13th ICATPP Conference on Astroparticle, Particle, Space Physics and Detectors for Physics Applications

Direct Detection of Dark Matter using Cryogenic Germanium Detectors

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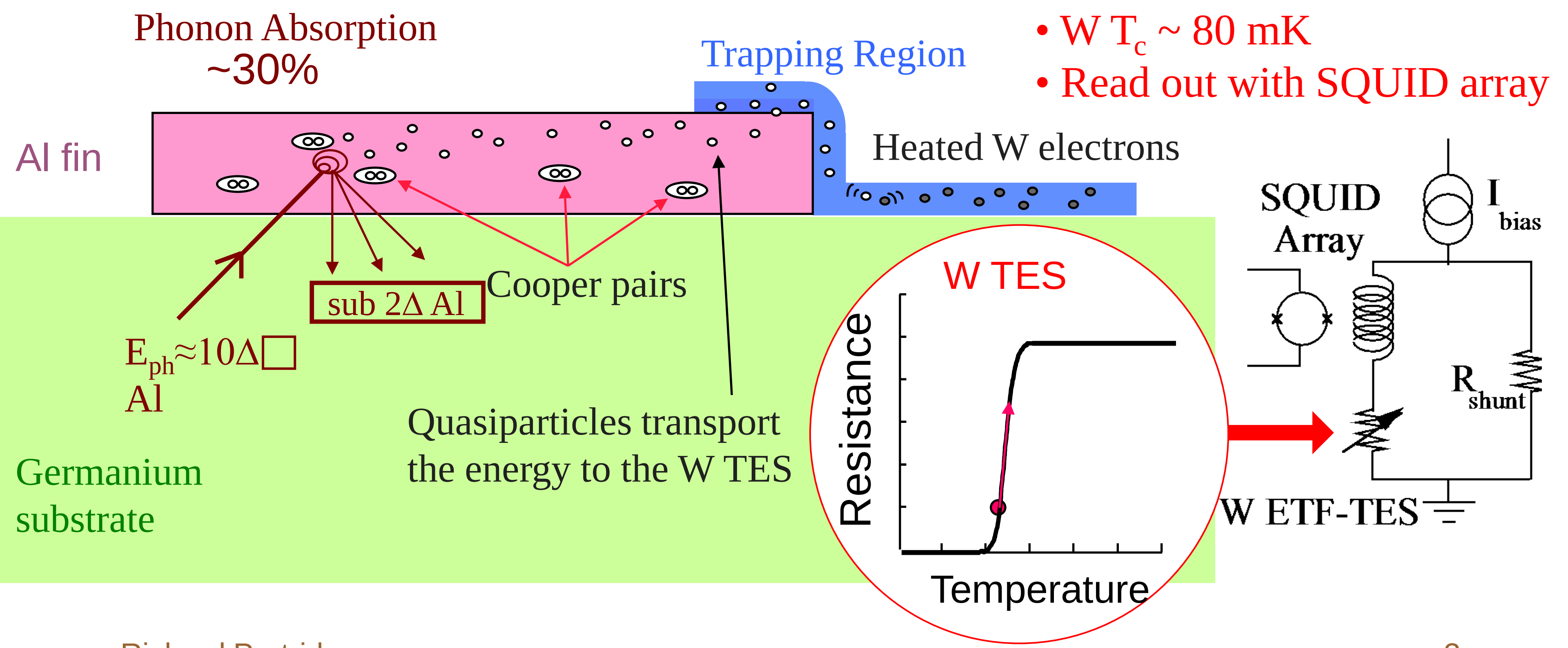
CDMS Approach to DM Detection

- Use high purity Ge to minimize radioactive contamination within the detector material
  - External sources of background are minimized by deep underground site, multiple layers of shielding and careful choice of materials
- "Calorimetric" measurement of total energy deposit through cryogenic phonon detectors
  - ~10^6 phonons produced per keV of energy deposit
- Independent measurement of ionization charge allows electron recoils to be distinguished from nuclear recoils
  - ~300 electron-hole pairs produced per keV for electron recoils
  - ~100 electron-hole pairs produced per keV for nuclear recoils
- Operate in "background free" regime
  - Aim for <1 event of expected background in 2 years of running
  - Avoid difficulties associated with background subtraction

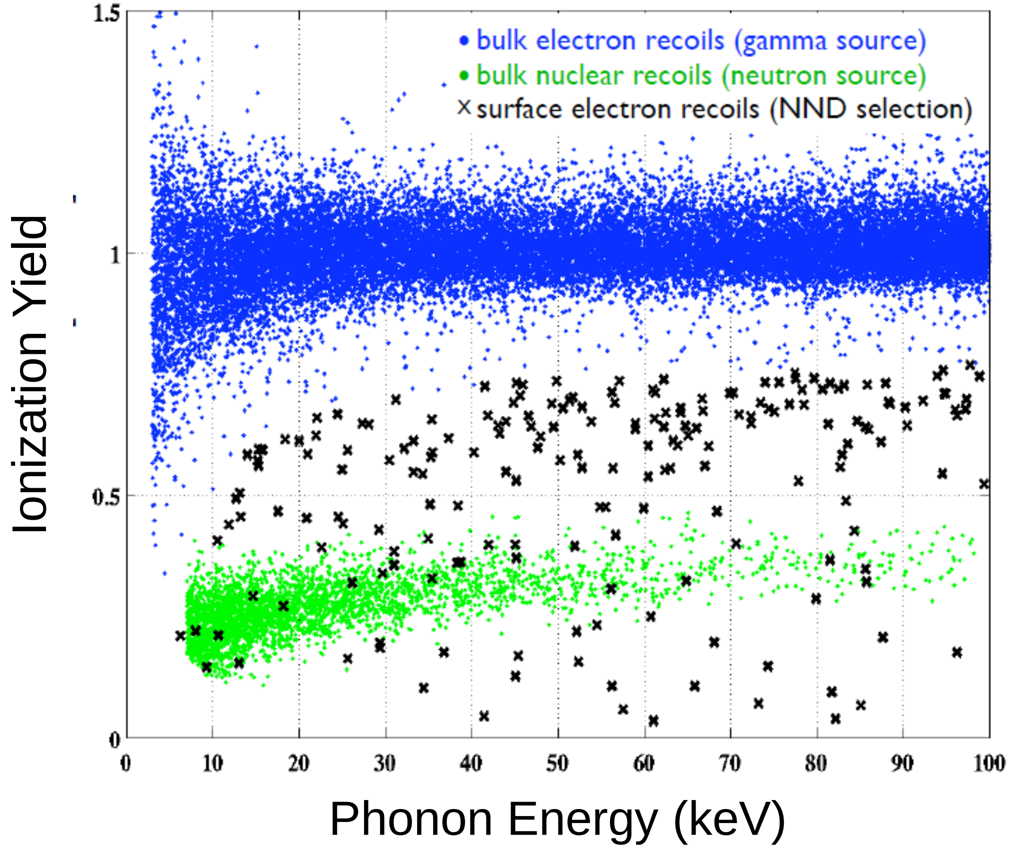
CDMS Phonon Detectors

- Thin-film deposition and photolithography used to create phonon detectors on surface of Ge crystal
- Tungsten Transition Edge Sensor (TES) biased to T_C using electro-thermal feedback, read out with SQUIDS



CDMS II Limited by Surface Events

- CDMS II detectors had charge electrodes on one face and phonon electrodes on opposite face
- Incomplete charge collection near phonon face



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

~ 1 for bulk electron recoils (γ source)

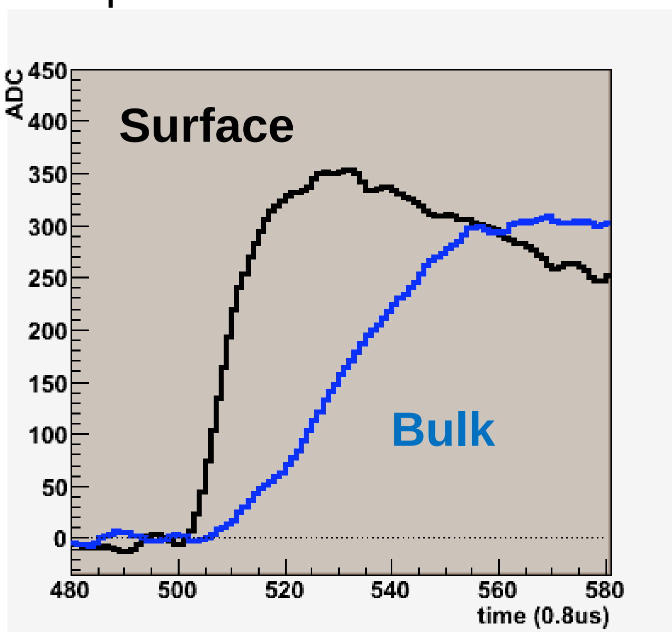
.1 – 1 for surface events (β source)

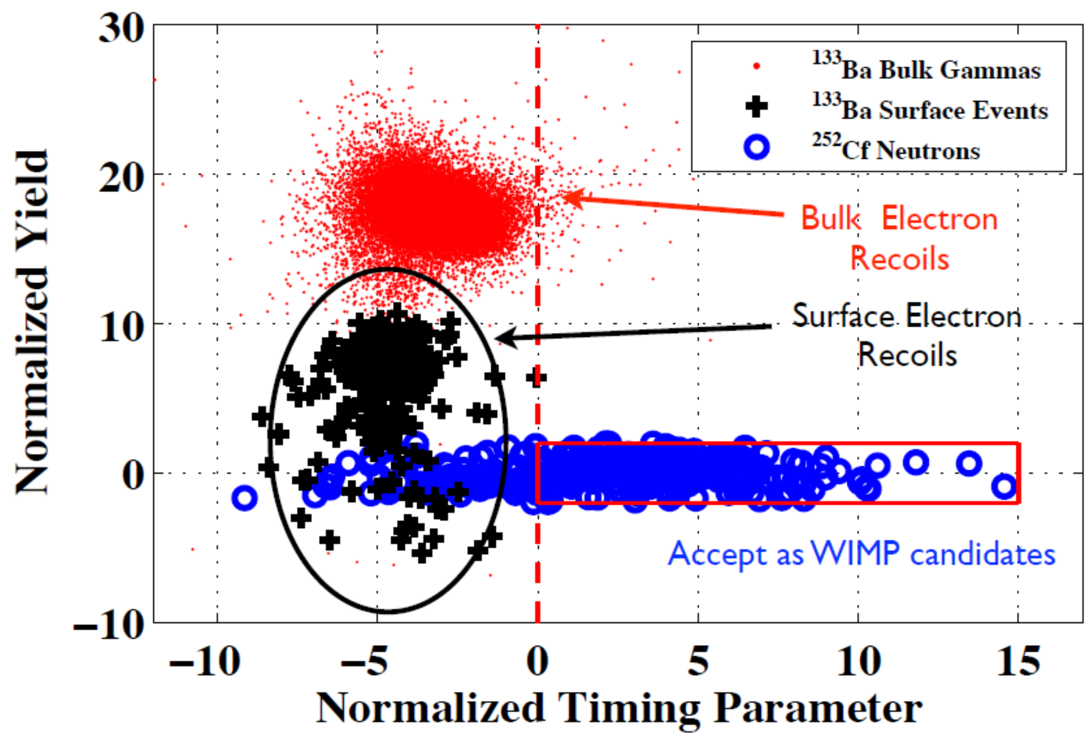
~0.3 for nuclear recoils (n source)

CDMS II Timing Discrimination

- Fully digitized waveforms for phonon and charge signals provide additional handles for rejecting surface events
- Final CDMS II high-mass result: 2 events with expected background of 0.8 events

Sample Phonon Waveforms



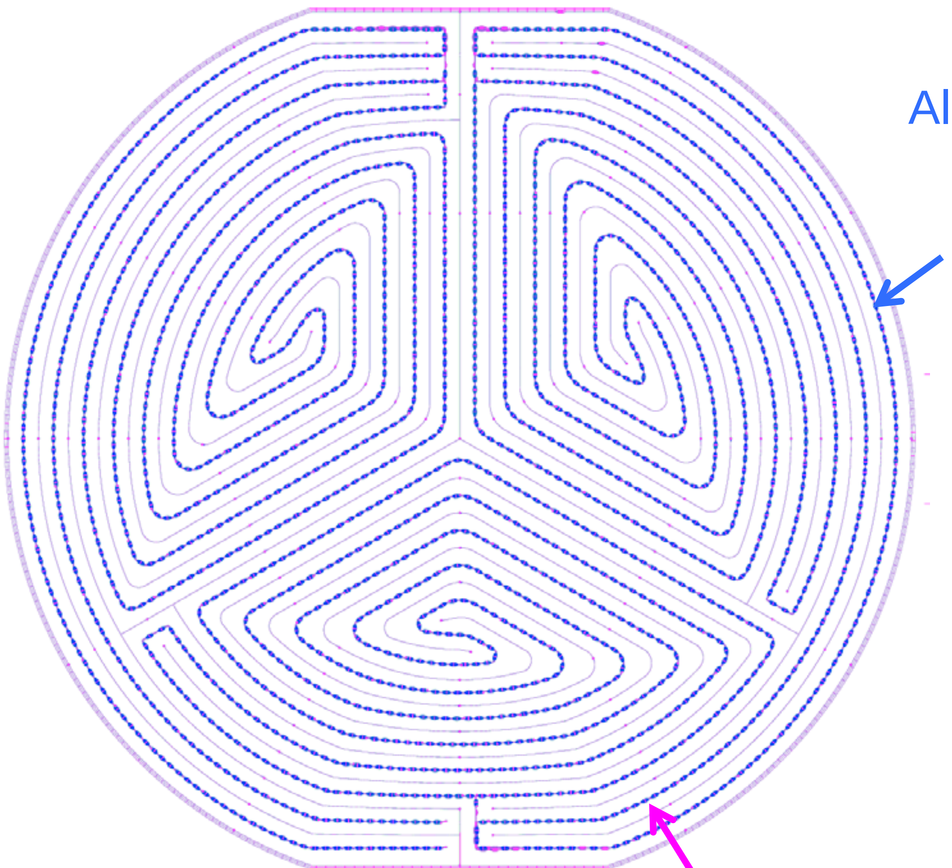


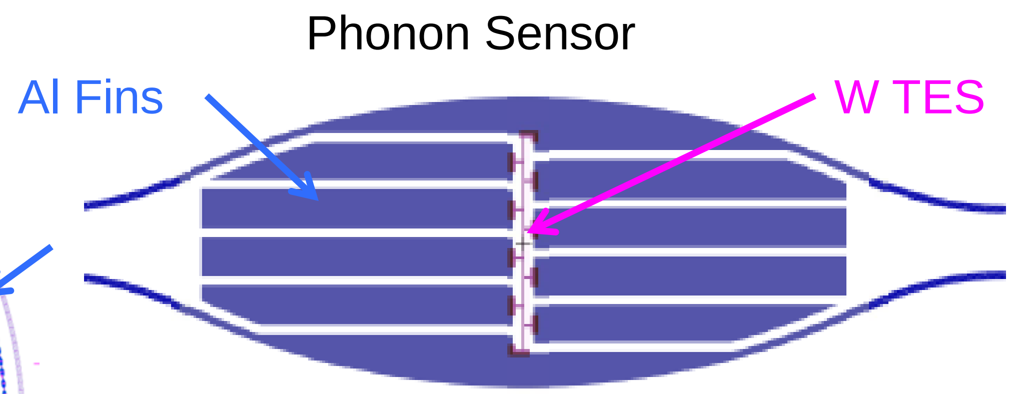
SuperCDMS: The Next Generation

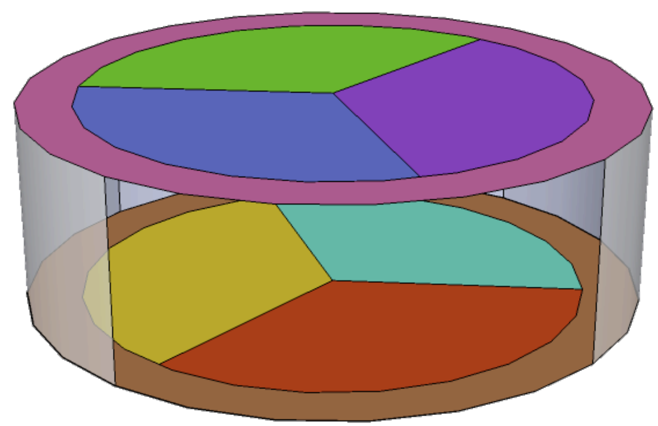
- New IZip detector design follows the CDMS approach of measuring phonon and ionization signals while largely eliminating the surface event background
  - Ionization and phonon measurements on both faces
  - Transverse electric fields at surface allow surface event identification
- Stage 1: SuperCDMS-Soudan
  - 10 kg of IZip detectors at Soudan (~2000 mwe)
  - Engineering run Jan – Mar 2011 (ended by shaft fire)
  - Full payload (and shaft repairs) completed - installation this month
- Stage 2: SuperCDMS-SNOLAB
  - ~100 kg of IZip detectors at SNOLAB (~6000 mwe)
  - R&D effort underway to scale up CDMS design/fab to 100 kg scale
  - DOE OHEP requested funding for 2nd generation DM projects in FY13
- Future: Scale cryogenic Ge detectors to ton scale

SuperCDMS-Soudan IZip Layout

- 4 phonon + 2 charge channels (inner & outer) per side
- Charge electrodes interleaved with phonon sensor rails

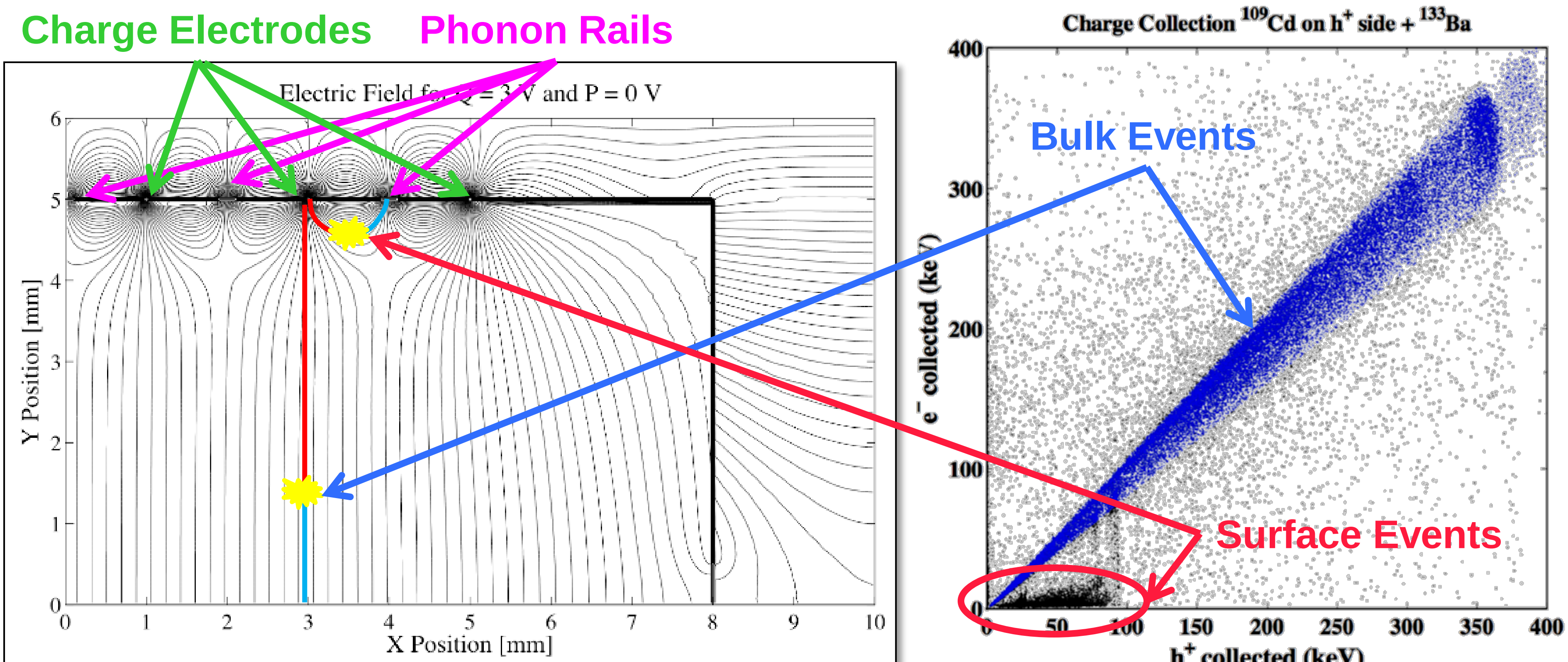






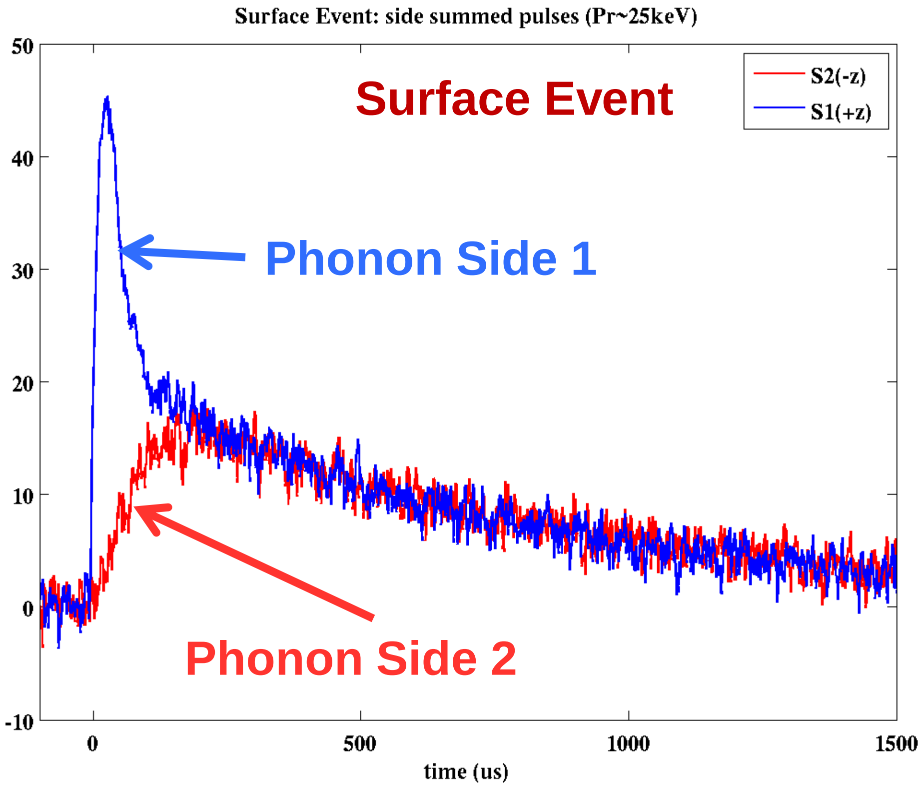
IZip Electric Field Configuration

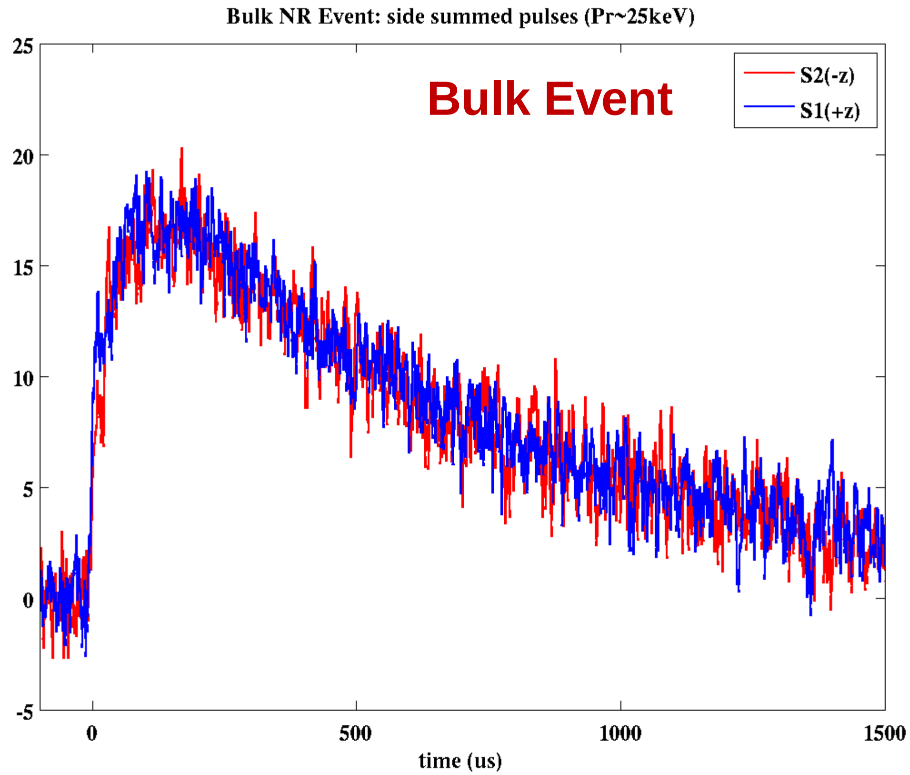
- Transverse surface field in addition to bulk drift field
  - Typical charge electrode bias is +2V (side 1) and -2V (side 2)
  - Phonon rails are set to ground potential on both sides
  - Surface events can be identified through their charge asymmetry



IZip Pulse Shape Discrimination

- Phonon waveforms provide further BG discrimination
  - Position dependence can help identify surface events
  - Prompt Luke-Neganov phonon contribution from accelerated e/h pairs may allow independent estimate of ionization charge





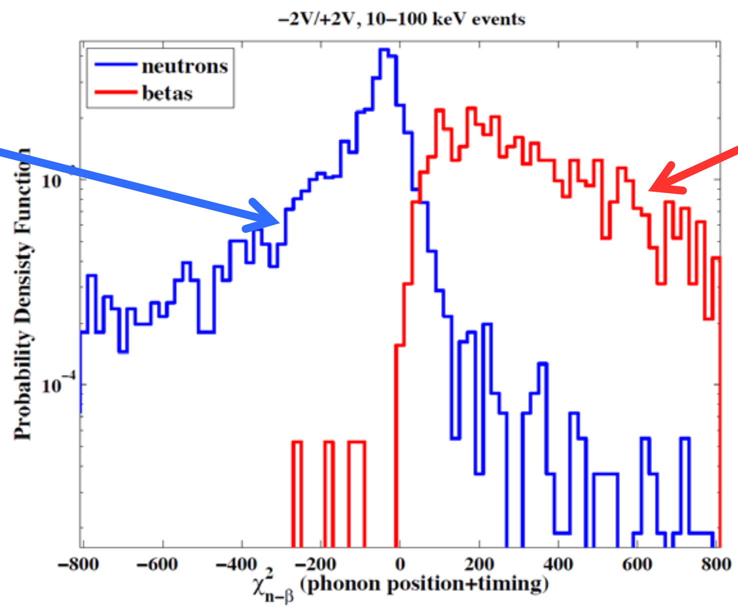
IZip BG Discrimination Summary

- Multiple techniques for rejecting electron recoils
  - Ionization yield ~1 for electron recoils in bulk
  - Charge asymmetry for electron recoils near surface
  - Pulse shape analysis provides additional discrimination power

Nuclear Recoils

Electron Recoils

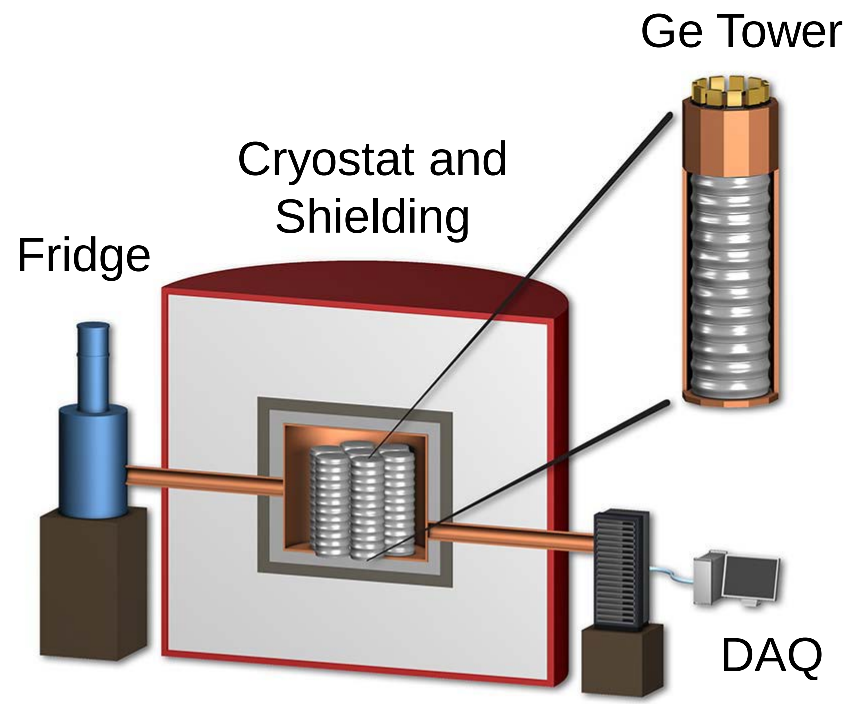
Example of a pulse shape discrimination algorithm



- Neutrons are the limiting BG at Soudan
  - Soudan OK for 10 kg target mass, move to SNOLAB for 100 kg

SuperCDMS-SNOLAB

- Goal is ~100 kg of target mass in a new cryogenic system located in Ladder Lab at SNOLAB
  - Cosmic ray muon flux ~500x smaller than Soudan
  - Plan to commission SNOLAB Test Facility in late 2012 using CDMS-I dilution refrigerator for deep underground detector testing



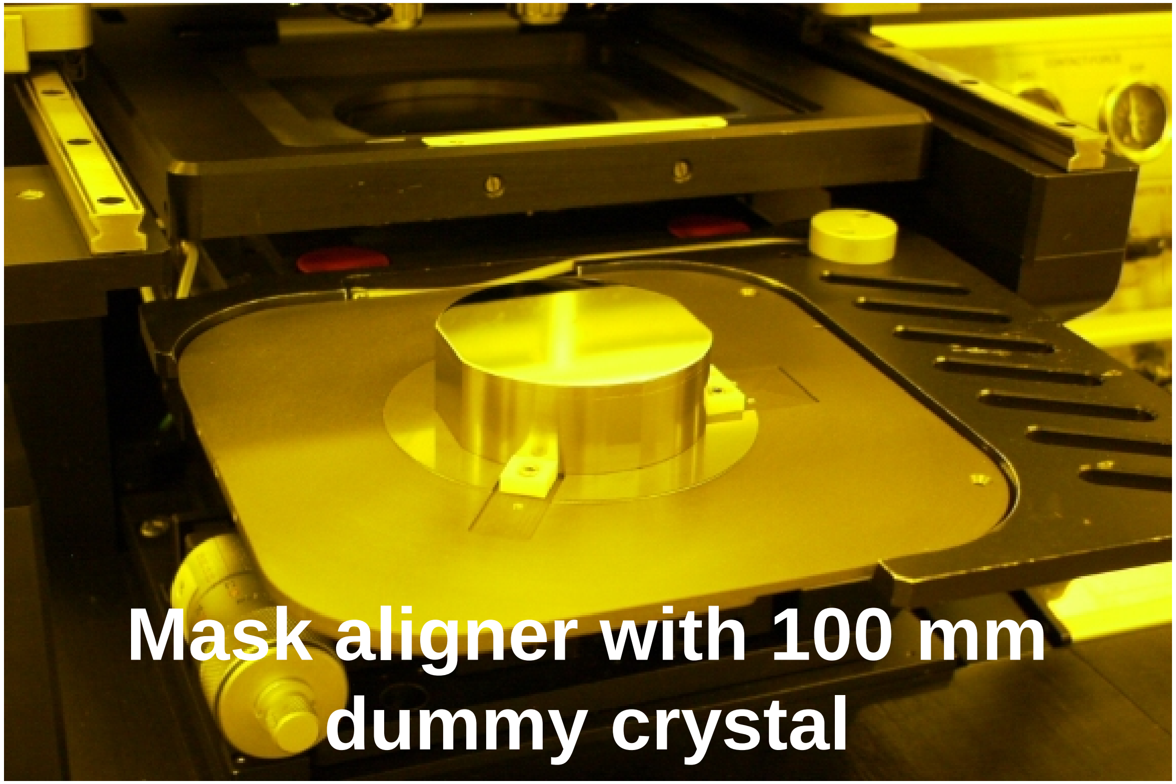
Cartoon Layout of SuperCDMS-SNOLAB

SNOLAB IZip Detectors

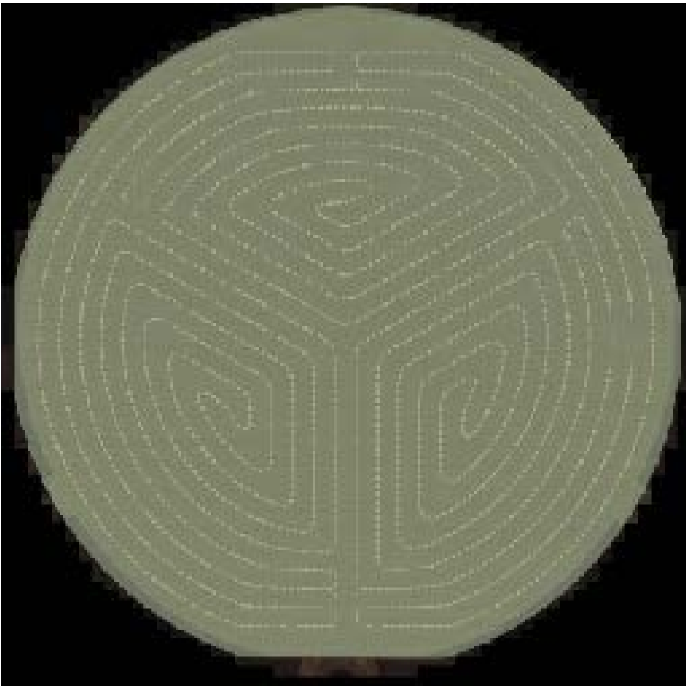
- Baseline design is to use 100 mm diameter, 33 mm thick 100 Ge crystals
  - 1.4 kg per detector, plan to fabricate ~80 IZip detectors @ ~6 / month
  - ~2.3 more mass per crystal than for 76 mm Soudan IZip detectors

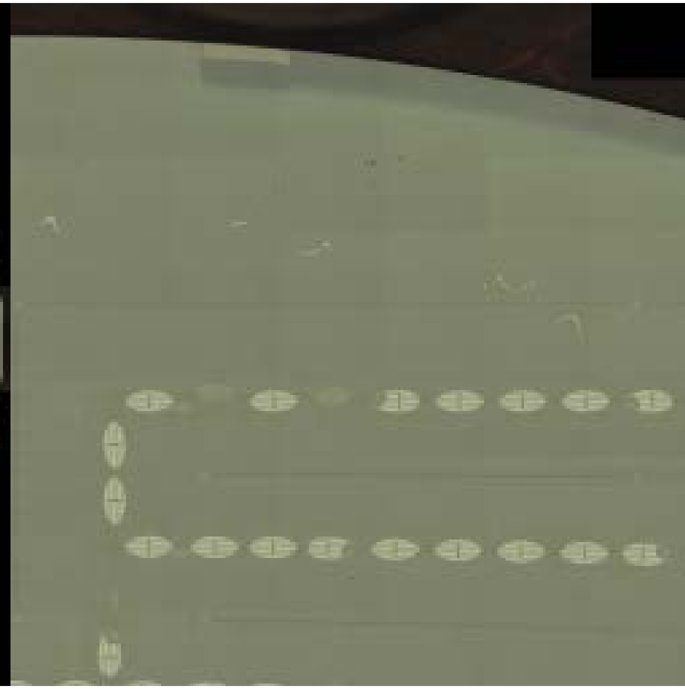
100 mm Fabrication Tooling

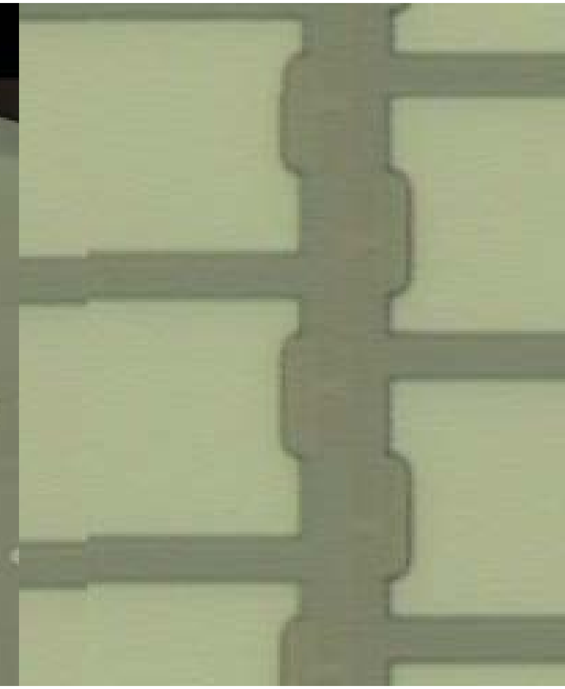
- CDMS uses customized semiconductor fabrication equipment for detector photolithography
  - Commercial equipment designed for thin wafers
  - Custom fixturing developed for 100 mm work



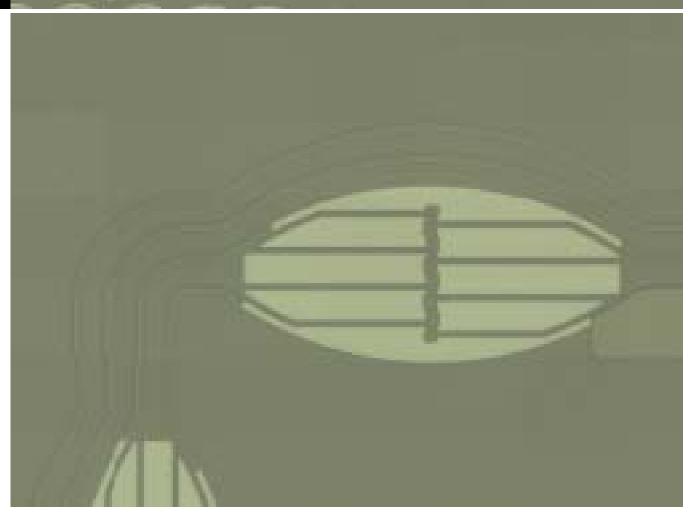
Detecting Photolithography Defects







Optical CMM used to image entire detector surface (~20K images, 0.6μm pixel size)

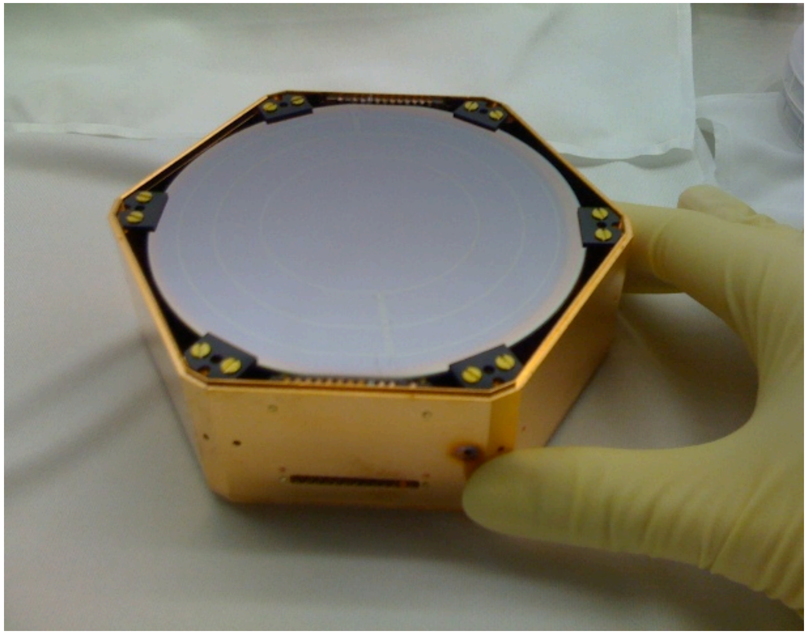


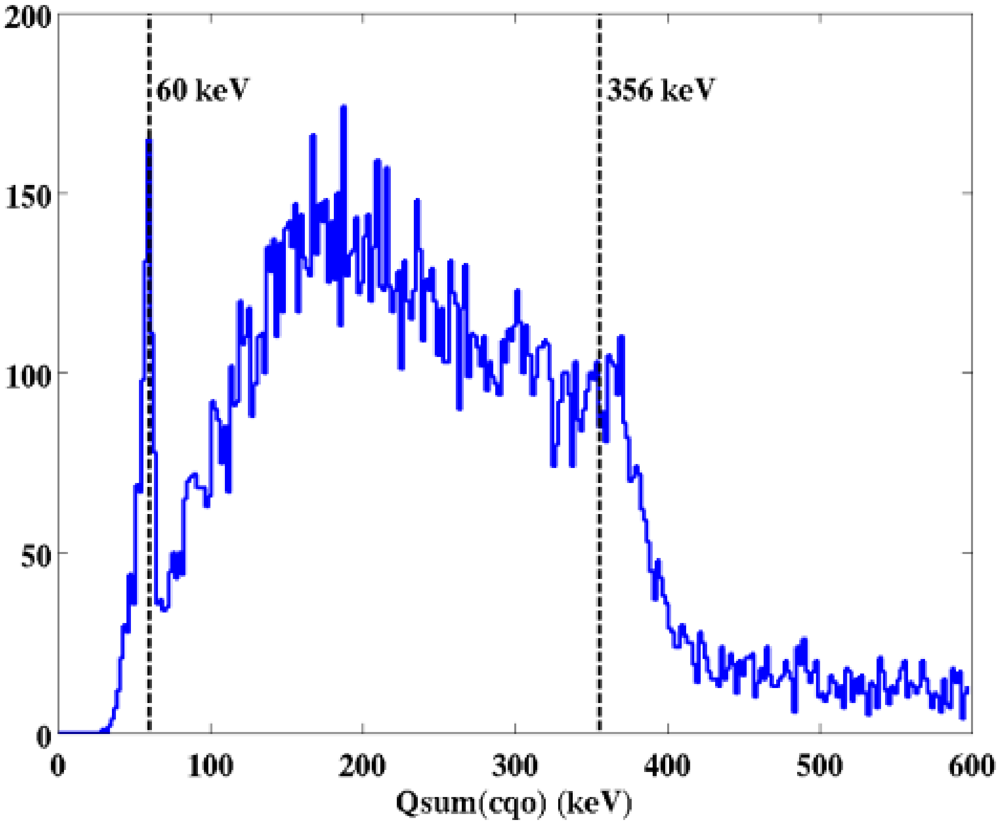
Images tiled using Google Maps API for easy navigation

Working on automated inspection software

100 mm Ionization Test

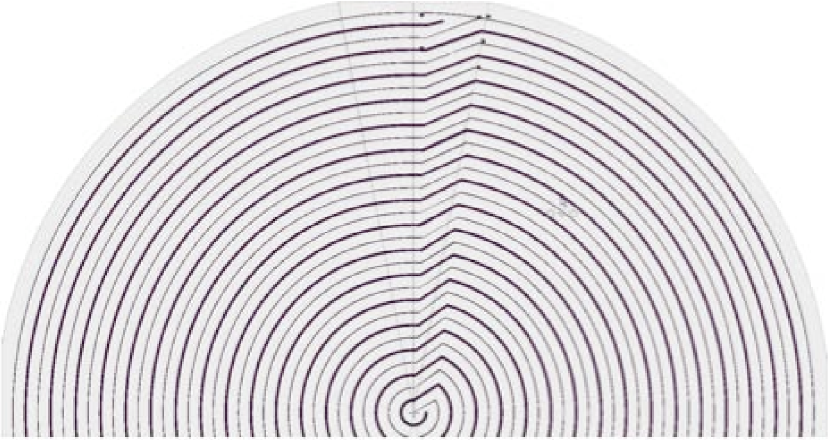
- 100 mm detector fabricated with ionization electrodes to verify good charge collection in 33 mm thick Ge crystal
  - See expected gamma lines from ^{133}Ba source





Progress Towards a 100 mm IZip

- Have developed a "Spiral Mask" that simulates the electric field configuration of an IZip detector
  - Includes both transverse and drift fields
  - Mask design complete, fabrication this month



- Work has begun on the 100 mm IZip mask design
  - Includes both charge and phonon readout
  - Initial design will be targeted at using "Soudan" readout electronics
  - Final design will take advantage of improvements planned for SNOLAB

Summary

- Due to time constraints, this talk focused on Ge detector technology
  - Much good work on cryogenics, cold and warm electronics, test facility etc. not included (apologies to my hard-working colleagues!)
  - Also skipped was detector simulation work, including extensions to GEANT4 that provide for cryogenic phonon / charge transport
- New IZip detector design expected to allow background-free performance up to the ton scale
- Installation of 10 kg IZip payload at Soudan this month
- Performing R&D for 100 kg experiment at SNOLAB
  - First 100 mm test devices have been fabricated and tested
  - Fabrication transitioning from hand-crafted to volume production

SuperCDMS Road Map