Scalability of the SuperCDMS experiment

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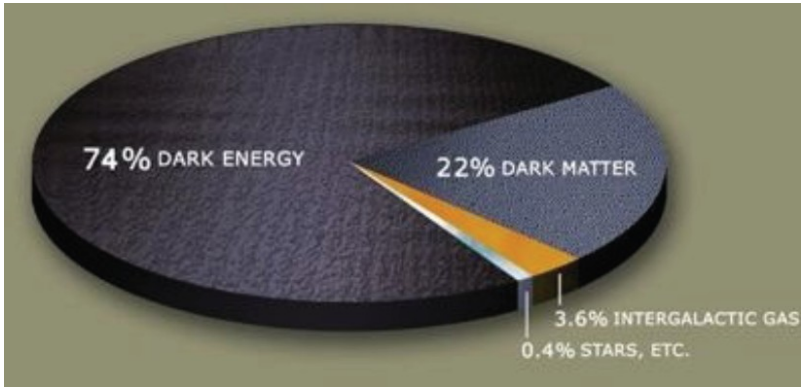
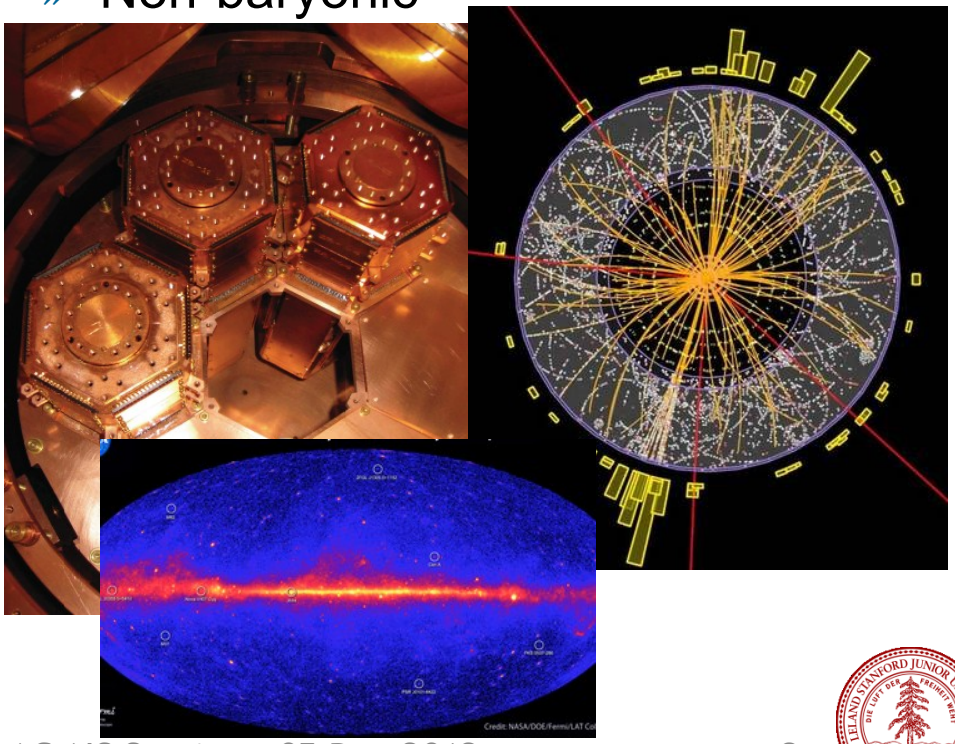
Detecting dark matter

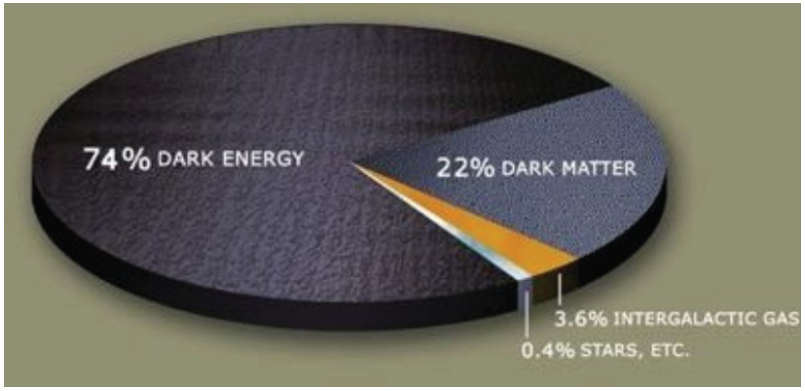


- The majority of the mass energy in the Universe is dark matter
  - » No EM interaction
  - » Gravitational interaction
  - » Non-baryonic



- Three paths for investigation:
  - ➢ Indirect detection
  - ➢ Accelerator production
  - ➢ Direct detection

Detecting dark matter



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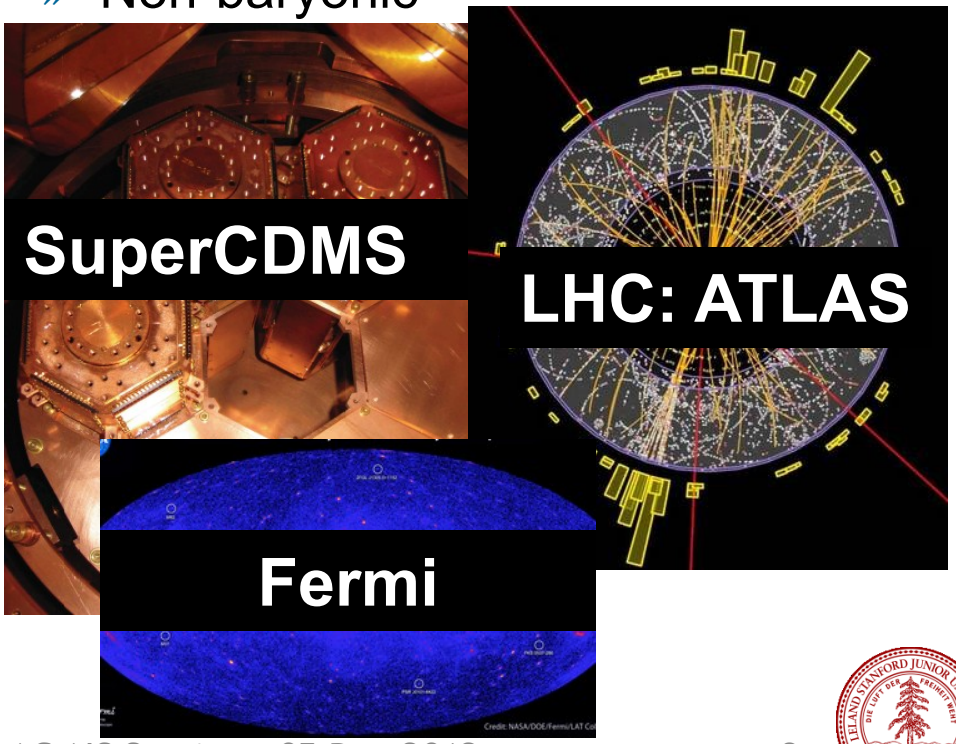


Dark matter candidates

- Theory provides a number of potential candidates spanning a vast parameter space
- Weakly Interacting Massive Particles (WIMPs) seem particularly well motivated

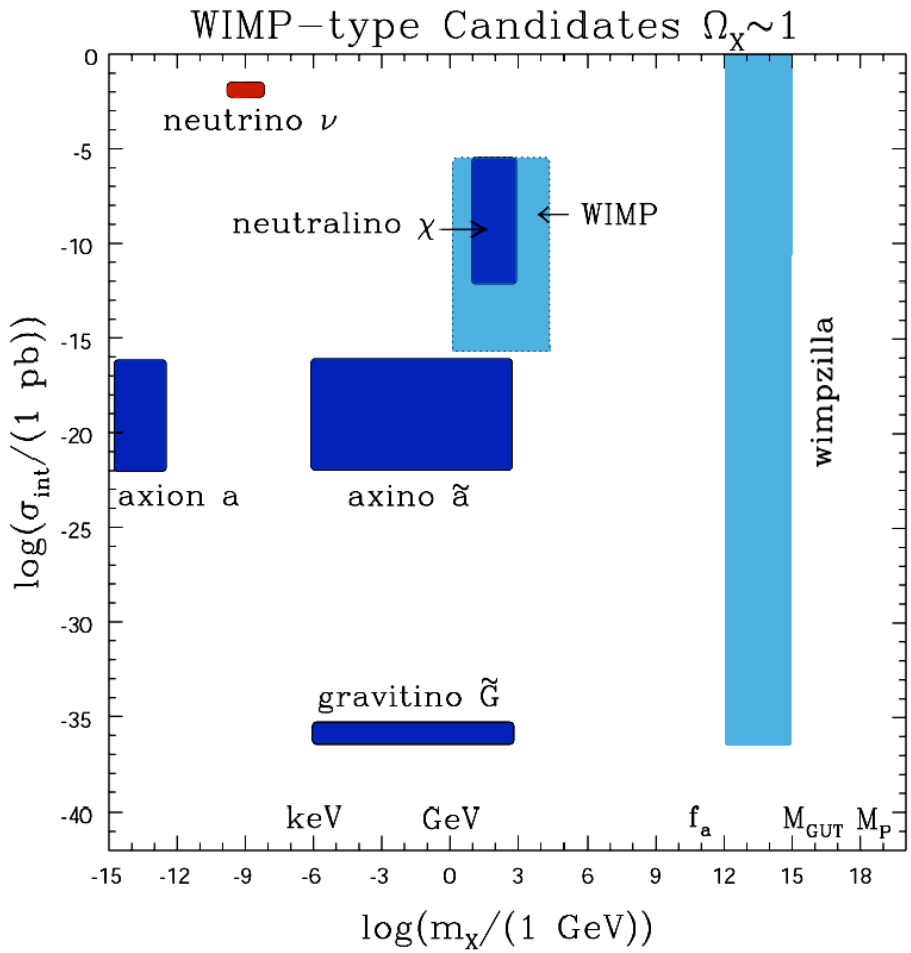
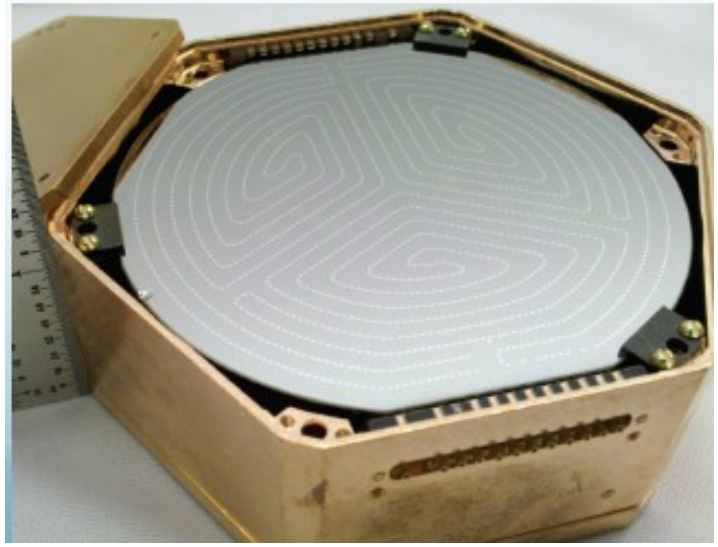


Figure taken from Rozkowski, 2004

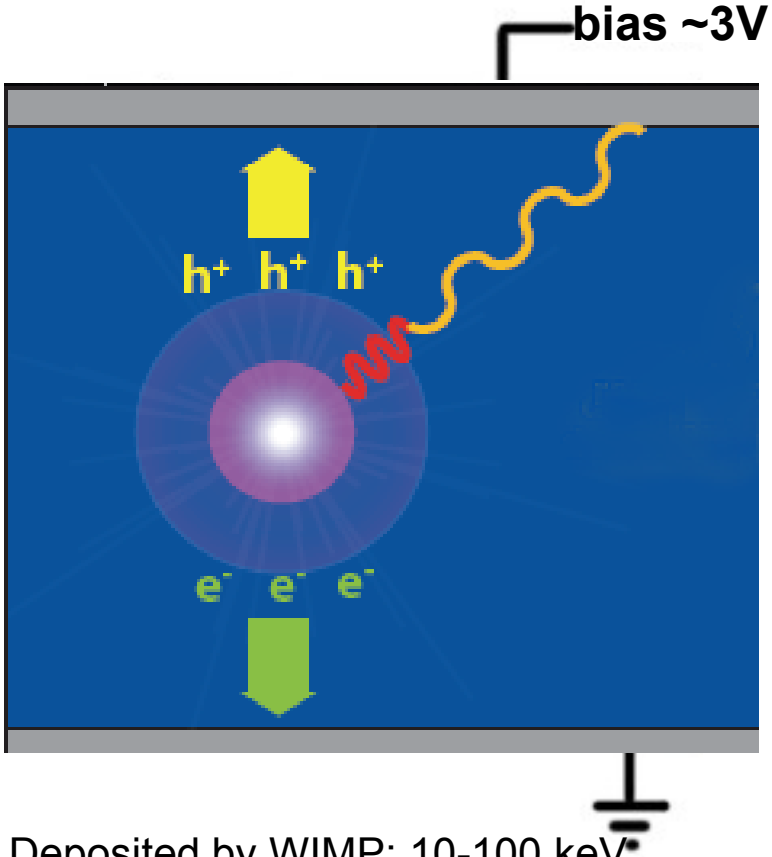
The Cryogenic Dark Matter Search (CDMS)



- The CDMS experiment attempts the direct detection of WIMPs
- WIMPs scatter off target nuclei via the weak interaction
- Target material is high purity Ge
- Current detectors are 3“ x 1“ cylinders

Z-sensitive Ionisation and Phonon detector (ZIP)

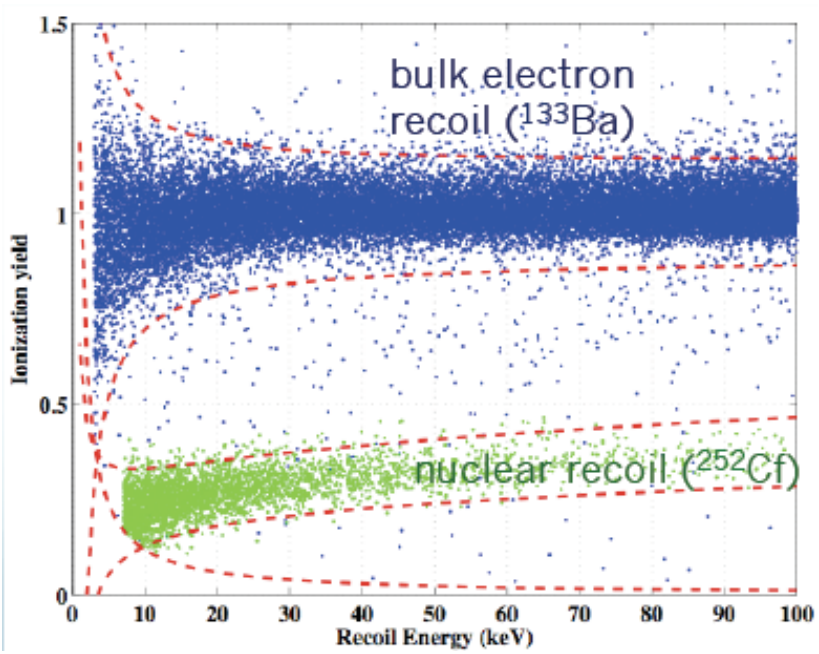
- A particle scattering in a crystal will create both phonons and electron-hole pairs
- Electron-hole pairs are collected by a small drift field
- Phonons are collected by Transition Edge Sensors (TESs)

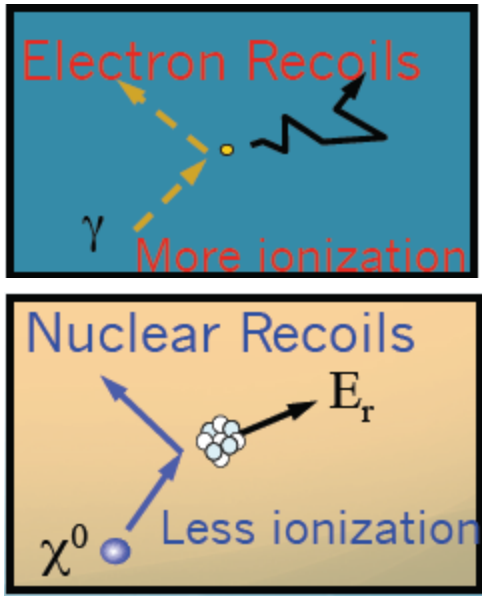


Deposited by WIMP: 10-100 keV
e-/hole pair: 3 eV to create
Individual phonon: ~80 meV to create

Background rejection

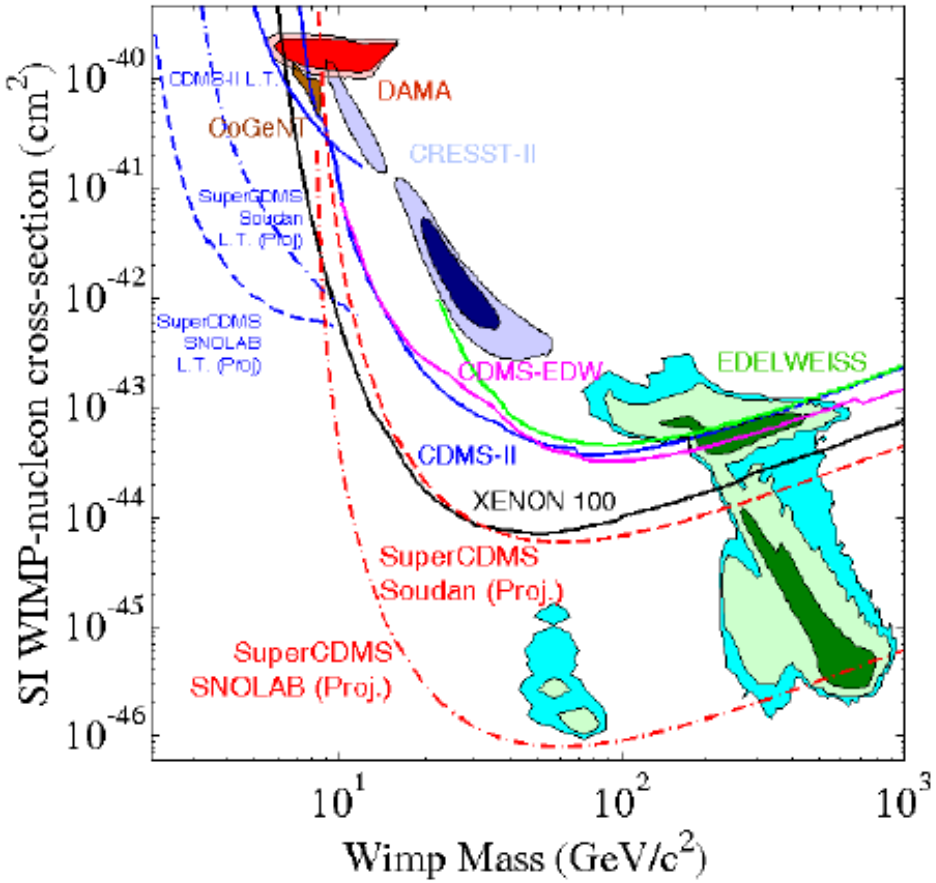
- The ratio of charge energy to phonon energy is the ionization yield
- Electron recoils and nuclear recoils have different yields
- Yield discrimination allows great background rejection





Current and projected limits

- SuperCDMS Soudan will match current XENON 100 limit
- SuperCDMS Lite will produce world leading low-mass limits
- SuperCDMS SNOLAB to improve limit by two orders of magnitude



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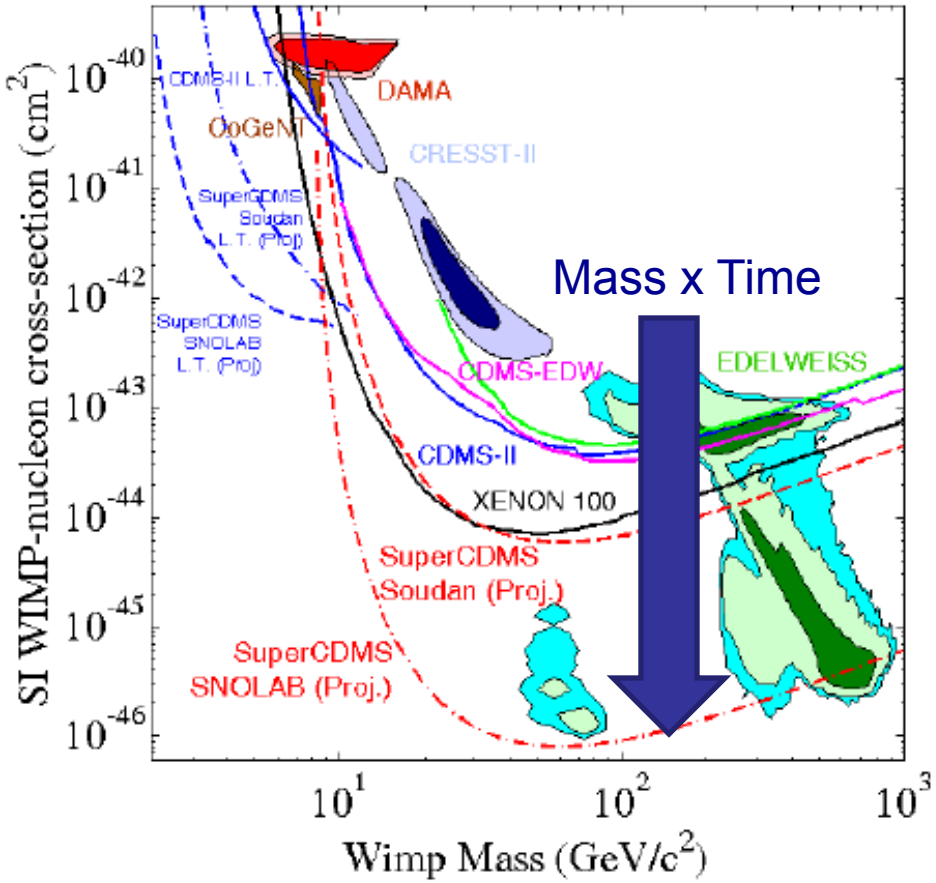
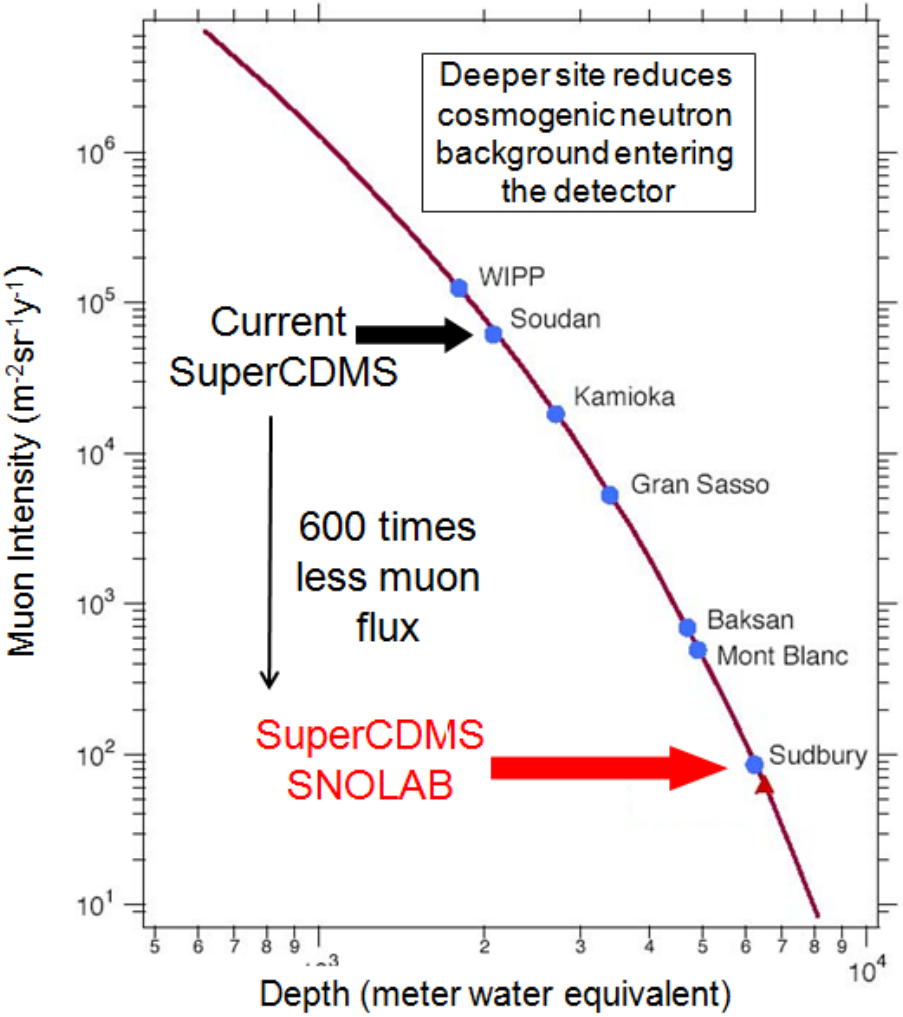


Underground sites



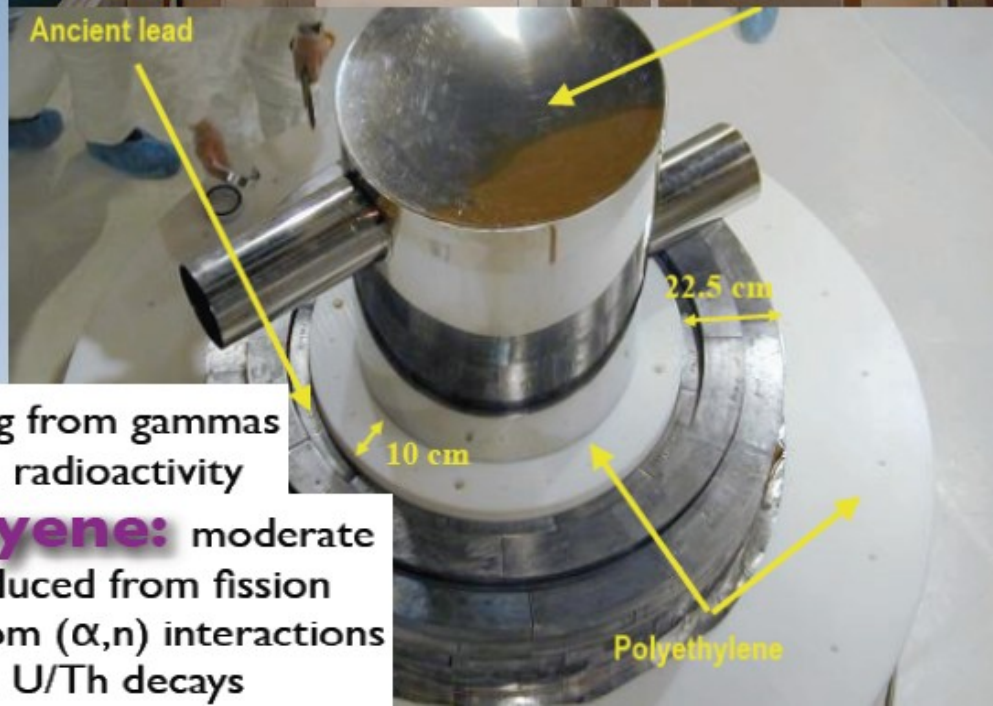
- SuperCDMS Soudan
  - Detector mass: 15 kg
  - 2090 mwe (~0.7 km)
  - 50 n/y/t
- SuperCDMS SNOLAB
  - Detector mass: 200 kg
  - 6060 mwe (~2.0 km)
  - 0.2 n/y/t

2100 mwe underground

Passive Shielding

Active Muon Veto:

rejects events from cosmic rays



Pb: shielding from gammas resulting from radioactivity

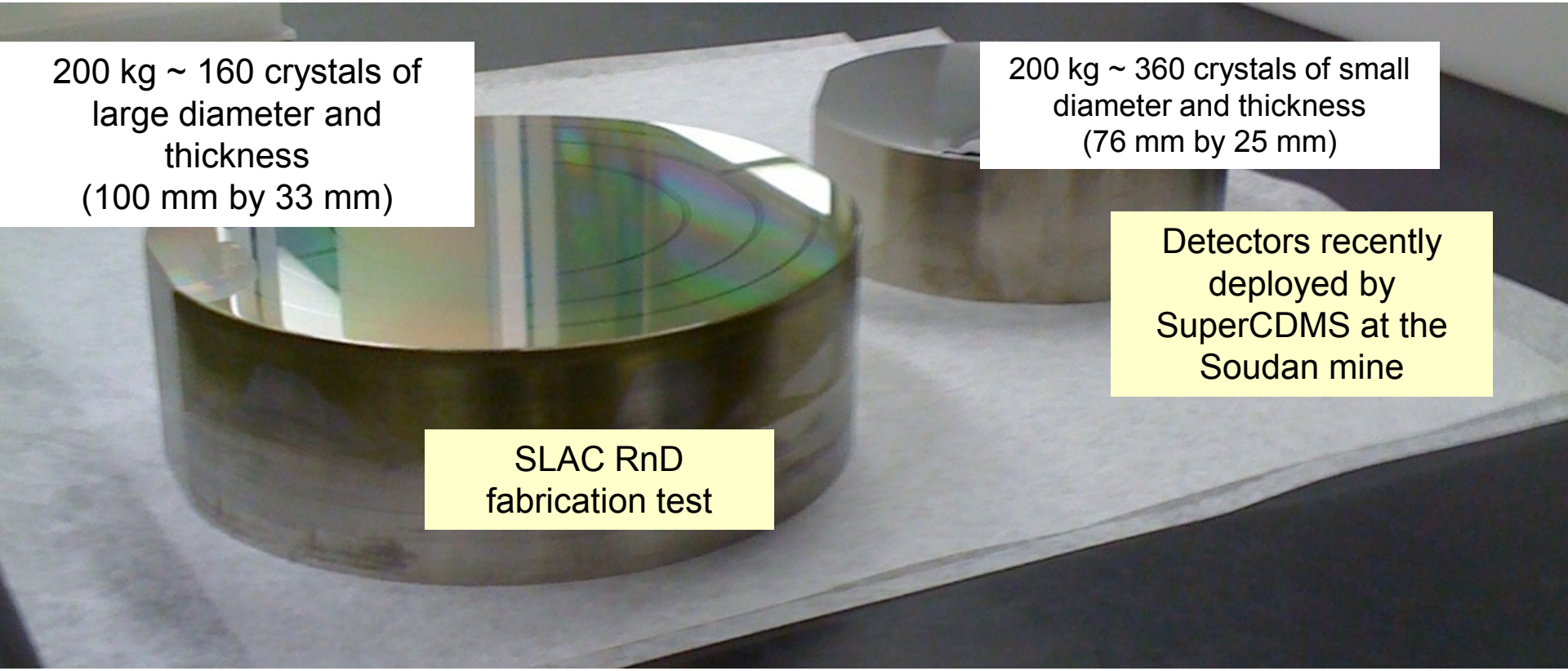
Polyethyene: moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays

Scaling up for SuperCDMS SNOLAB

- In order to reach the SNOLAB target mass of 200 kg:
  - » Demonstrate manufacturing capability (at sufficient rate)
  - » Design, fabricate and test larger detector
  - » Demonstrate good understanding of detector response
    - Estimate backgrounds
    - Estimate fiducial volume fraction
      - Can be achieved by robust detector Monte Carlo Simulation

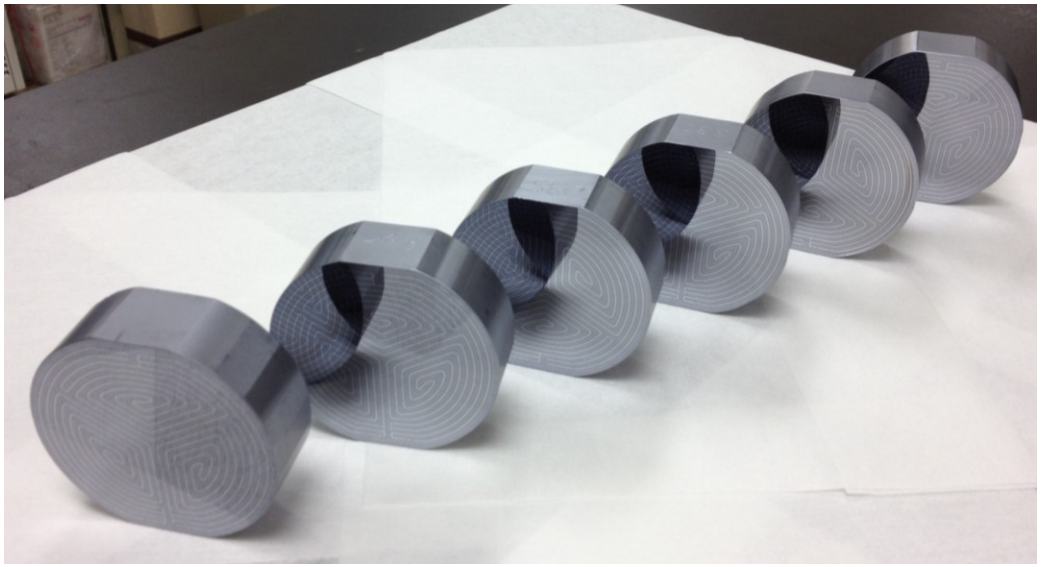
Scalability of Ge detectors

- Production time scales with number of detectors, not mass
- Qualify larger crystals and demonstrate production rate



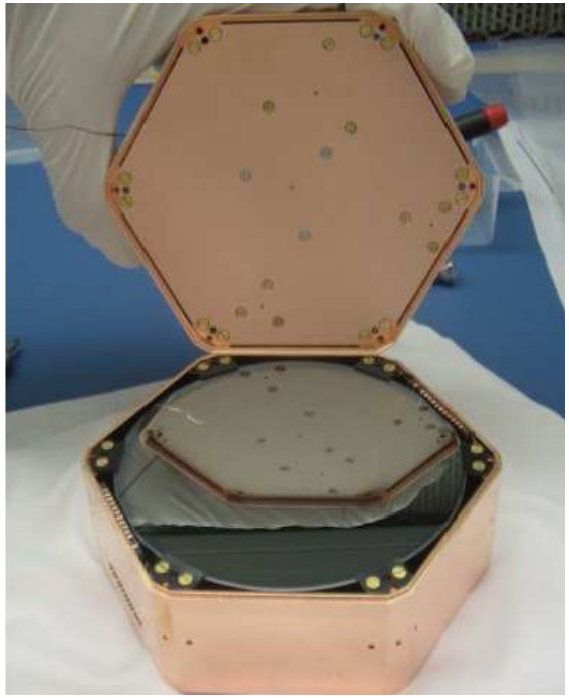
Detector fabrication throughput test

- 200kg-scale experiment requires production rate of 6 per month
  - » Successfully demonstrated required fabrication rate with SLAC/ Stanford personnel using 3x1 inch Si crystals.
  - » Followed existing Ge ZIP recipe used for SuperCDMS Soudan.

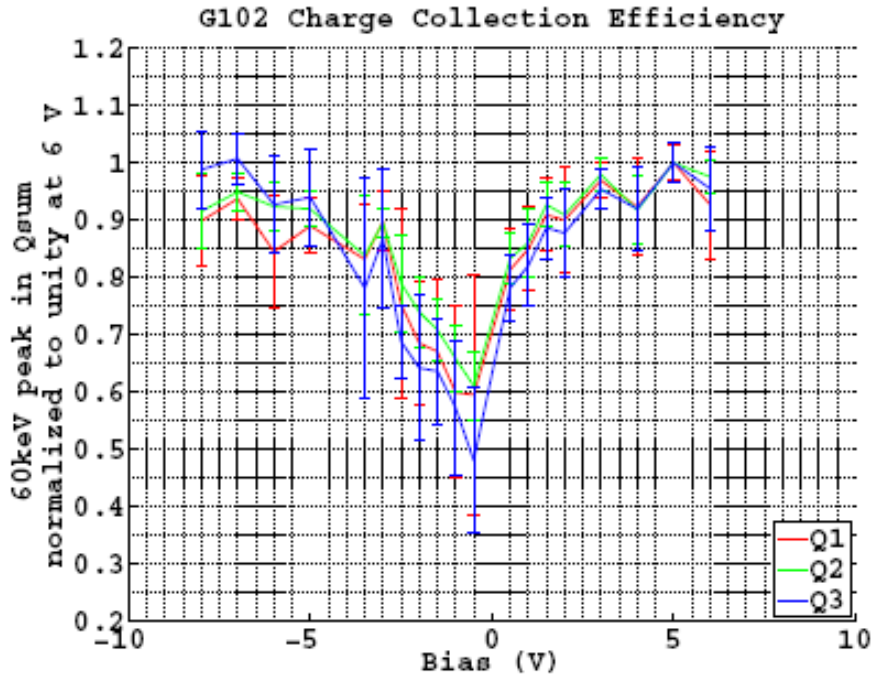


Qualifying a 100mm crystal

- Need to demonstrate charge transport properties of crystal
  - » Vary bias and determine change in position of 60 keV peak
  - » Is full charge collection achieved before break down?

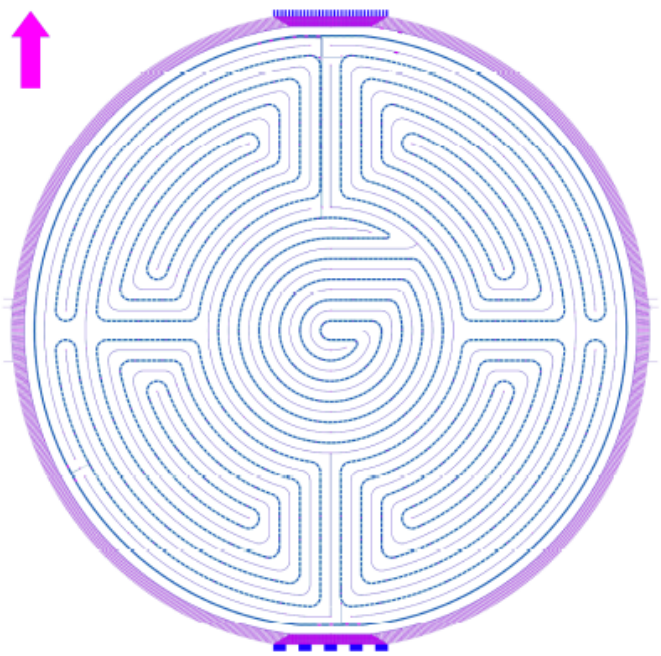


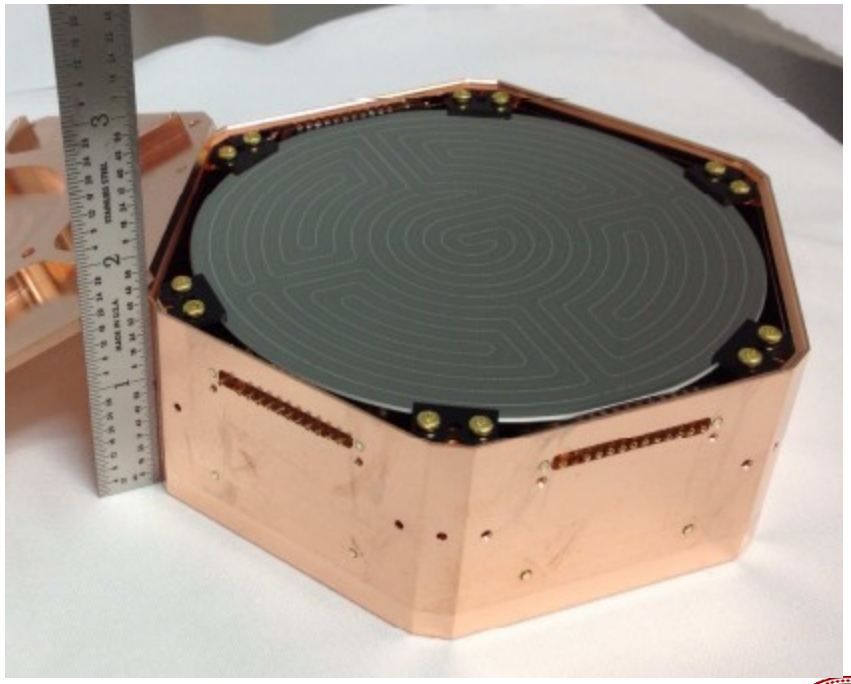
100 mm $\phi \times$ 33.3 mm thick crystal
from H. Chagani et al., J. Low Temp. Phys. 167 (2012) 1125



The first 100mm diameter detector

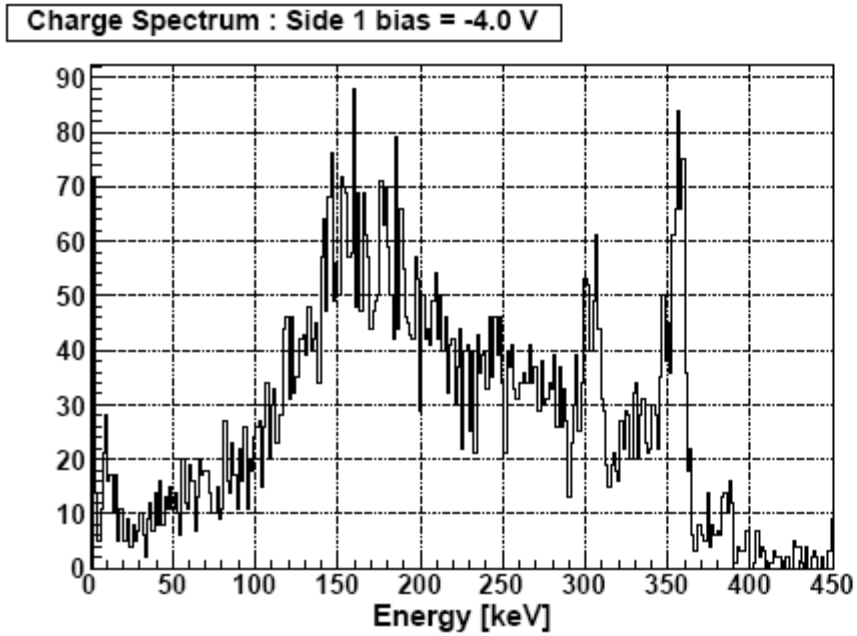
- Sputtering mask of the first 100mm detector (left) and fully fabricated detector in housing (right)
- Interleaved with phonon collection channels are 2 charge collection electrodes per detector face

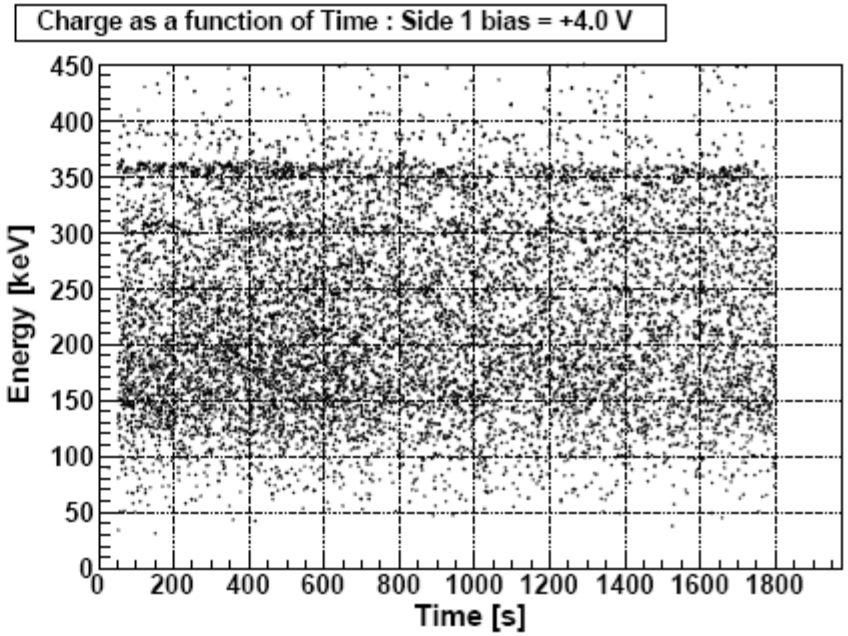




Preliminary: data from first 100mm iZIP

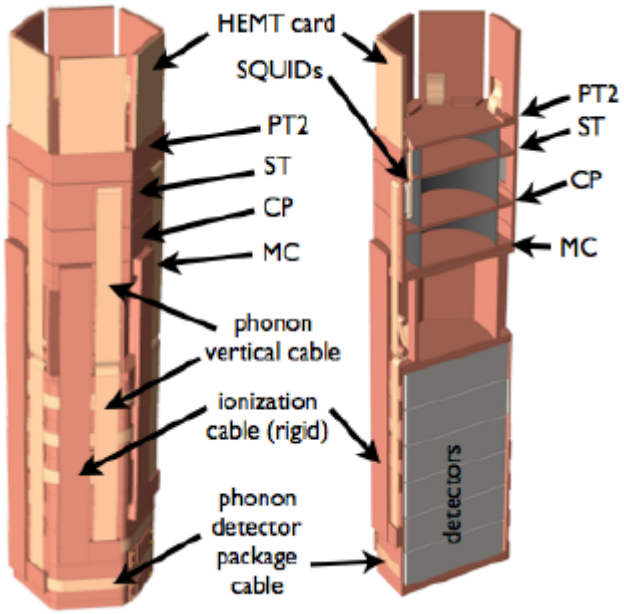
- First 100mm iZIP tested at UMN in early 2012
- Can observe Ba calibration lines
- Good charge collection stability over time despite low field in the bulk

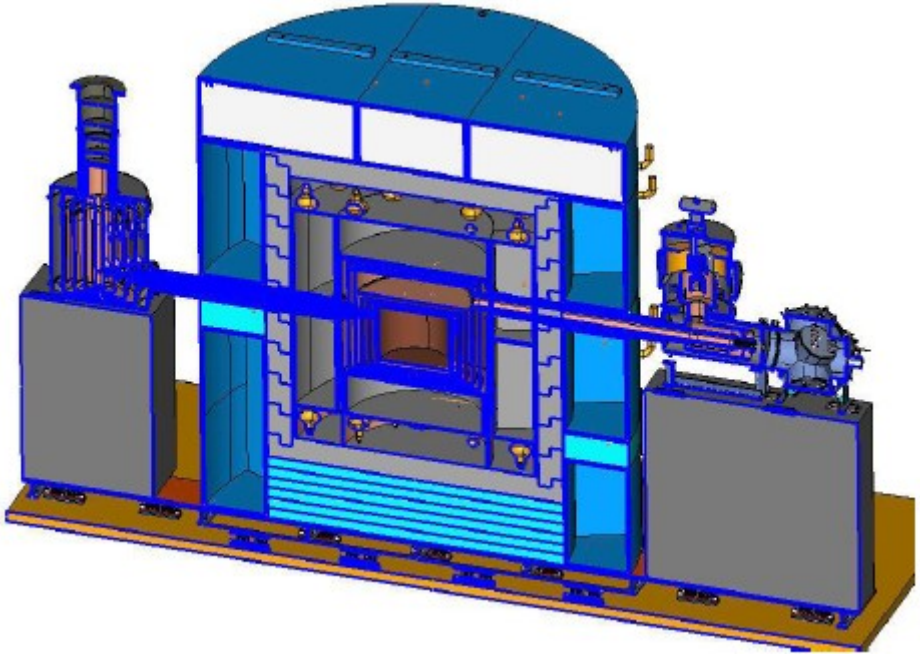




Experiment & cryostat

- Detector towers will be accomodated inside
- Need to cool hundreds of kg to tens of mK
- Requires improvements compared to SuperCDMS Soudan
  - » Use HEMT instead of JFET for charge read-out to control heat load

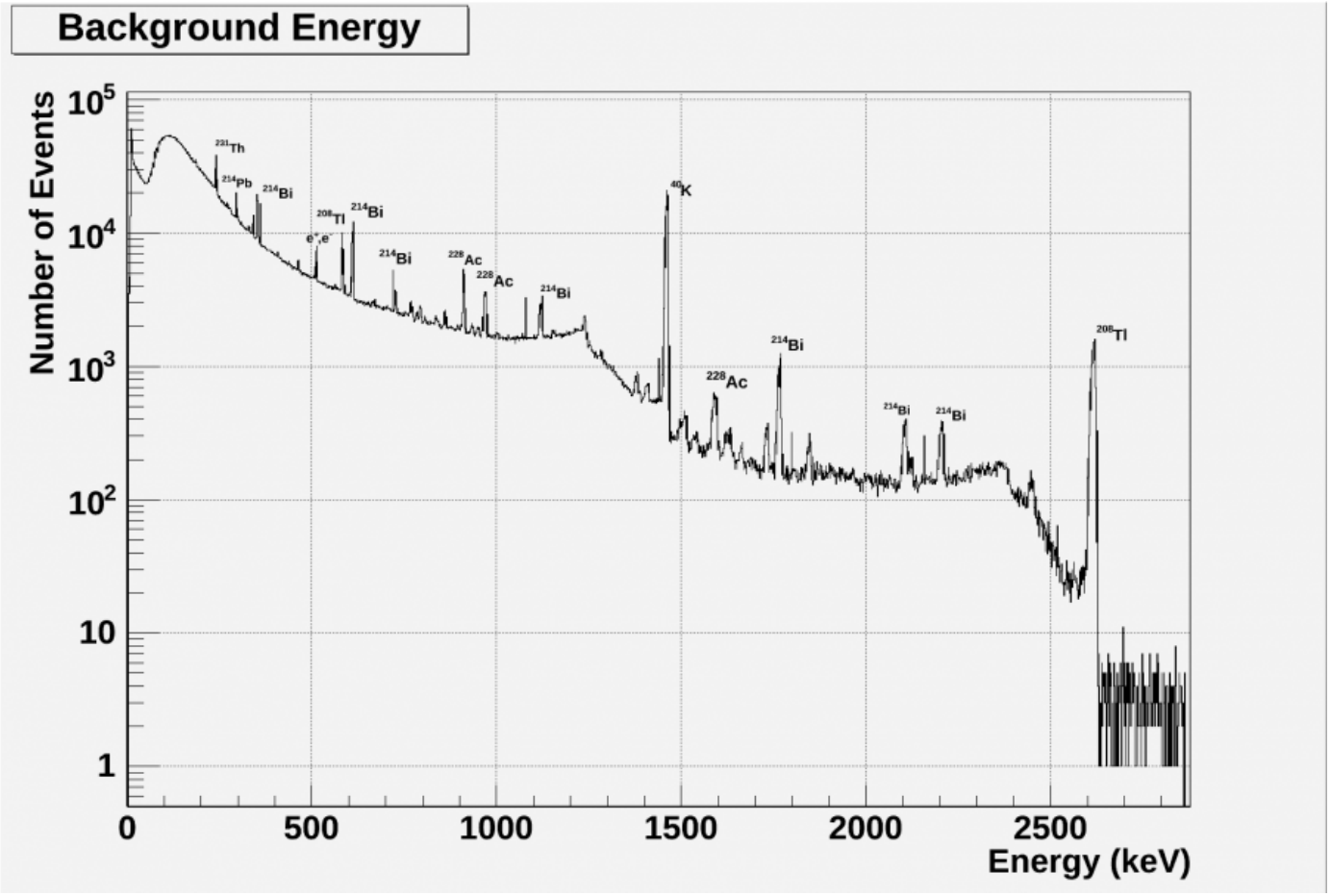




The need for a Detector Monte Carlo simulation

- To support SuperCDMS SNOLAB, a robust Monte Carlo simulation of the experiment is required
  - » Estimate backgrounds
  - » Estimate fiducial volume fraction
  - » Can be achieved by robust detector Monte Carlo simulation

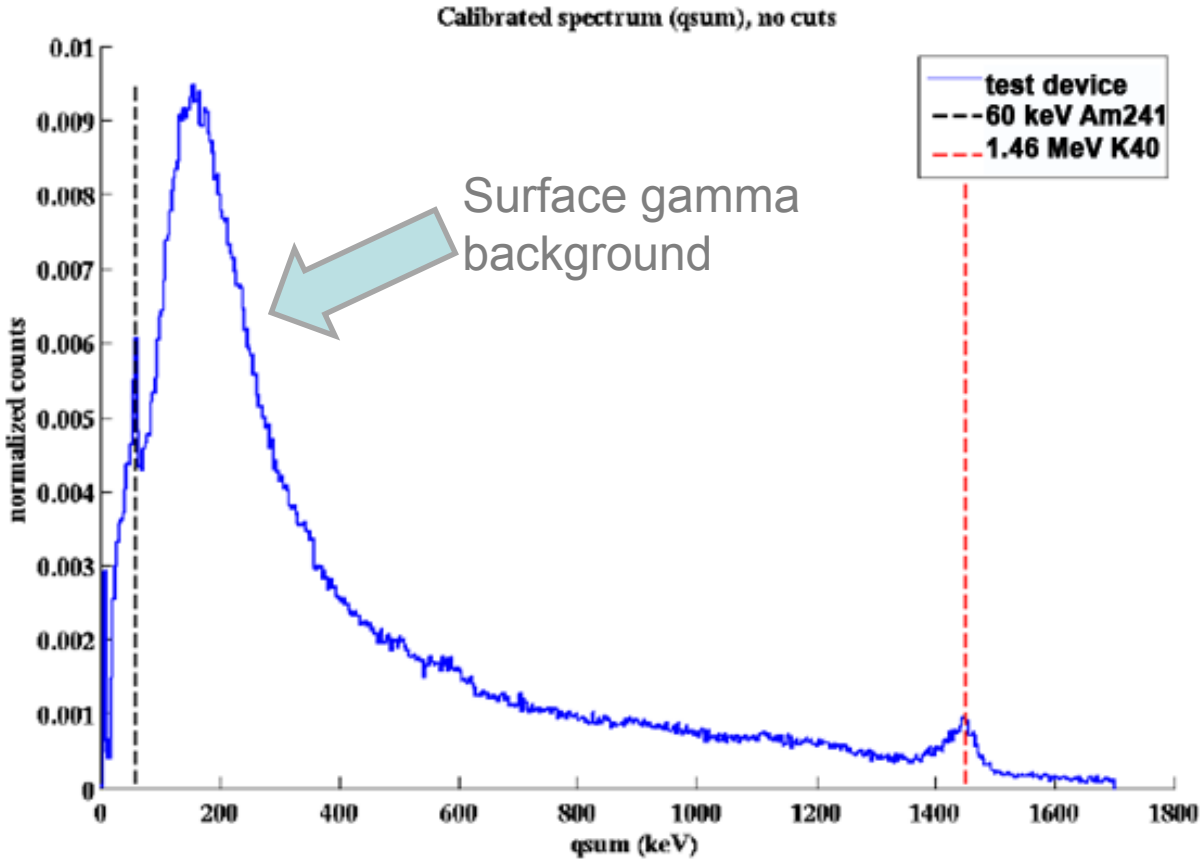
Surface test facility gamma background



Lab gamma background, after 18h integration. Spectrum recorded at UMN surface test facility by A. Kennedy.

Test device spectrum

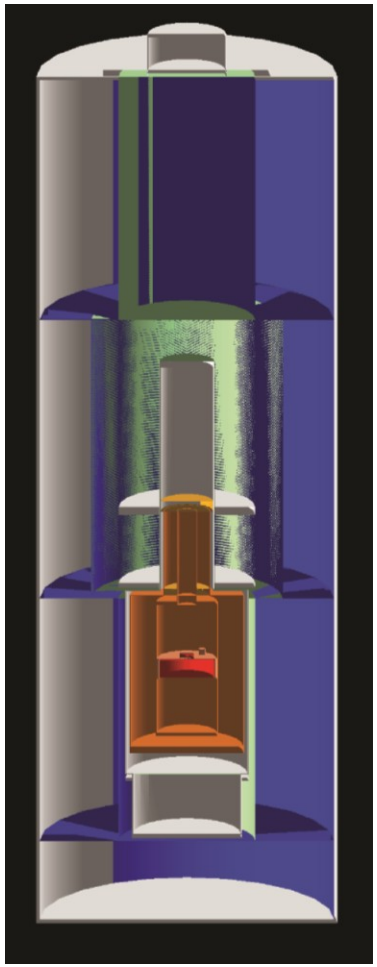
- Recorded spectrum using test device
- 60 keV Am241 test source was used
- Both the 60 keV Am 241 peak and a 1.46 MeV K40 peak are clearly visible



Above: *Charge spectrum recorded under -8V bias (blue) with 60 keV (black-dashed) and 1.46 MeV (red-dashed) features indicated*

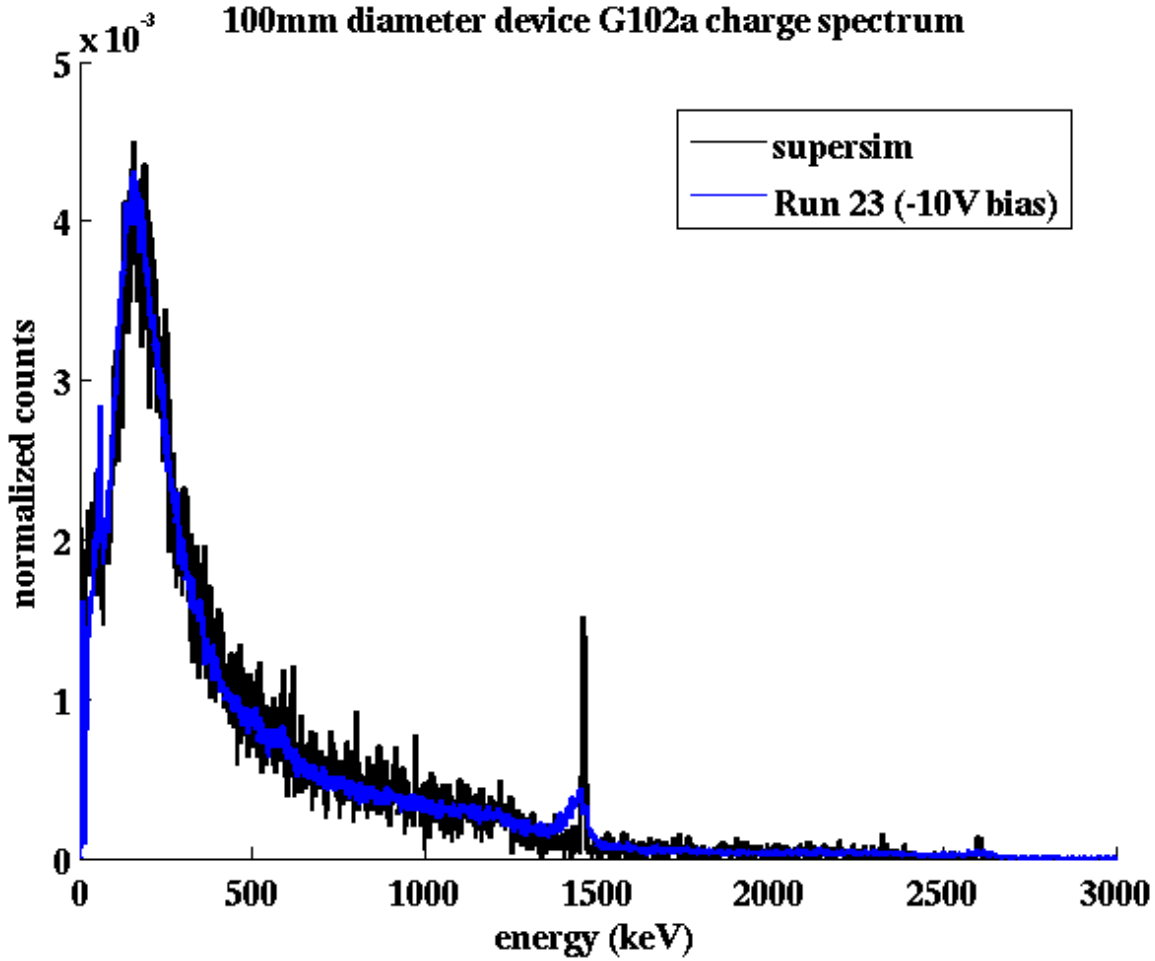
Geant4 Monte Carlo simulation

- Cryostat provides some shielding from lab background
- Background simulation implemented using the Geant4 C++ toolkit
- Simulation captures all major lab background sources
- ***Right:*** *Cryostat geometry at UMN surface test facility*



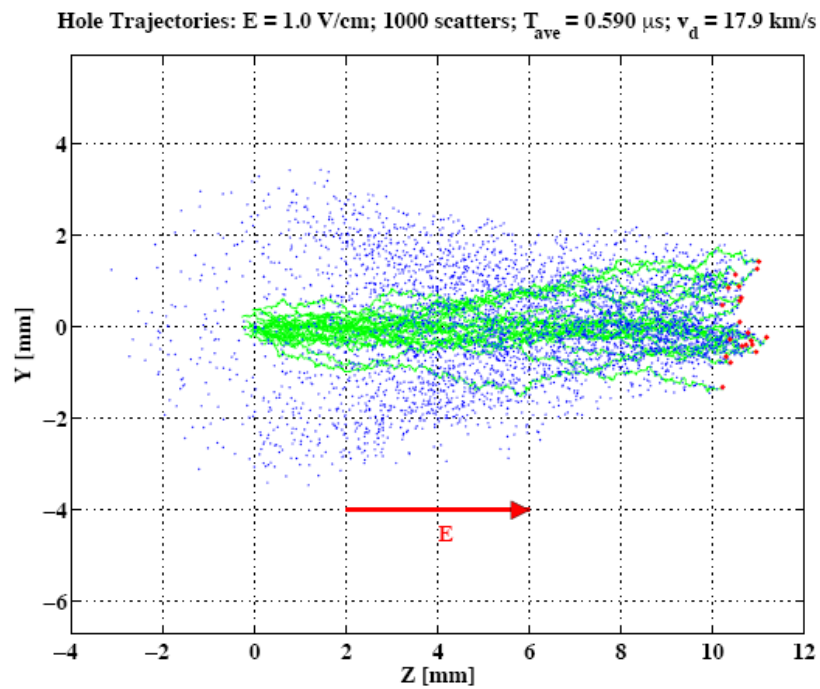
Monte Carlo simulation of surface gamma spectrum

- Simulated and observed background spectrum are in good agreement (right)
- In order to capture broadening of K40 line, need detector simulation



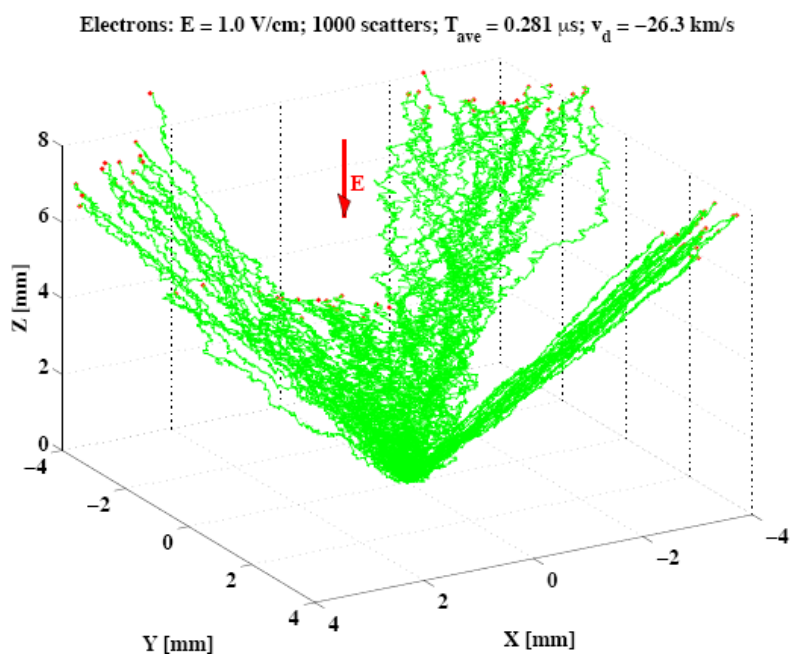
Detector Monte Carlo simulation - I

- Capture all event physics:
  - » e- / h+ propagation
    - Carrier scattering
    - Oblique propagation
    - Impurity trapping
    - Surface trapping
  - » Phonon
    - Focusing
    - Down conversion
    - Emission by carriers



Above: *Accelerated h+ (green trajectories) scattering and emitting phonons (blue). Image from Cabrera et al., 2010*

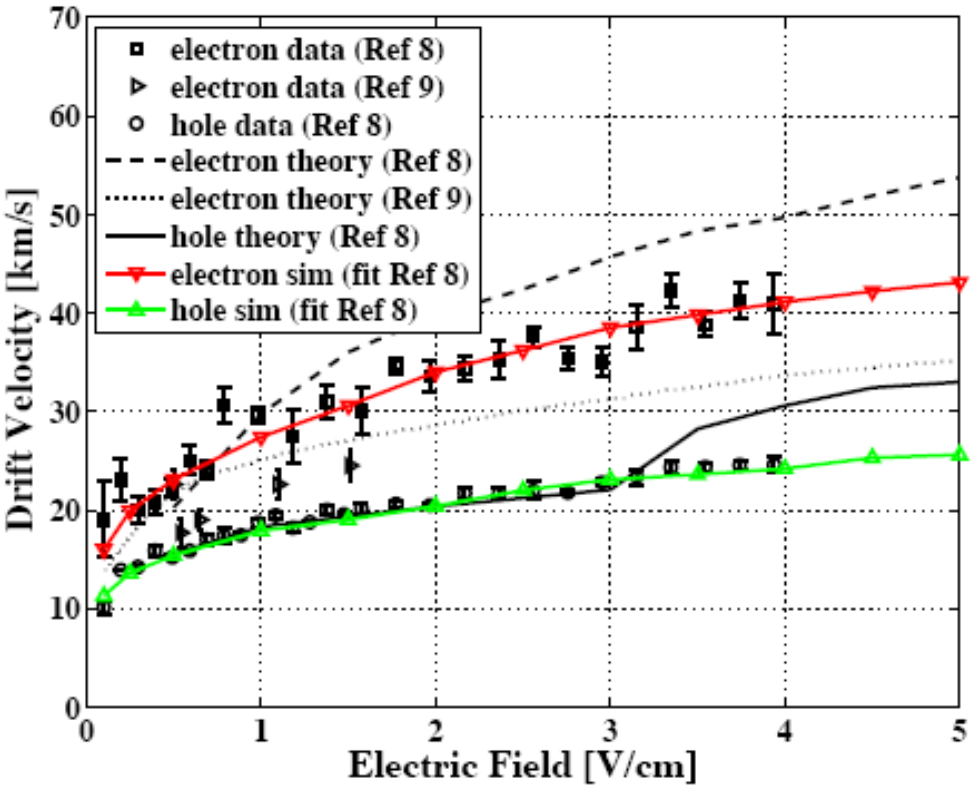
Detector Monte Carlo simulation - II



Above: *e- (green) propagating in different conduction band minima. Image from Cabrera et al., 2010*

- Conduction band is the energy vs. momentum relationship for e-
- The Ge conduction band is anisotropic at minimum
- Consequently e- mass appears anisotropic

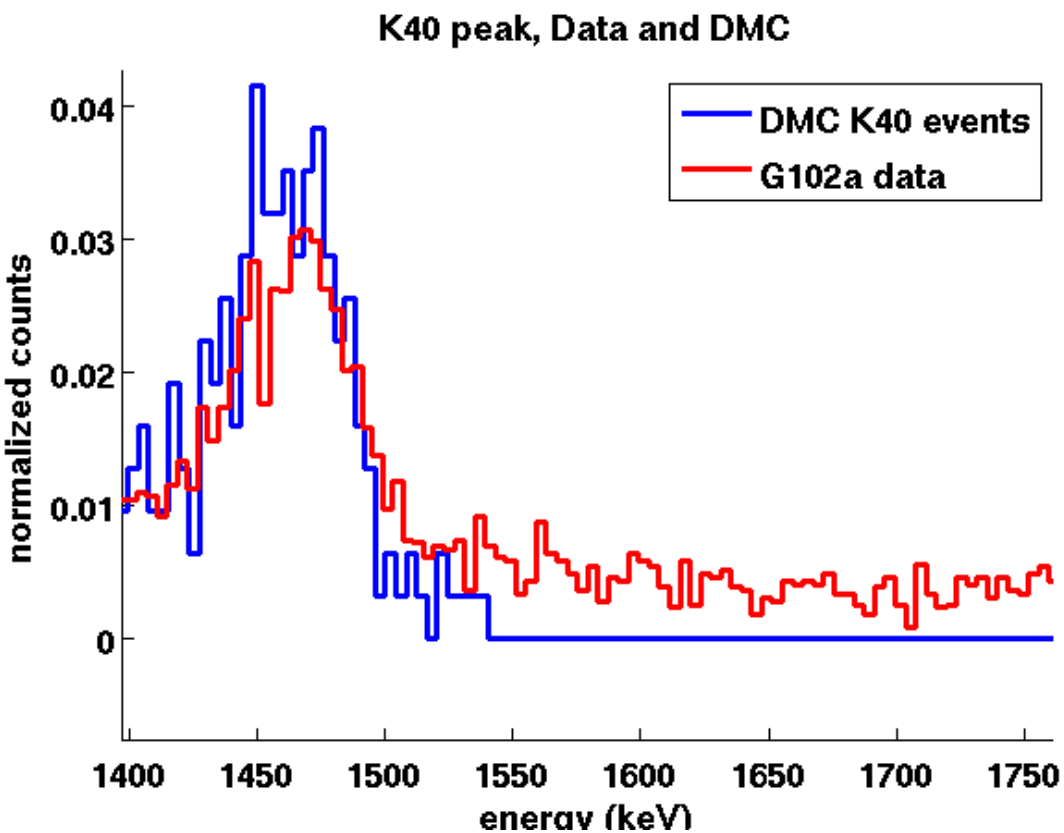
Validating carrier propagation model



Cabrera et. al, arxiv:1004.1233v1

- Figure shows simulated e- drift velocity (red) and h+ drift velocity (green) as a function of drift field
- Drift velocities are in good agreement with experimental data
- This agreement indicates accurate oblique propagation and phonon emission models

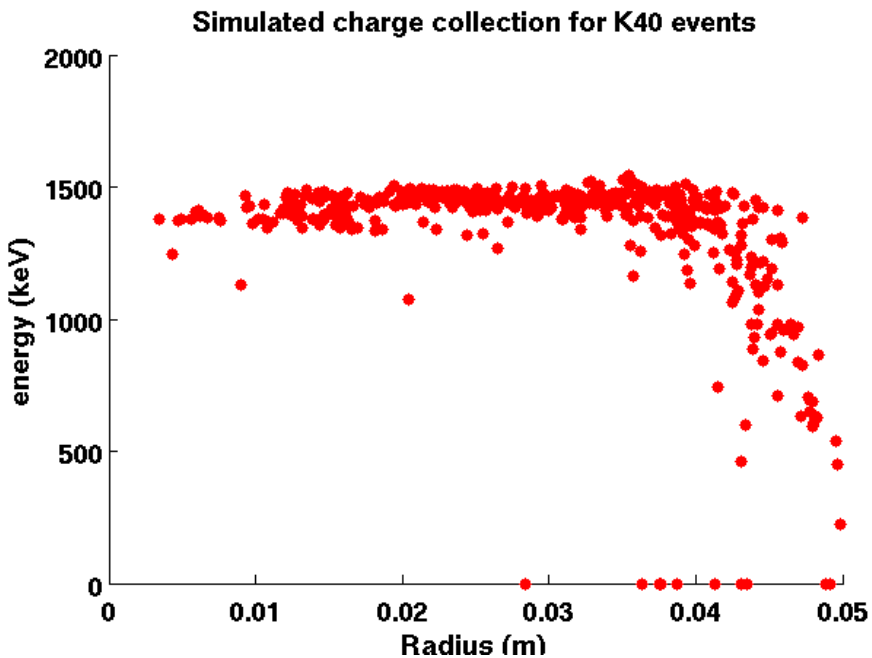
Detector Monte Carlo: spectral broadening

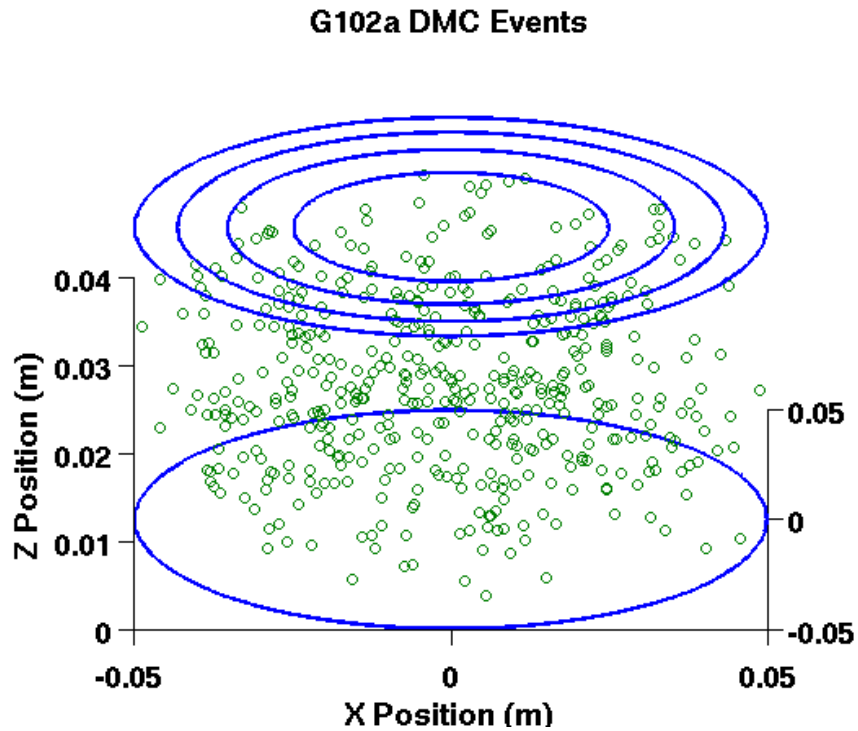


- ***Left:*** *Broadened K40 peak as observed (red) and simulated (blue)*
- There is good agreement between simulation and data
- K40 line broadening due to variance in charge collection efficiency with event location

Source of the spectral broadening

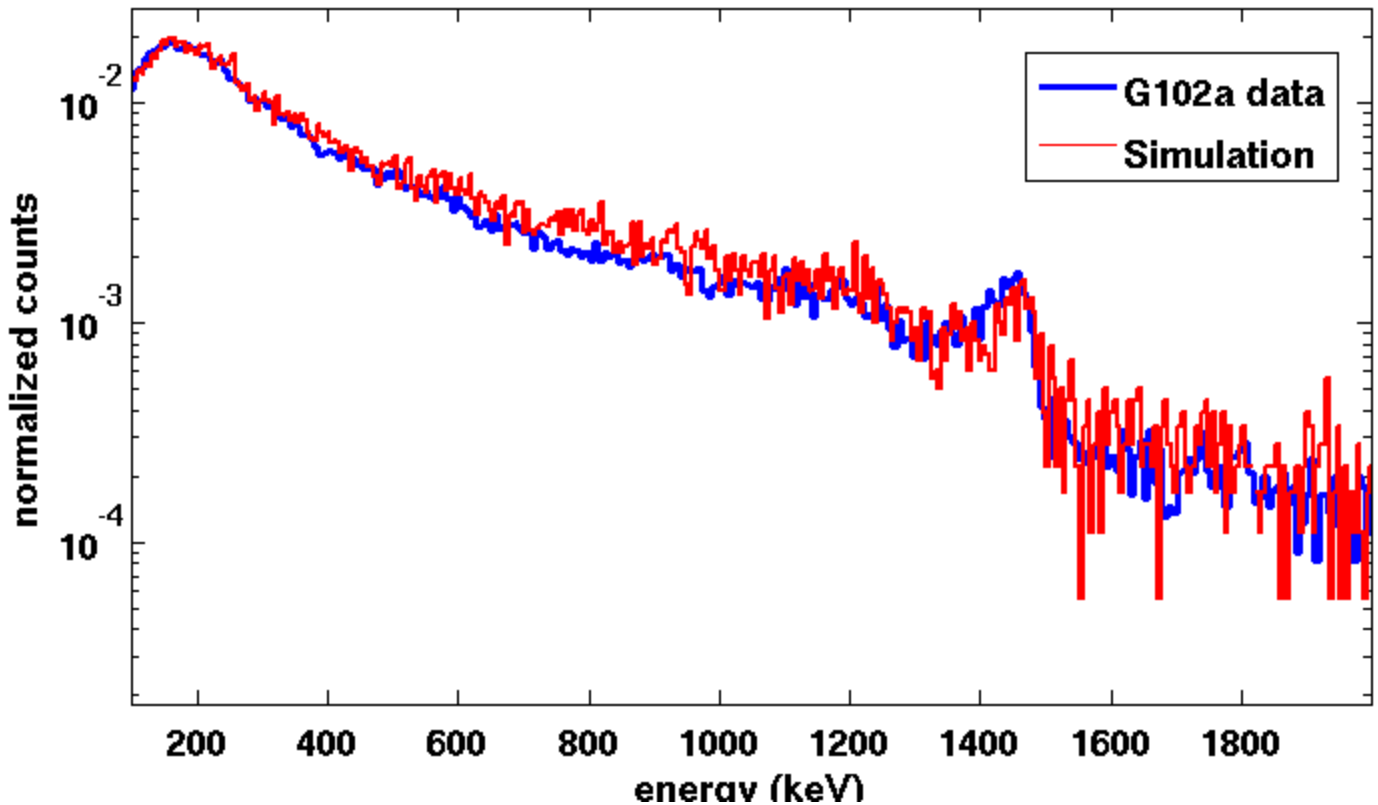
- Detector charge collection efficiency varies with event location
- Spacial distribution of K40 events is the source of spectral broadening





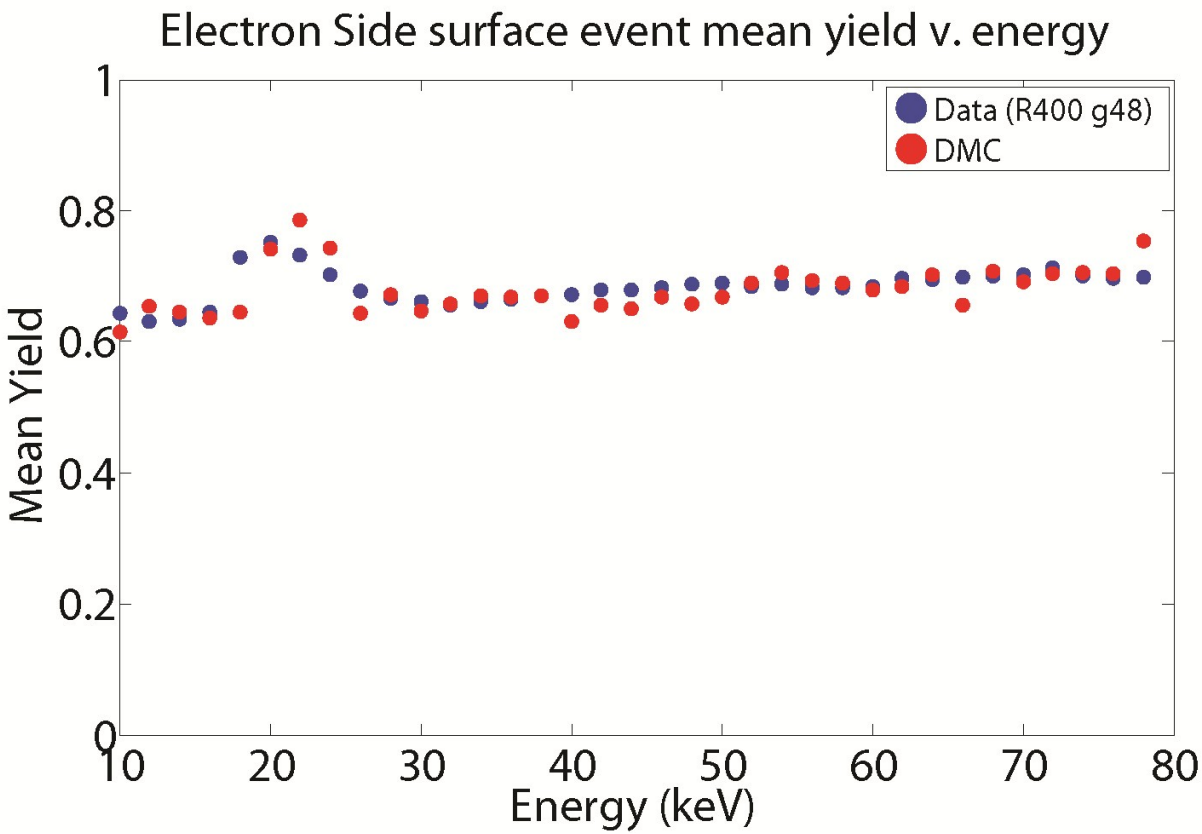
Comparing simulated and recorded spectra

- The figure shows good agreement between simulated (red) and recorded (blue) charge spectra



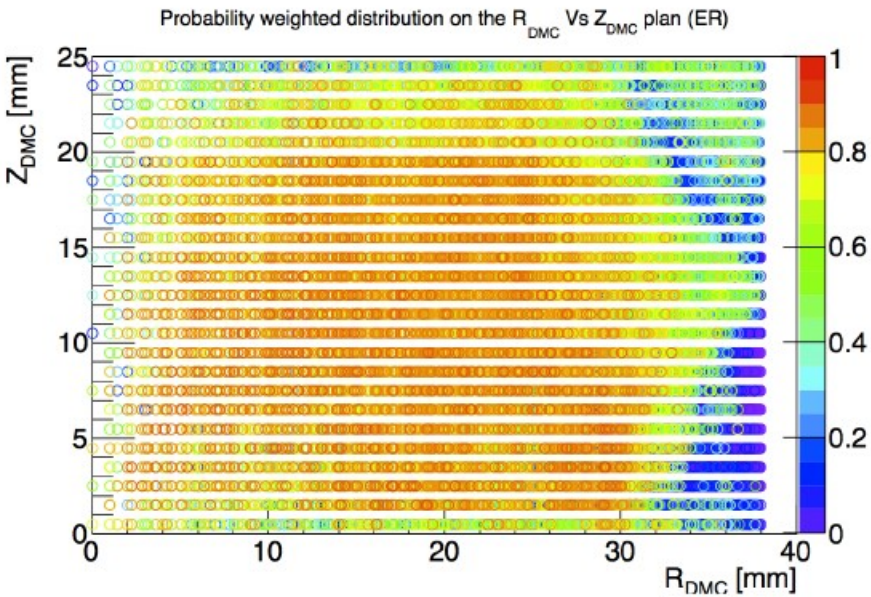
Detector simulation vs experiment

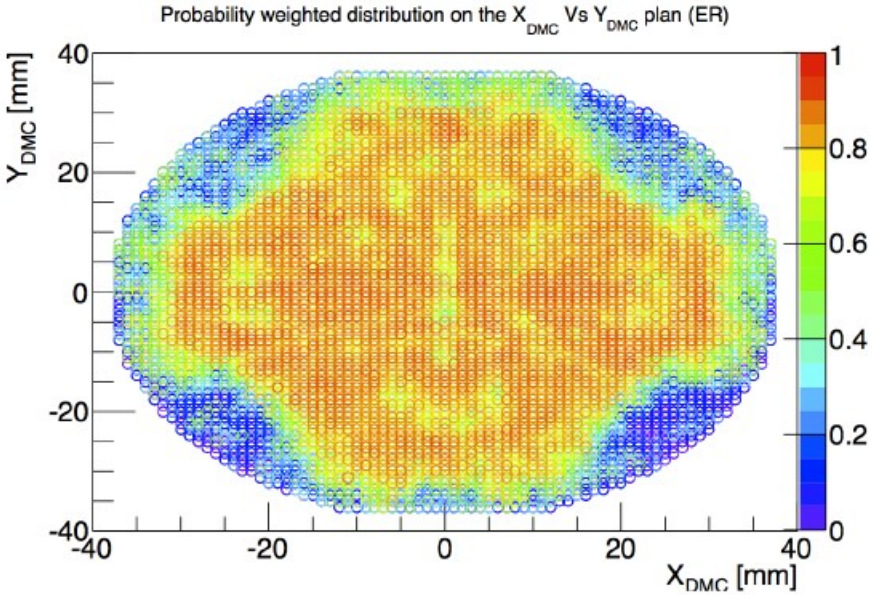
- Ionization yield (charge energy / phonon energy) is central to CDMS background rejection strategy



Visualizing and predicting the fiducial volume

- The detector Monte Carlo simulation can be used to visualize detector fiducial volumes
- It can be used to estimate the fiducial volume of an new detector design
- Simulated leakage events can help in data quality cut design





Summary

- SuperCDMS SNOLAB improves sensitivity by 2 orders of magnitude
- Can manufacture detectors at sufficient rate if detector size is 100mm diameter
- 100mm detectors have been designed, fabricated and are currently undergoing testing. Results are promising.
- An accurate Monte Carlo simulation demonstrates good understanding of detector physics and can help in predicting backgrounds and fiducial volumes
- SuperCDMS collaboration in great shape to move forward with the SNOLAB 2nd generation experiment

The SuperCDMS collaboration

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