The CDMS II Experiment: 2 Events! What's Next?

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for the CDMS Collaboration

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UF
UNIVERSITY of FLORIDA

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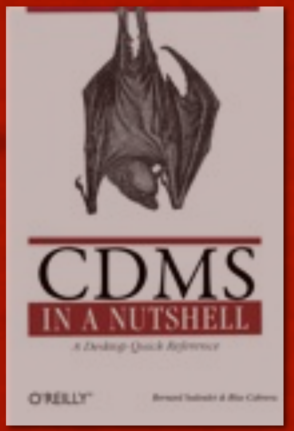
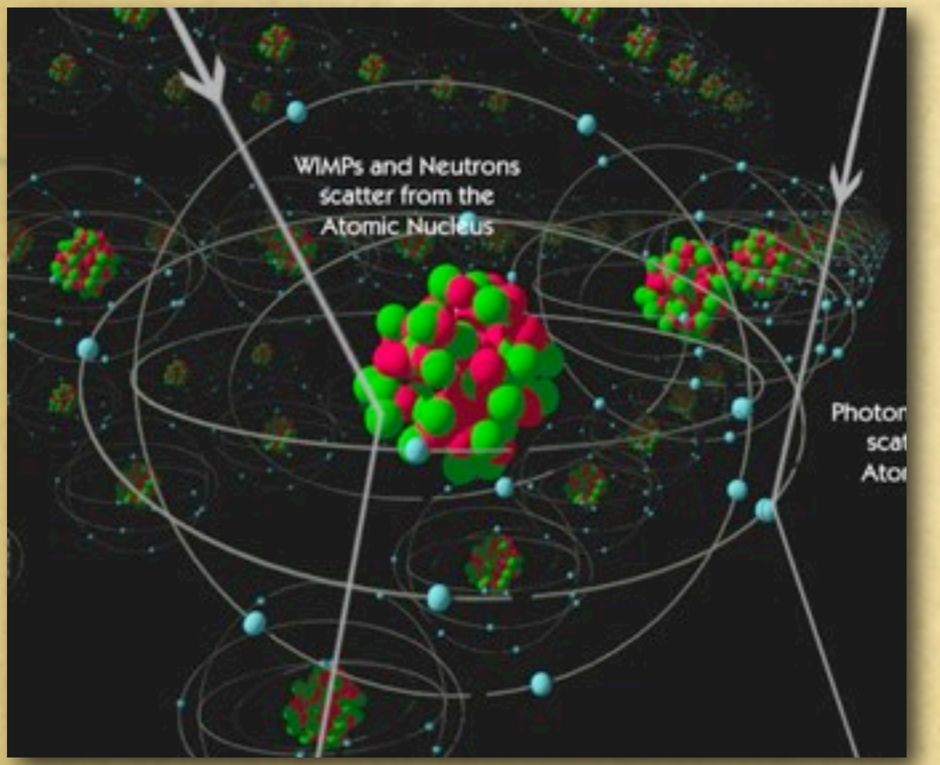
The CDMS Collaboration

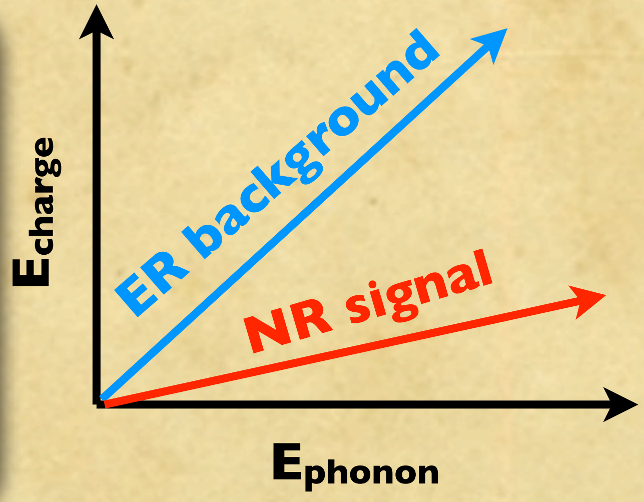
CDMS: The Big Picture



Use a combination of **discrimination** and **shielding** to maintain a “<1 event expected background” experiment with low temperature semiconductor detectors

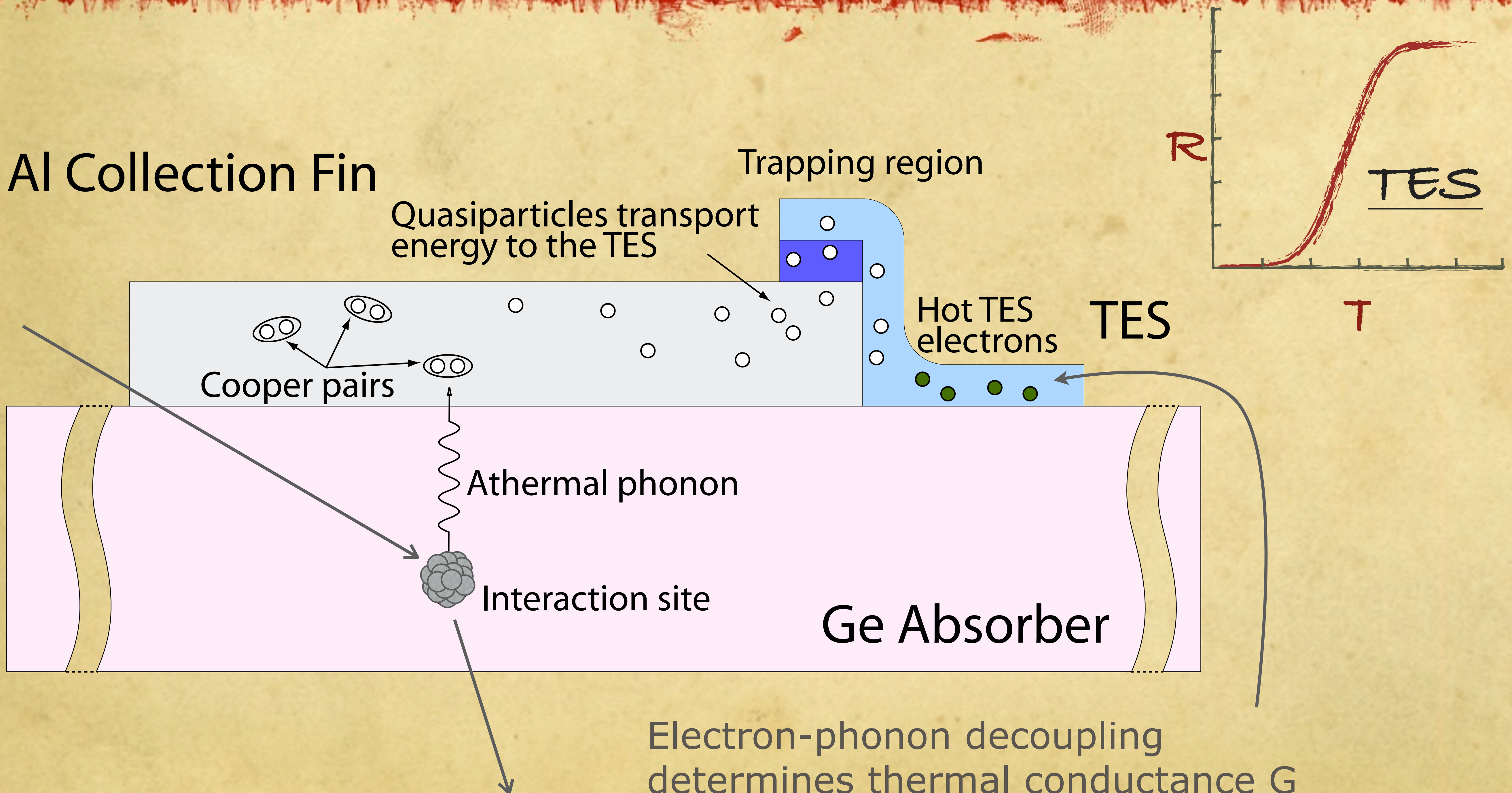


Discrimination from measurements of ionization and phonon energy.



Keep backgrounds low as possible through shielding and material selection.

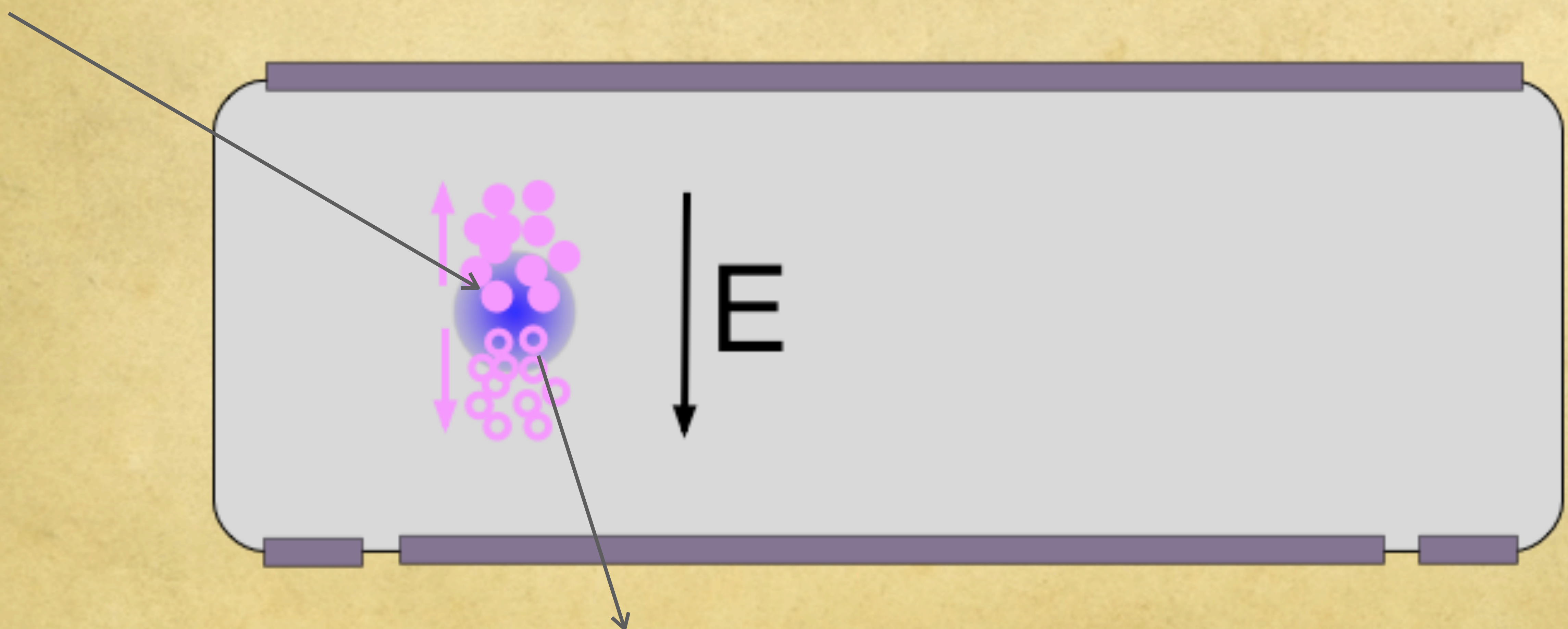
Background discrimination: How is it done? The Phonon Signal



Electron-phonon decoupling determines thermal conductance G

Background discrimination: How is it done? The Ionization Signal

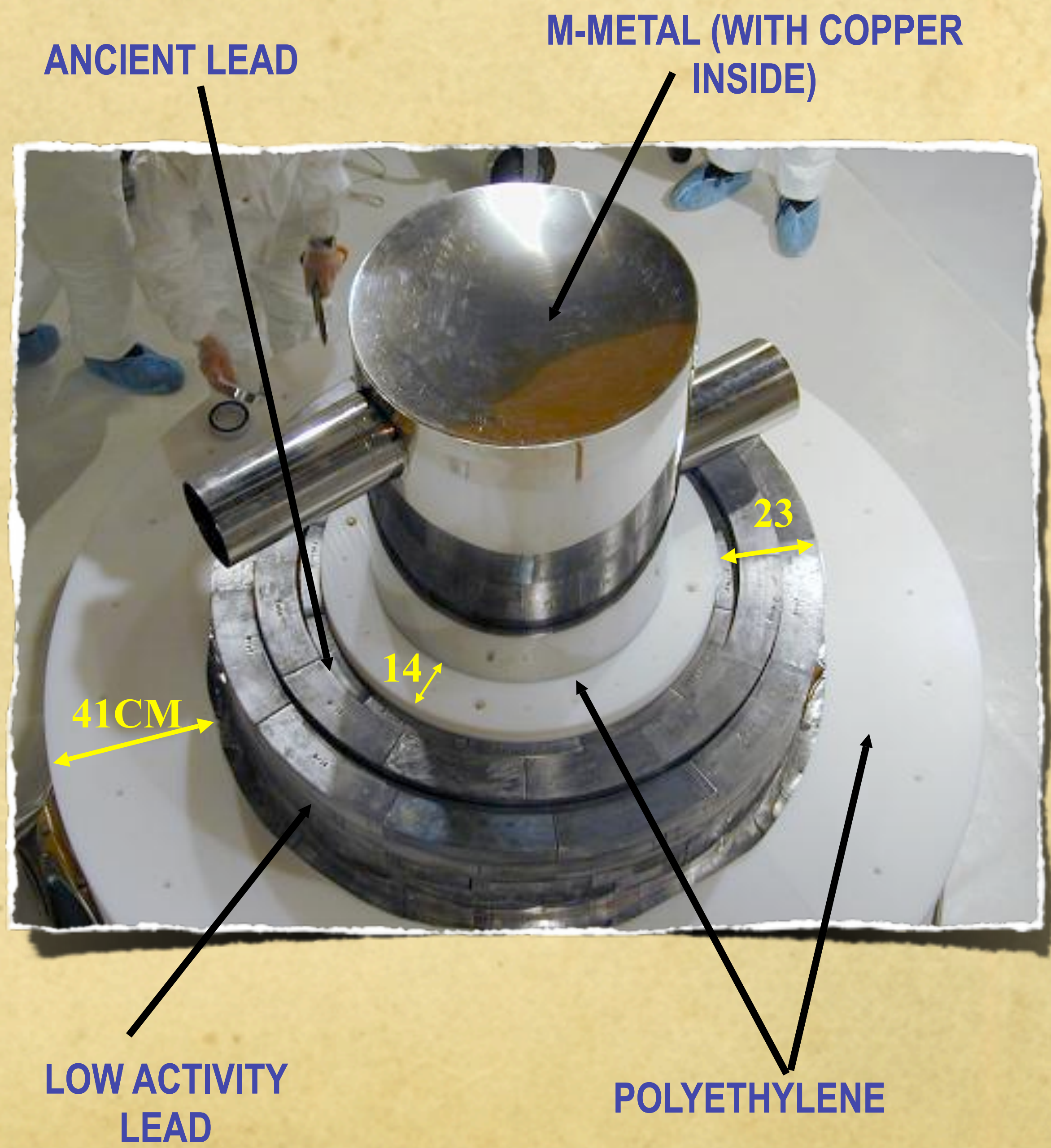
Electrons and holes are drifted across the crystal by an electric field of a few V/cm



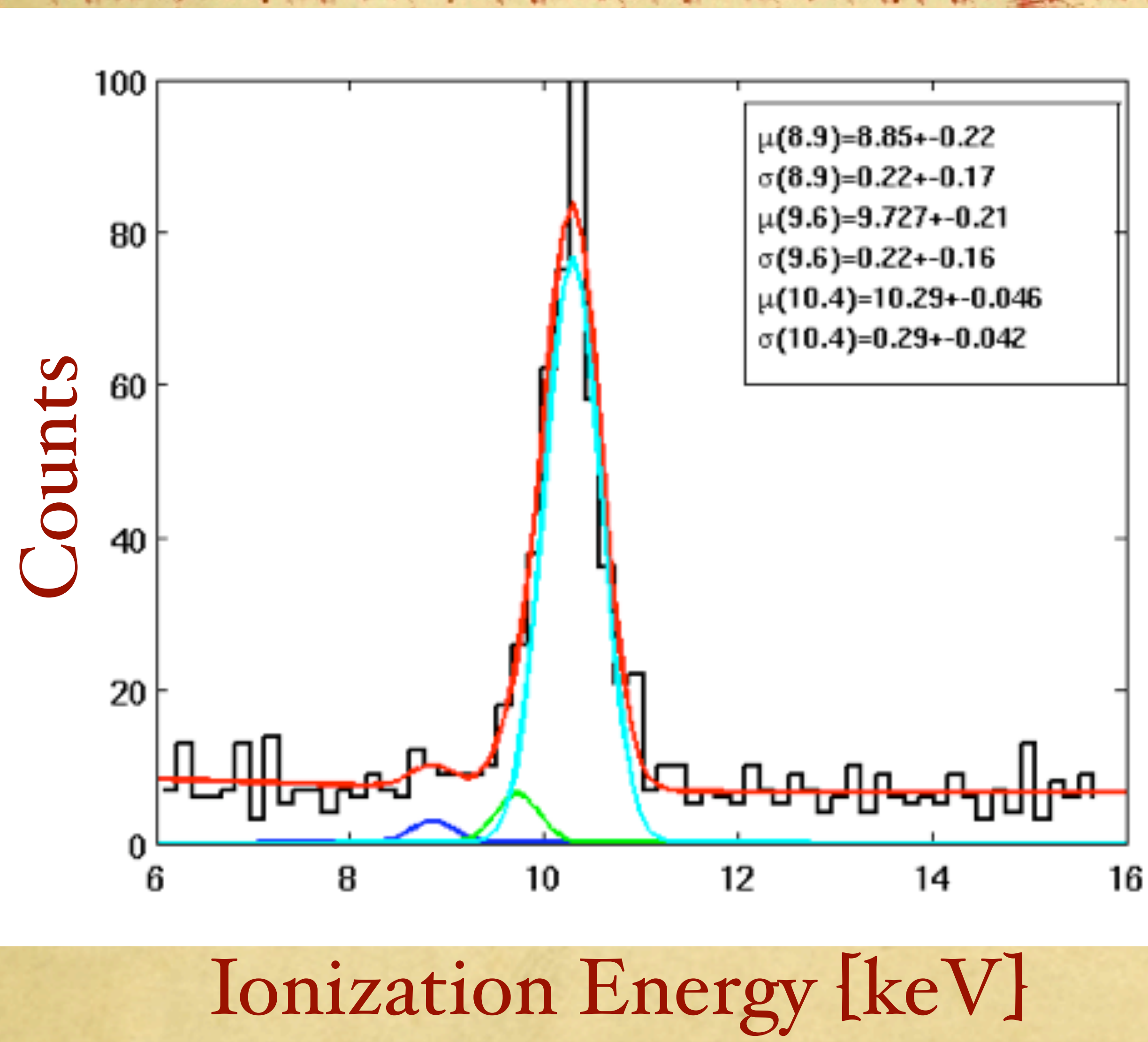

This the
superconducting
thermometer
1x250 μm

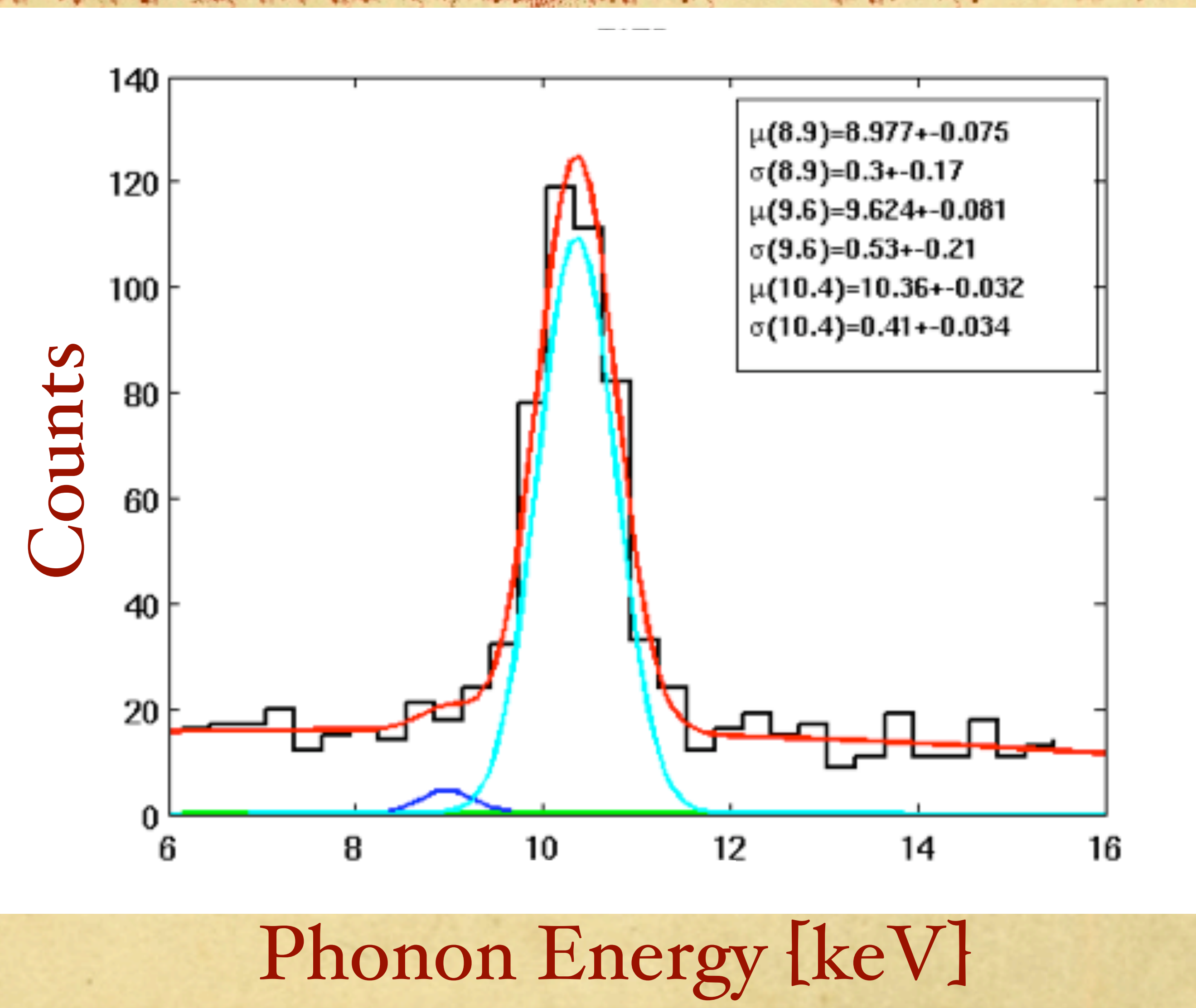
The CDMS Shielding Scheme

- Surround detectors with active muon veto
- Use passive shielding to reduce γ/n
  - Overburden reduces μ-induced neutrons
  - Polyethylene for low-energy neutron
  - Lead and Copper for gammas
- 5 Towers now installed and taking data



Energy Resolution

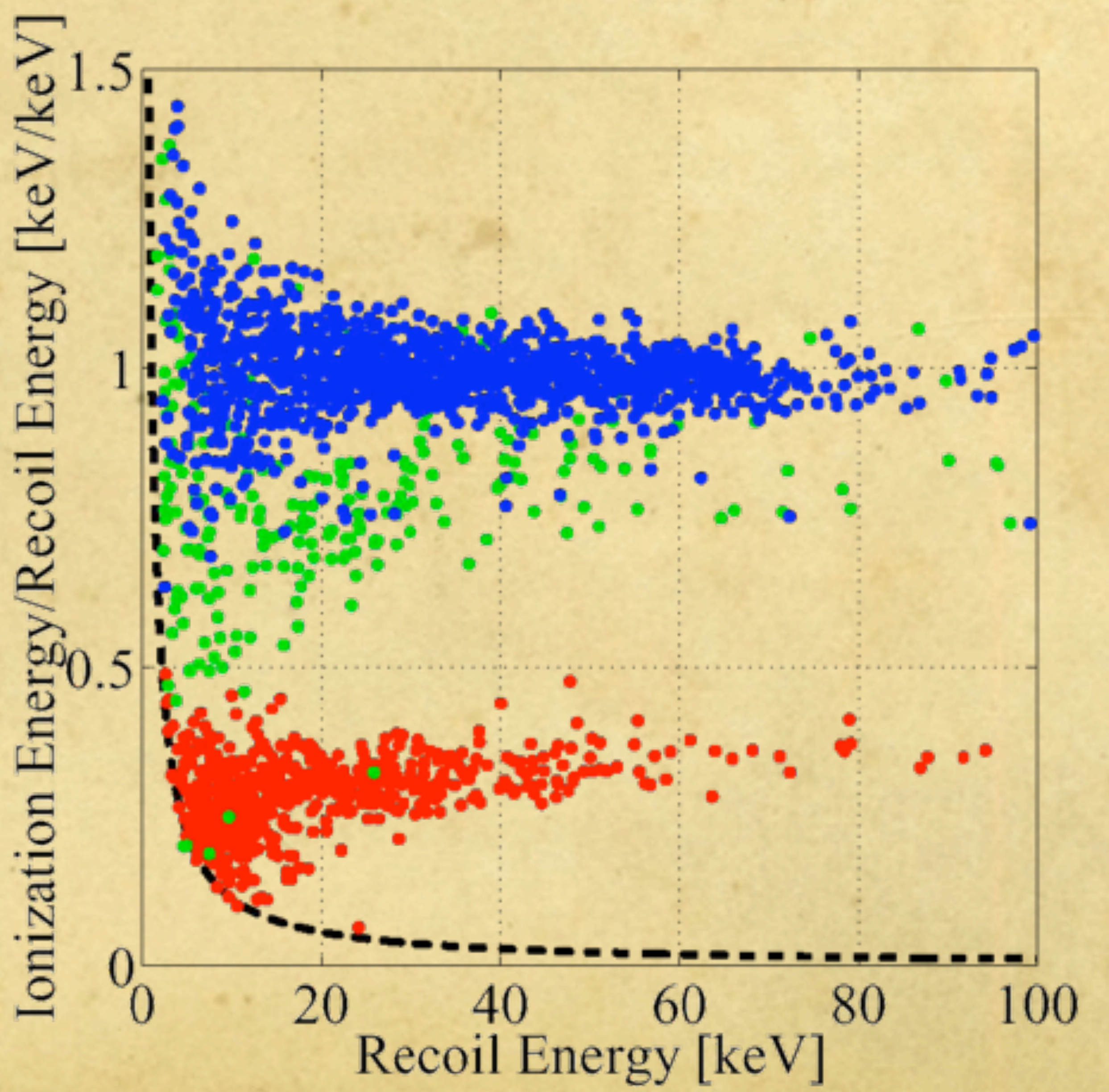




Fits of the lines 10.36 keV, 8.9 keV and 9.7 keV in the phonon and ionization channels for a single detector.

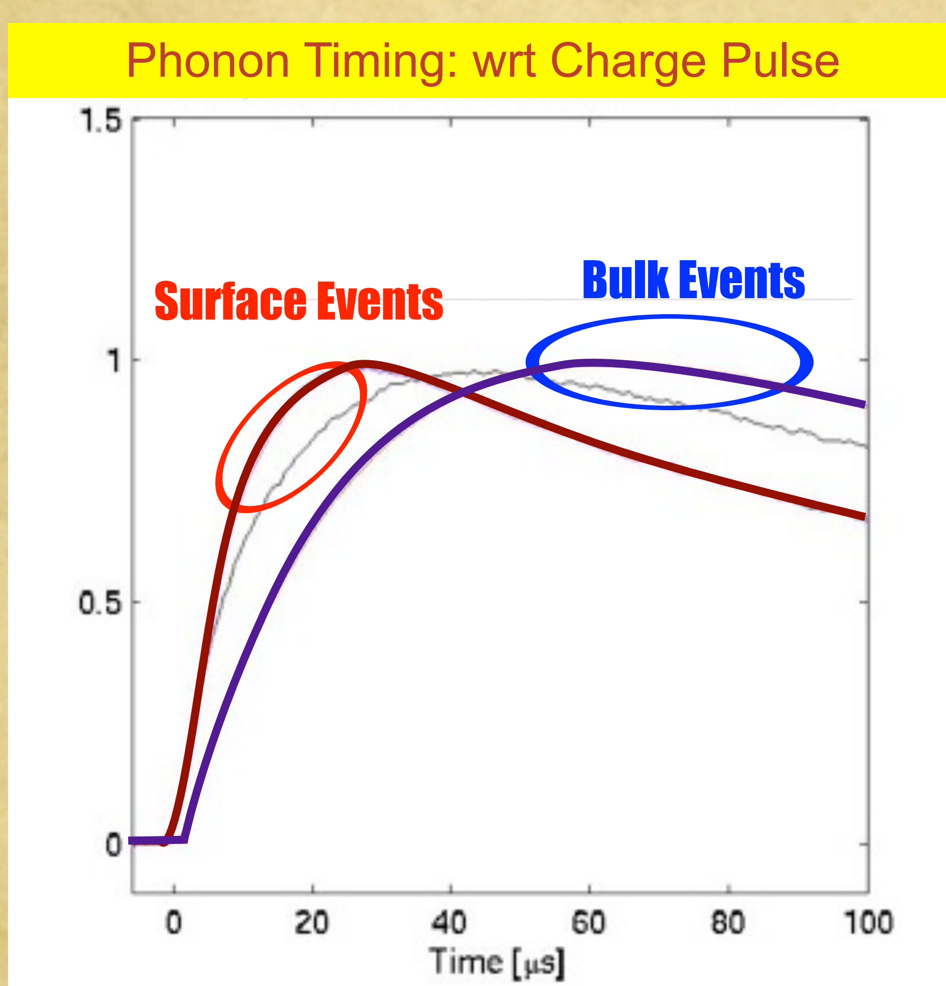
Background Rejection: Yield

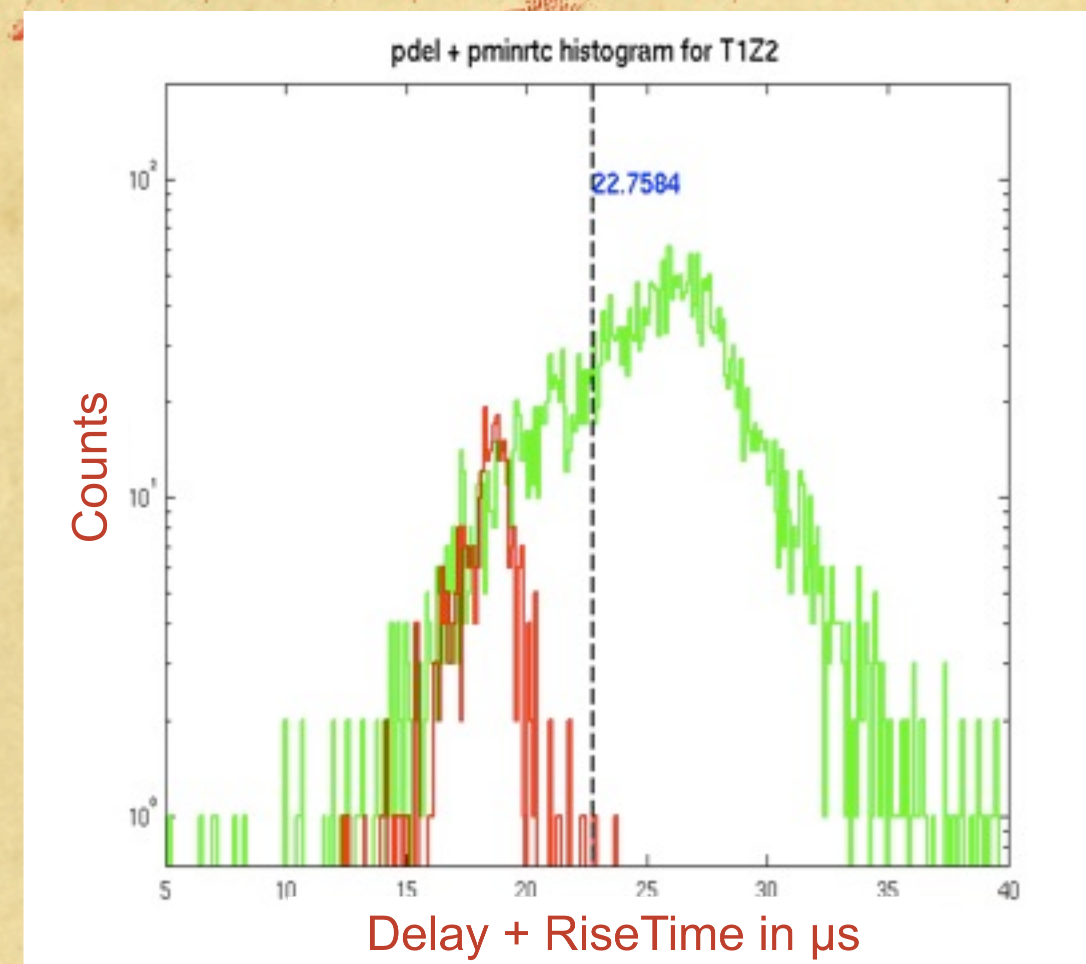
- Calibration with ^{133}Ba (γ) source results in the blue (high yield) electron recoils
- Calibration with ^{252}Cf (n) source results in the red (low yield) nuclear recoils
- Surface electron recoils also have low yield (green)
- Mis-identification of electron recoils < than 1 in 10^{-4}



Background Rejection: Pulse Shape

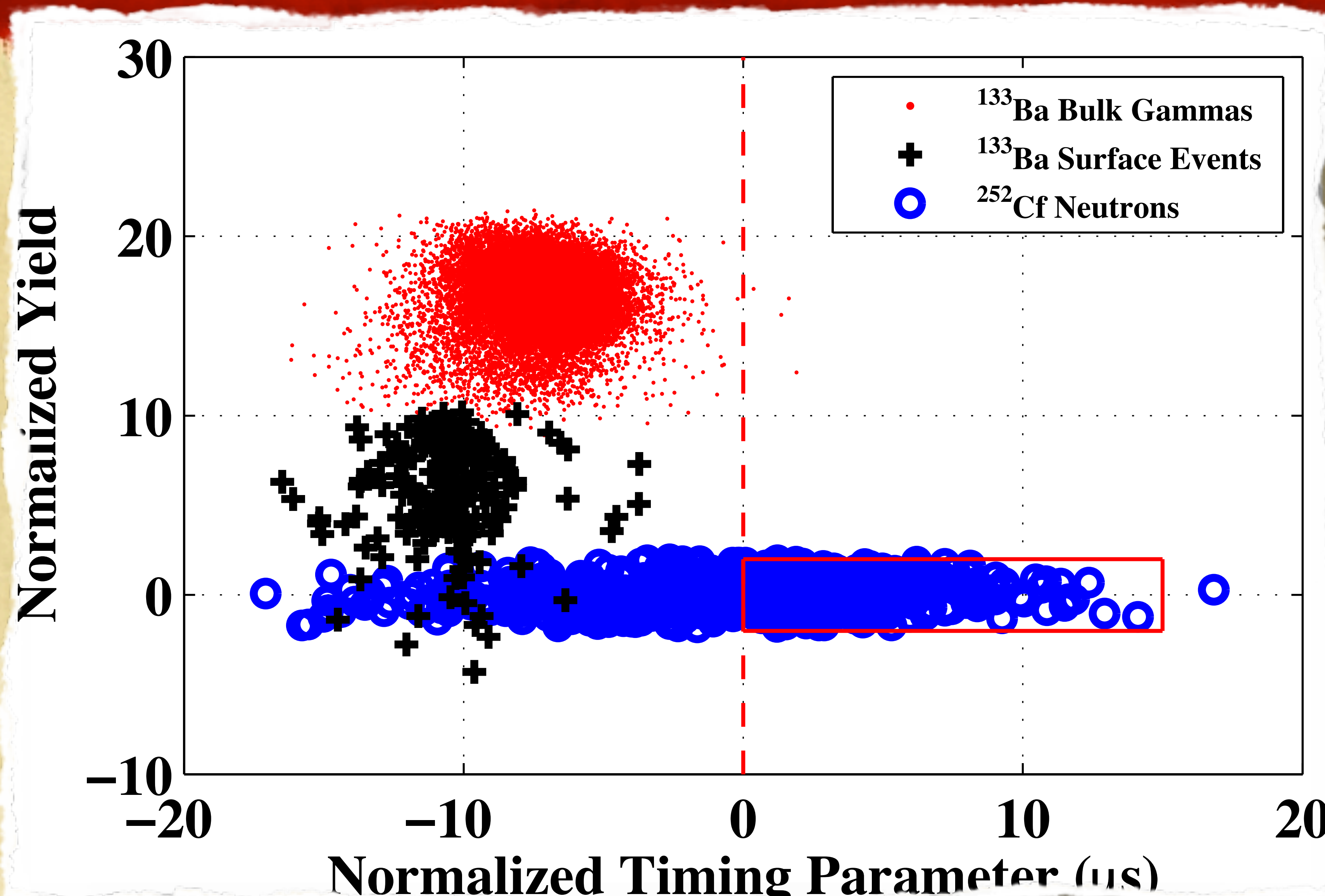
Faster down conversion of athermal phonons at surface provides faster phonon signal for βs





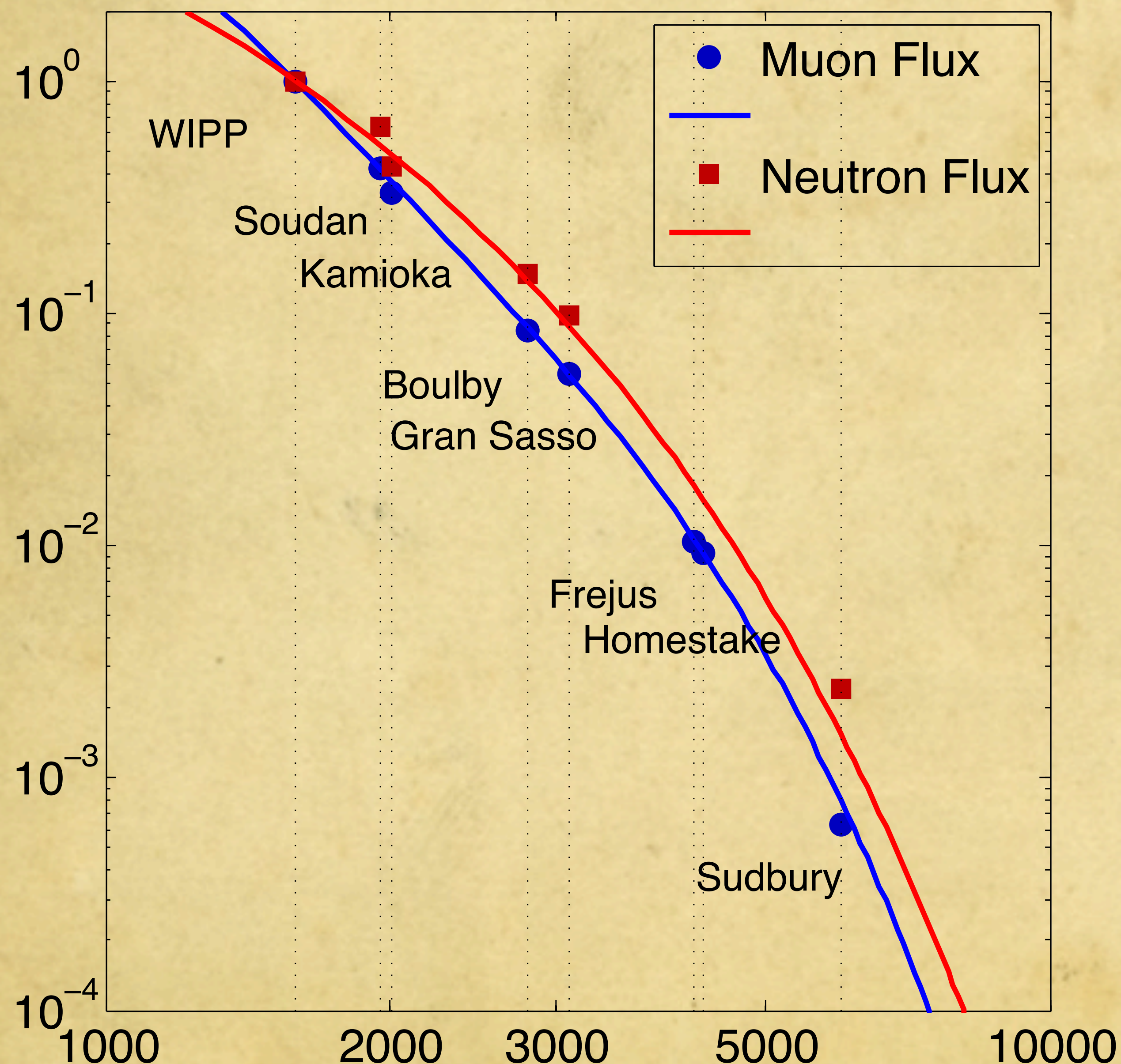
Cut chosen at a level to contribute ~ 0.5 event total leakage to WIMP candidate

Background Rejection: Combined



Combined electron recoil mis-identification < 10^{-6}

Background Reduction: Nuclear Recoils



SUF

17 mwe

0.5 n/d/kg

(182.5 n/y/kg)

Soudan

2090 mwe

0.05 n/y/kg

SNOLab

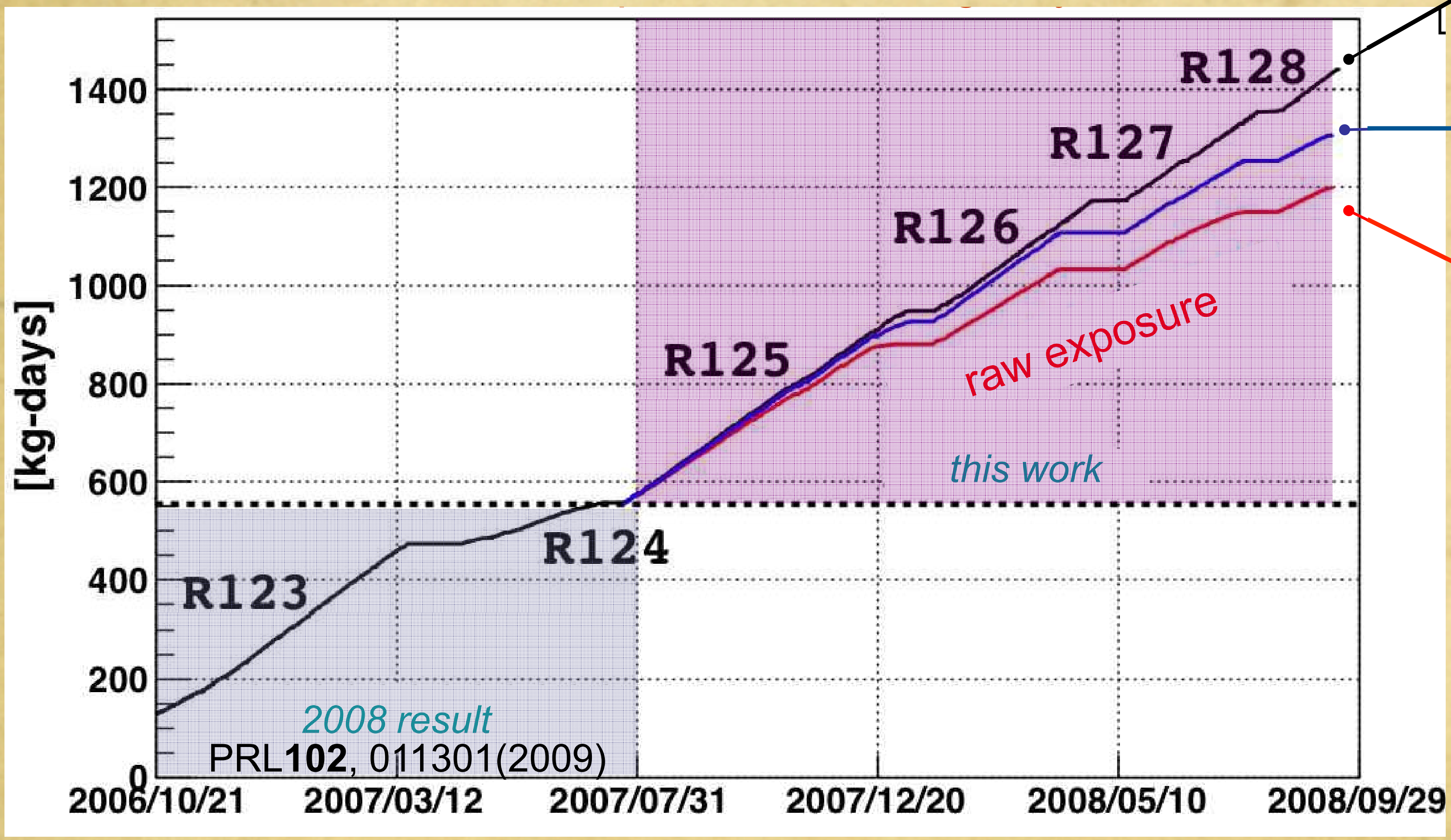
6060 mwe

0.2 n/y/ton

(0.0002 n/y/kg)

Wimp Search Data

Total raw exposure is 612 kg-days



All recorded data

Some detectors not analyzed for WIMP scatters

Periods of poor data quality removed

Surface Event Background

$$\text{Expected Surface ``leakage''} = \frac{N^{\text{Sideband}}_{\text{pass cut}}}{N^{\text{Sideband}}_{\text{fail cut}}} * N^{\text{data}}_{\text{fail cut}}$$

Sample 1

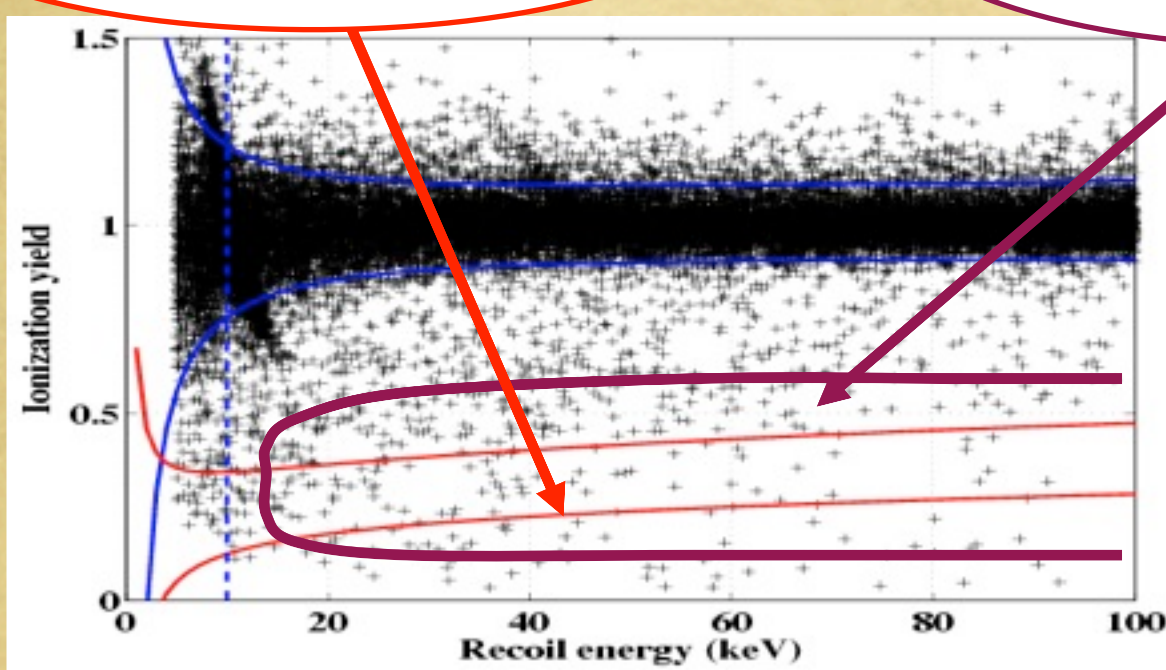
Use multiple-scatters in NR band

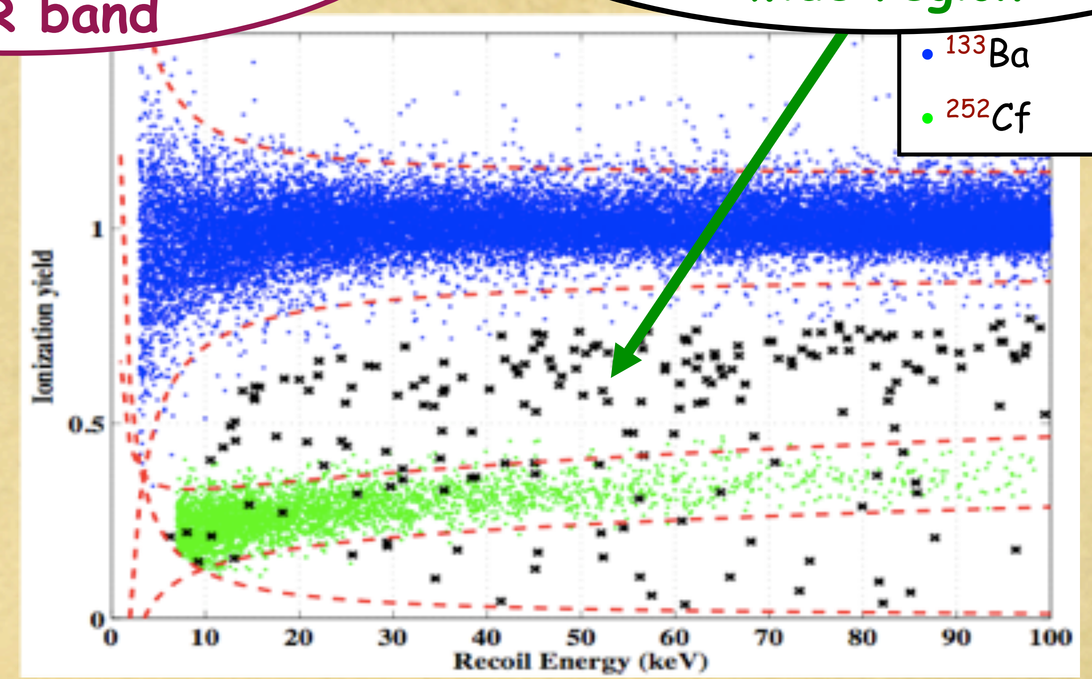
Sample 2

Use singles and multiples just outside NR band

Sample 3

Use singles and multiples from Ba calibration in wide region





Combined Estimate = 0.6±0.1 (stat)

Neutron Background

Cosmogenic:

3 vetoed, single scatter events

$$\frac{N^{MC}_{unvetoed,\ SS,\ NR}}{N^{MC}_{vetoed,\ SS,\ NR}} * N^{data}_{vetoed,\ SS,\ NR} = 0.04^{+0.04}_{-0.03}(\text{stat})$$

Radiogenic:

- Materials measured using conventional HPGe detector @ 77 K
- Spectra confirmed by Monte Carlo
- Contamination levels used as inputs to Geant4 simulation.

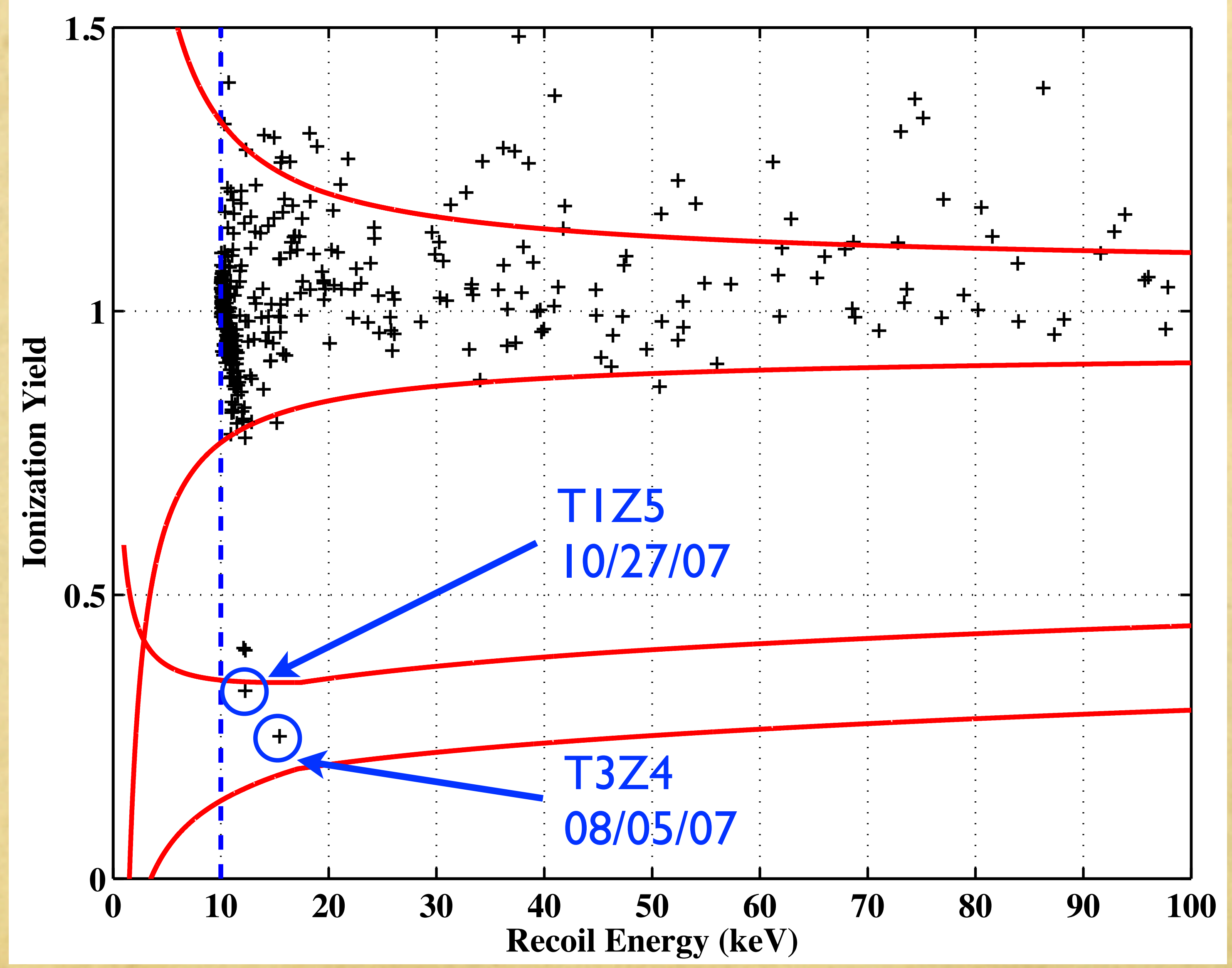
0.03 - 0.06 events

The CDMS II Results

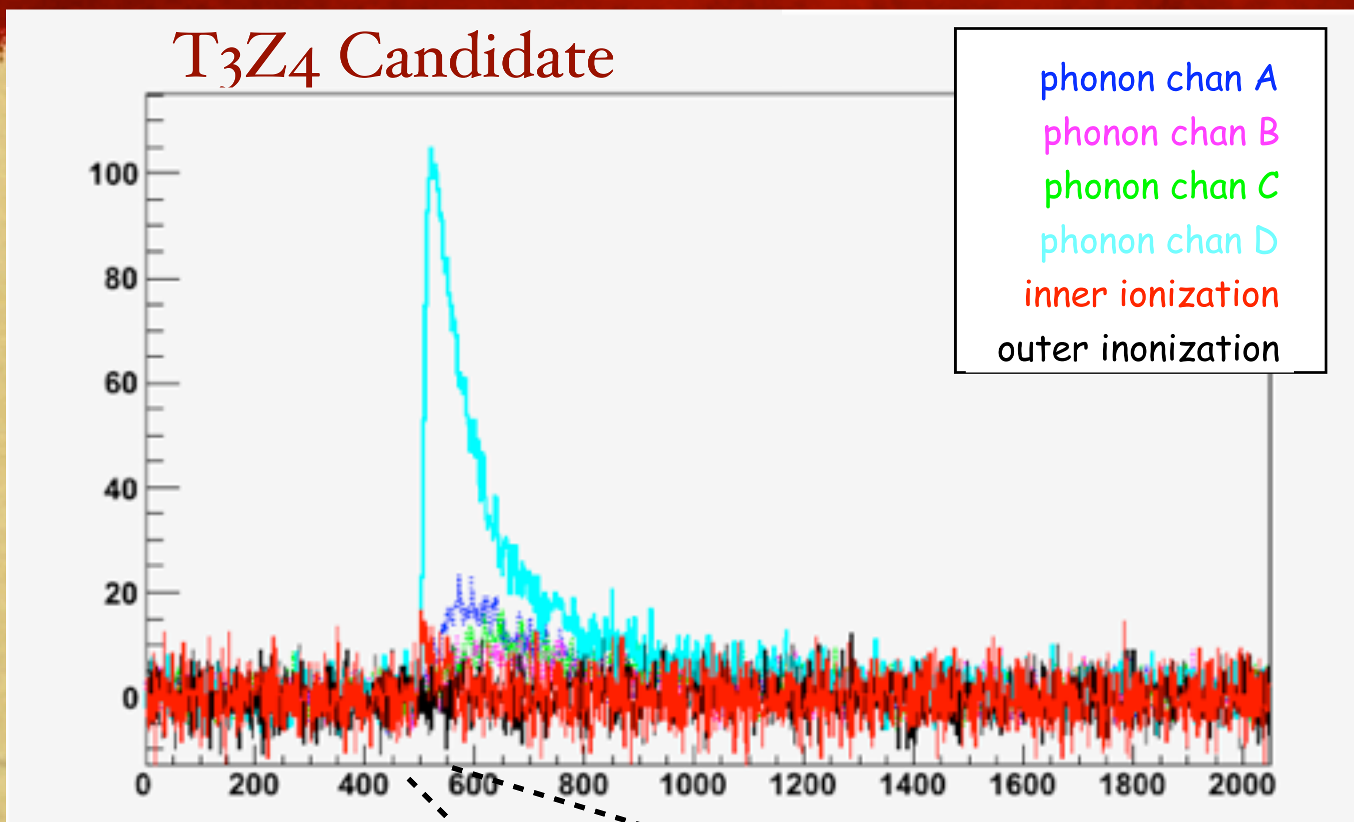
Data unblinded November 5 , 2009 for 14 Ge ZIP detectors

612 raw kg-days.
194.1 kg-d WIMP equiv.
@ 60 GeV/c^2
(10 -100 keV analysis energy range)

2 EVENTS OBSERVED!

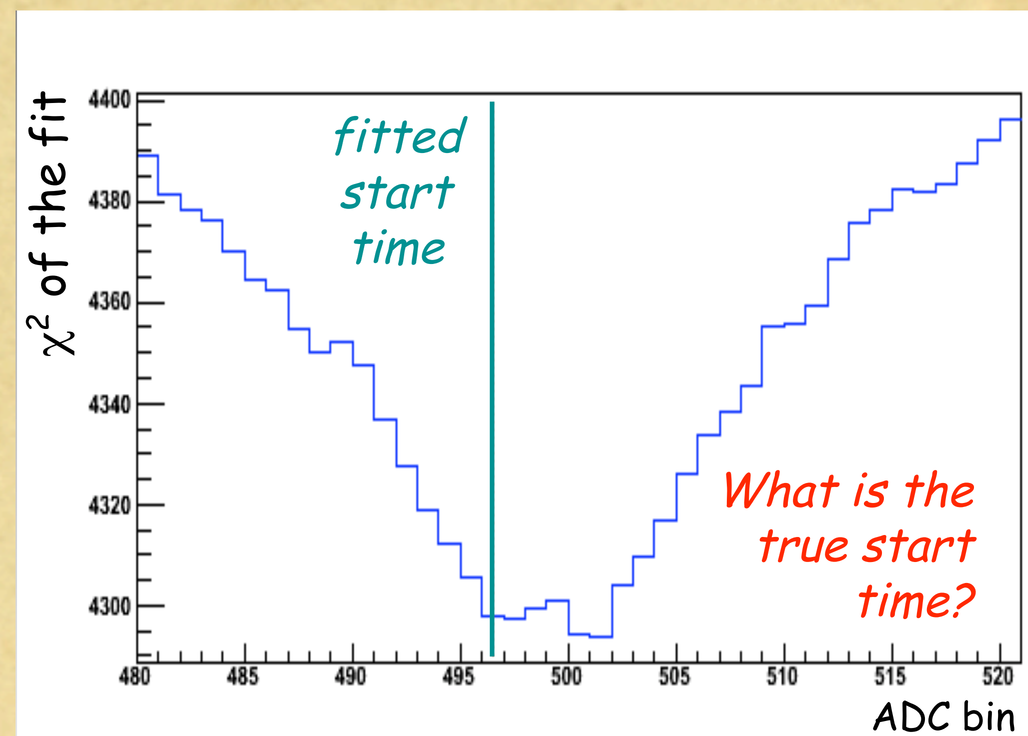


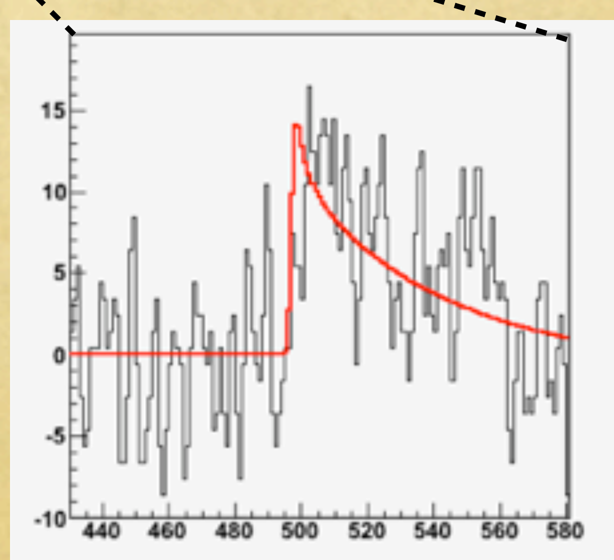
Reconstruction Checks



ionization and phonon energies look good, phonon timing looks good, ...

... but could be problem with charge start time



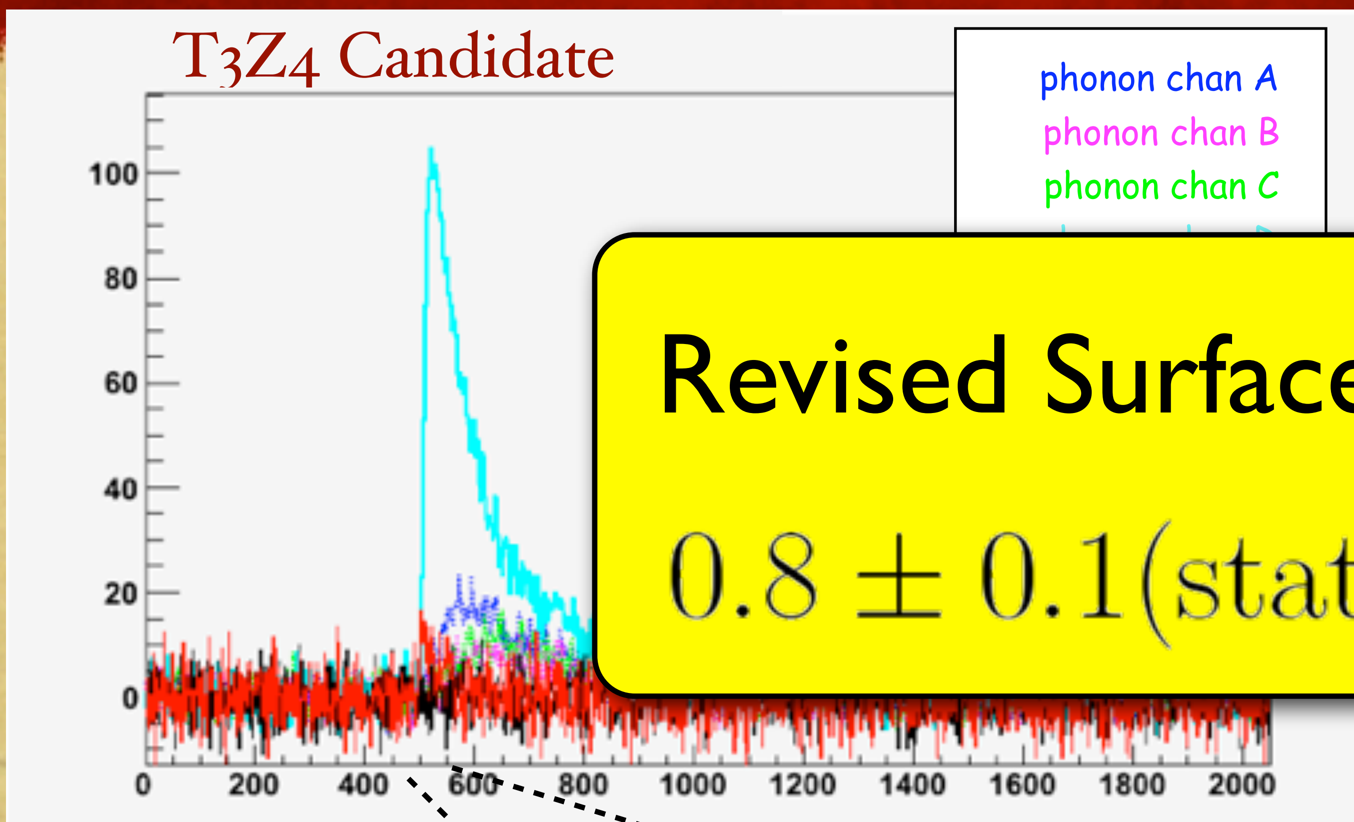


Raw Unfiltered Data.

Note: This effects some events with ionization energy < ~6 keV. It does not effect candidate event on T1Z5.

Reconstruction Checks

T3Z4 Candidate



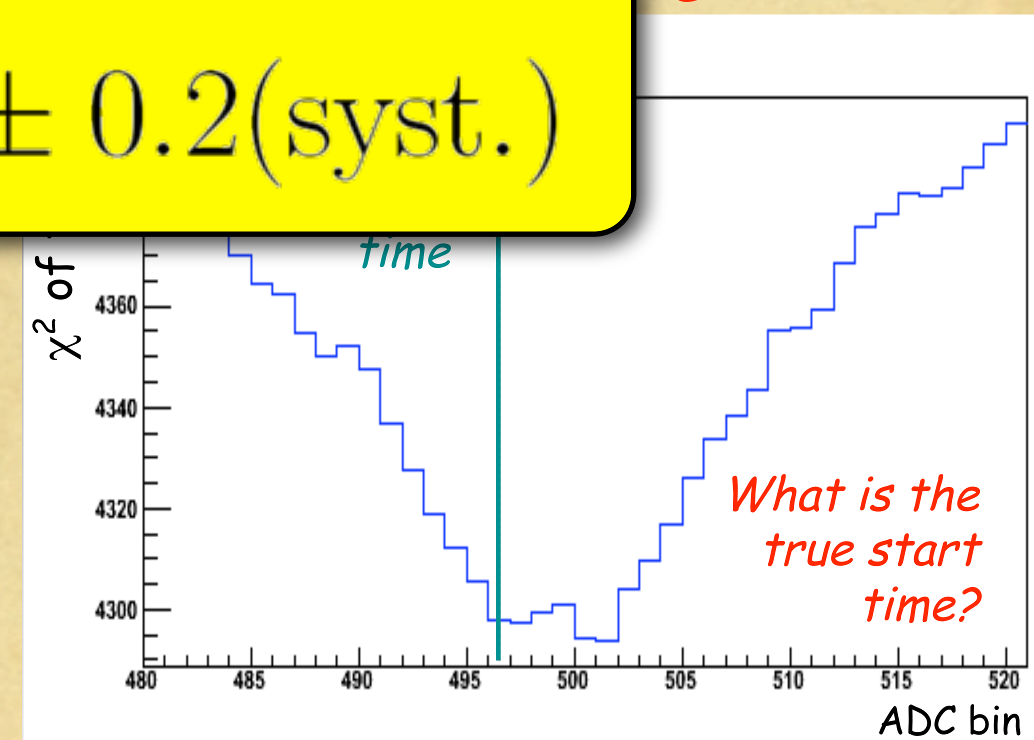
Revised Surface Event Estimate

$$0.8 \pm 0.1(\text{stat.}) \pm 0.2(\text{syst.})$$

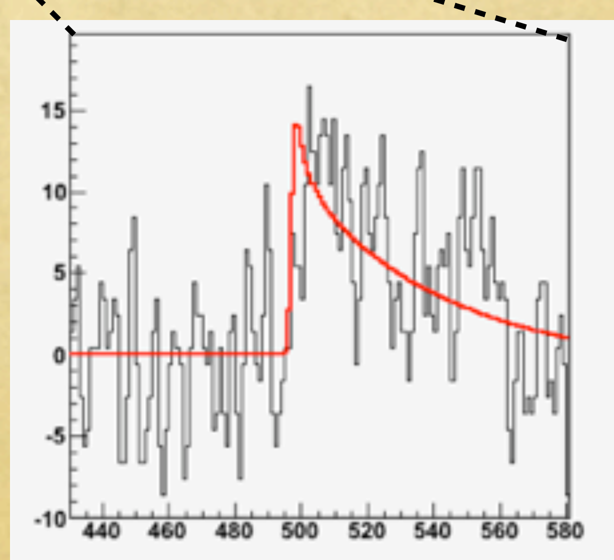
ionization and phonon energies look good, phonon timing looks

uld be problem

rge start time



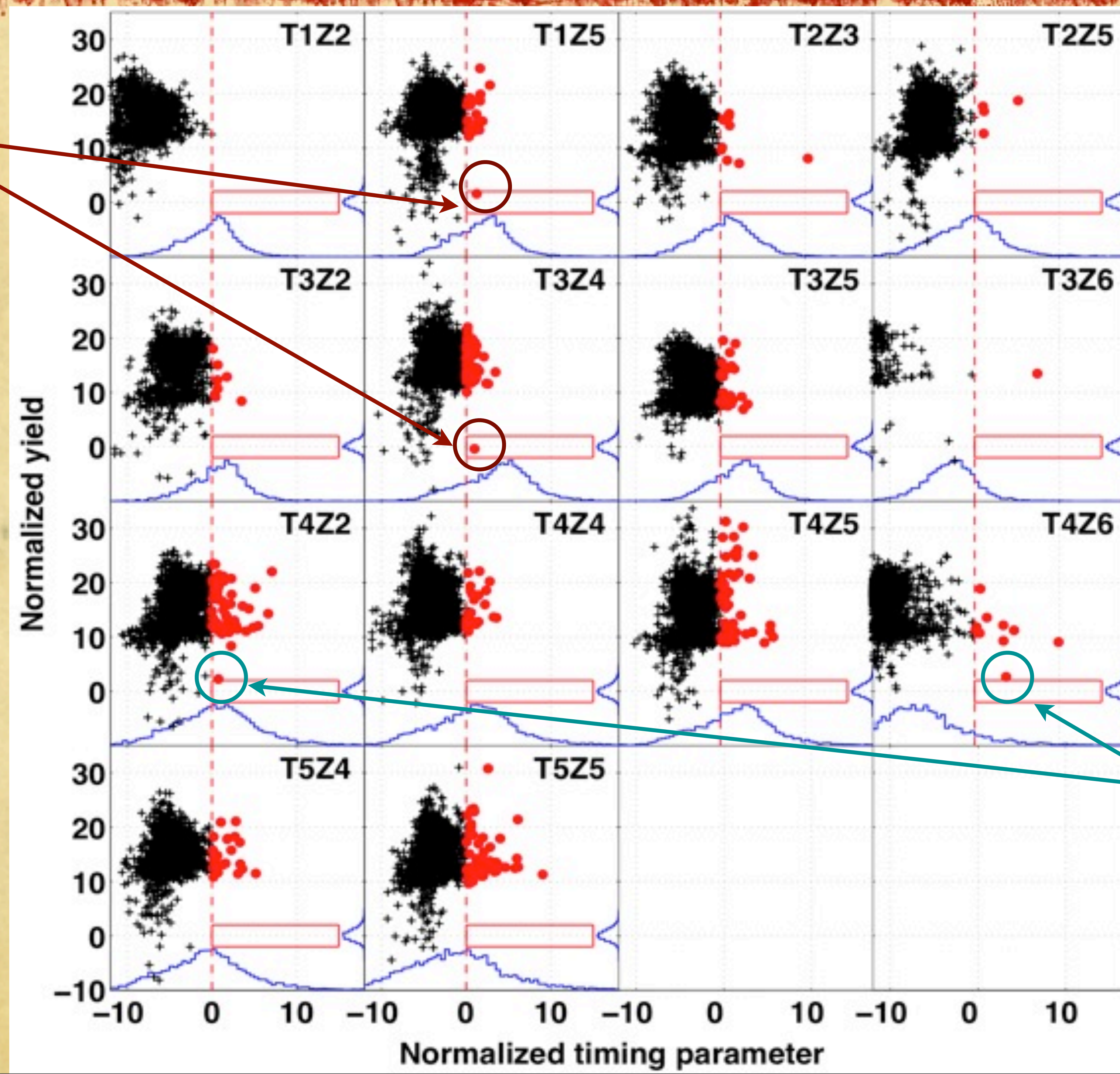
Raw Unfiltered Data.



Note: This effects some events with ionization energy < ~6 keV. It does not effect candidate event on T1Z5.

The CDMS II Results:
In more detail

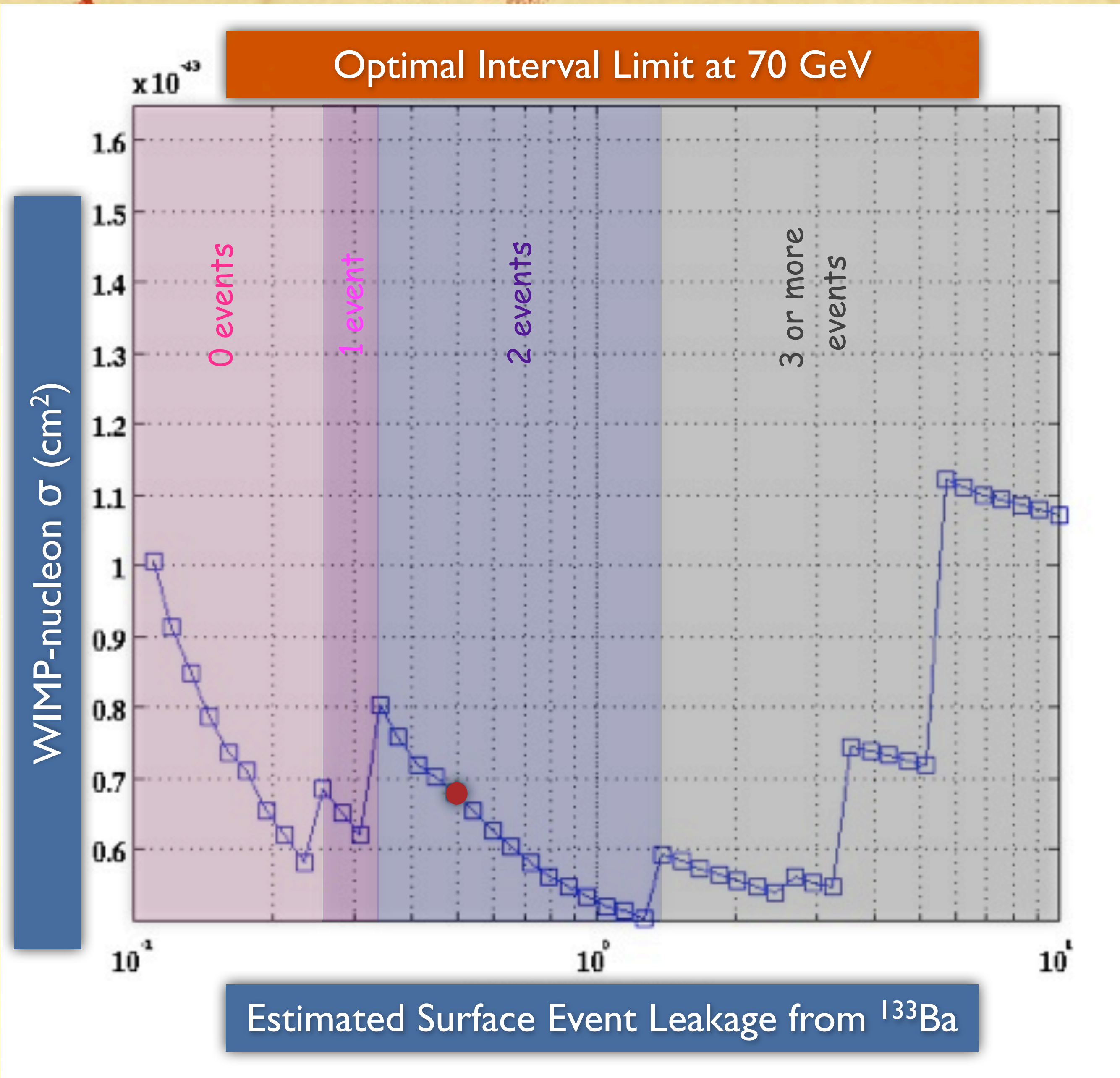
Events passing the cuts



Events close to the cut boundaries

Can we make the event go away?

- Reducing the surface event estimate by ~1/2 would remove both candidates while reducing our exposure by 28%
- Additional events would not enter the signal region until we increased the surface event estimate by a factor of ~2.



Likelihood Analysis

- Compare nuclear scatters from neutron calibrations to electron scatters from gamma calibrations.
- Likelihoods only for detectors that recorded candidate events.
- Three independent methods to construct likelihood distributions
  - Binned/unbinned
  - distribution fitting/no fitting
  - 2D (yield, timing) / 3D (yield, timing, energy)

Question 1: What is the probability (over the entire distribution) of observing one surface electron event with a nuclear scattering likelihood greater than the candidate events in these detectors?

Event	3D unbinned	2D with fit	3D with fit
1	24 +/- 5 %	12 +/- 2 %	12 +/- 2 %
2	4 +/- 2 %	5 +/- 1 %	5 +/- 1 %

Question 2: What is the probability that a true nuclear recoil in the acceptance region is as close to the cut boundaries as the observed events in these detectors? (in acceptance region)

Event	3D unbinned	2D with fit	2D with fit
1	1 %	3 %	4 %
2	12 %	2 %	19 %

Question 3: What is the probability of an electron recoil appearing to look more like a nuclear recoil in the acceptance region of these detectors?

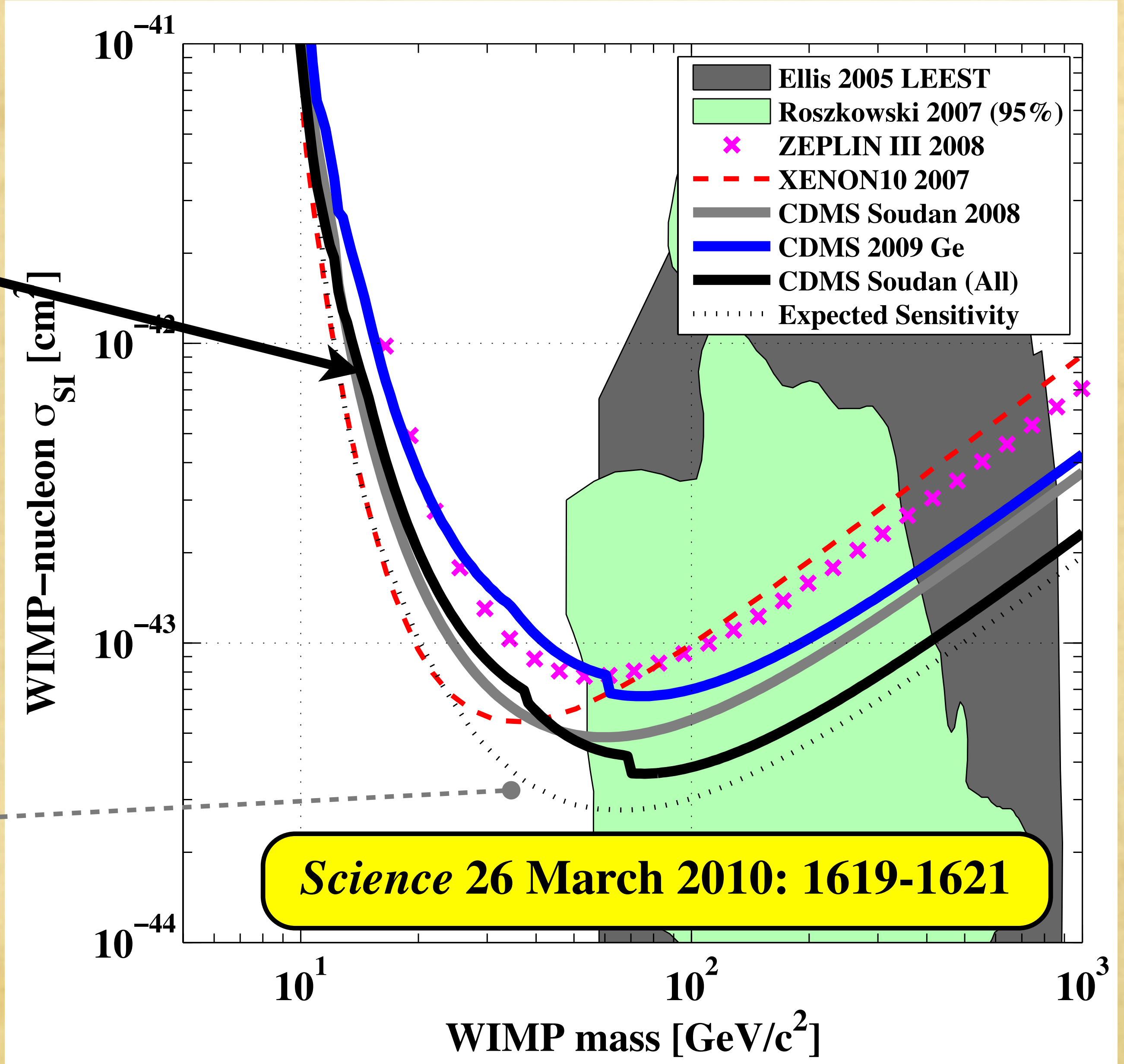
Event	3D unbinned	2D with fit
1	83 %	28 %
2	54 %	34 %

Final Comments on the Analysis

- Two events observed
  - Consistent with 0.9 ± 0.2 events expected from known backgrounds
  - Probability of observing 2 or more events is 23%
  - Neither are golden events
    - Likelihood encourages suspicion about one event
    - Event reconstruction encourages suspicion about the other event
- No obvious errors to exclude either event

The CDMS II Results

- Upper limit at the 90% C.L. on the WIMP-nucleon cross-section is 3.8 x 10^{-44} cm^2 for a WIMP of mass 70 GeV/c^2
  - No background subtraction (i.e. using the 2 events)
  - Note: An improved estimate of our detector masses (~9% decrease) was used in calculating these limits.
  - Sensitivity curve assuming:
    0.8 ±0.1(stat.) ±0.2(sys.) surface events
    $0.04^{+0.04}_{-0.03}$ cosmogenic neutrons
    $0.04_{-0.06}$ radiogenic neutrons

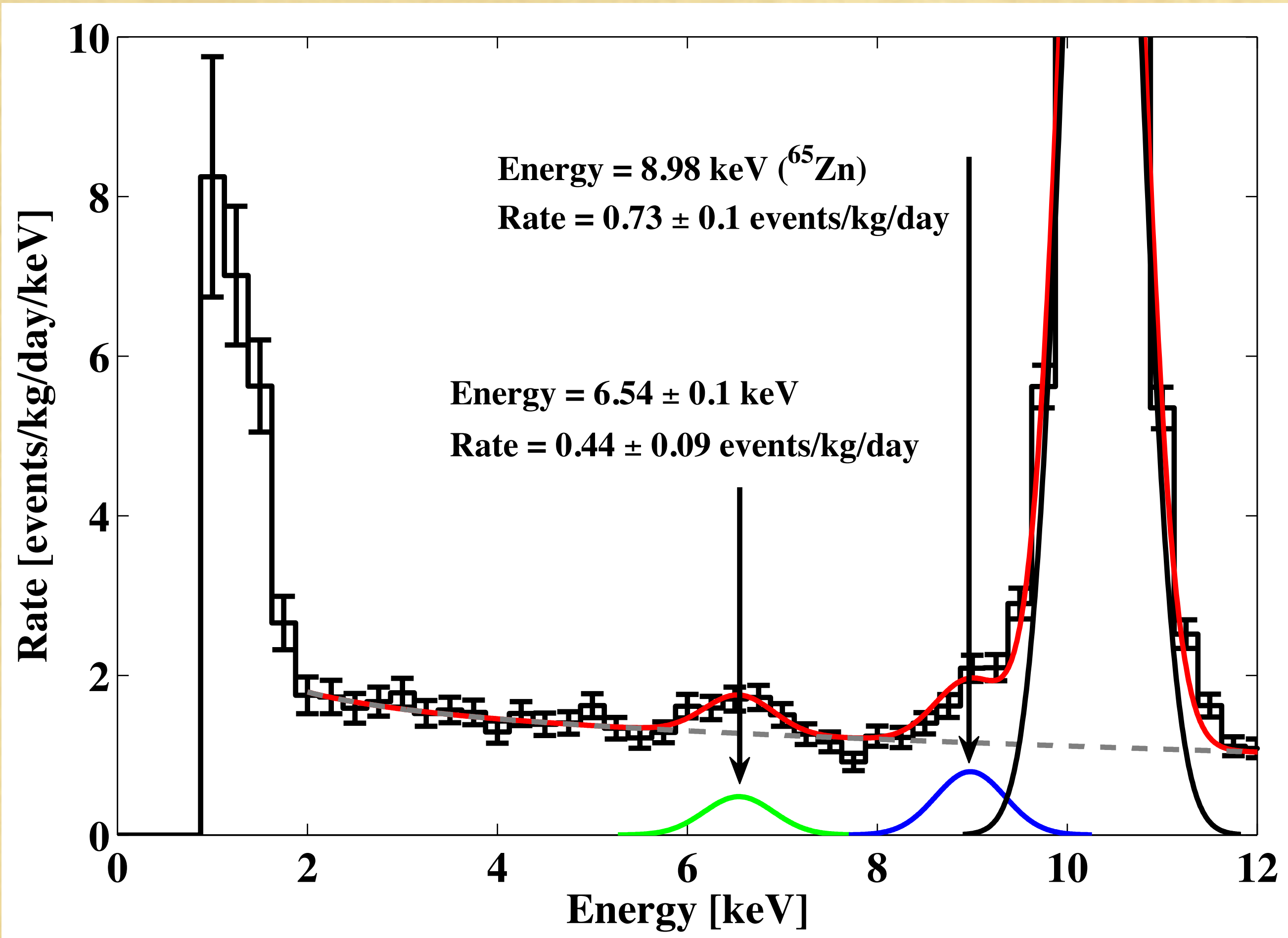


See Sebastian Arrenberg’s talk for an interpretation of the CDMS II results from an inelastic scattering perspective

Electron Recoil Analysis: The Electron Recoil Spectrum

- Electromagnetic signatures in CDMS detectors: possibly new physics.
- Similar to the standard analysis:
  - Keep the electron-recoil events.
  - Do not impose the timing cut.
- Low recoil energies particularly interesting.
- Understand the backgrounds well.
  - Several lines due to cosmogenic activation.
  - Line widths (energy resolution) well understood.
- Look at the 2-8.5 keV window.
  - Feature at 6.54 keV likely due to de-excitation of ^{55}Mn (cosmogenic activation).

Observed Electron-Recoil Spectrum

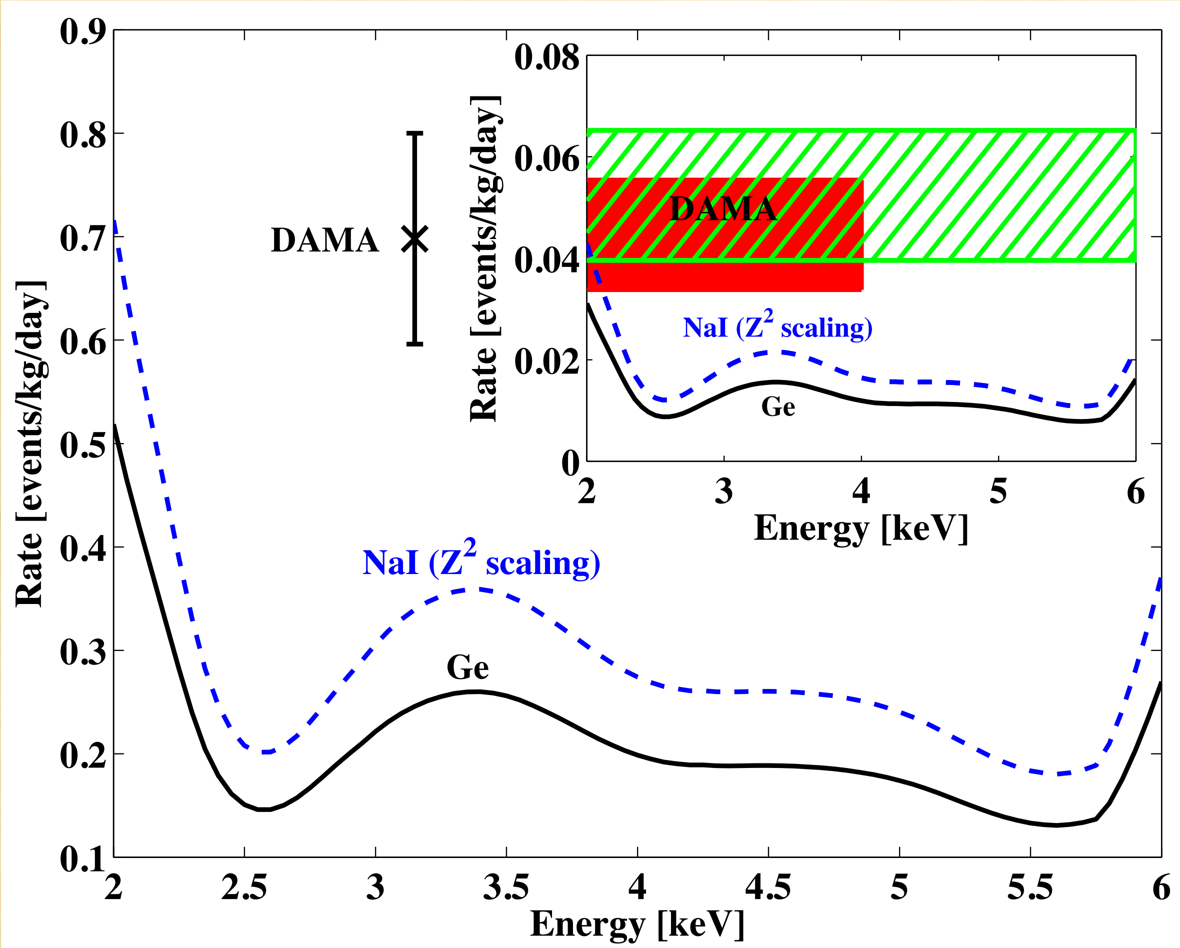


PRD 81, 042002 (2010)

Electron Recoil Analysis: The Low Energy Spectrum

- Can attempt a comparison with DAMA/LIBRA signal, in the interpretation of electromagnetic energy deposition by WIMPs.
- Big uncertainty – how does cross section change between Ge and NaI?
    - Assume Z^2 dependence.
    - Scale CDMS (Ge) rate to estimate total rate in NaI.
    - Compare with total rate observed by DAMA at the 3.15 keV peak.
- Observe large discrepancy.
    - Could be reduced if the ^{40}K (leading to a 3.2 keV line) contamination is understood .

Low Energy Electron-Recoil Spectrum



PRD 81, 042002 (2010)

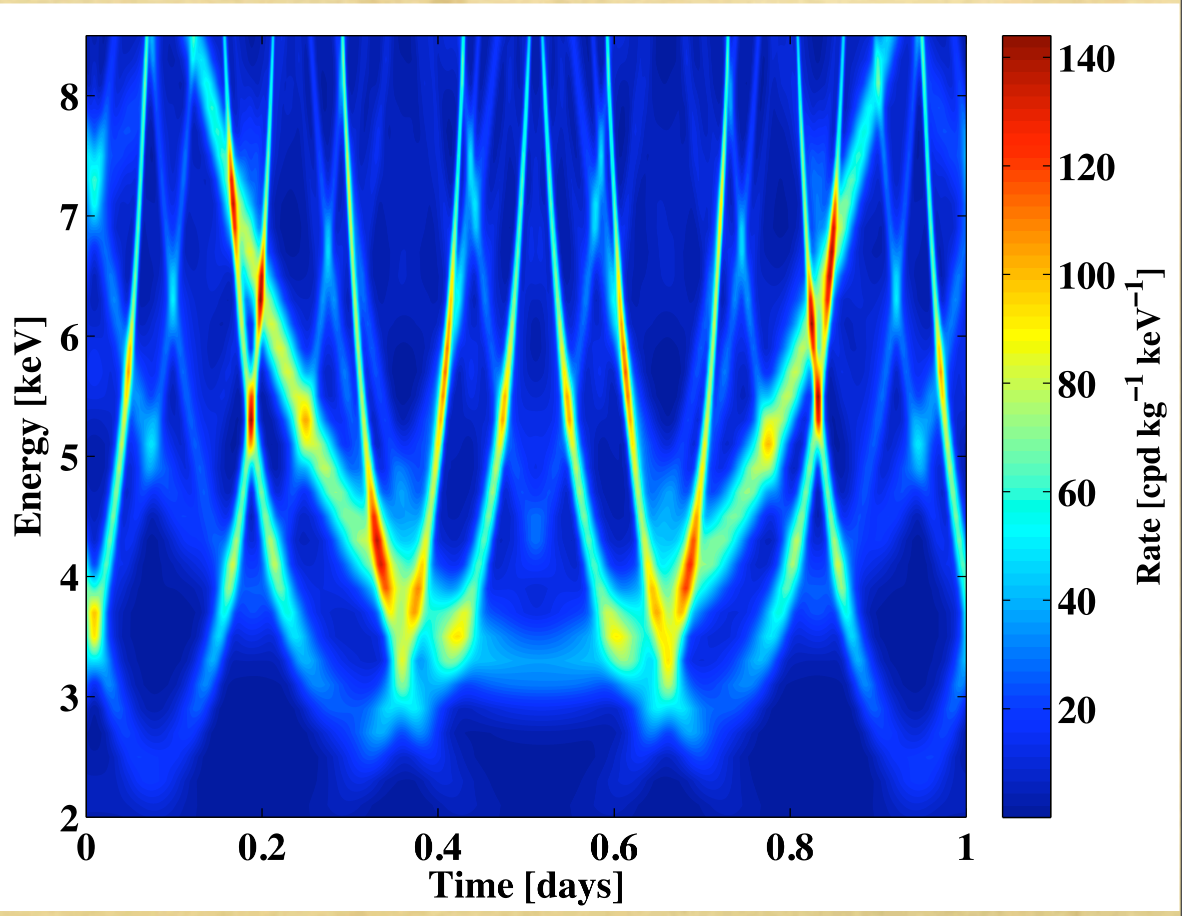
Electron Recoil Analysis: Solar Axion Search

- Axion-photon coupling:
  - In the Coulomb field of the nucleus: $a \rightarrow \gamma$
- Standard solar model gives the axion flux:

$$\frac{d\Phi_a}{dE_a} = \frac{6.02 \times 10^{14}}{\mathrm{cm}^2\,\mathrm{s\,keV}} \left(\frac{g_{a\gamma\gamma} \times 10^8}{\mathrm{GeV}^{-1}} \right)^2 E_a^{2.481} e^{-E_a/1.205}$$

- Coherent Bragg diffraction: momentum transfer equal to reciprocal lattice vector.
  - For a given direction (sky location) there are preferred recoil energies.
- Complex modulation pattern, dependent on incident/recoil energy.

Time and energy dependence of solar axion conversion rate for $g_{a\gamma\gamma} = 10\,\mathrm{GeV}^{-1}$

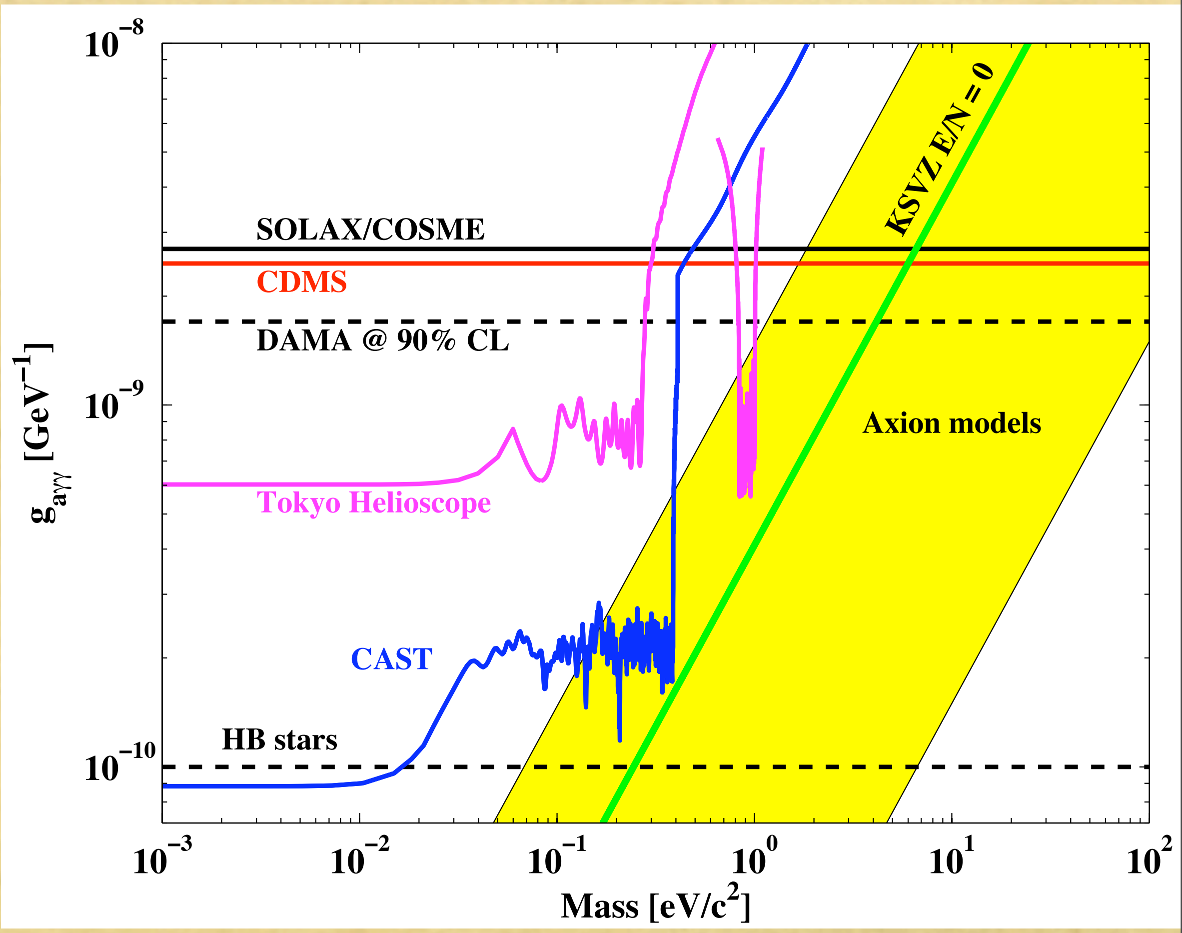


PRL 103, 141802 (2009)

Electron Recoil Analysis: Solar Axion Search

- Similar studies also done with crystal detectors:
  - SOLEX,COSME,DAMA...
- CDMS II angular orientation is well understood:
  - Uncertainty of 3° dominated by the relative tower-cryostat orientation.
- Place a new 95% C.L. on the axion-photon coupling: $g_{a\gamma\gamma} < 2.4 \times 10^{-9}$ GeV^{-1}
- Applies to axion mass below 0.1 keV.
  - Larger masses suppressed in the solar axion flux.

Limits on the axion-axion coupling $g_{a\gamma\gamma}$

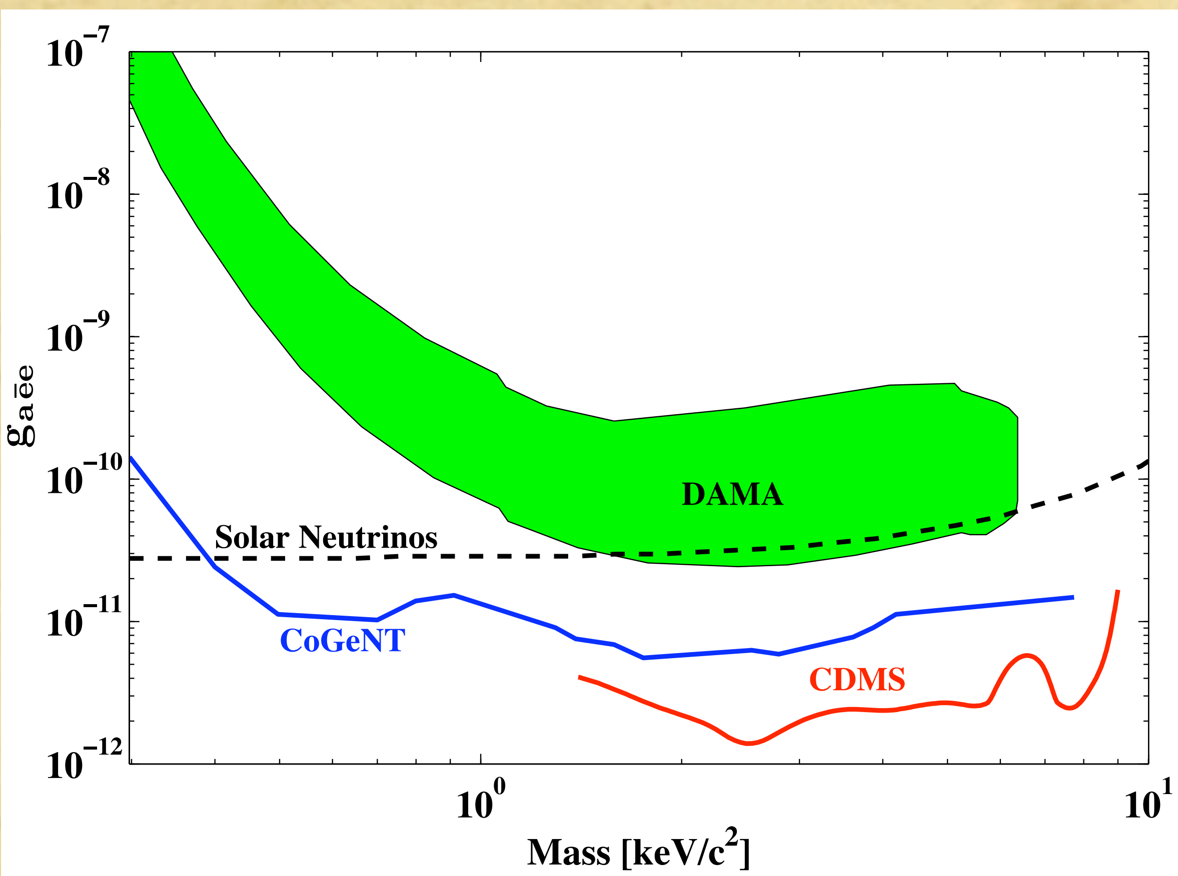


PRL 103, 141802 (2009)

Electron Recoil Analysis: Galactic Axion Background

- Apply the analysis to galactic axions.
  - Non-relativistic, axio-electric coupling.
  - Signal appears at the axion rest mass.
- Place an upper limit on g_{aee} at each axion mass.
  $g_{aee} < 1.4 \times 10^{-12}$ for a 2.5 keV axion
- Incompatible with galactic axion interpretation of DAMA signal.
- ^{55}Mn feature at 6.54 keV not subtracted (no direct constraint on this contribution).

Limits on the axio-electric coupling g_{aee}



PRL 103, 141802 (2009)

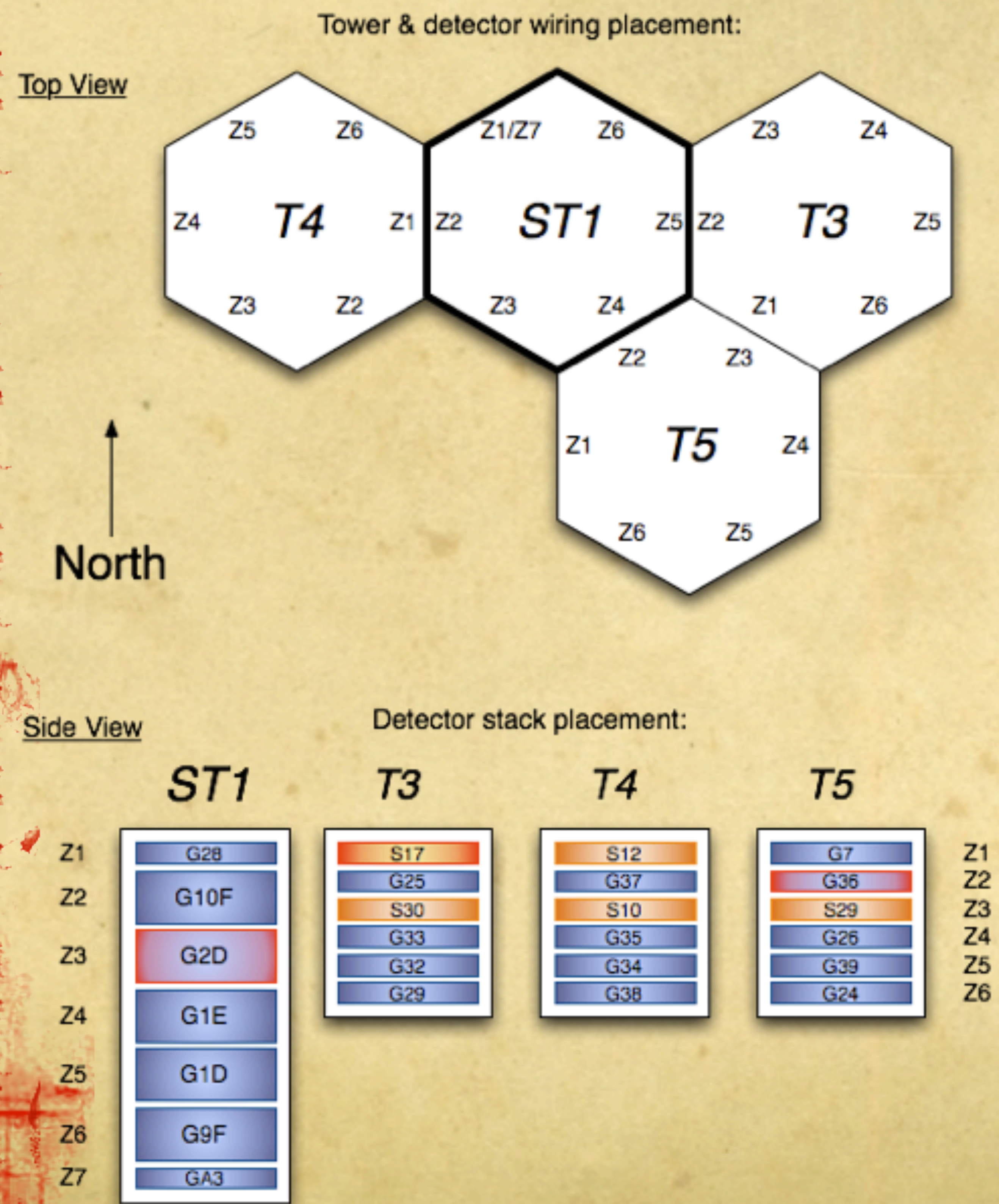
The CDMS Program overview

- CDMS II (finished)
  - Last CDMS II data taken March 18, 2009
- SuperCDMS @ Soudan (funded)
  - March 19, 2009: warm up to install and commission first SuperCDMS detectors
  - Fabrication of detectors for SuperCDMS Soudan (~13 kg Ge) project underway
- SuperCDMS SNOLAB (PASAG endorsed)
  - Project proposal in 2011 for ~100 kg Ge experiment
- GEODM (NSF DUSEL "S4" funded)
  - GErmanium Observatory for Dark Matter (1.5 tons Ge) proposed for Dusel

SuperCDMS @ Soudan

- Supertower: five 1-inch thick mZIP Ge detectors + two 1-cm thick CDMS II ZIP detectors or three 1-inch thick iZIP detectors
- Supertower 1 (ST1) Engineering Run 130 at Soudan completed
- Summer 2010: deployment of iZIP tower for validation run
- ST2 (mZIP) fabricated, testing nearly complete
- ST3, 4 & 5 (iZIP) in the fabrication pipeline
- Start of operations ⇒ 2011

Run 130 configuration



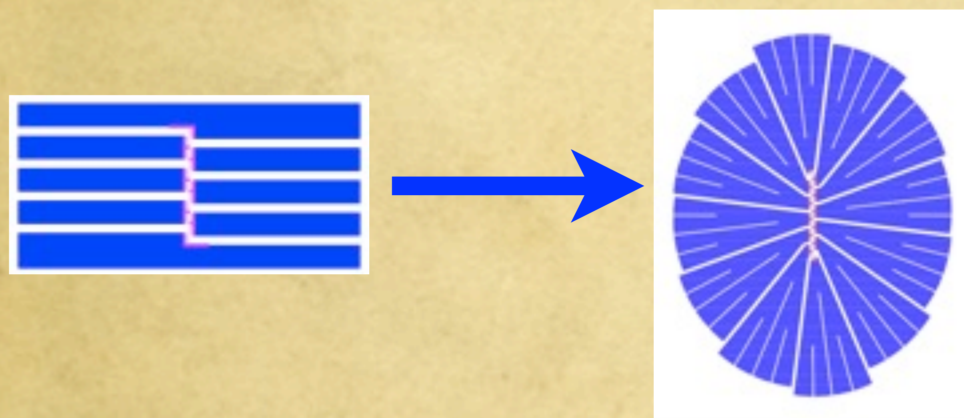
SuperCDMS Soudan: Baseline Detector Design

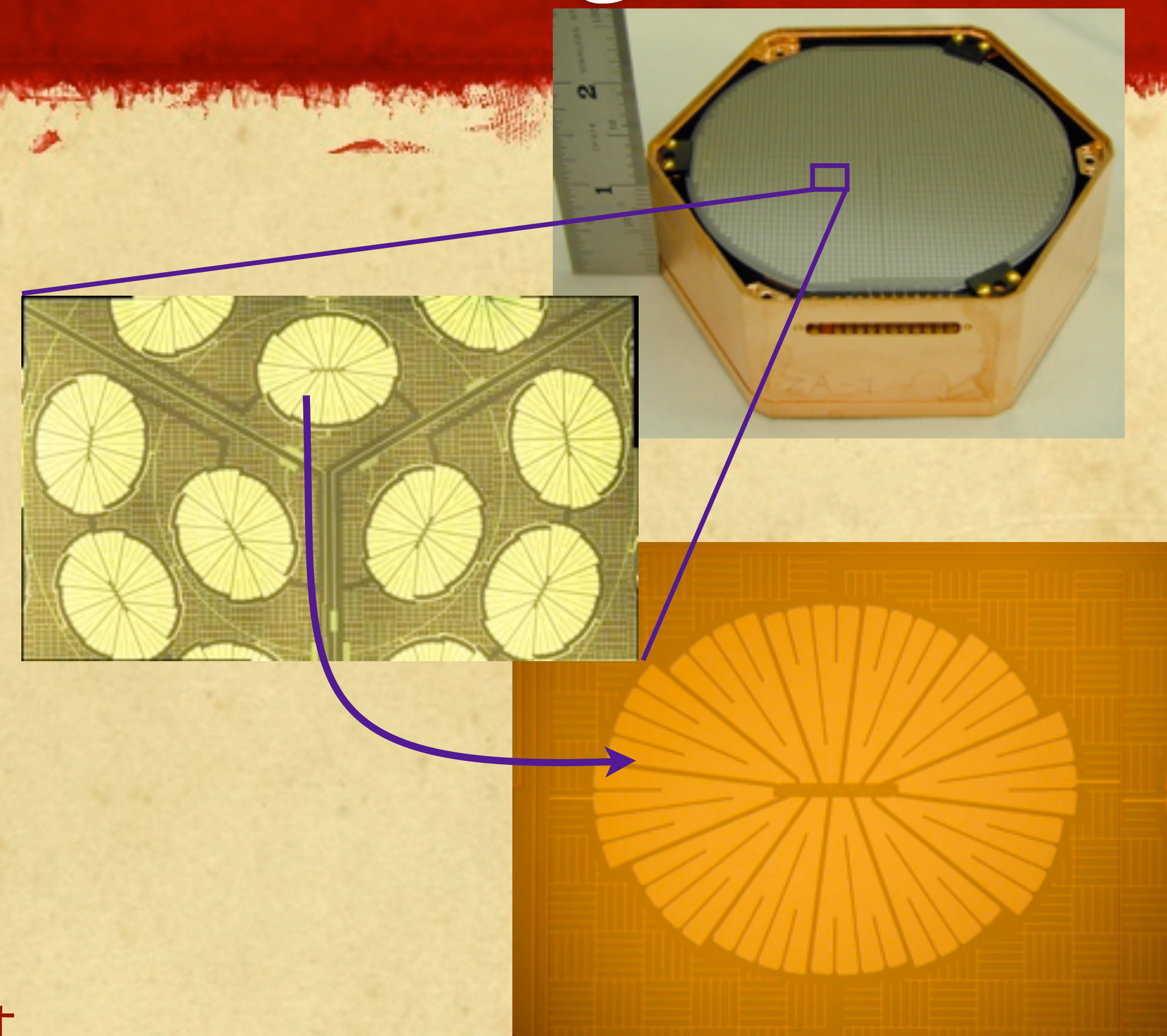
- Increase thickness (2.5 x)
  - Better surface/volume
  - Increase manufacture speed

CDMS II Ge:
7.5 cm diameter,
1.0 cm thick, ~230 g

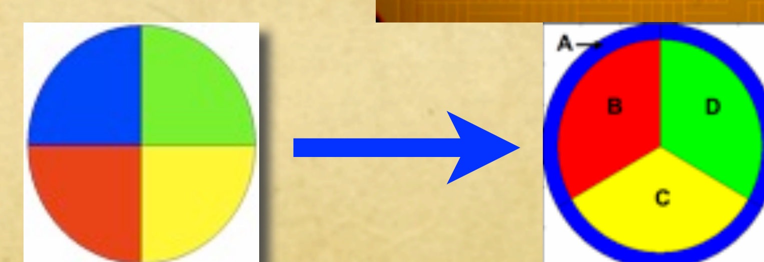
SuperCDMS Ge:
7.5 cm diameter,
2.5 cm thick, ~600 g

SuperCDMS Soudan: mZIP Detector Design





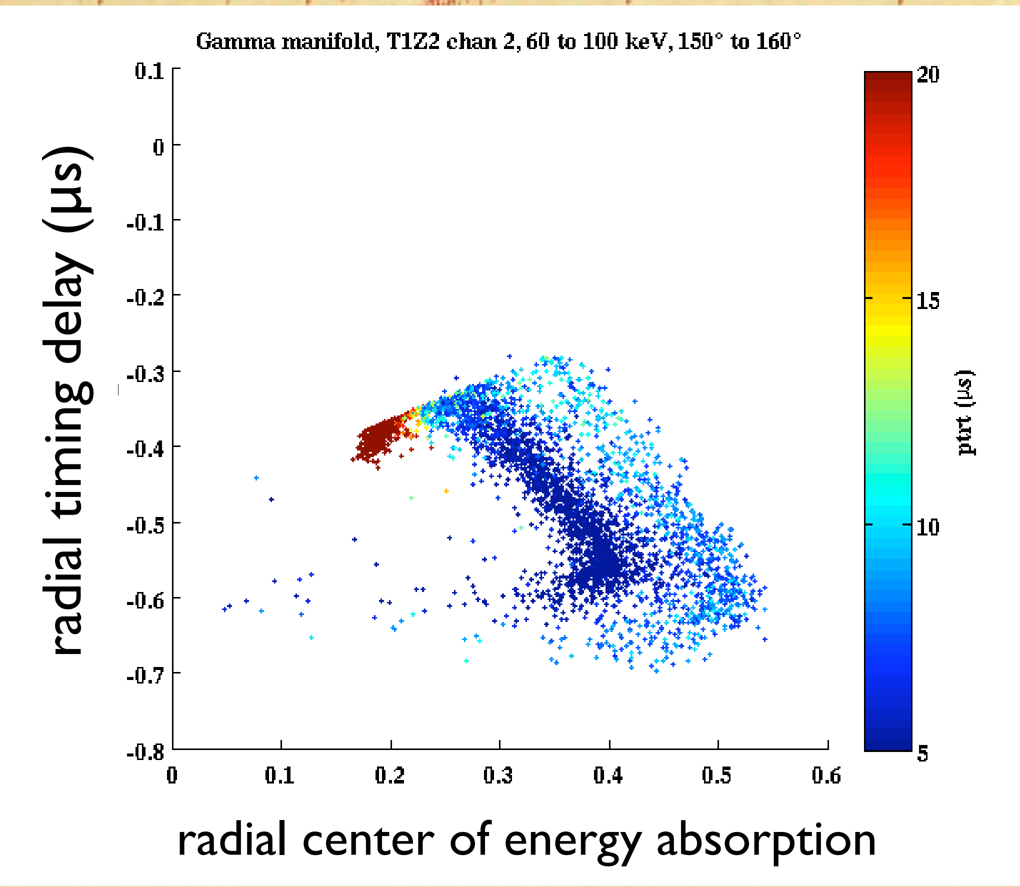
- Optimized Al Fin design (increase Al coverage)
  - Enhance phonon signal to noise
- Optimized phonon sensor layout
  - Better rejection of surface events

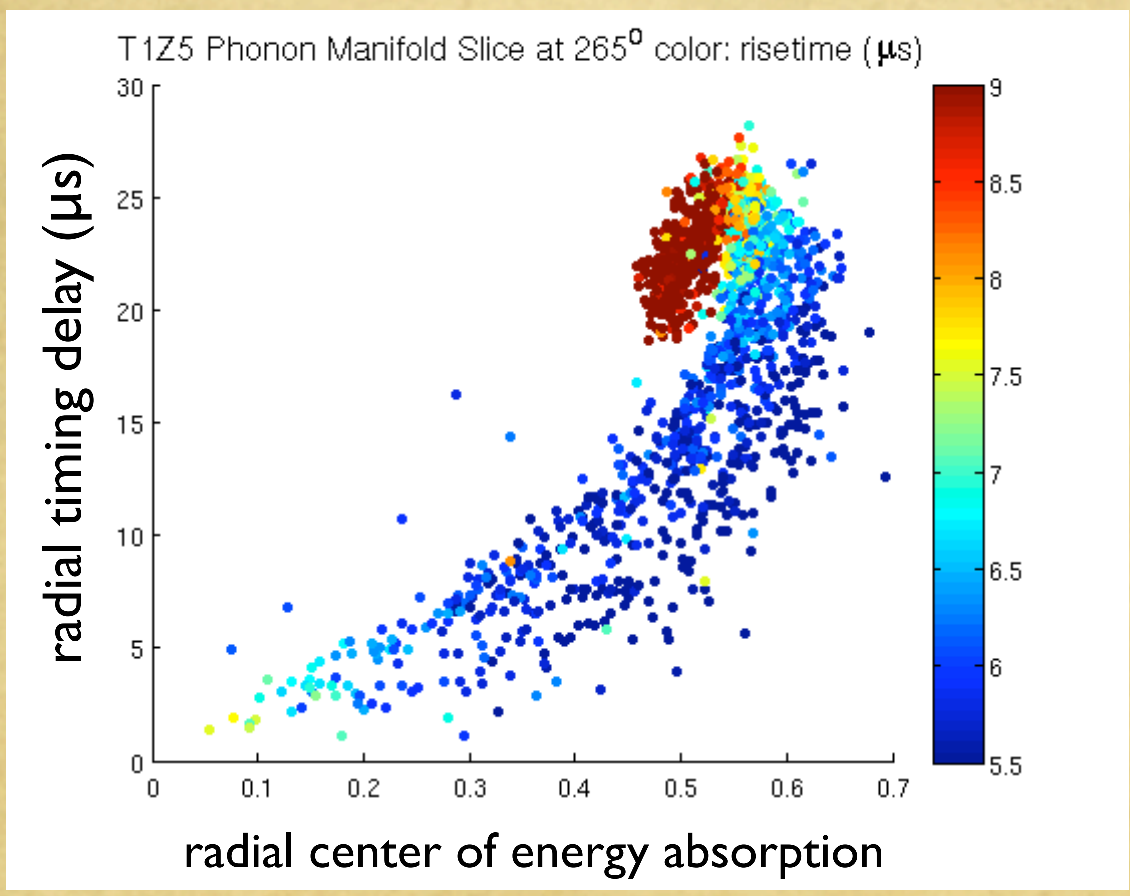


“BMW” “Mercedes”

SuperCDMS Soudan: mZIP Detector Design

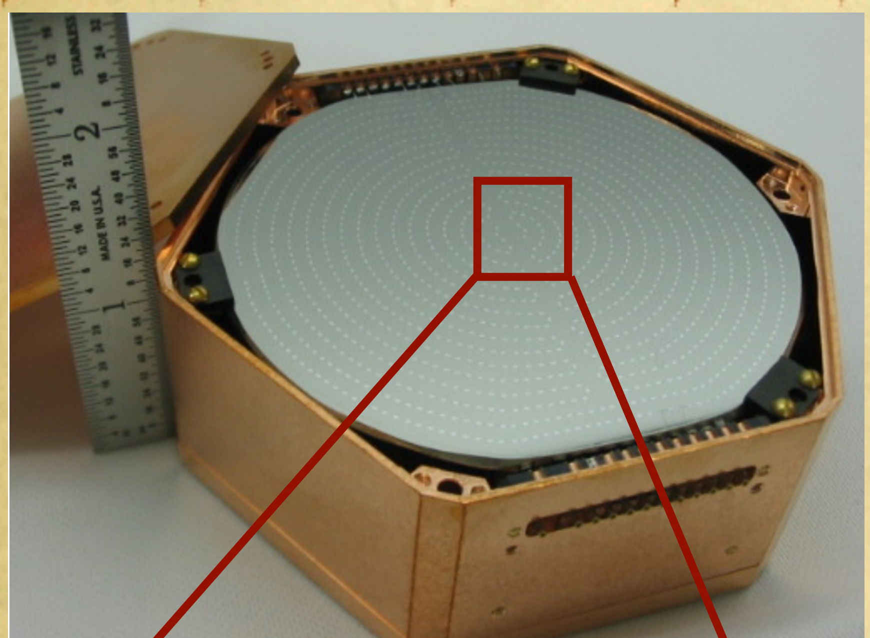
- New metric compares start times of inner 3 channels to the start time of outer channel, breaks degeneracy.



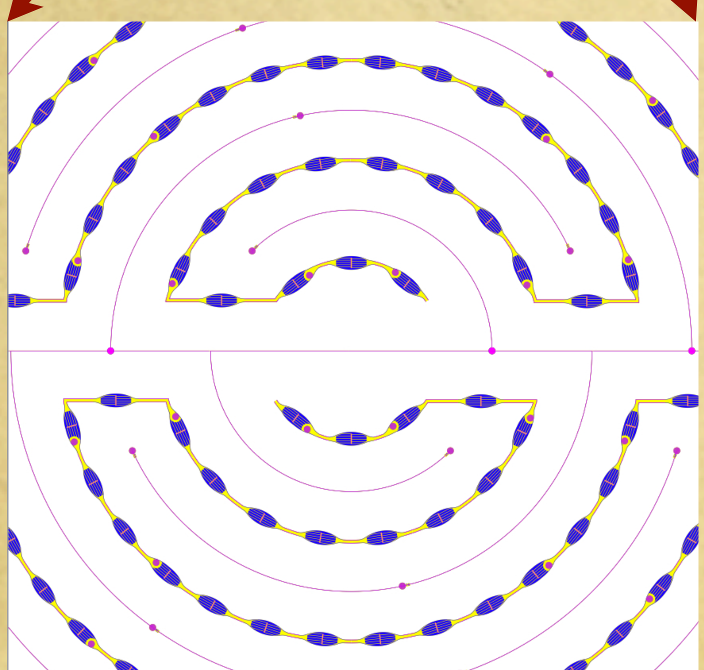


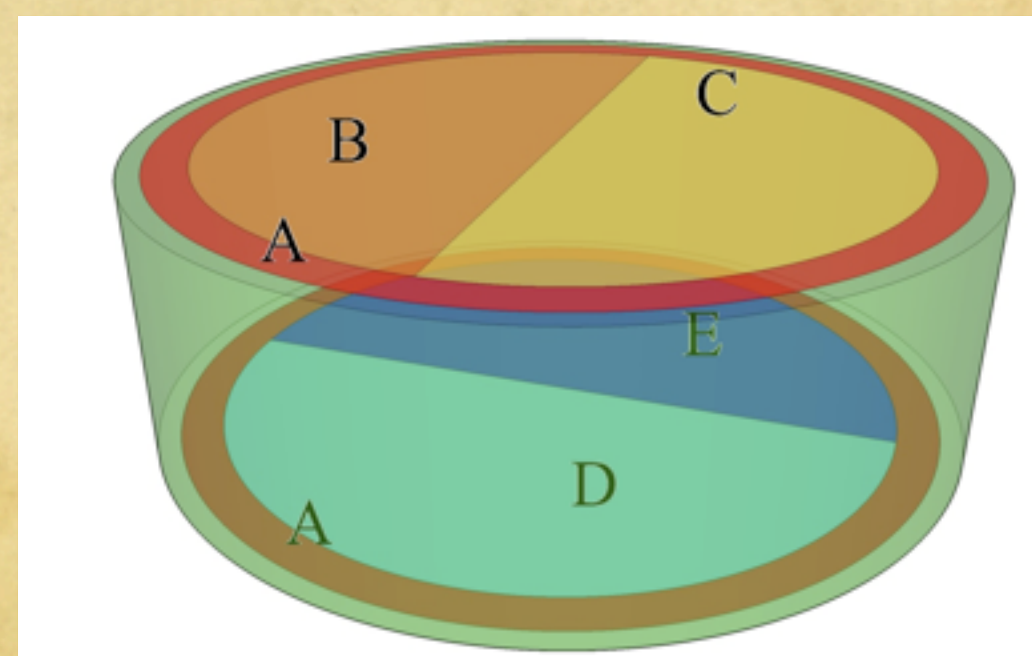
- Events at large radius have delay times similar to events at intermediate radius.
- Effect due to phonons reflecting off outer cylindrical walls back into central region of detector.

SuperCDMS Soudan: Advanced iZIP Design



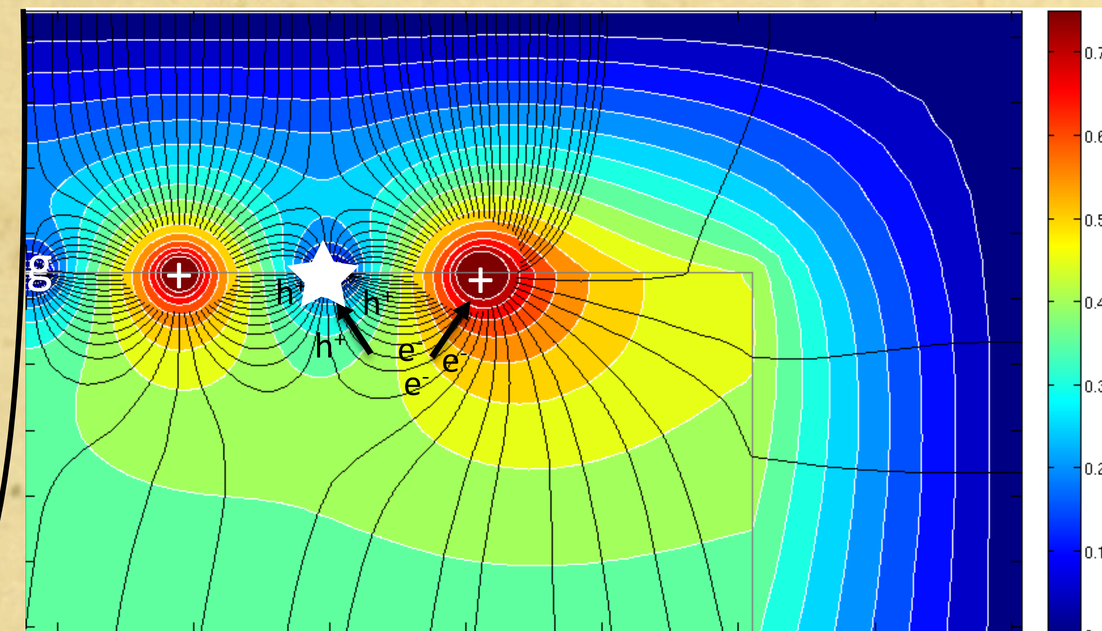
- Interleaved zip (iZIP) double sided detector
- Electrodes interleaved with strips of phonon sensors
- Each side has 2 inner phonon channels and an outer phonon channel to reject edge events
- Charge channels can veto surface events
- Less phonon timing information available for surface event rejection

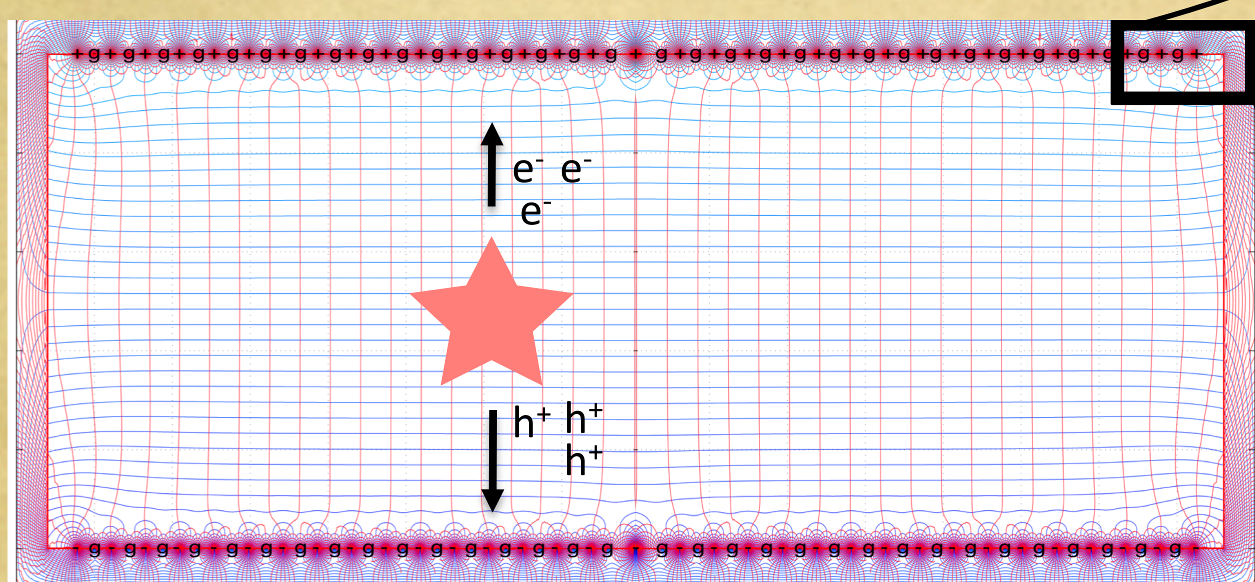




SuperCDMS Soudan: Advanced iZIP Design

- Event type discrimination from ionization signal
  - Bulk events: Equal but opposite ionization signal appears on both detectors sides (symmetric)
  - Surface events: Ionization signal appears on one detector side (asymmetric)

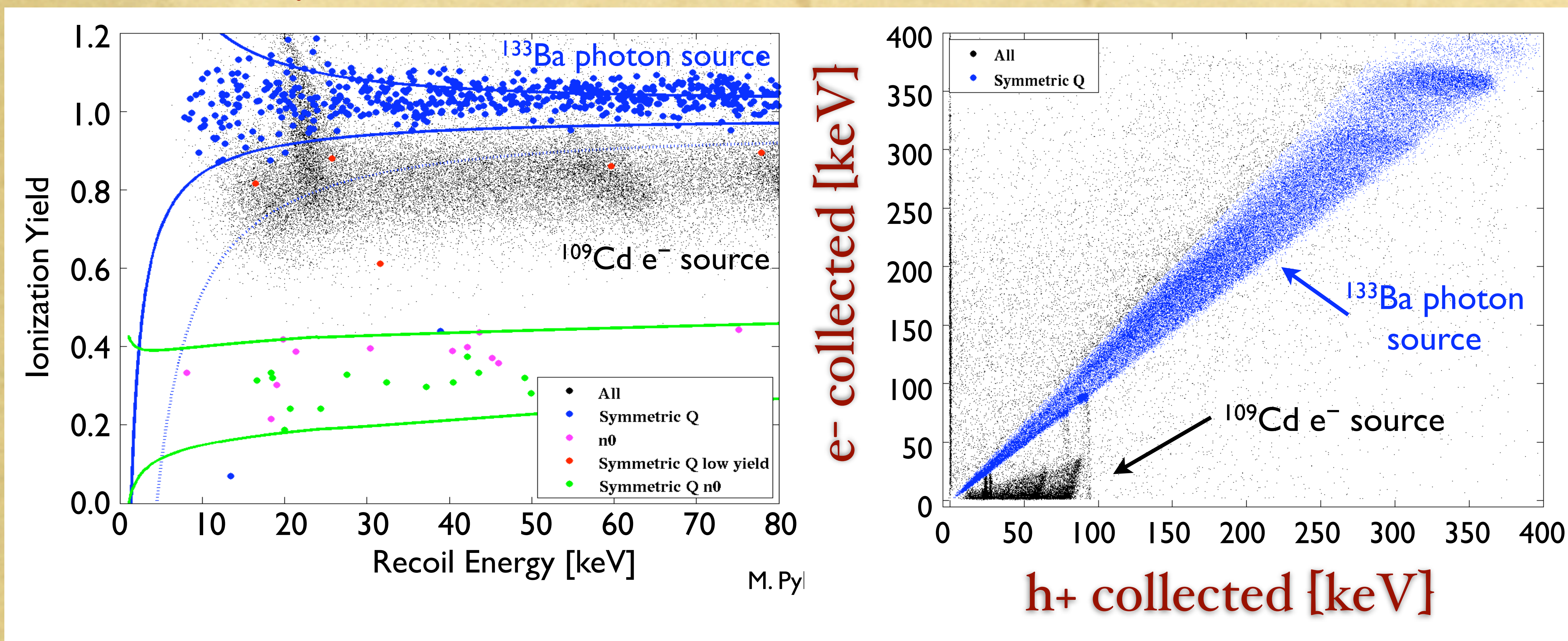




- Yield discrimination still exists
- Phonon timing pulse information still possible

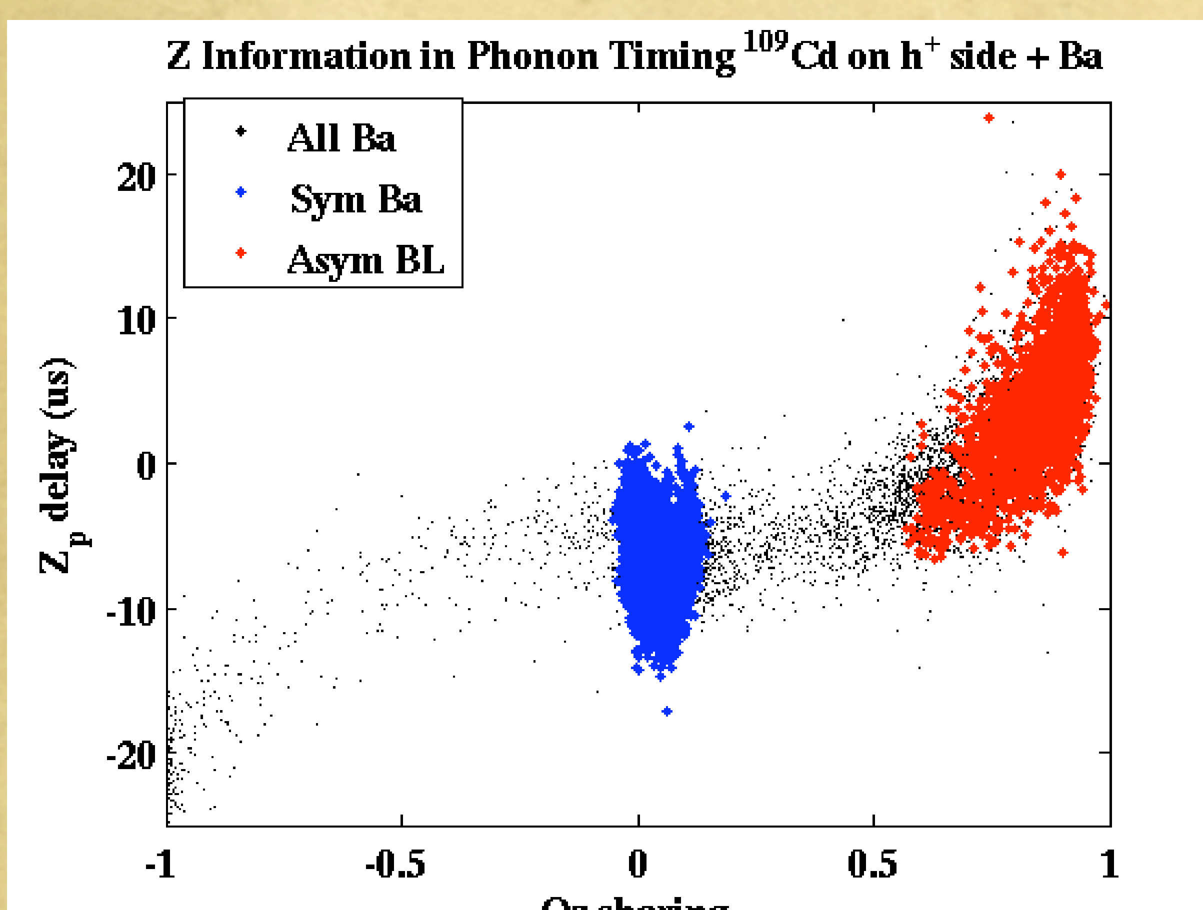
iZIP: Surface Event Rejection

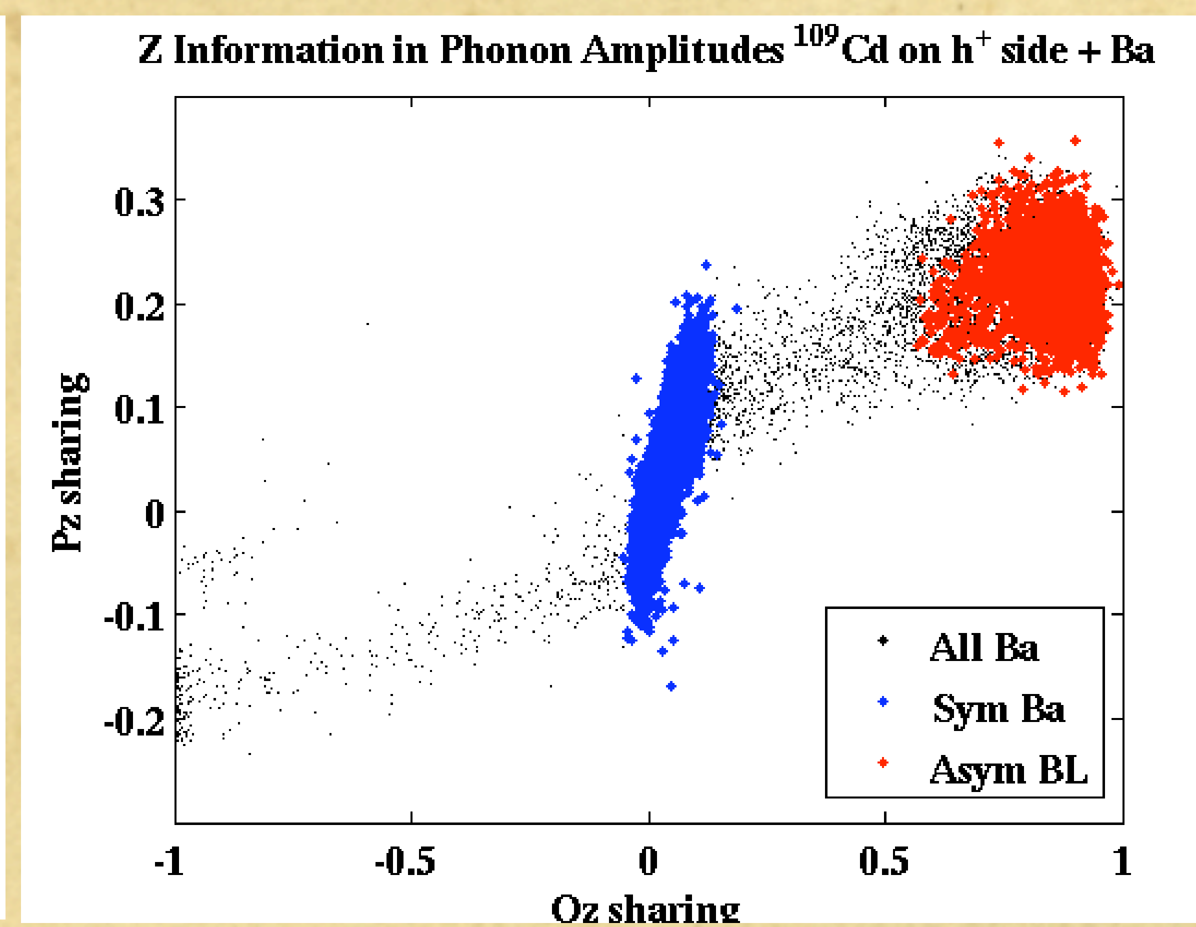
Preliminary data indicates iZIP is superior to ZIP performance



- Basic ionization yield improved for surface events from 0.2 (ZIP) to 3 x 10^{-4} mis-id (iZIP)
- Charge side asymmetry: < 10^{-3} mis-id

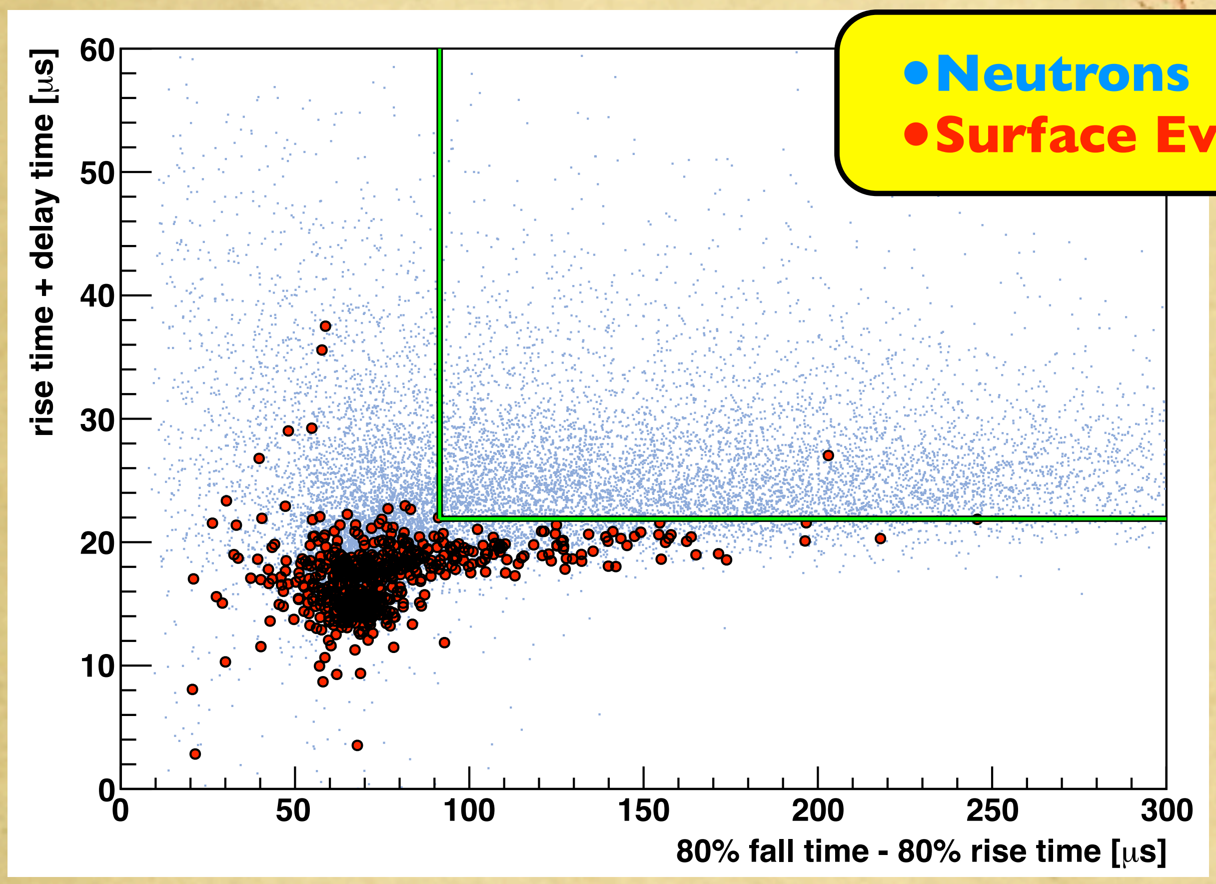
iZIP: Surface Event Rejection

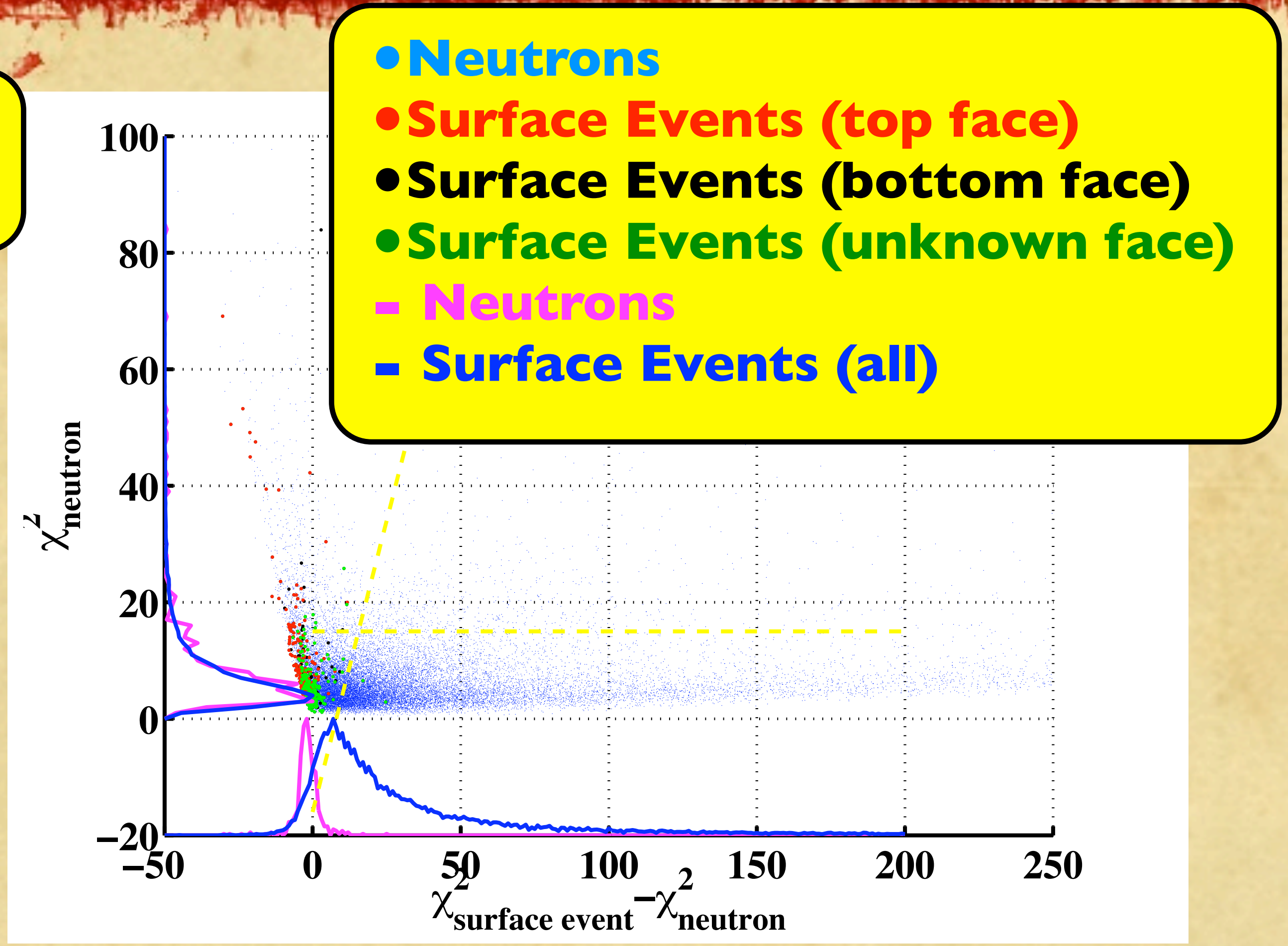




- Phonon energy partition & timing information: < 3×10^{-3} mis-id

iZIP: Surface Event Rejection

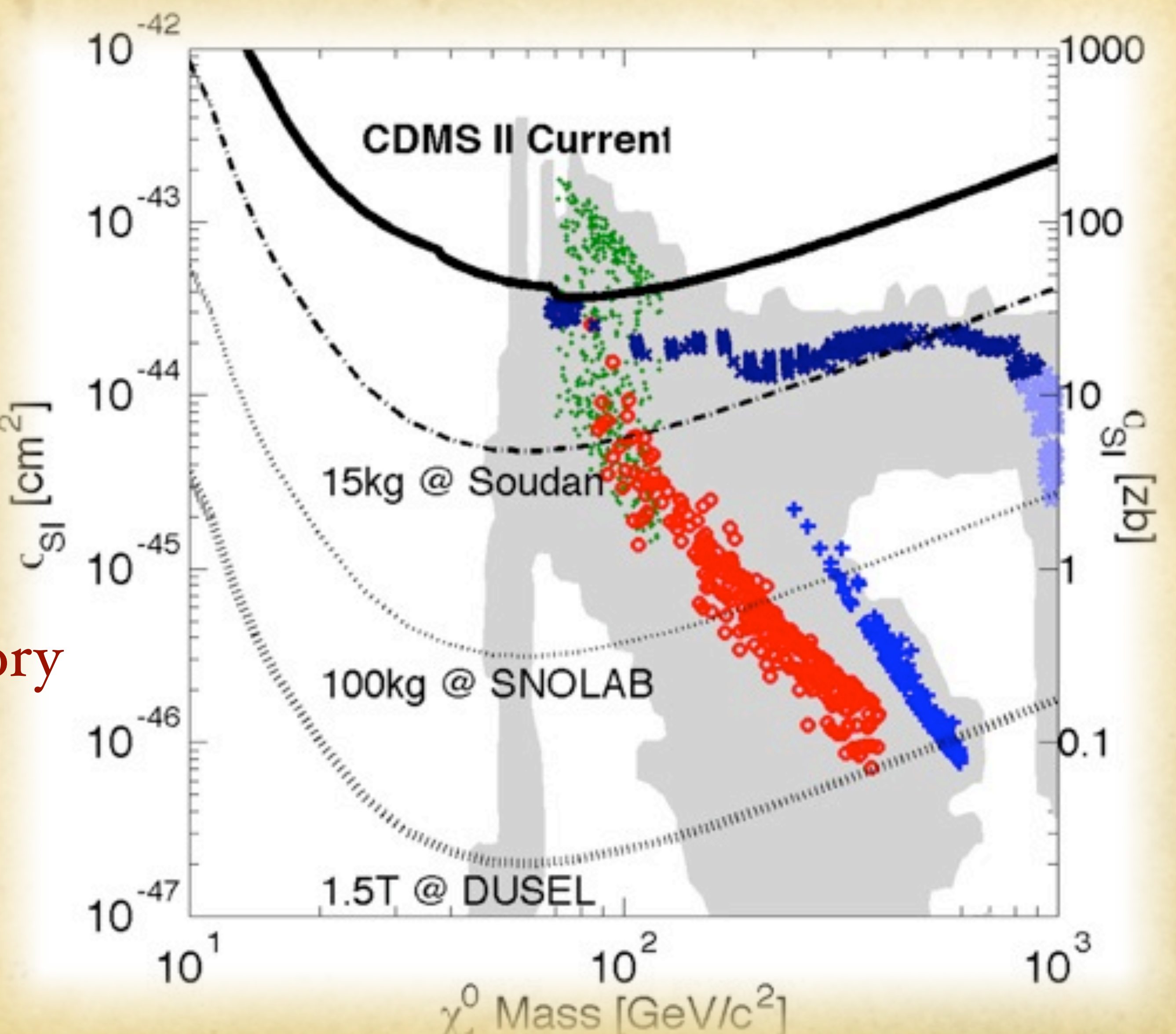




- Simple 2D timing cut gives surface event background mis-id ratio of 1:400 with 43% signal efficiency.
- More sophisticated χ^2 timing cut gives surface event background mis-id ratio of 1:750 with 52% signal efficiency.

Looking ahead: Sensitivity Goals

- CDMS II
  - 3" x 1 cm → 0.25 kg/det
  - 16 detectors = 4 kg, ~2 yrs operation
- SuperCDMS
  - 3" x 1" → 0.64 kg/det
    - Soudan: 25 detectors = 15 kg, 2 yrs ~8000 kg-d
    - SNOlab: 150 detectors = 100 kg, 3 yrs ~38000 kg-d
- SuperCDMS SNOlab & Ge-Observatory for Dark Matter (GEODM)
  - 6" x 2" → 5.1 kg/det
    - SNOlab: 20 detectors = 100 kg 3 yrs ~ 100,000 kg-d
    - DUSEL 300 detectors = 1.5 ton 4 yrs ~ 1.5 Mkg-d



Conclusions

- We observe 2 events in the first analysis of the final data taken by CDMS II between July 07 and September 08. This yields a cross-section limit of $< 3.8 \times 10^{-44} cm^2$ (90% CL) for a WIMP of mass 70 GeV/c^2 when combining this result with previous analyses.
- The results of this analysis cannot be interpreted as significant evidence for WIMP interactions, but we can not reject either event as a signal.
- The first SuperTower of detectors has been installed and a test run was performed in the Soudan Underground Laboratory.
- Advanced interleaved (iZip) detector to be installed for test runs underground later this summer (2010).
- Exciting times ahead on the DM detection front

IDM 2010 in Montpellier

The CDMS II Experiment: 2 Events! What's Next?

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