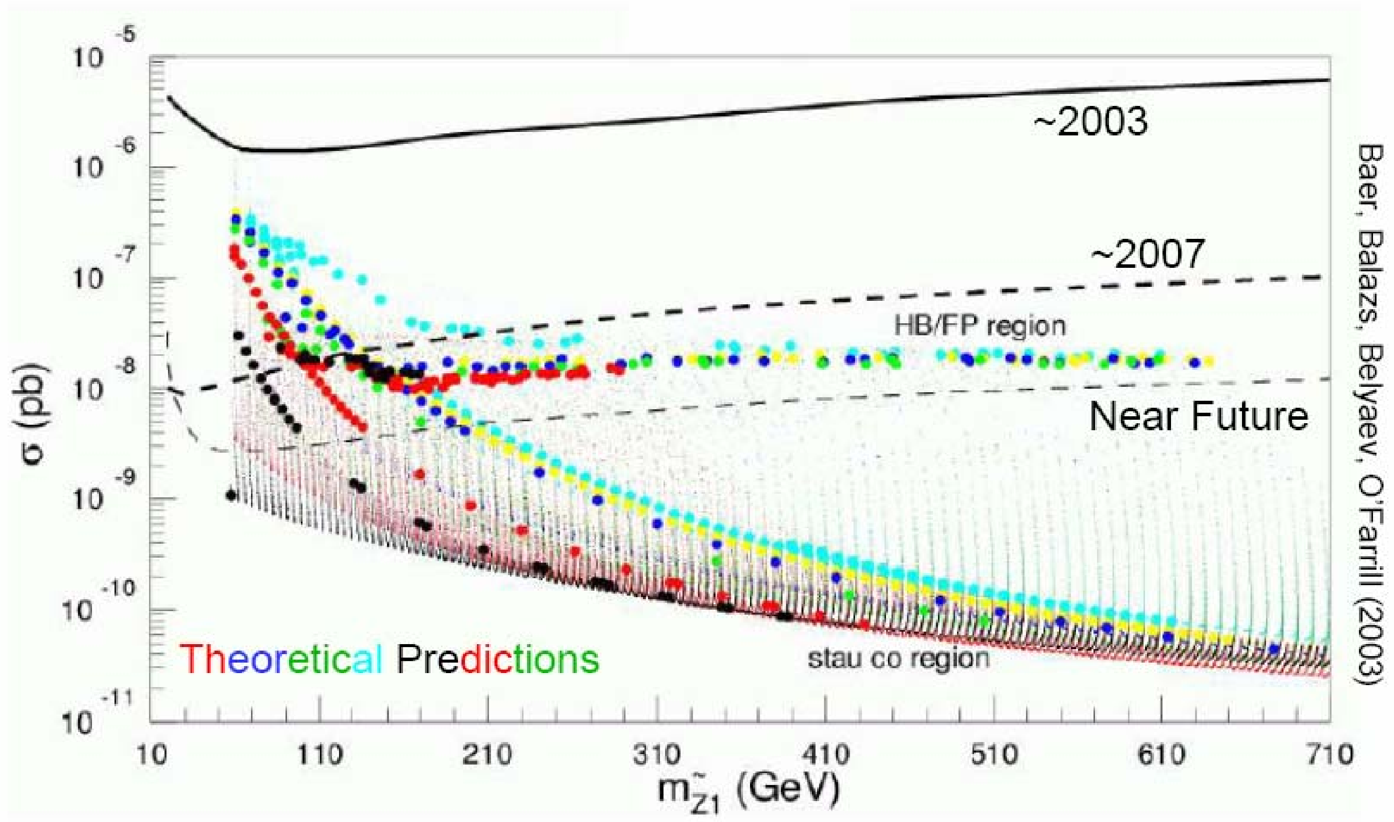
CDMS: Methods, Results, and Prospects

Fritz DeJongh, Fermilab

CDMS Collaboration

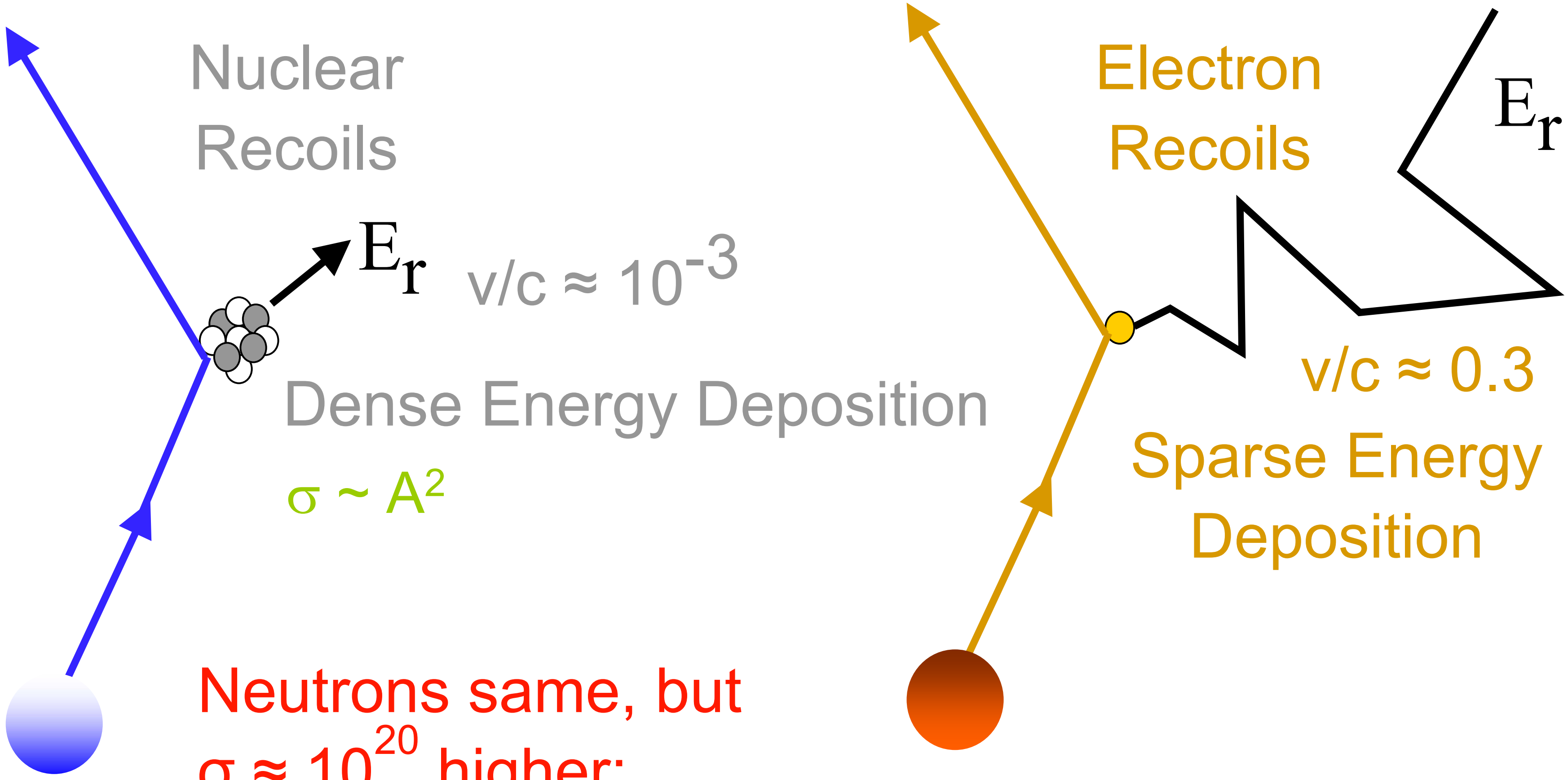
- Introduction
- CDMS Detectors
- CDMS-2: Data analysis and WIMP limits
- SuperCDMS -25kg
- Conclusions

Introduction



Nuclear Recoil Discrimination

Signal



Nuclear Recoils

E_r

v/c ≈ 10^{-3}

Dense Energy Deposition

$\sigma \sim A^2$

Neutrons same, but
$\sigma \approx 10^{20}$ higher;
must shield

$\sigma \sim A$

Background

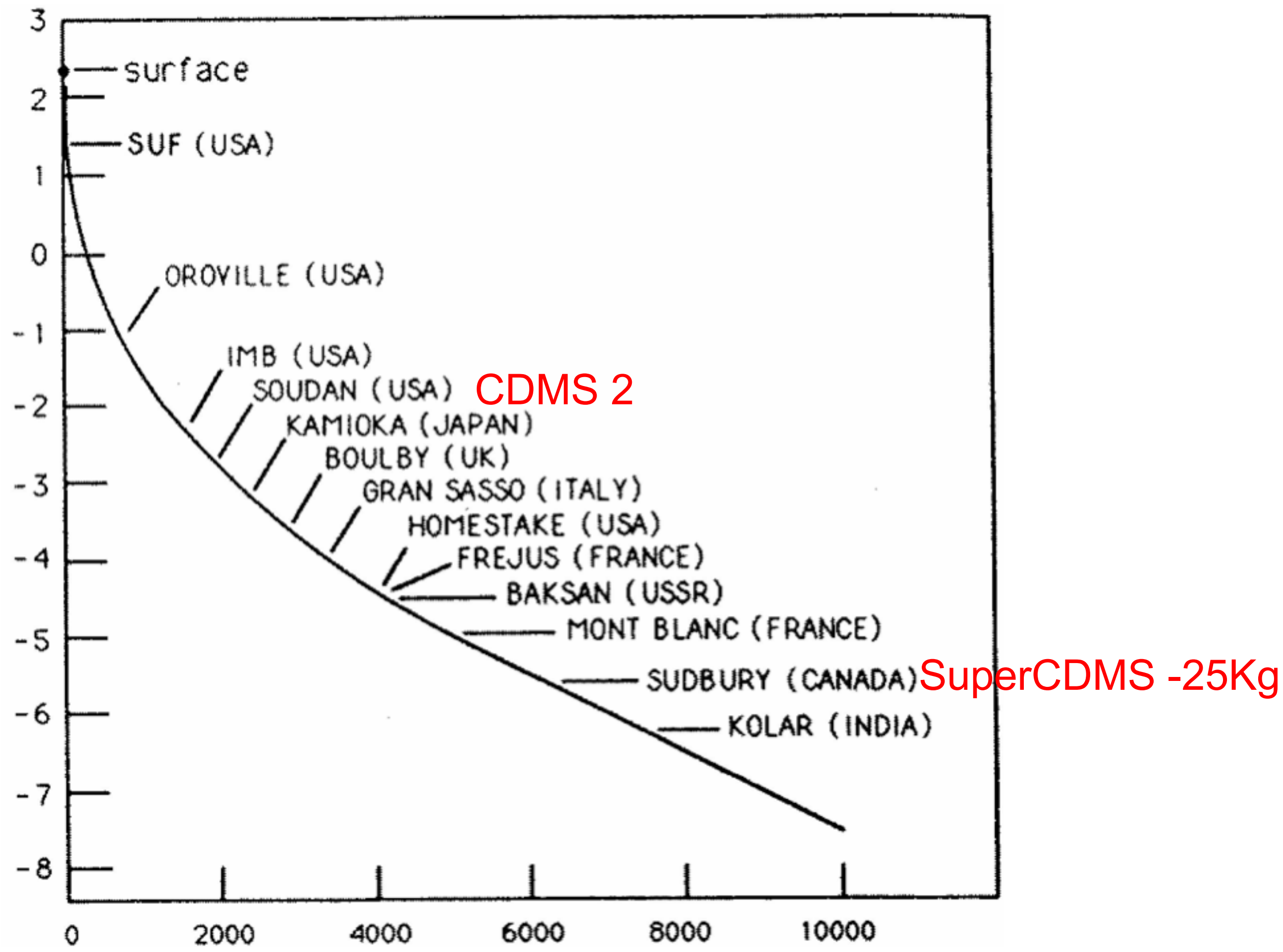
Electron Recoils

E_r

v/c ≈ 0.3

Sparse Energy Deposition

Depth: Eliminates cosmic-induced neutrons



CDMS: Phonons & Ionization in semiconductor crystals

Phonons: ~100/eV, measure total energy

- QET technology: Ballistic phonon energy & timing

Ionization: electron-hole pairs

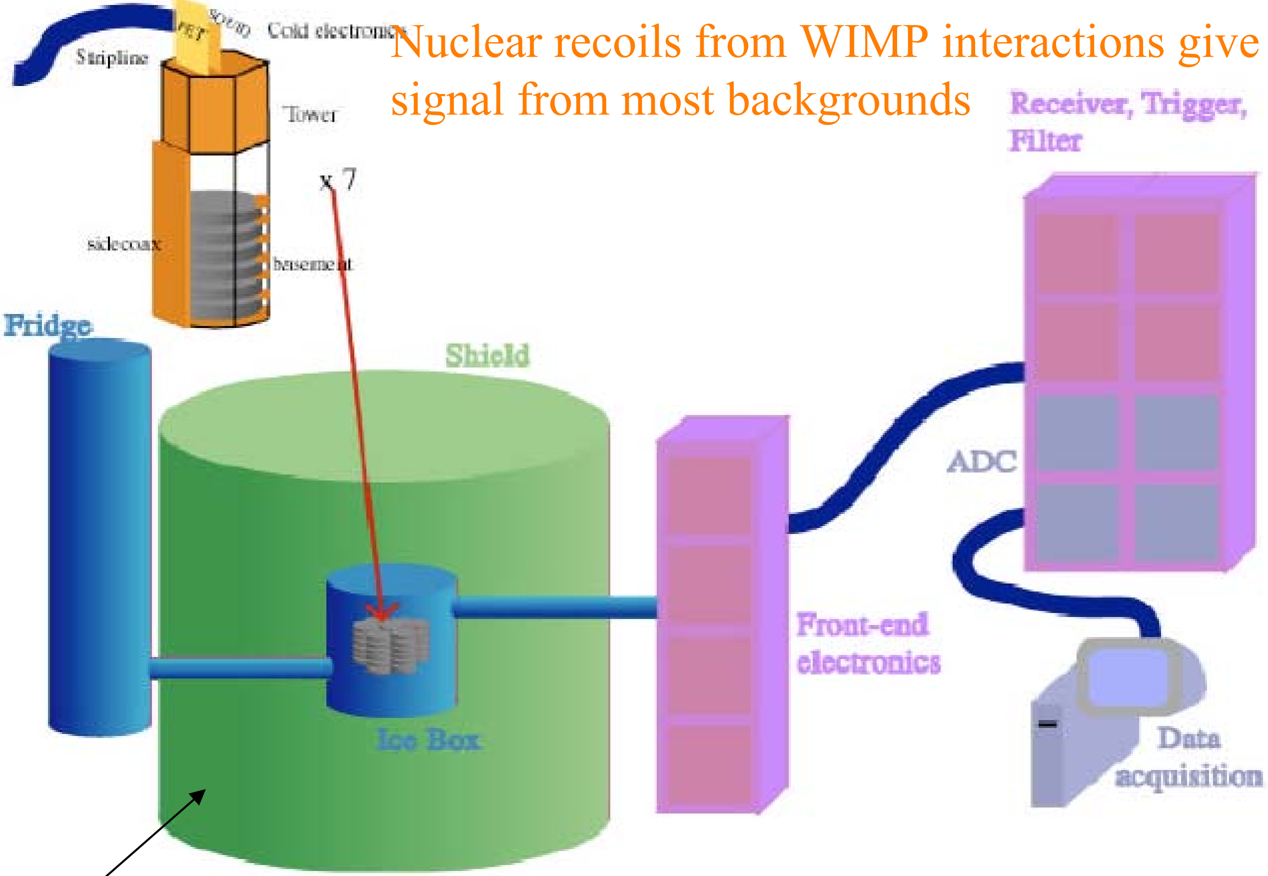
- Electron recoils: 1 e-h / 3 eV
- Nuclear recoils: 1 e-h / 10 eV

Ge: A ~ 72, 250 g/det 3 inch diam.

Si: A ~ 28, 100 g/det X 1 cm thick

Detectors

Ge and Si crystals, 6/tower
Measure phonons –QET patterning
Measure ionization
Nuclear recoils from WIMP interactions give distinctive signal from most backgrounds



Cryogenics

Maintain detectors at 50 mK

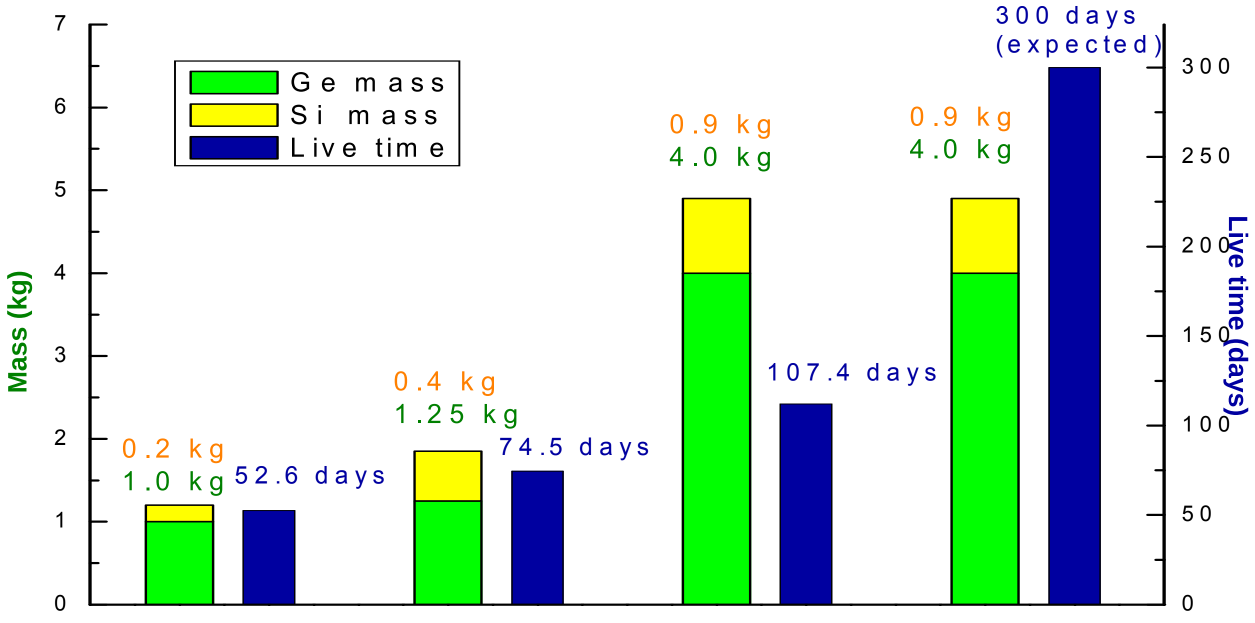
Electronics/ DAQ

Record signals from detectors and veto; form trigger

Shielding

Layered shielding (Cu, Pb, polyethylene) reduces radioactive backgrounds and active scintillator veto is >99.9% efficient against cosmic rays.

CDMS II Soudan WIMP Search Exposure



🟩 Ge (250g)

🟨 Si (100g)

Ge raw exposure before physics cuts

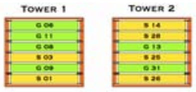
1st Run:

10/11/2003
- 1/11/2004

52.6 kg-days

2nd Run:

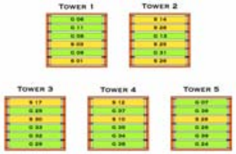
3/25/2004
- 8/8/2004



93.1 kg-days

3rd Run

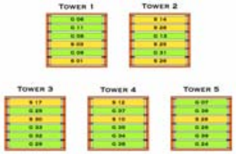
10/21/2006
- 3/20/2007



430 kg-days

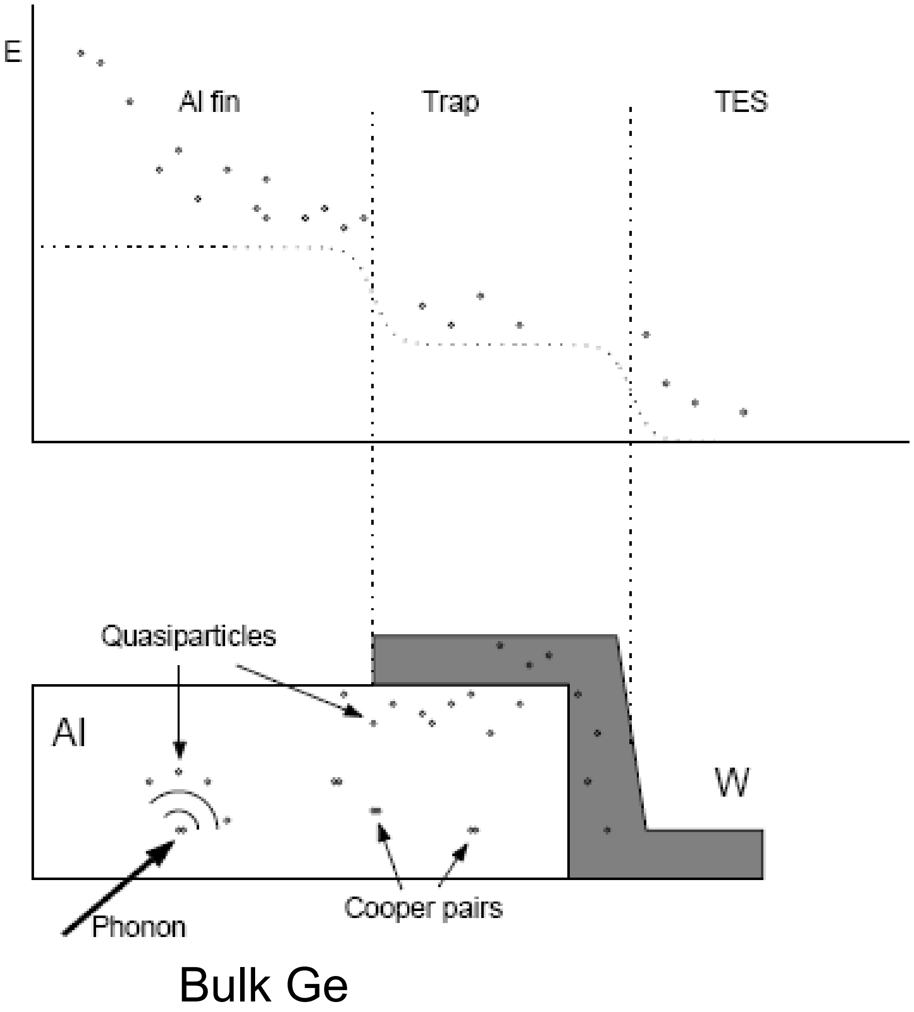
4th Run

April 2007
- 2008



1200 kg-days

Ballistic Phonon Detection: QET



QET: Quasi-particle Trap Assisted

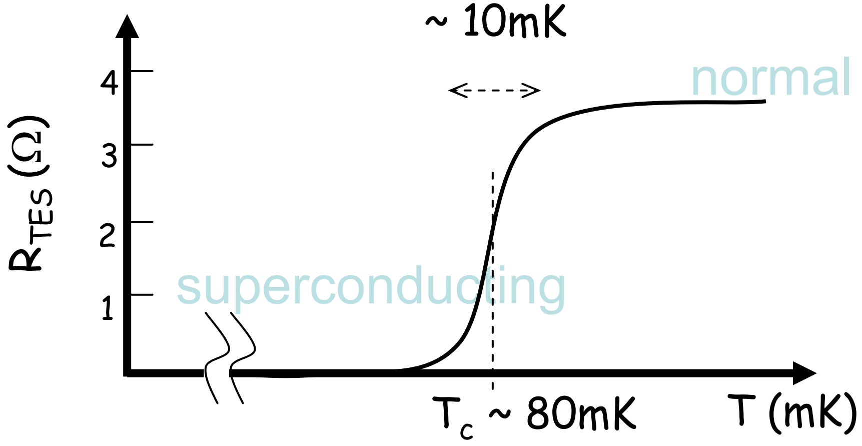
Detectors are patterned with 300nm superconducting Aluminum films

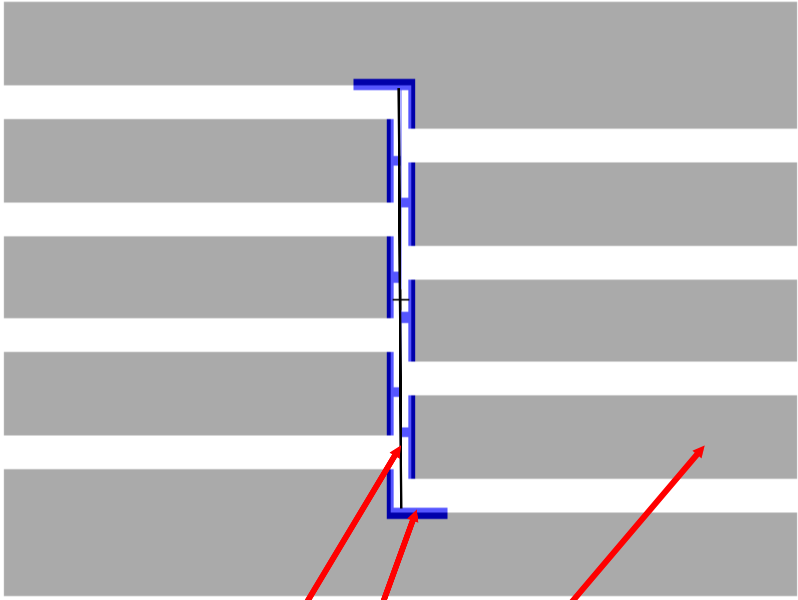
Phonons in crystal enter Al, break Cooper pairs, → quasiparticles

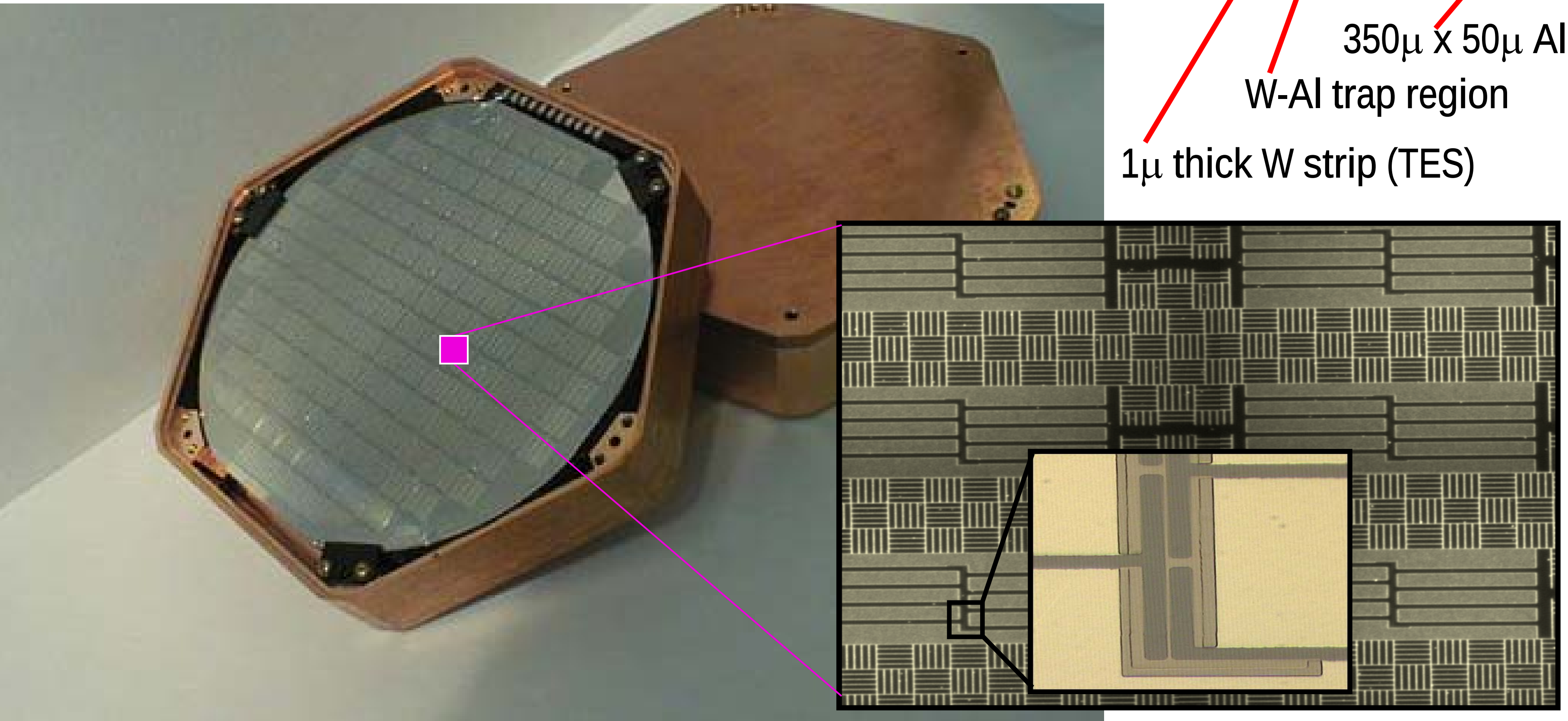
Quasiparticles diffuse to Tungsten overlap region, where they are trapped.

Quasiparticles eventually detected as heat in Tungsten

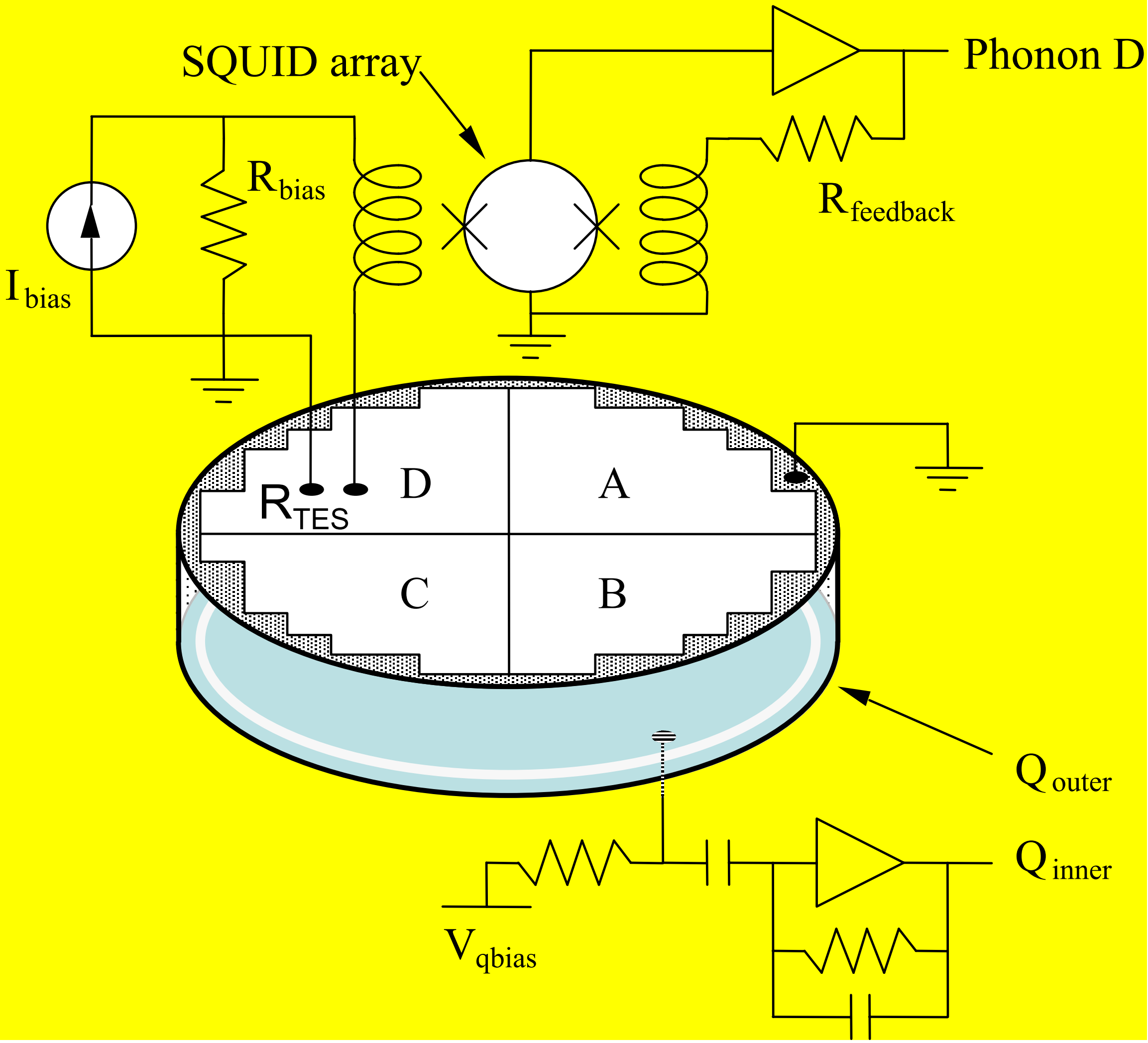
QET: Transition Edge Sensor







QET: Electro-thermal Feedback

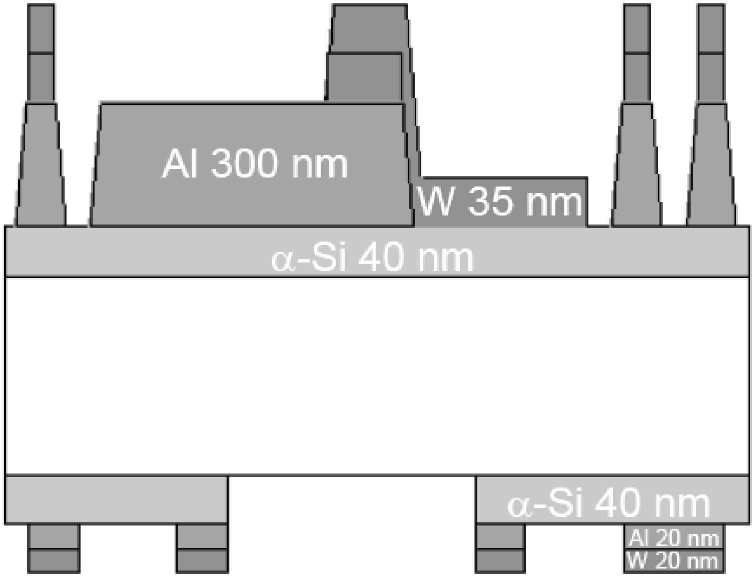


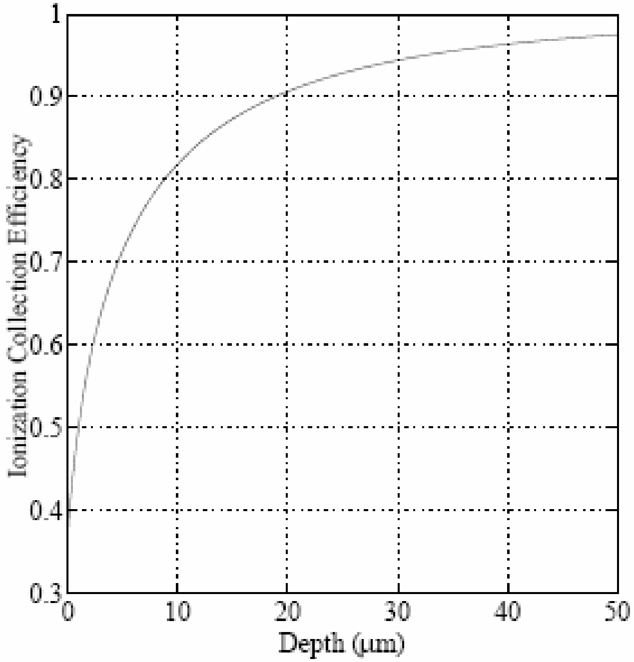
Bias current keeps TES at Tc (Tc > T substrate)

1. Event deposits heat in TES
2. R_{TES} increases
3. Bias current decreases
   - Change in current is detected by SQUID array, measures energy
4. TES cools, moves toward equilibrium

V_{bias} = 3V for charge collection

Q_{outer} guard ring allows rejection of events near outer edge





Dead layer:

Incomplete charge collection for surface betas:

- Charge generated near surface should drift across detector
- Instead, can back-diffuse to nearby electrode, and is lost.
- Ionization yield shifts toward nuclear-recoil expectation.

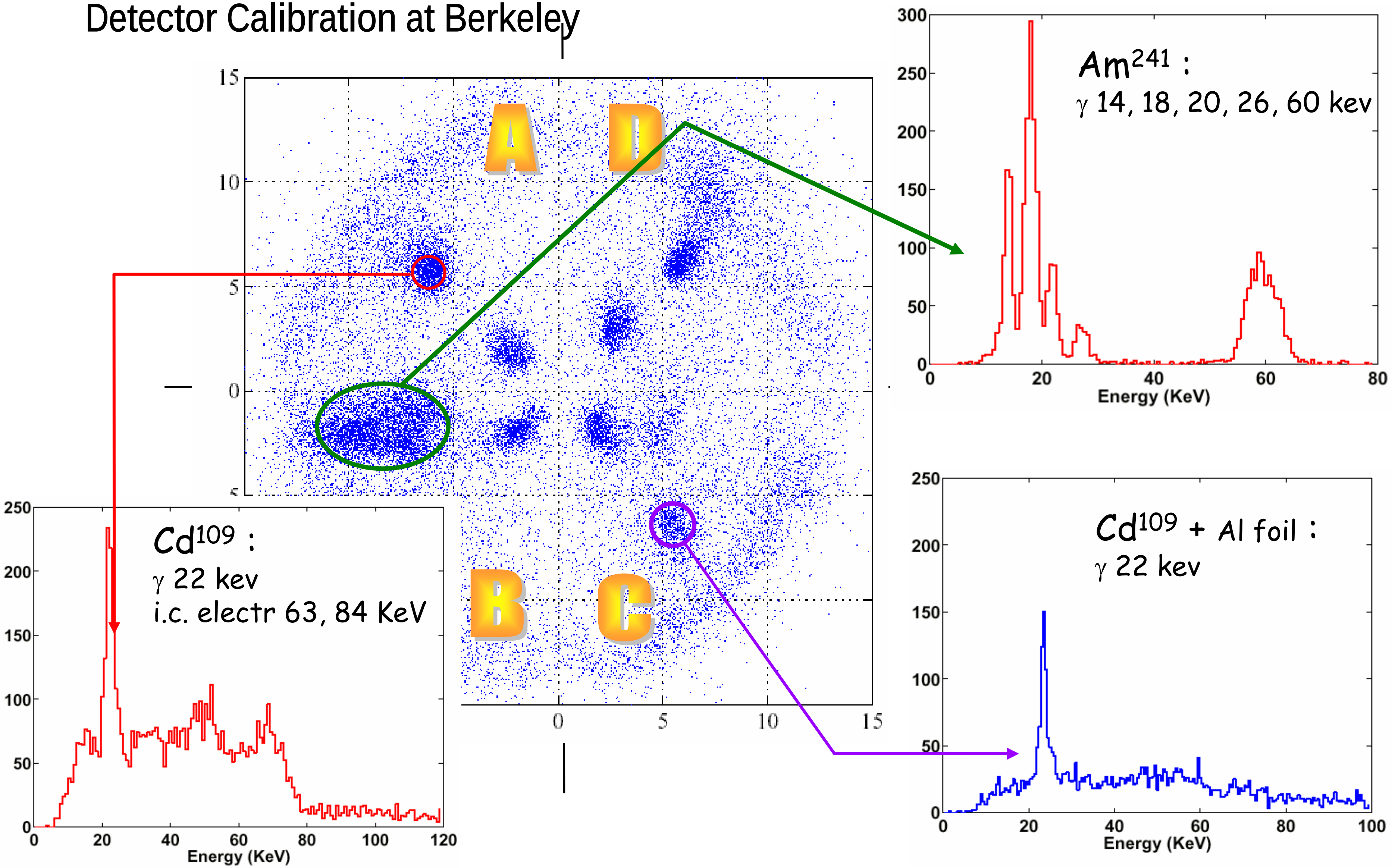
Amorphous Silicon layer suppresses back-diffusion.

Limits depth of dead layer to 10 microns.

Reduces, but does not eliminate, surface beta background.

Excellent Energy, X-Y Position Reconstruction

Detector Calibration at Berkeley



Am^{241} :

γ 14, 18, 20, 26, 60 kev

Cd^{109} :

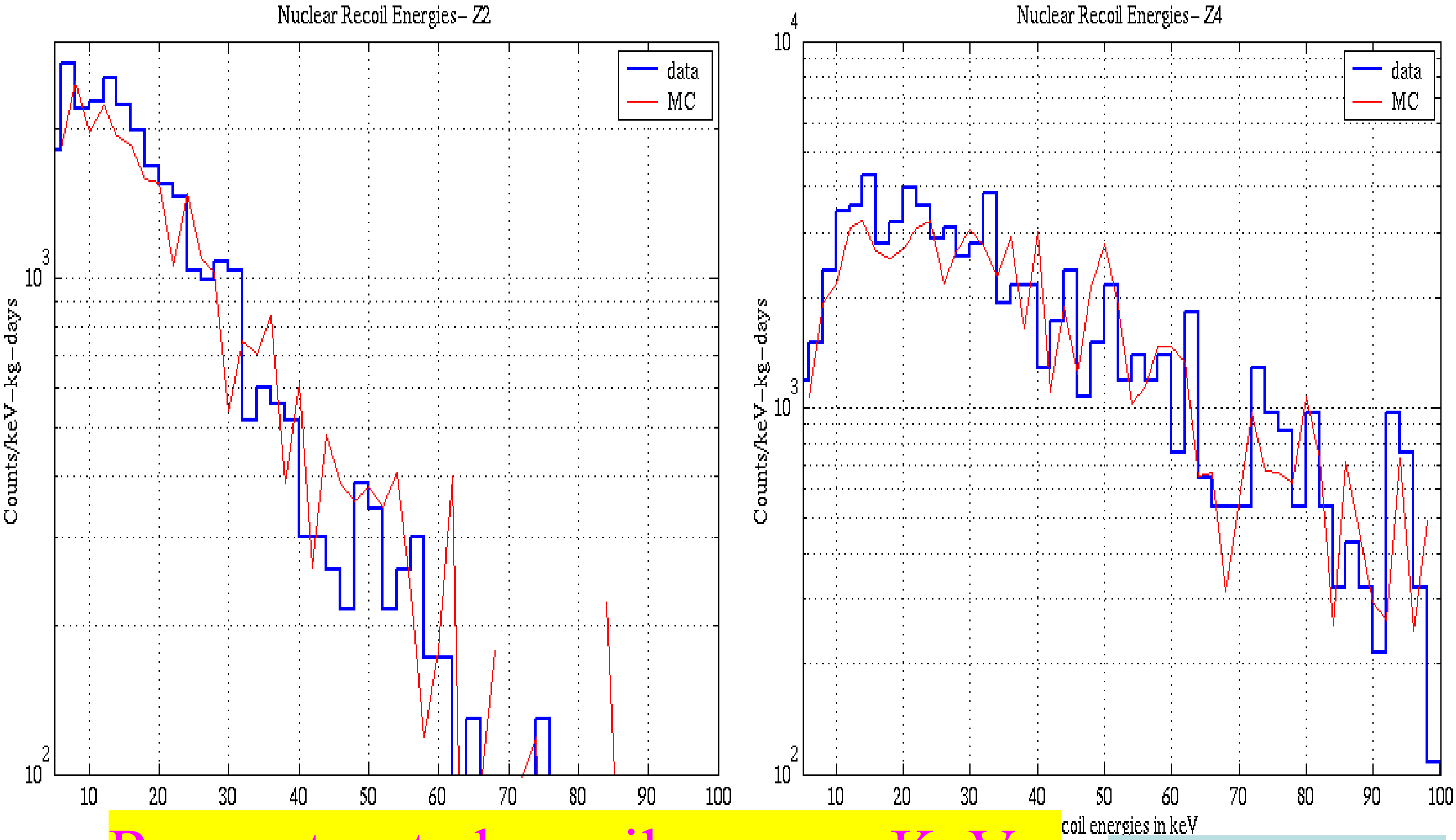
γ 22 kev

i.c. electr 63, 84 KeV

Cd^{109} + Al foil :

γ 22 kev

n Calib. (^{252}Californium) (nuclear recoils)



Reconstructed recoil energy, KeV

Sharmila Kamat

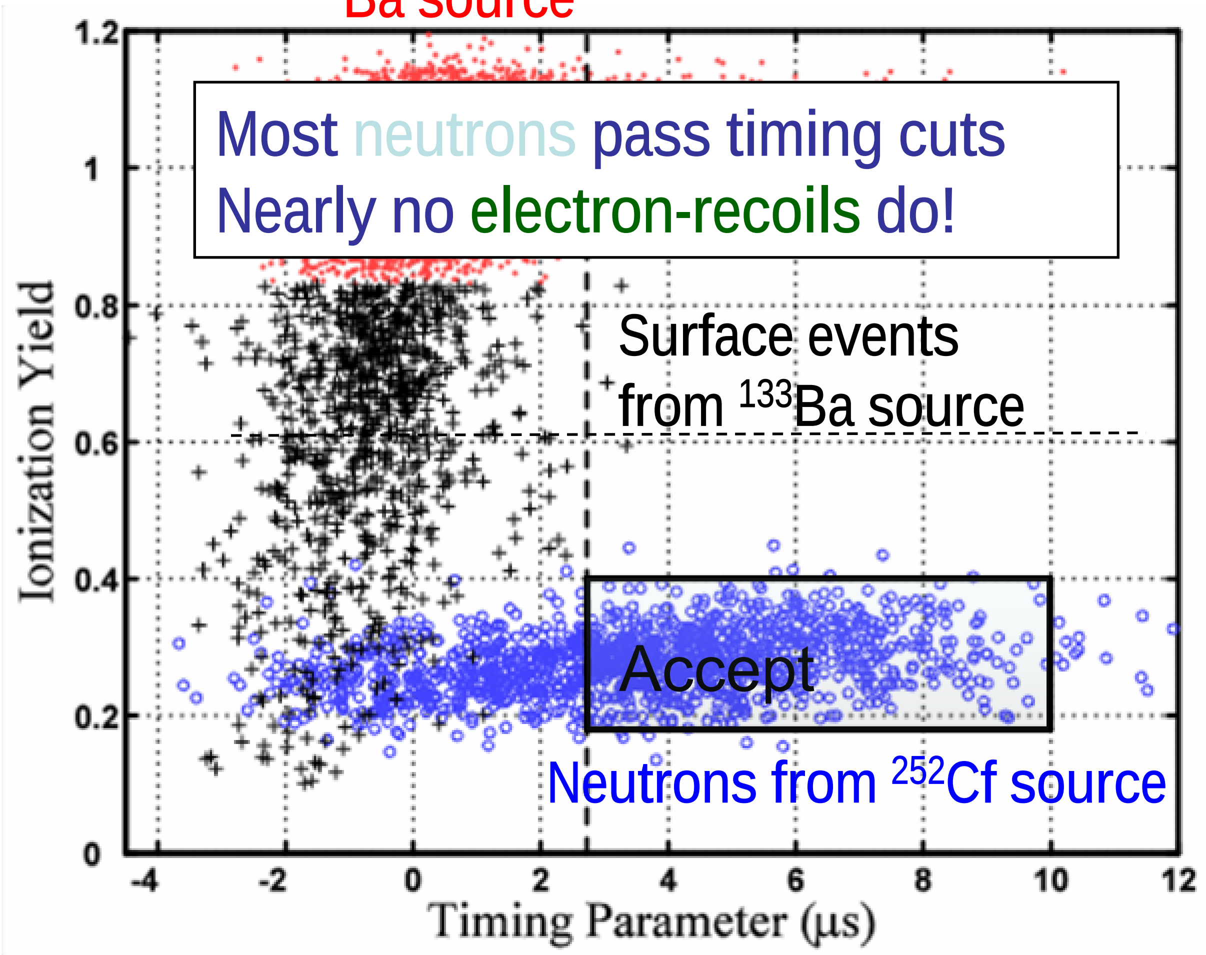
CDMS Rejection of Surface Events

- Nuclear recoils result in slower phonon signals than electron recoils
  - Surface-electron recoils are faster yet!

Ionization Yield:
ratio

Charge energy
phonon energy

31k photons from
^{133}Ba source



Most neutrons pass timing cuts
Nearly no electron-recoils do!

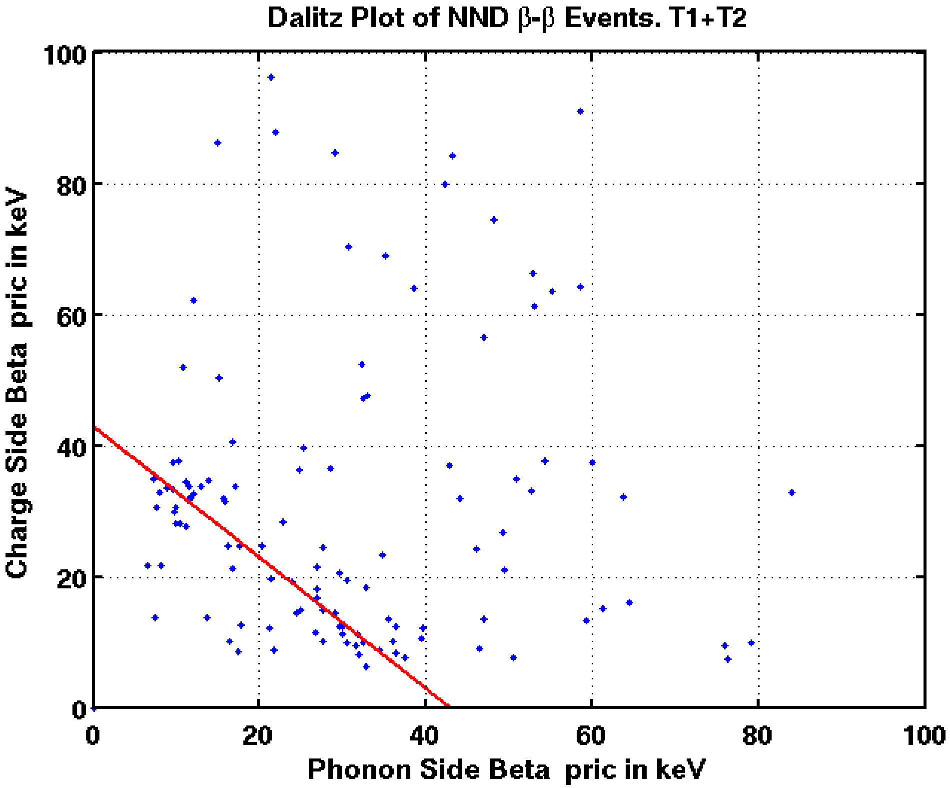
Surface events
from ^{133}Ba source

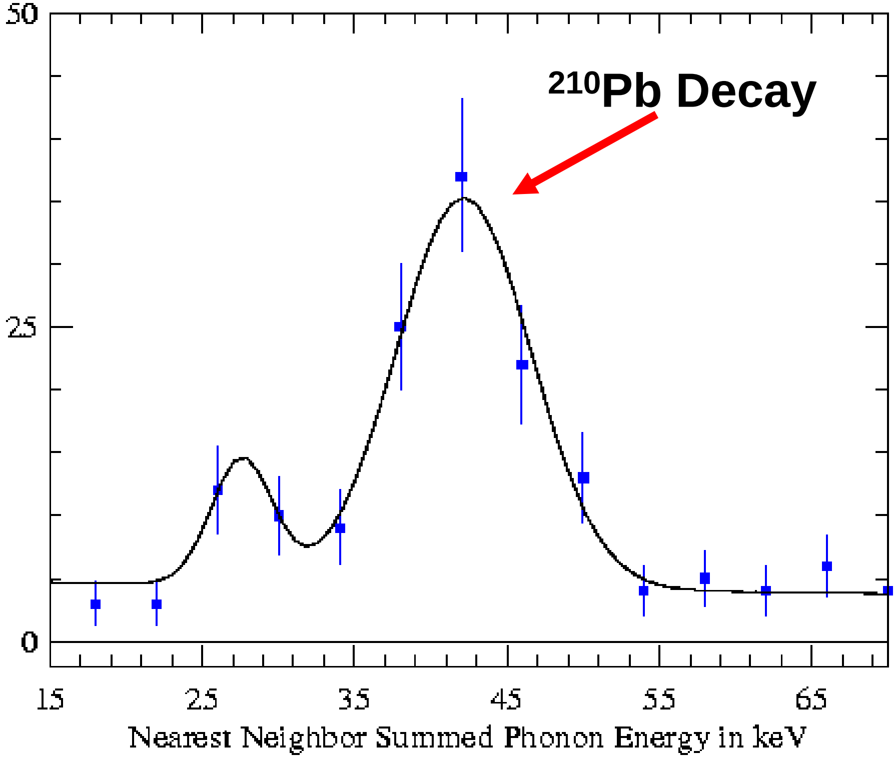
Accept

Neutrons from ^{252}Cf source

Source of CDMS β Background

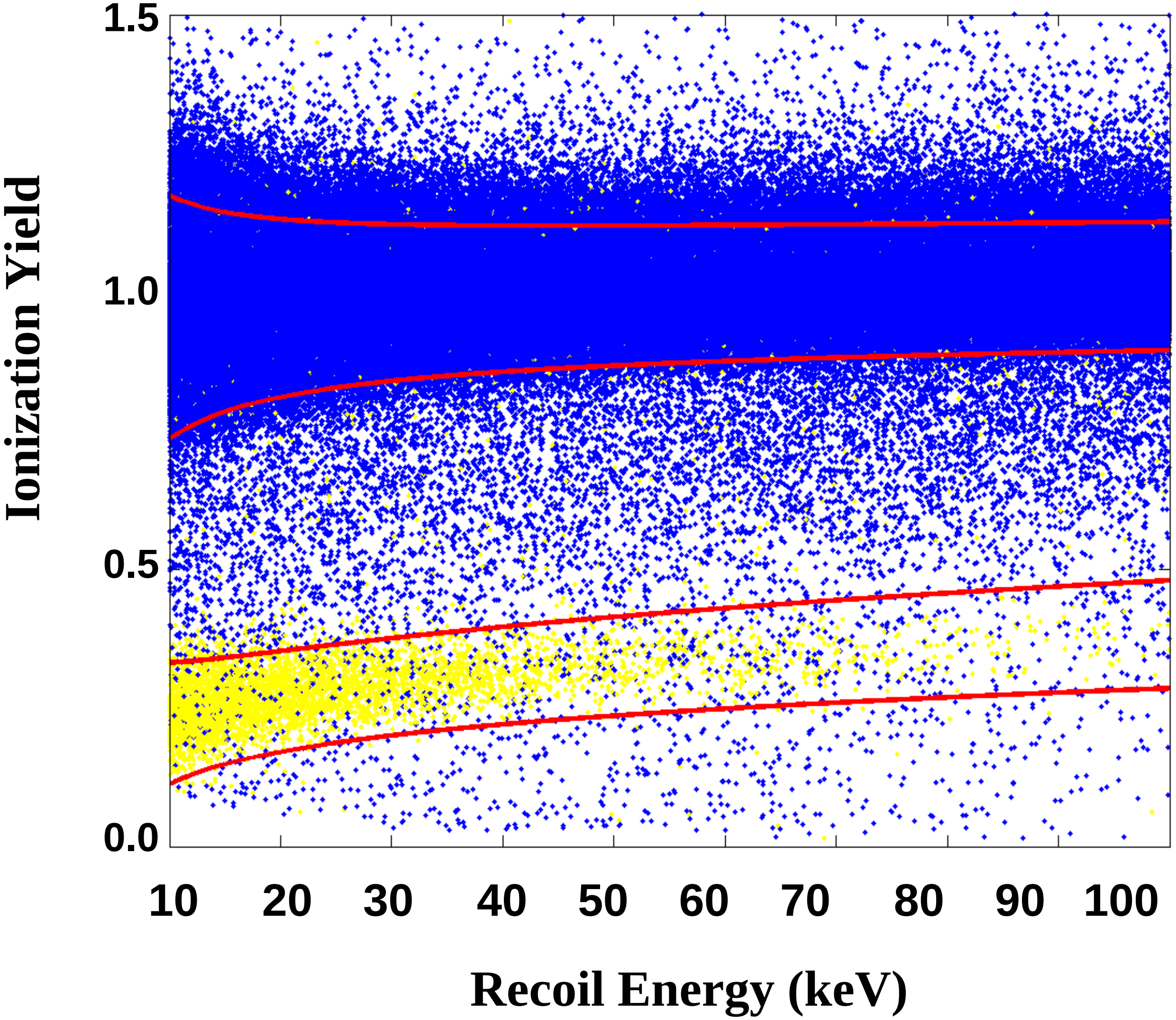
- Conversion electrons from ^{210}Pb decay chain cause the ~ 46 keV line
- Radon in air causes the ^{210}Pb deposition on detectors. We always guessed that this would be a source of contamination, hence were always careful about Radon exposure.





Rupak Mahapatra

Setting cuts blind with calibration data

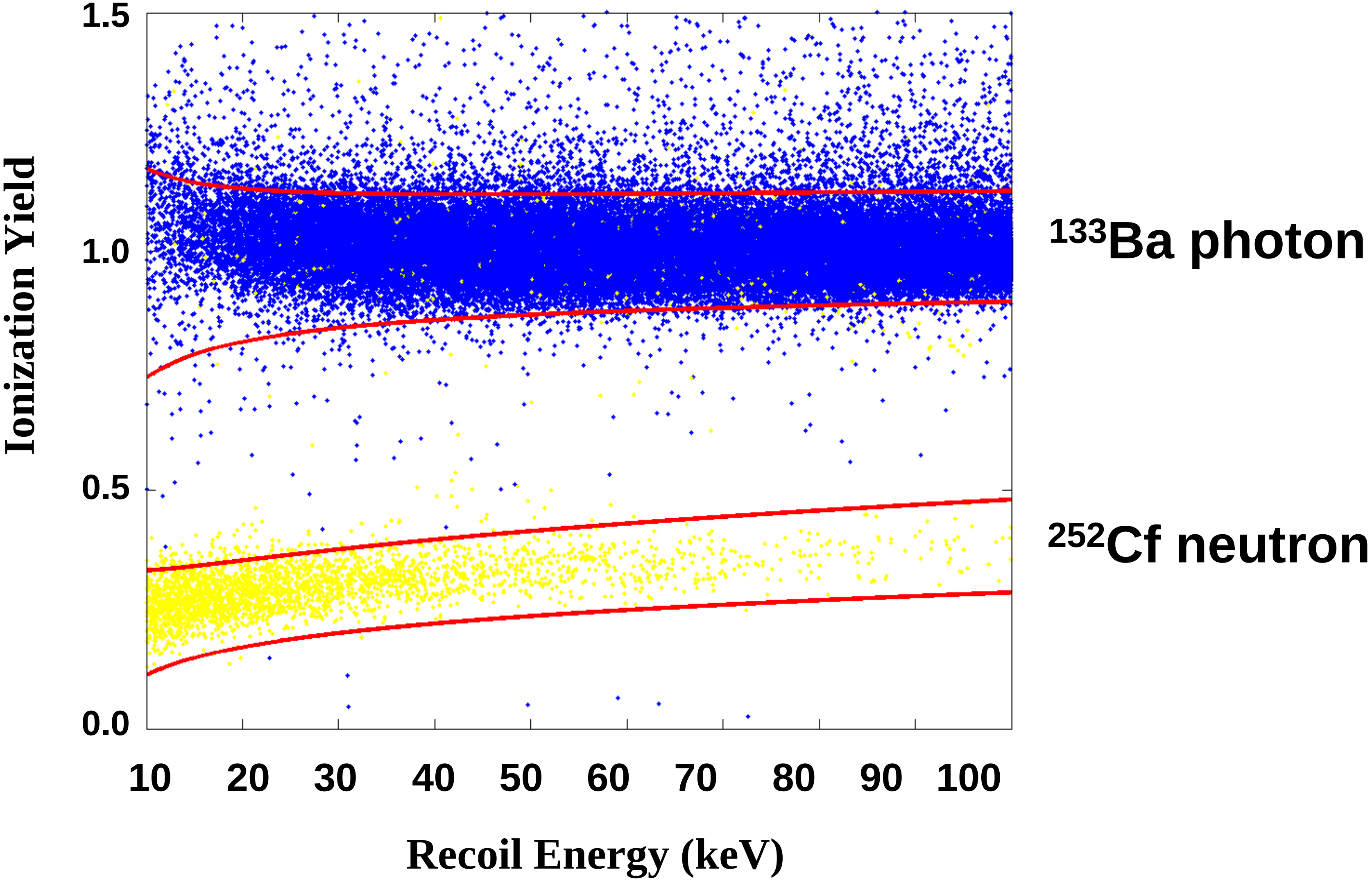


^{133}Ba
Photon source

^{252}Cf Neutron

Setting Cuts Blind with Calibration Data

After Timing Cut

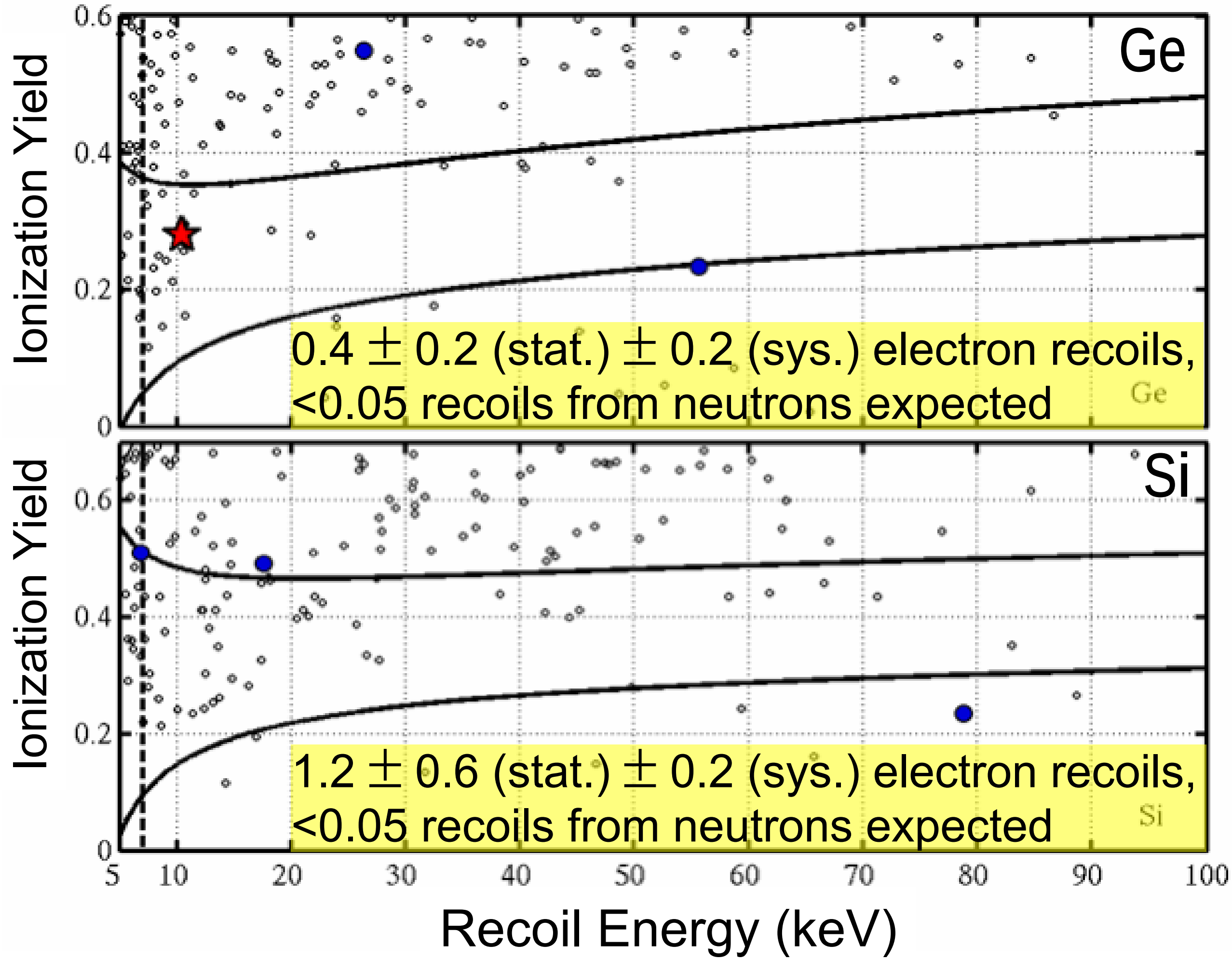


CDMS WIMP-search Data

PRL 96, 011302 (2006)

(with yield=1 photons suppressed)

○ Fail timing cuts
● Pass timing cuts, fail yield cut
☆ Nuclear-recoil candidate



0.4 ± 0.2 (stat.) ± 0.2 (sys.) electron recoils,
<0.05 recoils from neutrons expected

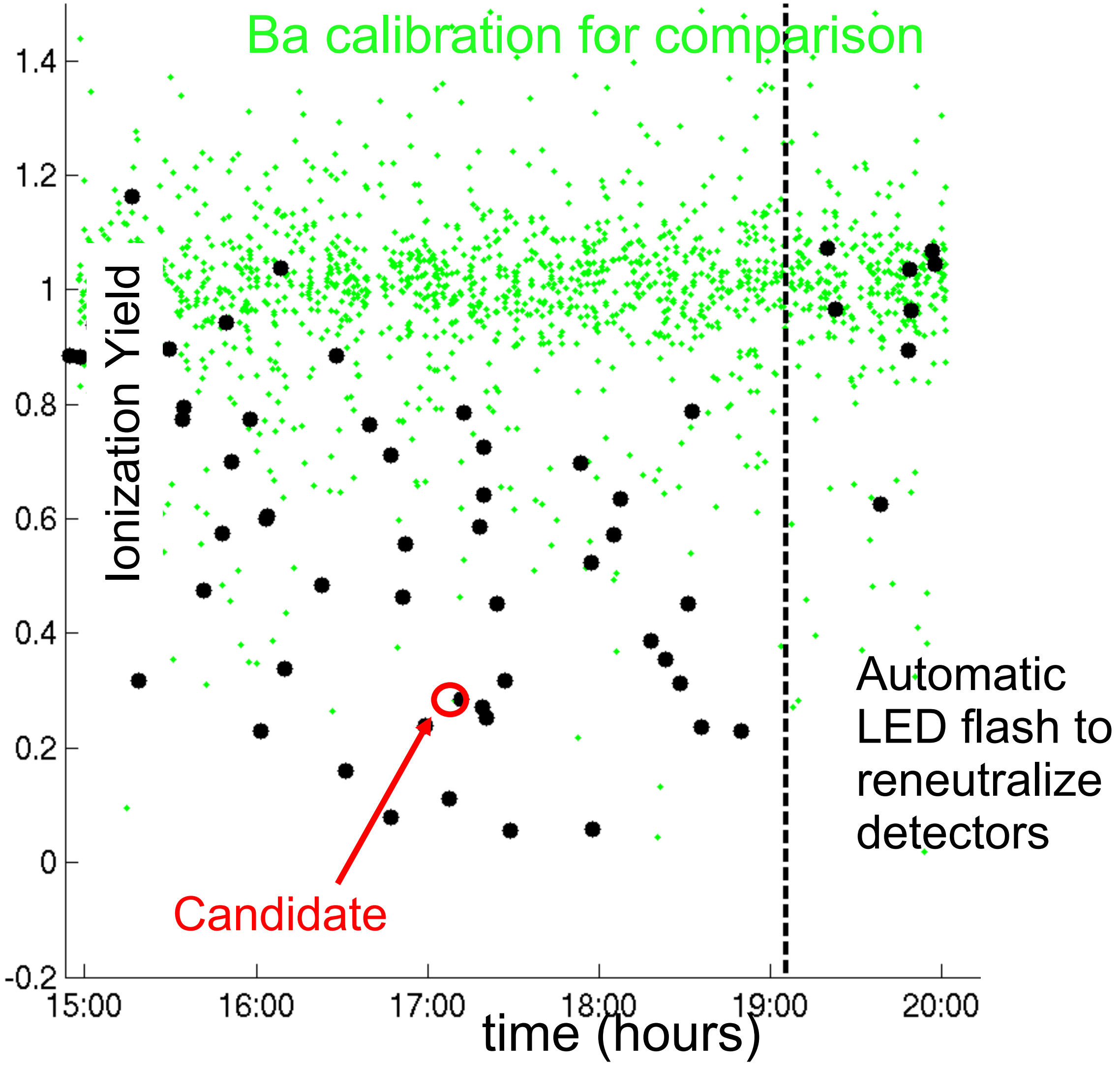
1.2 ± 0.6 (stat.) ± 0.2 (sys.) electron recoils,
<0.05 recoils from neutrons expected

- 1.25 kg Ge
- 0.4 kg Si
- 74 livedays before cuts

Results consistent with backgrounds alone (no evidence of WIMP interactions yet)

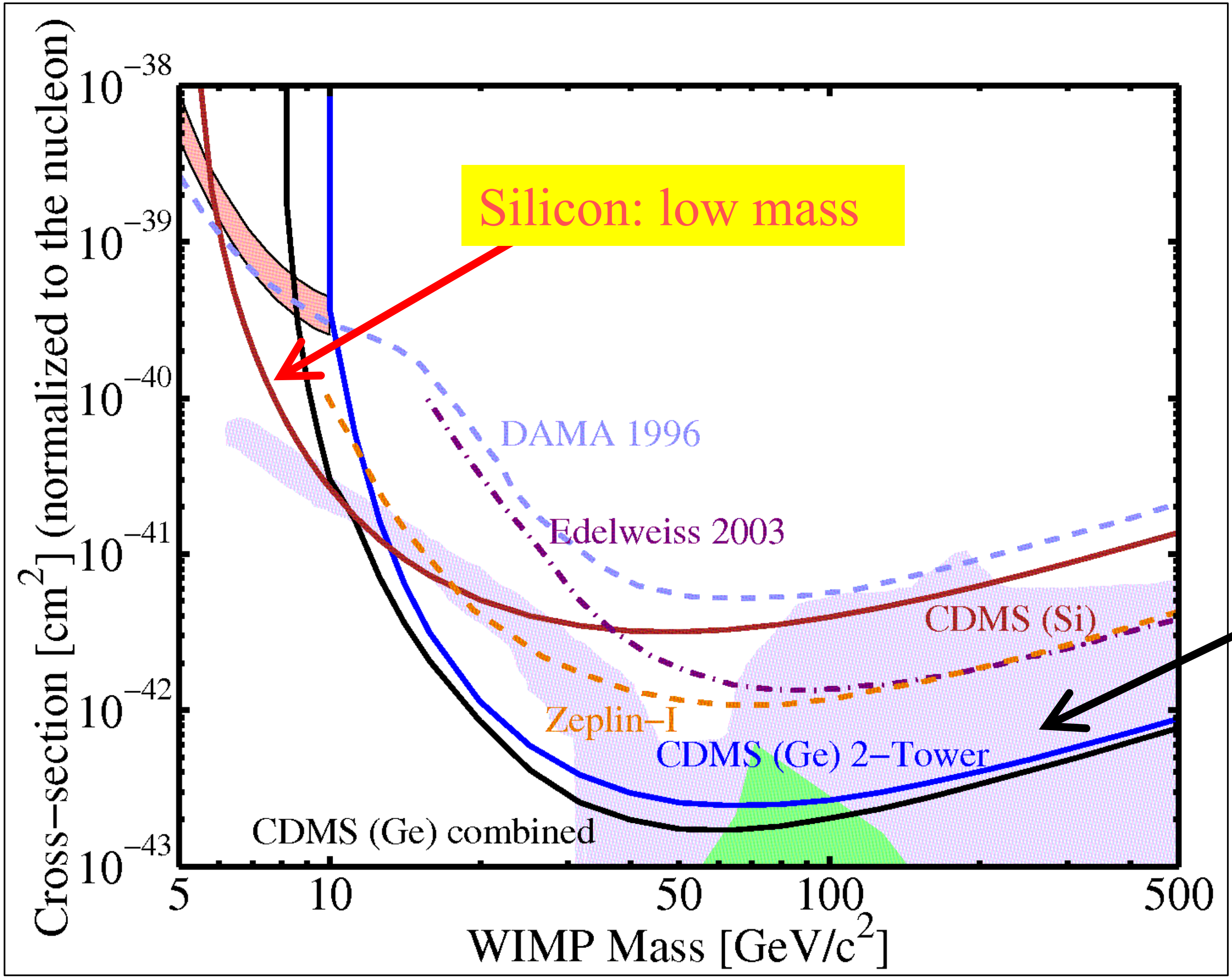
Run 119 results (blind)

- Data set with this event came immediately after extended exposure to strong ^{60}Co source.
- After many interactions, charges build up in the crystal: **deneutralization**.
- Ionization collection is depressed until **reneutralization** by LED flashes.
- So this event is a data quality issue!



Automatic LED flash to reneutralize detectors

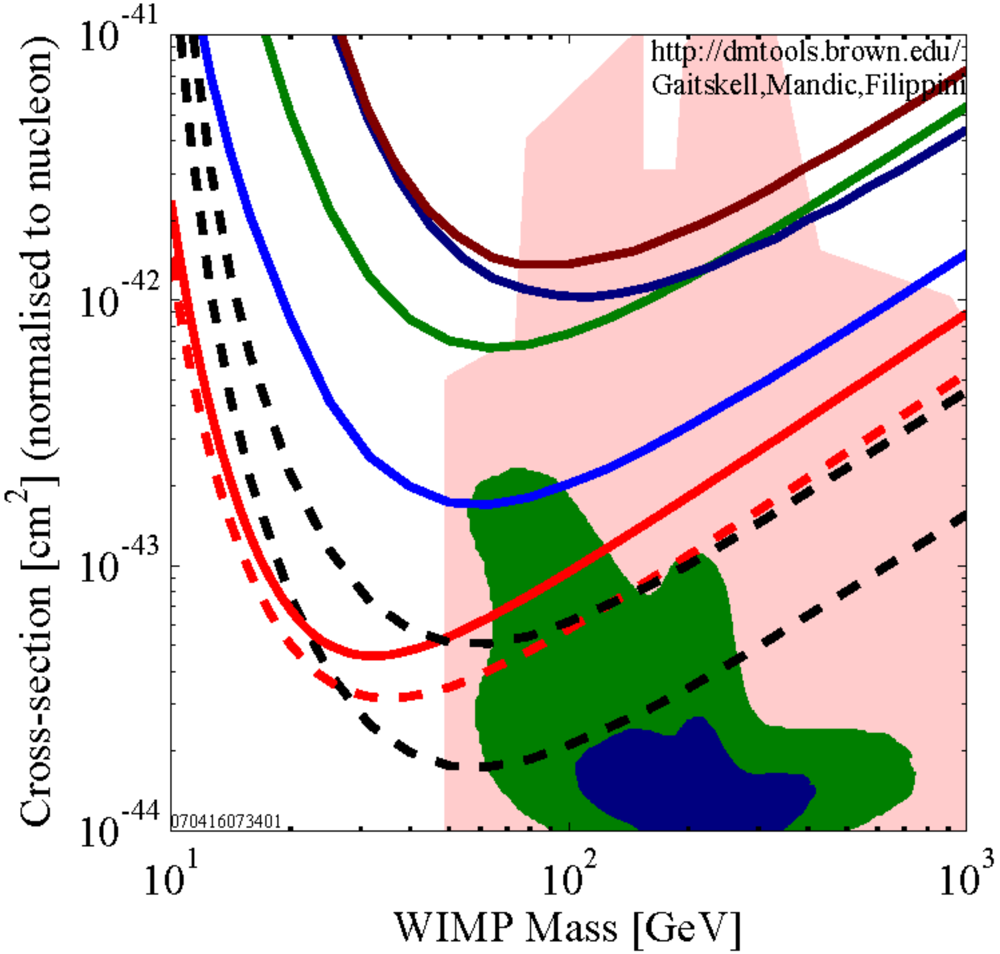
2-Tower Limits (Spin Independent)



90% CL

About twice more sensitive than 1-tower

Expectations for 5-Tower Runs



EDELWEISS
WARP
ZEPLIN II

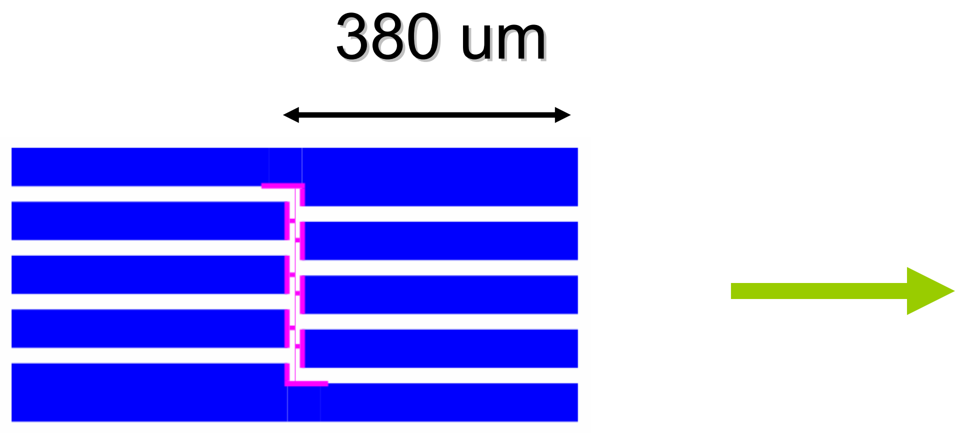
CDMS II (1T+2T)

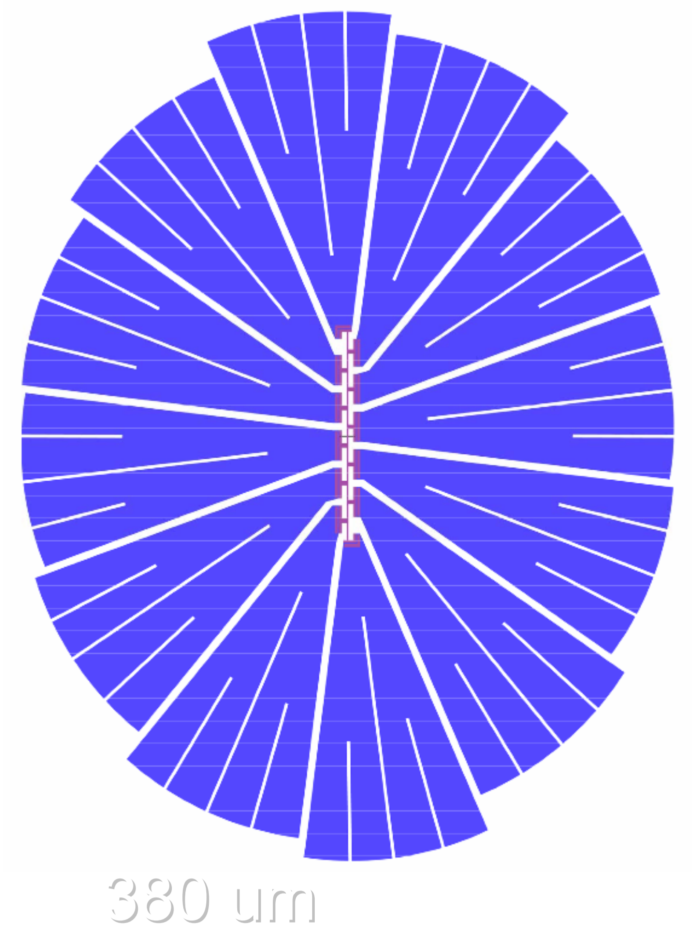
XENON-10 (solid is w/o bg subtraction)
XENON-10 (dashed w/ bg subtraction)
CDMS II (5-Tower, R123 projected)
CDMS II (5-Tower goal)

What is SuperCDMS 25 kg?

- Larger target mass
  - CDMS II at Soudan is running with 4.5 kg Ge => SuperCDMS 25 kg Ge
  - Thicker detectors, improved phonon sensor design (validate at Soudan)
- Reduced backgrounds
  - Better control of radioactivity in and around experiment
  - Better rejection of electromagnetic backgrounds
  - Deeper site (Soudan=2000 mwe => SNOLAB=6000 mwe)
    - No cosmic-induced neutrons at SNOLAB
- New cryogenic system
  - Larger (to accommodate more detectors) and better thermal performance
  - More robust and less expensive to operate
- Improved electronics, DAQ, controls
  - Reduce mechanical connections and heat load; improve reliability
  - Better remote monitoring and control
- Goal: 3 years of operations background free!

MAXIMUM ACTIVE AL COVERAGE

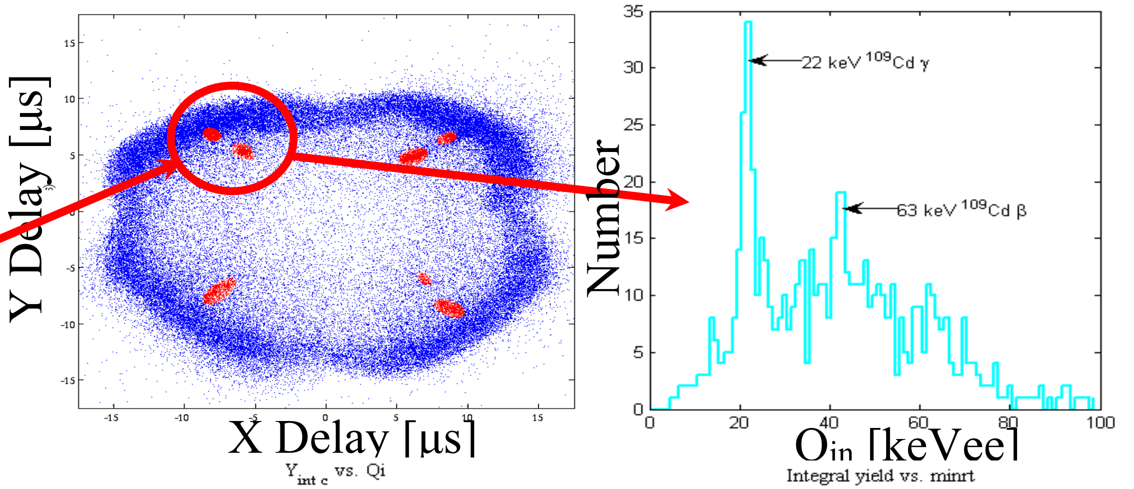


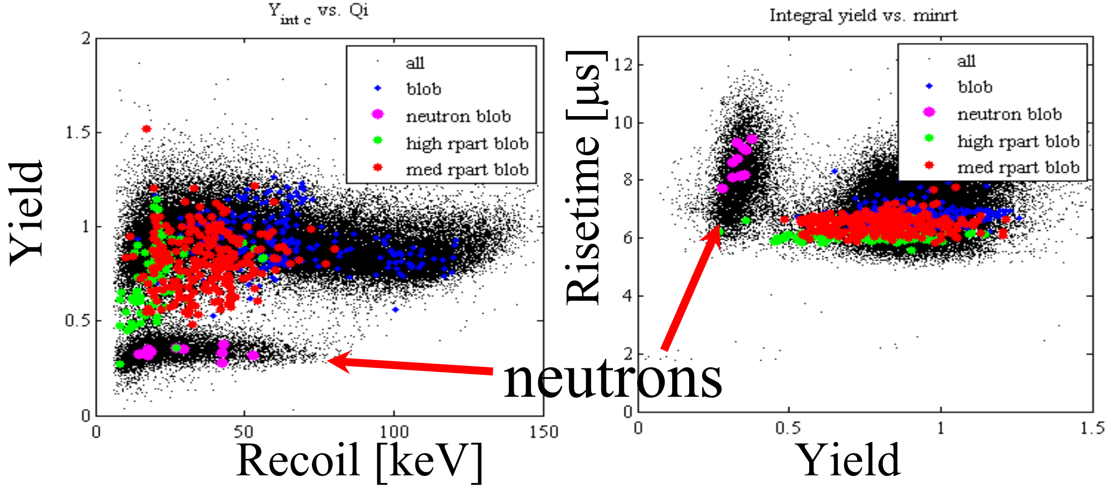


x2.5 Active Al change

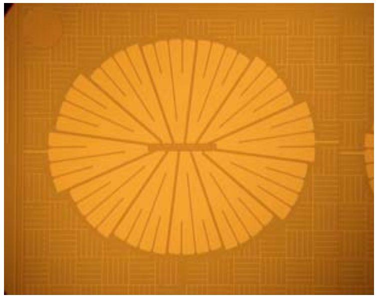
Data from UCB/Case TFs for Si 1” ZIP

- First data from 1” Si ZIP showing reconstructed location of ^{109}Cd events and spectrum

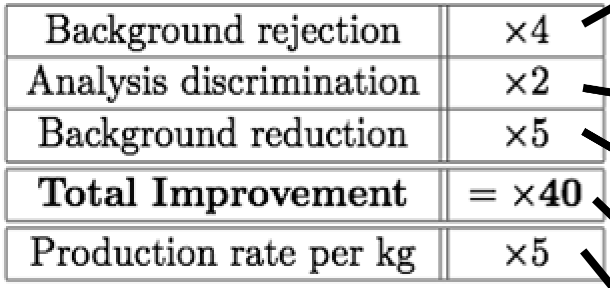




Improved background rejection and reduction



Increase phonon collection area x2 and new H-a-Si electrodes suppress charge back-diffusion x2



Background rejection	×4
Analysis discrimination	×2
Background reduction	×5
Total Improvement	**= ×40**
Production rate per kg	×5

Table 2: Targeted improvement factors over CDMS II advanced analysis levels (see Section 3.2) to achieve SuperCDMS 25 kg sensitivities with zero background from internal sources. The cosmogenic fast-neutron background is eliminated by the SNO-LAB overburden of 6000 mwe.

Expect at least an additional x2 from advanced timing analyses

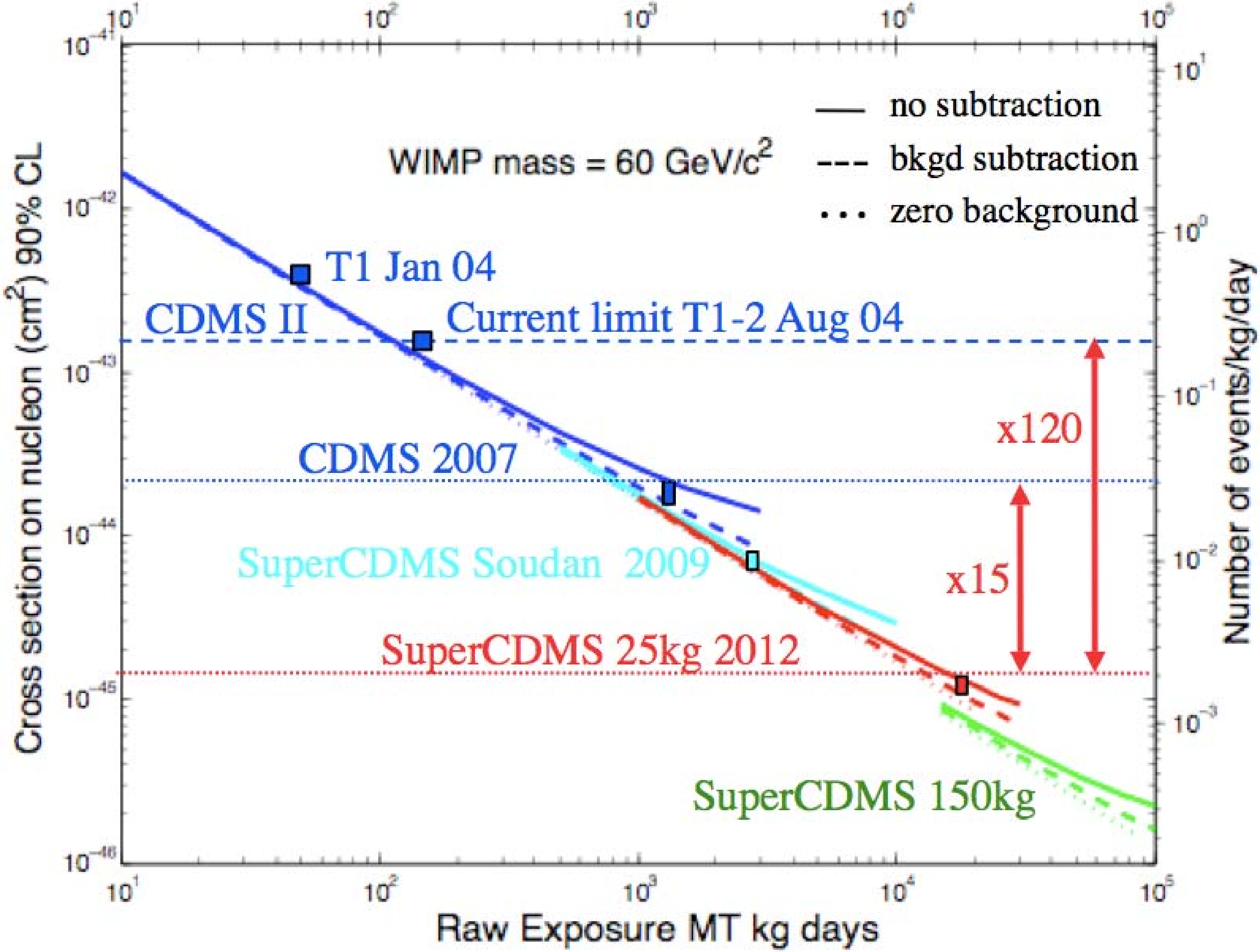
Expect x2.5 from additional thickness and x2 from better control of Rn

Need x20 of this x40 total for the SuperCDMS 25 kg target background

Expect x2.5 from additional thickness and x2 from improved fabrication efficiency

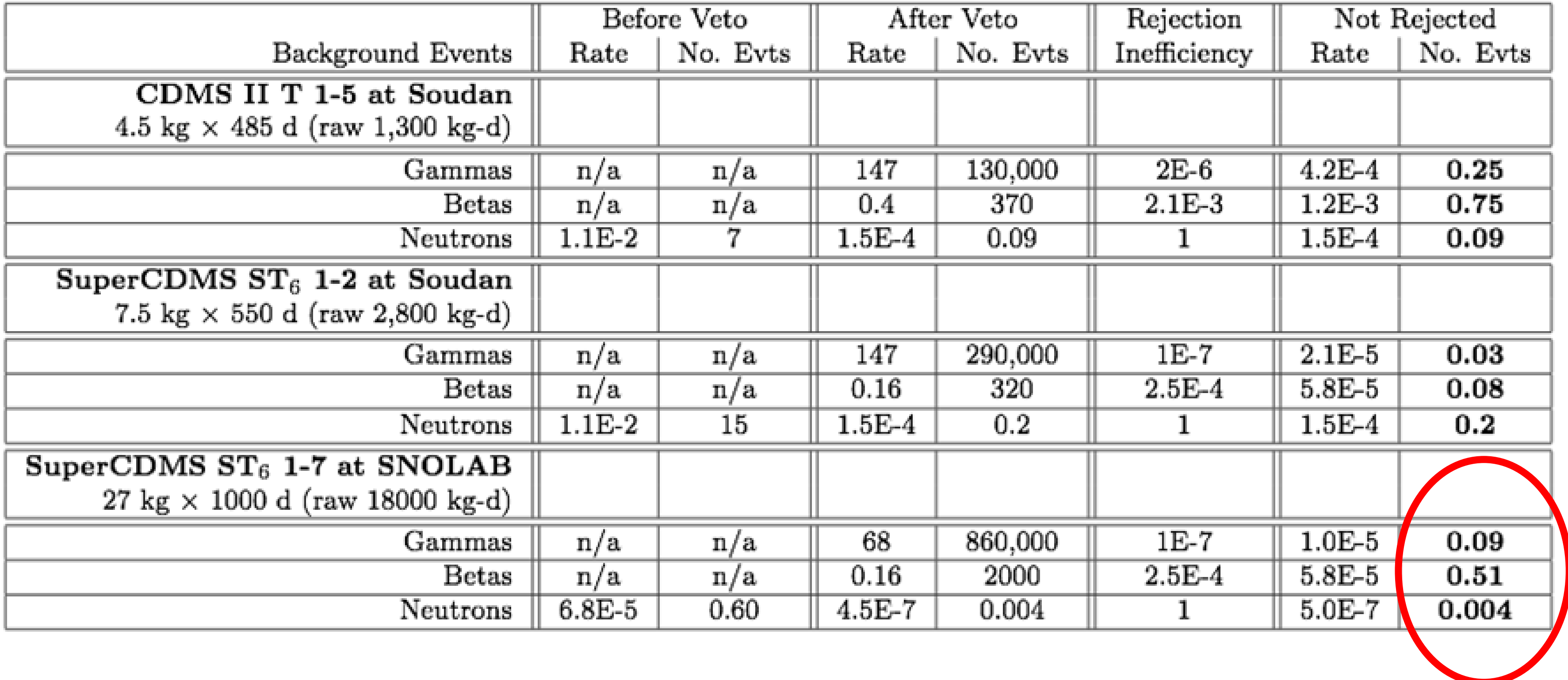
- to meet SuperCDMS 25 kg goals only need x20 actual performance gain out of x40 predicted gain

Sensitivity reach with full bkgd analysis



Full accounting of expected backgrounds

- To achieve zero-background experiments we expect the following backgrounds for the five-Tower run CDMS II at Soudan, two-SuperTower run at Soudan and seven-SuperTower run at SNOLAB



	Before Veto		After Veto		Rejection Inefficiency	Not Rejected	
Background Events	Rate	No. Evts	Rate	No. Evts		Rate	No. Evts
CDMS II T 1-5 at Soudan 4.5 kg × 485 d (raw 1,300 kg-d)							
Gammas	n/a	n/a	147	130,000	2E-6	4.2E-4	**0.25**
Betas	n/a	n/a	0.4	370	2.1E-3	1.2E-3	**0.75**
Neutrons	1.1E-2	7	1.5E-4	0.09	1	1.5E-4	**0.09**
SuperCDMS ST$_6$ 1-2 at Soudan 7.5 kg × 550 d (raw 2,800 kg-d)							
Gammas	n/a	n/a	147	290,000	1E-7	2.1E-5	**0.03**
Betas	n/a	n/a	0.16	320	2.5E-4	5.8E-5	**0.08**
Neutrons	1.1E-2	15	1.5E-4	0.2	1	1.5E-4	**0.2**
SuperCDMS ST$_6$ 1-7 at SNOLAB 27 kg × 1000 d (raw 18000 kg-d)							
Gammas	n/a	n/a	68	860,000	1E-7	1.0E-5	**0.09**
Betas	n/a	n/a	0.16	2000	2.5E-4	5.8E-5	**0.51**
Neutrons	6.8E-5	0.60	4.5E-7	0.004	1	5.0E-7	**0.004**

Summary

- 2-Tower limits published
- First 5-Tower data-set undergoing blind analysis
- 5-Tower data-taking continues
- Next step: SuperCDMS 25 kg

We're ready to go!