The Cryogenic Dark Matter Search

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Fermilab

on behalf of the CDMS Collaboration

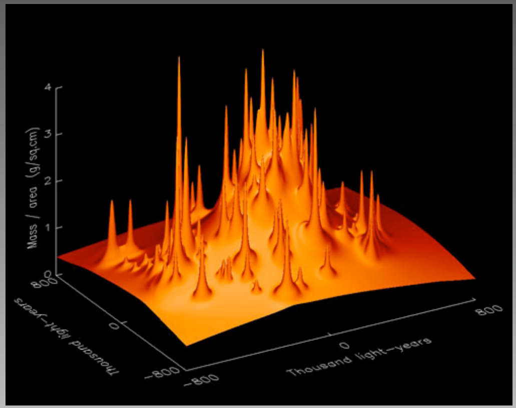
Rencontres de Moriond EW 2010

March 6-13

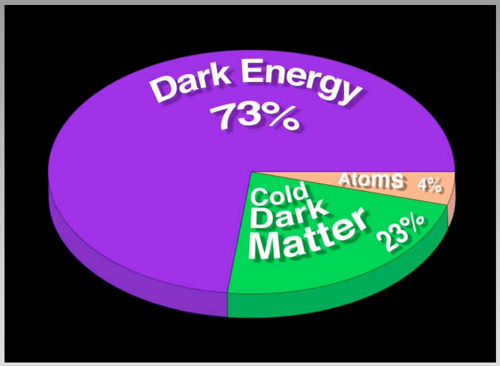
What is Dark Matter?

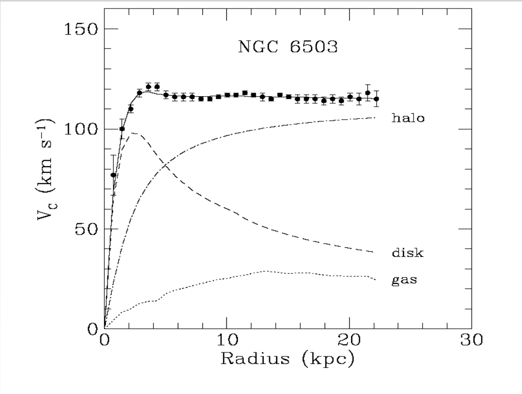
Bullet Cluster

We know the Dark Matter is
stable / non-baryonic / non-relativistic / interacts gravitationally



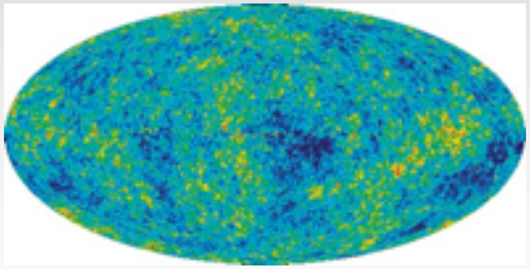
Strong Lensing





Rotational Curves

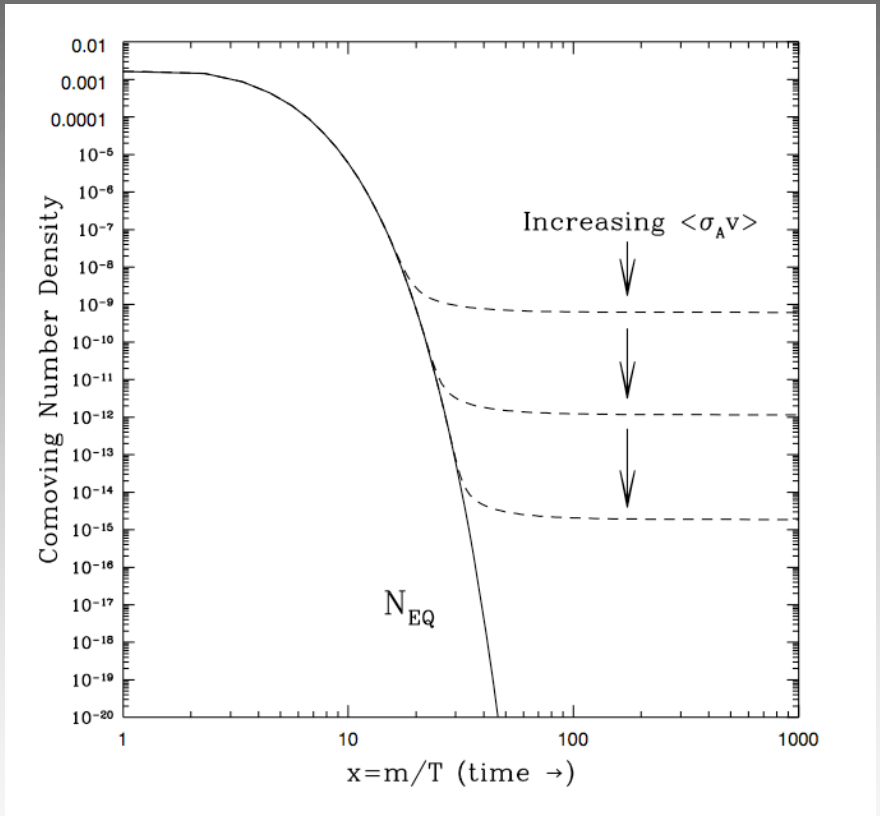
We don't know what it actually is
mass / coupling / spin / composition / distribution in the Universe …



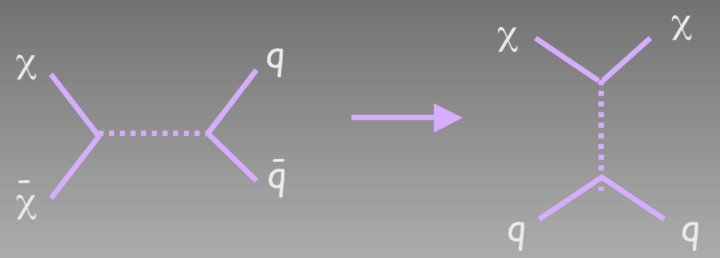
WMAP 5-year

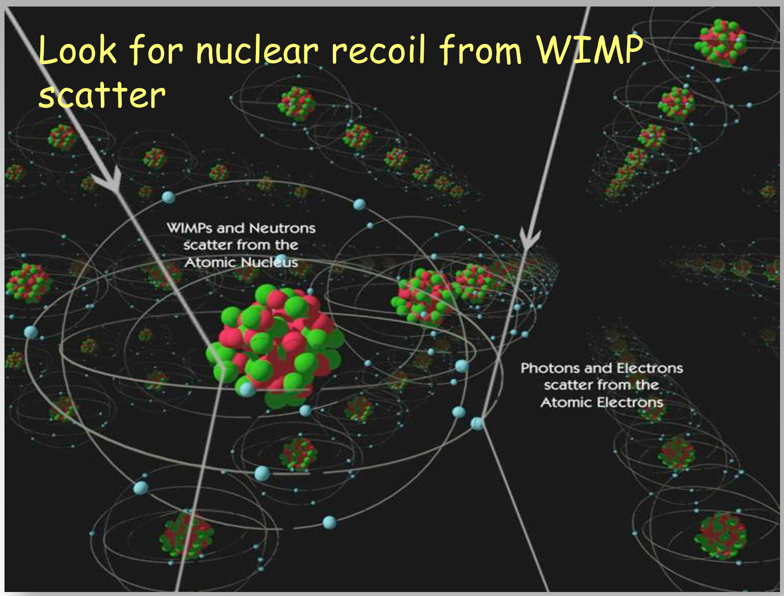
Is Dark Matter a WIMP?

particles with mass and annihilation cross section at the weak scale naturally yield correct relic density of CDM



Kolb & Turner, "The Early Universse"





M. Attisha

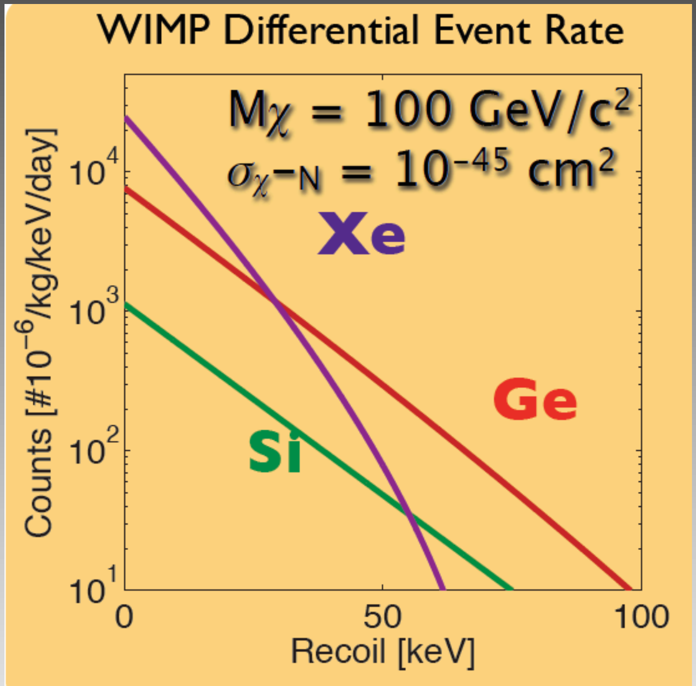
Direct Detection of Dark Matter

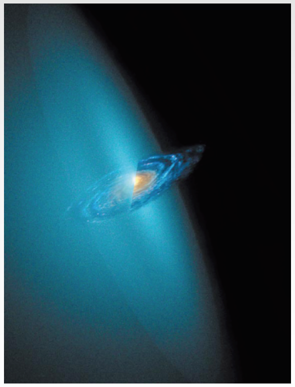
Expected signal:

- nuclear recoil
- featureless exponential ~ few 10's of keV
- rates <0.1 events /kg/day

Challenges:

- low energy thresholds (~10 keV)
- mitigation of natural radioactive background (1 banana ~1M decays/day)
- long exposures, underground operation

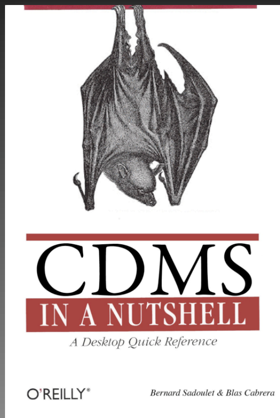


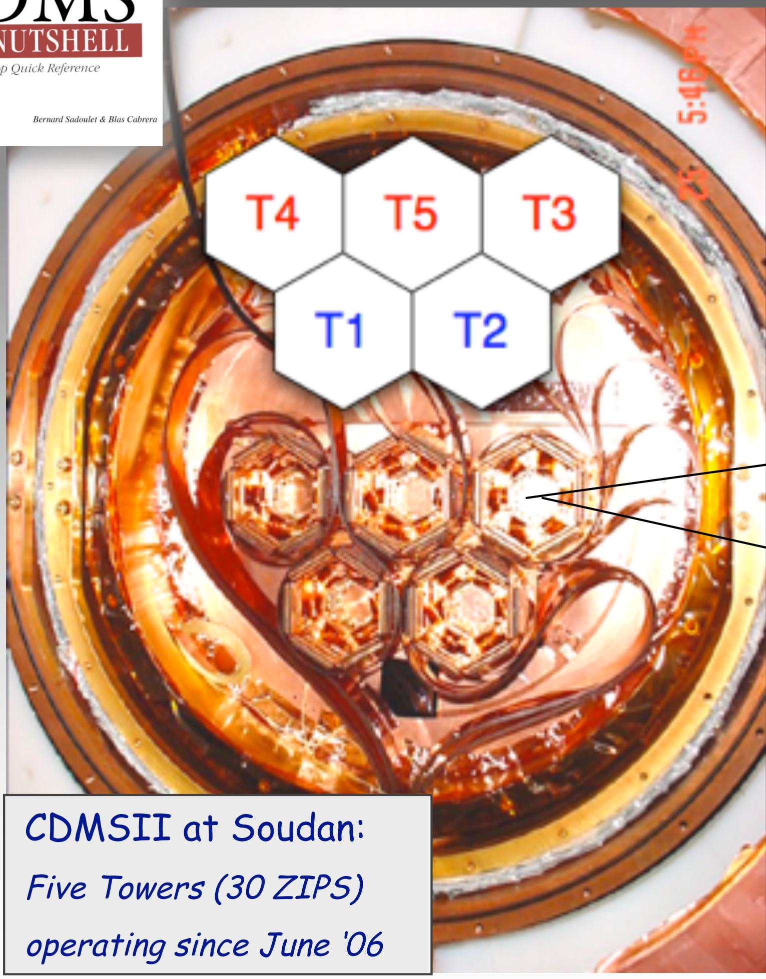


How are WIMPs Distributed?

- spherical NFW halo profile
- local density ~0.4 GeV/cm^3

CDMS Experiment

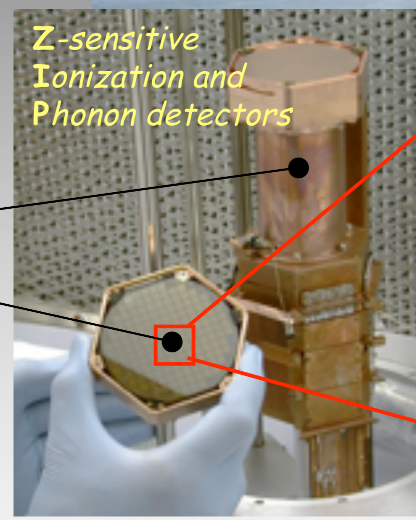


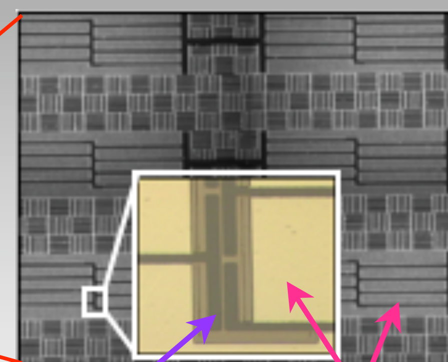


CDMSII at Soudan:

Five Towers (30 ZIPS)

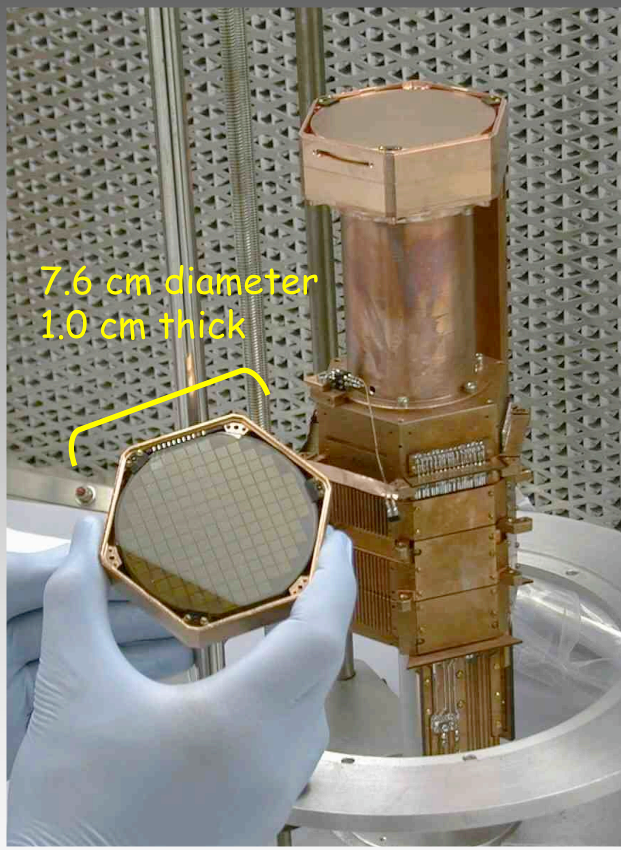
operating since June '06

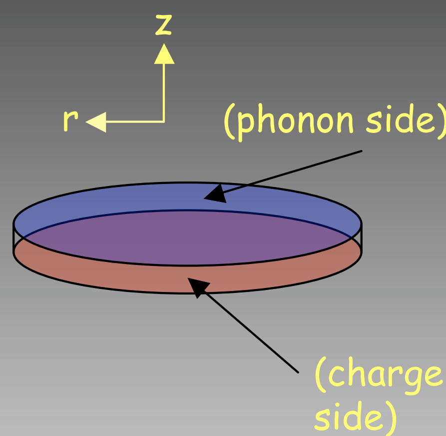


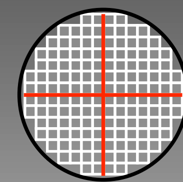


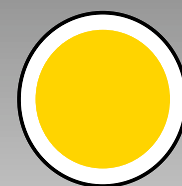
Most sensitive to spin-independent scattering: $\sigma \propto A^2$
4.75 kg Ge(A=73), 1.1 kg Si(A=28)

Z-sensitive Ionization and Phonon Detectors









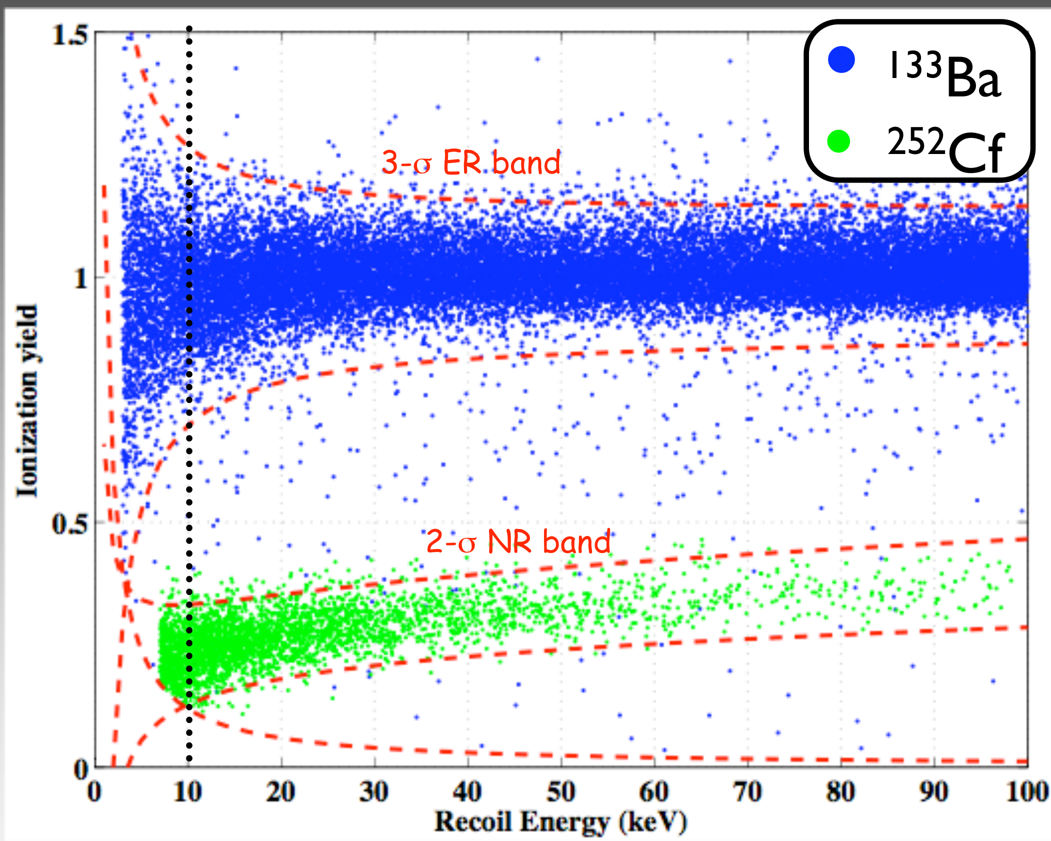
Signature of a Nuclear Recoil:

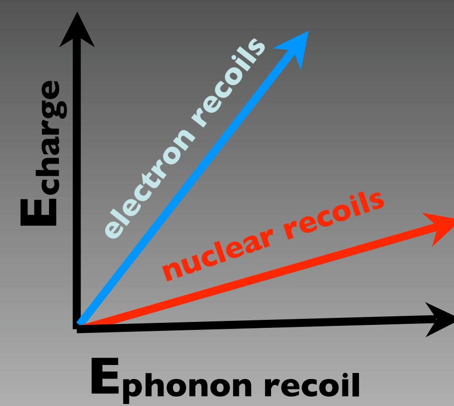
reduced ionization signal relative to phonon signal

Major Backgrounds:

- *Gammas /betas (electron recoils)*
- *Neutrons (nuclear recoils)*
- *Surface Events (betas)*

Gamma Rejection





$$\text{ionization yield} = \frac{E_{charge}}{E_{phonon\ recoil}}$$

$$E_{phonon\ recoil} = E_{phonon\ total} - (V/\varepsilon)^{*}E_{ionization}$$

BETTER THAN 1:10^4 rejection of gammas based on ionization yield alone

Neutron Background

1. Go Deep:

Soudan Mine: 2090 mwe
(muon rate reduced by >10^4)

2. Use Active Shielding:

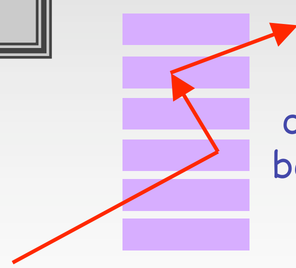
muon veto ~98% efficient

<< 1 unvetoed single scatter neutron / kg /year

3. Use Passive Shielding:

2 layers polyethylene - shields from cosmogenic and radiogenic neutrons

4. Use Event Topology



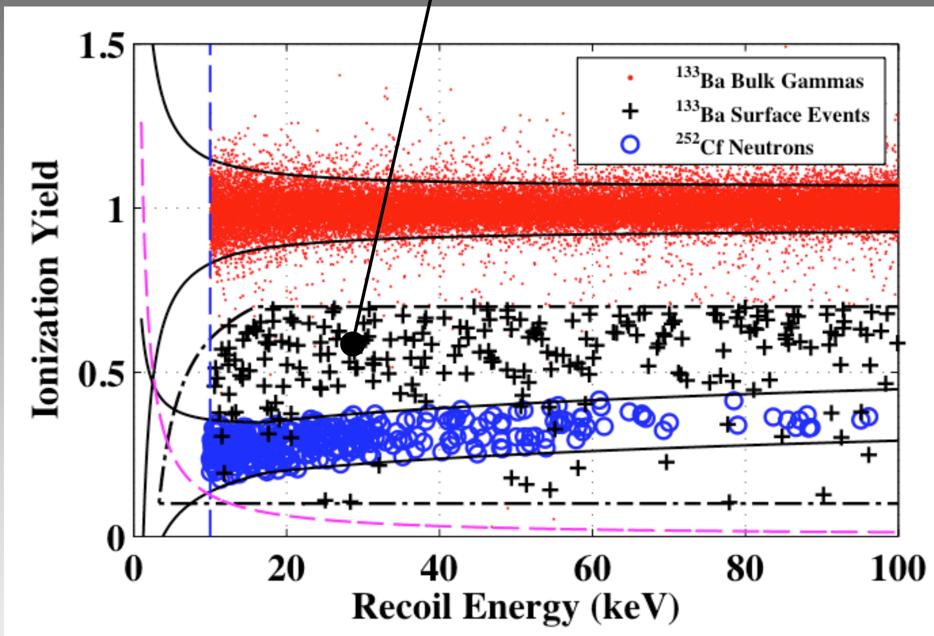
Neutrons may double scatter or be accompanied by EM shower

5. Run Extensive Simulations:

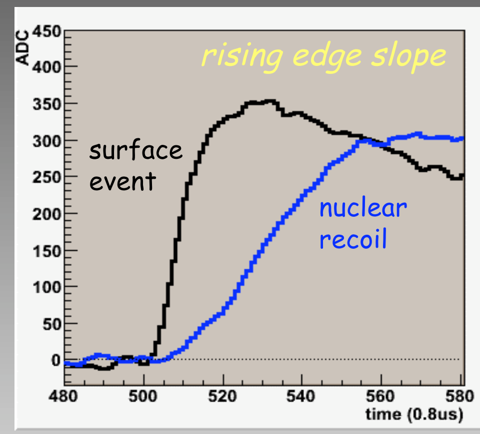
- GEANT4
- FLUKA+MCNPX
- MUSIC

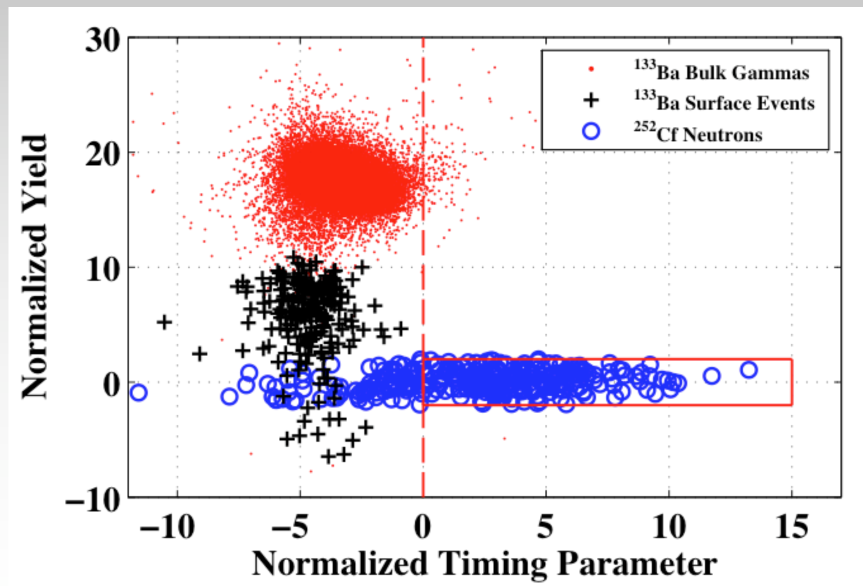
Surface Event Rejection

10 μm "dead layer" results in reduced ionization collection



Phonon pulse shape (timing) distinguishes surface events



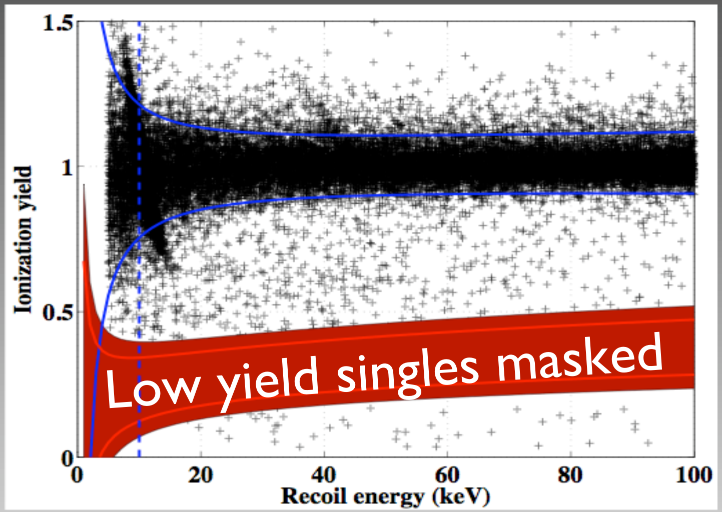


Both yield and "timing" rejects these events

timing parameter = risetime + offset from ionization pulse

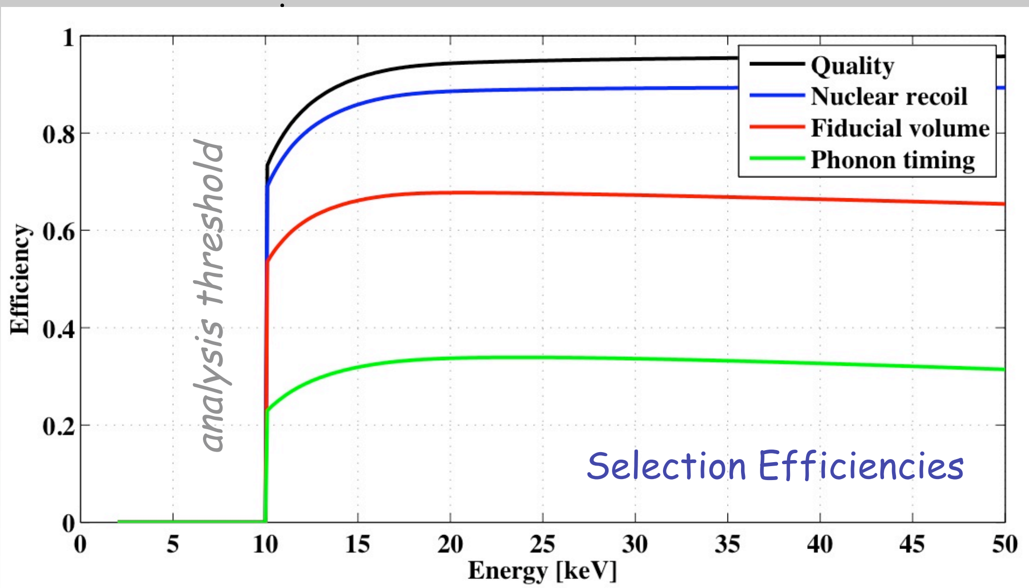
Analysis Overview

Dates of data collection: 7/2007 - 9/2008



Candidate Criteria:

- Data Quality + Fiducial Volume Cuts
- Muon-veto anticoincident
- Single Scatter (only 1 zip w/ signal)
- Ionization yield inside 2σ nuclear recoil band
- Phonon "timing" cut

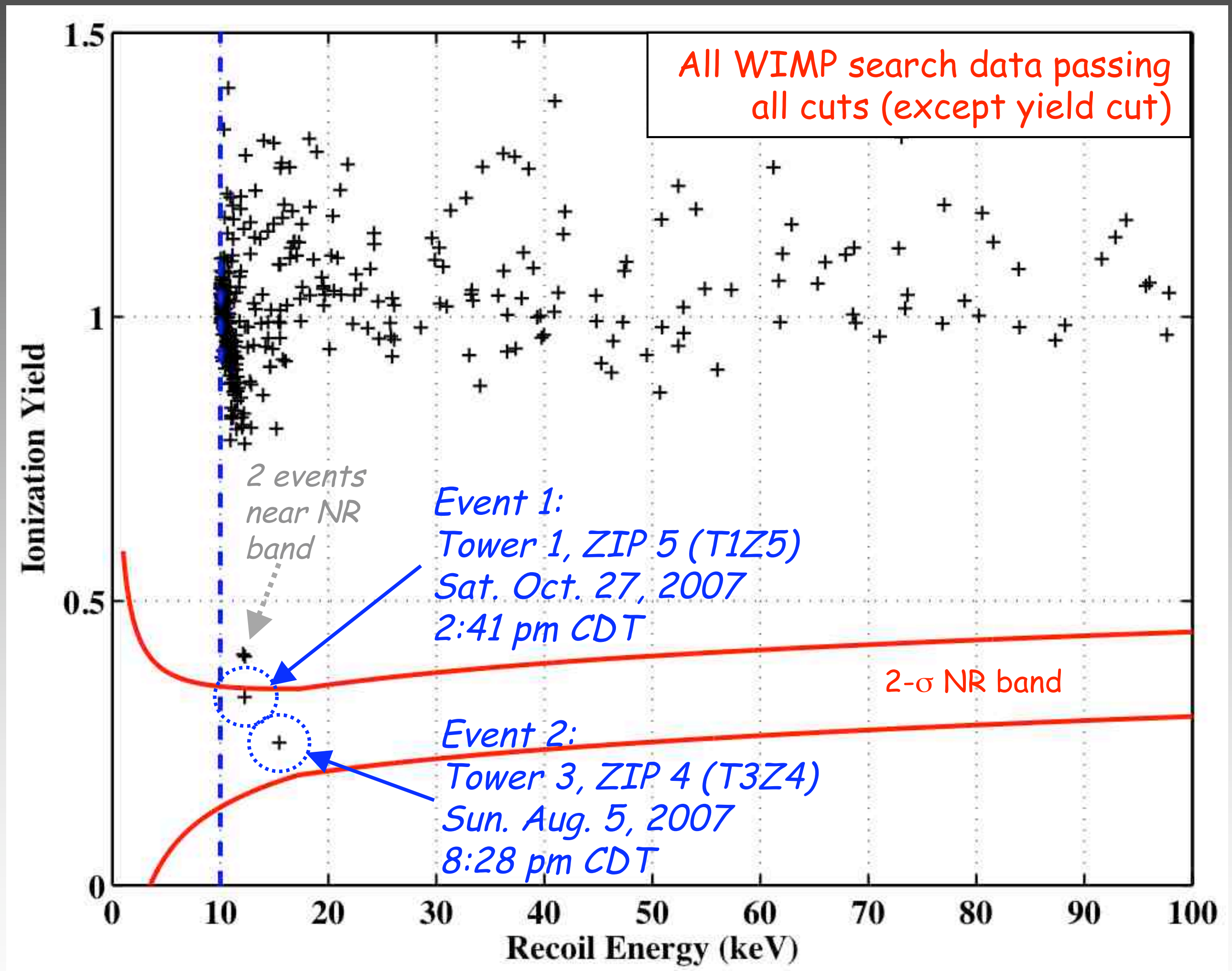


All cuts established before unblinding!

(sidebands and calibration data are used for cut development)

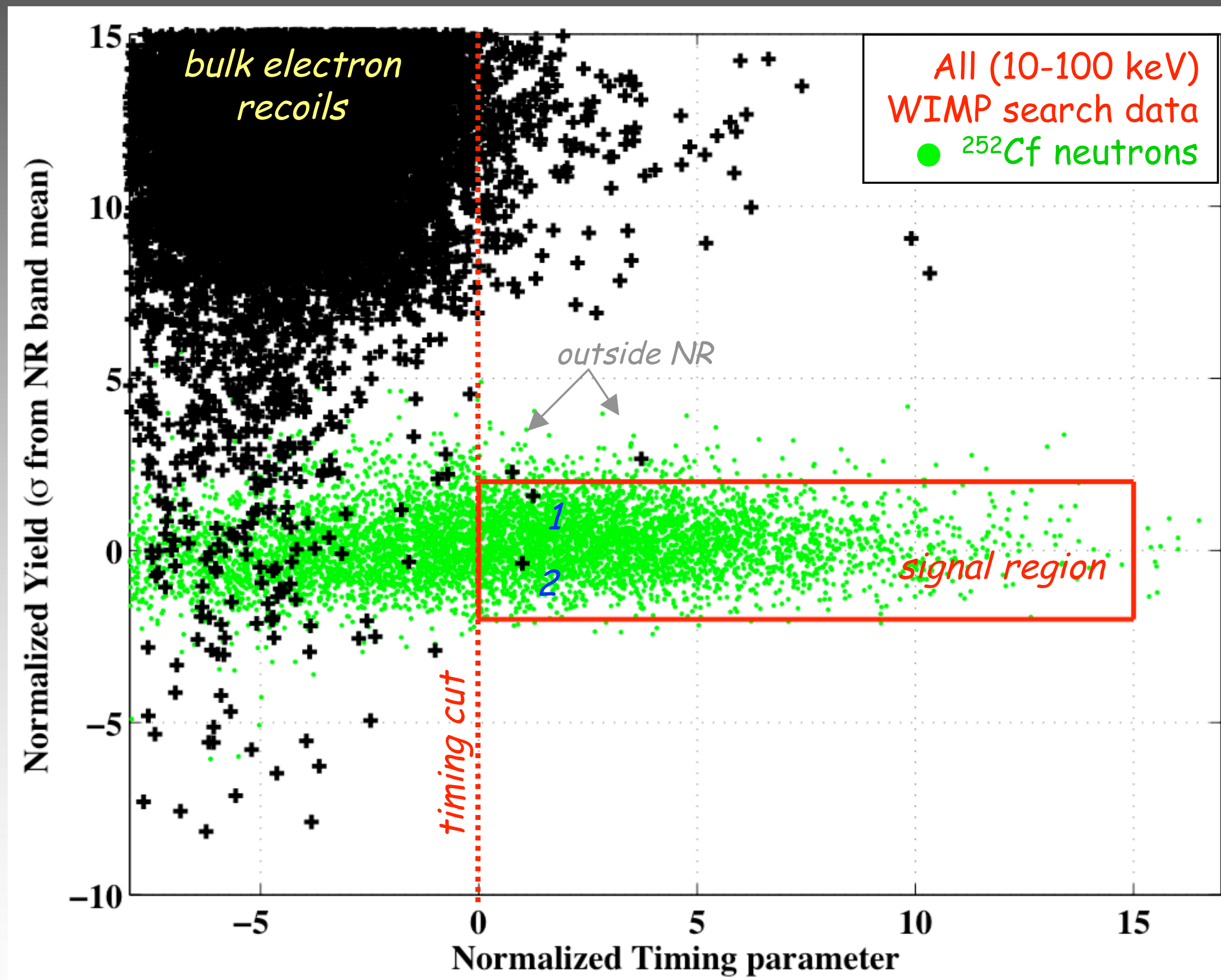
Final Exposure after all cuts: 194.1 kg-days

Unblinded Signal Region (194 kg-days)



2 events in the signal region

Alternate View w/ Timing w/ Calibration Data



Interpretation

final estimated surface-event background:
0.8±0.1(stat)±0.2(sys) events

final estimated neutron background:

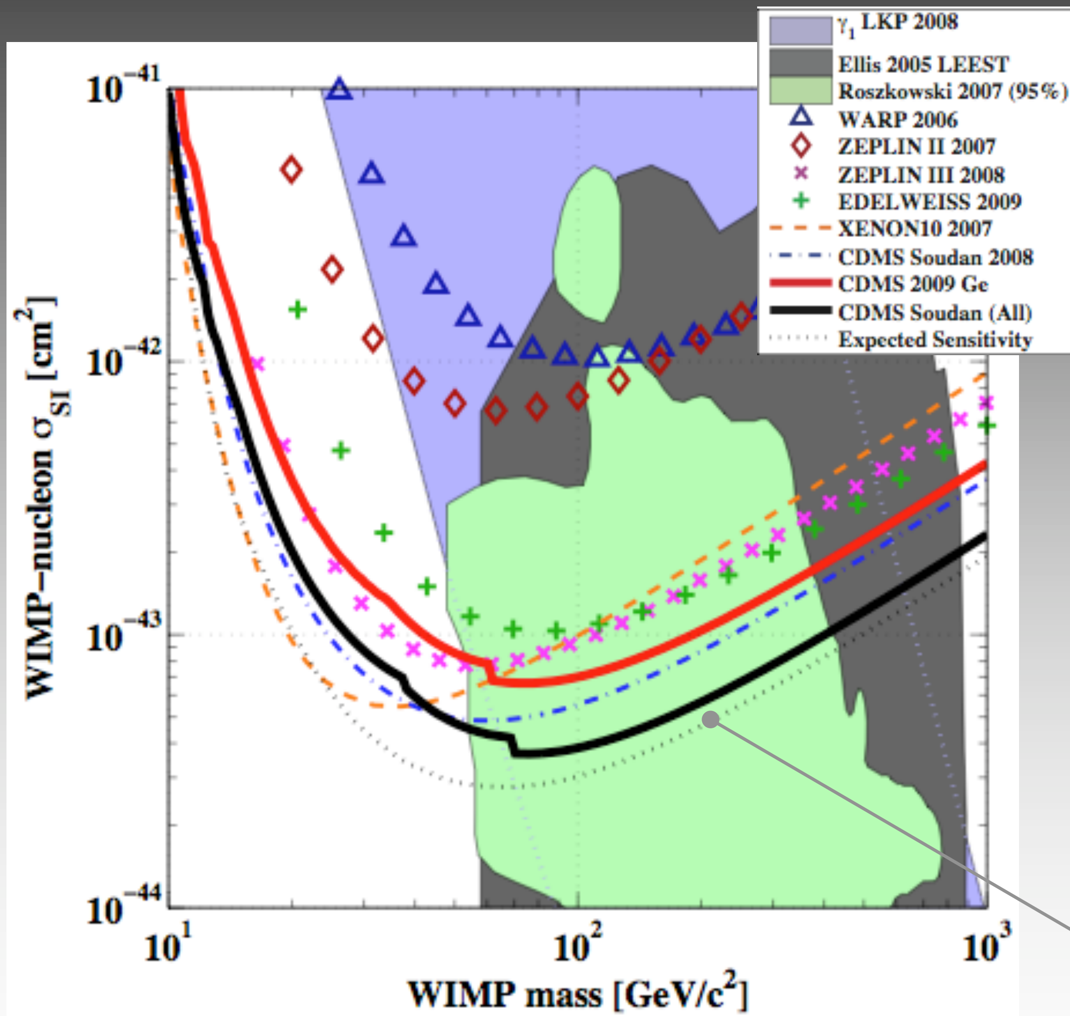
$0.04^{+0.04}_{-0.03}$ cosmogenic neutrons

0.04 – 0.06 radiogenic neutrons

based on background estimates, the probability to observe 2 or more background events is 23%

This is non-negligeable - we cannot interpret the results of this analysis as significant evidence for WIMP interactions.

90% C.L. Spin-Independent Limit



limit calculation: optimal interval method

exposure after all cuts:
194.1 kg-days

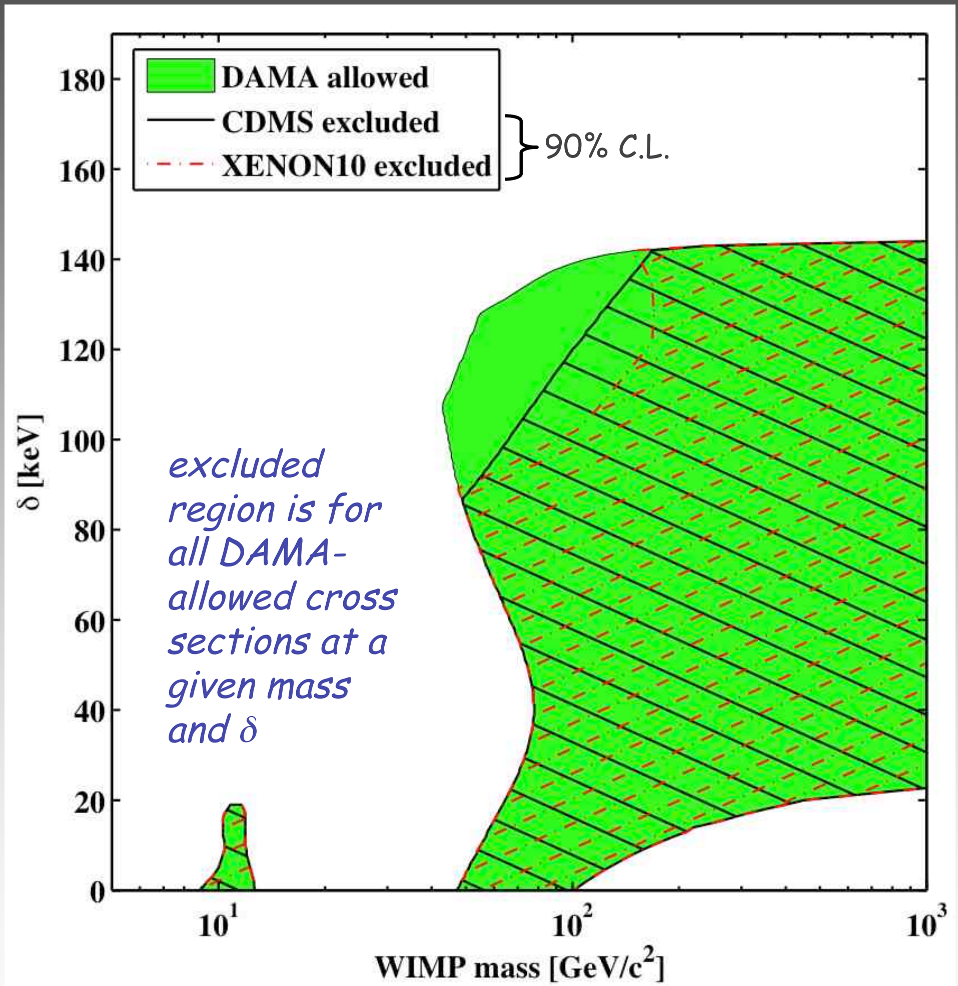
In the presence of 2 events (no bg subtraction):

CDMS 2009
@WIMP mass 70 GeV
σ = 7.0 x 10^{-44} cm^2 (90% C.L.)

CDMS Combined Soudan Data
@WIMP mass 70 GeV
σ = 3.8 x 10^{-44} cm^2 (90% C.L.)

Sensitivity curve based on final bg estimate

Inelastic Dark Matter



channeling not considered here

Has been invoked by Weiner et al. to explain DAMA/LIBRA data, among other things.
[Phys. Rev. D 64, 043502 (2001)]

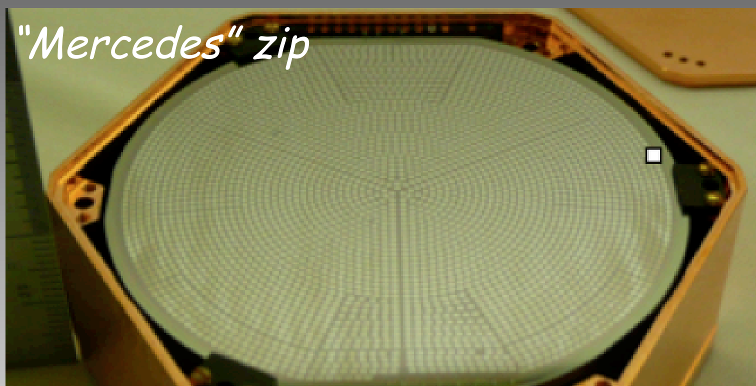
Scattering occurs via transition of WIMP to excited state (with mass splitting δ)

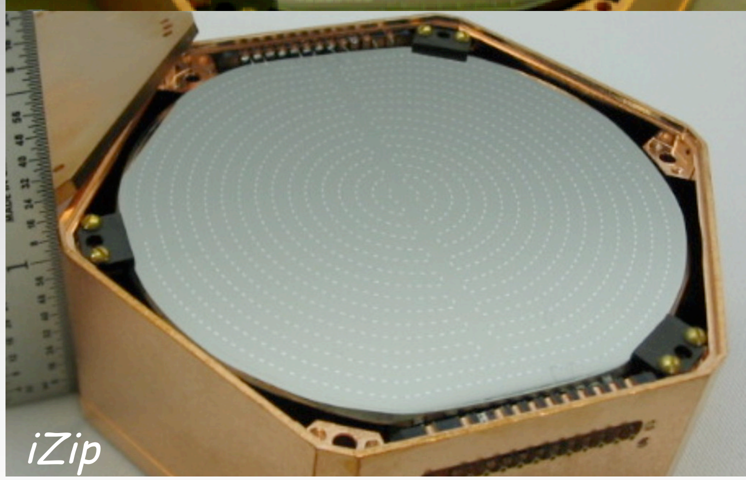
spectrum peaks at higher recoil energies

DAMA, allowed regions (at 90% C.L.) computed from χ^2 goodness-of-fit and standard truncated halo-model [JCAP 04 (2009) 010]

SuperCDMS

15 kg of Ge at Soudan, arranged as 5 SuperTowers



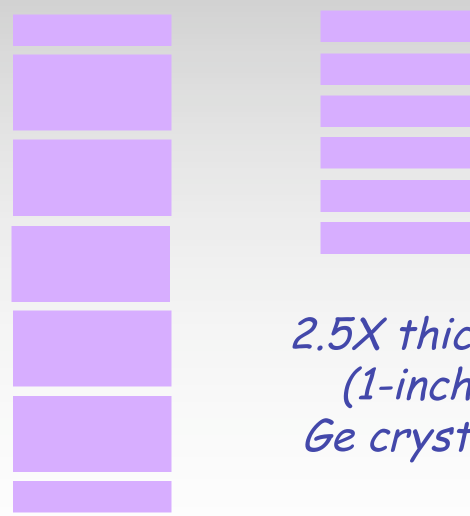


first physics w/ interleave design by Edelweiss-II - see next talk for more details

Mercedes or iZip design?

- *Mercedes: older design, 1 ST in operation since June '09, several more ready for deployment*
- *iZip: "hot off the press", 10X better surface event rejection, better long term*

SuperTower *CDMSII Tower*



2.5X thicker (1-inch) Ge crystals

Summary and Future

CDMS II (completed)

4 kg Ge

$3.8 \times 10^{-44} cm^2$ at 90% CL

(for 70 GeV/c^2 WIMP)

SuperCDMS @ Soudan

15 kg Ge

~ 2 yrs operation

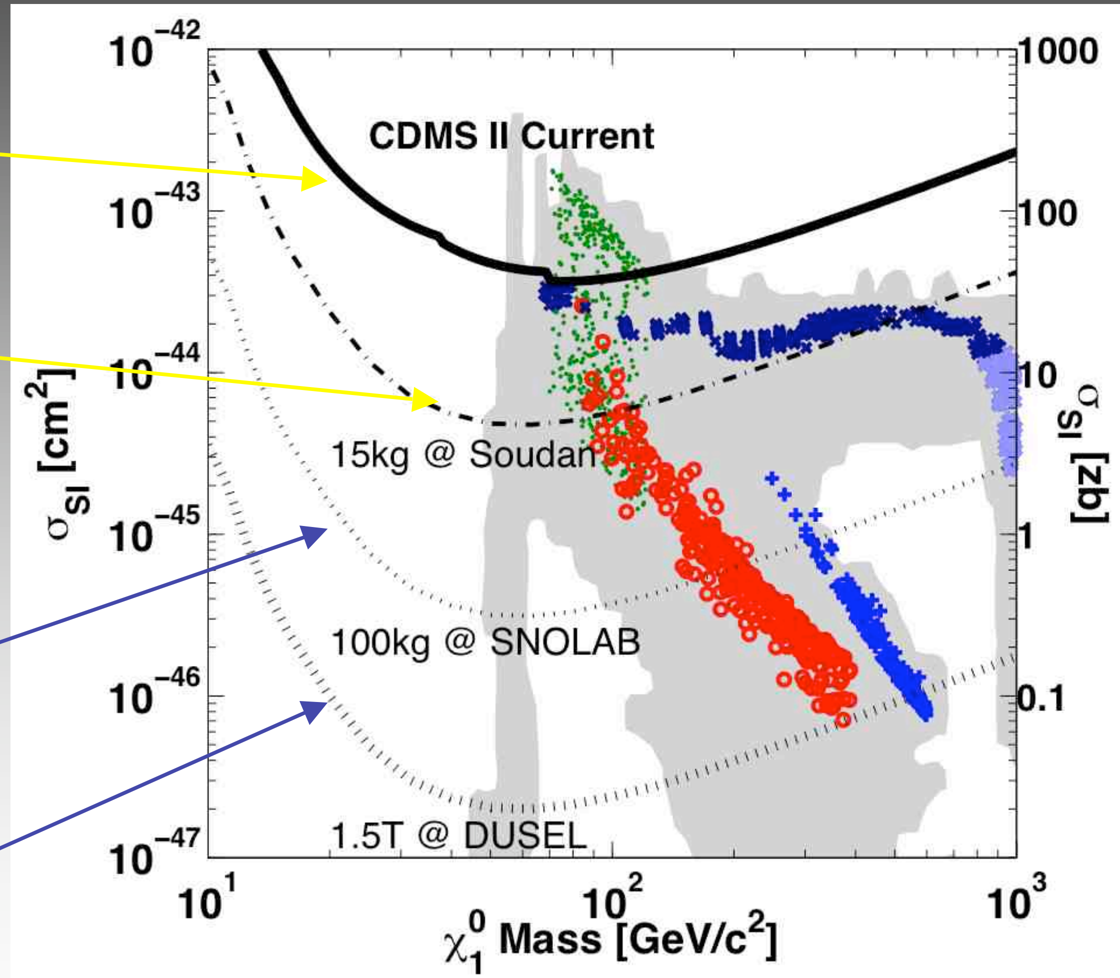
SuperCDMS @ Snolab

100 kg Ge

~ 3 yrs operation

DUSEL/GEODM

1.5T

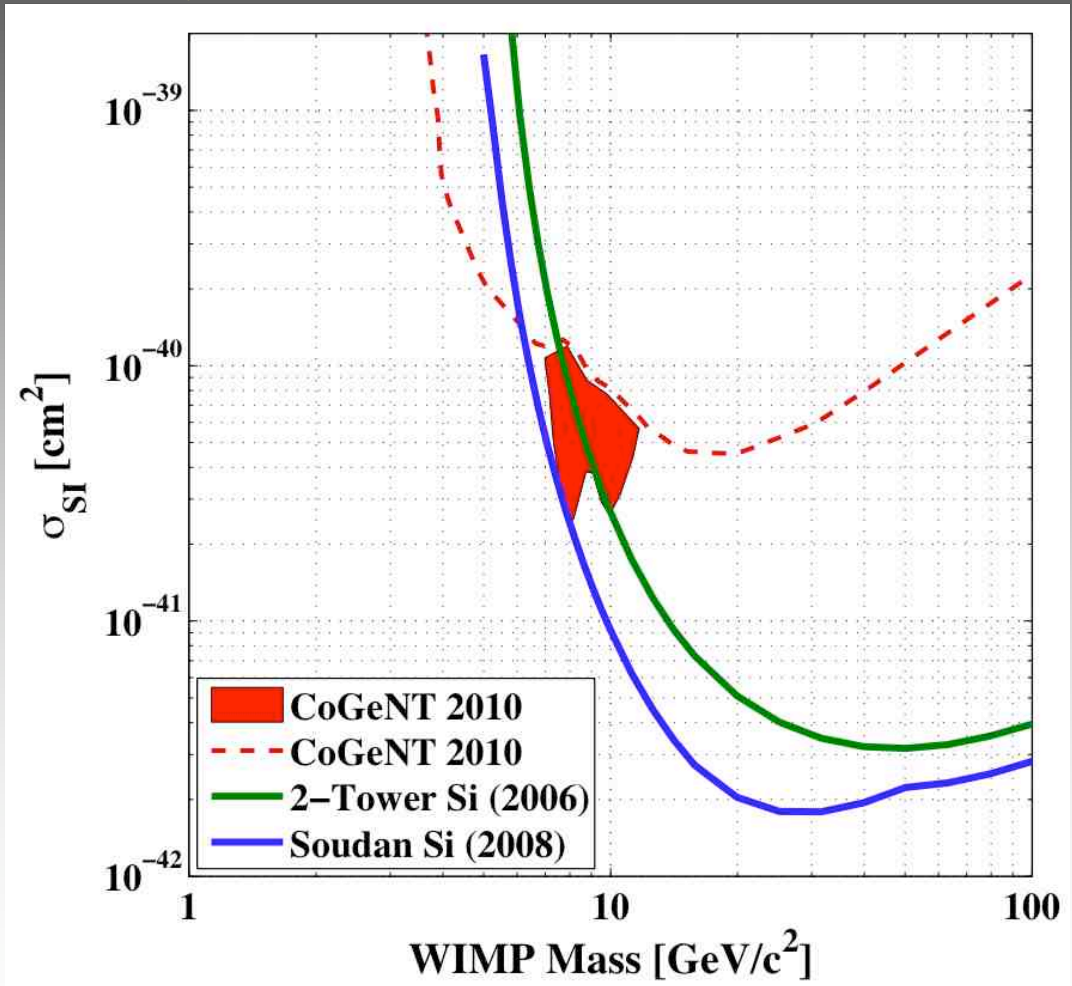


Thank You!

Z. Ahmed,[19] D.S. Akerib,[2] S. Arrenberg,[18] C.N. Bailey,[2] D. Balakishiyeva,[16] L. Baudis,[18] D.A. Bauer,[3] P.L. Brink,[10] T. Bruch,[18] R. Bunker,[14] B. Cabrera,[10] D.O. Caldwell,[14] J. Cooley,[9] P. Cushman,[17] M. Daal,[13] F. DeJongh,[3] M.R. Dragowsky,[2] L. Duong,[17] S. Fallows,[17] E. Figueroa-Feliciano,[5] J. Filippini,[19] M. Fritts,[17] S.R. Golwala,[19] D.R. Grant,[2] J. Hall,[3] R. Hennings-Yeomans,[2] S.A. Hertel,[5] D. Holmgren,[3] L. Hsu,[3] M.E. Huber,[15] O. Kamaev,[17] M. Kiveni,[11] M. Kos,[11] S.W. Leman,[5] R. Mahapatra,[12] V. Mandic,[17] K.A. McCarthy,[5] N. Mirabolfathi,[13] D. Moore,[19] H. Nelson,[14] R.W. Ogburn,[10] A. Phipps,[13] M. Pyle,[10] X. Qiu,[17] E. Ramberg,[3] W. Rau,[6] A. Reisetter,[17,7] T. Saab,[16] B. Sadoulet,[4,13] J. Sander,[14] R.W. Schnee,[11] D.N. Seitz,[13] B. Serfass,[13] K.M. Sundqvist,[13] M. Tarka,[18] P. Wikus,[5] S. Yellin,[10,14] J. Yoo,[3] B.A. Young,[8] and J. Zhang[17]
(CDMS Collaboration)

backup slides

Silicon Low Mass WIMP Limits (Comparison to CoGeNT)



Estimated Neutron Background

Cosmogenic Neutron Estimate:

$$\frac{N^{MC}_{unvetoed,\ single\ NR}}{N^{MC}_{vetoed,\ single\ NR}} * N^{data}_{vetoed,\ single\ NR} * \varepsilon_{neutron} = 0.04^{+0.04}_{-0.03}\ (stat)\ events$$

From GEANT4 and FLUKA simulations

3 vetoed, single NR (in Soudan dataset)

correct for efficiency and exposure

Radiogenic Neutron Estimate:

0.03 - 0.06 events

- fission, (α,n) in Cu, Poly, Pb

Detector contamination measured with HP Ge detector + global gamma simulation

→ GEANT4 simulation of U/Th chains in detector materials

Surface Event "Leakage" Estimate

$$\text{Expected surface leakage} = \frac{N^{sideband}_{passing\ cut}}{N^{sideband}_{failing\ cut}} * N^{data}_{failing\ cut}$$

3 independent sidebands for estimating the passing/failing ratio

SIDEBAND 1

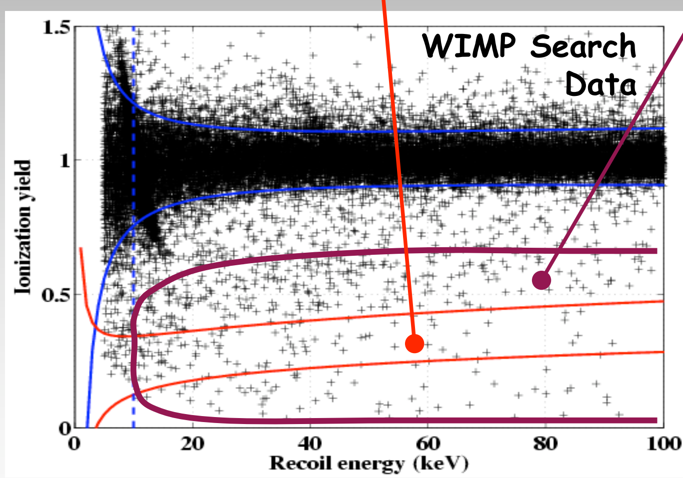
Use multiple-scatters in NR band

SIDEBAND 2

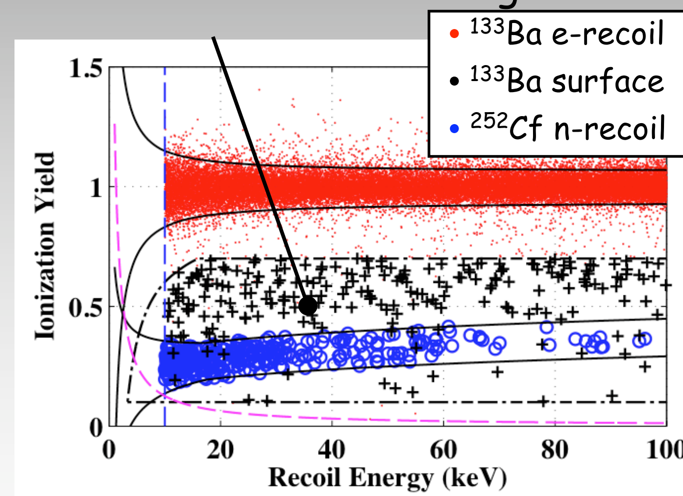
Use singles and multiples just outside NR band

SIDEBAND 3

Use singles and multiples from Ba calibration in wide region



Correct for systematic effects due to different distributions in energy, yield and face



All 3 consistent, blind estimate = 0.6 ± 0.1 (stat) events

Yield vs Timing Det-By-Det

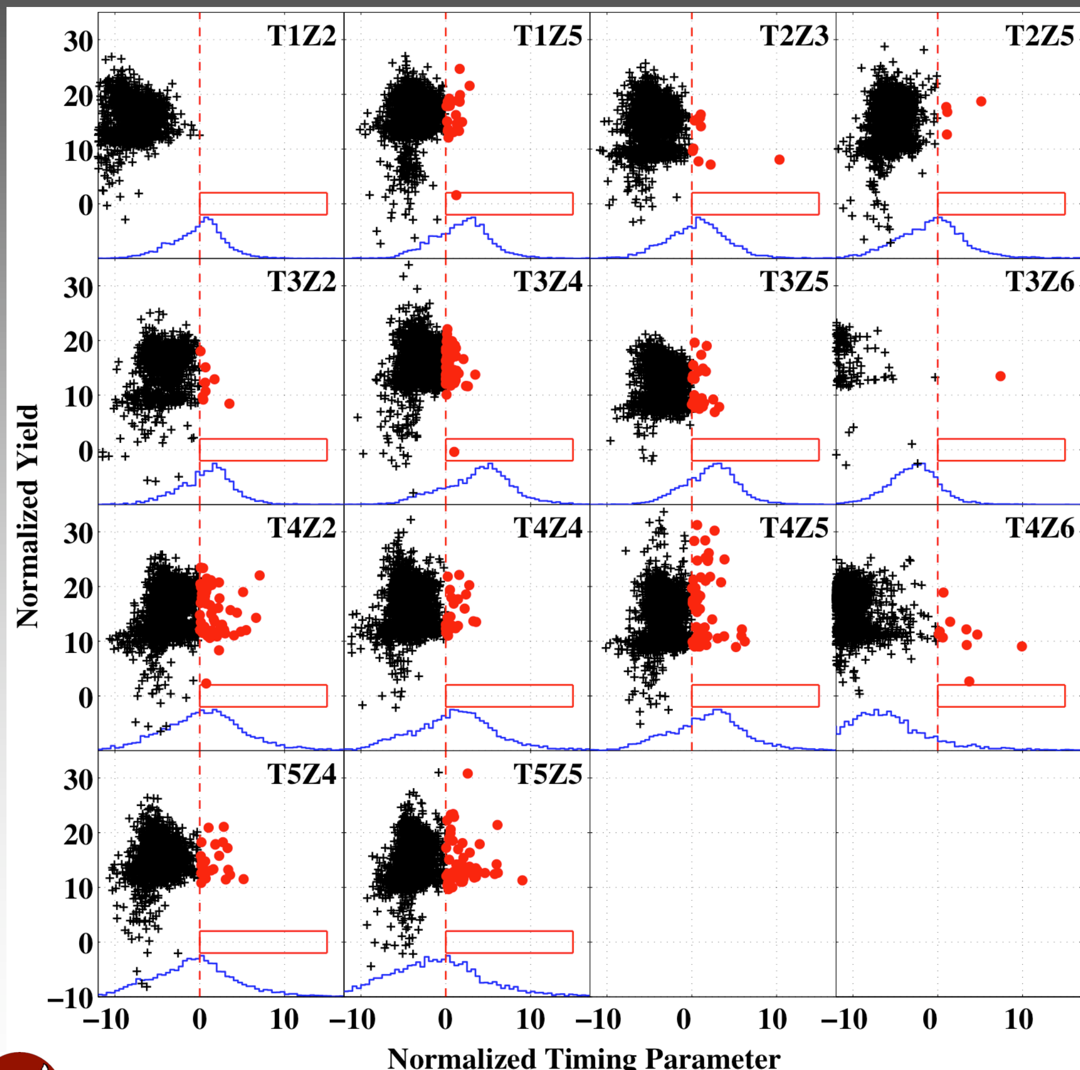
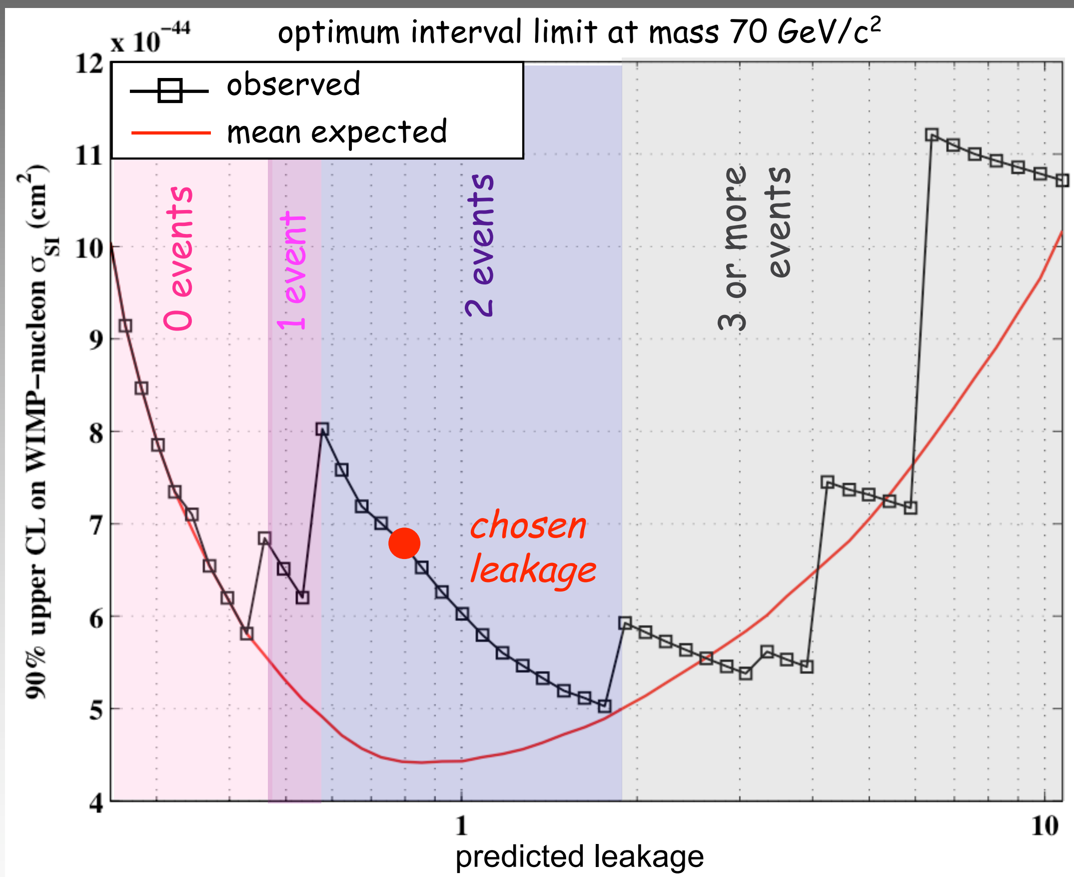


Figure available in supporting online material for Science paper:

http://www.sciencemag.org/cgi/content/full/science.1186112/DC1

What if we had chosen a different cut value?



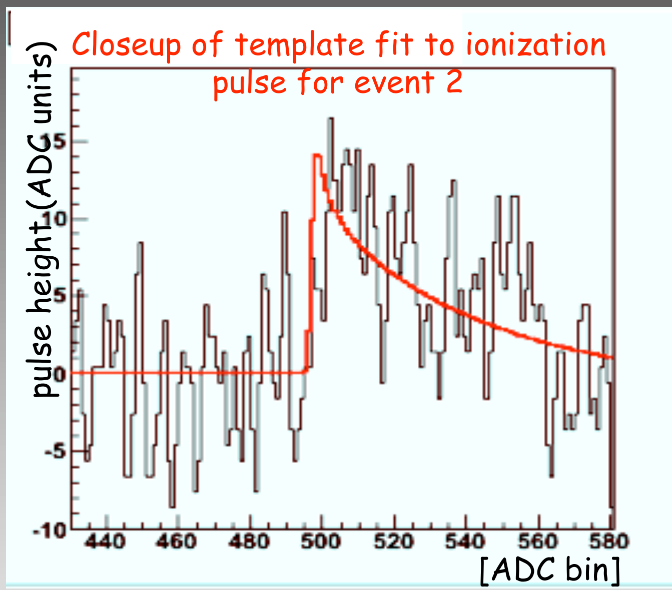
Tightening the cut to yield ~1/2 the expected surface events, removes both events from the signal region and reduces the exposure by ~28%

Additional events appear in the signal region after loosening the cut to ~2X the expected leakage

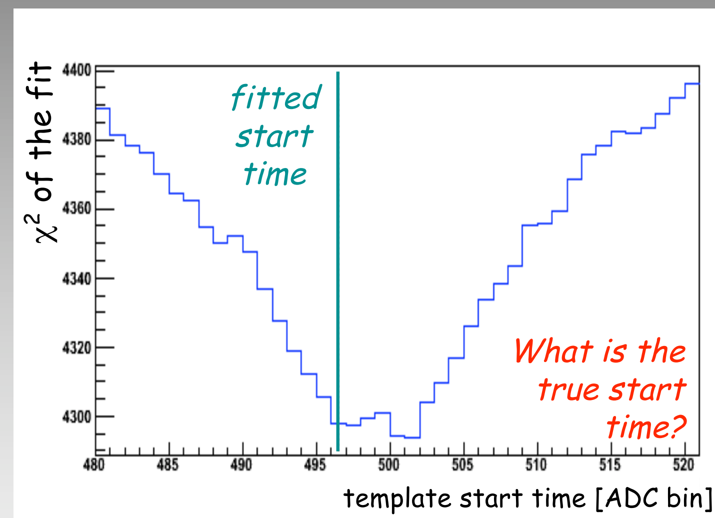
The observed limit doesn't depend strongly on chosen surface-event rejection cut value

Reconstruction Checks

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



Could there be a problem with the start time of the charge pulse? (affects timing parameter)

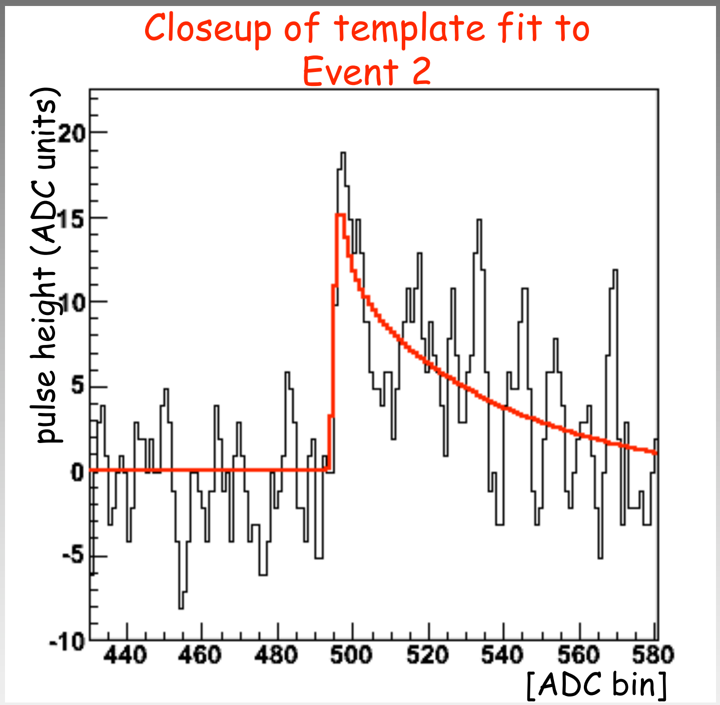


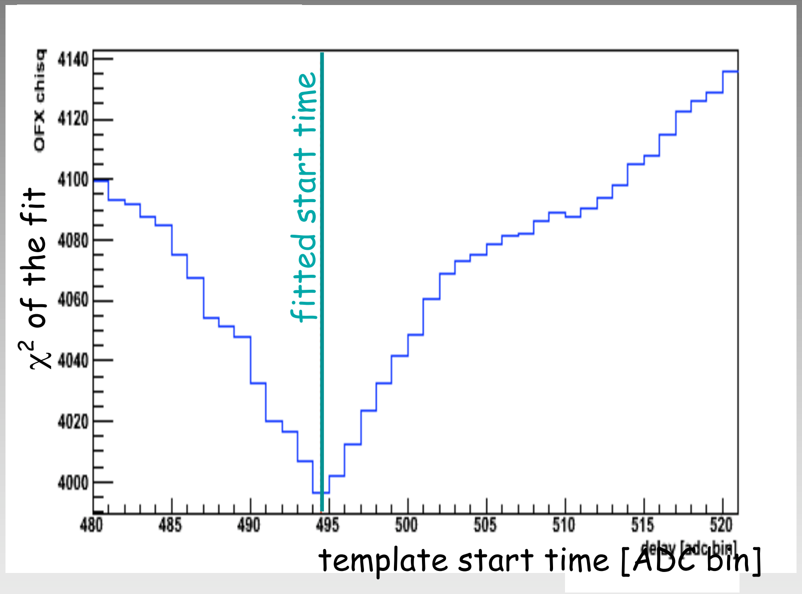
This effect is strongly correlated with the ionization energy *(affects ~1% of events with < 6 keV ionization energy)* and was mostly accounted for in the pre-unblinding leakage estimate.

A more careful accounting revised the surface event leakage from 0.6 to 0.8 events

(Note: event 1 does not appear to be affected by this issue)

Event 1 Reconstruction Checks





Likelihood Analysis

- Comparing nuclear scatters from neutron calibrations to surface electron scatters from gamma calibrations
- Likelihoods constructed only for the detectors that recorded the candidate events
- 3 independent methods constructing the likelihood distributions
  - Use of variety of methods helps check technique dependent systematic errors
  - Binned/Unbinned
  - Distribution fitting/no fitting
  - 2D (yield, timing) / 3D (yield, timing, energy)

Likelihood Results
(in the acceptance region)

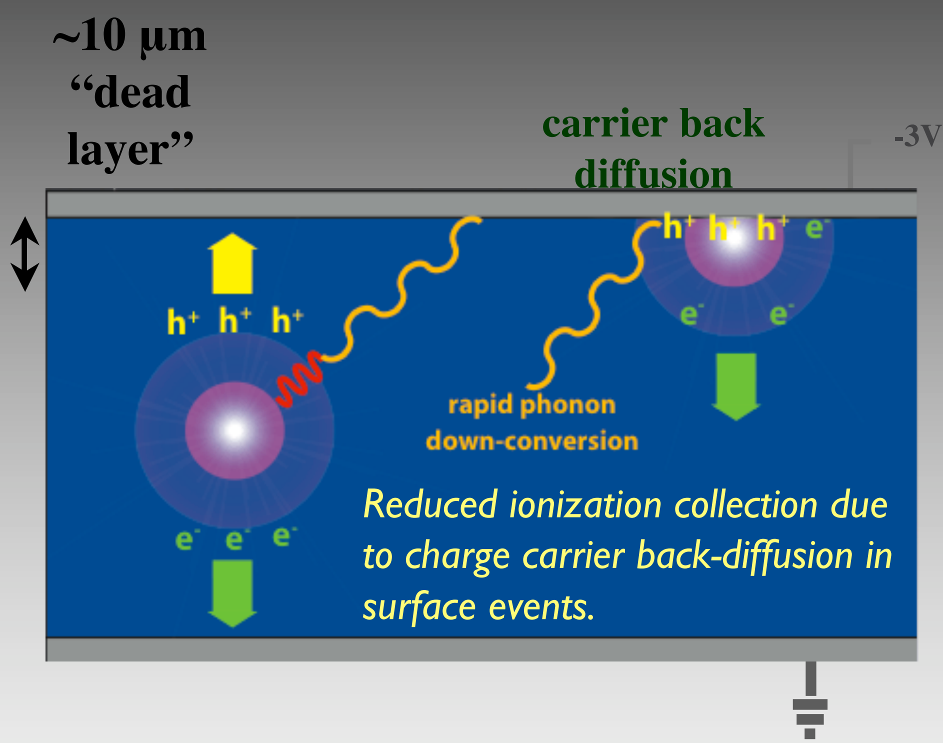
- What is the probability that a true nuclear recoil in the acceptance region is as close to the cut boundaries as the observed events in these detectors?

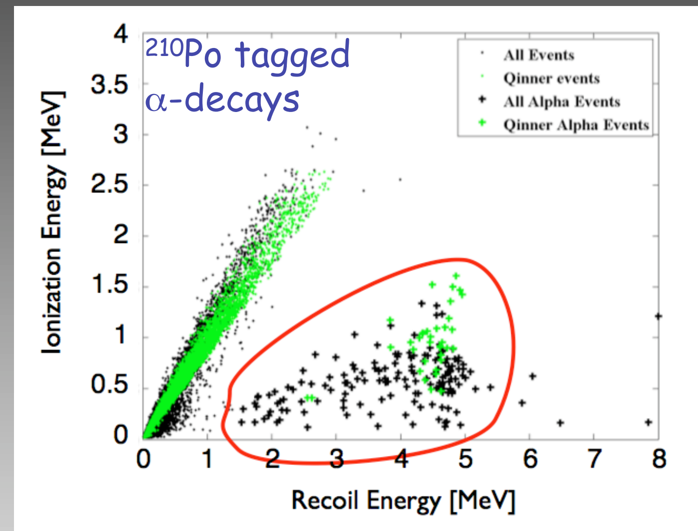
Event	Unbinned 3D	2D with fit	Unbinned 2D no fit
1	1 %	3 %	4 %
2	12 %	2 %	19 %

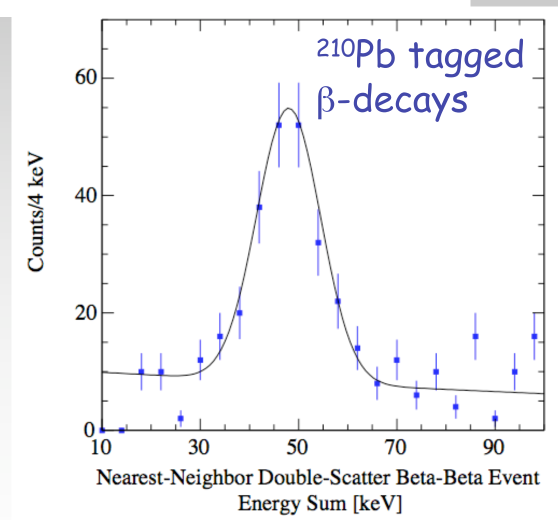
- What is the probability of observing an electron recoil appearing to look more like nuclear recoils in the acceptance region in these detectors?

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

What are Surface Events?







These events are primarily electrons, and soft x-rays originating from surfaces of the detectors and surrounding materials

Correlations to ^{222}Rn daughter contamination observed

Surface Event Leakage Estimates

Method 1: least systematic uncertainty, but poor statistics and no estimate for endcap detectors

$\text{leakage}_1 = 0.5 \pm 0.3$ *(stat.)*

Method 2: includes endcap detectors, but added systematic uncertainty and poor statistics

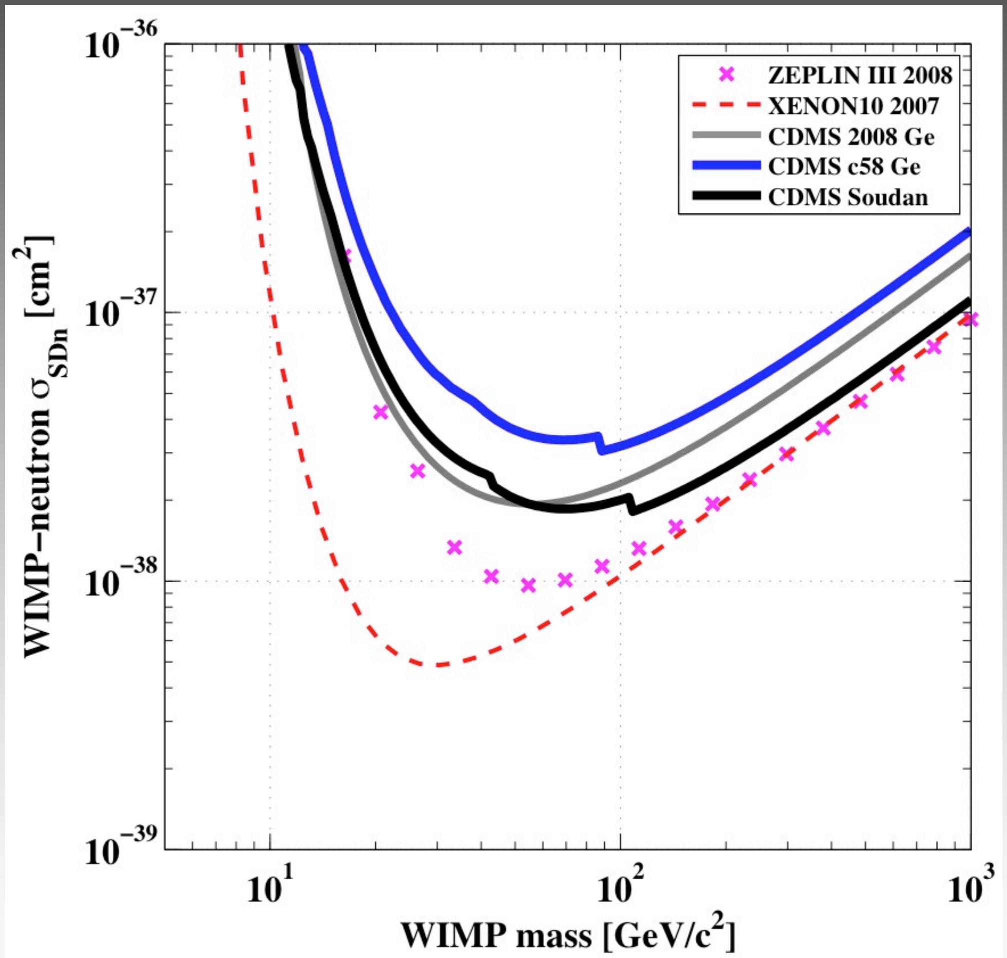
$\text{leakage}_2 = 0.8 \pm 0.6$ *(stat.)*

Method 3: best statistical power, but most systematic uncertainty

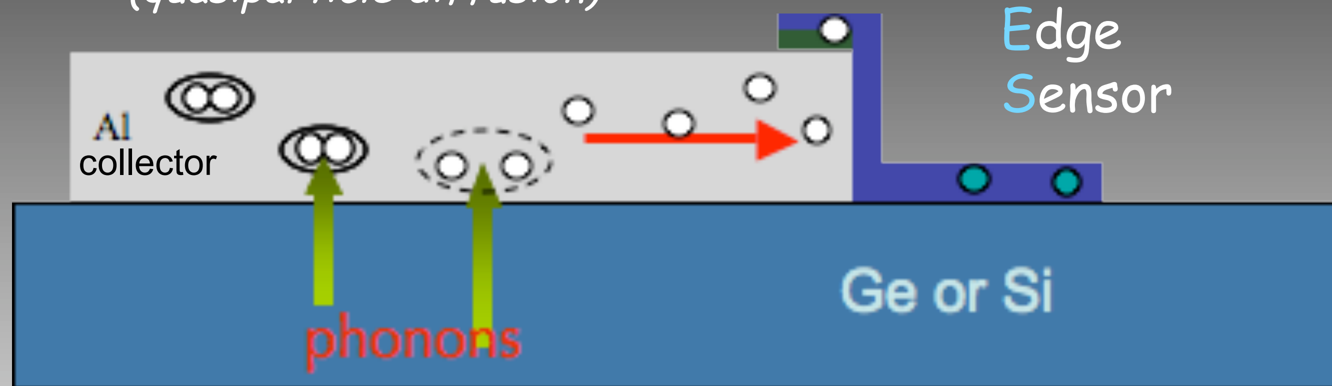
$\text{leakage}_3 = 0.5 \pm 0.1$ *(stat.)*

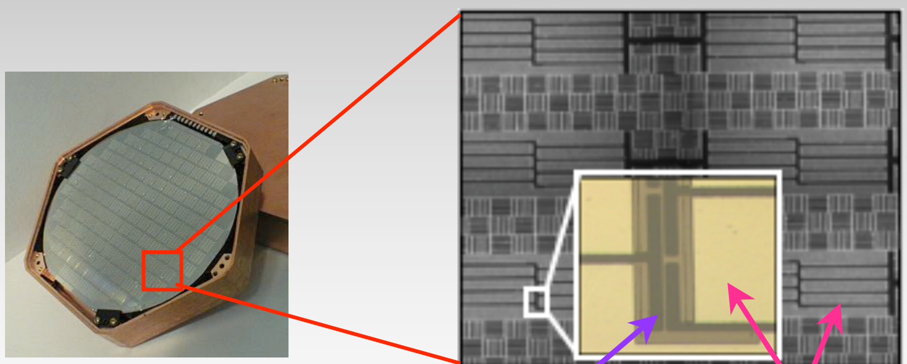
$\text{leakage}_{\text{combined}} = 0.6 \pm 0.1$ (stat.)

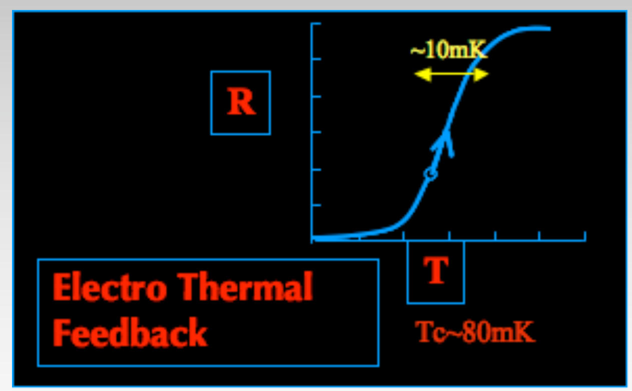
90% C.L. Spin-Dependent Limit



Phonon Detection

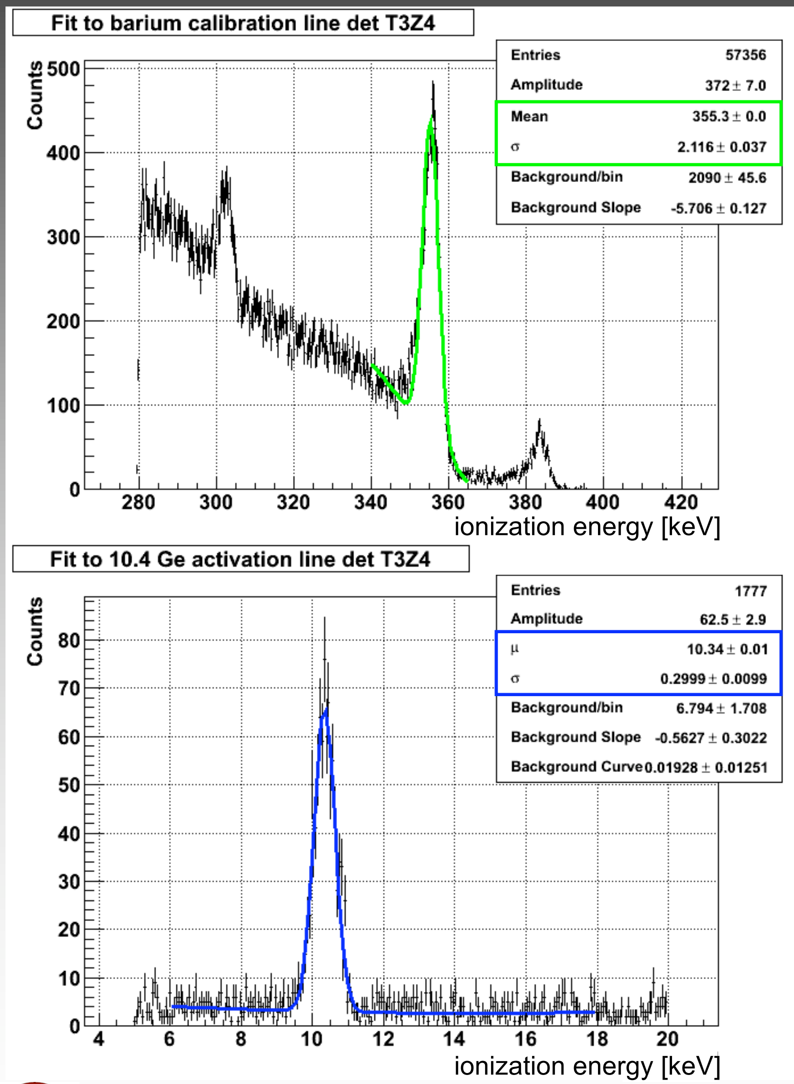






each of 4 phonon channels reads out 1036 TES in parallel

Calibration Data



Two Sources:

^{133}Ba: γ-lines at 303, 356 & 384 keV

^{252}Cf: neutrons ~few MeV, neutron activation of Ge → 10.4 keV γ-line

Many Uses:

In-situ measurement of energy scale

resolution and linearity

position correction

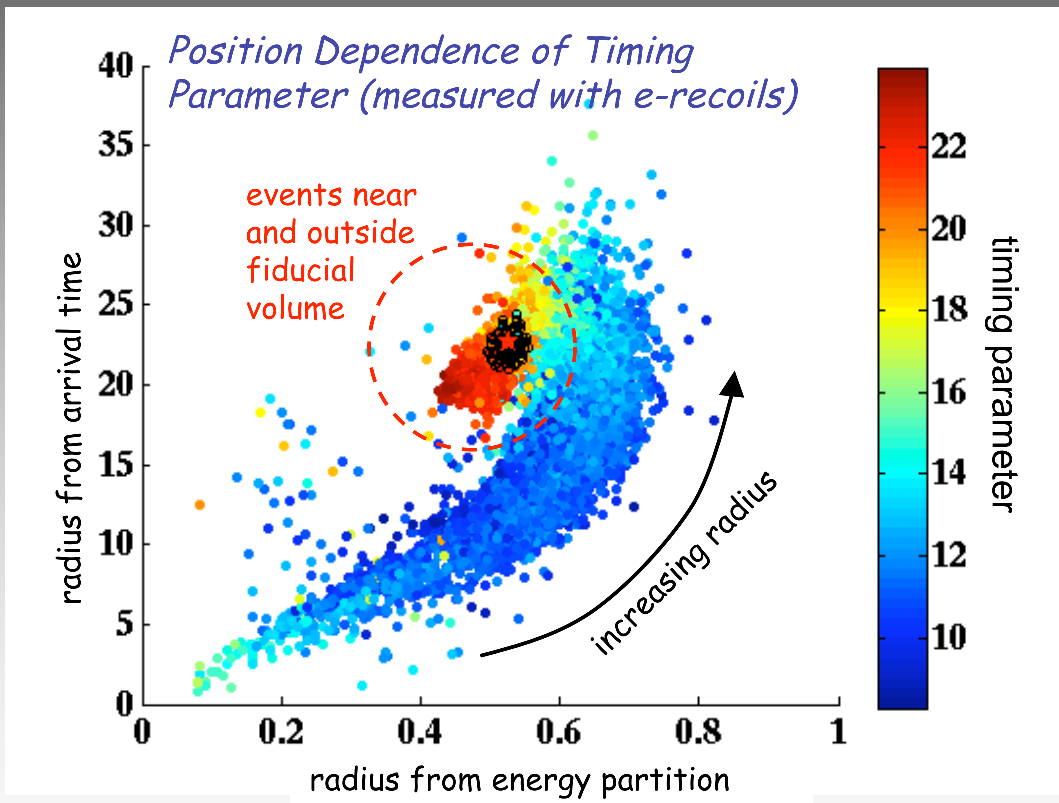
set cuts & measure selection efficiencies

develop surface event rejection (^{133}Ba ~40X the number of WS events)

Phonon Position Correction

Timing and energy response vary across the detector

Construct a lookup table from ^{133}Ba data to correct the variation



2009 Improvement:

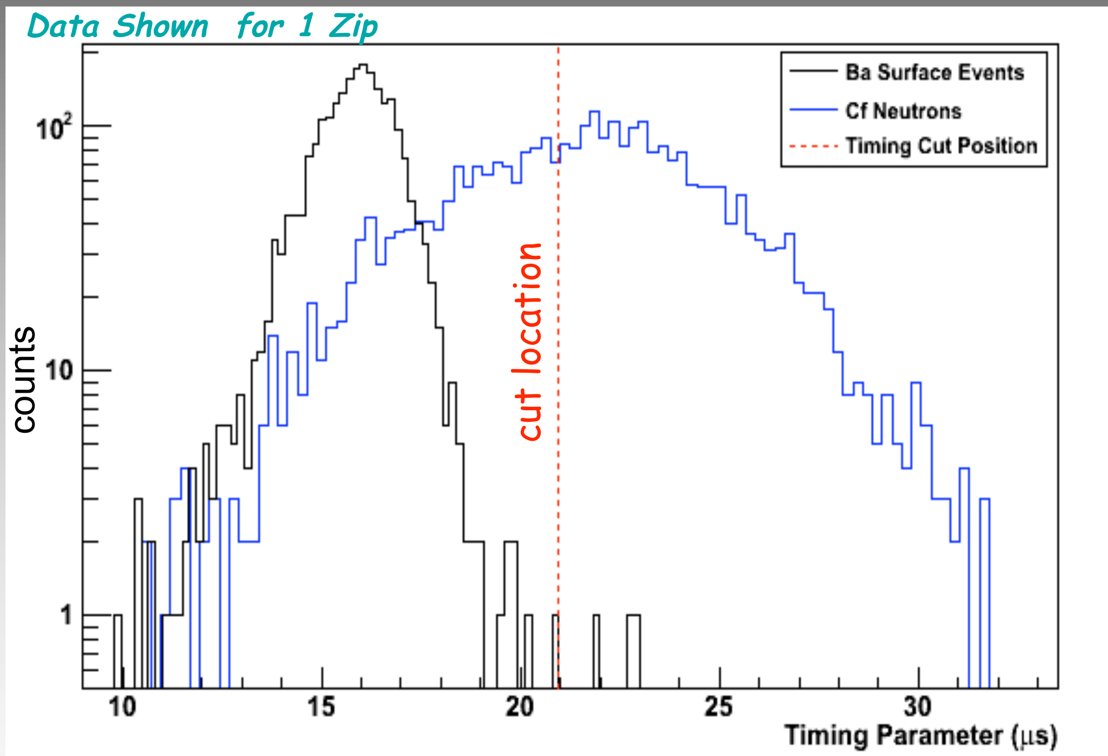
Include events just outside the fiducial volume to better correct events at high radius.

→ *Significantly reduces timing outliers (we cut on the tails)*

Neither partition nor arrival time provide a unique measurement of position at high radius. Together, they unfold the degeneracy.

Surface Event Background

^{133}Ba provides surface events for tuning the surface event rejection cut.



We optimized for the best sensitivity (results in < 1 expected background).

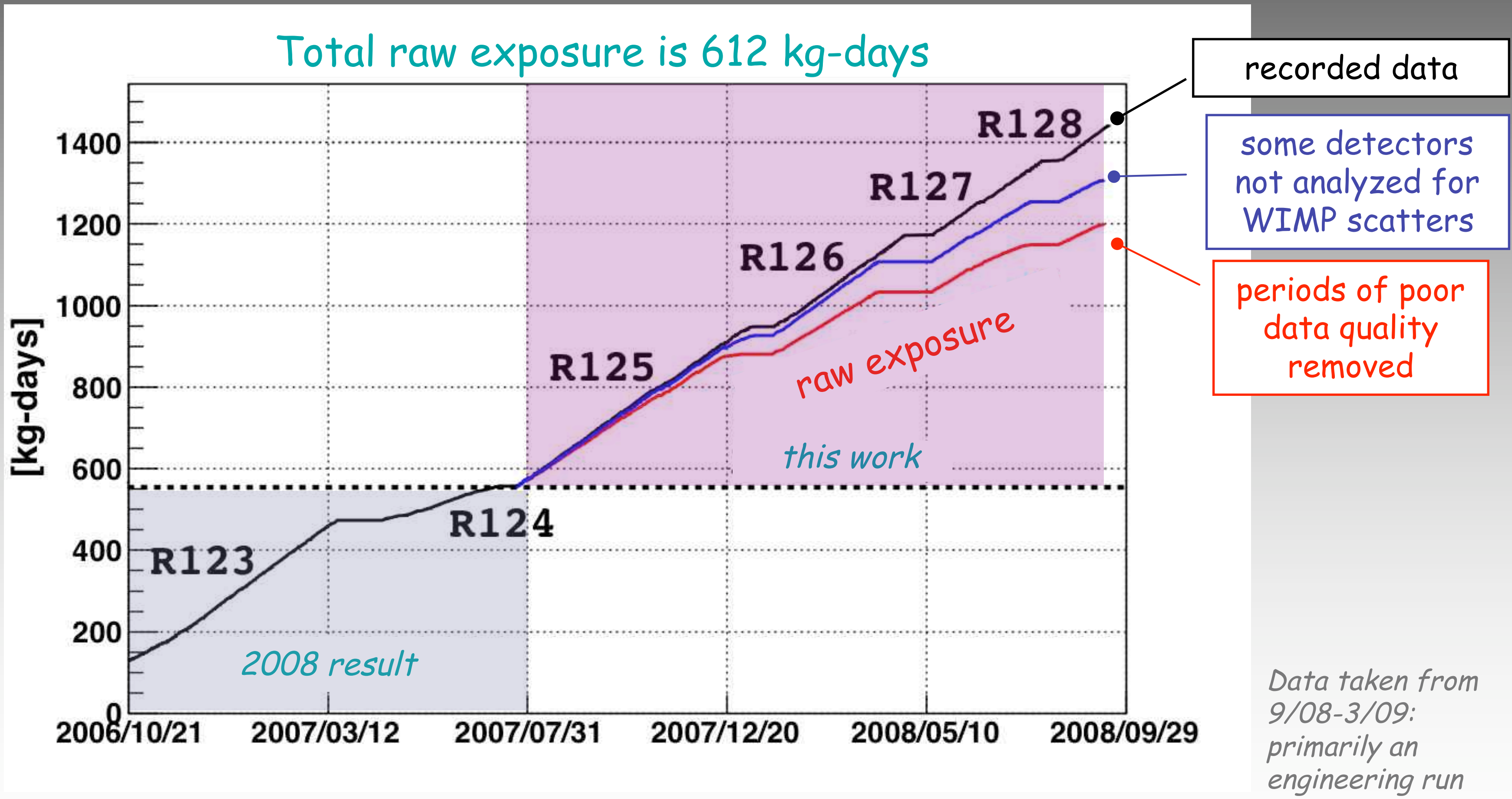
Challenges (!)

Setting the cut on the tails of the distribution

Accounting for systematic differences between surface events in ^{133}Ba and WIMP-search datasets

WIMP Search Exposure

4 stable periods separated by partial warmups of cryostat



Data taken from 9/08-3/09: primarily an engineering run

Other CDMS Results for 2009

"Analysis of the low-energy electron-recoil spectrum of the CDMS experiment" - *arXiv: 0907.1438 [astro-ph]*

"Search for Axions with the CDMS Experiment" - *arXiv:0902.4693 [hep-ex]*

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