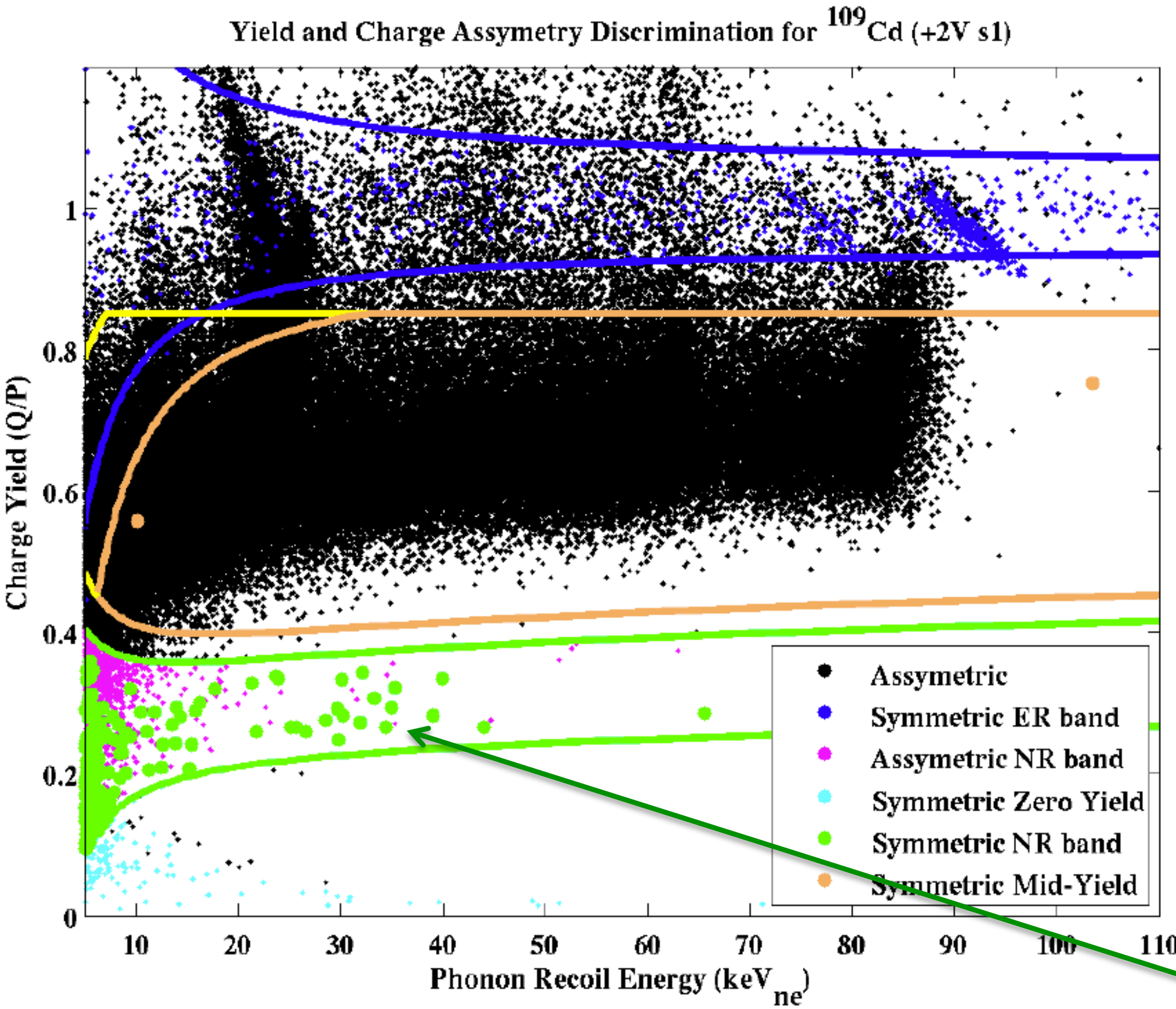






iZIP: Yield Discrimination

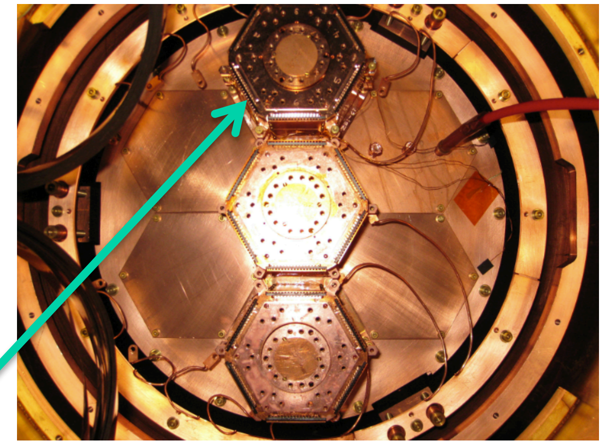


- Yield-only discrimination of surface events in NR band is >10^3:1.
- Discrimination starts to degrade at ~10 keV.
- Measurements of yield and charge asymmetry combined discrimination are limited by neutron background events in NR band.

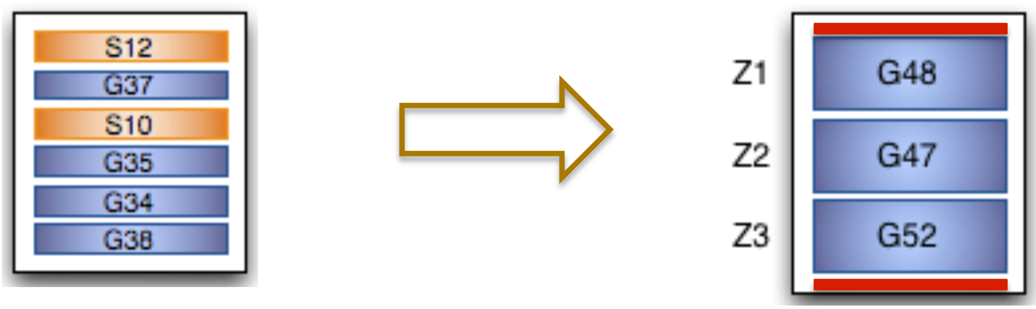
Data taken at Test Facility above ground with NR background of ~7 evt/hr

iZIPs @ Soudan

- iZIP detectors are arranged in SuperTowers
- The first iZIP SuperTower was installed at Soudan in October 2010:



CDMS-II Tower **iZIP SuperTower**



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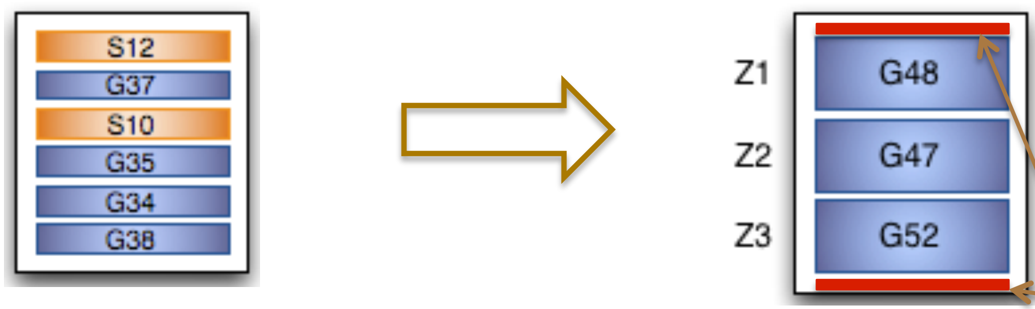
  - engineering run with the goal to perform background assessment
  - run was interrupted due to the fire in mine shaft in March 2011
  - collected data to assess stability of the detectors underground and improve operation of iZIPs in the future runs

CDMS-II Tower **iZIP SuperTower**



wafers with Pb-210 on top and bottom (for engineering run to assess discrimination against surface events)

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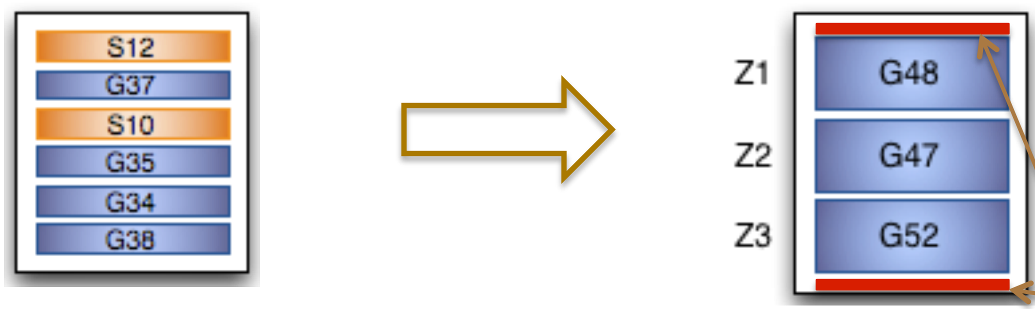
- Approved to deploy a total of 5 iZIP SuperTowers at Soudan.

CDMS-II Tower **iZIP SuperTower**



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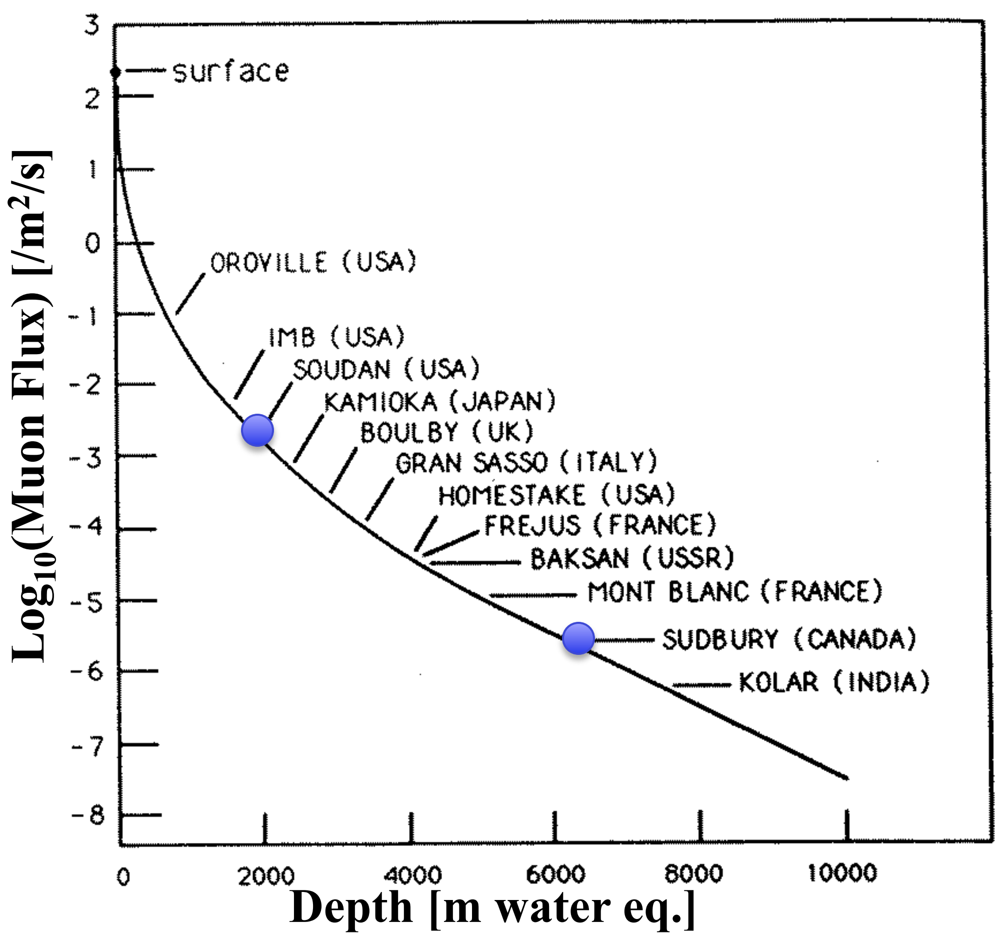
SuperCDMS @ SNOLAB

- SuperCDMS @ Soudan will eventually become background limited due to cosmogenic neutrons;
- to get to ~3×10^{-46} cm^2 (100 kg of Ge phase) need to move to deeper site.



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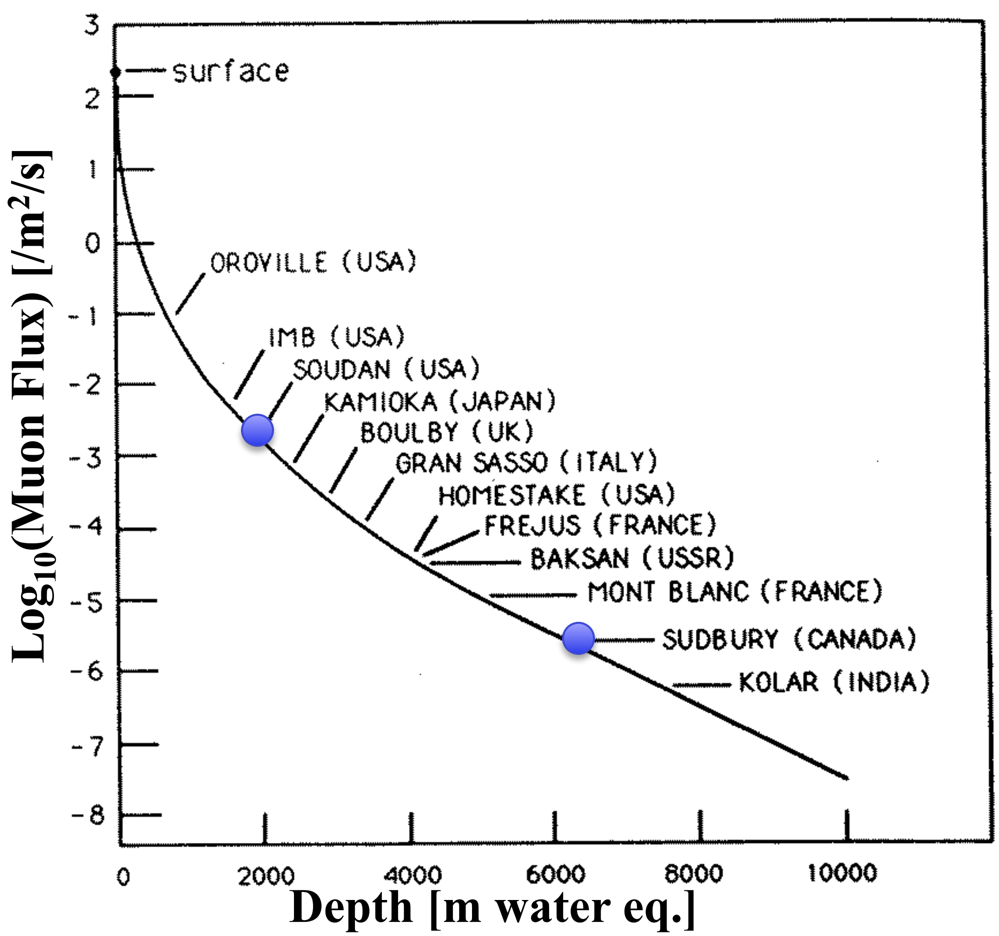
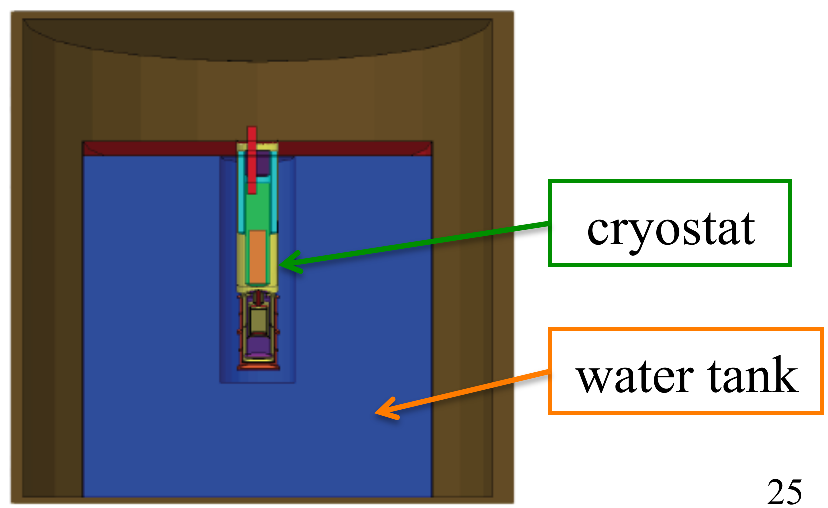


Detector Test Facility @ SNOLAB:

- need a shielded underground TF to characterize detectors w/o the presence of limiting neutron background;
- background achievable @ SNOLAB with 5' of water shielding (MC simulations):
  - <1 Hz of external gammas
  - <1 neutron/day
- short turn-around time between runs.



Summary

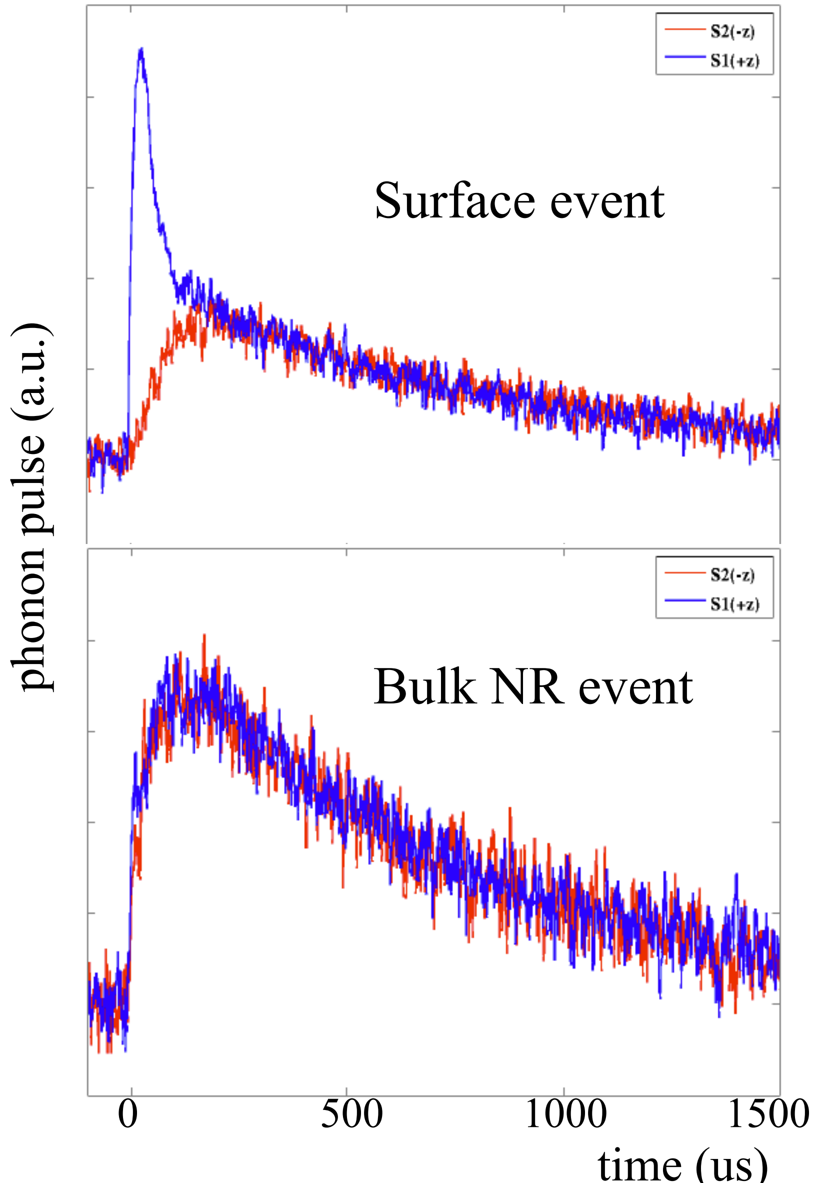
- CDMS-II has completed operation:
  - has set a limit of 3.8×10^{-44} cm^2 @ 70 GeV/c^2 on WIMP-nucleon spin-independent cross-section;
  - observed 2 candidate events in the first analysis of the final data taken between July 07 and Sept. 08;
  - cannot claim nor reject these events as possible WIMPs;
  - CDMS and EDELWEISS collaborations have produced a common analysis of their results that gives improved constraint on WIMPs heavier than 50 GeV/c^2.

- New generation of CDMS advanced detectors, iZIP:
  - meets requirements for SuperCDMS @ Soudan to reach WIMP-nucleon cross-section of 5×10^{-45} cm^2 for 60 GeV/c^2 WIMPs with <1 expected background event;
  - SuperCDMS @ Soudan is expected to install 5 iZIP SuperTowers and resume operations later this year.

- Intend to start running 100 kg at SNOLAB in 2015.

Backup Slides

iZIP: Phonon Pulse Shape Discrimination

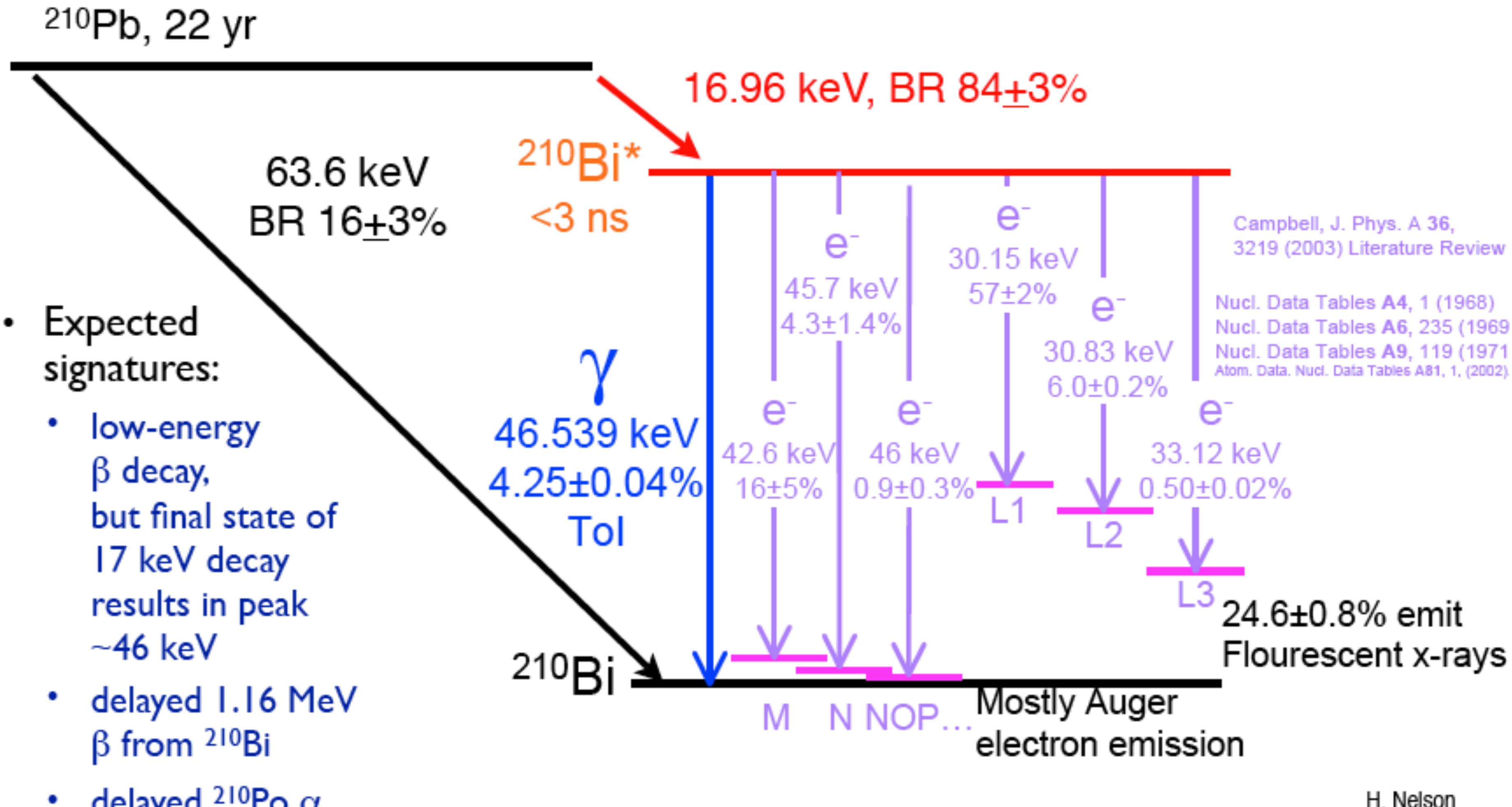


Additional background rejection technique:

- Phonon pulse shape for surface ER events look different than for bulk NR;
- Pulse shape quantities are included into calculated χ^2 function for event;
- Discrimination based on χ^2 difference between surface ER and NR events is 10^4:1 with ~60% NR passage efficiency.

^{210}Pb

- Environmental ^{222}Rn in air can deposit long-lived ^{210}Pb β source on surfaces



- Expected signatures:
  - low-energy β decay, but final state of 17 keV decay results in peak ~46 keV
  - delayed 1.16 MeV β from ^{210}Bi
  - delayed ^{210}Po α