OUTLINE:

1. Direct Dark Matter Search: SuperCDMS
2. Backgrounds
3. iZIP design
4. Interactions in the detectors
5. Background discrimination techniques
   - Yield
   - Ionization
   - Phonon Pulse Shape

SuperCDMS STATUS AND PROSPECTS

Bedile Karabuga
Southern Methodist University
SuperCDMS Collaboration
APS-2011

SuperCDMS COLLABORATION

California Institute of Technology
Z. Ahmed, B. Doughthery, J. Filippini, S.R. Golwala, D. Moore, R. Nelson, R.W. Ogburn

Fermi National Accelerator Laboratory
D. A. Bauer, F. DeJongh, J. Hall, S. Hansen, D. Holmgren, L. Hsu, R.L. Schmitt, R. B. Thakur, J. Yoo

Massachusetts Institute of Technology
A. Anderson, E. Figueroa-Feliciano, S. Hertel, S.W. Leman, K.A. McCarthy, P. Wikus

NIST
K. Irwin

Queen's University
C.H. Crewdson, P. Di Stefano, J. Fox , O. Kamaev, S. Liu , C. Martinez, P. Nadeau, K. Page, W. Rau, Y. Ricci, M.A. Verdier

Santa Clara University
B. A. Young

Southern Methodist University
J. Cooley, B. Karabuga, H. Qiu, S. Scorza

SLAC/KIPAC
M. Asai, A. Borgland, D. Brandt, P.L. Brink, W. Craddock, E. do Couto e Silva, G.G. Godfrey, J. Hasi, M. Kelsey, C. J. Kenney, P. C. Kim, R. Partridge, R. Resch, D. Wright

Stanford University
B. Cabrera, M. Cherry , R. Moffatt, L. Novak, M. Pyle, M. Razeti, B. Shank, A. Tomada, S. Yellin, J. Yen

Syracuse University
M. Kos, M. Kiveni, R. W. Schnee

Texas A&M
R. Harris, A. Jastram, K. Koch, R. Mahapatra, M. Platt , K. Prasad, J. Sander

University of California, Berkeley
M. Daal, T. Doughty, N. Mirabolfathi, A. Phipps, B. Sadoulet, D. Seitz, B. Serfass, D. Speller, K.M. Sundqvist

University of California, Santa Barbara
R. Bunker, D.O. Caldwell, H. Nelson

University of Colorado Denver
B.A. Hines, M.E. Huber

University of Florida
D. Balakishiyeva, T. Saab, B. Welliver

University of Minnesota
J. Beaty, H. Chagani, P. Cushman, S. Fallows, M. Fritts, T.Hoffer, V. Mandic, X. Qiu, R. Radpour, A. Reisetter, A. Villano, J. Zhang

SuperCDMS EXPERIMENT

- CDMS : Cryogenic (~40mK) Dark Matter Search
- Soudan Underground Laboratory
  - 780 m. rock = 2080 m. water

→ "**0 background**" experiment

<1 event → **Science goal of SuperCDMS**

Why???

WIMPS: **Weakly interacting** → high background,
small interaction rate (<1event/kg/week)

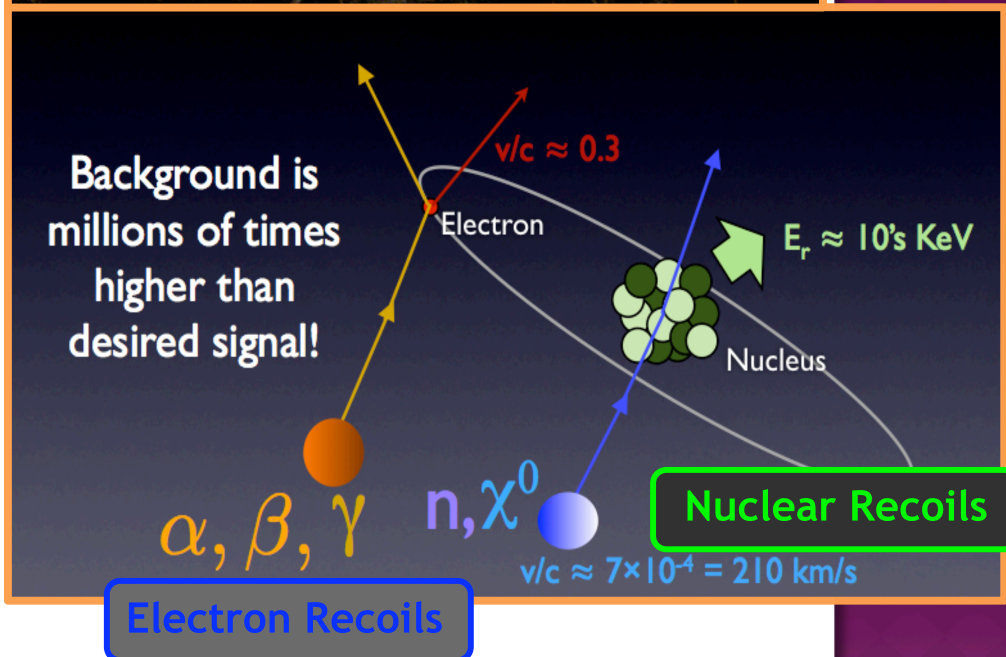
Massive → interaction with nucleus and remaining
recoiling nucleus has low energy ~10's keV

Particles

SuperCDMS EXPERIMENT

Challenges	Detection Requires	SuperCDMS
Low interaction rate **(< 1 event/kg/week)**	High exposure = Large Detector Mass + long run	**Increased the exposure by 2.5** **1 cm → 1 inch height**
Low recoil energy **(~10s of keV)**	Low energy threshold Excellent Resolution	**Cryogenic detectors** **→Phonons**
High Background	1. Background knowledge 2. Low radioactivity 3. Powerful rejection	See next slide

BACKGROUNDS



Background Sources:

<u>Cosmogenic muons</u>

➔ leading cosmogenic neutrons

➔ rejected by active veto

<u>Radioactive neutrons</u>

➔ polyethylene shielding

<u>Gammas from radioactive impurities</u>

➔ Lead shielding

<u>Rn exposure</u>

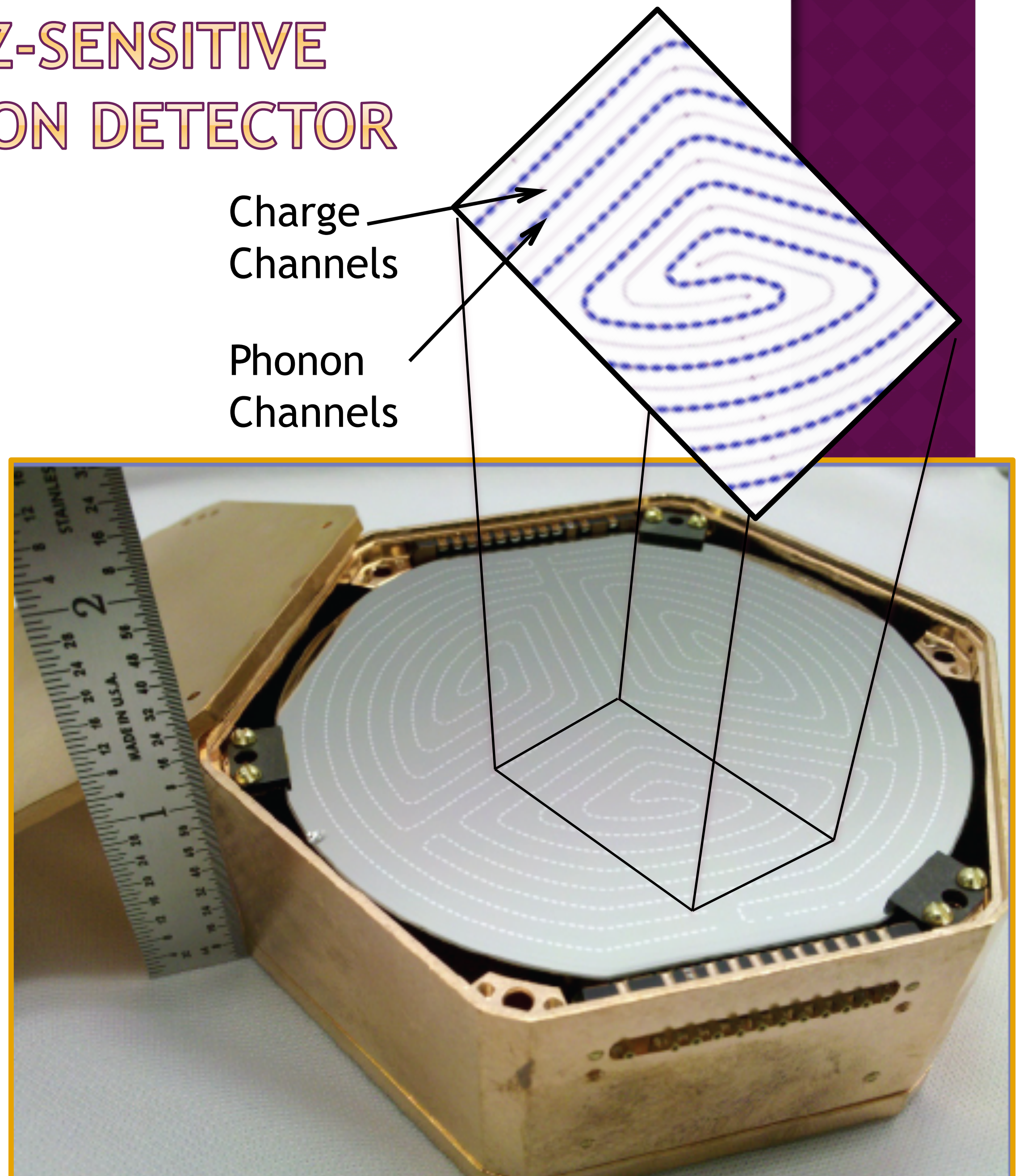
➔ implants ^{210}Pb on detector surfaces

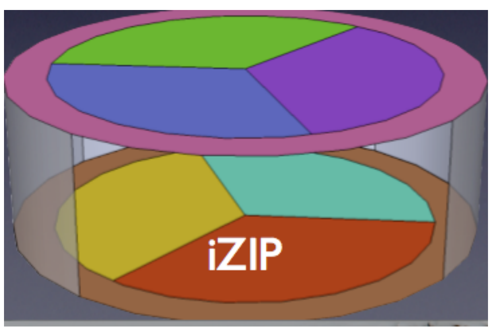
Inside the crystals:

1. Gamma interactions in the bulk of the crystal : BULK GAMMAS
2. Interactions near surface : SURFACE EVENTS
    1. Beta emitted by ^{210}Pb implanted on the surfaces of the detector while fabrication and testing
    2. Low energy electron interactions in the crystal near surfaces

IZIP : INTERLEAVED Z-SENSITIVE IONIZATION AND PHONON DETECTOR

- 1 inch thick Ge
- NEW interleaved layout of ionization and phonon sensors
- Phonon and charge sensors on BOTH sides
- The 3 inner -1 outer phonon channels layout and rotation in bottom channels by 60 degree enable very good position reconstruction

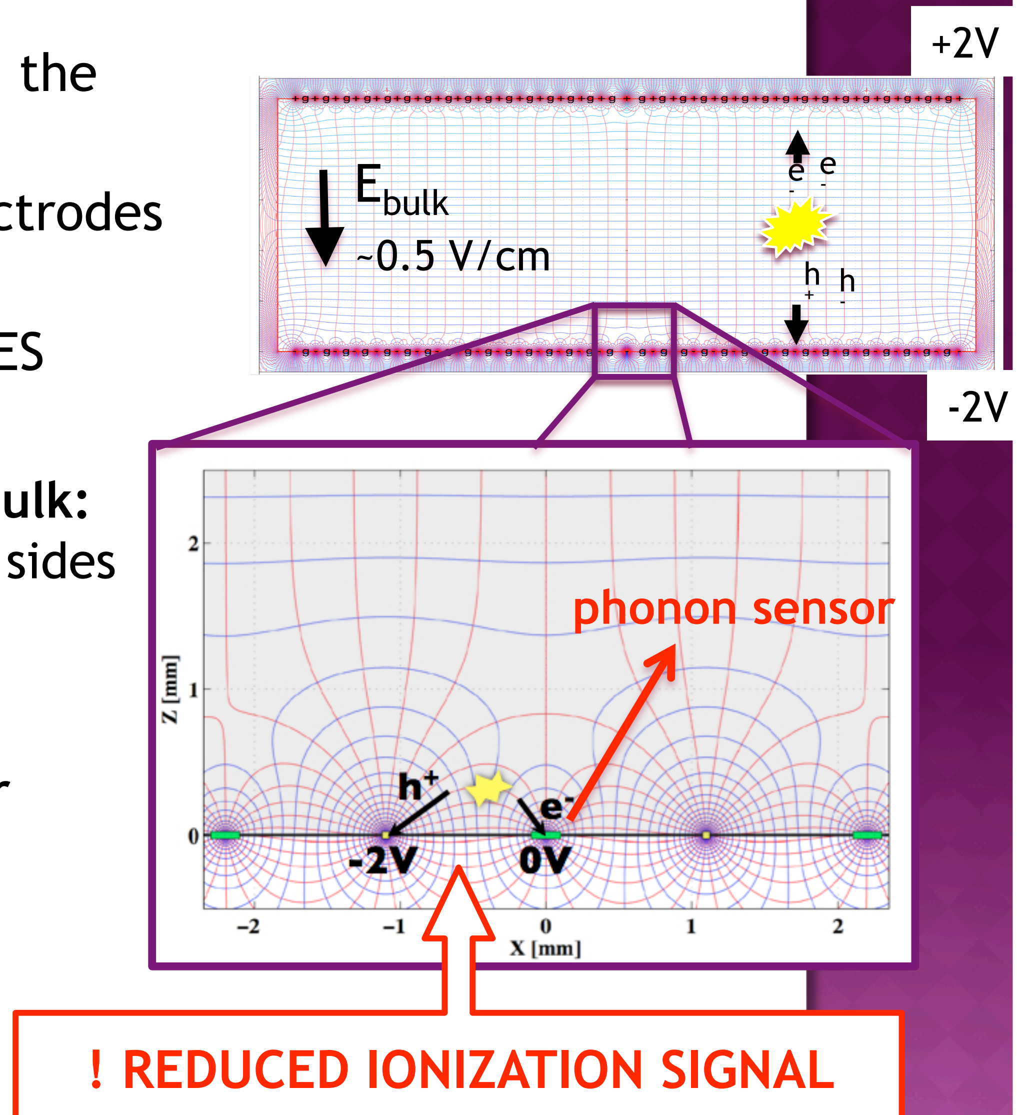




INTERACTIONS IN THE CRYSTAL

2 signals from each interaction in the crystal:

1. e-h pairs collected by electrodes (3 eV/pair)
2. Phonons collected by W-TES



BULK EVENTS - Interactions in the bulk:

- Phonons collected by both sides
- e-h pairs are collected by opposite sides

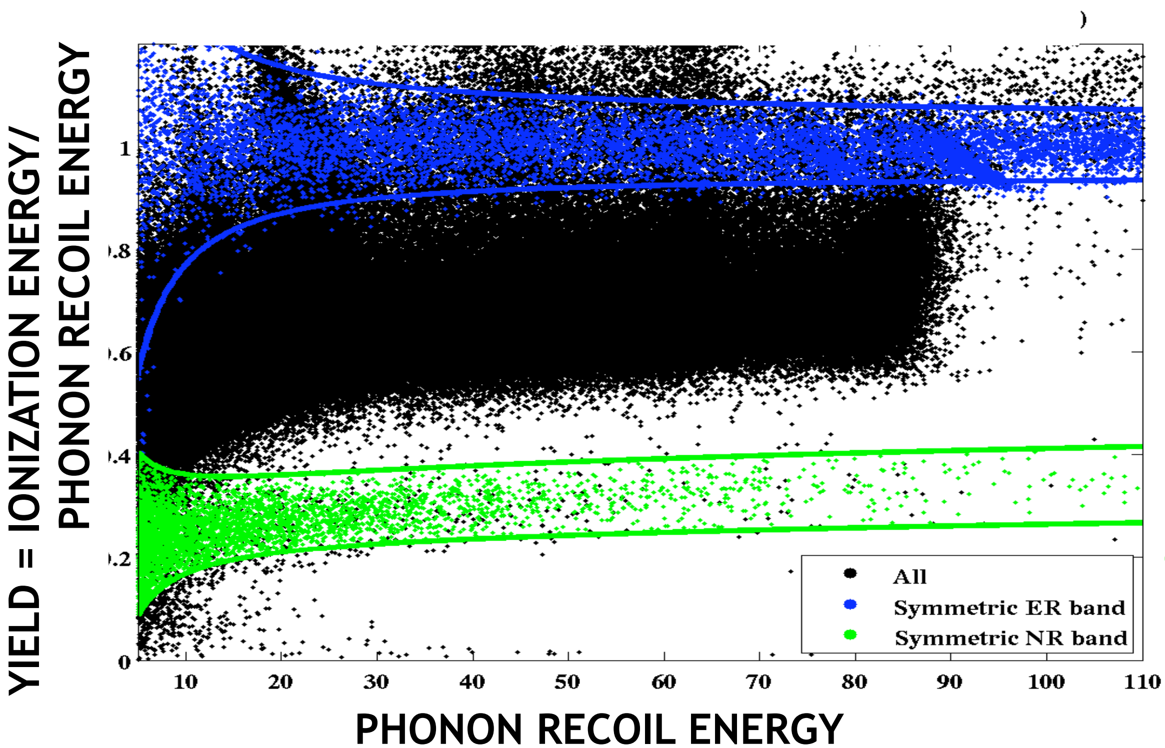
SURFACE EVENTS - Interactions near surface:

- Phonons collected by both sides
- e-h pairs are collected by the same side !!!!

YIELD

Electron Recoils: ~25% e^-/h^+ ~75% phonon
Nuclear Recoils: ~8% e^-/h^+ ~92% phonon
} Q_{ne} ~0.3 Q_{ee}

In test facilities we use;
^{133}Ba ➔ *gammas* ^{109}Cd ➔ *surface electrons* ^{252}Cf ➔ <u>neutrons</u>
to mimic our *backgrounds* and <u>signal.</u>



Y ^{133}Ba
external source

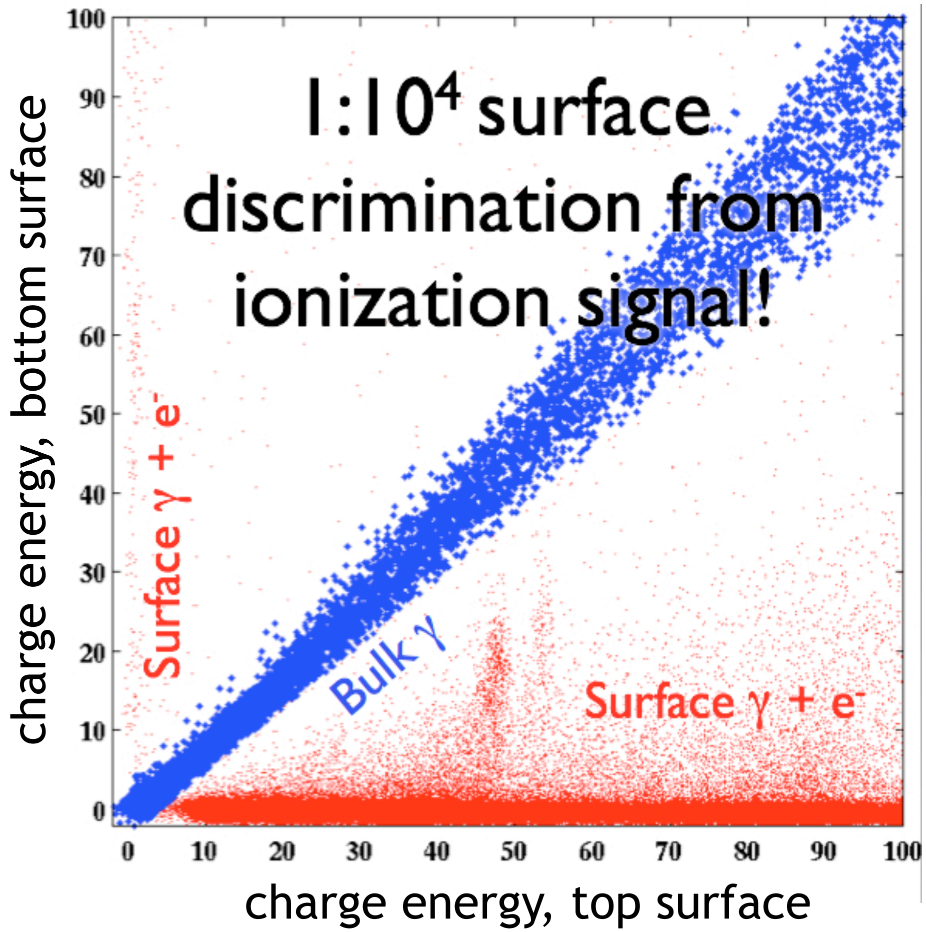
e ^{109}Cd
internal source

n ^{252}Cf
external source
& cosmogenic background
(7events/hour)

IONIZATION

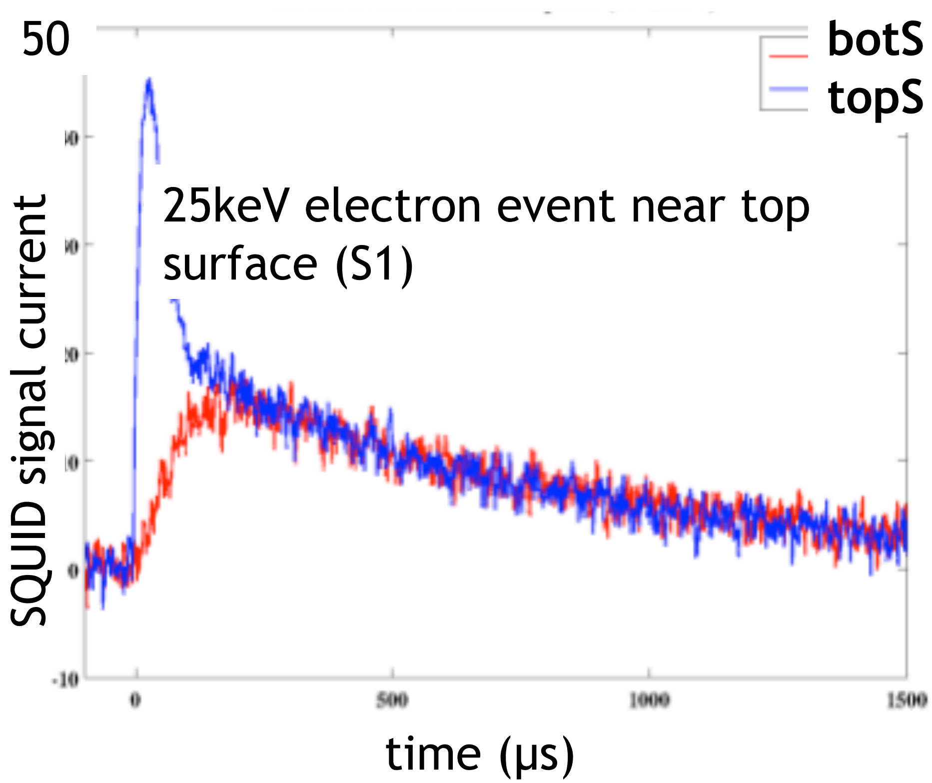
- Surface events from bulk events

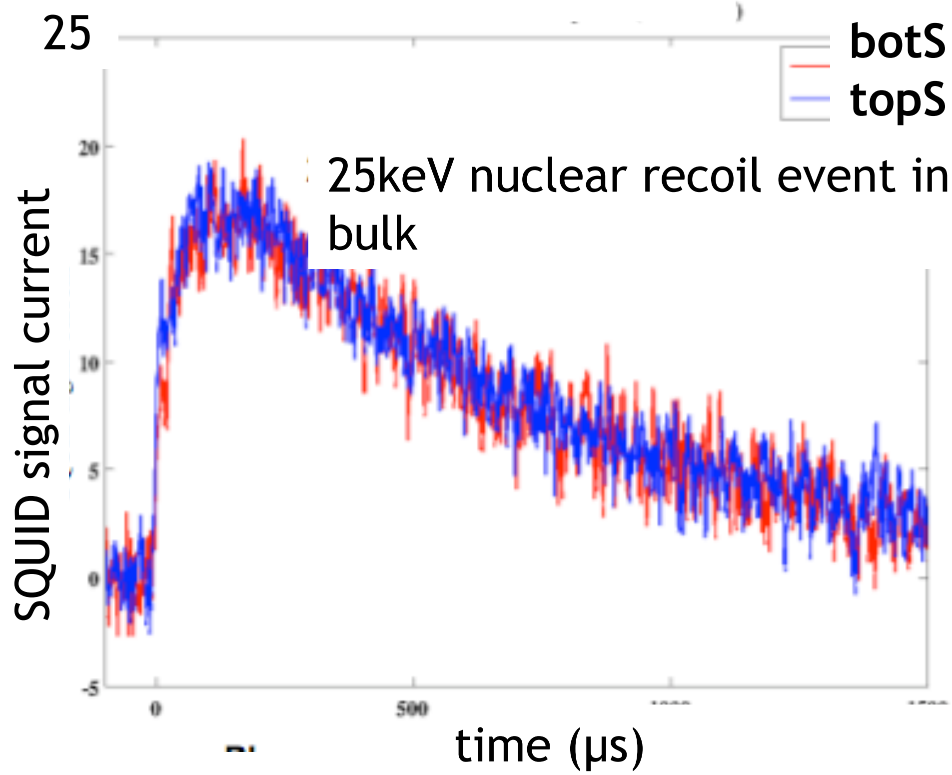
Electrodes on both surface ➔



PHONON PULSE SHAPE

- Surface events from bulk events





Bulk Event Rejection

Discrimination Type	SuperCDMS Rejection
Yield Based	> $1:10^6$
Phonon Pulse Shape (NR/ER discrimination)	>$1:10^3$ will improve significantly

Surface Event Rejection

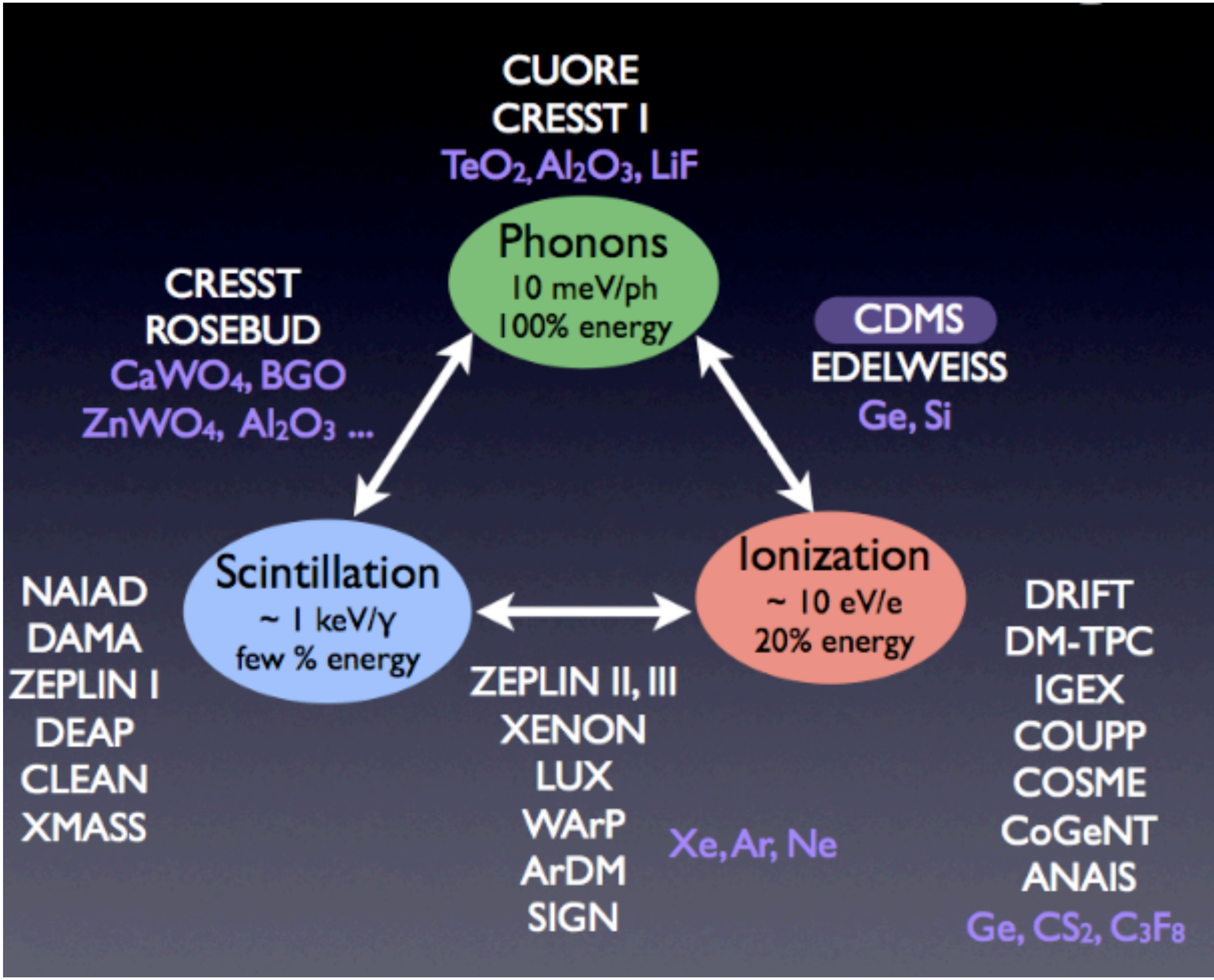
Discrimination Type	SuperCDMS Rejection
Yield Based	>$1:10^3$
Ionization Based	>$1:10^4$
Phonon Based	>$1:10^3$

TOTAL Surface Event Rejection >$1:10^6$
Way more than 1:3000 rejection required for the science goal of SuperCDMS !!

CONCLUSIONS

- CDMS collaboration produced iZIP detectors for increased rejection of background and higher probability to observe WIMPs.
- Promising iZIP performance in test facilities in both rejection and stability.
- 5 towers of iZIPs will be deployed to the Soudan mine in this November.
- Science run is expected to start in the following months in 2012.

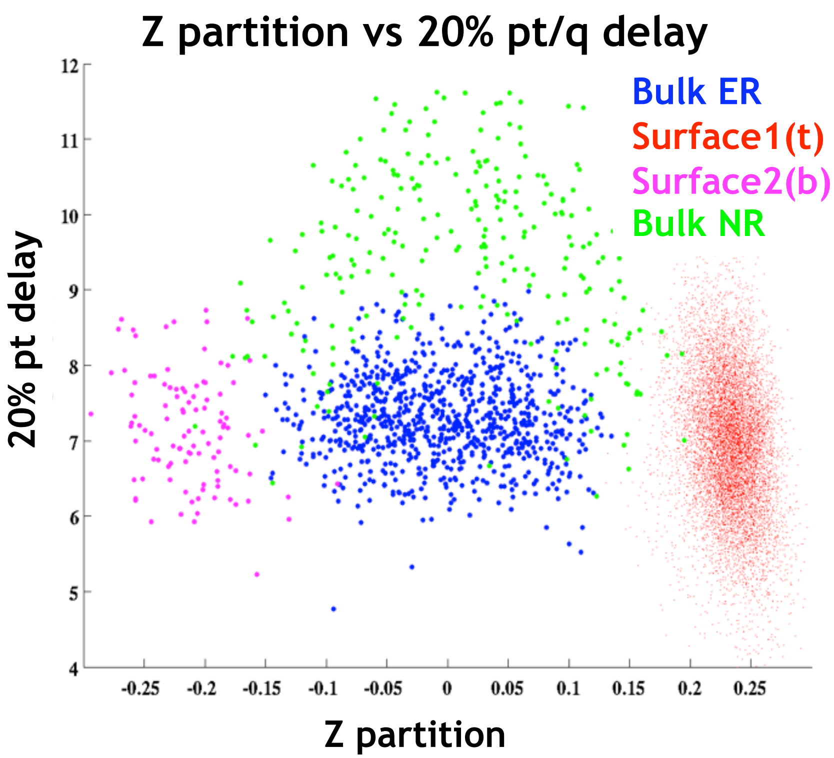
BACK-UP SLIDES

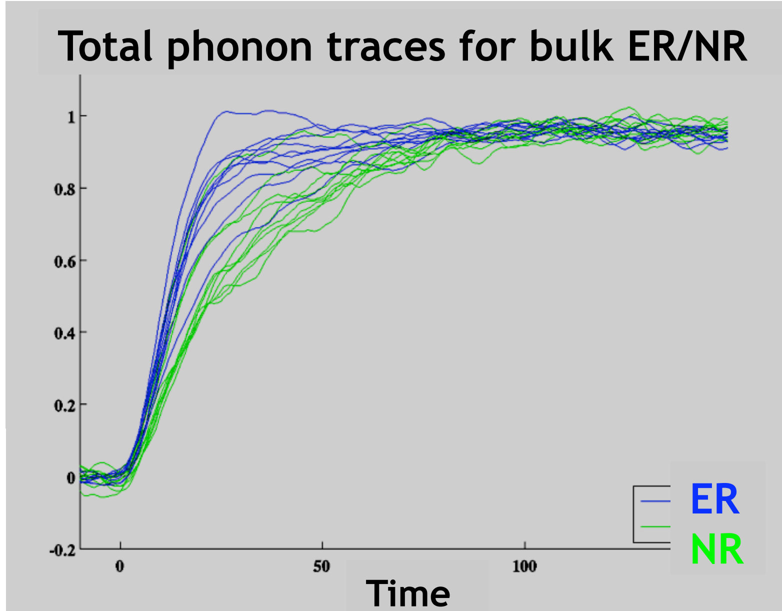

CUORE
CRESST I
TeO2, Al2O3, LiF
Phonons
10 meV/ph
100% energy
CRESST
ROSEBUD
CaWO4, BGO
ZnWO4, Al2O3 ...
CDMS
EDELWEISS
Ge, Si
Scintillation
~ 1 keV/γ
few % energy
Ionization
~ 10 eV/e
20% energy
NAIAD
DAMA
ZEPLIN I
DEAP
CLEAN
XMASS
ZEPLIN II, III
XENON
LUX
WArP
ArDM
SIGN
Xe, Ar, Ne
DRIFT
DM-TPC
IGEX
COUPP
COSME
CoGeNT
ANAIS
Ge, CS2, C3F8

To get the sensitivity to spin independent cross section per nucleon from WIMP interaction to be better than $9*10^{-45}$ cm^2 for a WIMP mass of 60 GeV/c^2

PHONON PULSE SHAPE ER/NR DISCRIMINATION

- Random 10 phonon traces for bulk ER and bulk NR





- z partition is defined as: (height side 1 trace- height side 2 trace)/(height side 1 trace + height side 2 trace)

- ER outliers:
  - Event pile-up
  - High radius events

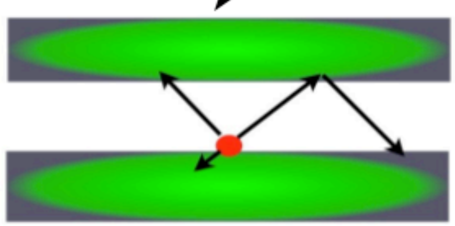
Inside the crystals:

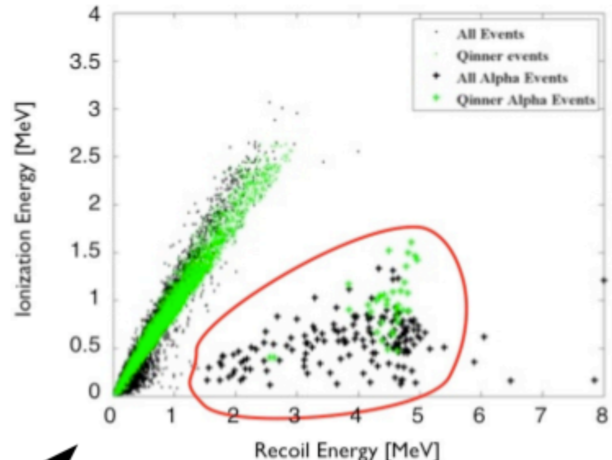
1. Interactions in the bulk of the crystal
    1. Compton scattering of the ambient photon flux
    2. 10.4 keV Gallium X-rays from e-capture decays of cosmogenically created 68Ge and 71Ge
2. Interactions near surface
    1. Beta emitted by ^{210}Pb implanted on the surfaces of the detector while fabrication and testing
    2. Low energy electron interactions in the crystal near surfaces

$$^{210}\mathrm{Pb} \xrightarrow[\beta]{22.3\mathrm{y}} {}^{210}\mathrm{Bi} \xrightarrow[\beta]{5.0\mathrm{d}} {}^{210}\mathrm{Po} \xrightarrow[\alpha]{138\mathrm{d}} {}^{206}\mathrm{Pb}$$

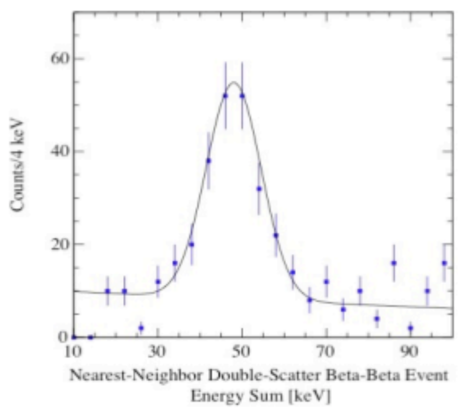
Evidence for ^{210}Pb contamination

Sum over adjacent detectors (NND) to search for 46.5 keV peak!

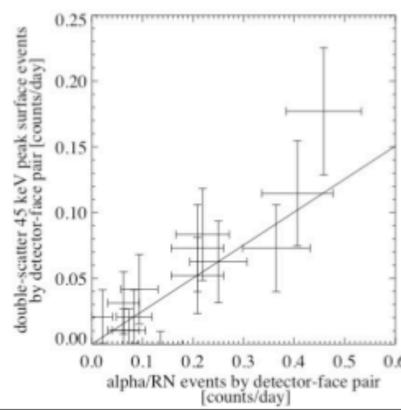




Check for low yield α's!

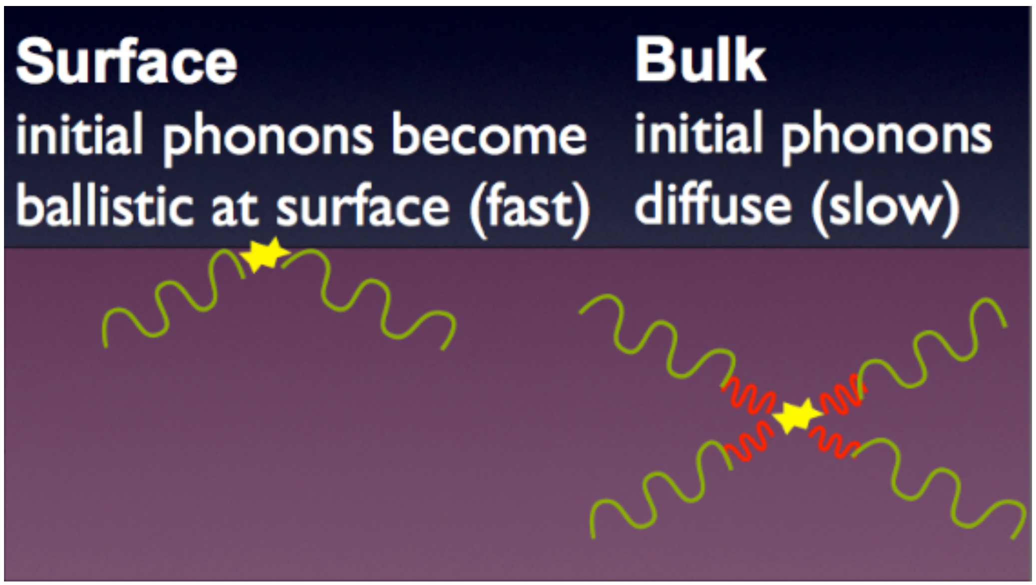


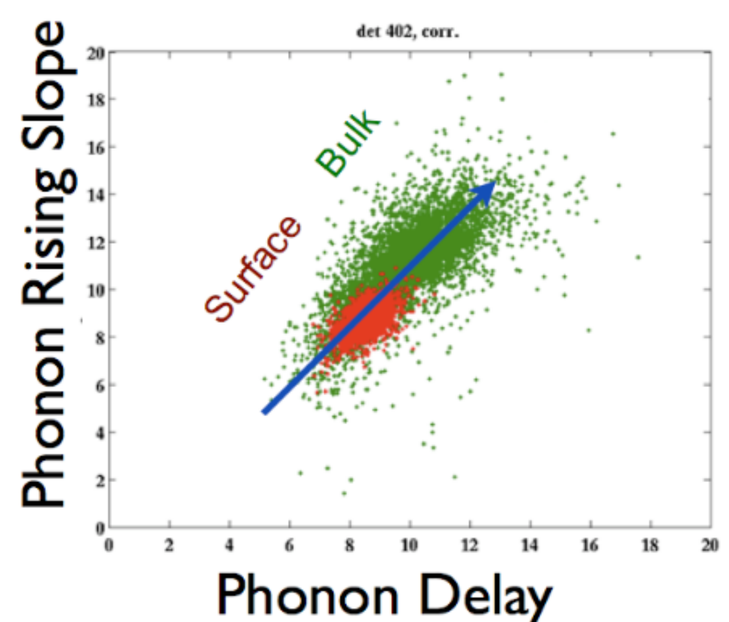
We see a strong correlation between both signatures.

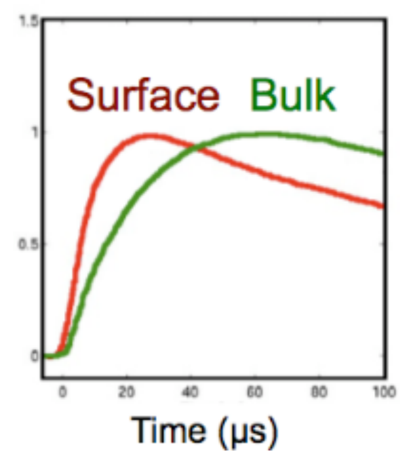


SURFACE EVENTS REJECTION

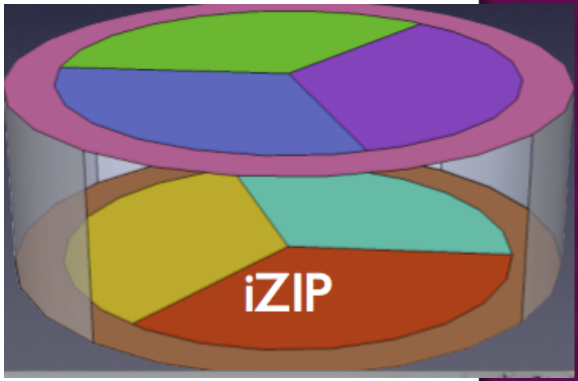
- Phonon timing based:





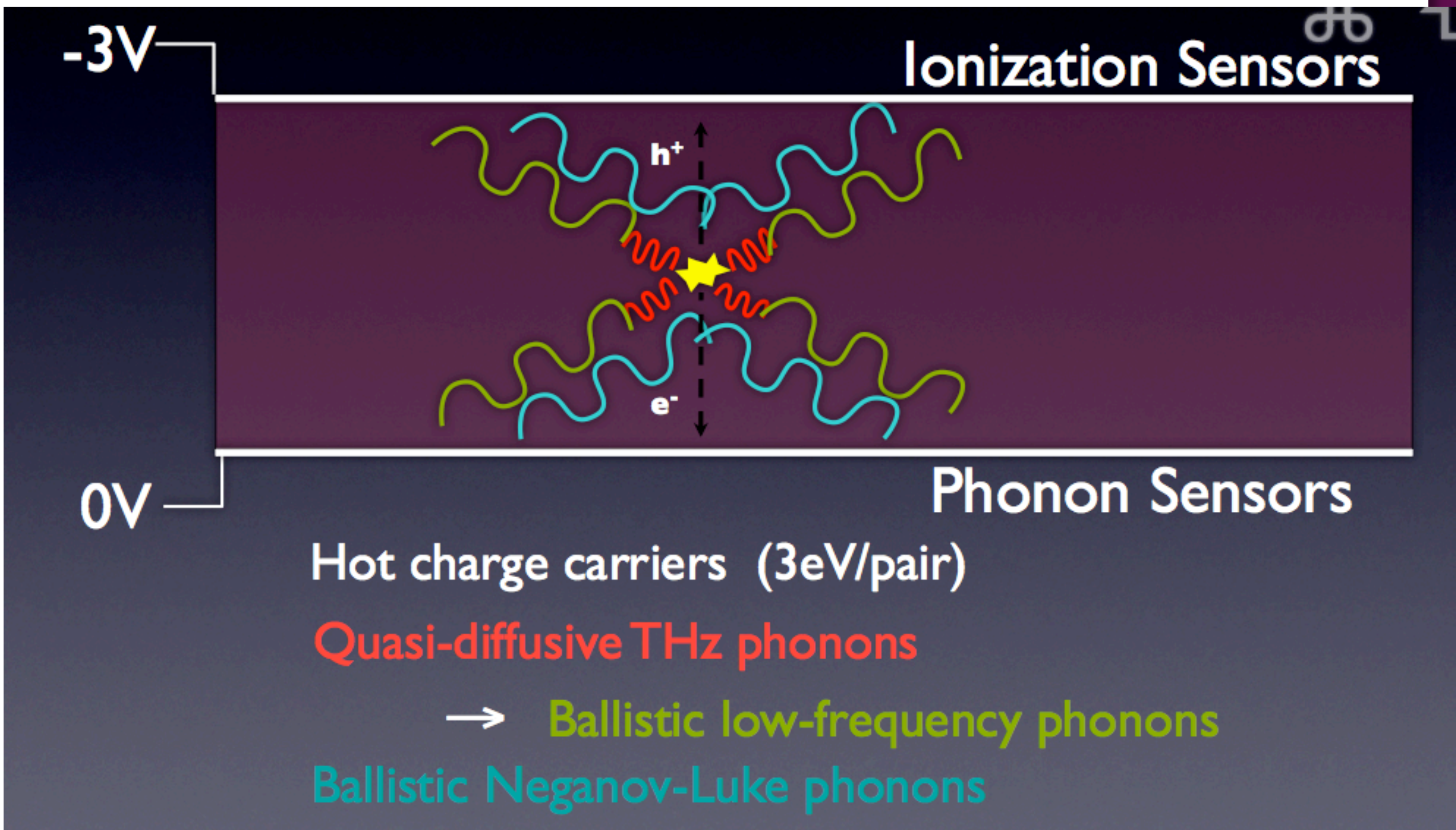


IZIP : INTERLEAVED Z-SENSITIVE IONIZATION AND PHONON DETECTOR



	ZIP of CDMSII	iZIP of SuperCDMS
Thickness x diameter	1 cm. x 7.5 cm.	2.5 cm. x 7.5 cm.
Mass	230 g.	607 g.
Number of Charge Channels	2 (single sided)	4 (2 per side)
Number of Phonon Channels	4(single sided)	8 (4 per side)

PHONON TYPES



PHONON DETECTION

- Thin superconducting Al strip operated close to T_C
- mechanism:

Tungsten strips set just below the edge of the superconductivity using bias voltage

as phonons interact with strip temperature increase

⇓

Resistance, R(T), increased dramatically due to temperature rise

⇓

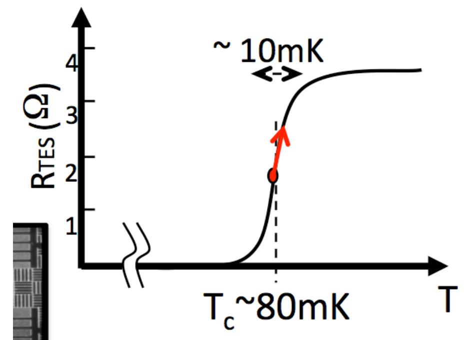
Current decrease due to R(T) increased

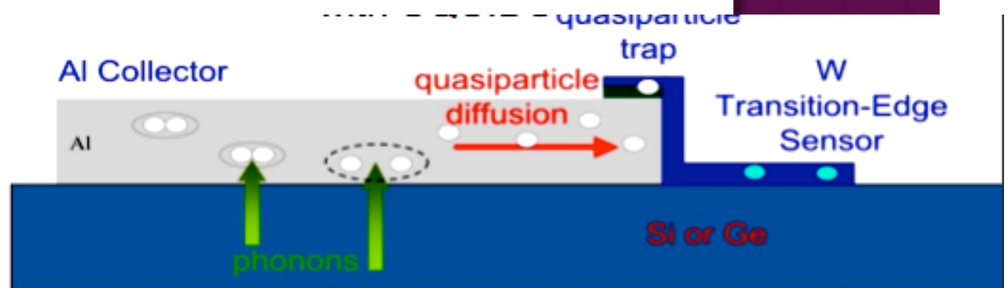
⇓

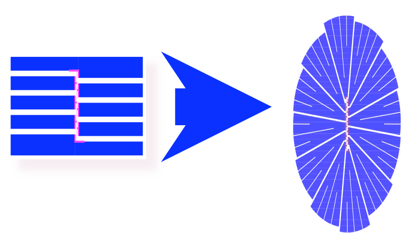
change in current cause magnetic flux change

⇓

measured with high sensitivity by SQUID



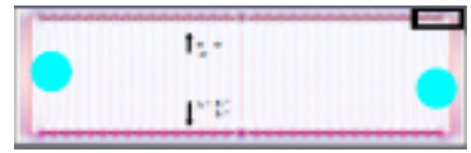




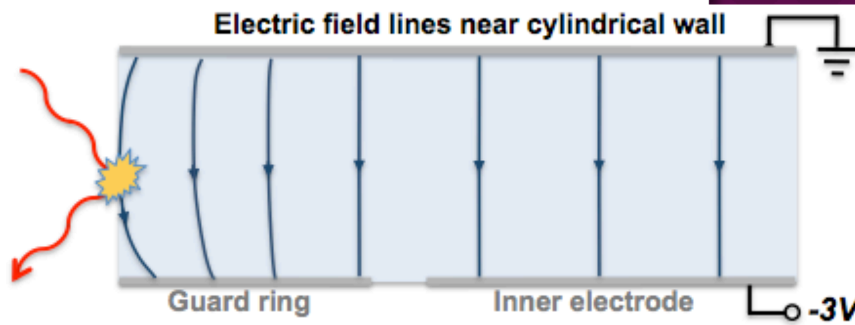
the surface area coverage from 19% to 37% by extending the phonon collection fin area for each TES

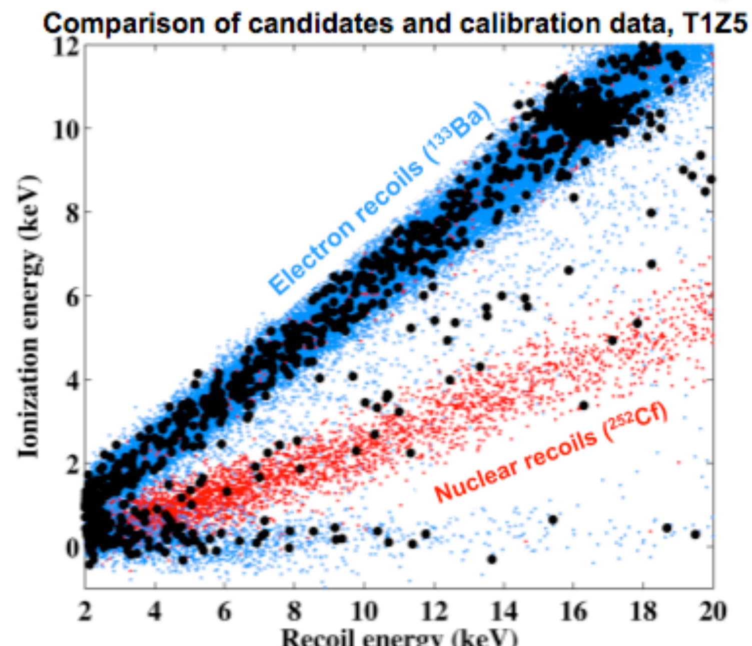
CDMSII → SuperCDMS

0 YIELD EVENTS



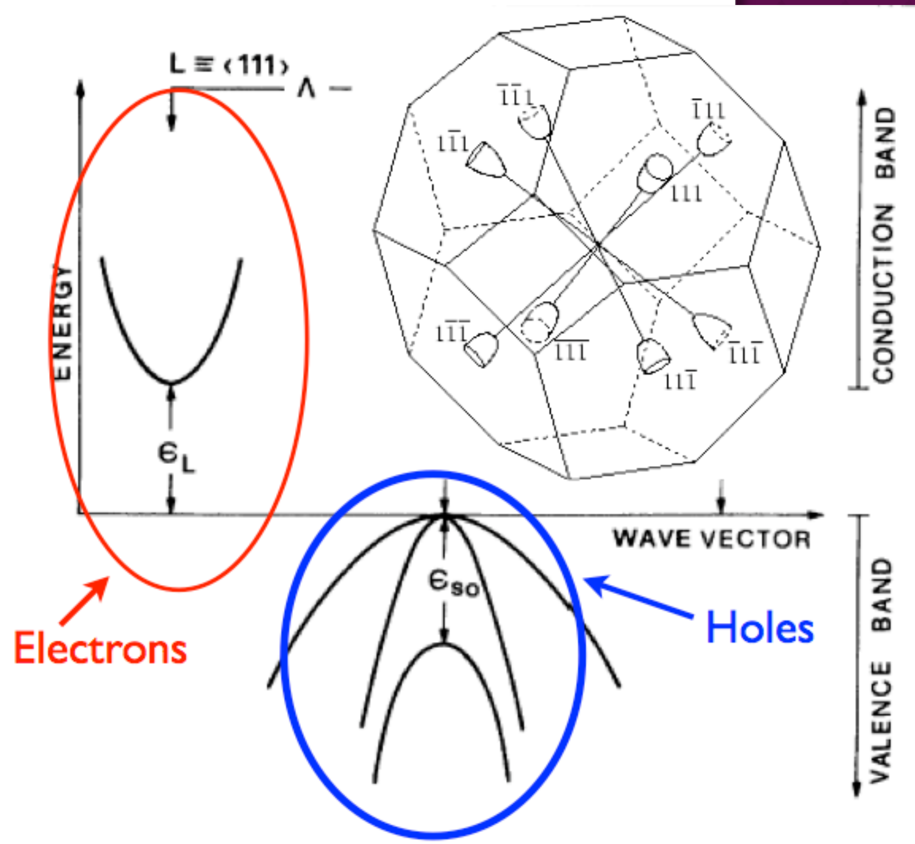
- Zero---charge events scale with electron---recoil rate, not exposure
- Consistent with electron recoils where charge is collected on cylindrical surfaces
- Pass fiducial volume selection since guard electrode signal consistent with noise
- Comparison of candidates and calibration data, T1Z5 Guard ring Inner electrode





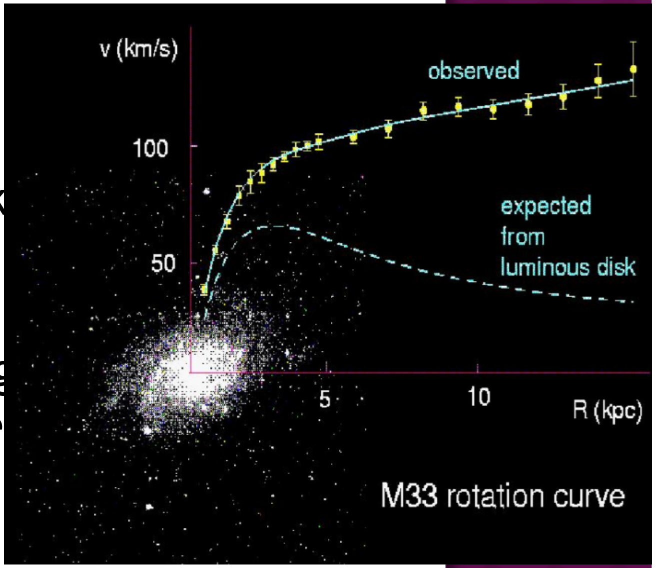
ELECTRON TRAPPING

- Ge has an indirect band gap
- Conduction band minima (8) along diagonal [111] directions
- Electrons experience oblique propagation, moving at an angle (~33 degrees) relative to applied field in the [100] direction



Evidence

Galactic Dynamics :

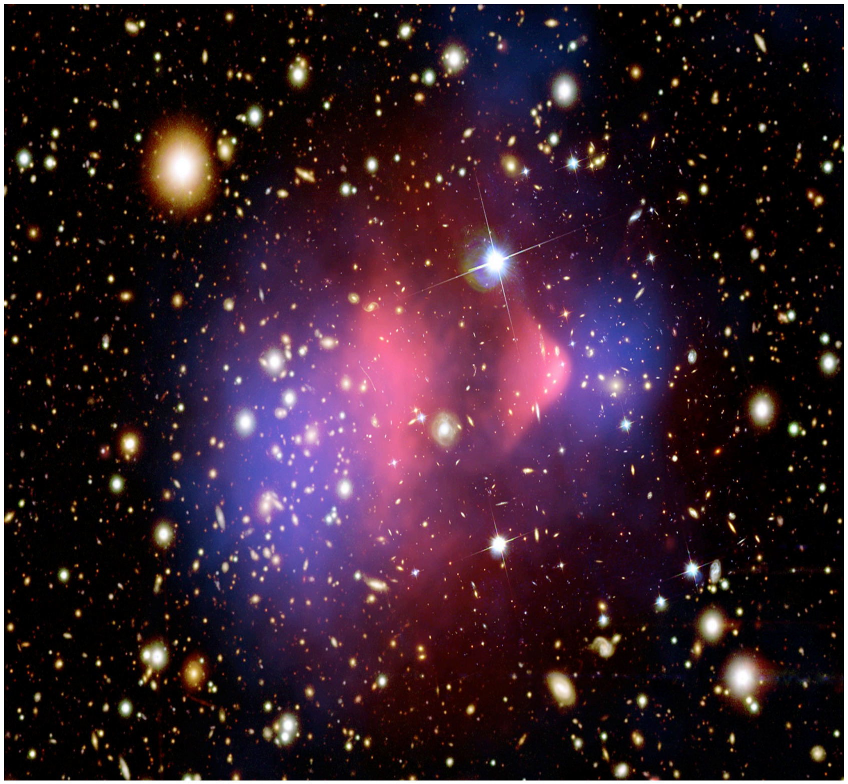


Some of the clearest evidence for the existence of dark
comes from the rotational dynamics of spiral galaxies.

A spiral galaxy such as our own consists of a central brig
surrounded by a rotating disk of younger stars. Measure
the galactic rotation speed as a function of radius have
conducted for many spiral galaxies.

We expect the orbital velocity of galactic material to decrease as $\sim r^{-1/2}$ at radii outside the visible disk. We see in the measurements, however, that observed rotation curves are remarkably flat at large radii. From Newtonian mechanics, this behavior is consistent with a roughly spherically-symmetric mass distribution with a total enclosed mass proportional to radius ($M(\leq r) \propto r$). These data suggest that the visible galaxies are embedded in substantially larger "dark matter halos," which extend well beyond the edge of the visible disk. Without the gravitational mass of this halo, the disk would fly apart.

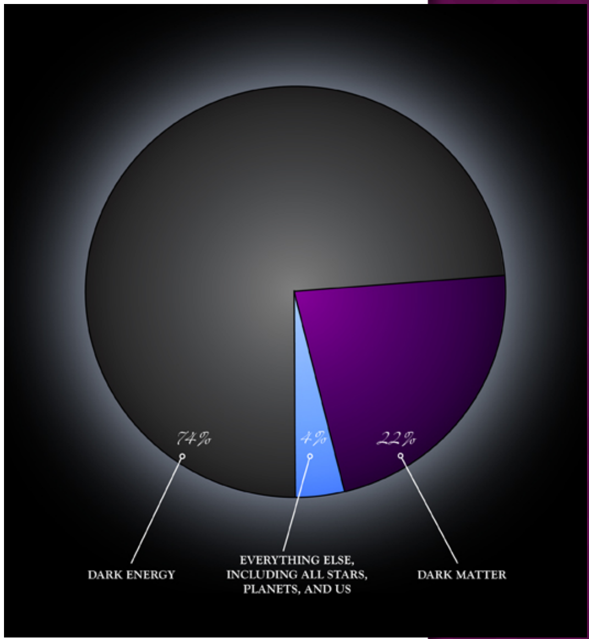
BULLET CLUSTER :



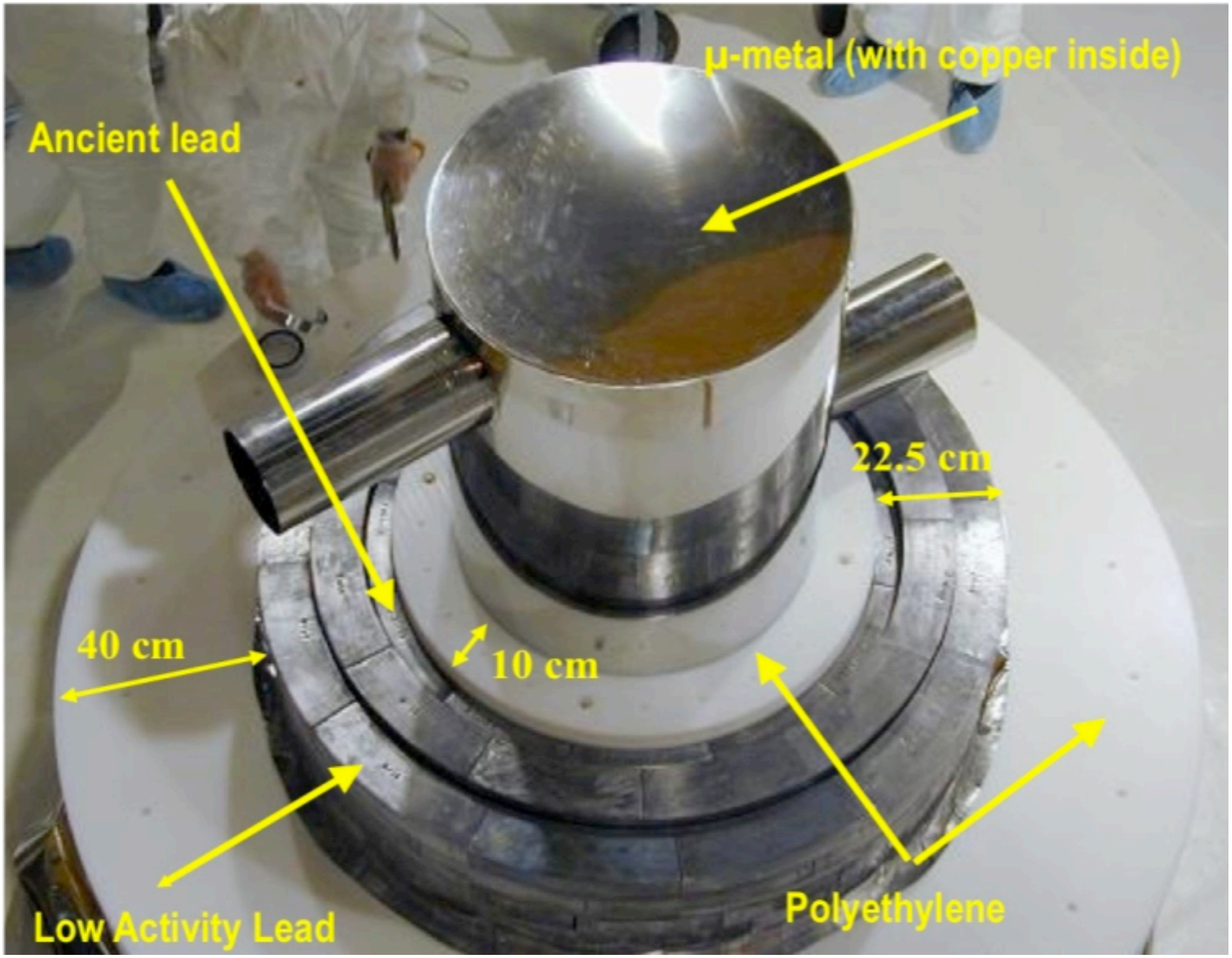
In a textbook example of a shock front, the bullet-shaped cloud of gas at the right was distorted during the titanic collision between two galaxy clusters that created the larger bullet cluster itself. However, the dark matter present has not interacted with the cluster gas except by gravity. The clear separation of dark matter and gas clouds is considered direct evidence of the existence of particle dark matter.

Cosmogenic Pie :

With the most recent measurements of the cosmic microwave background anisotropies (CMB) and simulations of large scale structures (LSS) of the universe as well as various other astronomical observations, it is now possible to have a clear and consistent picture of the history and content of the universe since nucleosynthesis.



The baryon (ordinary matter we observe) ratio calculated based on the baryon-to-phonon ratio calculations using deuterium abundances is about 4%. Shows that ordinary, baryonic matter thus only constitutes a small fraction of the universe's total matter density. The dominant dark Matter contribution must therefore be non-baryonic.


μ-metal (with copper inside)
Ancient lead
22.5 cm
40 cm
10 cm
Low Activity Lead
Polyethylene