Germanium Route to Ton-Scale Dark Matter Detection

Recent Developments

for the CDMS Roadmap

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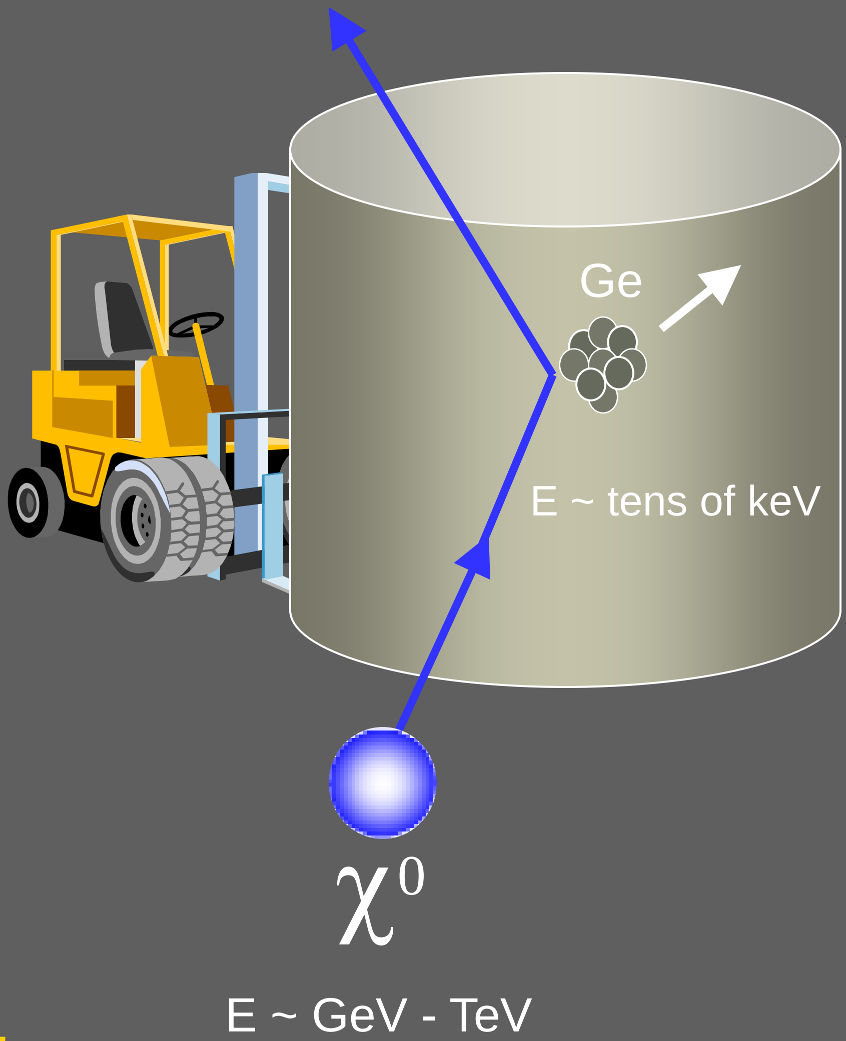
on behalf of the

SuperCDMS Collaboration (P.I. Blas Cabrera, Stanford)

and

the GEODM Collaboration (P.I .Sunil Golwala, Caltech)

SLAC Users Organization Annual Meeting
August 30, 2010



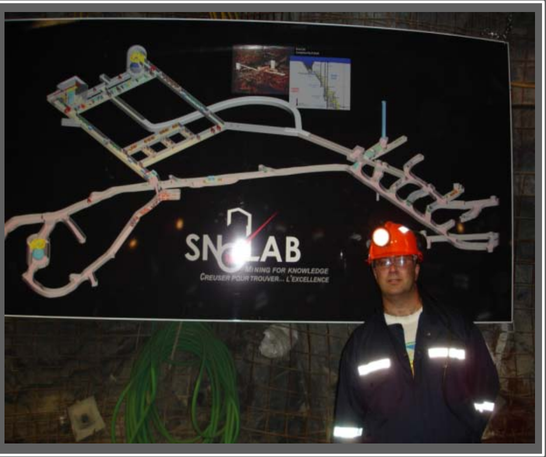
Outline

- Overview of Cryogenic Dark Matter Experiments (CDMS)
  - Few words on the SLAC involvement
- Scalability of Background Rejection Methods
- Scalability of Ge Target masses
- Summary

Overview of Current SLAC Involvement

- **Large Diameter Germanium Detectors – 100 mm (4 inch)**
  - **Fabrication and assembly of modules and testing**
  - **Data/Monte Carlo validation**
- **Background Rejection (Geant4)**
  - **Hadronic physics**
  - **Phonon simulations**
  - **Geometry**

Today's talk



- **Software and Computing**
  - **Scalability of software systems**
  - **Frameworks and event processing**
  - **Batch processing on centrally managed database**
- **SNOLAB test facility**
  - **Engineering – refurbishment of a cryogenic set-up for testing Ge detectors at SNOLAB**
- **Management**
  - **System management**
  - **Support Project management**

Will not be discussed today

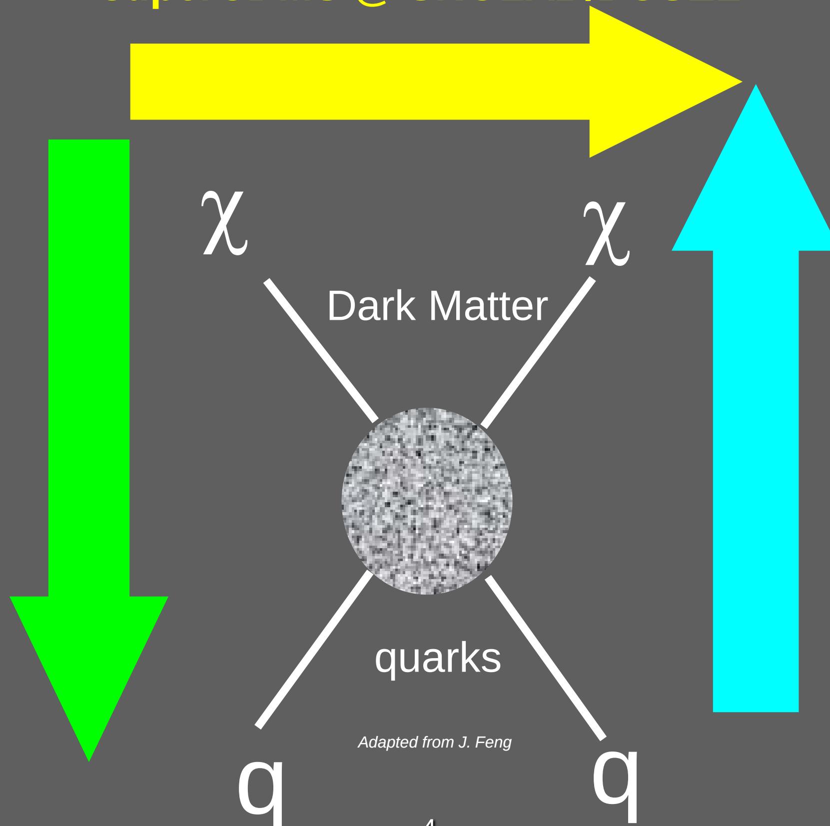
Comprehensive Dark Matter Searches at SLAC

Direct Searches

UNDERGROUND
superCDMS @ SNOLAB/DUSEL

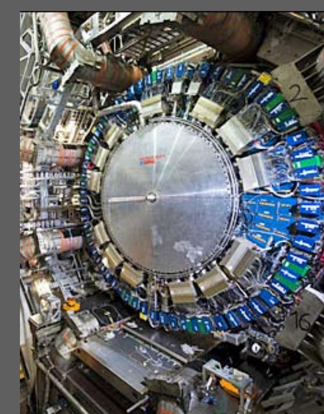
Indirect Searches

SPACE
Fermi Telescope



Adapted from J. Feng

Collider Searches



COLLIDER
ATLAS @ LHC

CDMS Roadmap : Four Experiments

Improve sensitivity by two orders of magnitude in the next decade

- **CDMS II** *no SLAC involvement so far*
  - **Soudan Mine, USA**
  - **Final results published in *Science Dec 2009***

  4 kg — Observed 2 events (expected background of 0.8)

- **SuperCDMS Soudan** *SLAC is learning*
  - **Soudan Mine, USA**
  - **Data taking expected for 2011-2012**

  15 kg — Deploy advanced detector technology

- **SuperCDMS SNOLAB** *SLAC has a visible role*
  - **Vale Inco Mine, Canada**
  - **Data taking expected for 2014-2016**

  ~100 kg — Discovery potential

- **GEODM DUSEL** *the future*
  - **Homestake Mine, USA**
  - **Data taking expected for 2018-2020**

  ~1500 kg — Map a large fraction of WIMP parameter space

The SuperCDMS and GEODM Collaborations

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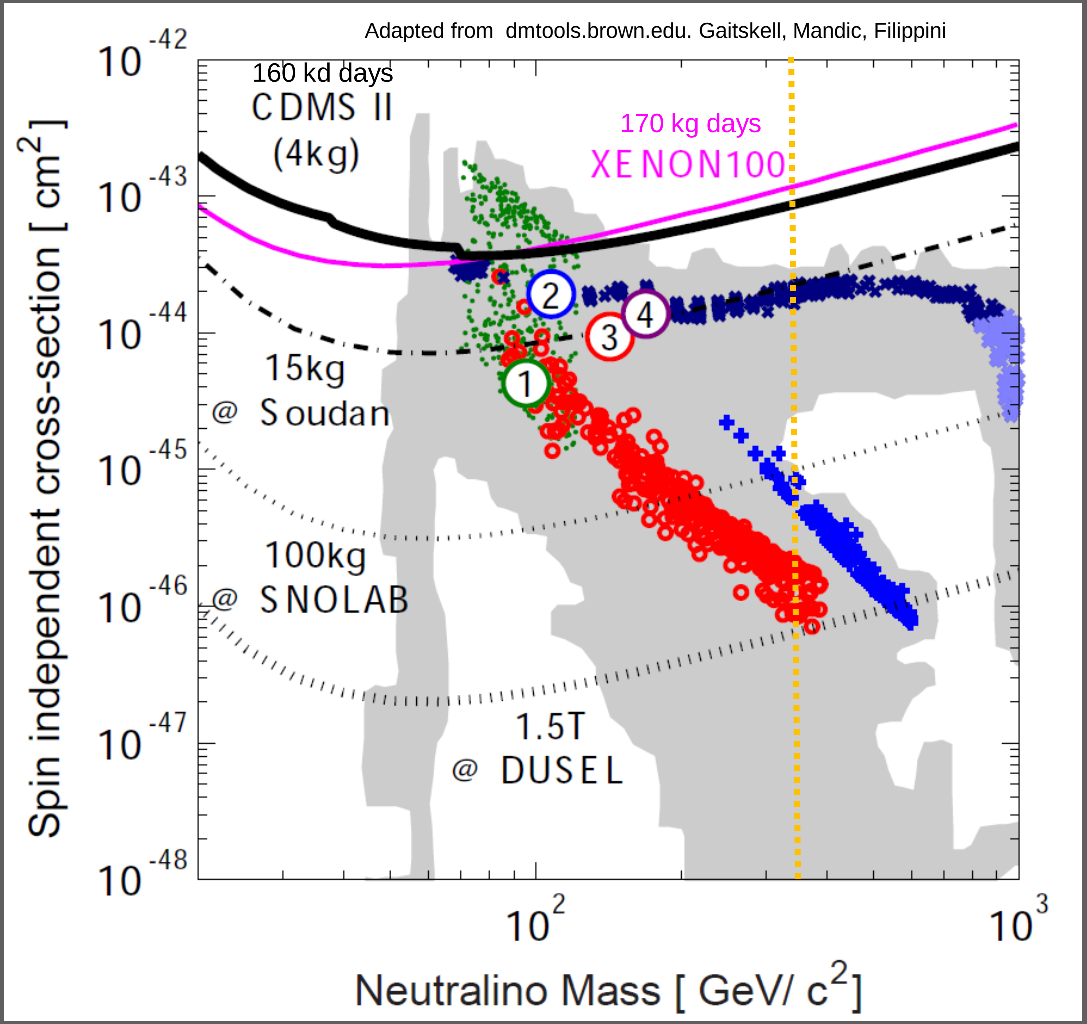
** new collaborators or new institutions in SuperCDMS*

Probe Physics Beyond the Standard Model

Improve sensitivity by three decades (few 10^{-44} to 2.10^{-47}) in the next 10 years

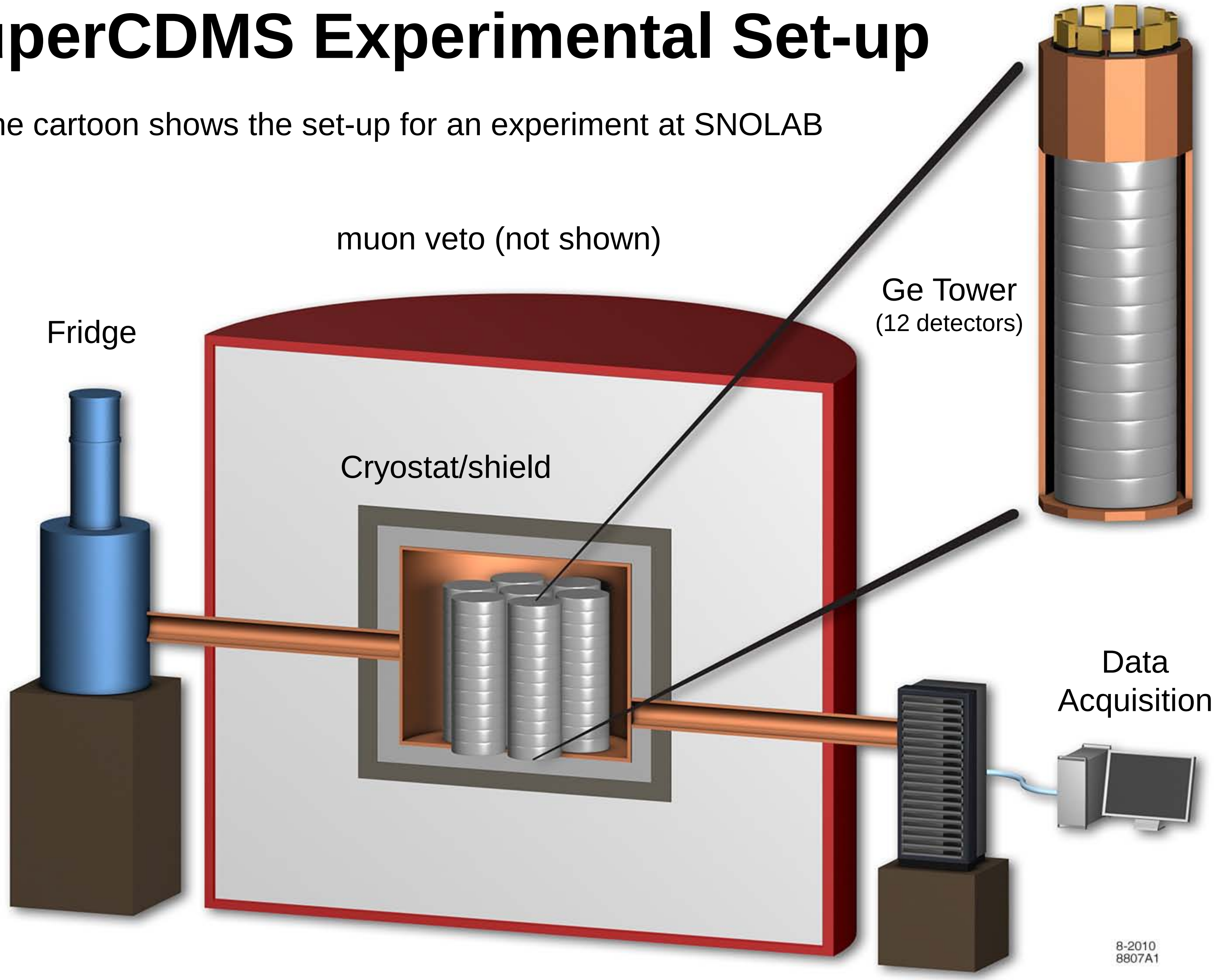
- **Discovery potential for the next 5-10 years**
  - **Search for WIMPs**
- **Projected Sensitivity**
  - **3.10^{-46} cm^{-2}**
    - **SNOLAB ~ 2016**
  - **2.10^{-47} cm^{-2}**
    - **DUSEL ~ 2020**



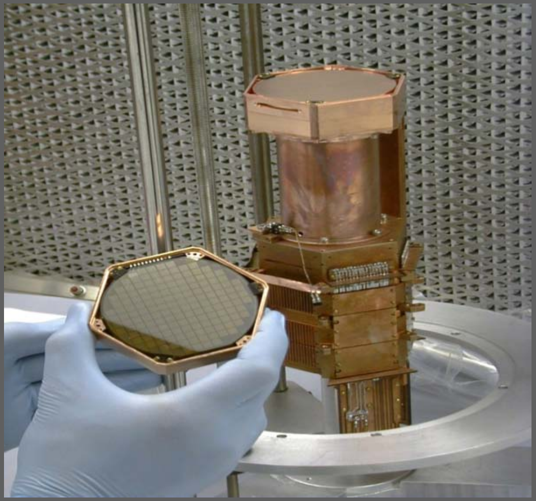
Mass of a Weakly Interacting Massive Particle (WIMP) (dark matter candidate)

SuperCDMS Experimental Set-up

the cartoon shows the set-up for an experiment at SNOLAB



Advanced Instrumentation to Improve Background Rejection

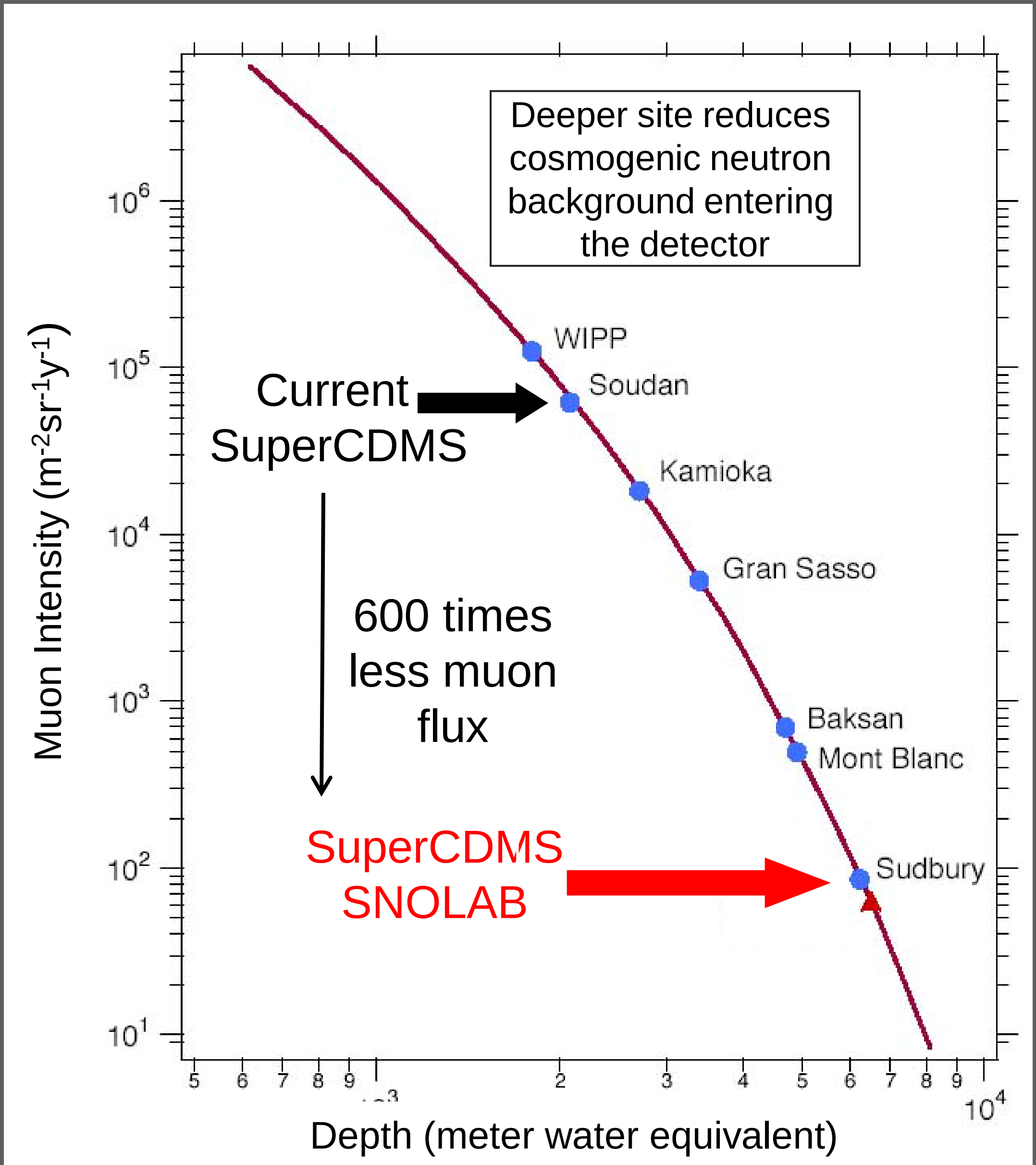


- State-of-the-art Ge detector
  - Phonon (lattice vibrations) and charge readout
    - Fabricated at Stanford
- Operate at low temperatures (40 mK)
  - Near absolute zero one can measure phonons and charge liberated by WIMP interactions.
- Reduce backgrounds to ensure sensitivity to WIMP signal
  - Use radiopure materials
    - Minimizing radiogenic neutron background is important for large experiments
  - Active detector discrimination against backgrounds
  - Operate underground
    - Cosmogenic neutron background is reduced

Goal is less than 1 background event for entire exposure

Operate Underground to Reduce Backgrounds

- **Soudan**
  - **< 1 unvetoed neutron for ~ 7000 kg-days**
  - **2090 mwe ~ 0.7 km**
- **SNOLAB**
  - **1 neutron / year / ton**
  - **6060 mwe ~ 2 km**
- **DUSEL**
  7100 mwe



The Challenges Ahead

- **All leading technologies plan experiments within a decade with target fiducial mass of order 1 ton**
  - **to map out the bulk of the interesting parameter space for WIMP searches**

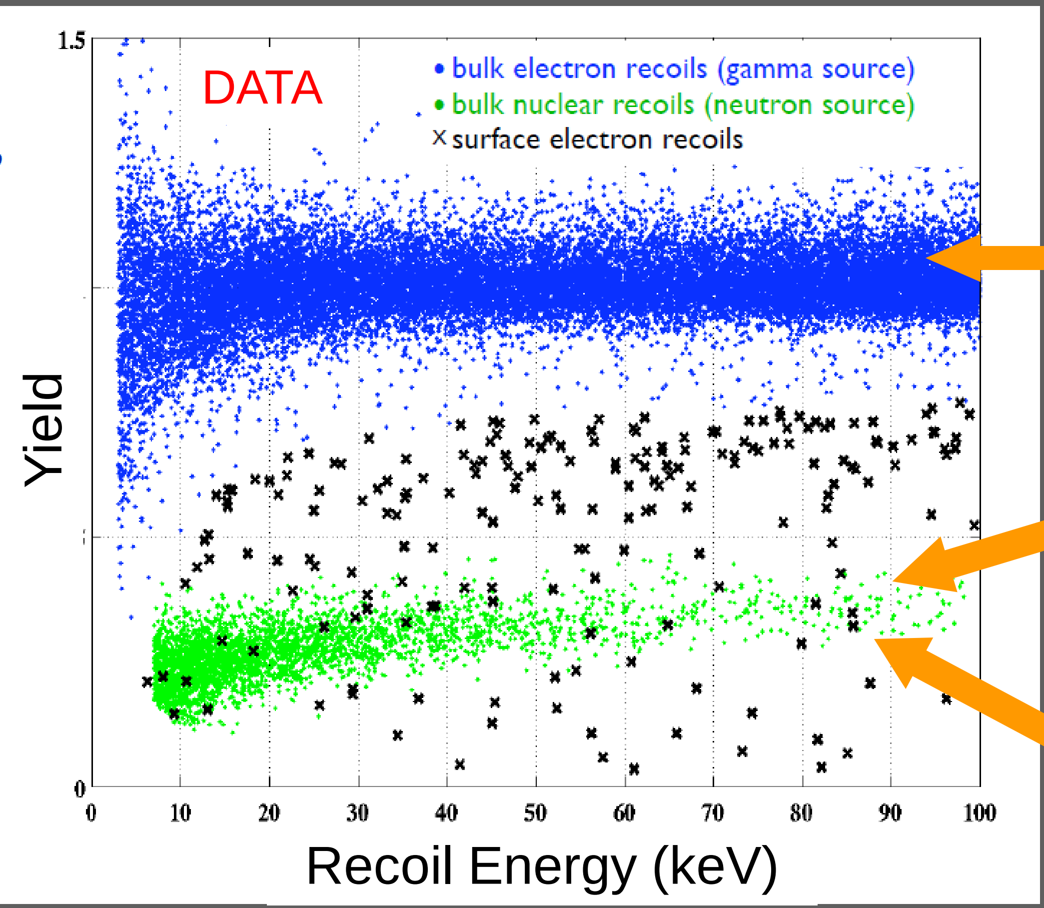
Opportunity to bring the current detector fabrication effort at Stanford to SLAC and partner with Universities and other National labs to enable a large target mass experiment

- **Scalability issues to be addressed**
  - **Provide new avenues to improve background rejection**
  - **Demonstrate feasibility of detector fabrication for large fiducial mass**

"Standard" CDMS II Technique

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

strong dependence
on <u>type</u> of recoil
(Lindhard)



Background

Yield	
1	bulk electromagnetic
0.1 to 1	surface electromagnetic
0.3	neutrons

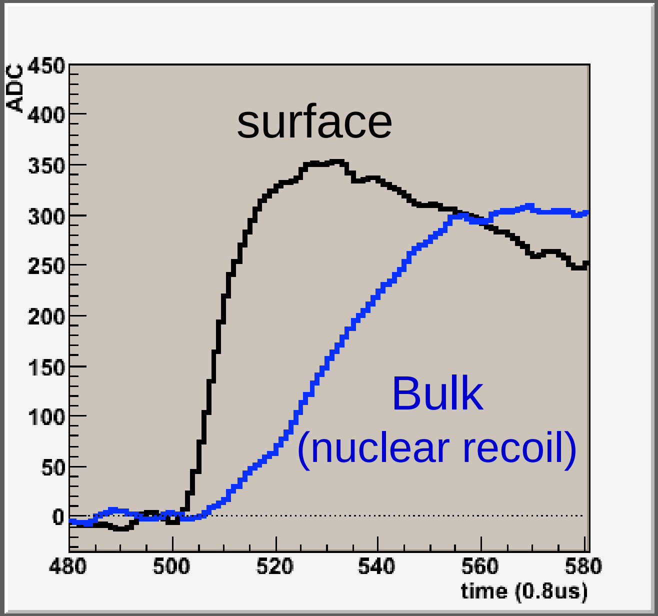
Signal

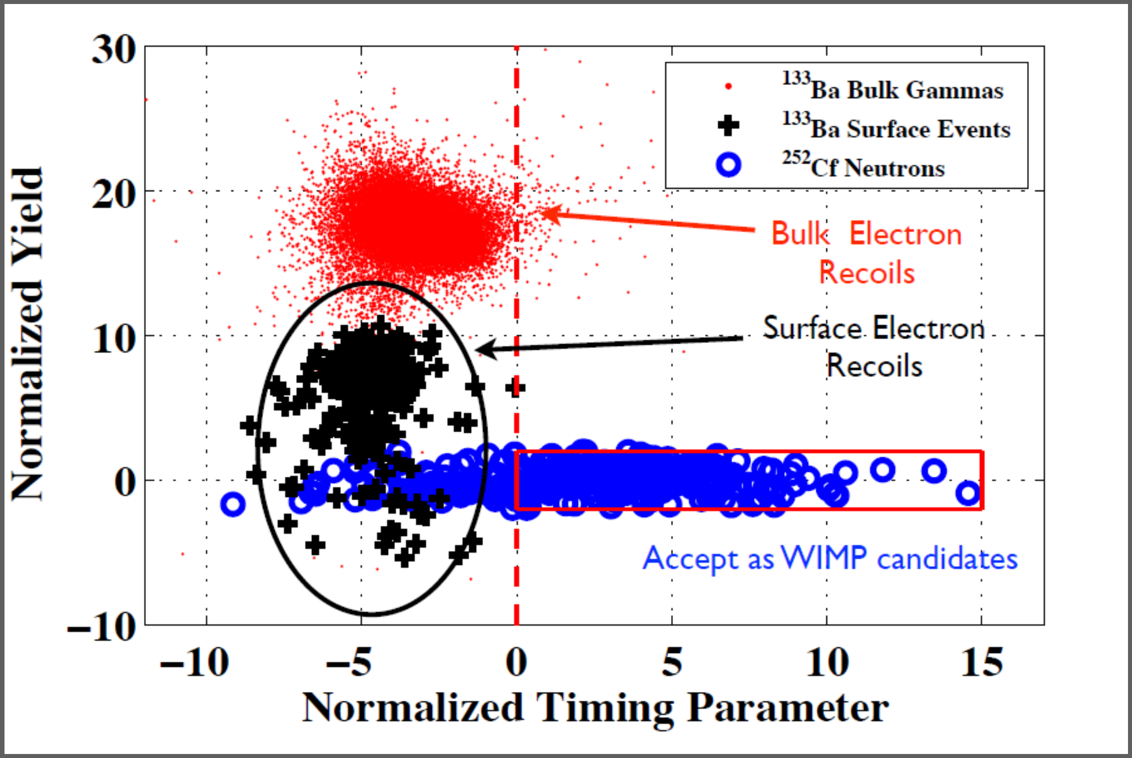
Yield ~ 0.3 for dark matter candidates

Recoil Energy measured via phonon readout

CDMS II - Robust Background Discrimination

Phonon signals provide an extra handle on background rejection





Time and shape of phonon pulses provide robust background discrimination

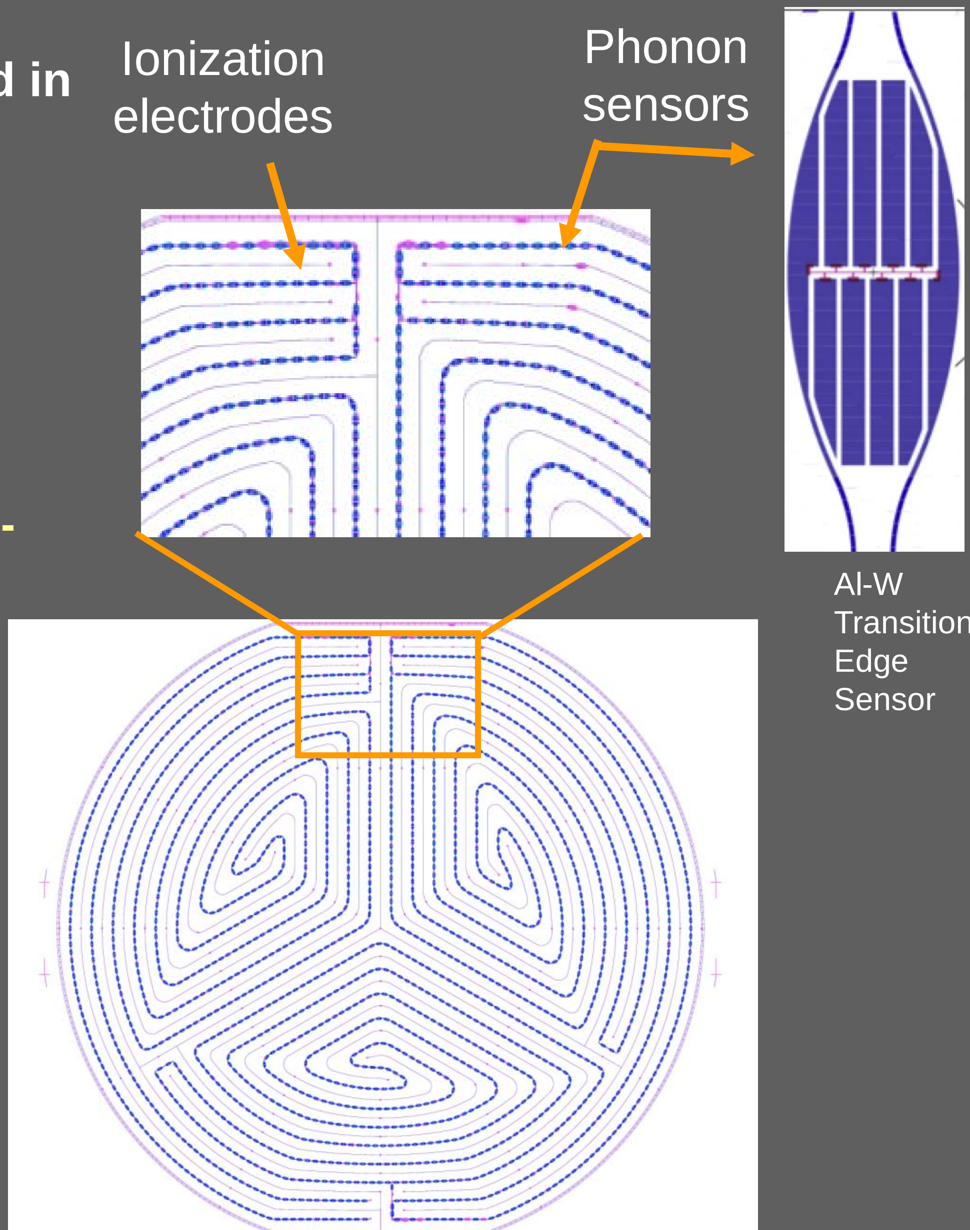
Use calibration sources to determine optimal phonon timing

Novel Detector Technology (iZIP)

- **New detector design will be deployed in**
  - **SuperCDMS Soudan - 2011**
  - **SuperCDMS SNOLAB - 2014**
  - **GEODM DUSEL - 2018**

- **Improved electromagnetic surface background rejection**
  - **performance expected to enable zero-background one-ton experiment!**

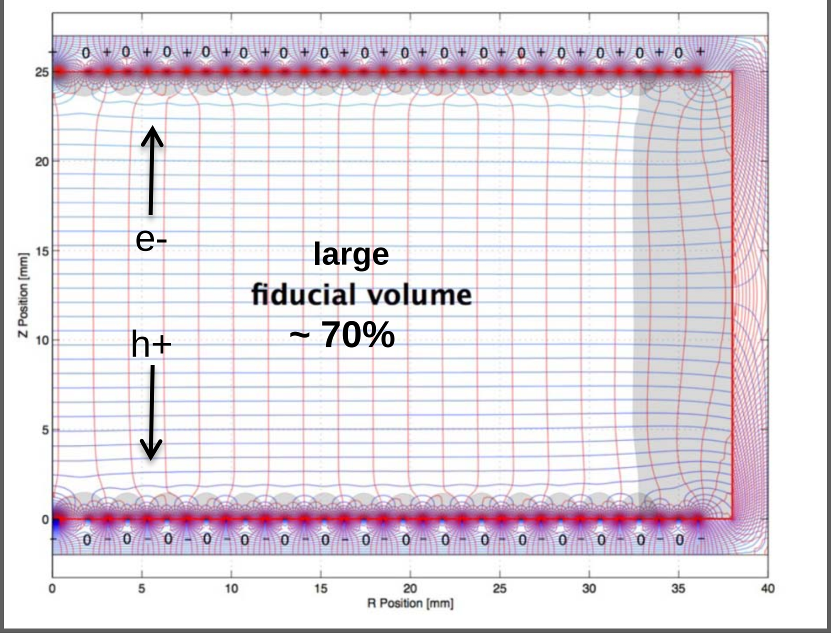
- **iZIP detector design**
  - **Interleaved phonon and charge ionization readouts**
  - **Double-sided phonon readout**

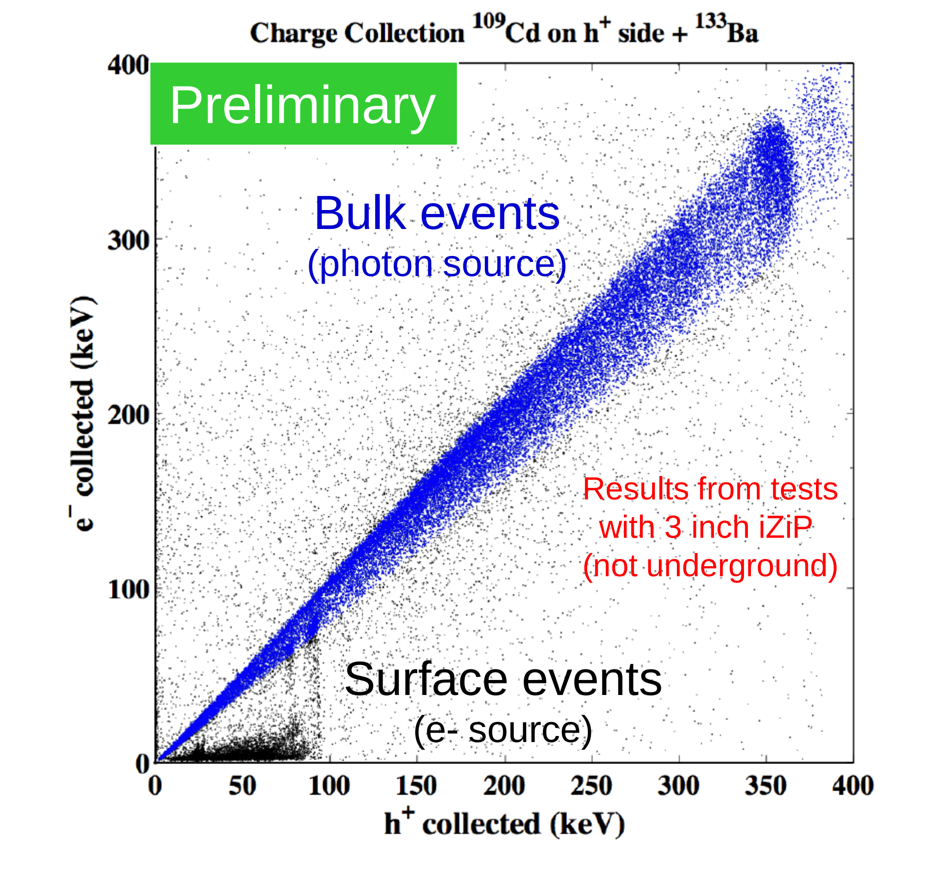


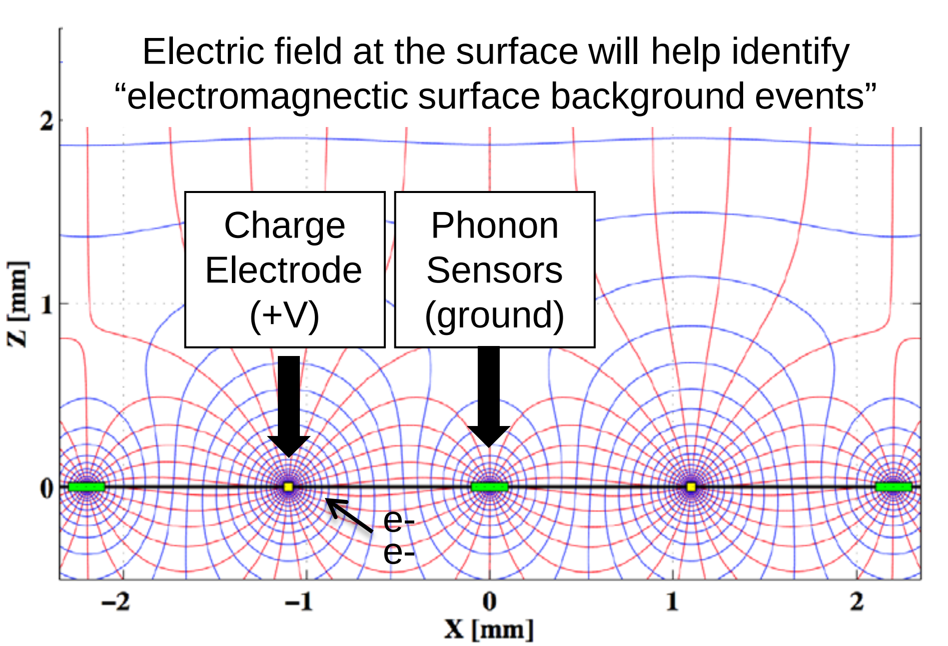
Rejection of Surface Background Events

Electromagnetic interactions in the bulk of the crystal will produce ionization signals that are symmetric between top and bottom faces of the detector

Will be tested underground at Soudan mine in 2011







Additional Rejection-Double Sided Phonon Readout

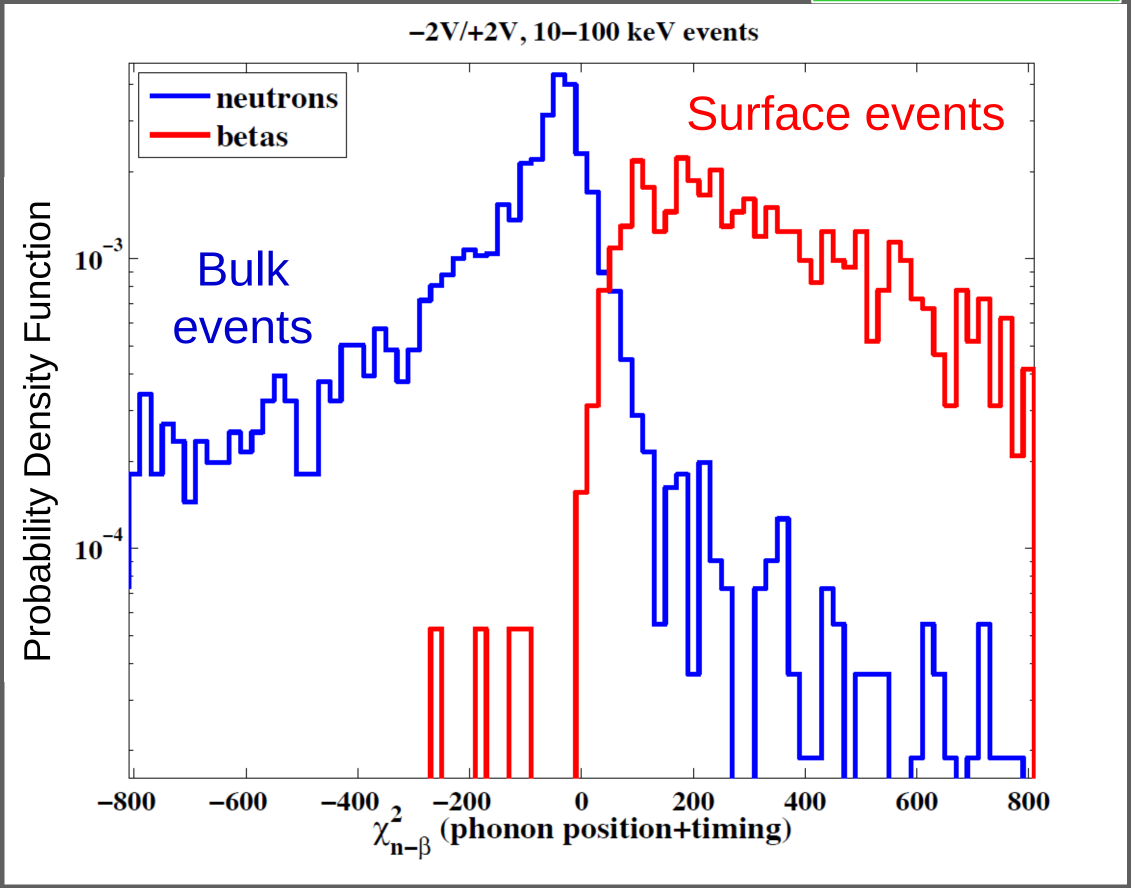
Electromagnetic surface background rejection is obtained by combining phonon signals on both sides of the detector

(event-by-event basis)

Preliminary

Key capability for future experiments

The chi-square includes the time rising edges of the phonon pulses and the phonon energies

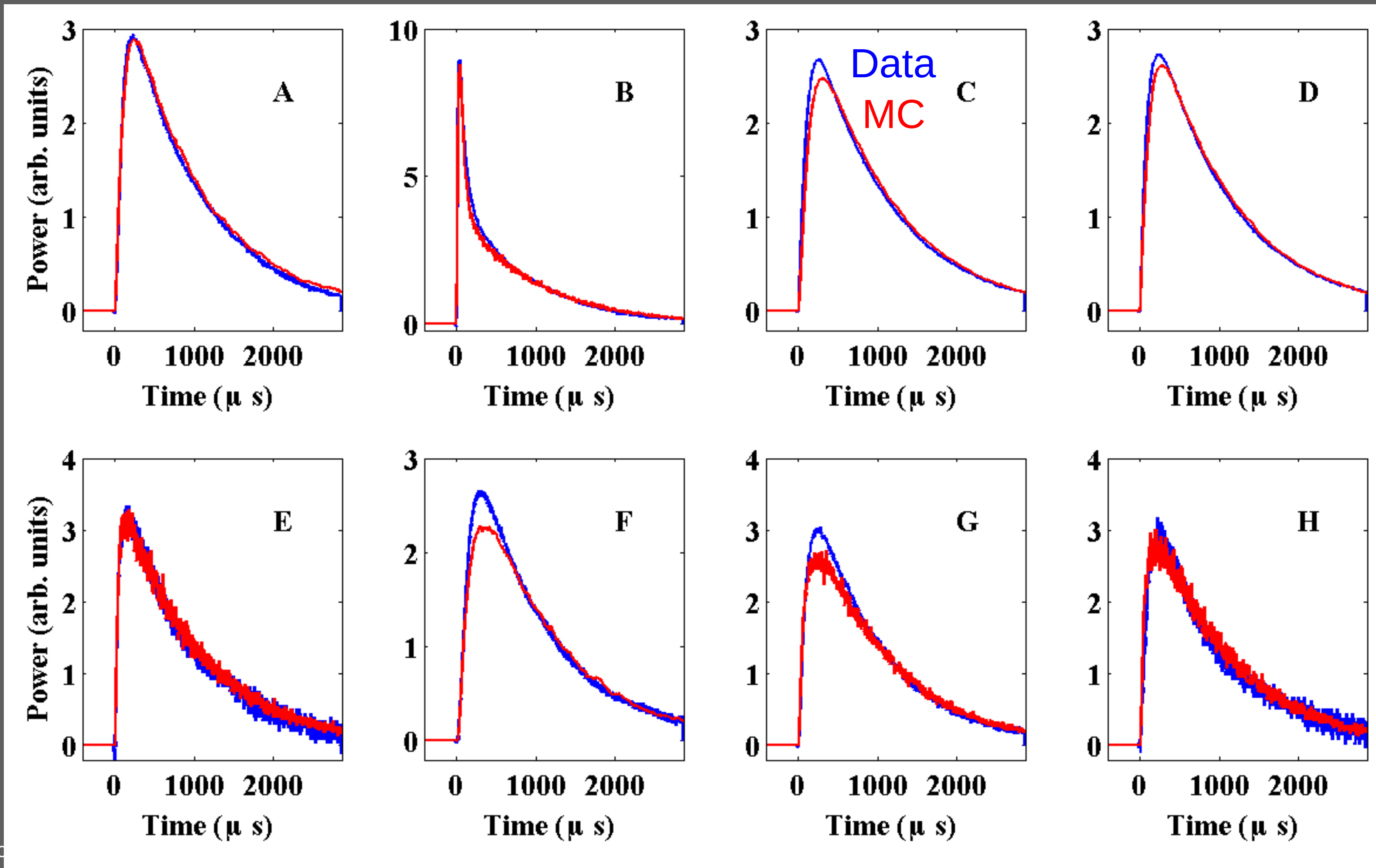


Further improve background rejection by validating the detector response

Preliminary

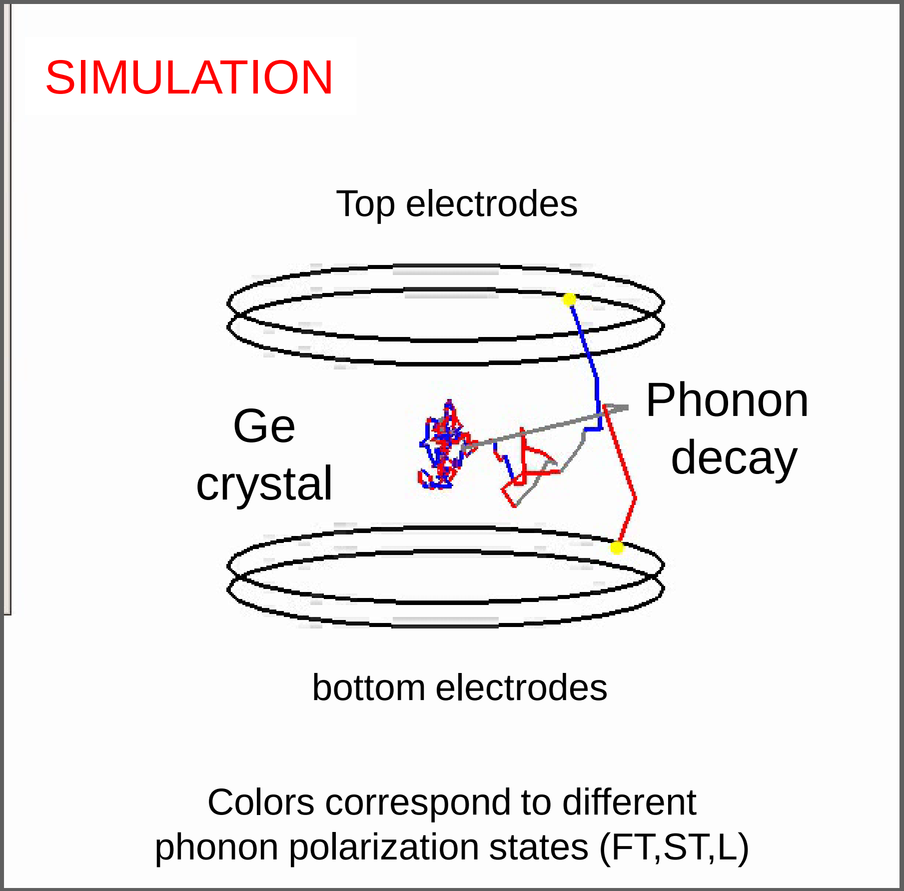
Phonon simulations show reasonable agreement between data and Monte Carlo for the new advanced detector design (iZIP).

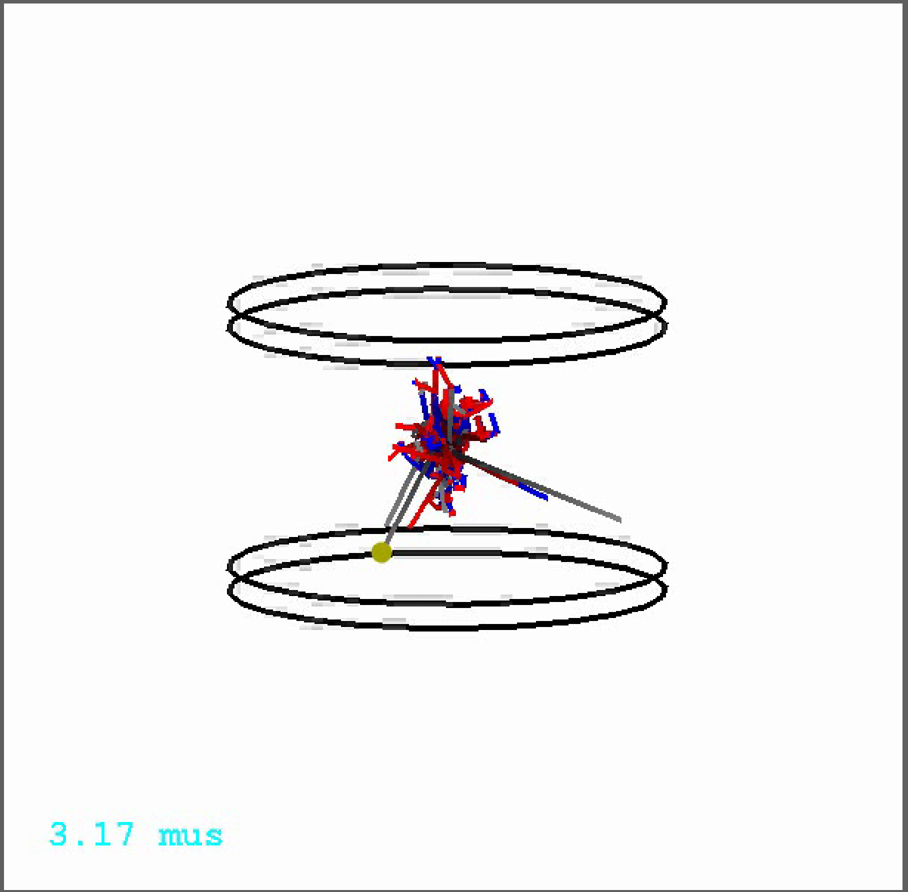
(Using SLAC batch farm for processing- heritage from the Fermi Large Area Telescope)



Can we improve it further by using Geant4?

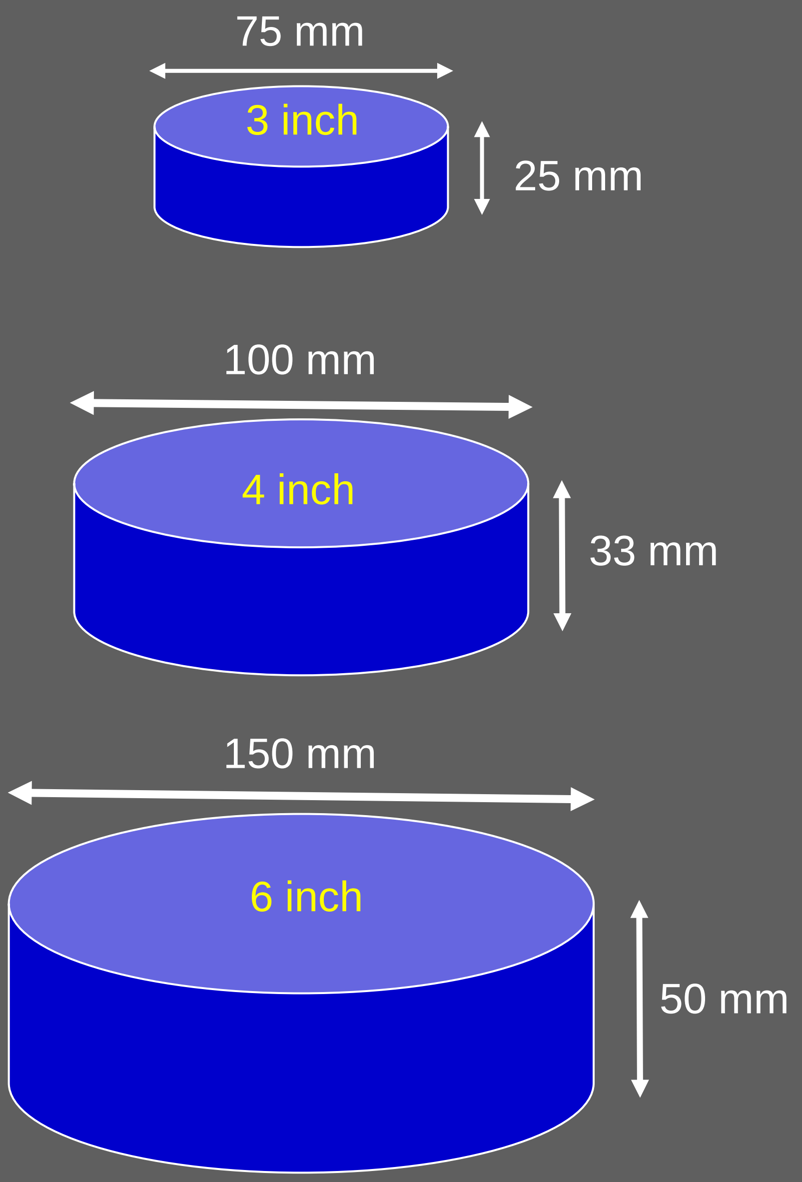
Investigating possible new avenues for improving background rejection





Our phonon transport test code includes crystal lattice orientation, anisotropic scattering (k space) and sound speed propagation for massless particles

Scaling of Ge Detector Target Mass



2011

Soudan

15 detectors – 15 kg

2014

SNOLAB

~ 80 detectors – ~100 kg

2018

DUSEL

~ 300 detectors – ~1500 kg

R&D for Large Diameter Ge Target Mass

Good progress in 2010

2010

- ✓ **Procure large crystals**
- ✓ **Adapt existing fabrication equipment**
- ✓ **Develop new photolithographic masks**
- ✓ **Produce R&D detector – charge only** ⟵ Today we are here
  - **Test bulk charge transport – crystal quality**

2011

- **Produce first R&D detector**
  - **Test phonon properties**

2012

- **R&D to streamline detector production**
- **R&D to evaluate yield and rate**

First Three 100 mm (4 inch) Crystals

These will be used for the R&D detectors for large target mass experiments

[100] lattice orientation

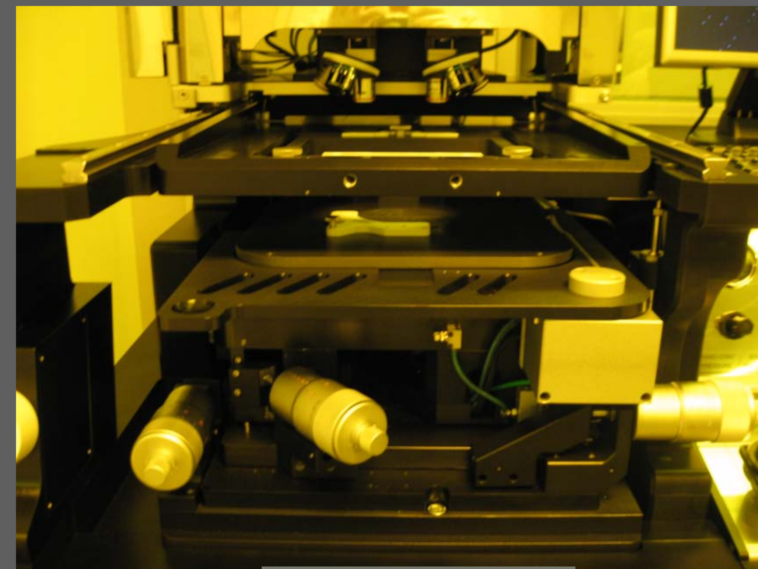
[111] lattice orientation

Fabrication Equipment for 100 mm (4 inch) Detectors

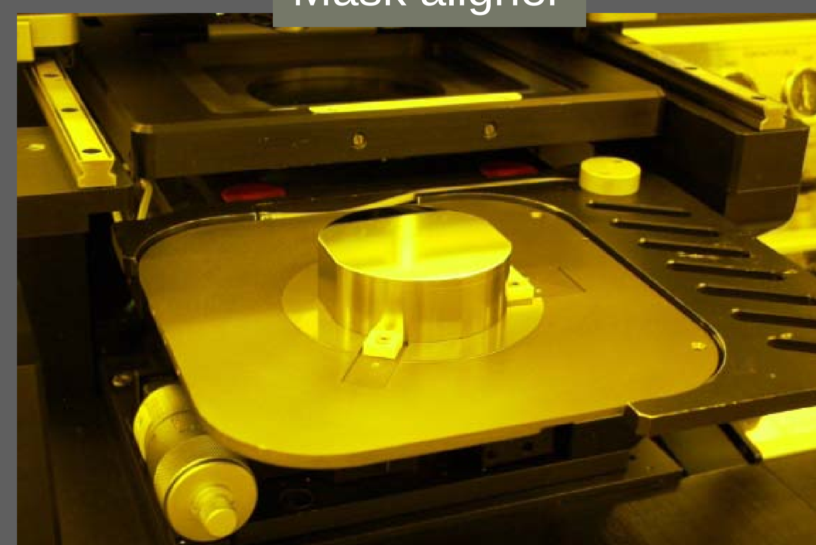
Equipment modified to allow fabrication of large diameter (100mm) detectors

- **Mask aligner fixture**
- **Plasma Etcher fixture**
- **Polypropylene Crystal holders**
- **Custom crystal cassette containers**
- **Holder for dipping crystal into developer**

Stanford Fabrication team
(has been training the SLAC team)



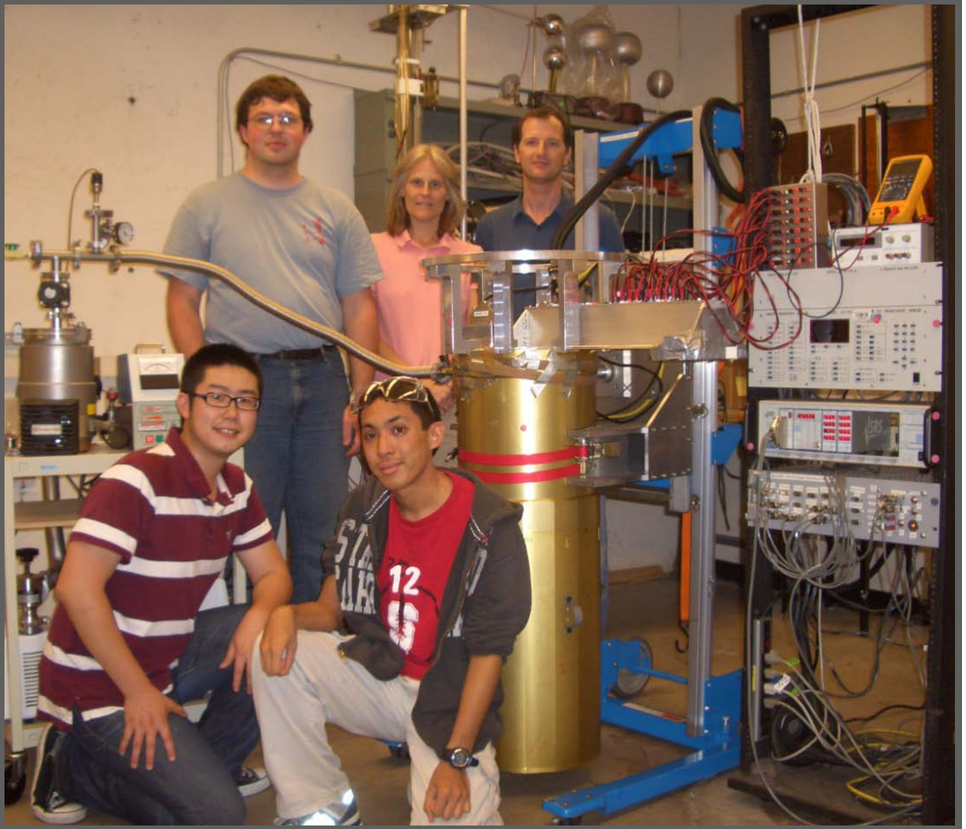
Mask aligner

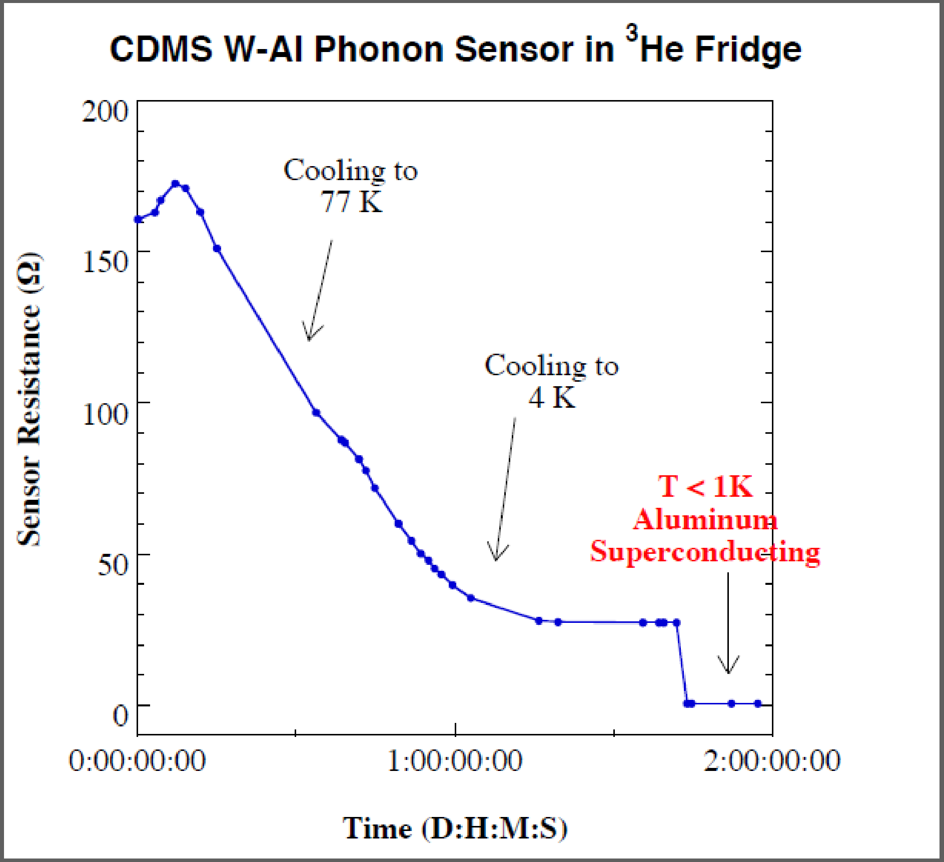


Fabrication Process Control – Al Continuity Test

To check continuity of Al electrodes requires a cryogenic test at superconducting temperatures

Current work is on 3 inch detectors (demonstration of the method)





Next step is to develop a system adequate for testing large diameter detectors

Automation of Visual Inspection

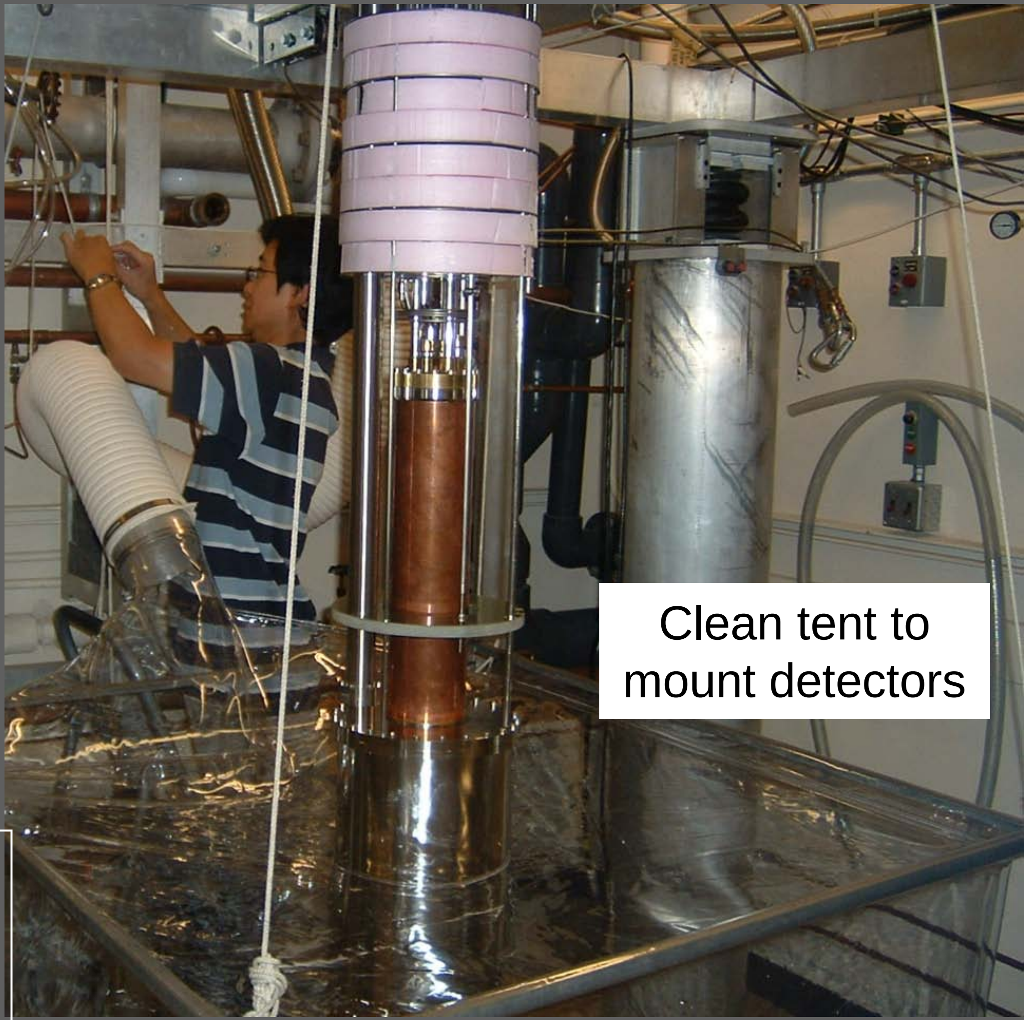
Next step is to develop an automated pattern recognition

Offline web tool to navigate through images

Automated Visual inspection equipment

It takes 4 hours to scan a 3 inch diameter detector (~10,000 images stitched together)

First Detector will soon be tested in Minnesota



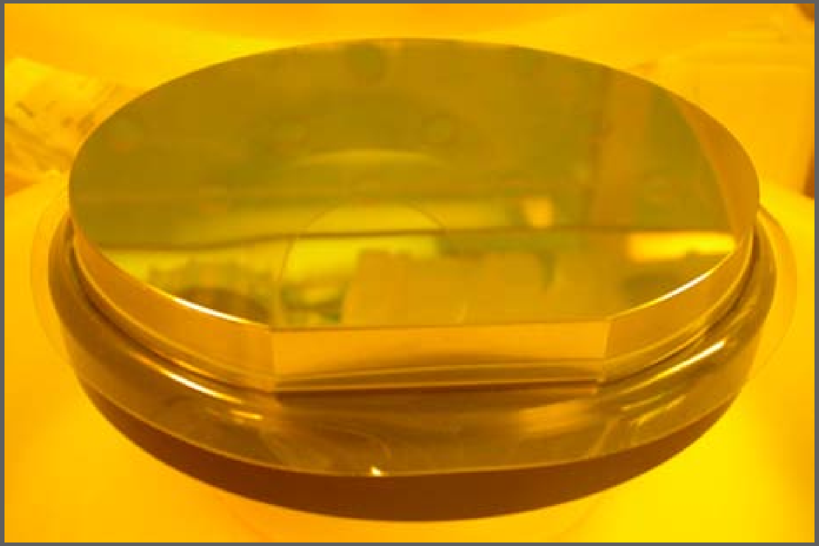
Verify charge transport in the bulk (2010) and phonon properties (2011) for large diameter (100 mm) detectors

Initial Steps towards 1 ton experiment

30 mm diameter x 10 mm thickness
test sample - dislocation free Ge
(LBNL E. Haller)

Crystal procurement is harder for
6- inch technology

Detectors dimensions:
150 mm in diameter
50 mm thickness



Mass simulator to test
photoresist deposition for 6 inch crystals

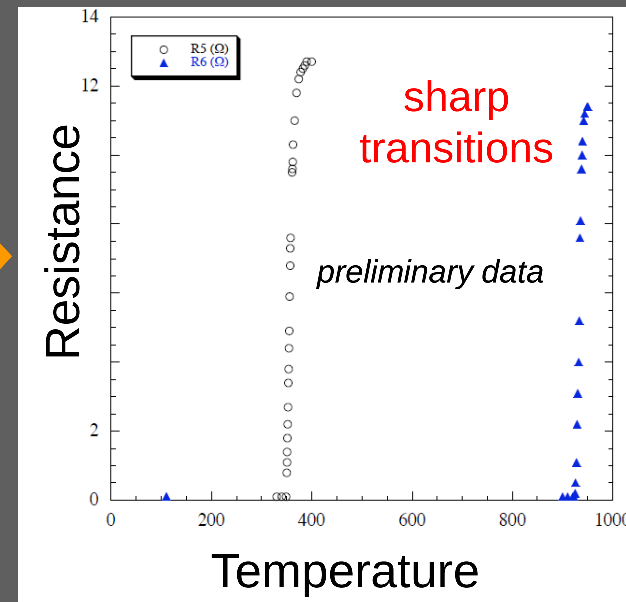
Automation of Equipment for 6 inch Detectors

Goal is to demonstrate full cycle of Ge fabrication

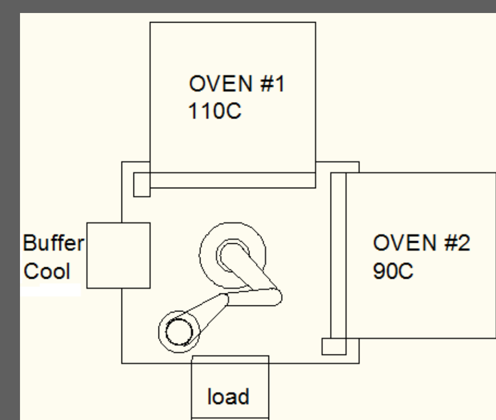
High quality Al deposition has already been demonstrated

Automated deposition system for phonon transition edge sensors coming online at TAMU

W deposition results are encouraging



Automation of baking steps



Summary of Developments

- **CDMS is complementary to other techniques**
  - **unique capabilities for identifying nuclear recoils without background contamination**
    - **Intrinsic scalability of background rejection**
  - **charge and phonon signals with high statistics**
    - **even at low energy deposits**

- **The advanced detector design (iZIP) provides robust and <u>redundant</u> capabilities for background rejection**
  - **Test results indicate "zero-background" sensitivity up to 1 ton**
    - **Ionization yield, charge asymmetry, and phonon pulse shape**

- **We have started addressing scalability issues for large Ge target mass experiments**
  - **First full R&D detector expected for 2011**

Last Words…

- The origin of Dark Matter is one of the top scientific questions of our times
  - Very little is actually known about the properties of dark matter
  - Next 10 years are exciting: expect results from many experiments

- CDMS experiments will probe a large fraction of the parameter space for a dark matter candidate (WIMP)
  - Deployment of 15 kg (2011), ~100kg (2014) and 1500 kg (2018)

- SLAC has identified areas to contribute to the CDMS roadmap and is partnering with Universities and other laboratories to enable large target mass experiments
  - SLAC is working on scalability of Ge detector fabrication and of software systems and on new avenues for background rejection

Thank you !