SuperCDMS SNOLAB: Road to 100 mm Germanium Detectors

H. Chagani

University of Minnesota
for the SuperCDMS Collaboration

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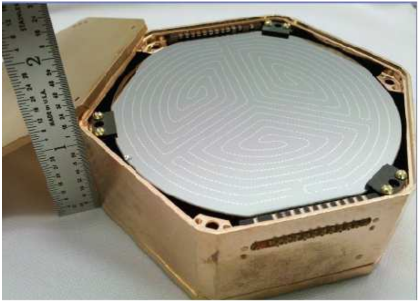
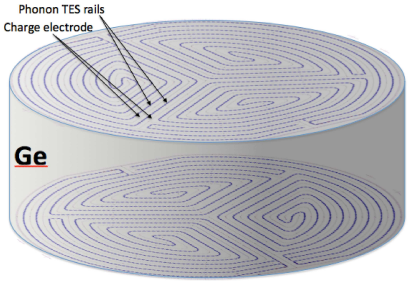
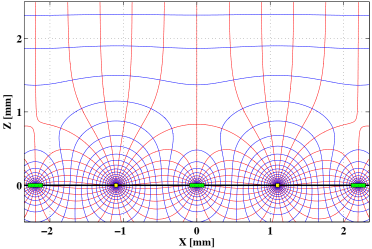
The SuperCDMS Soudan Detector: iZIP

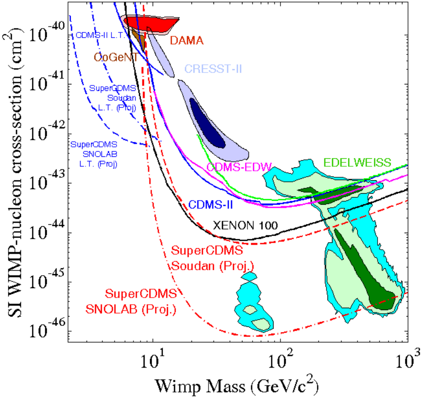
- interleaved Z-sensitive Ionisation & Phonon detector (iZIP)
- $3''\phi \times 1''$ thick, 600 g Ge crystals
- Simultaneous measurement of phonon & charge signals
- Interleaved electrodes so surface events show up on one detector side only







The SuperCDMS SNOLAB Experiment

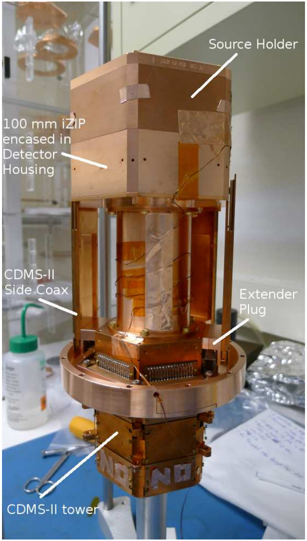


- iZIP technology appears to meet requirements for larger target masses
- Scaling difficult: $\sim 340\ 3''\phi \times 1''$ crystals for 200 kg mass
- A number of factors make this expensive:
  - Increased manpower: fabrication and testing are labour intensive
  - Increased heat load: additional wiring to room temperature
  - Increased cold hardware and warm electronics

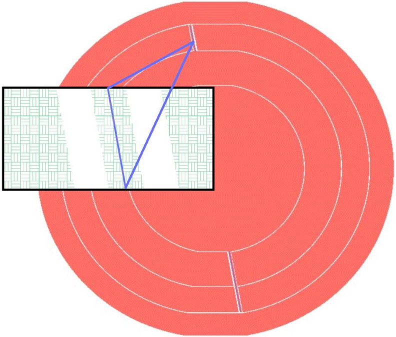
Increasing the size of individual detectors can help alleviate these issues

The Road to 100 mm Germanium Detectors

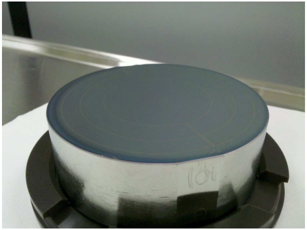
- Up to 100 mm diameter detector-grade Ge crystals can be grown
- Three crystals of thickness 33.3 mm and mass 1.37 kg have been/are being tested:
  1. Ionisation test device
  2. Spiral electrode device
  3. First 100 mm iZIP design
- Tests performed with existing CDMS-II 3″ cold hardware with minor modifications:
  - CDMS-II tower, side coaxes, cold electronics cards and striplines
  - New extender plug to bridge gap between tower and side coax
  - New detector housing to encase larger diameter crystal
- Tests utilise new warm electronics designed for SuperCDMS SNOLAB



The 100 mm Ionisation Test Device

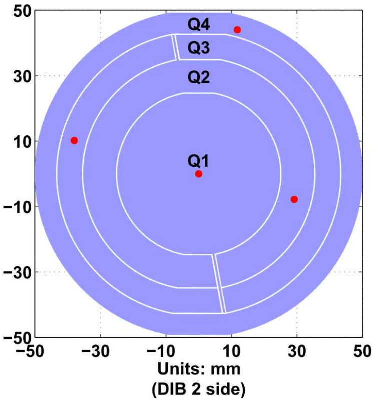


- Ionisation electrodes patterned as 4 concentric rings
- Crystal volume of 64.3 cm^3 lies under each electrode for comparable responses
- Electrodes separated by 400 $\mu\mathrm{m}$ wide trenches
- Each electrode consists of a grid of 2 $\mu\mathrm{m}$ thick wires at pitch of 40 $\mu\mathrm{m}$



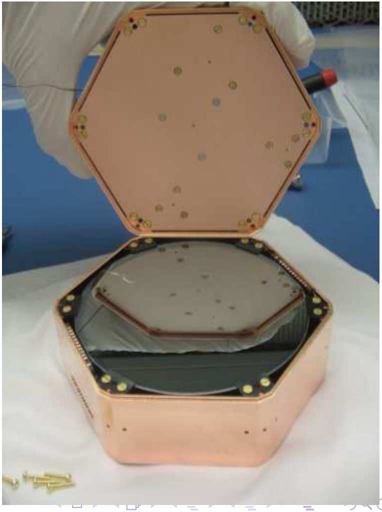
- Sections of two inner electrodes extend through gaps to bring them closer to the detector edge for readout
- Uniform grid at ground present on opposite face

Ionisation Measurements



- 60 keV γ-rays from four ^{241}Am sources used for ionisation measurements
- Each source collimated (activity $\approx$ 20 Bq)
- Each source placed above centre of electrode as shown by red dots

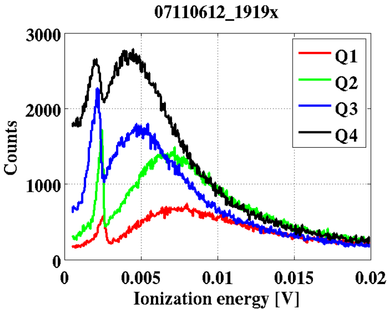
- Electrodes labelled Q1 from centre to Q4 at edge



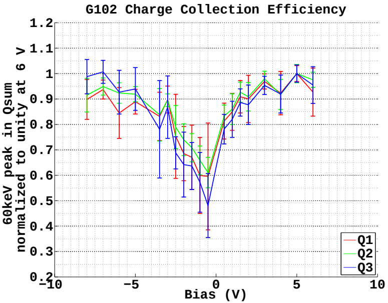
Charge Collection Efficiency

- Mean free path of 60 keV γ-rays in Ge is $\sim$ 1 mm
- Vary bias and determine change in position of 60 keV peaks
- Outer channel Q4 used as veto

Uncalibrated charge spectra
-4.0 V bias



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



Charge Collection Efficiency

- Mean free path of 60 keV γ-rays in Ge is $\sim$ 1 mm
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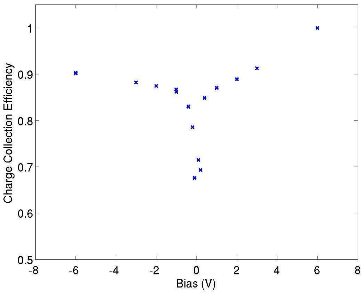
30 mm ϕ $\times$ 10 mm thick crystal
from T. A. Shutt Ph.D. thesis, Berkeley (1993)



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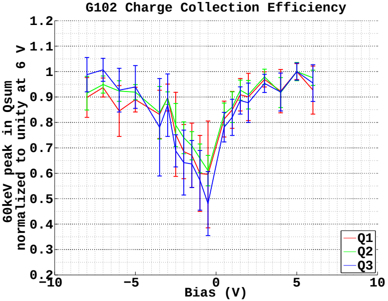
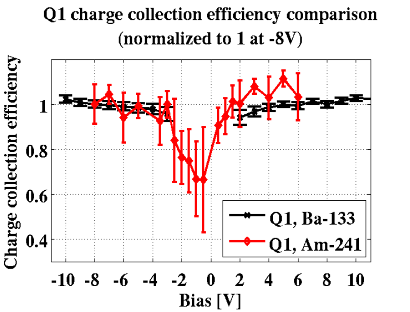
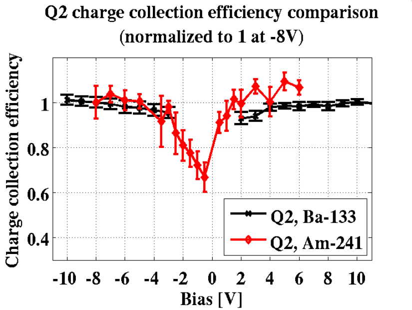


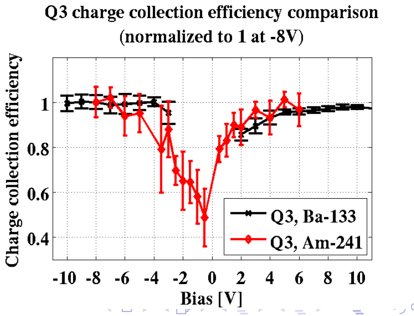
- Results consistent with scaling past measurements on 1 cm thick crystals:
    - Bias voltage of 1.7 V required for complete charge collection
- These crystals have necessary charge collection efficiency to be operated as dark matter detectors

Charge Collection Efficiency



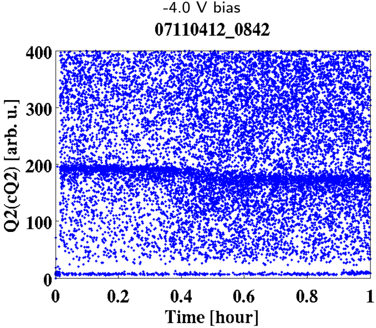
- Use 356 keV line from external ^{133}Ba source to measure charge collection efficiency in bulk
- Three inner electrodes exhibit similar response
- Charge collection efficiencies measured with ^{241}Am & ^{133}Ba sources are consistent

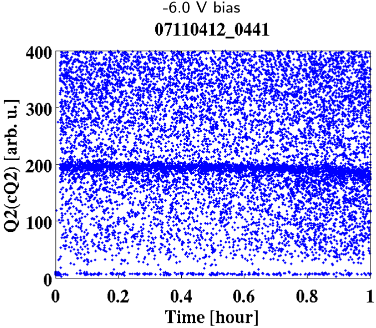




Ionisation Signal Stability

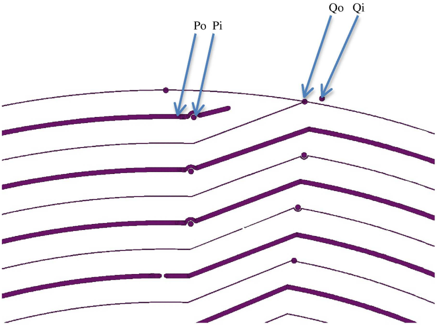
- Ionisation signal stability increases with bias
- Similar behaviour seen collecting electrons as that when collecting holes





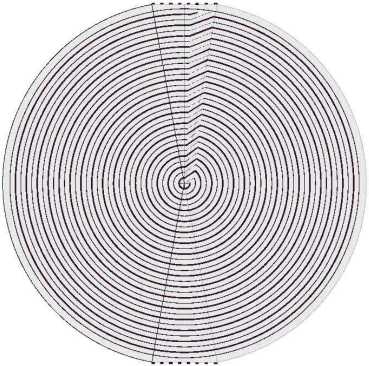
- Short bursts of LED flashes over a period of < 6 s successfully remove charge traps and reset detector to its original state

The Spiral Electrode Device



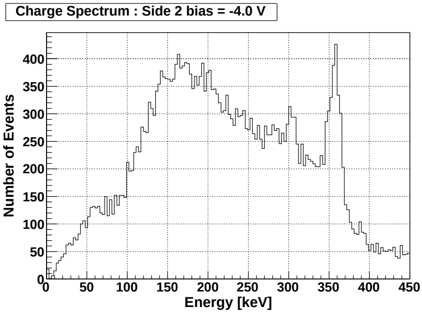
- Inner disk covers ∼ 66% of surface area
- Centres of grounded and charge ribbons lie 1.5 mm apart
- Top side is mirror of bottom face

- Two electrodes on each crystal face: inner disk and outer ring
- Grounded ribbon of width 250 μm interleaved with charge ribbons of width 40 μm



Identification of Surface Events

- One ^{241}Am source installed facing inner charge channel on Side 2
- Mean free path of 60 keV γ-rays in Ge is $\sim$ 1 mm
- Grounded and charge ribbon centres lie 1.5 mm apart
- Electrons/holes from 60 keV events mostly show up on Side 2



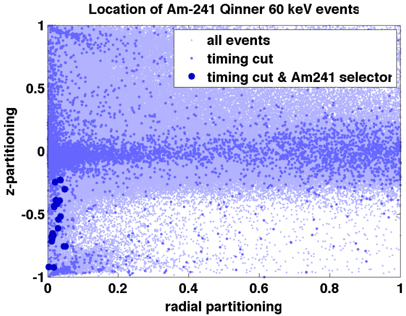
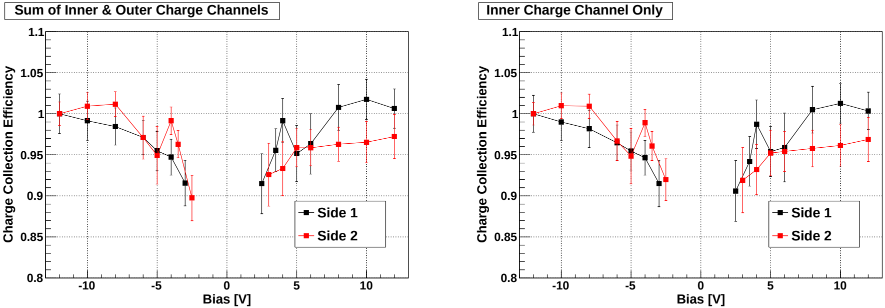


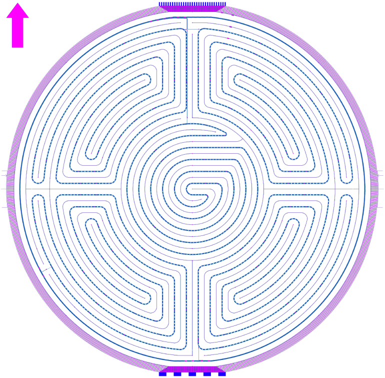
Figure on right:
z-partitioning $= \frac{(\mathrm{Side1}-\mathrm{Side2})}{(\mathrm{Side1}+\mathrm{Side2})}$, radial partioning $= 0$ is central cylinder axis, timing cut defined as (Time of event) < 150 s from start of data acquisition

Charge Collection Efficiency

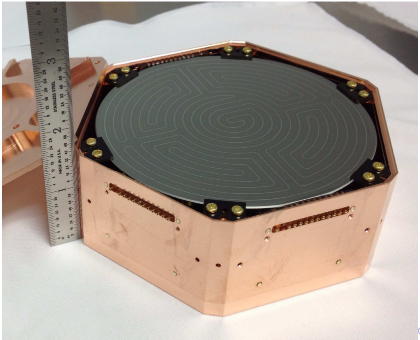


- 356 keV line from external ^{133}Ba source used to measure charge collection efficiency in bulk
- Curves normalised to unity at -12 V bias
- Charge collection efficiencies for both sides are reasonably uniform

The First 100 mm iZIP



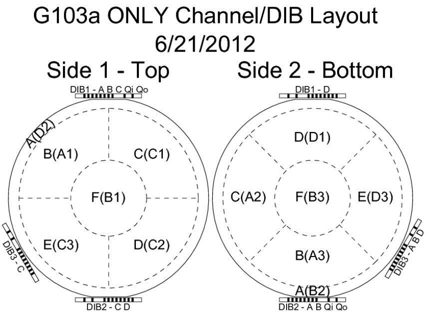
- Two electrodes on each crystal face: inner disk and outer ring
- 12 phonon channels, six on each side
- Phonon ribbons of width 260 μm interleaves with charge ribbons of width 50 μm



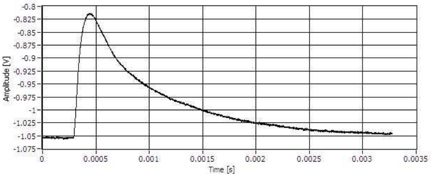
- Centres of phonon and charge ribbons lie 1.5 mm apart
- Phonon channels rotated by 45 degrees about central axis on bottom face

First Phonon Pulses

- Readout through 3 Device Interface Boards (DIBs), to which CDMS-II side coaxes are attached



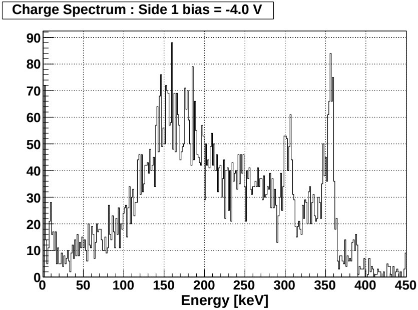
- Transition Edge Sensors' (TES) critical temperatures lie between 76 mK & 86 mK
- No significant difference between critical temperatures on both sides

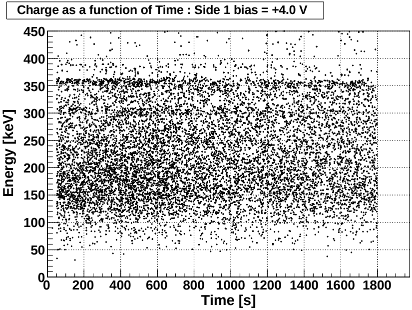


Side 1 Channel C

- Phonon pulse decay time ≈ 0.8 ms, in line with what we expect

First Ionisation Signals





- Cryostat surrounded by new lead-polyethylene shield which should reduce background flux by a factor of ~ 5 at surface testing facility
- Detector exposed to ^{133}Ba source for half-an-hour
- Peaks at 302 keV & 356 keV very clear
- Peak at 384 keV visible
- Ionisation signal stable for at least 30 minutes at -4.0 V bias

Conclusions

- 100 mm diameter Ge crystals have necessary charge collection efficiency to be operated as dark matter detectors
- iZIP principles, such as surface event rejection, can be applied to 100 mm diameter crystals
- The first 100 mm iZIP looks like a good detector and is currently undergoing detector characterisation tests
- Several 100 mm iZIP detectors in the pipeline