Current and Future Adventures with CDMS, SuperCDMS, and GEODM

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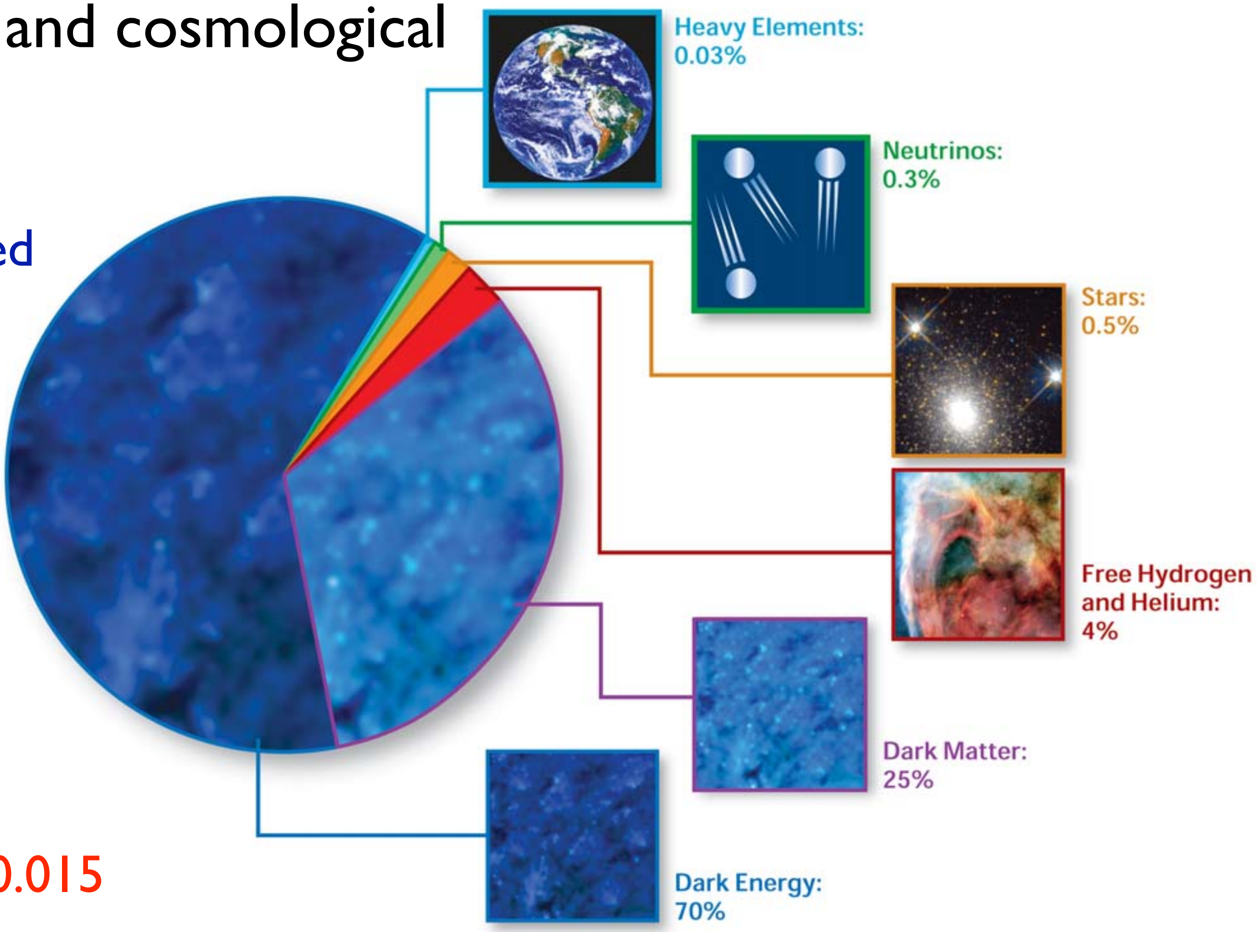
Feb 10, 2010

Outline

- Quick review of motivation for Weakly Interacting Massive Particle dark matter
- CDMS approach to WIMP detection
- Recent analysis/results
- New detector design and the future

Why Dark Matter?

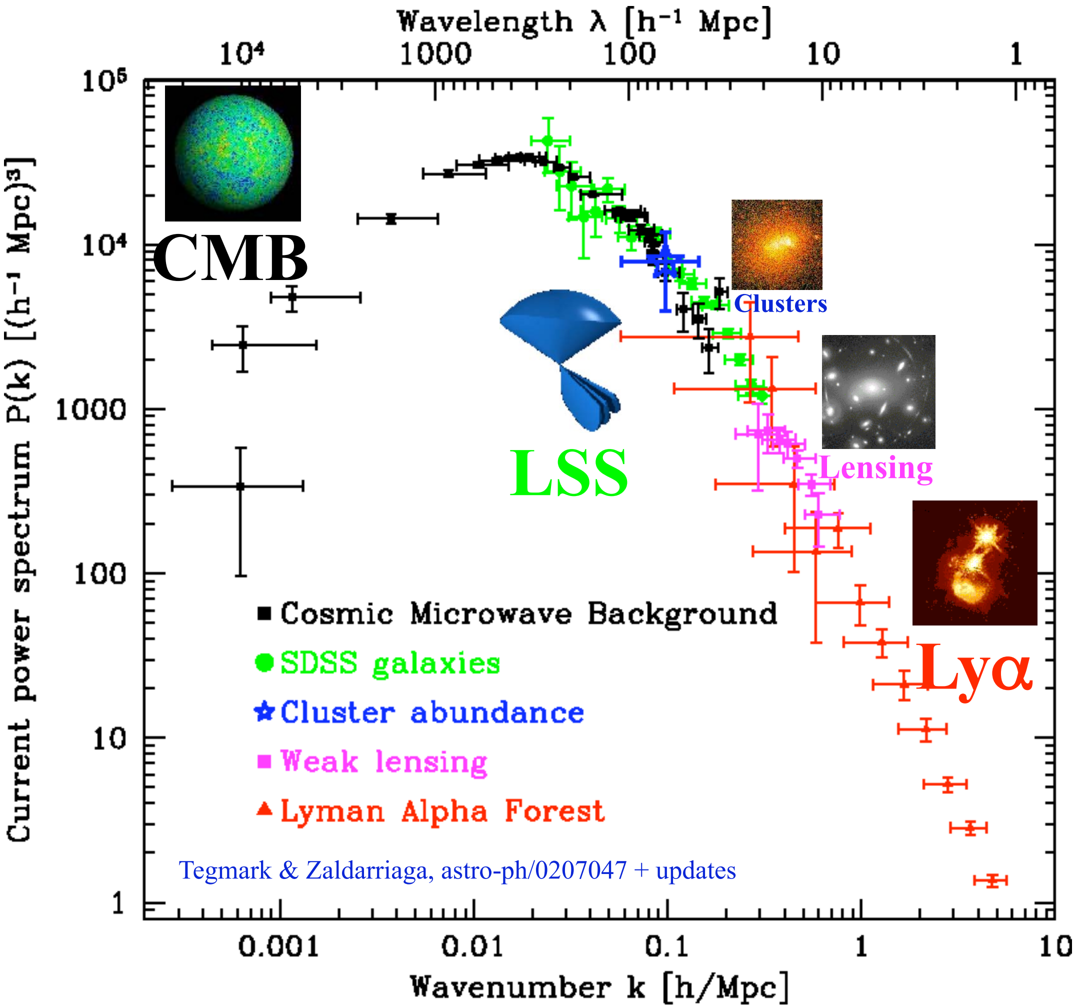
- A host of astronomical and cosmological observations indicate:
  - Total energy density = critical density ρ_{crit} needed for spatially flat universe (within errors)
  - The bulk is in the form of *dark energy*, a fluid that has negative pressure (causes the universe's expansion to accelerate) and does not clump gravitationally, $\Omega_{DE} = \rho_{DE}/\rho_{crit} = 0.726 \pm 0.015$



  - Most of the matter is in the form of *dark matter*, matter that interacts gravitationally but not electromagnetically, $\Omega_{DM} = \rho_{DM}/\rho_{crit} = 0.228 \pm 0.013$
  - The remaining matter is in the form of baryons, $\Omega_B = \rho_B/\rho_{crit} = 0.0456 \pm 0.0015$ (though much of this has not yet been directly observed!)

Required Dark Matter Characteristics

- Dark matter must be:
  - Cold/warm (not hot):
    - nonrelativistic at matter-radiation equality ($z \sim 3500$) to seed LSS. $M < \mathrm{keV}$ (e.g., ν) too hot.
  - Nonbaryonic
    - Light element abundances + Big Bang Nucleosynthesis measure baryon density: too low.
    - Baryonic matter could not collapse until recombination ($z \sim 1100$): too late to seed LSS

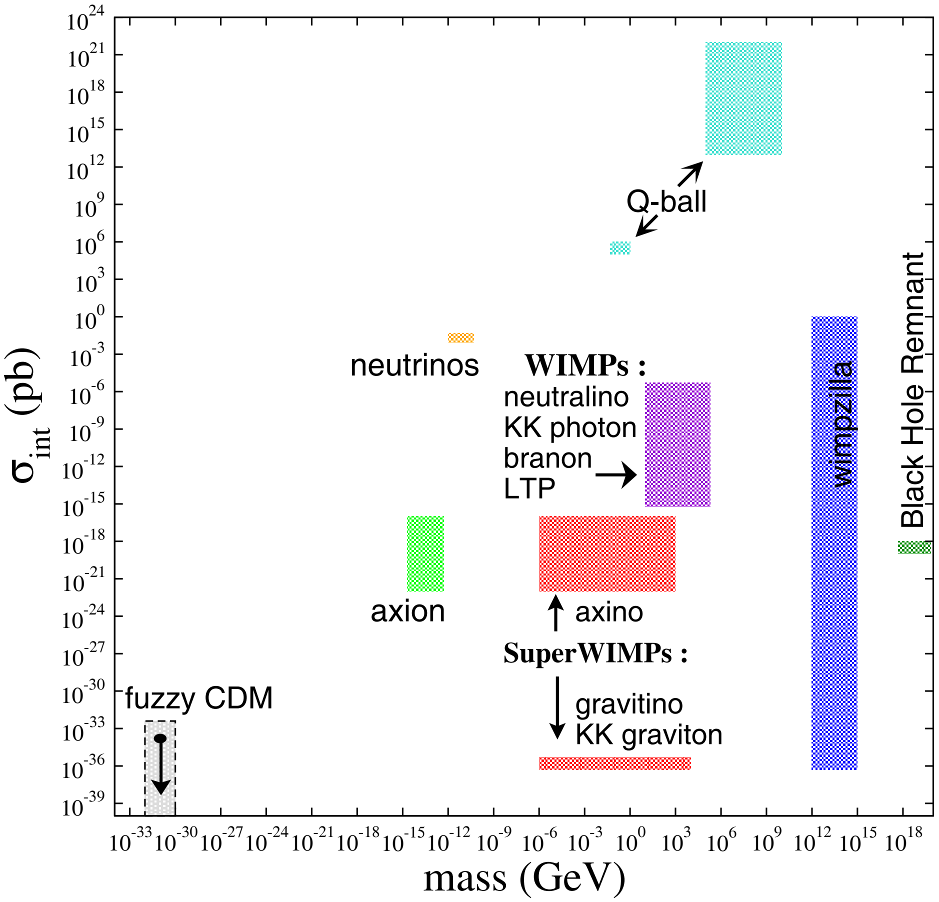


Tegmark & Zaldarriaga, astro-ph/0207047 + updates

- Locally, we know
  - density ~ 0.1-0.7 GeV/cm^3: ~1 proton/3 cm^3, ~1 WIMP/coffee cup
  - velocity: simplest (not necessarily most accurate!) assumption is truncated Maxwell-Boltzmann distribution with $\sigma_v \approx 270$ km/s, $v_{esc} = 544$ km/sec

The Particle Dark Matter Zoo

- Neutrinos
  - massive neutrinos can be cold or warm; low-mass neutrinos are hot
- Axions
  - Form as Bose condensate in early universe: cold in spite of low mass
- Weakly Interacting Massive Particles (WIMPs)
  - new massive (~100 GeV) particle with EW scale interactions
  - SUSY neutralino
  - Lightest Kaluza-Klein particle in universal extra dimensions



Park, in DMSAG 2007 report

- SUSY gravitinos (SuperWIMPs), axinos
- "Data-Driven" candidates: Inelastic dark matter, excited dark matter
- Others:
  - WIMPzillas, SIMPzillas, primordial black holes, Q-balls, strange quark nuggets, mirror particles, CHArged Massive Particles, self interacting dark matter, D-matter, cryptons, brane world dark matter...

WIMPs

- A WIMP δ is like a massive neutrino: produced when T >> m_δ via pair annihilation/ creation. Reaction maintains thermal equilibrium.
- If interaction rates high enough, comoving density drops as $\exp(-m_\delta / T)$ as T drops below m_δ : annihilation continues, production becomes suppressed.
- But, weakly interacting → will "freeze out" before total annihilation if

$$H > \Gamma_{ann} \sim \frac{n_\delta}{\langle \sigma_{ann}\, v \rangle}$$

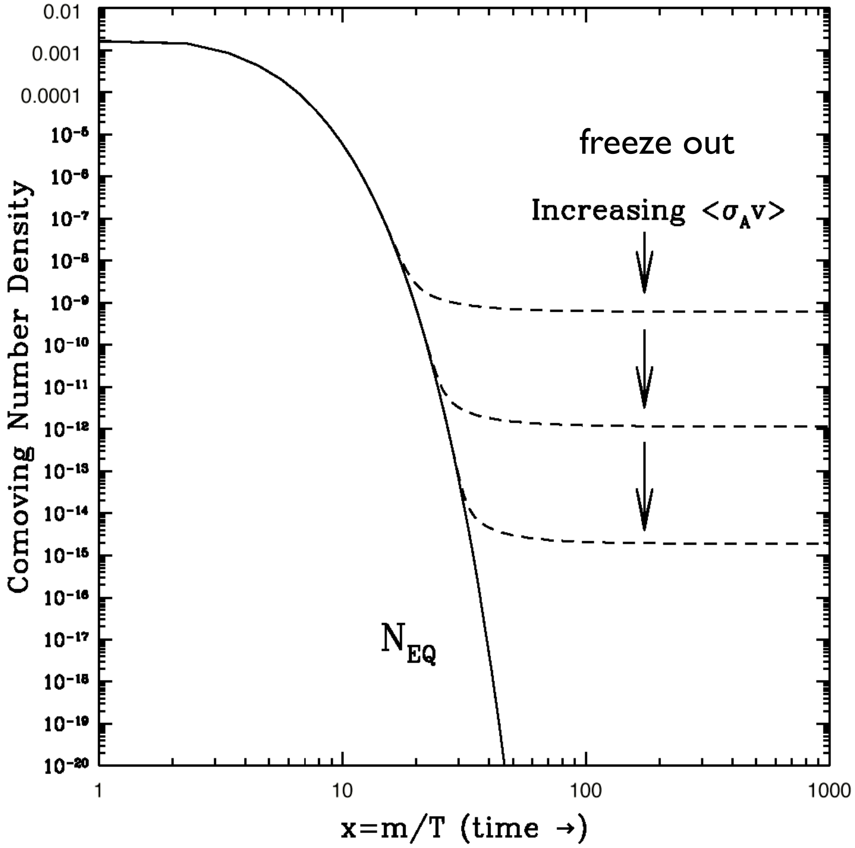
i.e., if annihilation too slow to keep up with Hubble expansion

- Leaves a relic abundance:

$$\Omega_\delta\, h^2 \approx \frac{10^{-27}}{\langle \sigma_{ann}\, v \rangle_{fr}}\ \mathrm{cm}^3\,\mathrm{s}^{-1}$$

for m_δ = O(100 GeV)
→ if m_δ and σ_{ann} determined by new weak-scale physics, then Ω_δ is O(1)

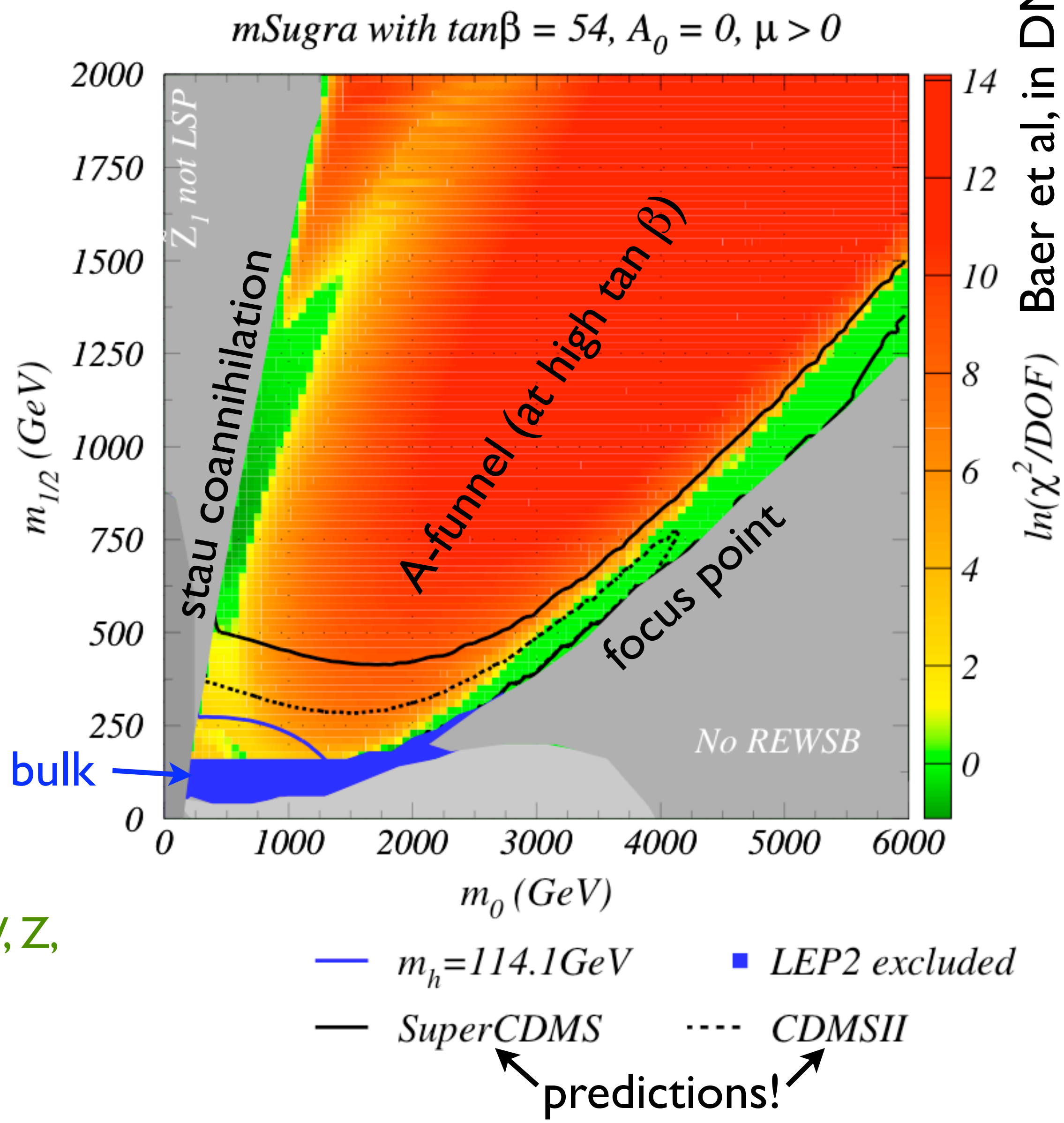
canonical Kolb and Turner freeze-out plot



Supersymmetric WIMPs

- Supersymmetry:
  - solves gauge hierarchy problem
  - improves coupling unification
- Neutralino LSP δ
  - mixture of bino, wino, higgsinos; spin 1/2 Majorana particle
  - Allowed regions
    - bulk: δ annih. via t-ch. slepton exchange, light h, high BR(b→sγ) and $(g\text{-}2)_\mu$; good DD rates
    - stau coann: δ and stau nearly degenerate, enhances annih., low DD rates
    - focus point: less fine-tuning of REWSB, δ acquires higgsino component, increases annih. to W, Z, good DD rates
    - A-funnel: at high tan β, resonant s-ch. annih. via A, low DD rates

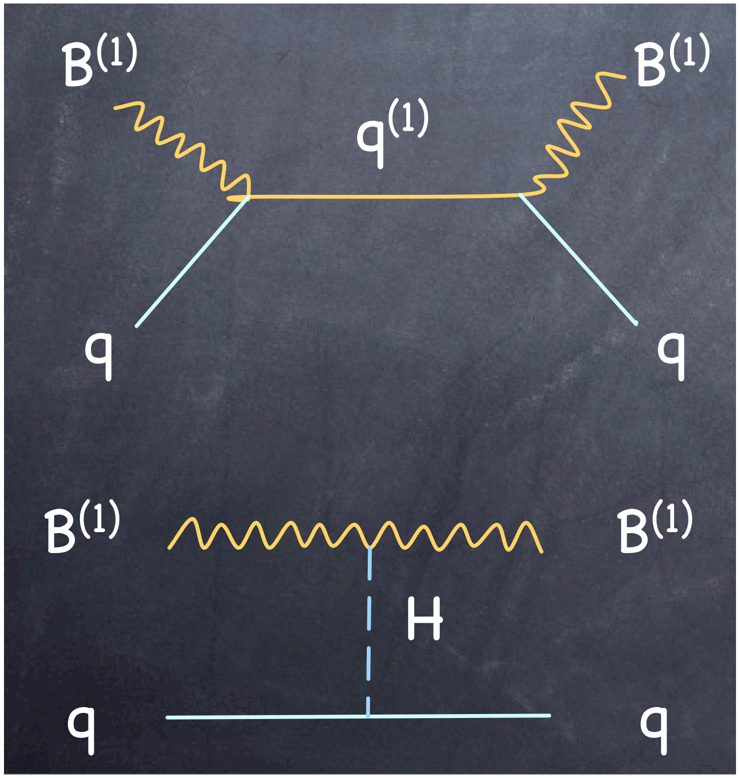
χ^2 of fit to BR(b→sγ), muon g-2, and relic density (dominated by relic density: avoid overclosure)



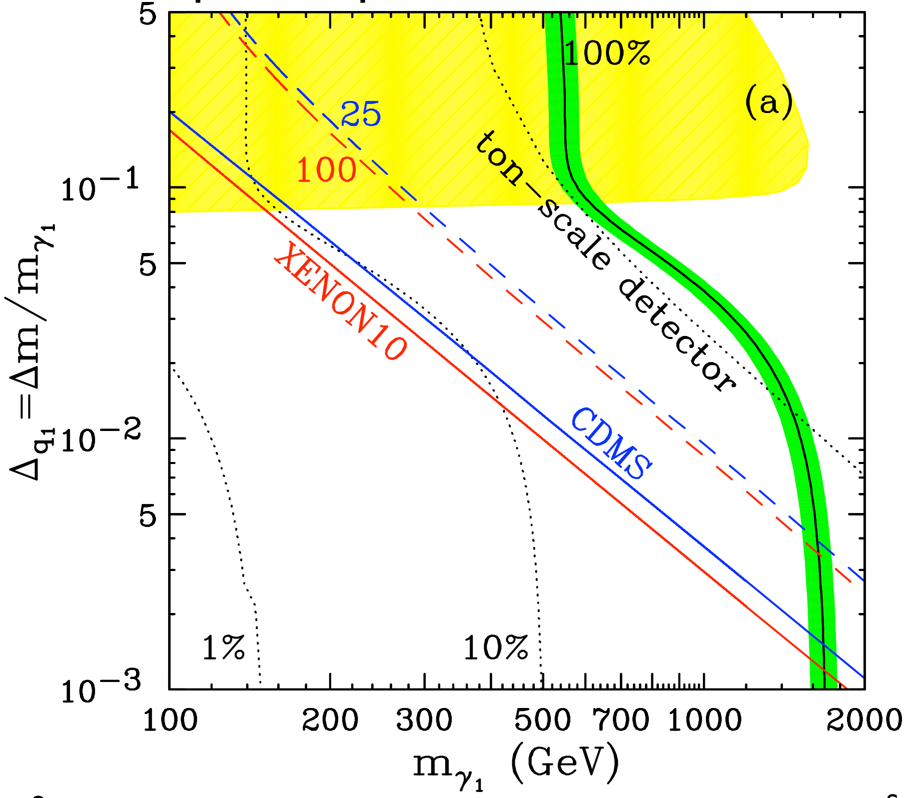
Baer et al, in DMSAG report

Universal Extra Dimensions WIMPs

- Kaluza-Klein tower of partners due to curled-up extra dimension of radius R
  - n = quantum number for extra dim., $m_n^2 \sim n^2/R^2$, conserved due to mom. cons. in extra dim.
  - compactification of extra dim reduces mom. cons. to discrete parity cons.
  - KK parity $P_{KK} = (-1)^n$ implies lightest KK partner ($n = 1$) is stable
- $B^{(1)}$, $n = 1$ partner of B gauge boson, is lightest KK partner in simple cases
- Cross-section on quarks depends on fractional mass difference between $B^{(1)}$ and 1st KK partner of quarks, $q^{(1)}$



spin-independent exclusion limits



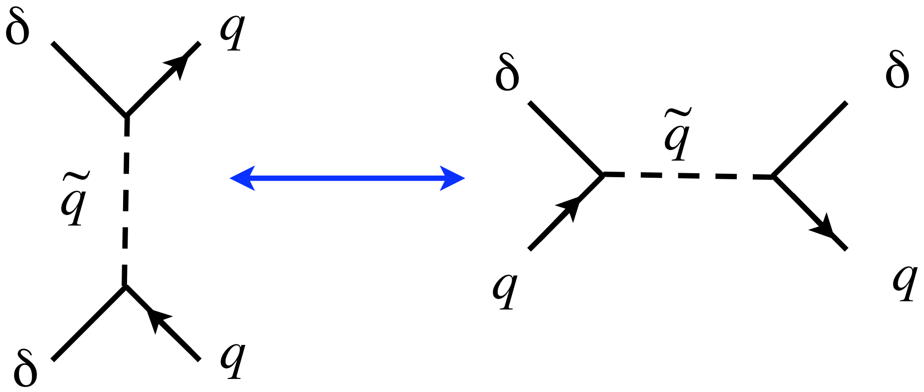
1 extra dim, LKP = $B^{(1)}$

yellow = LHC search

Arrenberg et al (2008)

Direct Detection of WIMPs

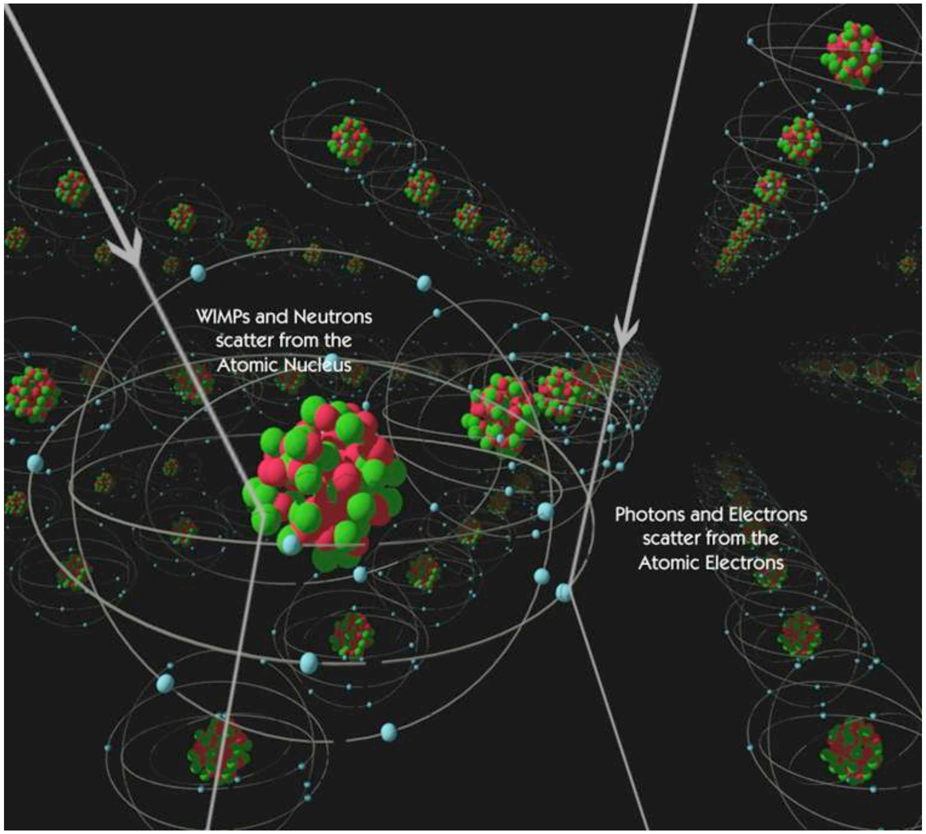
Diagram crossing → detectability?

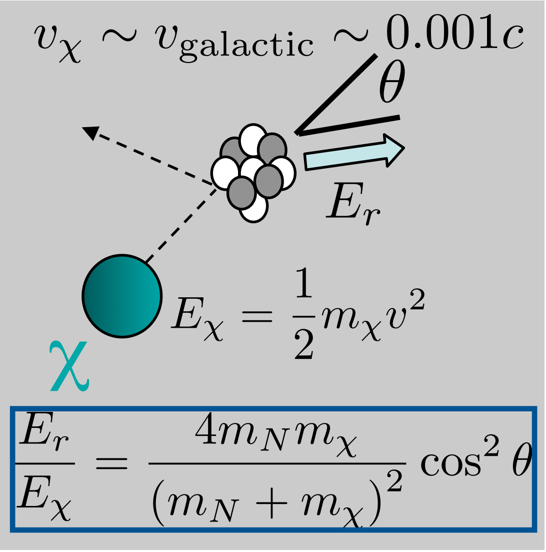


Isothermal halo: v_0=270 km/s, v_{esc}=544 km/s

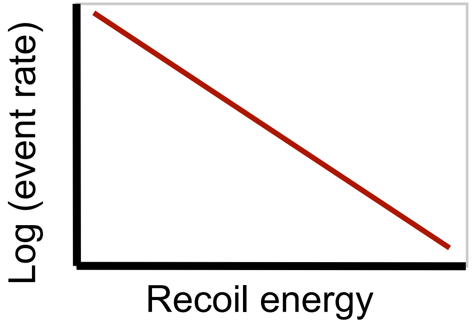
Maxwell-Boltzmann velocity dist'n

s-wave scattering





$$\boxed{\frac{E_r}{E_\chi} = \frac{4 m_N m_\chi}{(m_N + m_\chi)^2} \cos^2\theta}$$



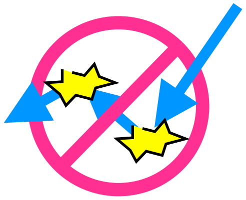
v_{galactic}~10^{-3}c →
coherent A^2 enhancement of scalar (spin-independent) scattering

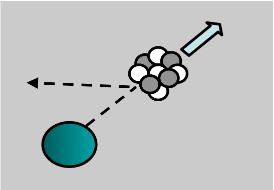
→

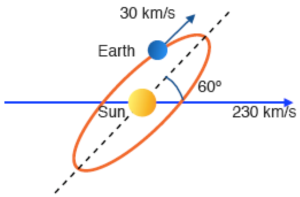
Exponential spectrum of ⟨E⟩ ~ 30 keV nuclear recoils, ≪ 1/kg/day

Direct Detection of WIMPs

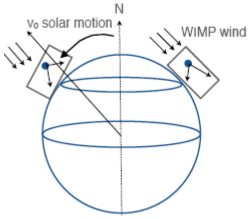
SIGNATURES


No multiplicity


Nuclear recoils



Annual flux modulation



Diurnal direction modulation

EVENT-BY-EVENT

STATISTICAL

Exponential spectrum of ⟨E⟩ ~ 30 keV nuclear recoils, ≪ 1/kg/day

Challenges

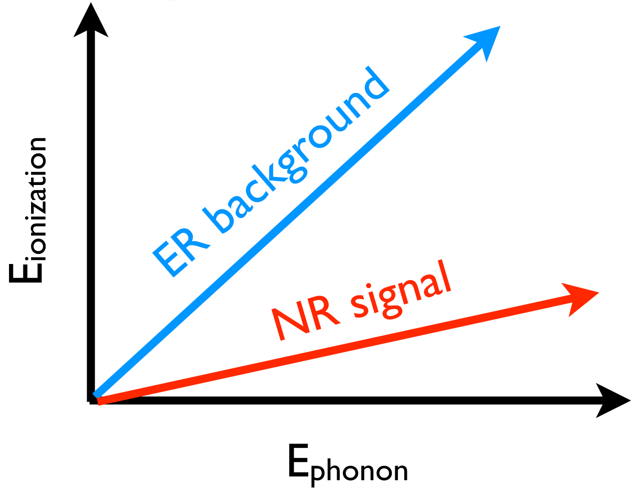
Very **low energy** thresholds (~10 keV)

Large **exposures** (large active mass, long-term stability)

Stringent **background control** (cosmogenic, radioactive)
Cleanliness
Shielding (passive, active, deep site)
Discrimination power

The Cryogenic Dark Matter Search (CDMS): The Big Picture

Use shielding and nuclear recoil discrimination in low temperature semiconducting detectors to obtain sensitivity to WIMPs while expecting < 1 misidentified background event

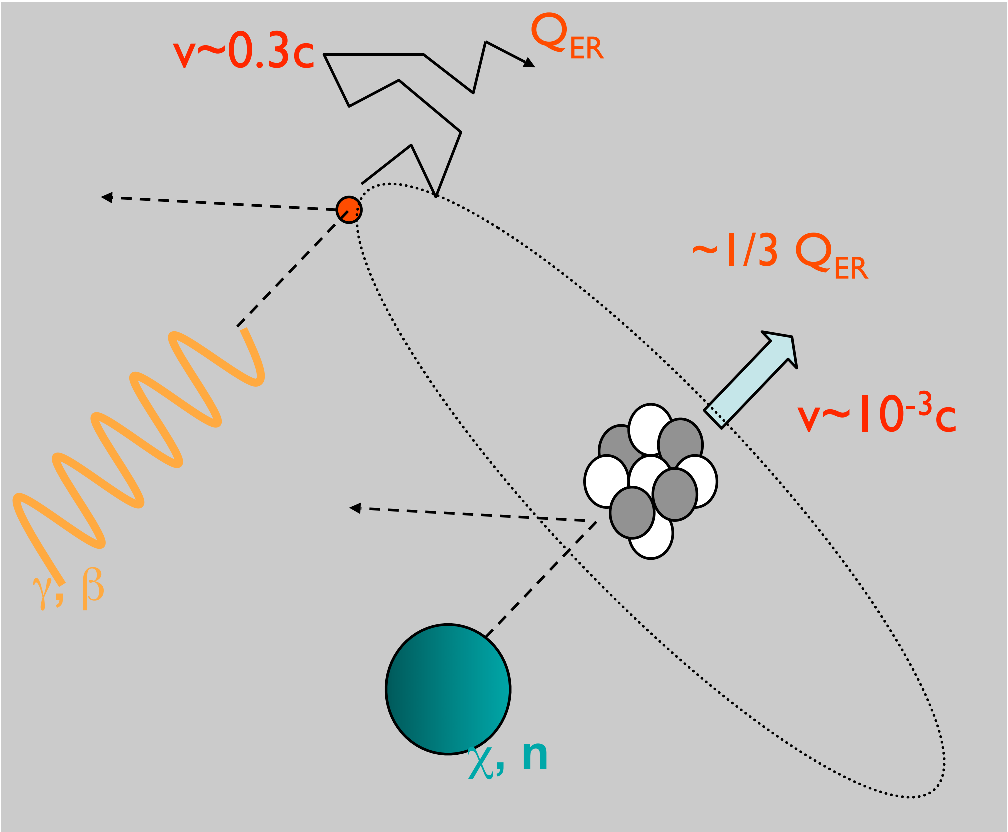


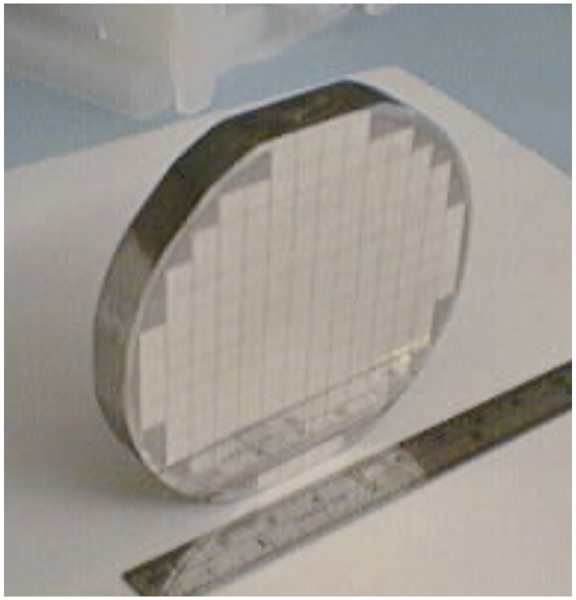
Shielding

- passive: Pb photon shielding, polyethylene neutron moderator, depth
- active: muon veto

Discrimination

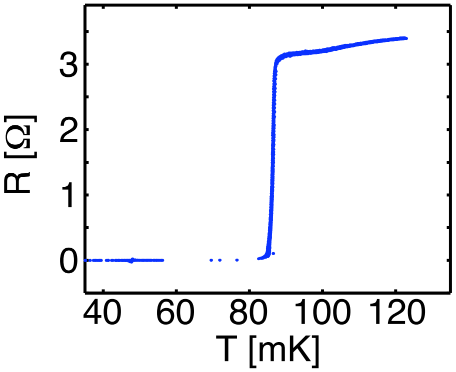
- Phonons
  - energy measurement
  - pulse shape
- Ionization
  - dE/dx discrimination



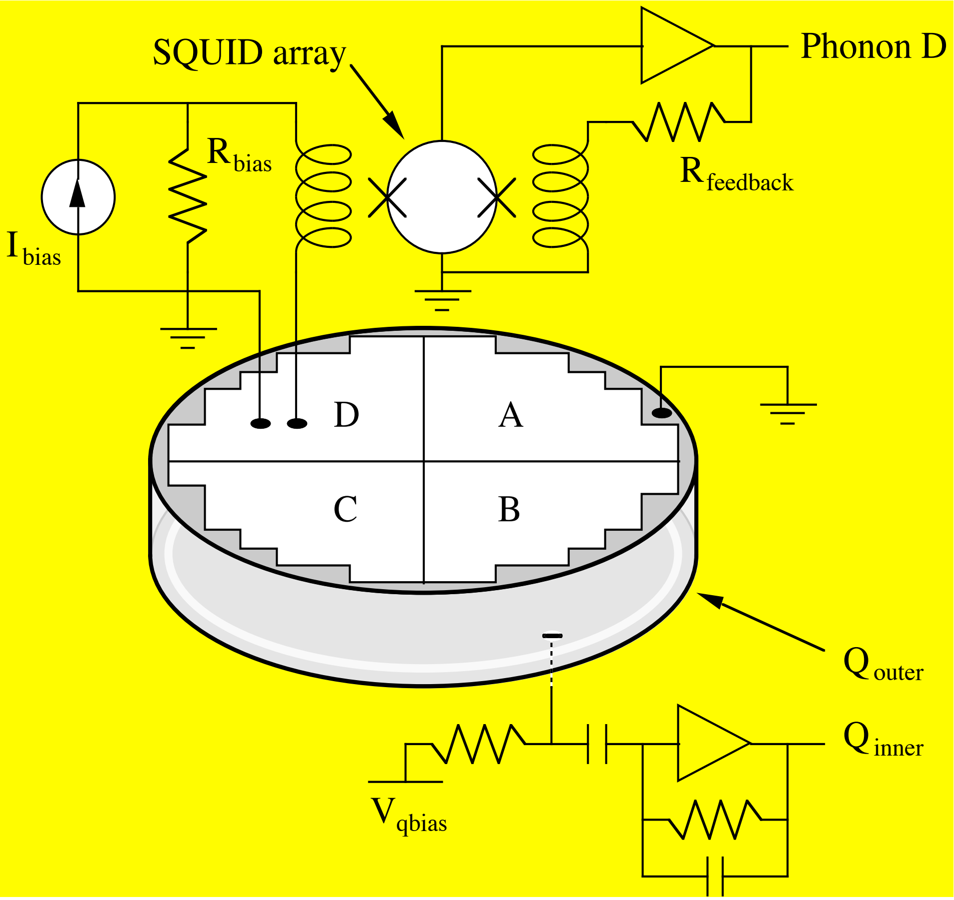


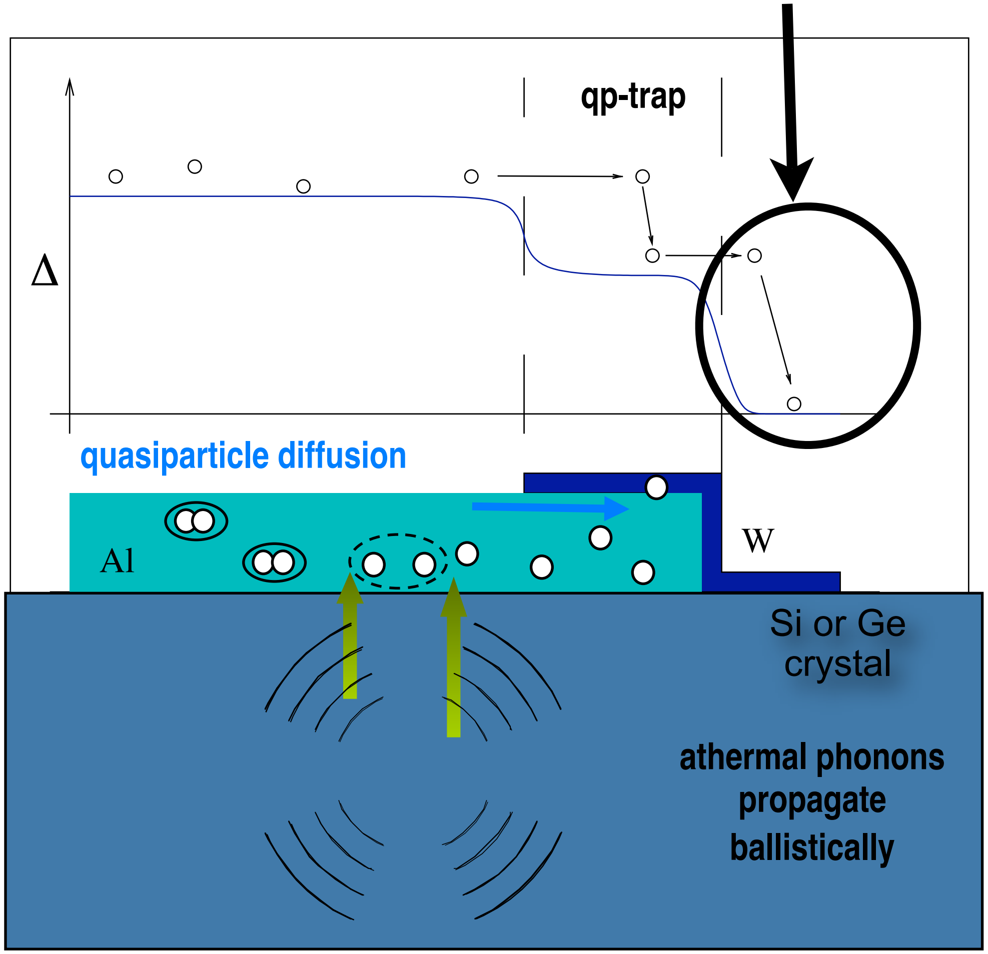
CDMS ZIP Detectors

TES = transition edge sensor



Z-sensitive **I**onization- and **P**honon-mediated detectors: Phonon signal measured using photolithographed superconducting phonon absorbers and transition-edge sensors.





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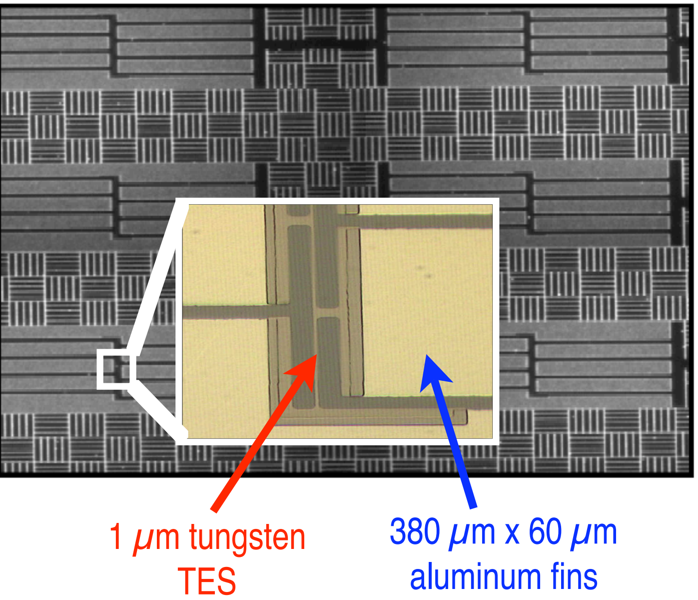

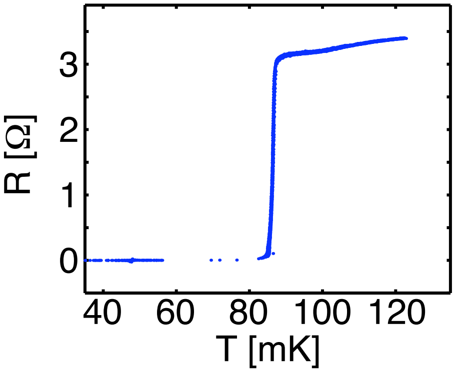

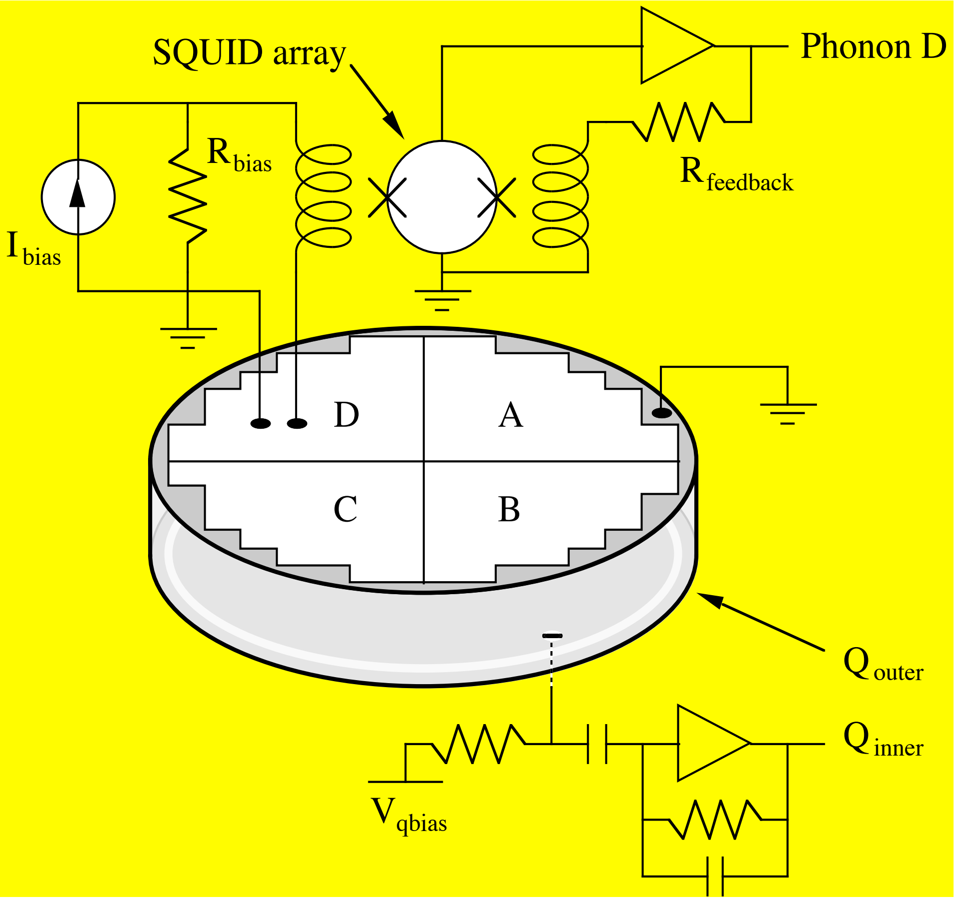

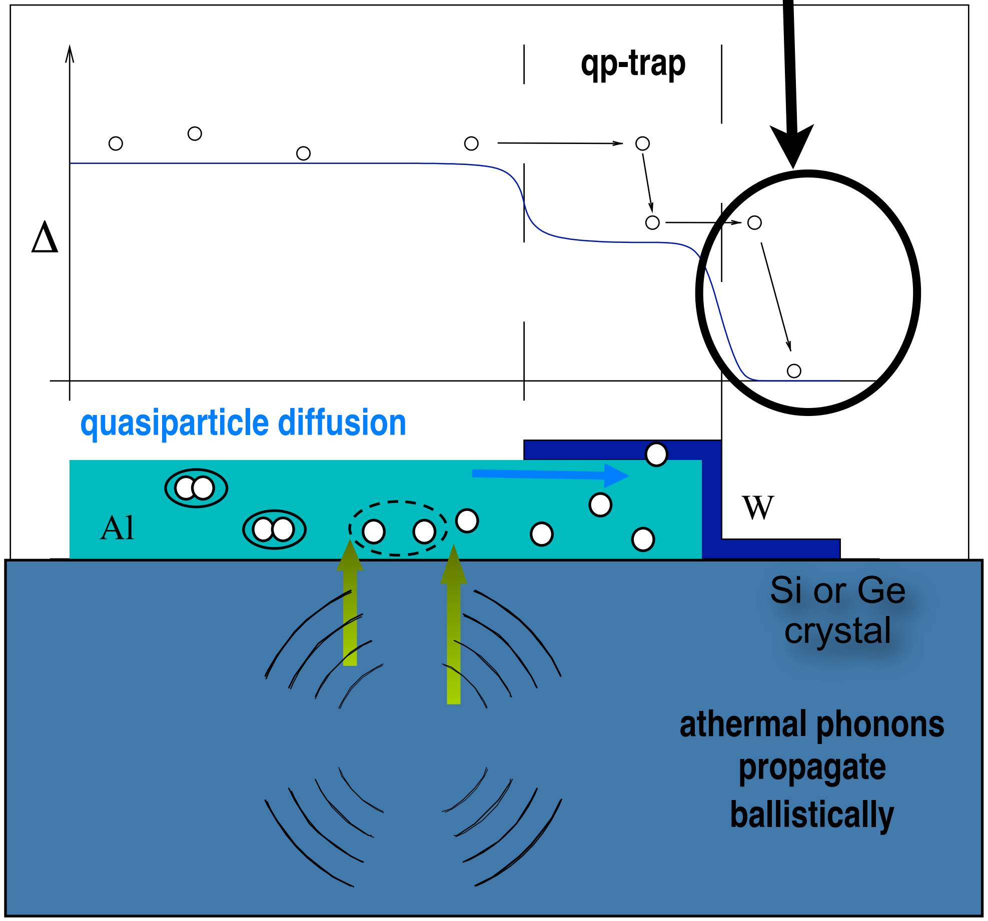

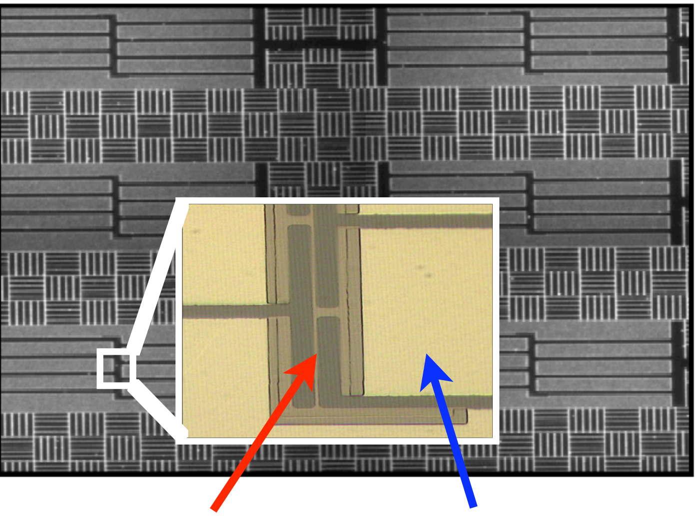

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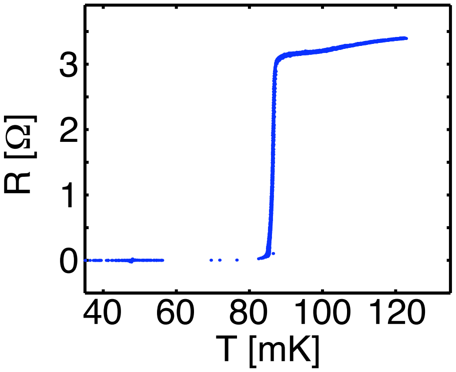
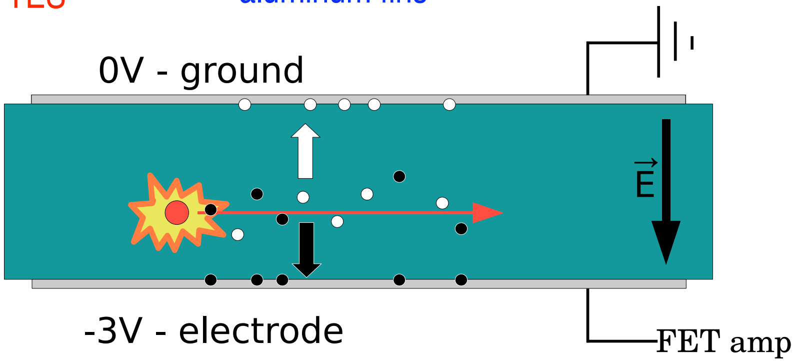
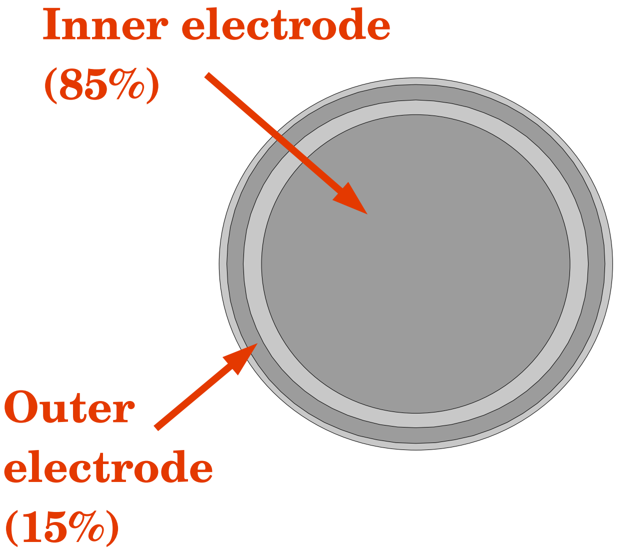
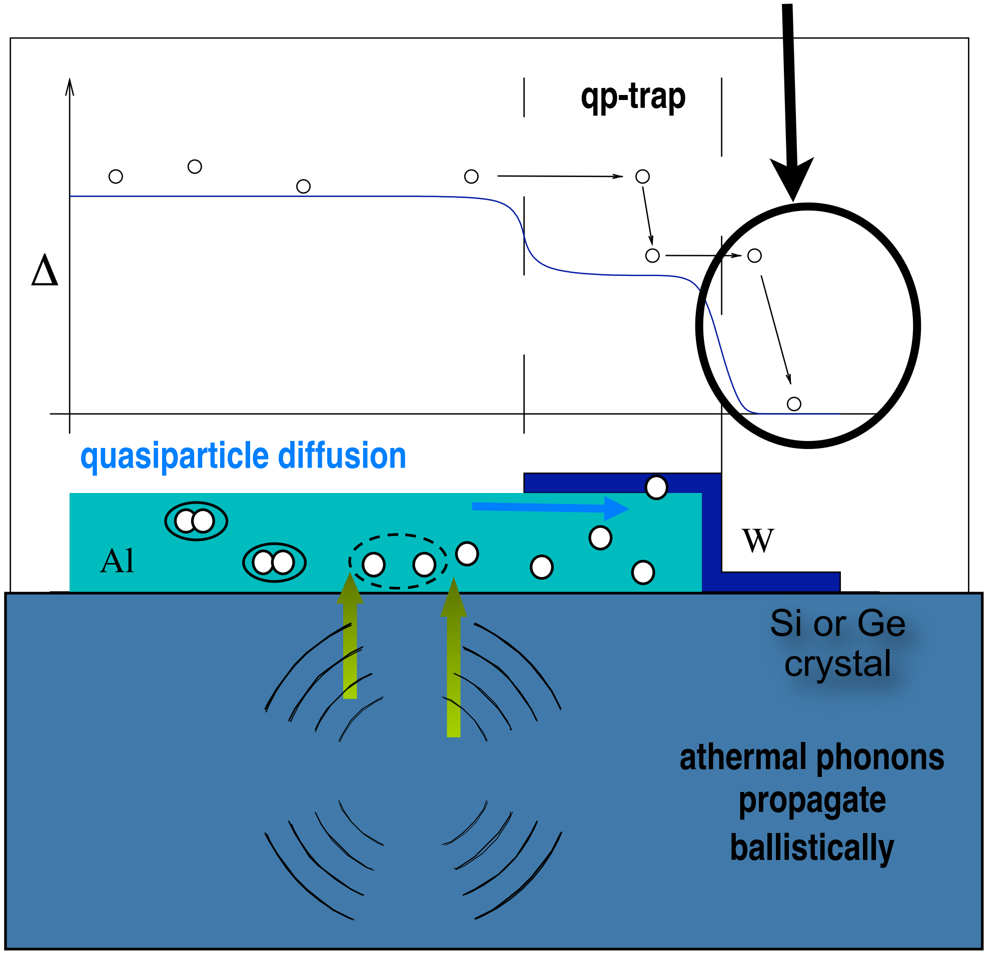
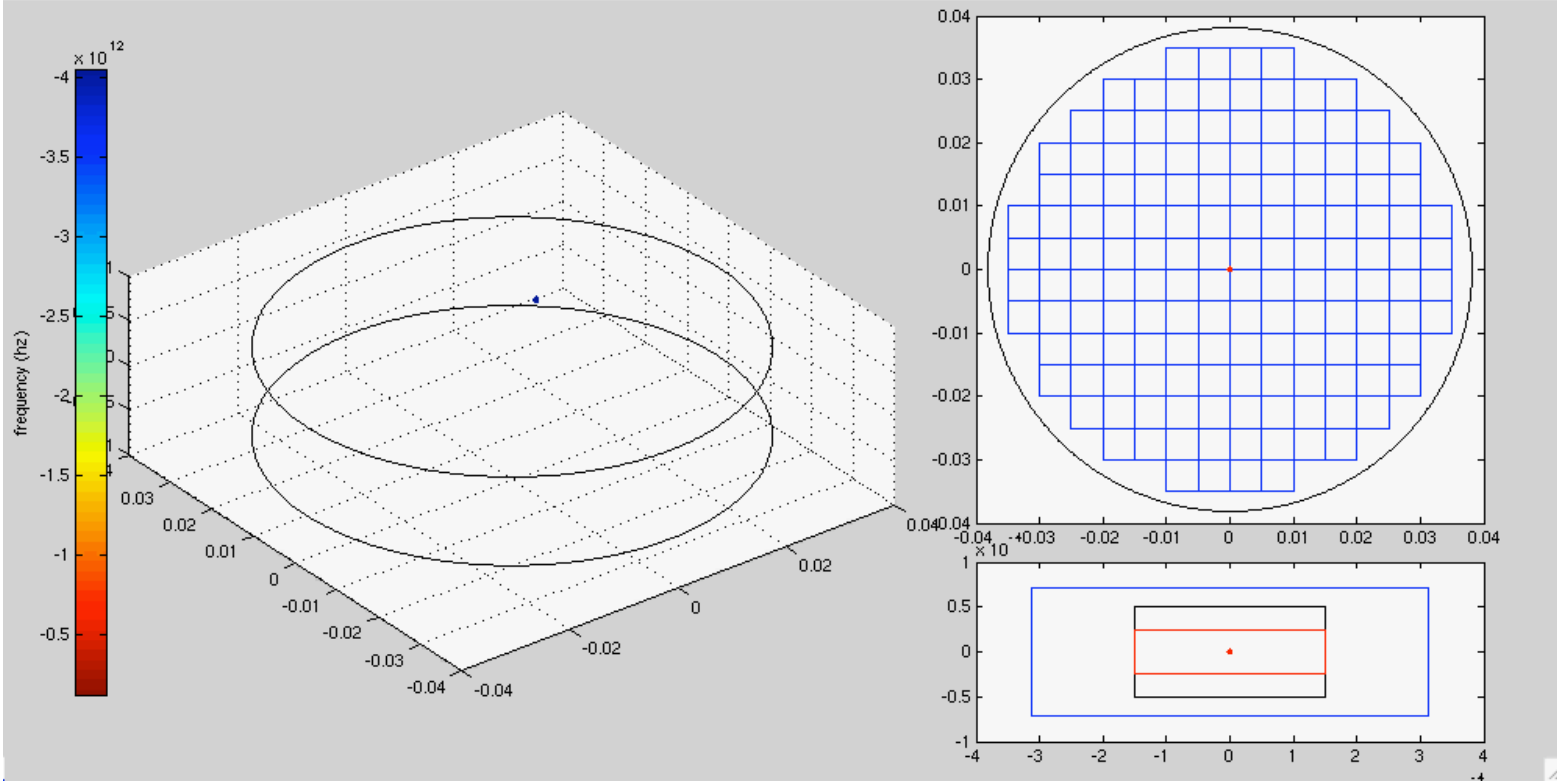








ZIP Detectors

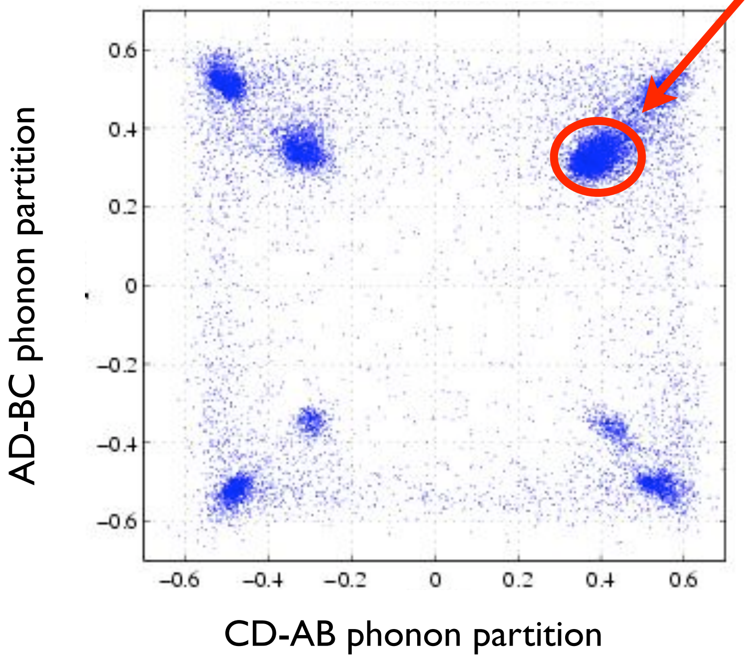


Position Reconstruction

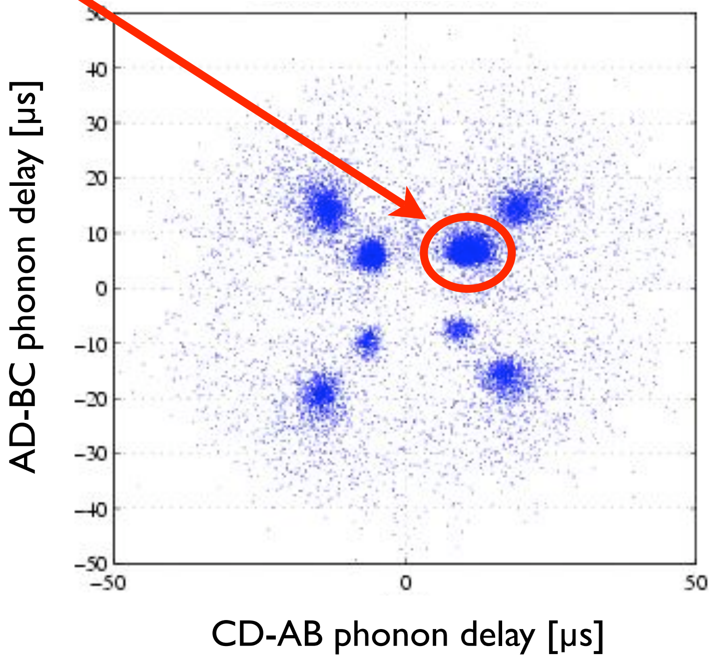
Crucial to
correct for position dependence
of athermal phonon signals

Collimated ^{109}Cd sources (β, 22 keV γ)

Phonon Energy Partition

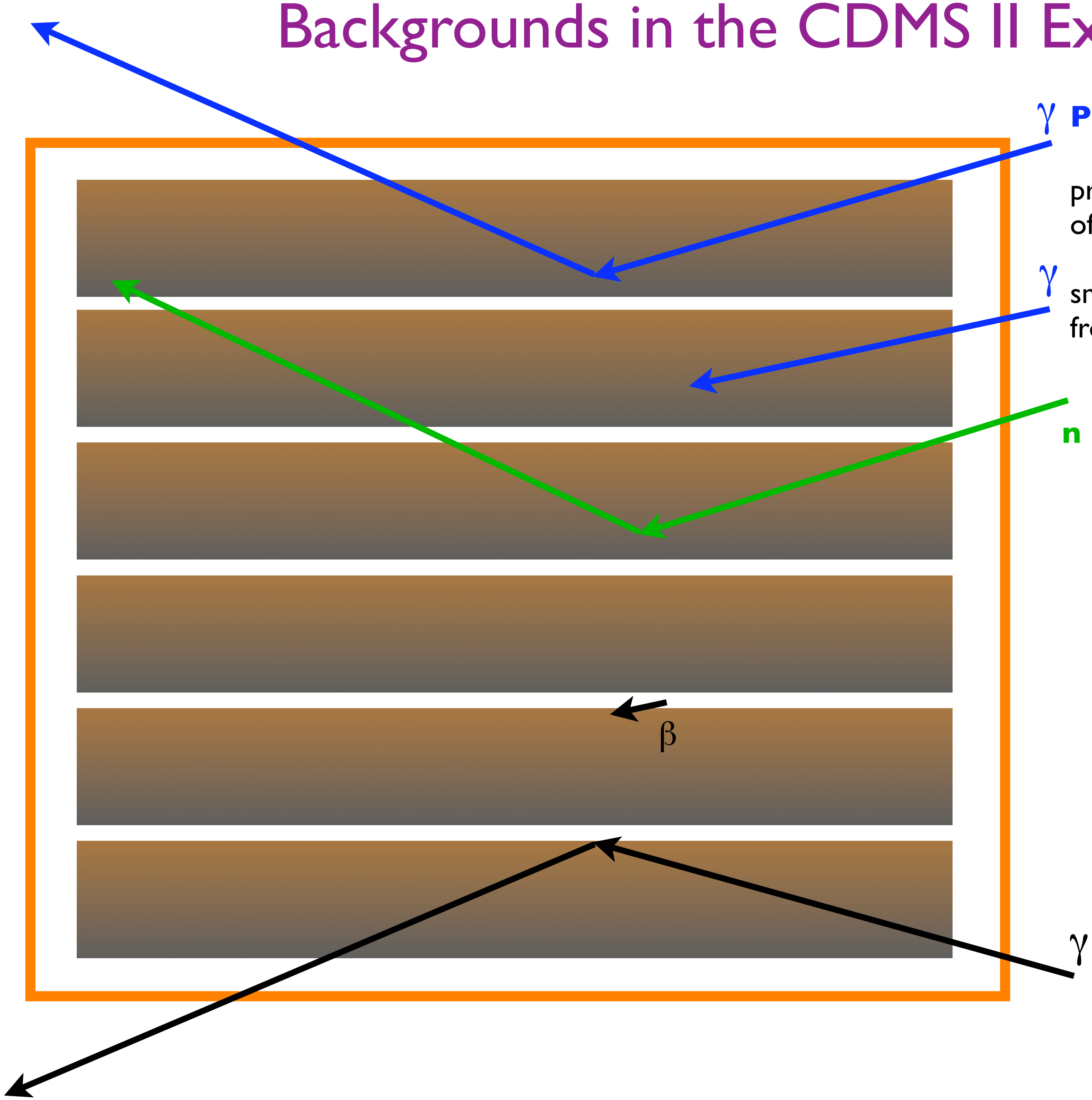


Phonon Timing



Data from UC Berkeley calibration of T2Z5, née G31
V. Mandic et al., NIM A **520**, 171 (2004)

Backgrounds in the CDMS II Experiment



Photons (γ)

primarily Compton scattering
of broad spectrum up to 2.5 MeV

small amount of photoelectric effect
from low energy gammas

Neutrons (n)

radiogenic: arising from fission and (α,n) reactions in surrounding materials (cryostat, shield, cavern)

cosmogenic: created by spallation of nuclei in surround materials by high-energy cosmic ray muons.

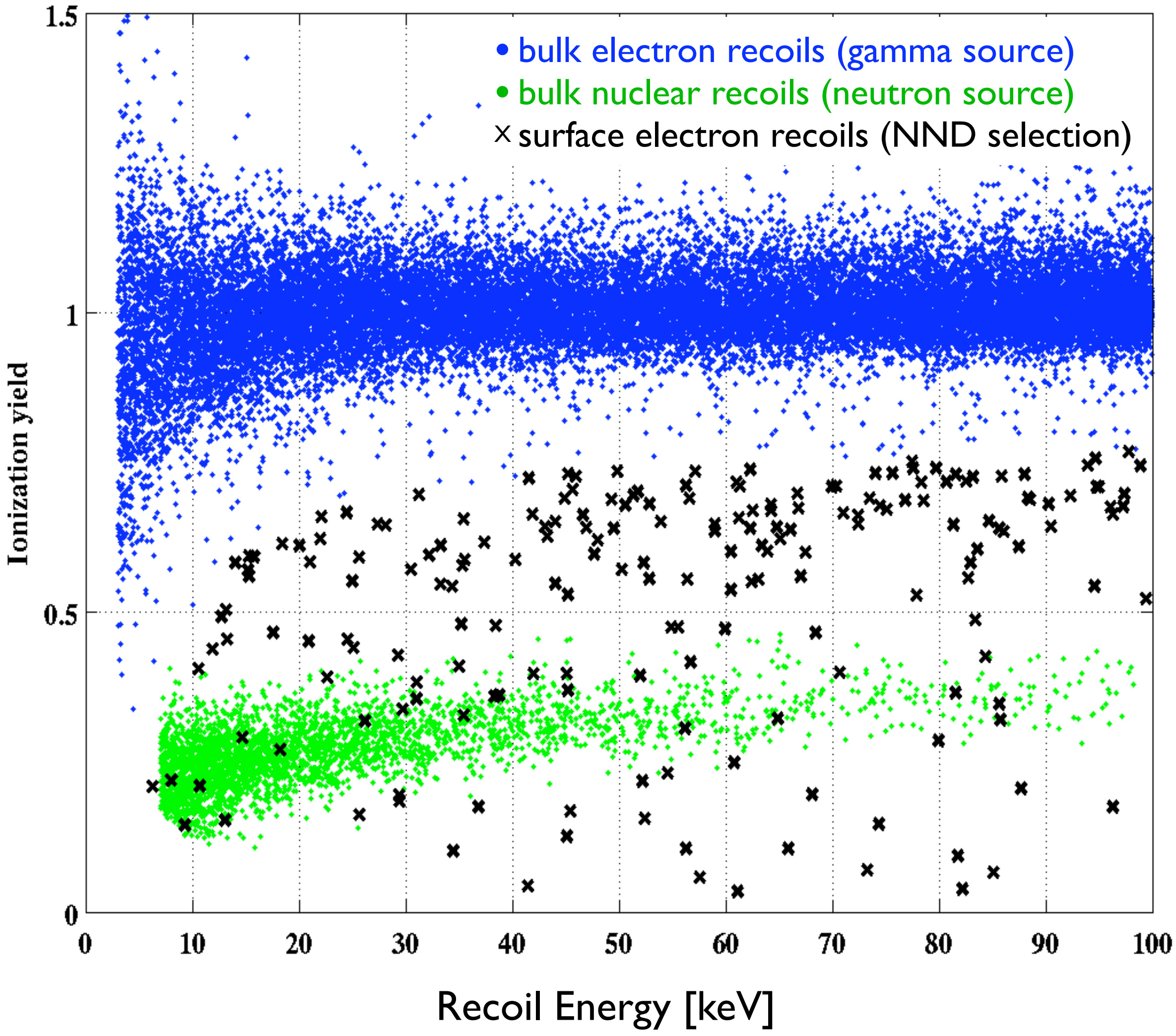
Surface events (“β”)

radiogenic: electrons/photons emitted in low-energy beta decays of ^{210}Pb or other surface contaminants

photon-induced: interactions of photons or photo-ejected electrons in dead layer

Nuclear Recoil Discrimination in CDMS II

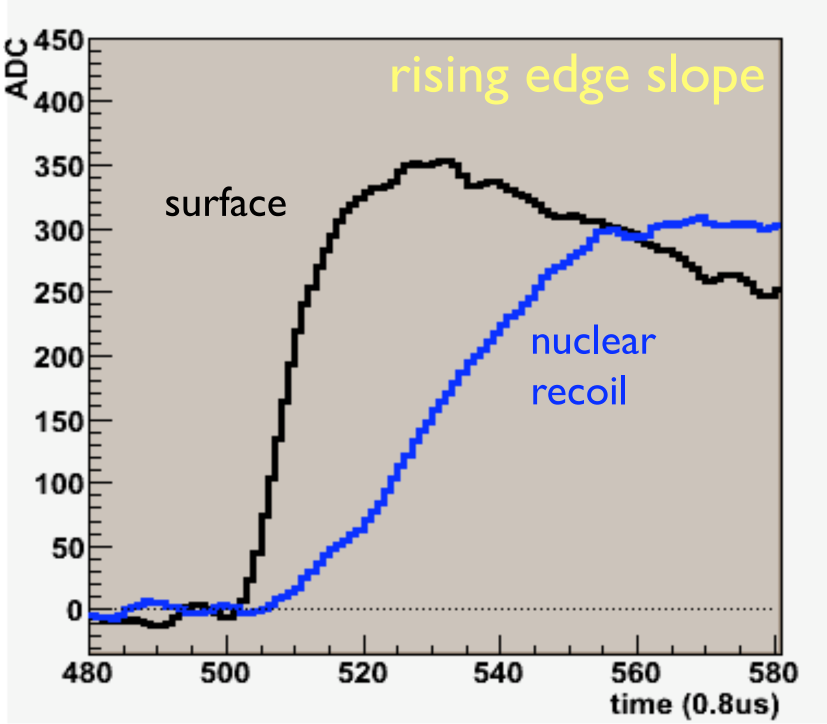
- Recoil energy
  - Phonon (acoustic vibrations, heat) measurements give full recoil energy
- Ionization yield
  - ionization/recoil energy strongly dependent on type of recoil (Lindhard)
- Excellent yield-based discrimination for photons
  - 2 x 10^{-4} misid
- Ionization dead layer:
  - low-energy electron singles (all surface ER): 0.2 misid
  - 1.2 x 10^{-3} of photons are surface single scatters, 0.2 of those misid'd (⇒ 2 x 10^{-4})
  - also, radiogenic low-energy electrons

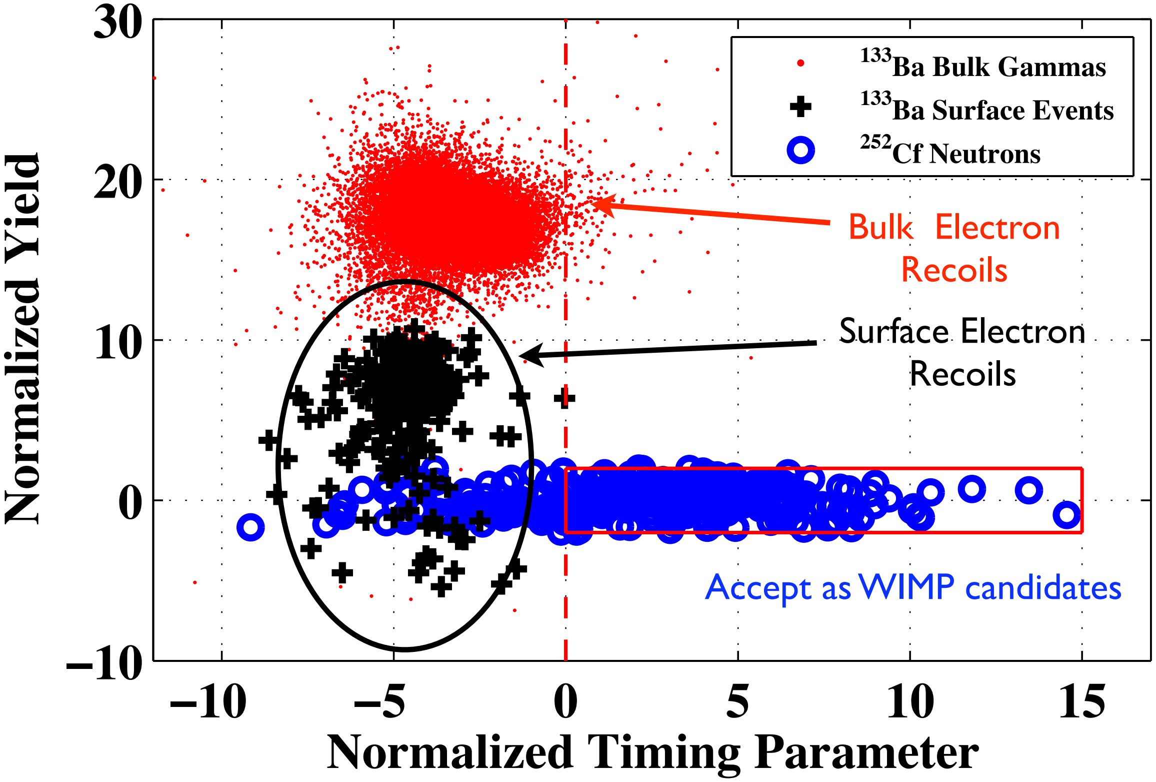


ZIP z Position Sensitivity

- Surface events produce faster phonon pulses (test sample: nearest neighbor low-yield doubles (NNDs)): provides discrimination

1:1 scale: 3 in. x 1 cm, 1 mm separation





Bulk Electron Recoils

Surface Electron Recoils

Accept as WIMP candidates

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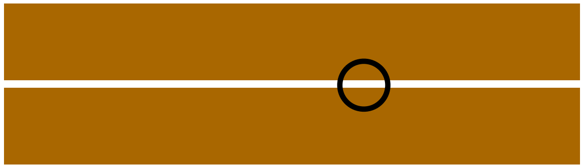

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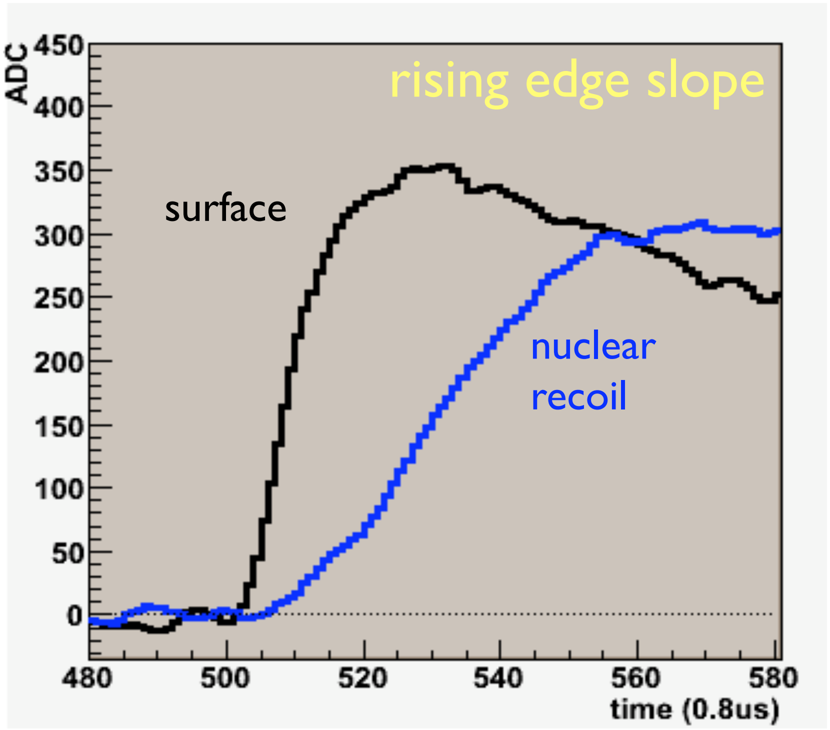

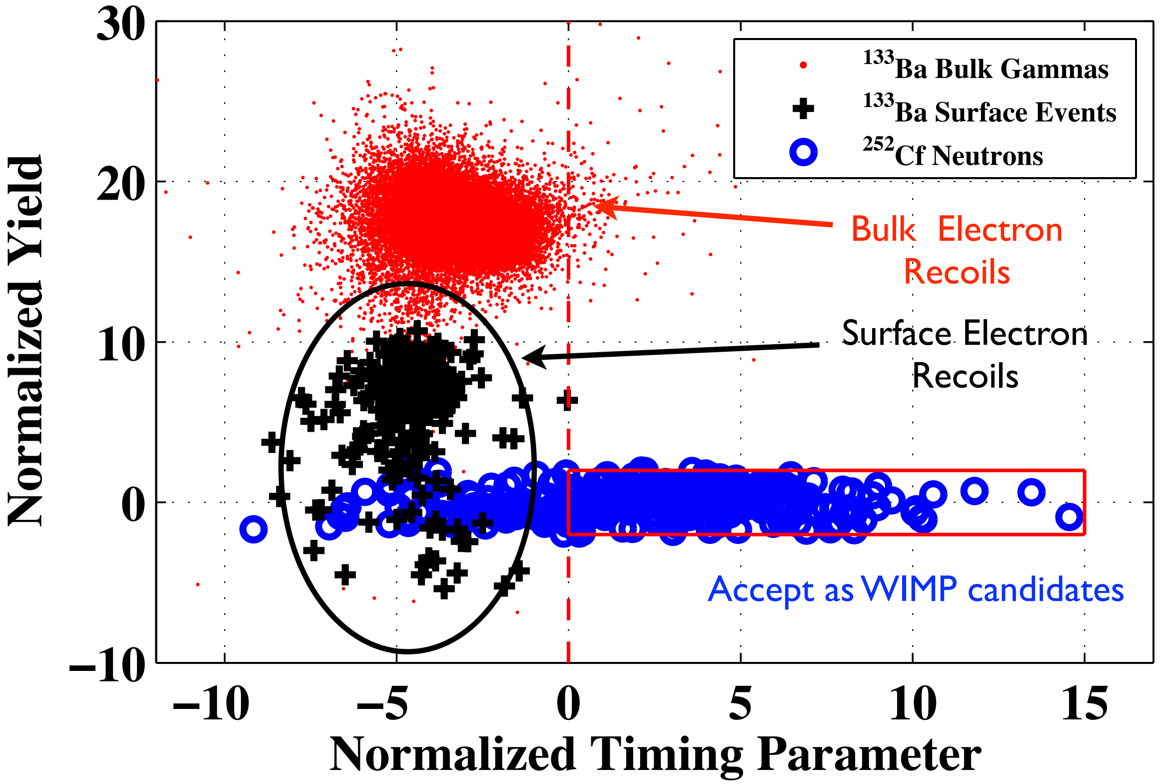

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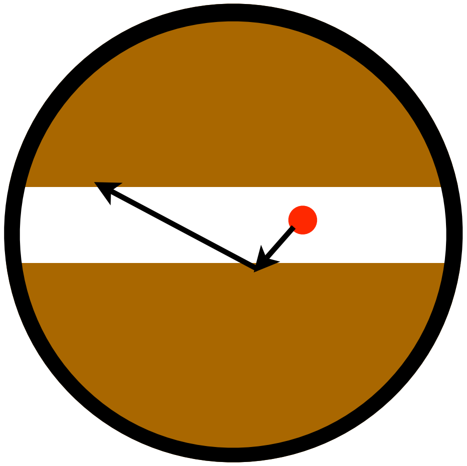
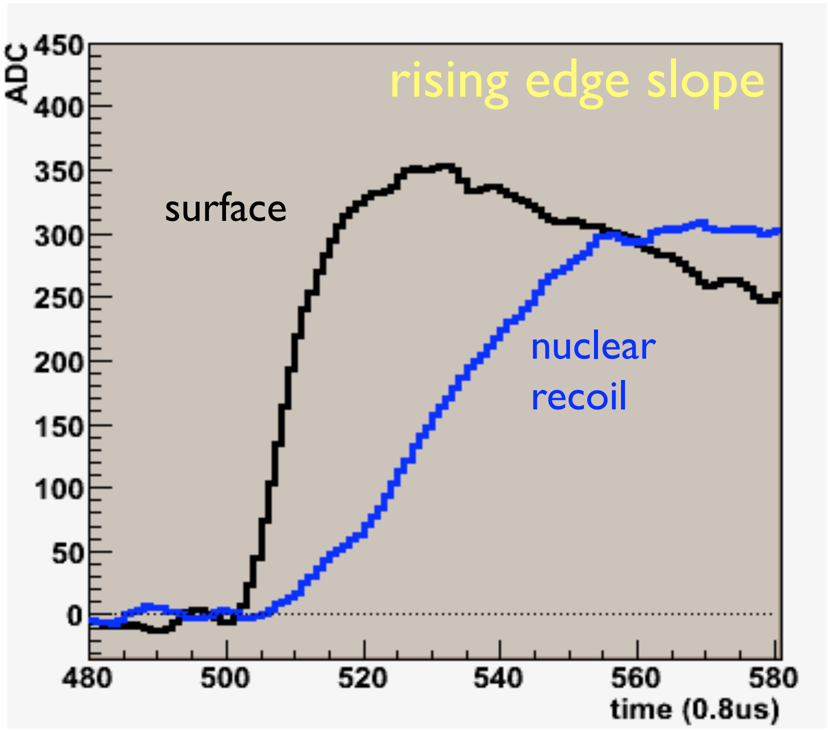
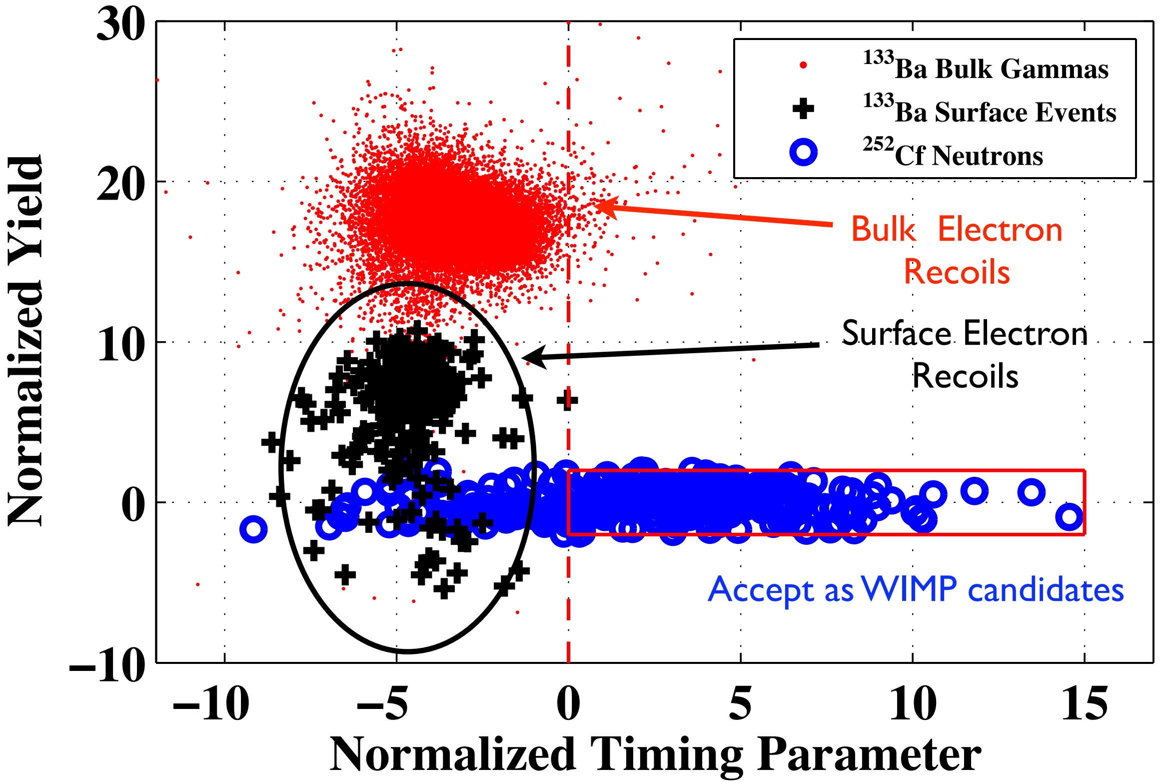
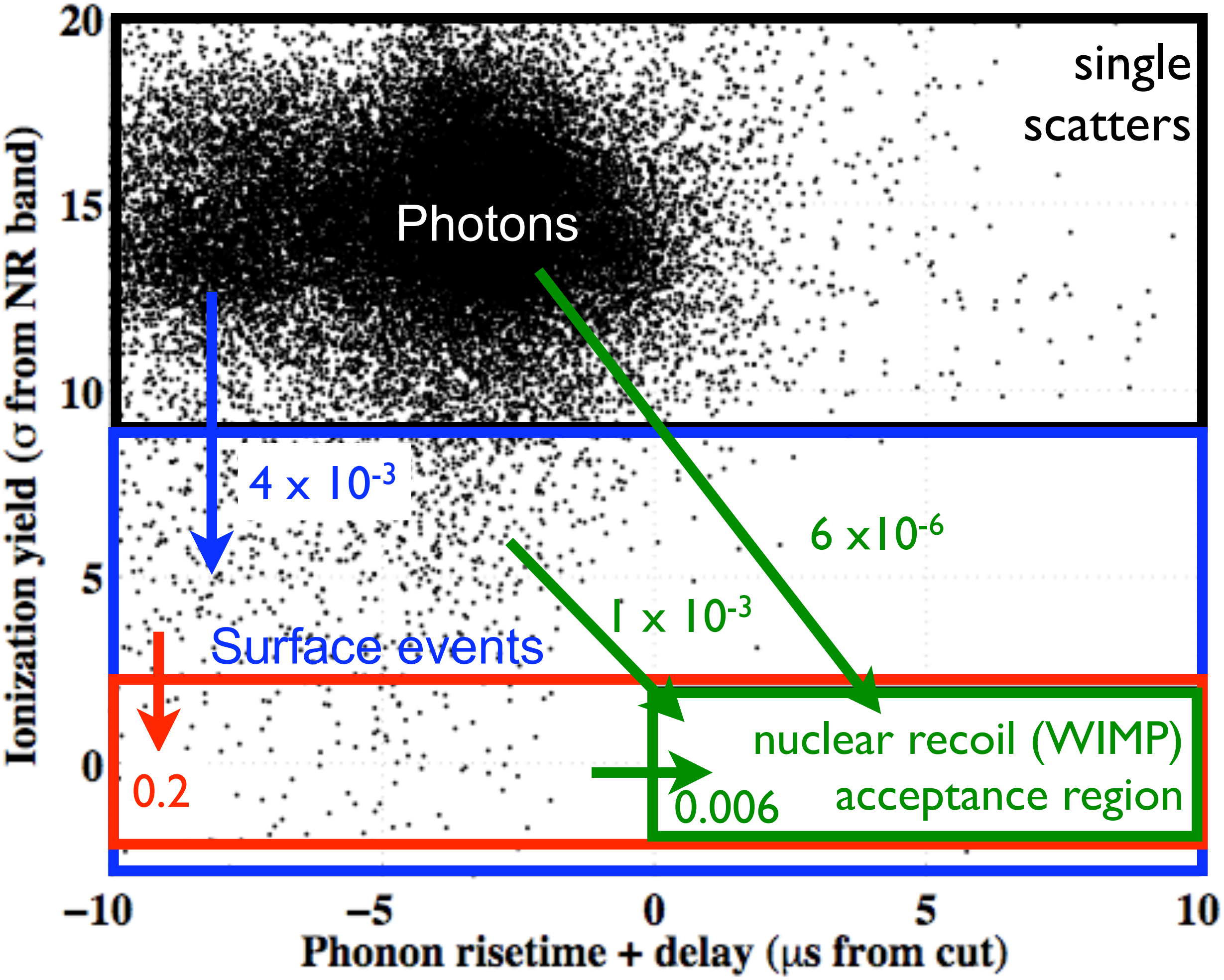






CDMS II Background Discrimination

- Photon rejection
  - Bulk photon rate (bulk ER) = 300/kg/day. Single-scatters = 90/kg/day
  - Single-scatter surface ERs = 0.3/kg/day
  - Surface ER singles/ bulk ER singles = 4 x 10^{-3}
  - Surface ER singles misid'd as nuclear recoils (NRs) /surface ER singles = 0.2 (ionization dead layer)
  - Phonon timing rejects surface events: 0.006 misid. prob.
  - Overall misid probability: 2 x 10^{-6} for bulk ER, 6 x 10^{-6} for single-scatter bulk ER



- Beta rejection
  - Comparable single-scatter ER rate of low-energy beta emitters (mainly ^{210}Pb)
  - 0.2 misid by yield and 0.006 misid by timing: 1 x 10^{-3} misid probability

The CDMS II/SuperCDMS/GEODM Collaborations

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R. Hennings-Yeomans, M.R. Dragowsky

Fermilab
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L. Hsu, E. Ramberg, J. Yoo

MIT
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University of Florida
T. Saab, D. Balakishiyeva

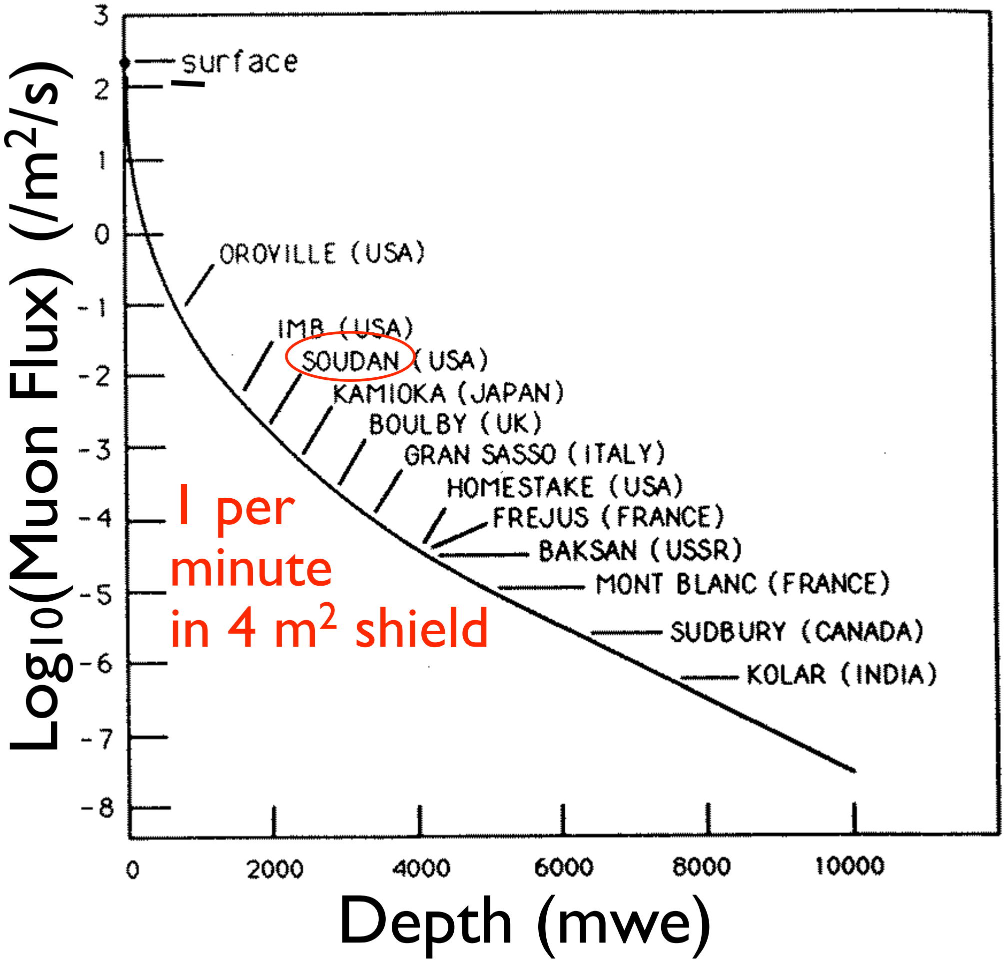
University of Minnesota
P. Cushman, M. Fritts, V. Mandic, X. Qiu, O. Kamaev

University of Zurich
S. Arrenberg, T. Bruch, L. Baudis, M. Tarka

The Happy Analyzers

2002–2008: CDMS II at Soudan

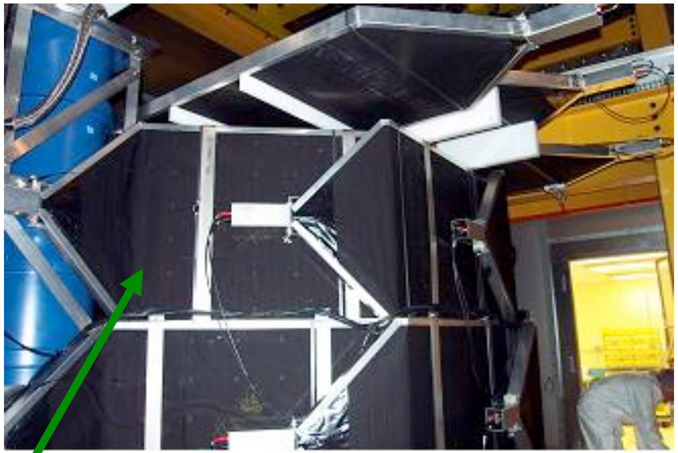
Depth of 2000 meters water equivalent reduces neutron background to ~1 / kg / year; veto down to 0.008 sgl / kg / yr



1 per minute in 4 m^2 shield

LEVEL NO. 27
2341 FEET BELOW THE SURFACE
689 FEET BELOW SEA LEVEL

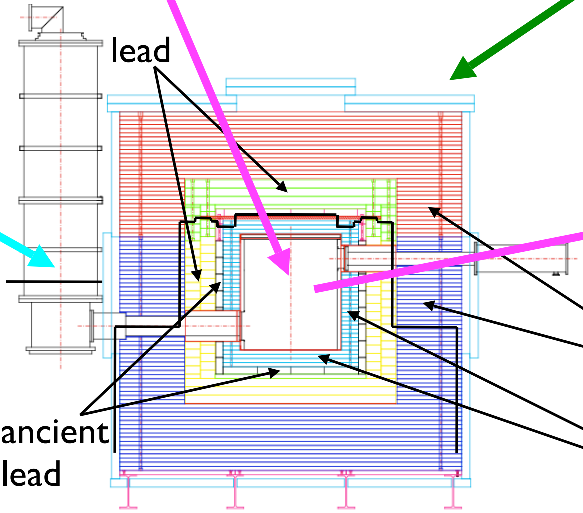
Soudan Installation



Plastic scintillator

Oxford Instruments 400 μW dilution refrigerator

detector cold volume ("icebox")



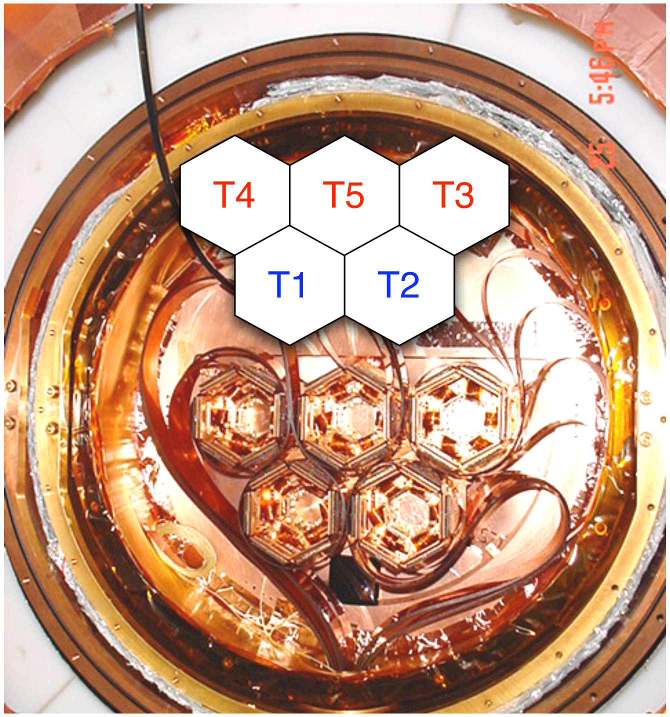
lead

outer polyethylene

ancient lead

inner polyethylene

RF shielded class 10,000 clean room



detectors operate @ 40 mK

CDMS II: The Story So Far

STANFORD TUNNEL

- 6 detectors @ shallow site

PRD **68** (2003) 082002

SOUDAN UNDERGROUND LAB

- 6 detectors, 53 kg-days

PRL **93** (2004) 211301

- 12 detectors, 93 kg-days

PRL **96** (2005) 011302

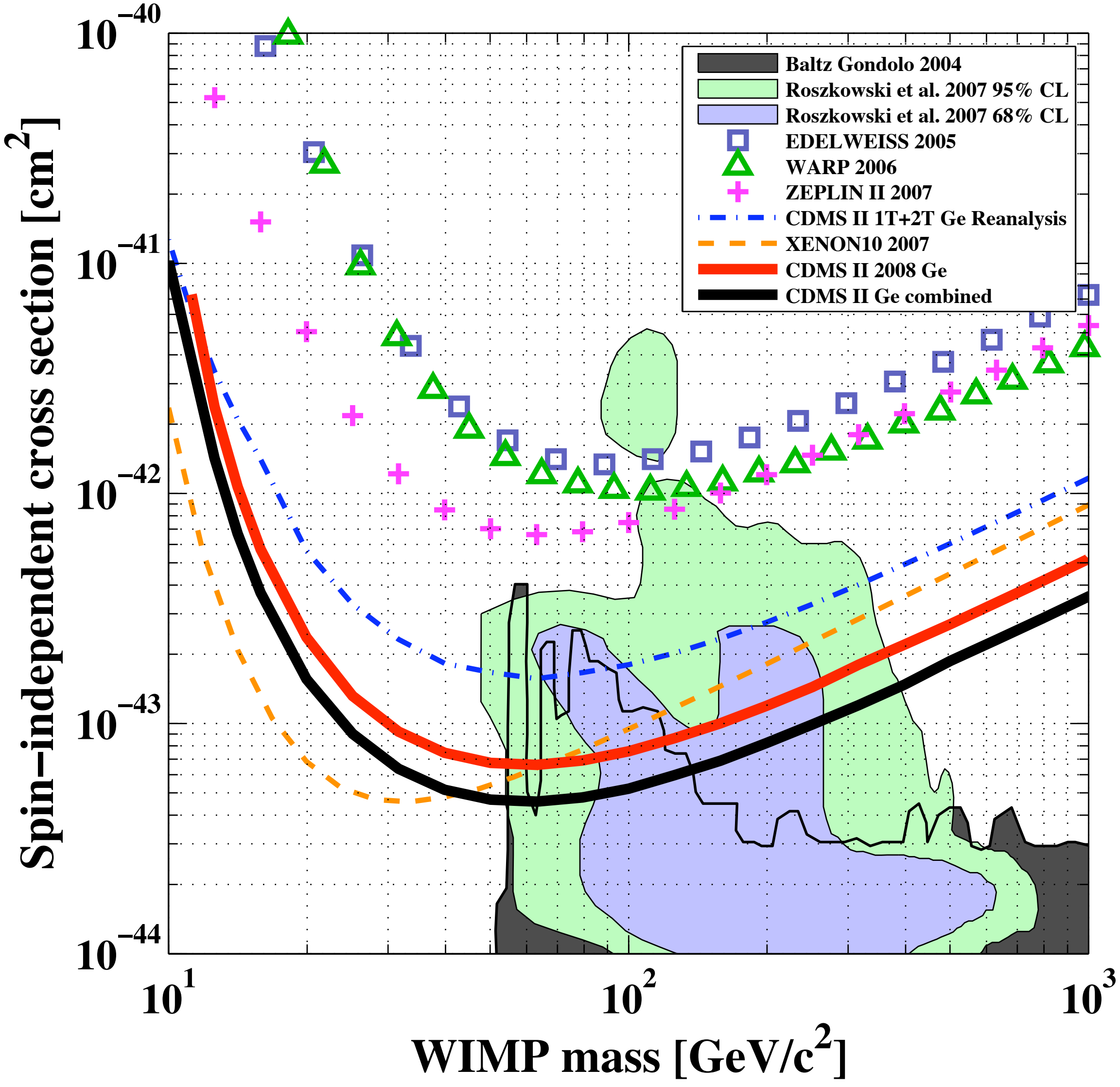
Extensive cryo upgrades...

- 30 detectors, 398 kg-days

PRL **102** (2009) 011301

0 candidates observed

***Combined**: World leading*
SI result above ~ Mz/2



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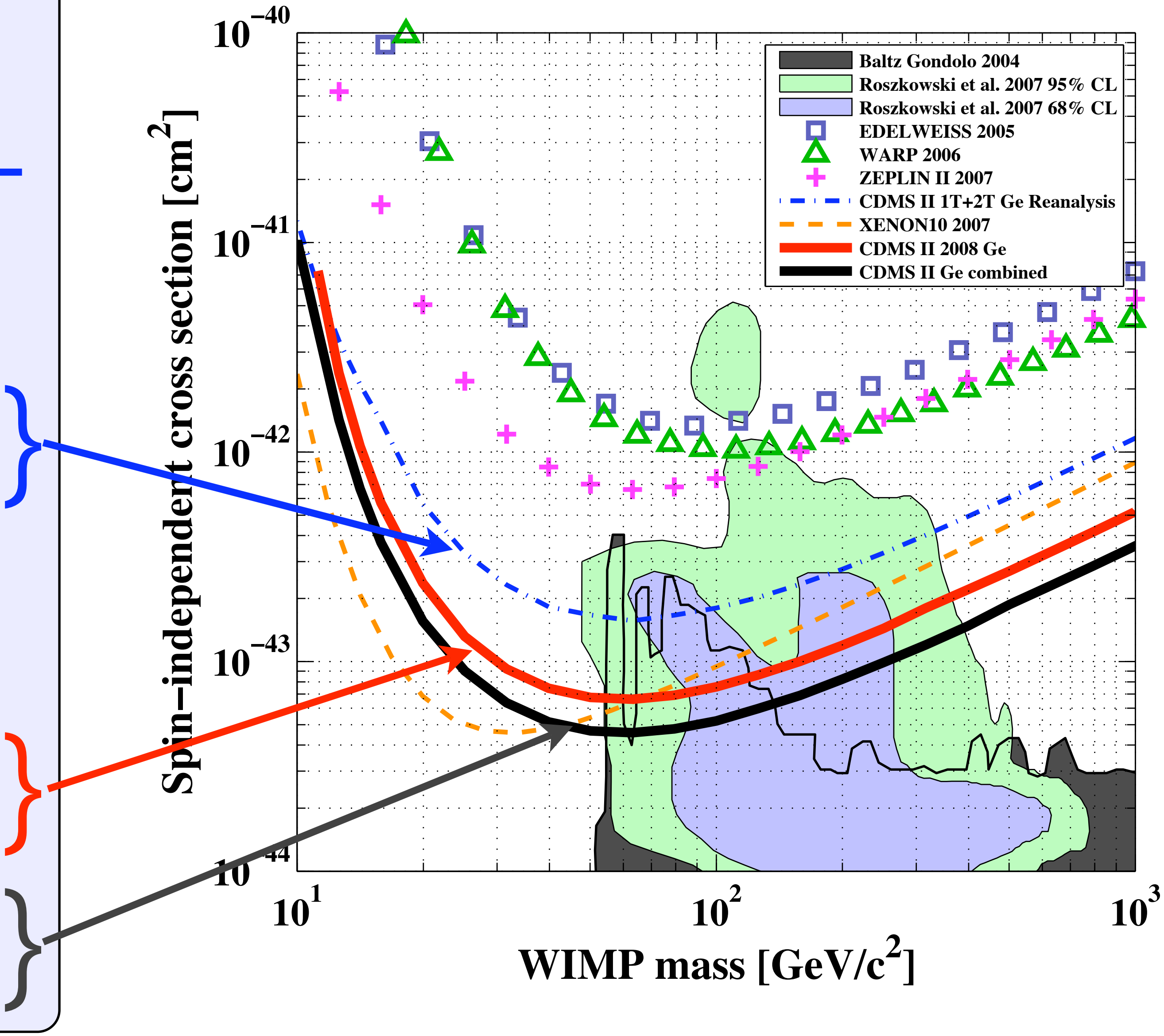

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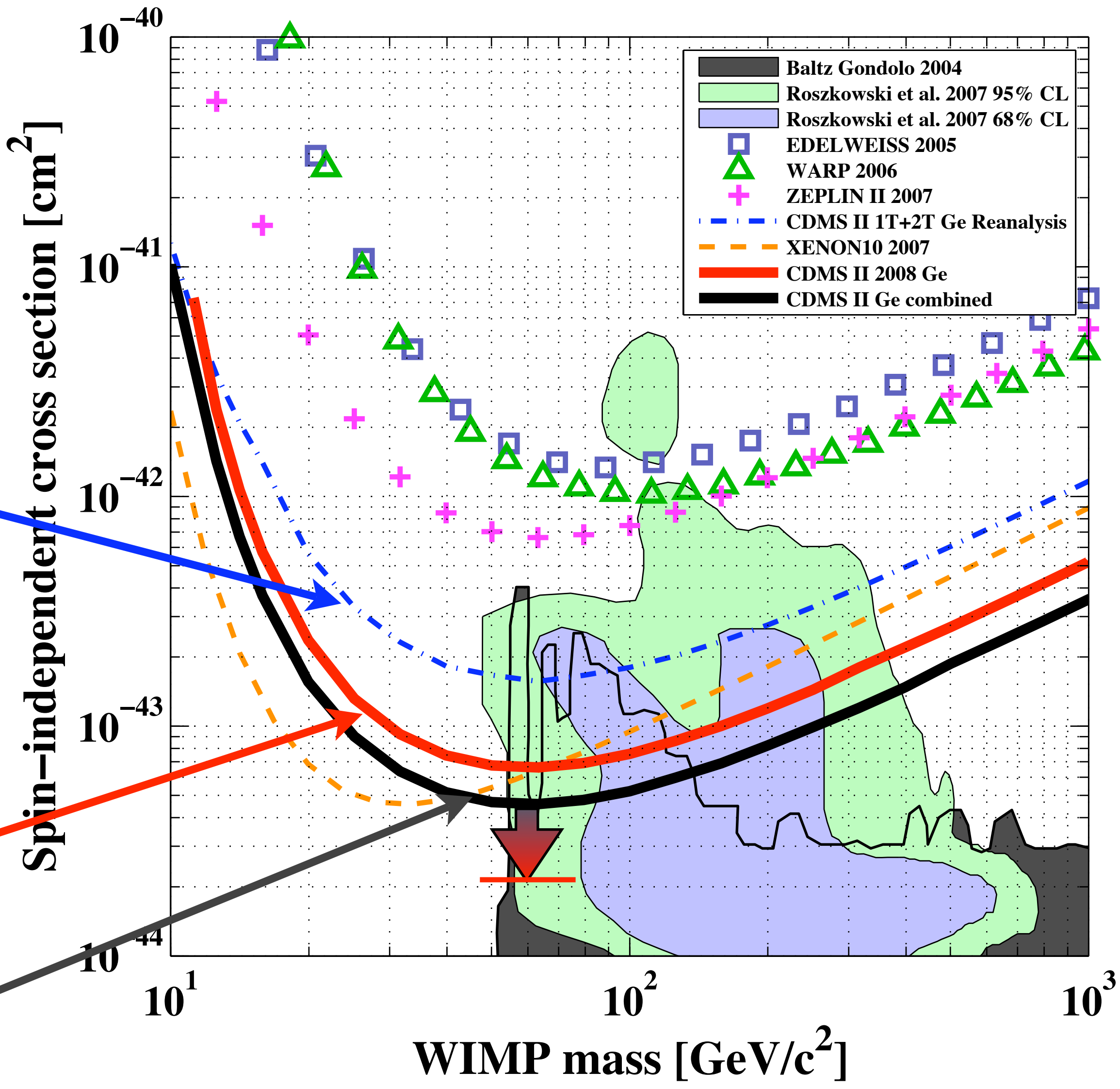
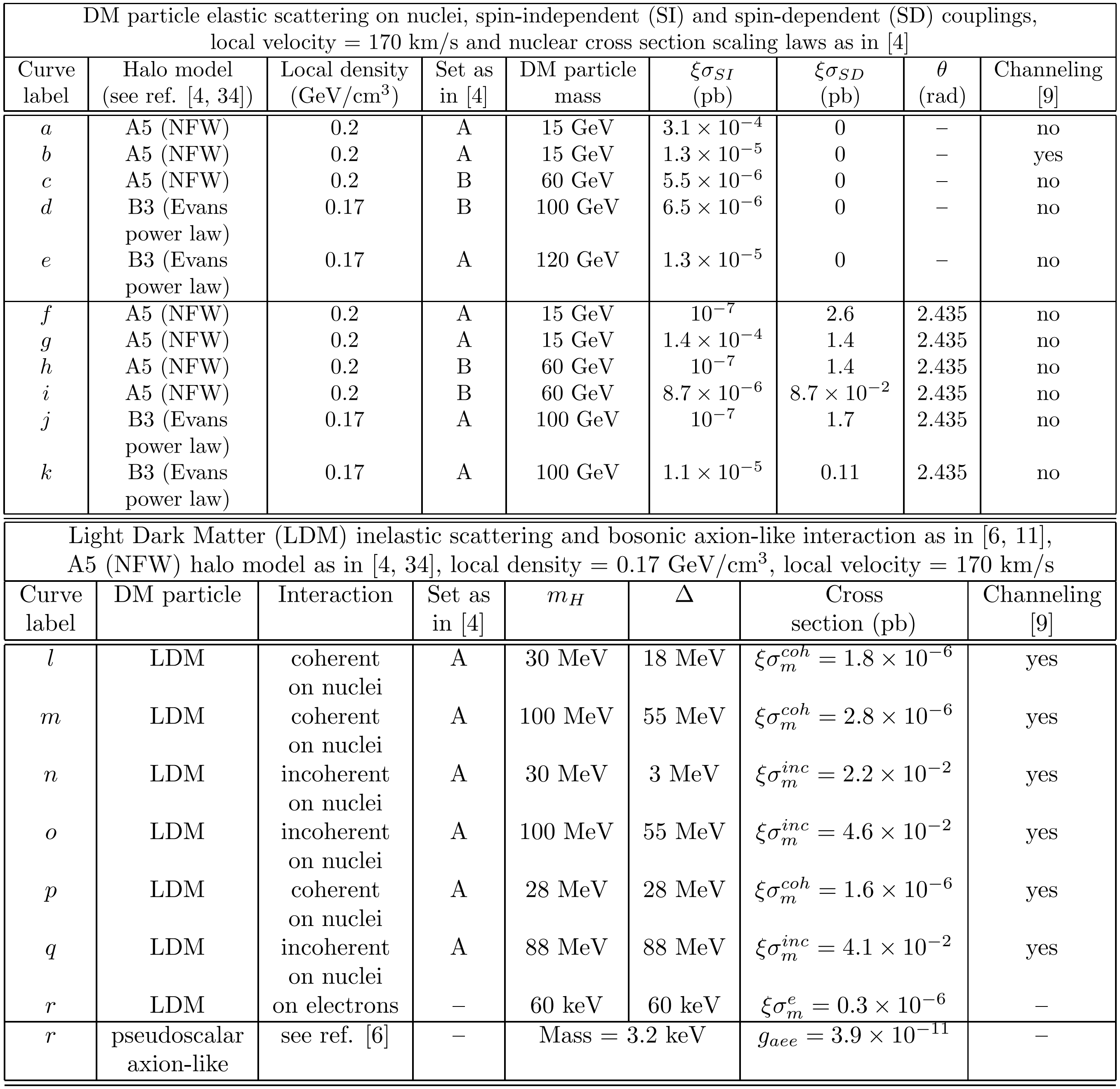


Testing Alternate Interpretations

- Standard WIMP
- Low-mass WIMP w/channeling
- Axion-like
- Other EM conversion
- Inelastic Dark Matter
- Excited Dark Matter



DM particle elastic scattering on nuclei, spin-independent (SI) and spin-dependent (SD) couplings, local velocity = 170 km/s and nuclear cross section scaling laws as in [4]

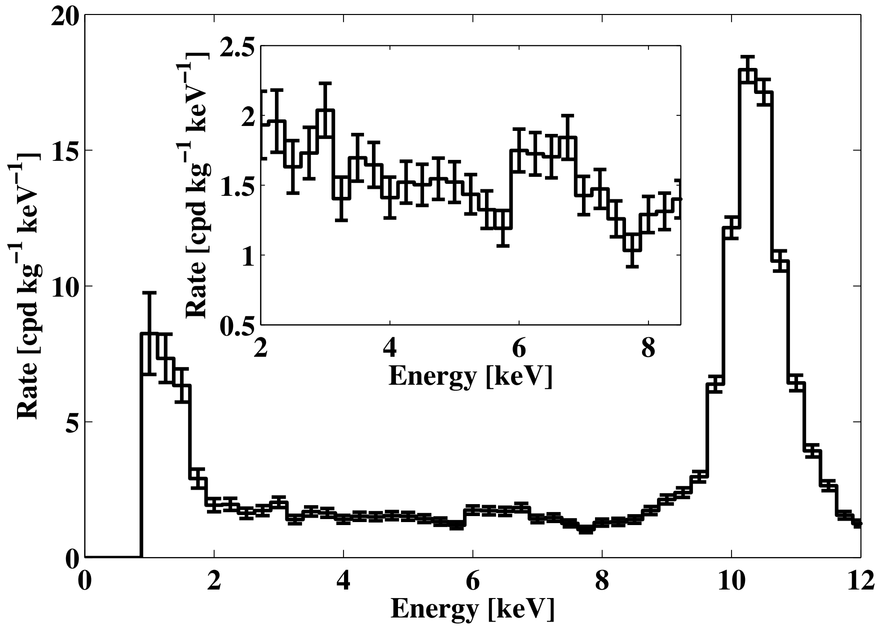
Curve label	Halo model (see ref. [4, 34])	Local density (GeV/cm^3)	Set as in [4]	DM particle mass	$\xi\sigma_{SI}$ (pb)	$\xi\sigma_{SD}$ (pb)	θ (rad)	Channeling [9]
a	A5 (NFW)	0.2	A	15 GeV	3.1×10^{-4}	0	–	no
b	A5 (NFW)	0.2	A	15 GeV	1.3×10^{-5}	0	–	yes
c	A5 (NFW)	0.2	B	60 GeV	5.5×10^{-6}	0	–	no
d	B3 (Evans power law)	0.17	B	100 GeV	6.5×10^{-6}	0	–	no
e	B3 (Evans power law)	0.17	A	120 GeV	1.3×10^{-5}	0	–	no
f	A5 (NFW)	0.2	A	15 GeV	10^{-7}	2.6	2.435	no
g	A5 (NFW)	0.2	A	15 GeV	1.4×10^{-4}	1.4	2.435	no
h	A5 (NFW)	0.2	B	60 GeV	10^{-7}	1.4	2.435	no
i	A5 (NFW)	0.2	B	60 GeV	8.7×10^{-6}	8.7×10^{-2}	2.435	no
j	B3 (Evans power law)	0.17	A	100 GeV	10^{-7}	1.7	2.435	no
k	B3 (Evans power law)	0.17	A	100 GeV	1.1×10^{-5}	0.11	2.435	no

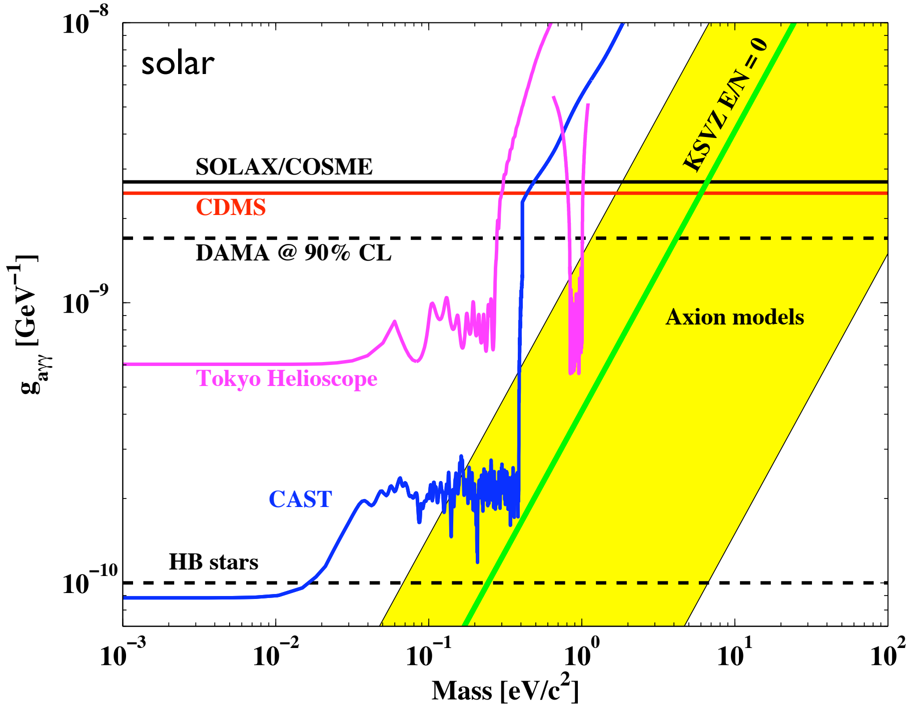
Light Dark Matter (LDM) inelastic scattering and bosonic axion-like interaction as in [6, 11], A5 (NFW) halo model as in [4, 34], local density = 0.17 GeV/cm^3, local velocity = 170 km/s

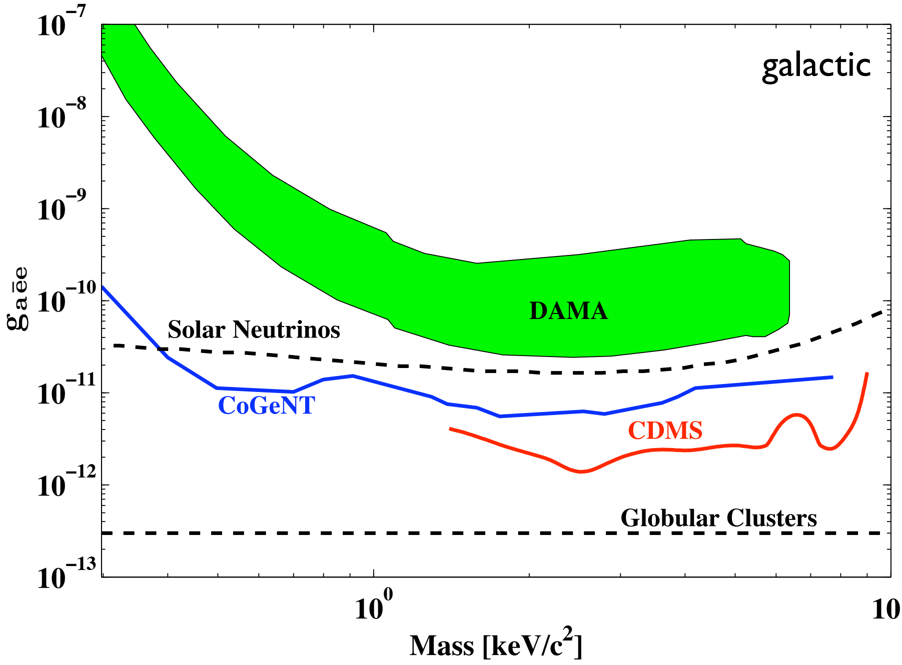
Curve label	DM particle	Interaction	Set as in [4]	m_H	Δ	Cross section (pb)	Channeling [9]
l	LDM	coherent on nuclei	A	30 MeV	18 MeV	$\xi\sigma_m^{coh} = 1.8 \times 10^{-6}$	yes
m	LDM	coherent on nuclei	A	100 MeV	55 MeV	$\xi\sigma_m^{coh} = 2.8 \times 10^{-6}$	yes
n	LDM	incoherent on nuclei	A	30 MeV	3 MeV	$\xi\sigma_m^{inc} = 2.2 \times 10^{-2}$	yes
o	LDM	incoherent on nuclei	A	100 MeV	55 MeV	$\xi\sigma_m^{inc} = 4.6 \times 10^{-2}$	yes
p	LDM	coherent on nuclei	A	28 MeV	28 MeV	$\xi\sigma_m^{coh} = 1.6 \times 10^{-6}$	yes
q	LDM	incoherent on nuclei	A	88 MeV	88 MeV	$\xi\sigma_m^{inc} = 4.1 \times 10^{-2}$	yes
r	LDM	on electrons	–	60 keV	60 keV	$\xi\sigma_m^{e} = 0.3 \times 10^{-6}$	–
r	pseudoscalar axion-like	see ref. [6]	–	Mass = 3.2 keV		$g_{aee} = 3.9 \times 10^{-11}$	–

Axion Search

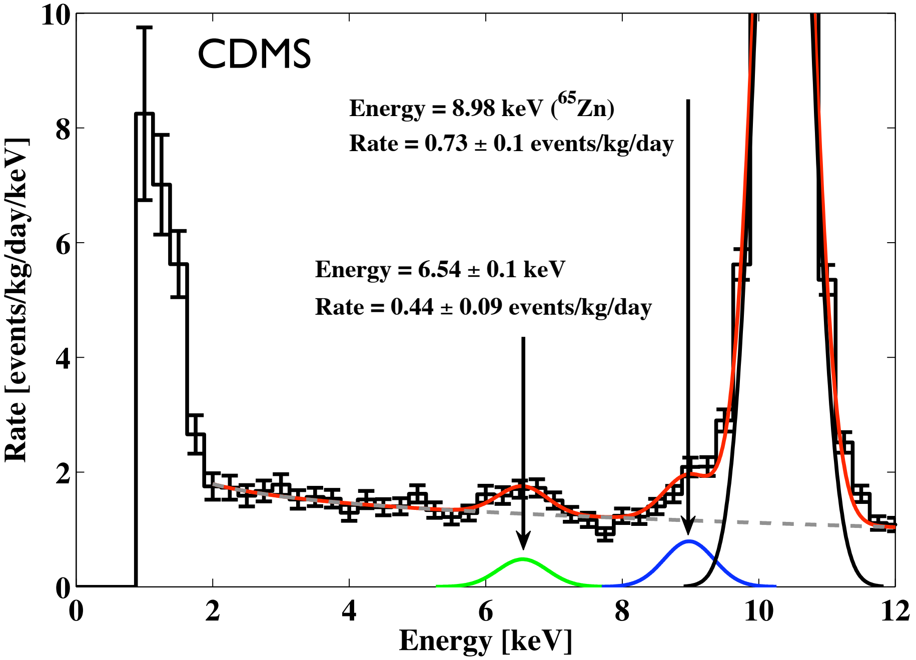
- Look for two phenomena:
  - Solar axion to photon conversion $(a + \gamma \rightarrow \gamma)$, with Bragg enhancement as a function of solar direction
  - Galactic halo axion axio-electric coupling $(a + e^- \rightarrow e^-)$
- Both yield electron recoils, which we look for on top of our electron-recoil background
  - yes, background subtraction



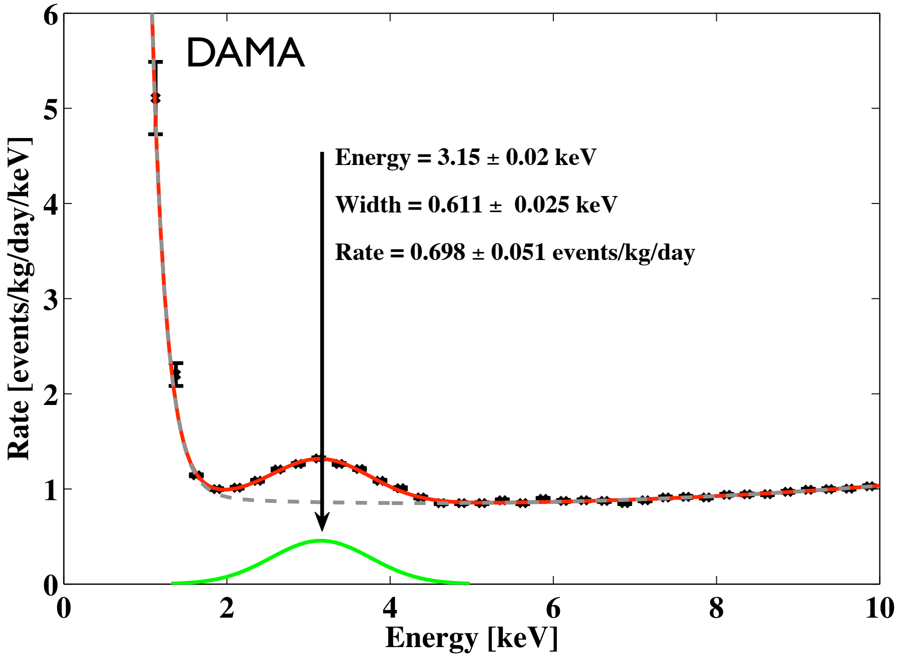


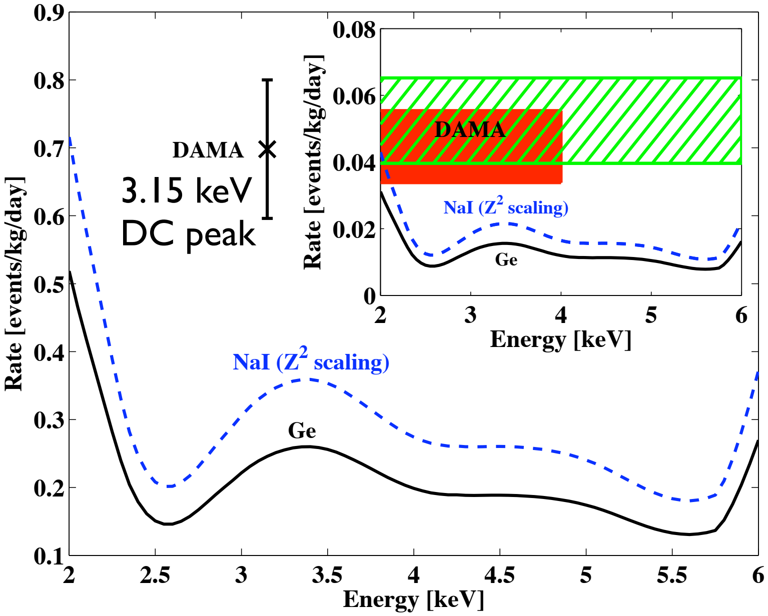


Generic Electron Recoil Search



- Direct conversion of DM to EM energy
- Model background and look for peak
  - yes, also a background subtraction
- Assuming Z^2 scaling on I, compare to
  - rate implied by 3.15 keV peak in DAMA DC background spectrum
  - DC rate consistent with annual modulation signal, assuming 6% flux modulation of DM flux only
- Excludes both substantially



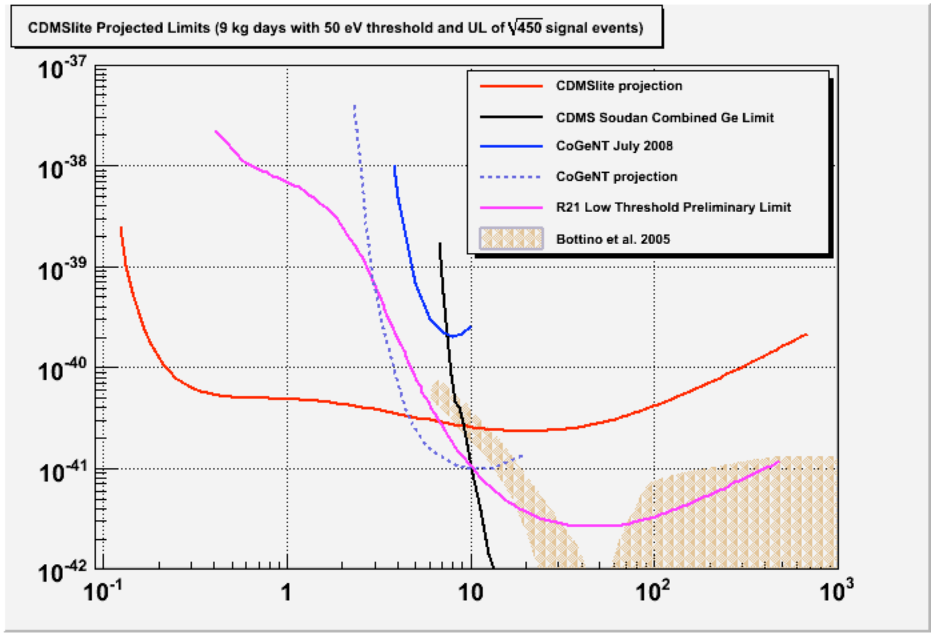


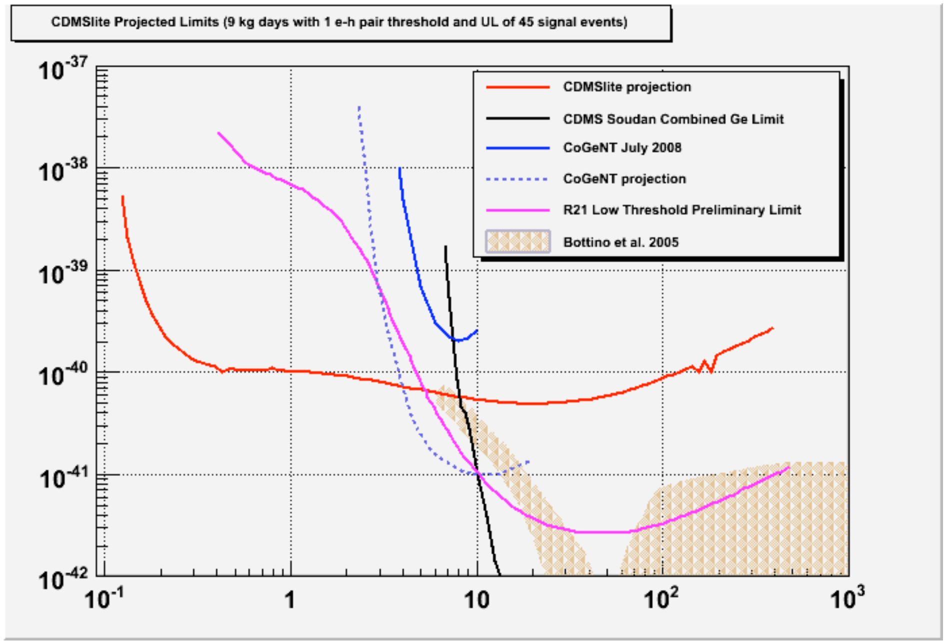
red:
DAMA AC
2-4 keV

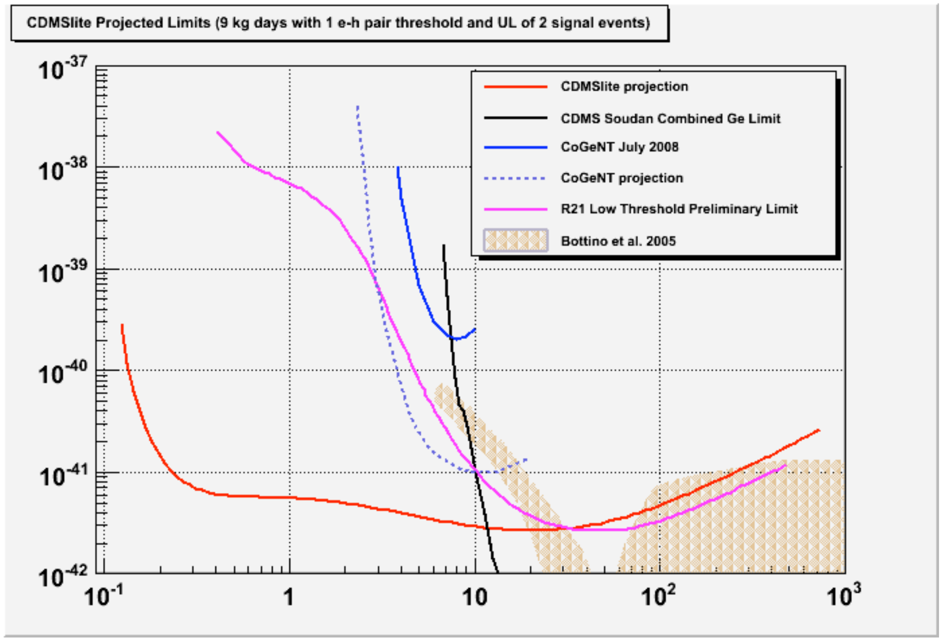
green:
DAMA AC
2-6 keV

CDMSLite

- Another approach to getting low-energy ER data: apply high-voltage (J. Hall, FNAL)
  - use phonon signal to measure ionization energy
  - eliminates NR discrimination
  - CDMSlite data in hand


CDMSlite Projected Limits (9 kg days with 50 eV threshold and UL of $\sqrt{450}$ signal events)


CDMSlite Projected Limits (9 kg days with 1 e-h pair threshold and UL of 45 signal events)

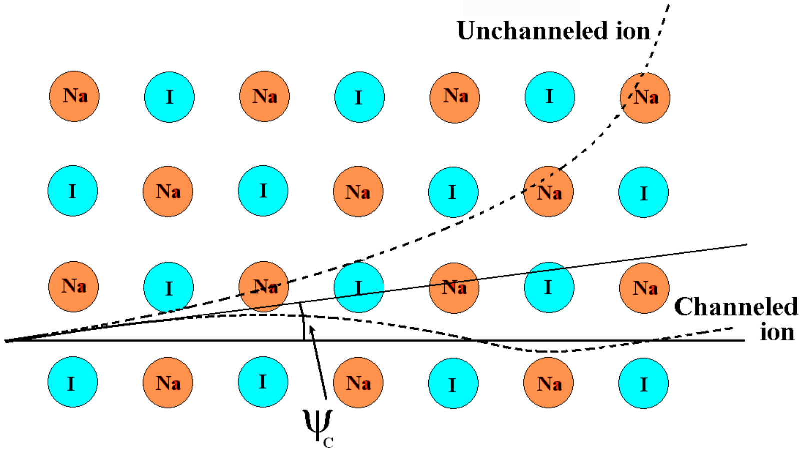

CDMSlite Projected Limits (9 kg days with 1 e-h pair threshold and UL of 2 signal events)

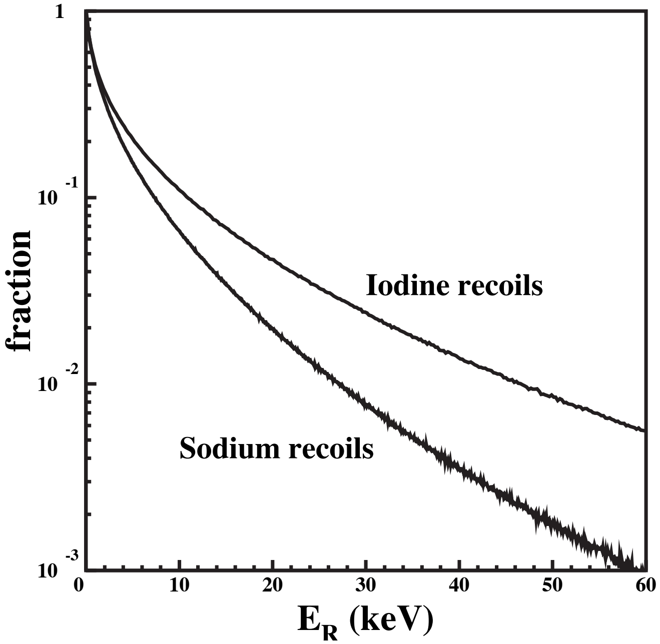
Low-Mass WIMP Searches

- We usually set an analysis threshold of 7 to 10 keV
  - Nuclear recoil discrimination degrades at low energy
  - Hard to calibrate backgrounds, leakage at low energy
  - Would spend most of our time understanding low-energy systematics, not important for >50 GeV WIMP masses
- But our detectors are pretty clean, we can do a background-limited analysis at low energy
  - Old 2003 SUF data still being analyzed
  - Low-energy-optimized analysis of Soudan 5-tower data set likely

Low-Mass WIMP w/Channeling

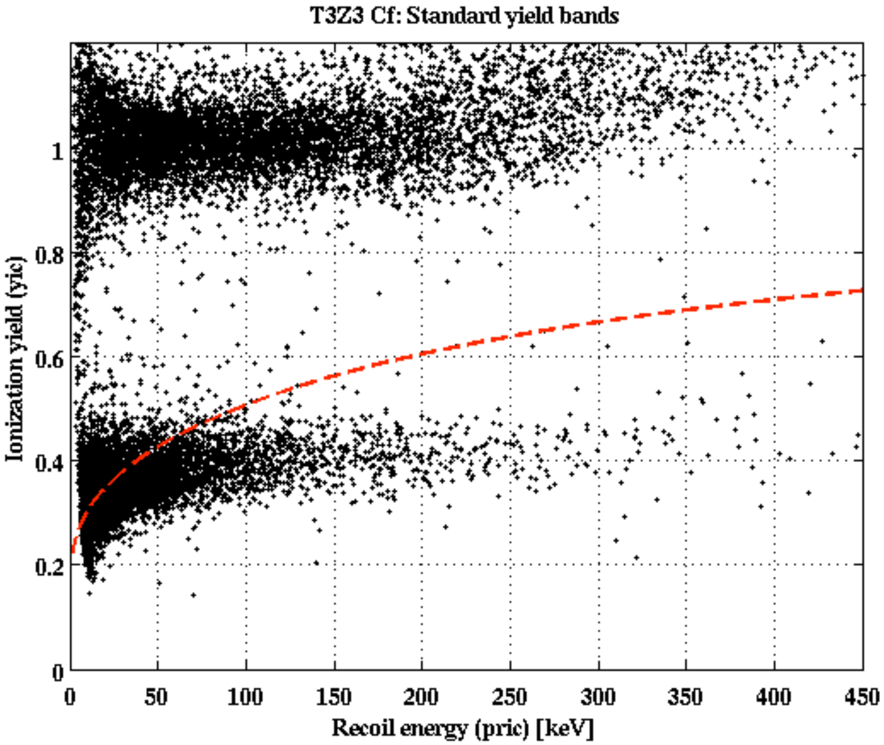
- DAMA channeling idea
  - channeling of ion recoils would make them appear electron-recoil-like and unquenched (full recoil energy appears)
  - channeling much more probable at lower energies
  - Are experiments with NR discrimination discarding these low-energy channeled events because they are ER-like and below analysis threshold?
    - crystalline detectors could be
    - don't understand how liquid detectors could be suffering this problem
  - Our current limits are not substantially affected because channeling would not be important at the recoil energies we have considered.
  - But a low-energy analysis that reaches to lower WIMP mass would be, so we would need to accept an efficiency hit with this.

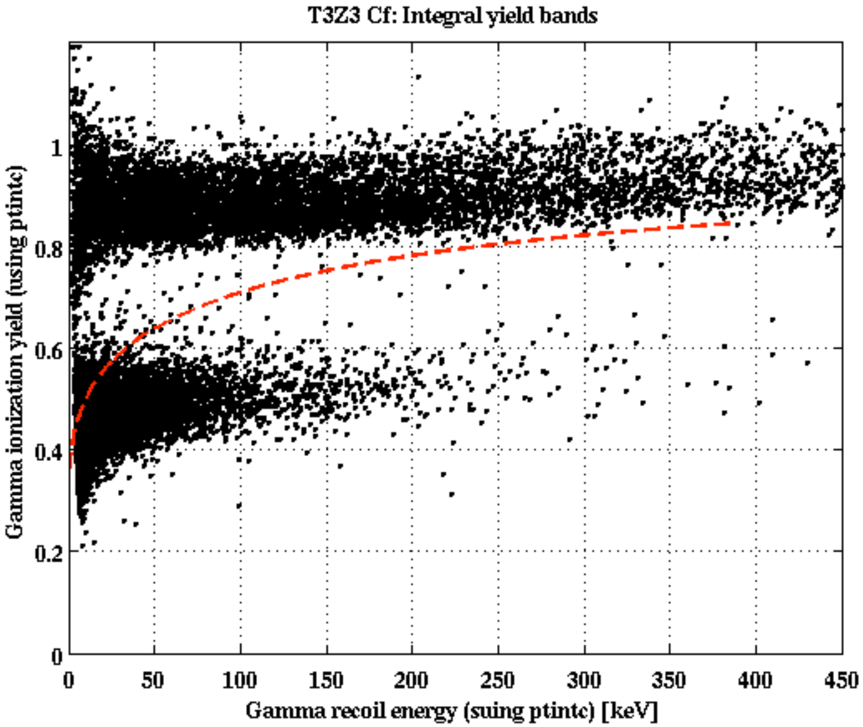




High-Energy Analysis

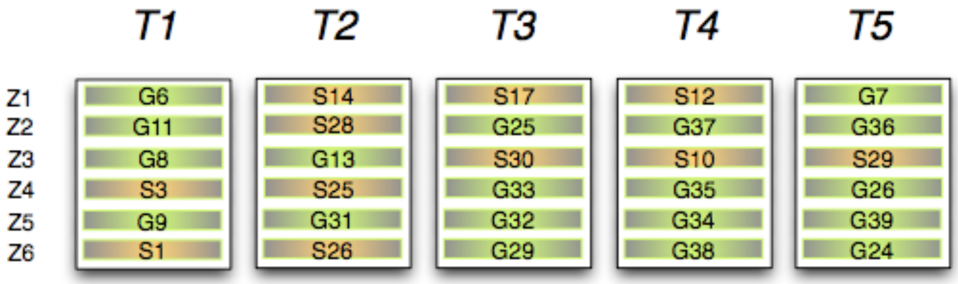
- Higher recoil energy analysis would be sensitive to inelastic DM deexcitation from excited DM states (E ~ 100 keV to 1 MeV)
- The problems:
  - detectors go nonlinear at higher energy
  - not enough NRs; risk activation if neutron exposure increased substantially
  - Seem to have largely excluded inelastic DM interpretation already; XENON100 will exclude full region if no background problems.





Five Tower Runs (2006-9)

30 ZIPs (5 Towers) installed in Soudan icebox: 4.75 kg Ge, 1.1 kg Si



	T1	T2	T3	T4	T5
Z1	G6	S14	S17	S12	G7
Z2	G11	S28	G25	G37	G36
Z3	G8	G13	S30	S10	S29
Z4	S3	S25	G33	G35	G26
Z5	G9	G31	G32	G34	G39
Z6	S1	S26	G29	G38	G24

- Runs 123 - 124
  - Acquired: Oct06-Mar07, Apr07-Jul07
  - Exposure: ~400 kg-d (Ge "raw")

THIS WORK

- **Runs 125 - 128**
  - Acquired: Jul07-Jan08, Jan08-Apr08, May08-Aug08, Aug08-Sep08
  - Exposure: ~600 kg-d (Ge "raw")

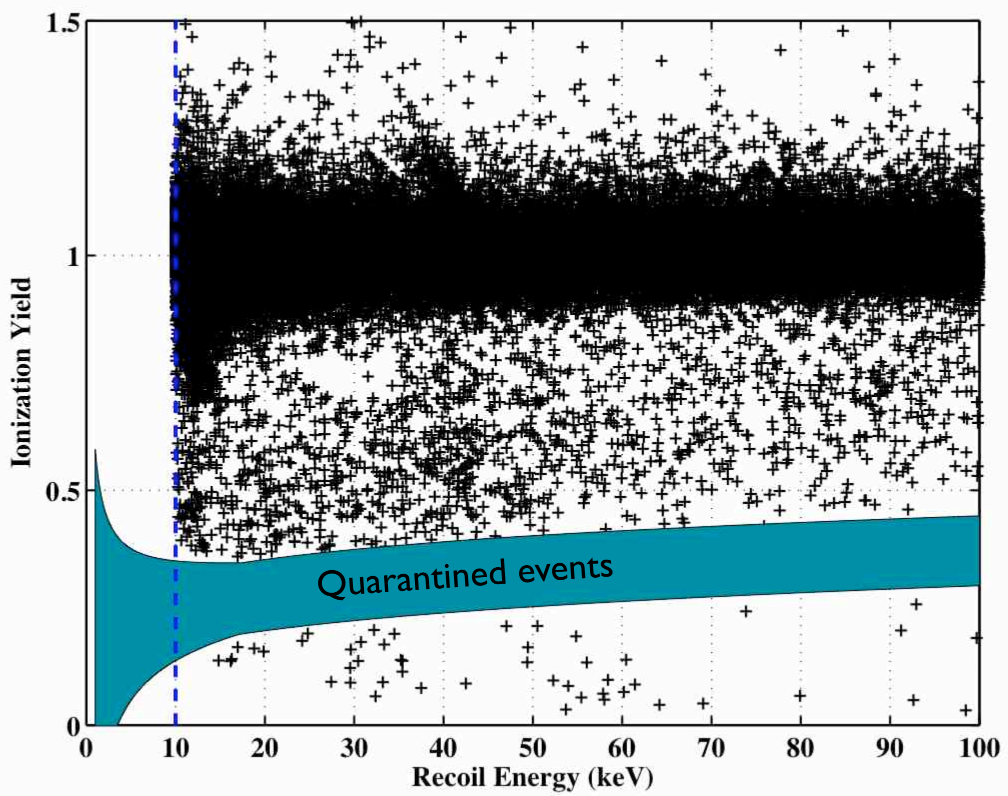
- Run 129 (Nov08-Mar09)
  - *Engineering run, some detector problems*

Some analysis upgrades

- New ROOT-based data reduction package on FNAL computer farm
- Increased analysis automation
  - Data quality checks
  - Data calibration and correction
- Improved event reconstruction near detector rim
- New optimization algorithms for surface event rejection
- Improved background modeling
- Improved estimates of detector masses (~9% lower)

Blind Analysis

- Quarantined signal-like events during data reduction
  - Single-scatter
  - No activity in veto shield
  - Ionization yield near nuclear recoil band
- These events have no effect on the definition of our signal criteria
- Quarantine broken only when all cuts are finalized: "unblinding"
- Avoids statistical bias: cut on independent event distributions, not observed candidate events



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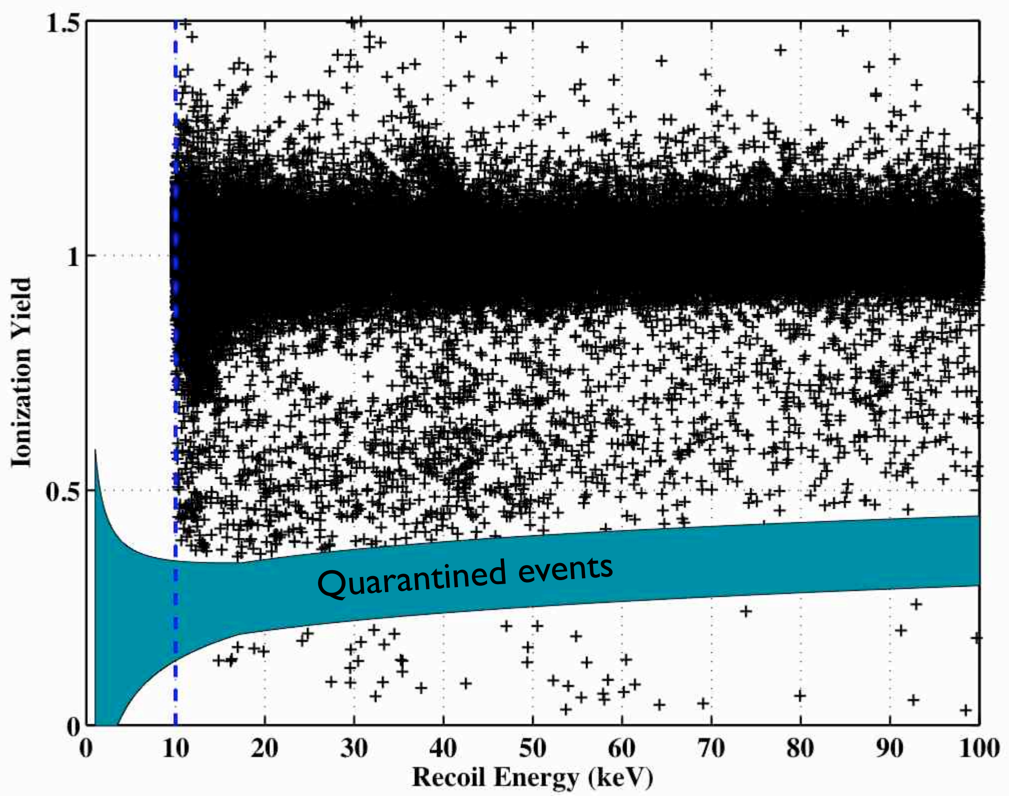
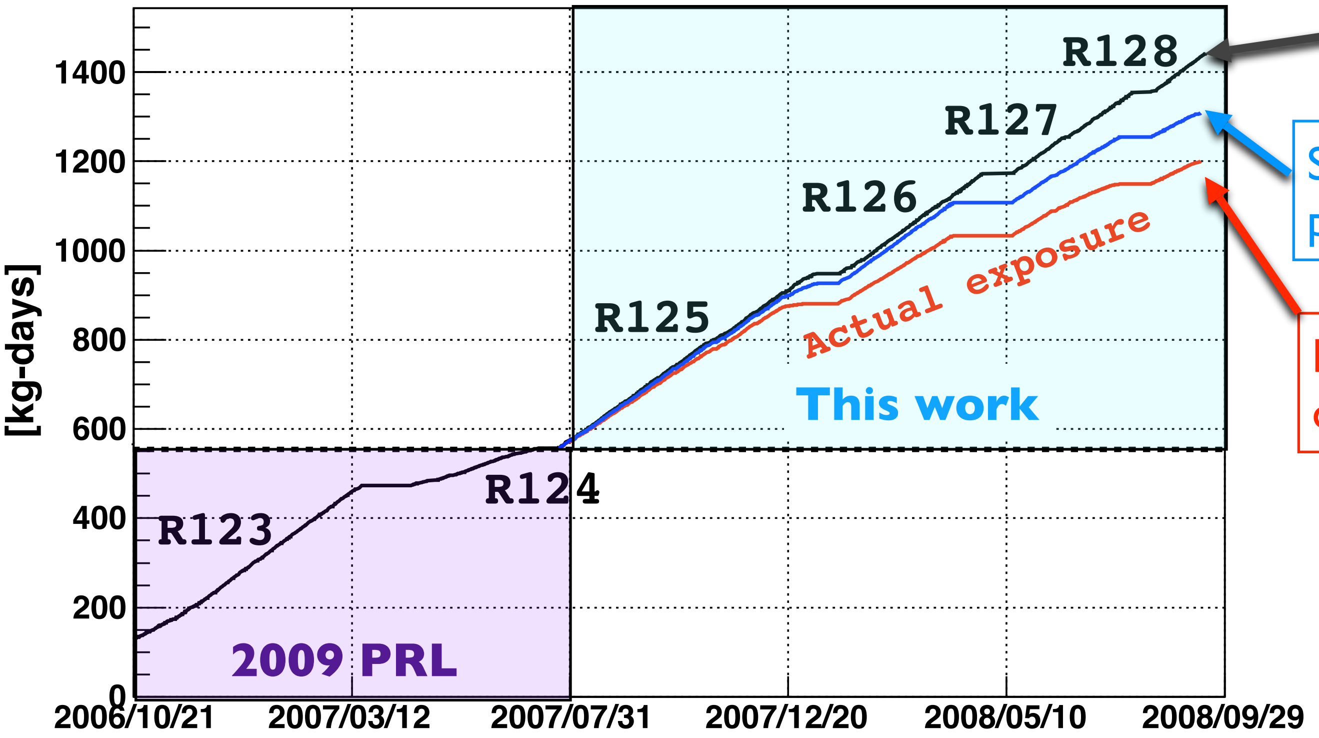


Data Quality

DATA QUALITY

Automated monitoring using KS tests and similar metrics excludes bad time periods on some detectors

Tests for goodness-of-fit, overlapping pulses, etc. exclude individual reconstruction failures



Data recorded

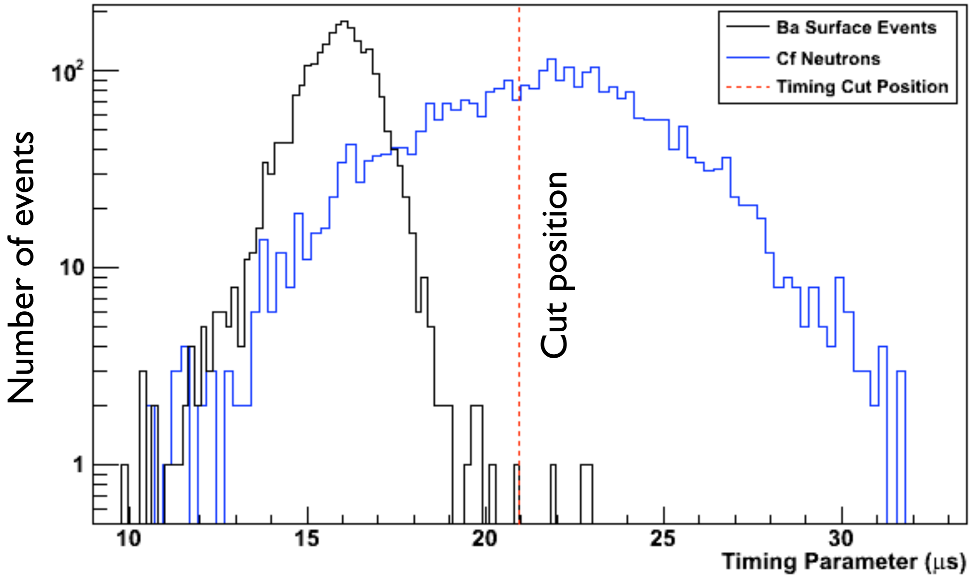
Some detectors excluded for poor performance

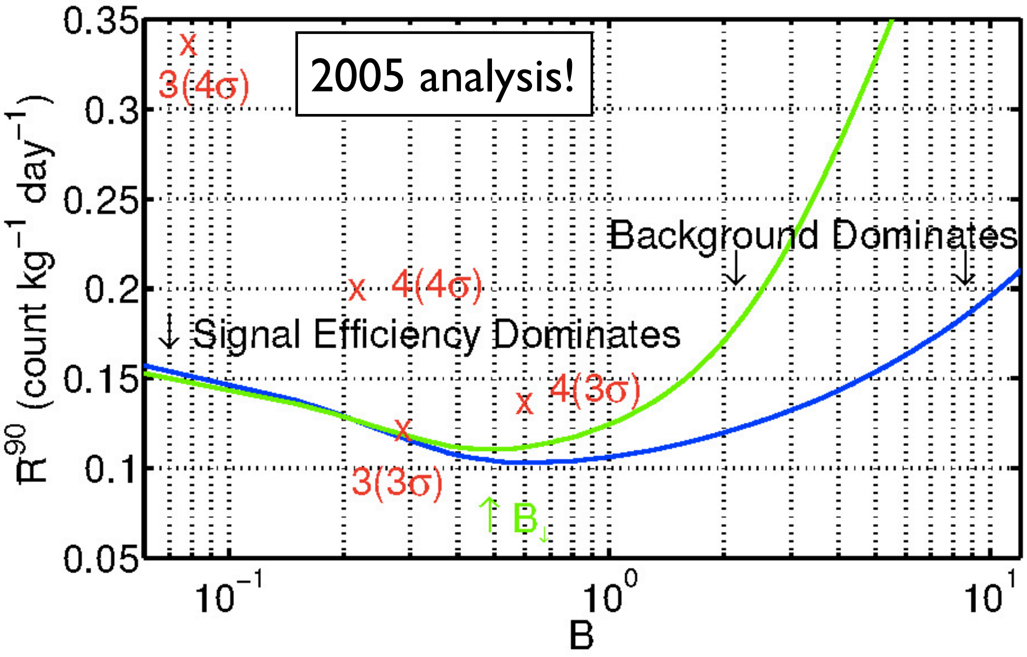
Periods of poor data quality removed

612 "raw" kg-days (before physics cuts)

Choosing our Misidentified Background

- Goal: Select surface event cut position to maximize expected sensitivity / discovery potential
  - Strongest expected upper limit
  - Greatest significance of a few observed events
- Usually a broad optimum near ~0.5 expected events
  - Each analysis employs tighter cuts
  - Improved analysis limits loss in signal acceptance
- Choose cut based on surface event background model

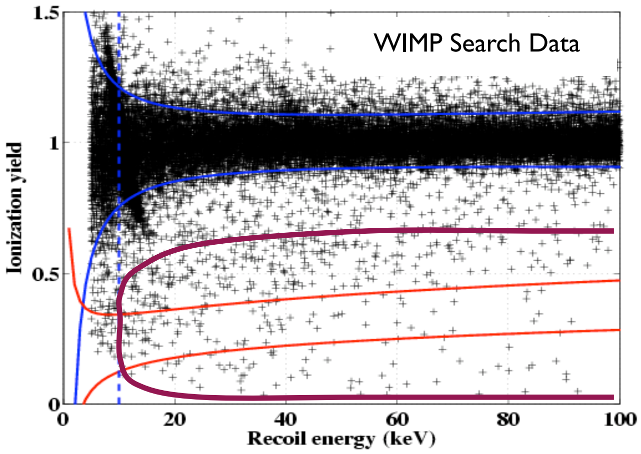


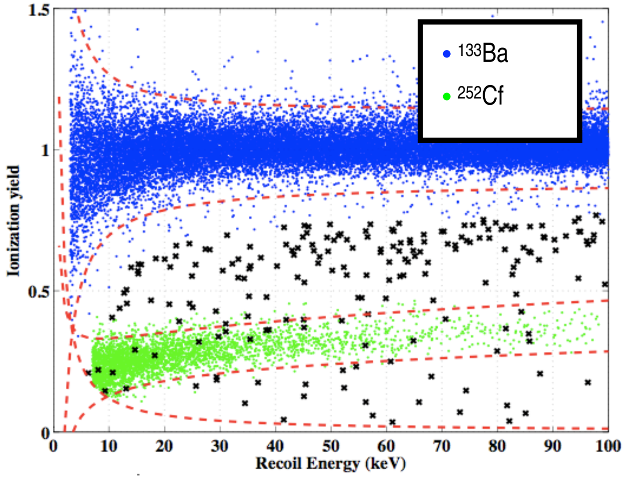


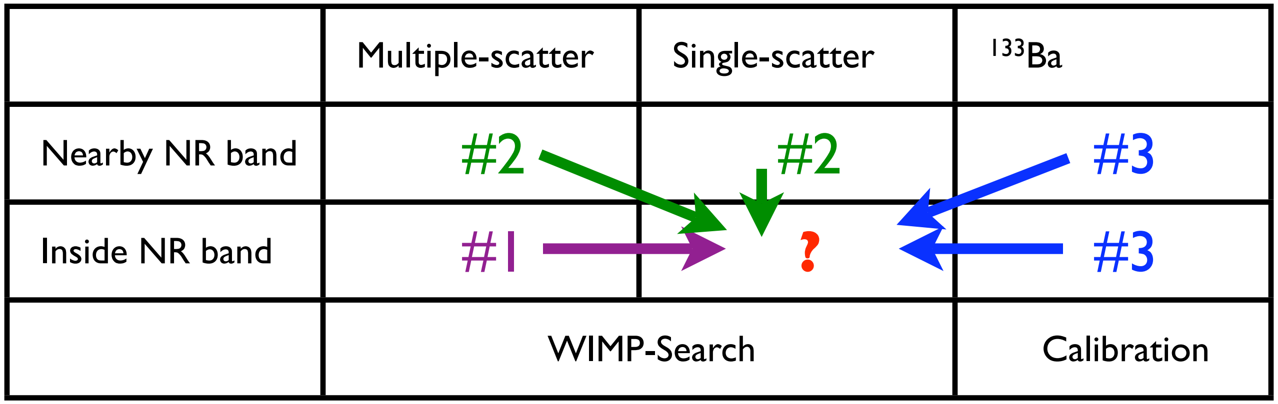
Surface Event Misidentified Background

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

3 independent sidebands for estimating the passing/failing ratio







	Multiple-scatter	Single-scatter	^{133}Ba
Nearby NR band	#2	#2	#3
Inside NR band	#1	?	#3
	WIMP-Search		Calibration

Correct #2, #3 (best statistics) for systematic differences in energy and detector face distributions

All three consistent:

0.6 ± 0.1 (stat.)

(... plus systematic error)

Neutron Background

RADIOGENICS

Estimate U/Th content of nearby materials with HPGe and fit to observed gammas

Simulate fission/α-n, propagate in GEANT

0.03 - 0.06 events expected

	U/Th (ppb)	Mass (kg)
Electronics	1.2	15
Cu	0.4	260
Poly	0.24	120
Pb	<0.05	14000

COSMOGENICS

$$\frac{N^{MC}_{\text{unvetoed, single NR}}}{N^{MC}_{\text{vetoed, single NR}}} \times N^{\text{data}}_{\text{vetoed, single NR}} \quad \times\ \varepsilon_{\text{neutron}}$$

$= 0.04^{+0.04}_{-0.03}$ (stat.) events expected

From GEANT4 and FLUKA simulations

3 vetoed, single NRs observed

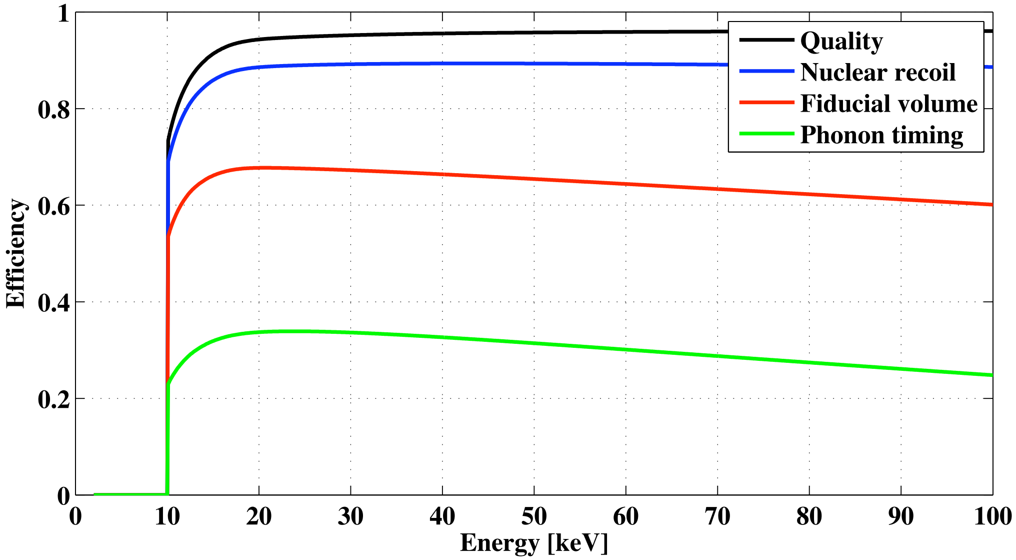
Correct for efficiency, exposure

Blind Analysis Summary

PHYSICS

- Veto-anticoincidence cut
- Single-scatter cut
- Q_{inner} (fiducial volume) cut
- Ionization yield cut
- Phonon timing cut

612 raw kg-d
194 kg-d WIMP equiv. @
60 GeV/c^2



Neutron background

Radiogenic: 0.03-0.06

Poly, Cu (α,n): <0.03

Pb (fission): <0.1

Cosmogenic: <0.1 (MC 0.03-0.05)

3 vetoed neutron singles seen

Surface background

Leakage computation based on signal region multiple scatters

0.6 ± 0.1 (stat.)

(... plus systematic error)

Blind Analysis Summary

PHYSICS

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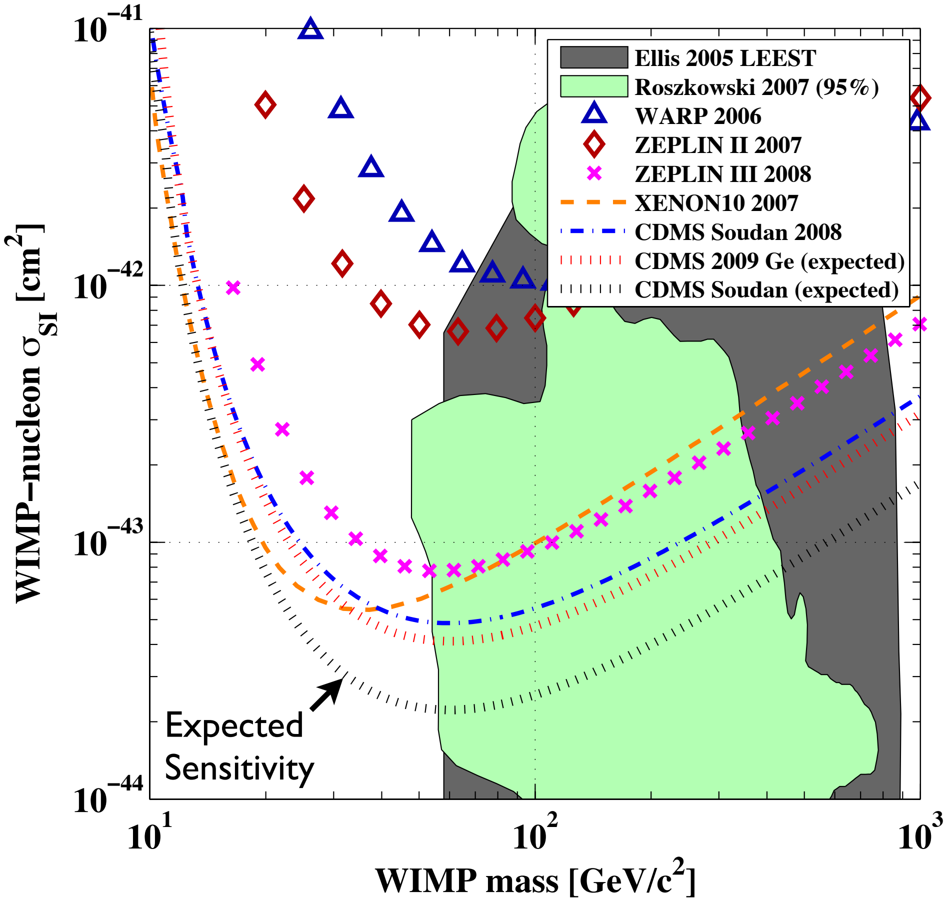

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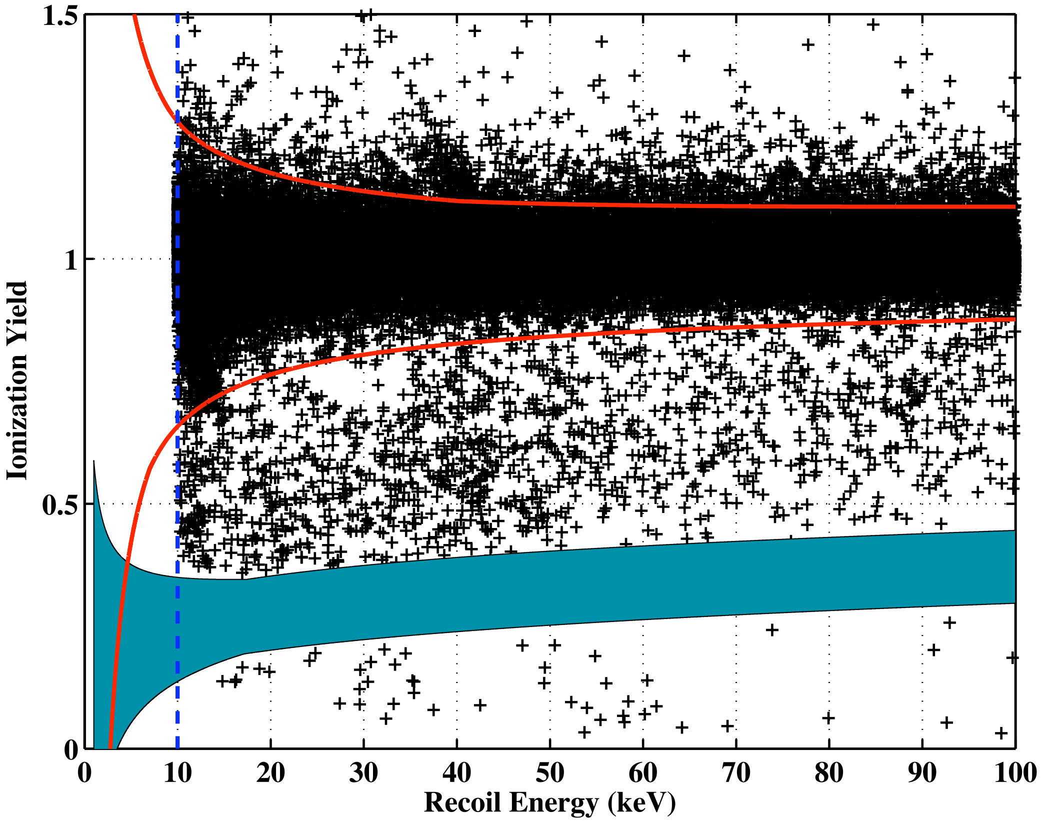
Opening the Box

Box opened **Thursday, November 5** for **14 Ge ZIPs**

3σ region masked
→ Hide unvetoed singles



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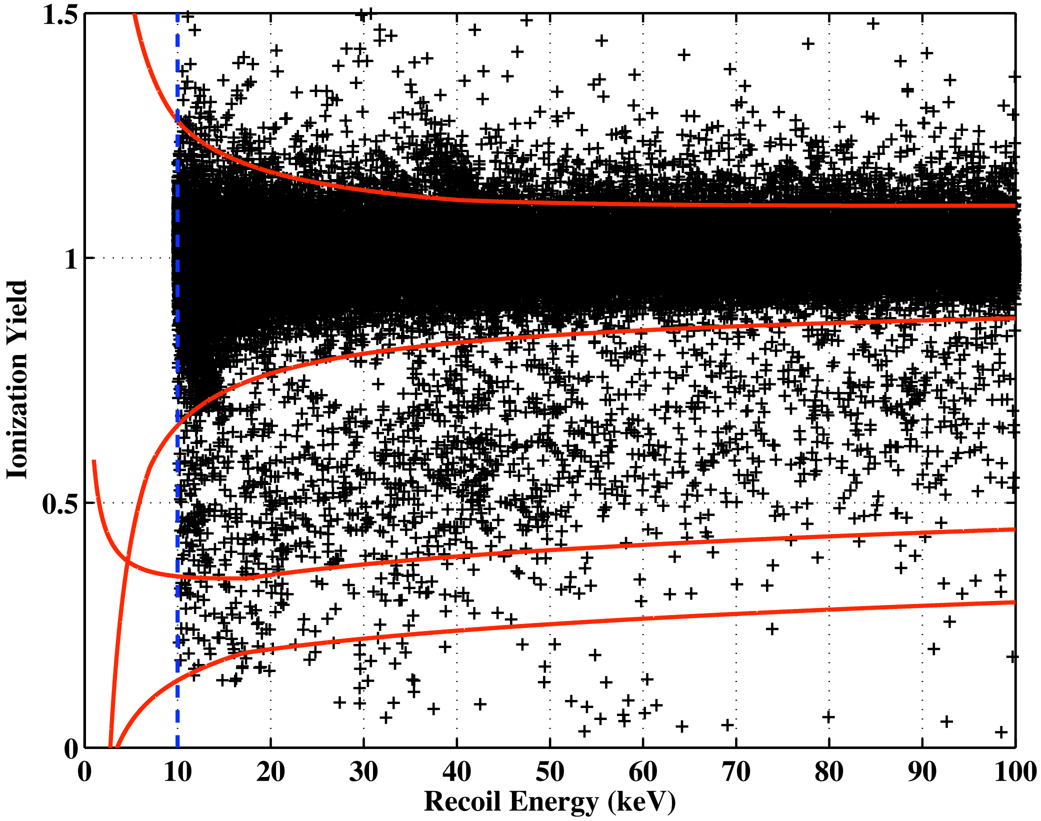
3σ region masked
→ Hide unvetoed singles

Lift the mask, see 150 singles *failing* timing cut



Opening the Box

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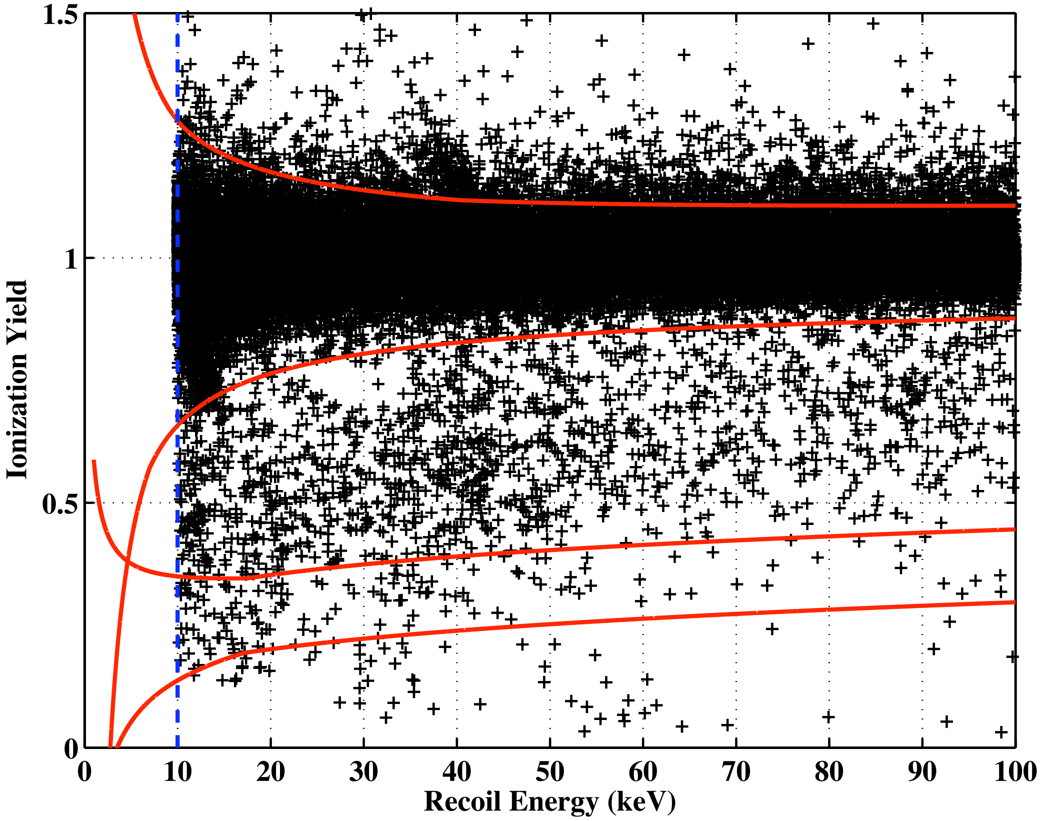
Lift the mask, see 150 singles *failing* timing cut

Apply the timing cut, count the candidates



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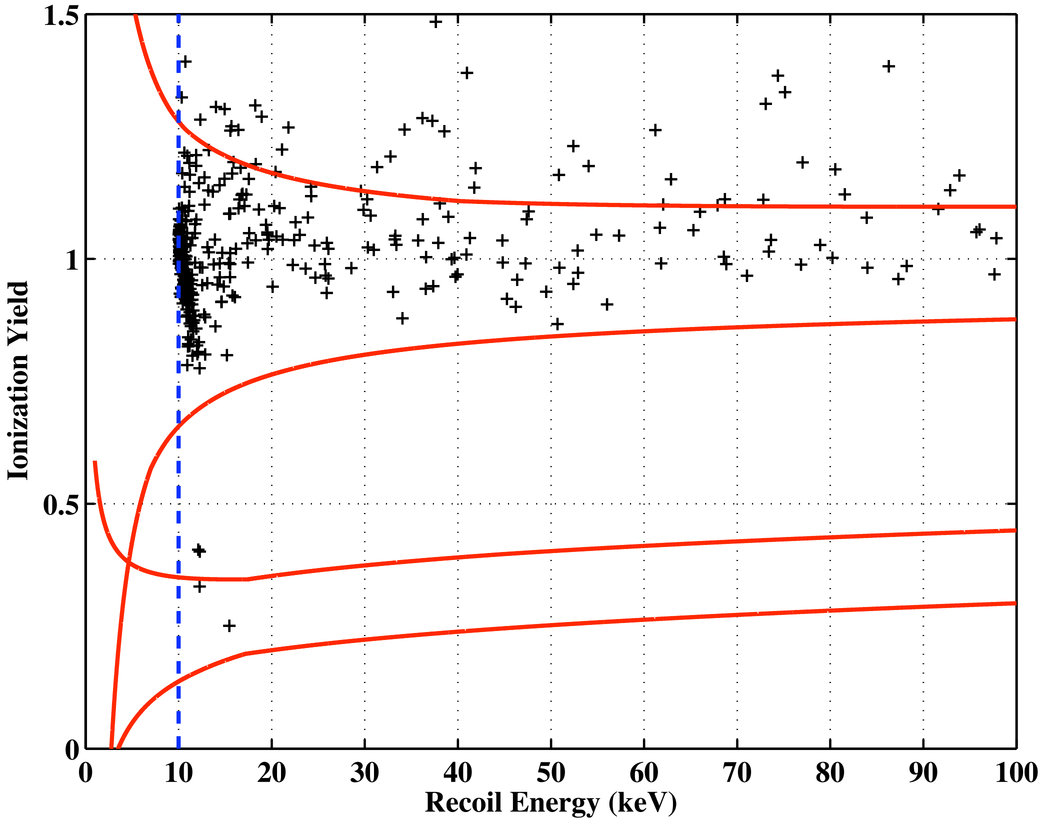


Lift the mask, see 150 singles *failing* timing cut

Apply the timing cut, count the candidates

Two events observed

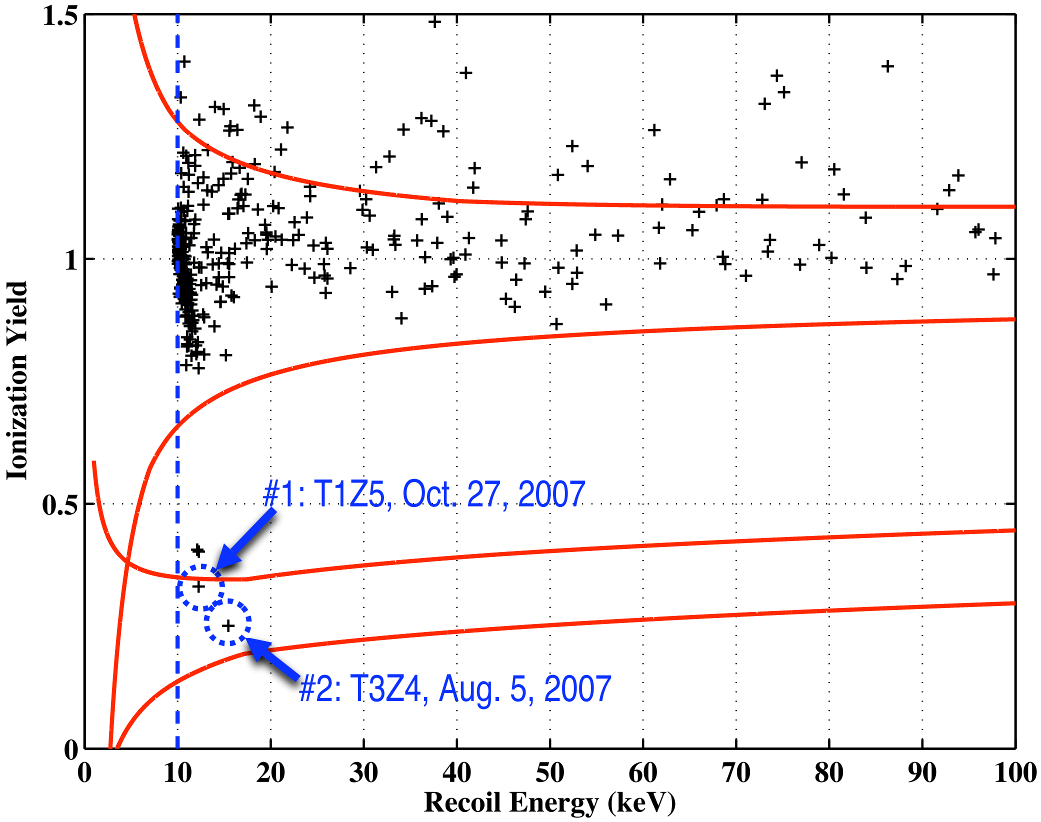
Opening the Box

Box opened **Thursday, November 5** for **14 Ge ZIPs**

3σ region masked
→ Hide unvetoed singles

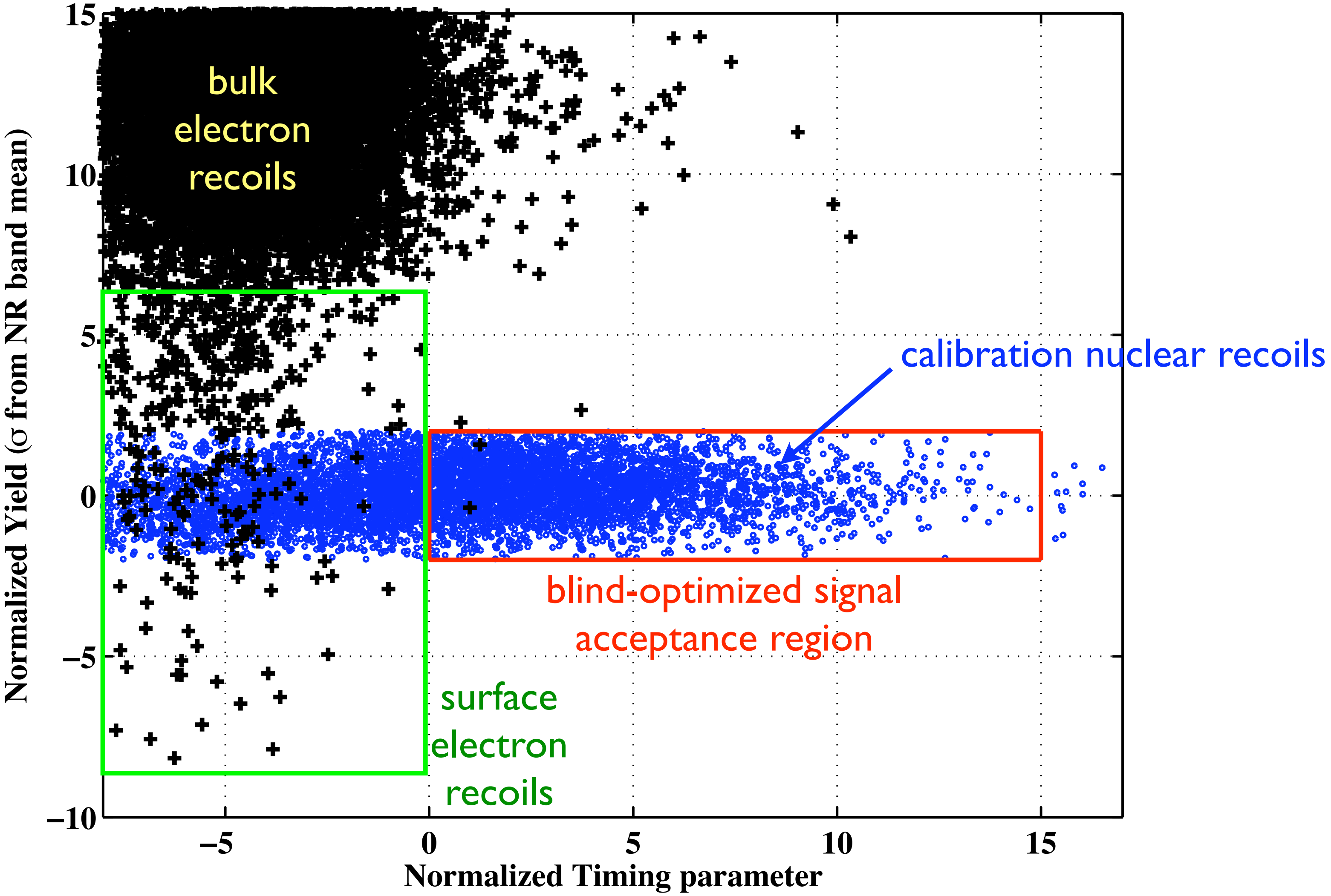
Lift the mask, see 150 singles *failing* timing cut

Apply the timing cut, count the candidates



Two **events observed**

Another View

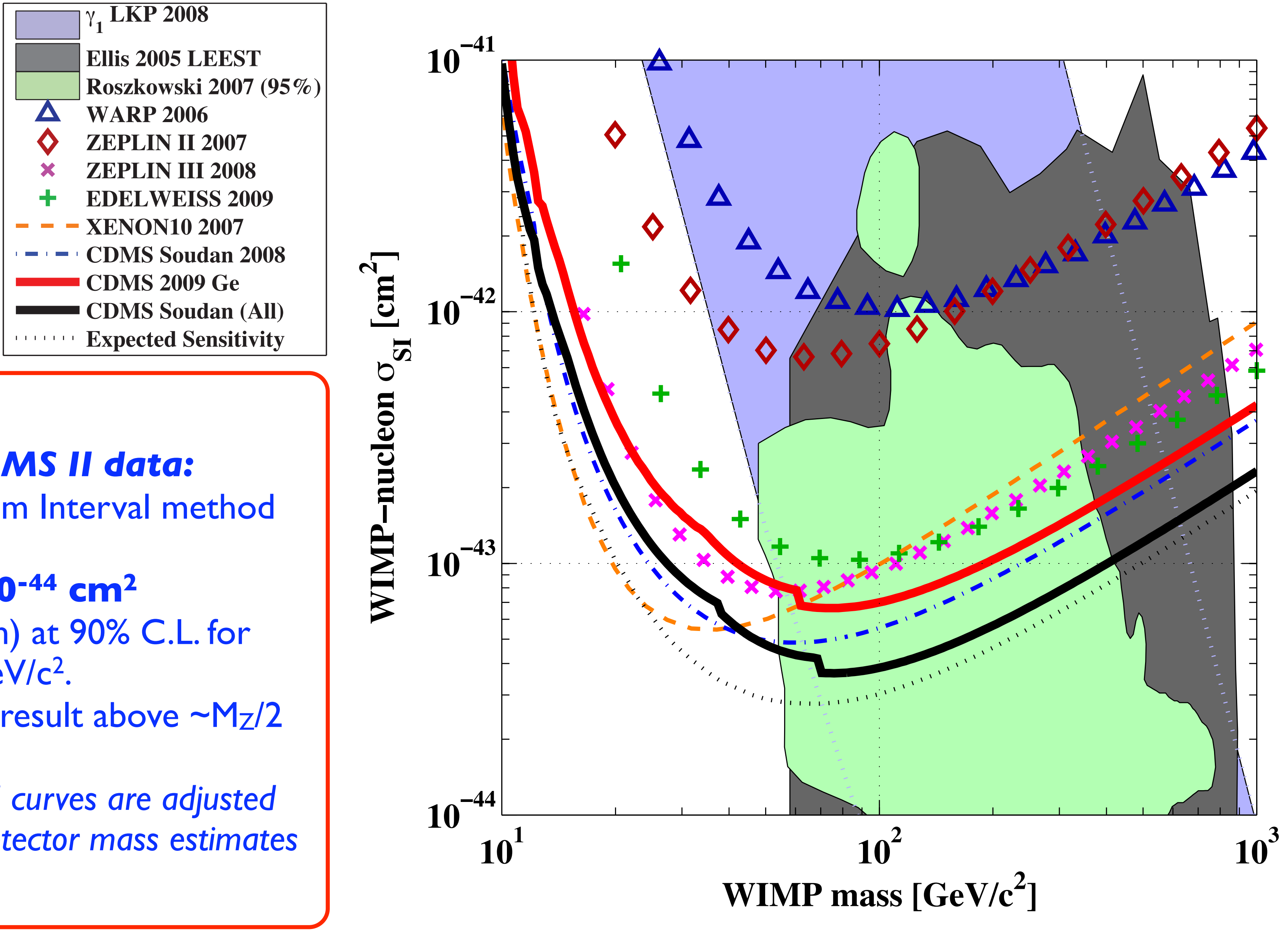


Spin-Independent Limits

KK/SUSY theory

Other searches

CDMS II results

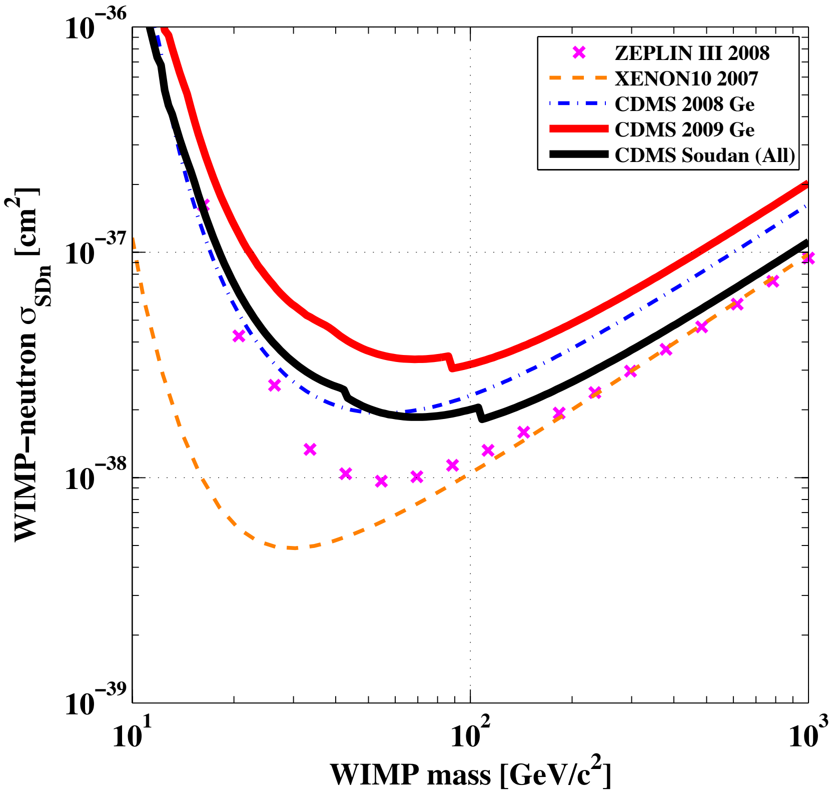


Combined CDMS II data:

- Yellin's Optimum Interval method (no bkg. subt.)
- **$\sigma_{SI} > 3.8 \times 10^{-44}$ cm^2** (>38 zeptobarn) at 90% C.L. for $M_{WIMP} = 70$ GeV/c^2.
- World-leading result above ~$M_Z/2$

Note: *All CDMS curves are adjusted for ~9% lower detector mass estimates*

Some Other Interpretations



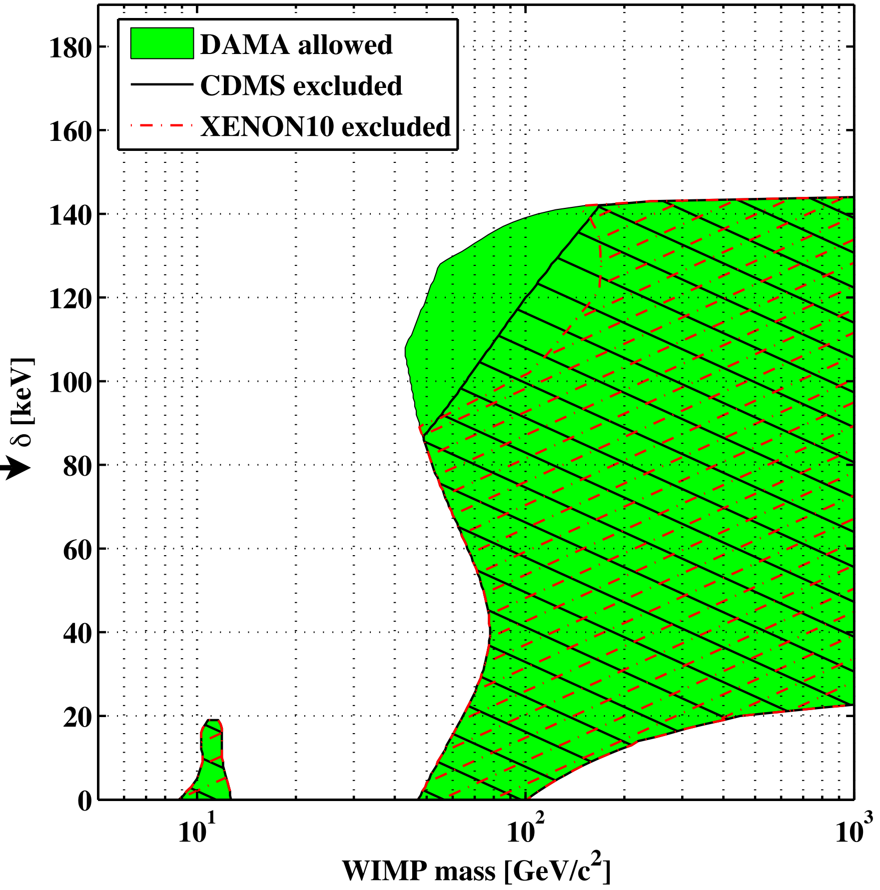
Spin-Dependent WIMP Couplings

Competitive limits on SD-neutron couplings, but no new parameter space excluded

Inelastic Dark Matter

Disfavor all DAMA/LIBRA allowed regions except for M~100 GeV, mass splitting of ~80-140 keV

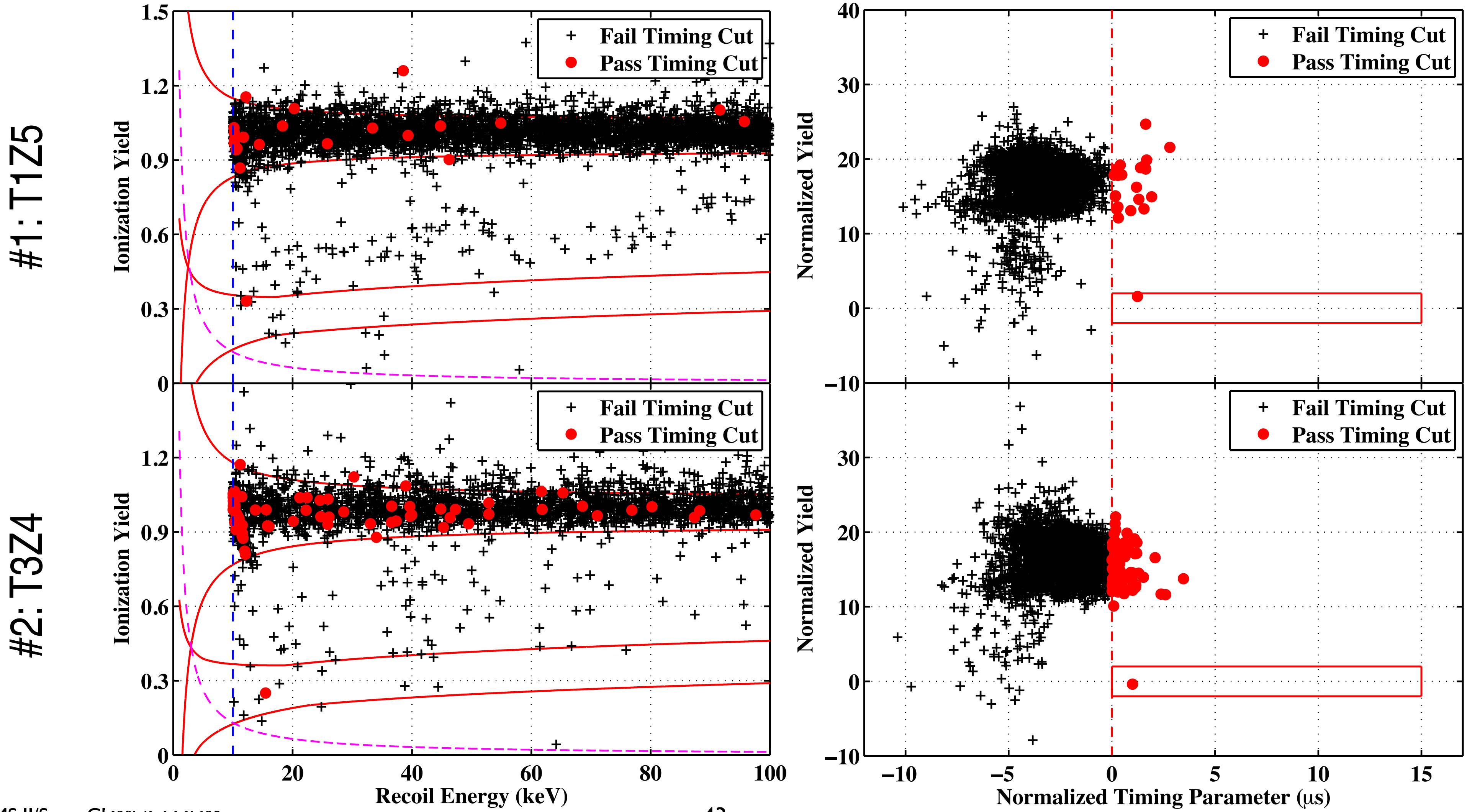
Only regions incompatible with DAMA/LIBRA at the 90% C.L. are shown



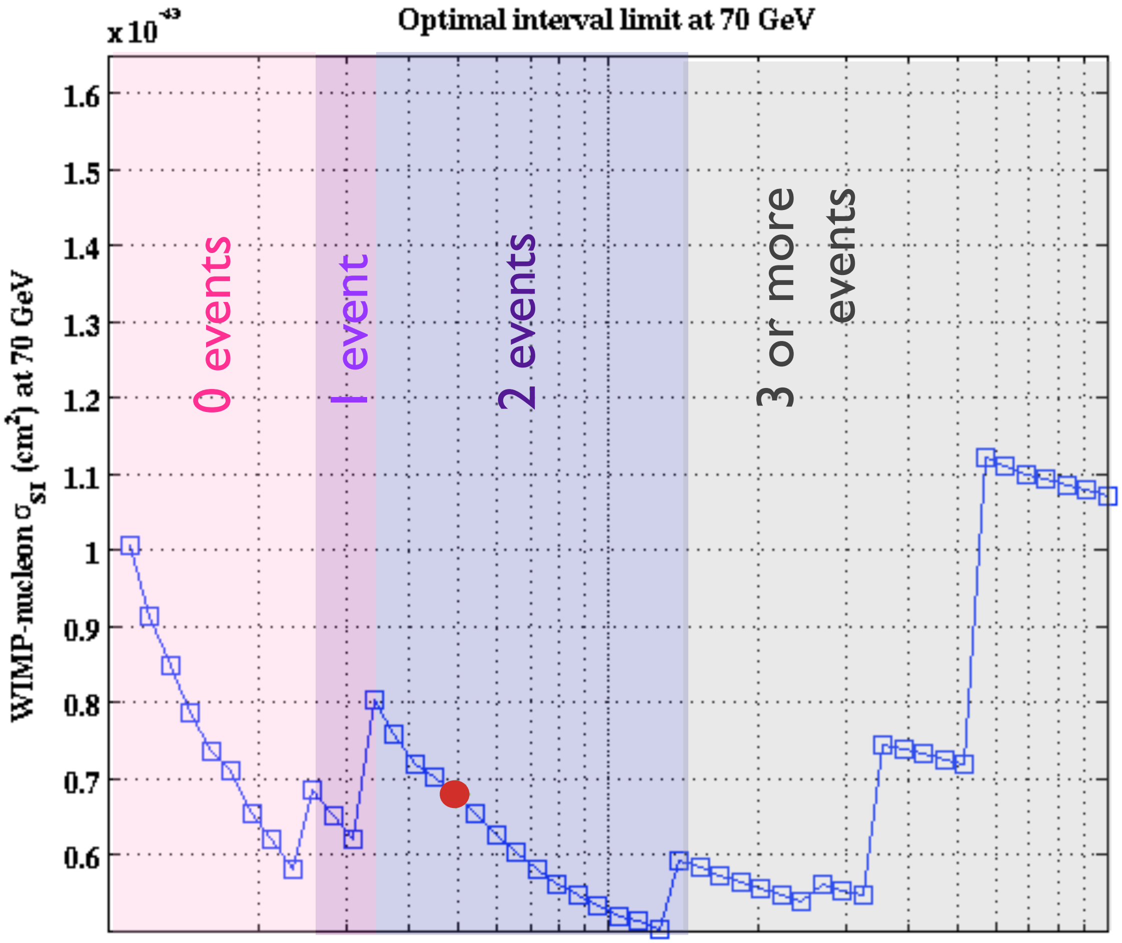
What about those two events?

The Two Candidates

#1 - T1Z5: October 27, 2007 - 12.3 keV
#2 - T3Z4: August 5, 2007 - 15.5 keV



Varying the Surface-Event Cut



To *exclude both candidates*, we must reduce the expected background by ~1/2 and the exposure by 28%

To *admit a third candidate*, we must increase the expected background to 1.7 events.

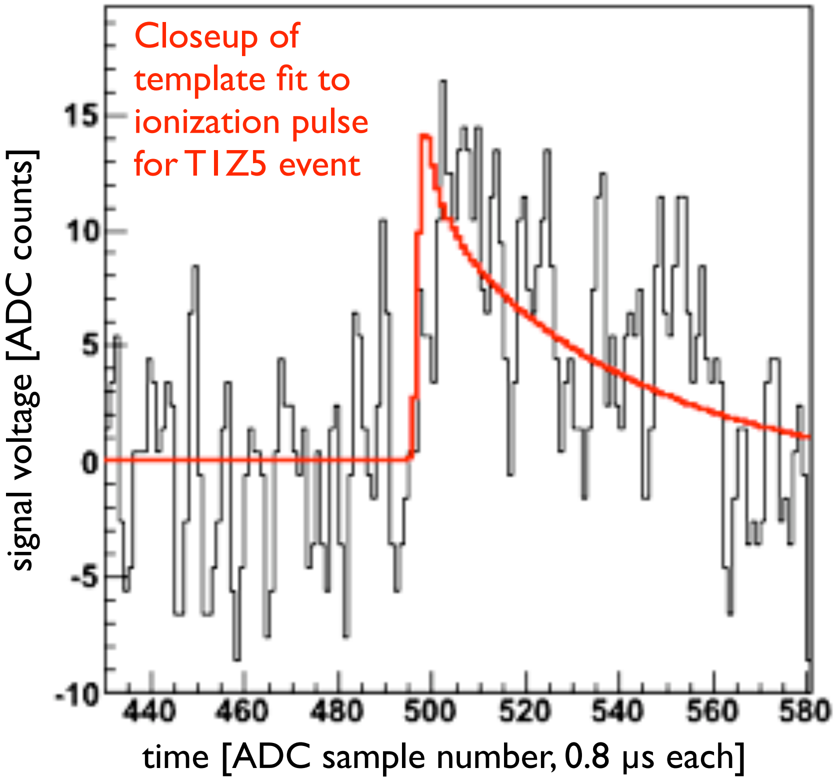
Our result is not overly sensitive to the cut position

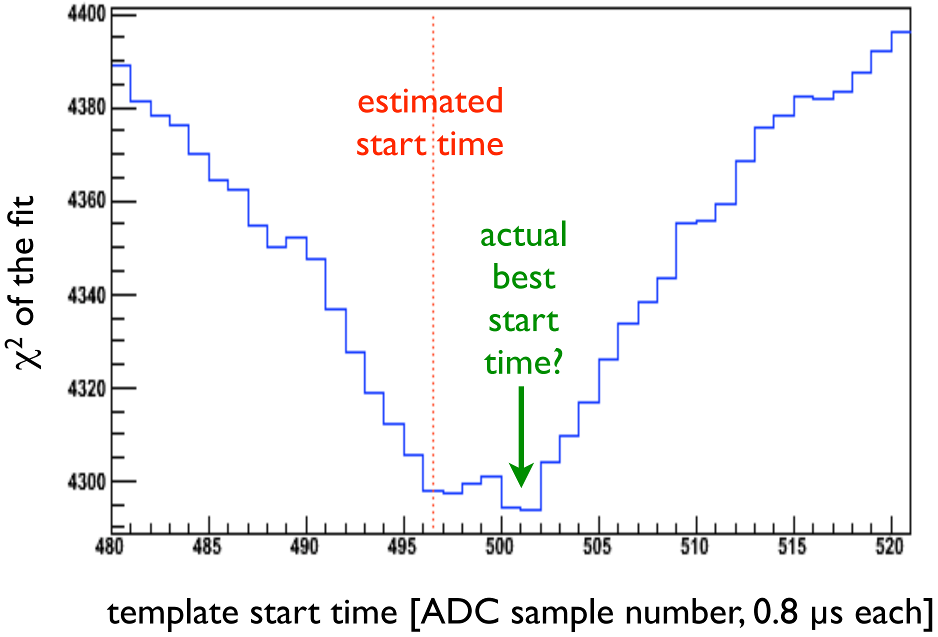
Operating Conditions

Special data conditions?	*No*
Issues noted by operator?	*No*
Activity in mine?	*No (weekend)*
NuMI / MINOS ν beam?	*Off*
Noise levels	*Typical*
Charge collection	*Typical*
KS tests	*Normal*
Background rates (ER/surface)	*Typical*
Muon veto performance	*Good*
Single-scatter identification	*Good*
Radial position	*Well-contained*

Candidates were observed during ideal running conditions, several months apart, in different interior detectors

Pulse Reconstruction


Closeup of template fit to ionization pulse for T1Z5 event


estimated start time

actual best start time?

Our reconstruction technique misestimates the ionization start time for a small fraction of events with <6 keV of ionization energy.

This issue does not affect the T1Z5 candidate.

With a better estimator, the T3Z4 candidate may fail the timing cut (other candidates might appear)

Event #1 (T1Z5) shows no reconstruction issues

Event #2 (T3Z4) has a misreconstructed start time

A full reprocessing is needed to study this definitively

Background Estimate Redux

A refined estimate of the surface background accounting for this effect yields

Surface background
0.8 ± 0.1 (stat.) ± 0.2 (syst.)

With this revised estimate (and including neutron backgrounds), *the probability for observing at least 2 events is ~23%.*

Our results cannot be interpreted as significant evidence for WIMP interactions.

However, we cannot reject the signal hypothesis for either event.

From CDMS II to SuperCDMS and GEODM

CDMS II

∅7.5cm x 1cm ZIP
0.25 kg/detector

16 detectors = 4 kg
2 yr, 1700 kg-d

SuperCDMS Soudan

∅7.5cm x 2.5cm mZIP
0.64 kg/detector

25 detectors = 15 kg
2 yr, 8000 kg-d

SuperCDMS SNOLAB

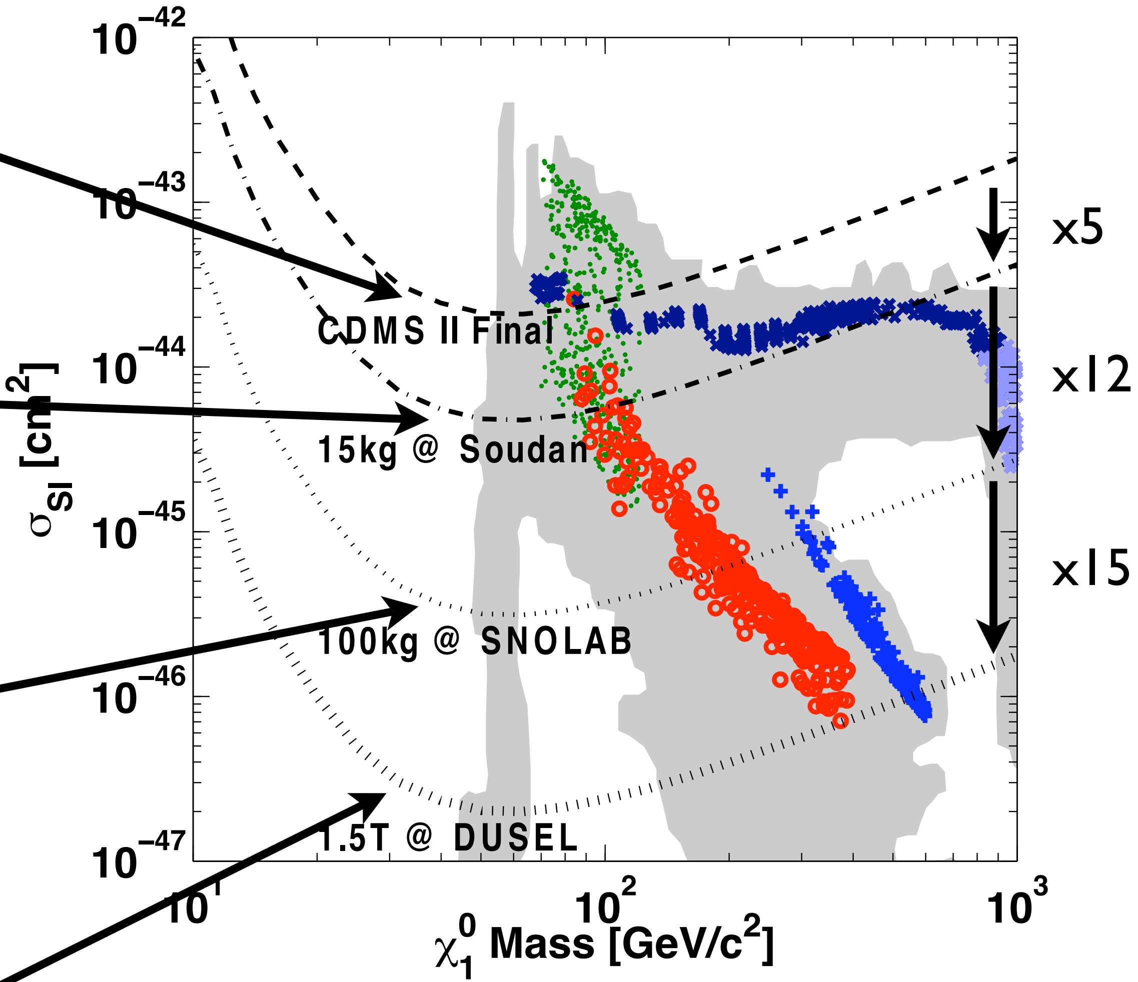
∅10cm x 3.5cm iZIP
1.5 kg/detector

70 detectors = 105 kg
3 yr = 100,000 kg-d

GEODM DUSEL

∅15cm x 5cm iZIP
5.1 kg/detector

300 detectors = 1.5 T
2 yr, 1.5 M kg-d



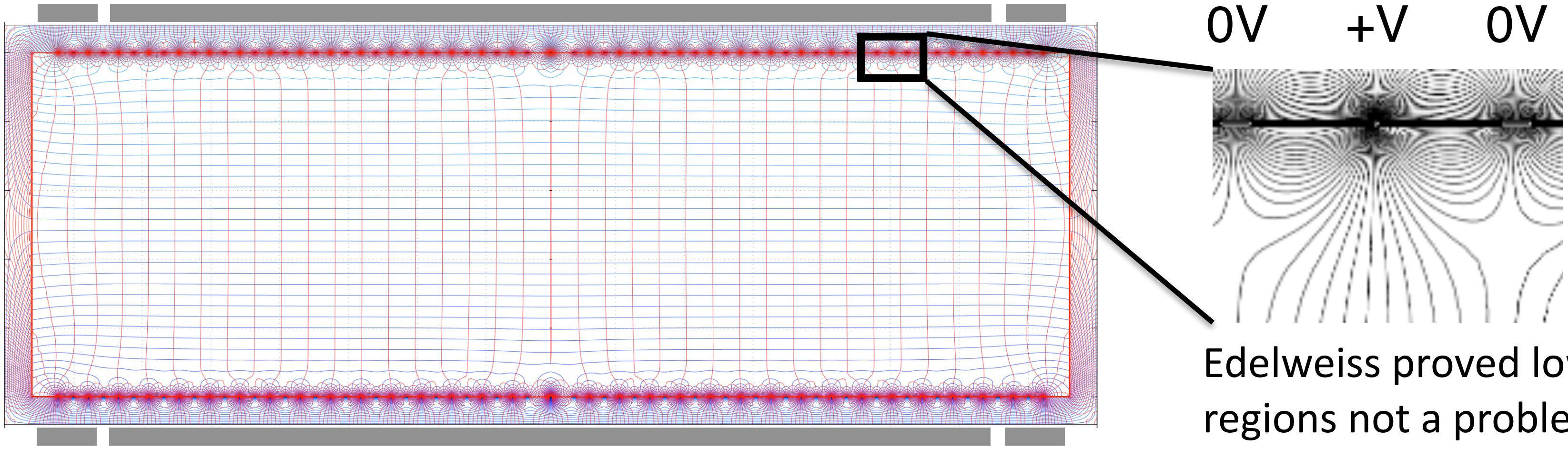
Staged three-prong program to explore MSSM or study a signal:

- decreased backgrounds
- improved background rejection
- increase in mass/detector and decrease in cost/detector

< 1 event misid'd bgnd at each stage

Improving Background Rejection

- Interdigitated ZIP (iZIP) design meets needs for SuperCDMS SNOLAB and GEODM

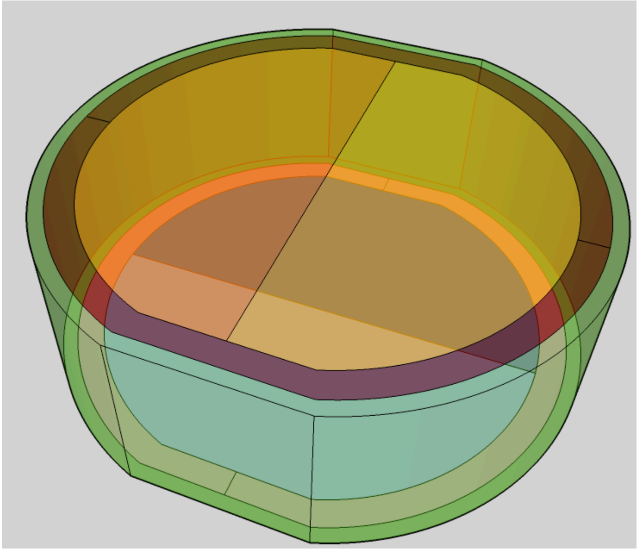


negative version on other face

Edelweiss proved low field regions not a problem

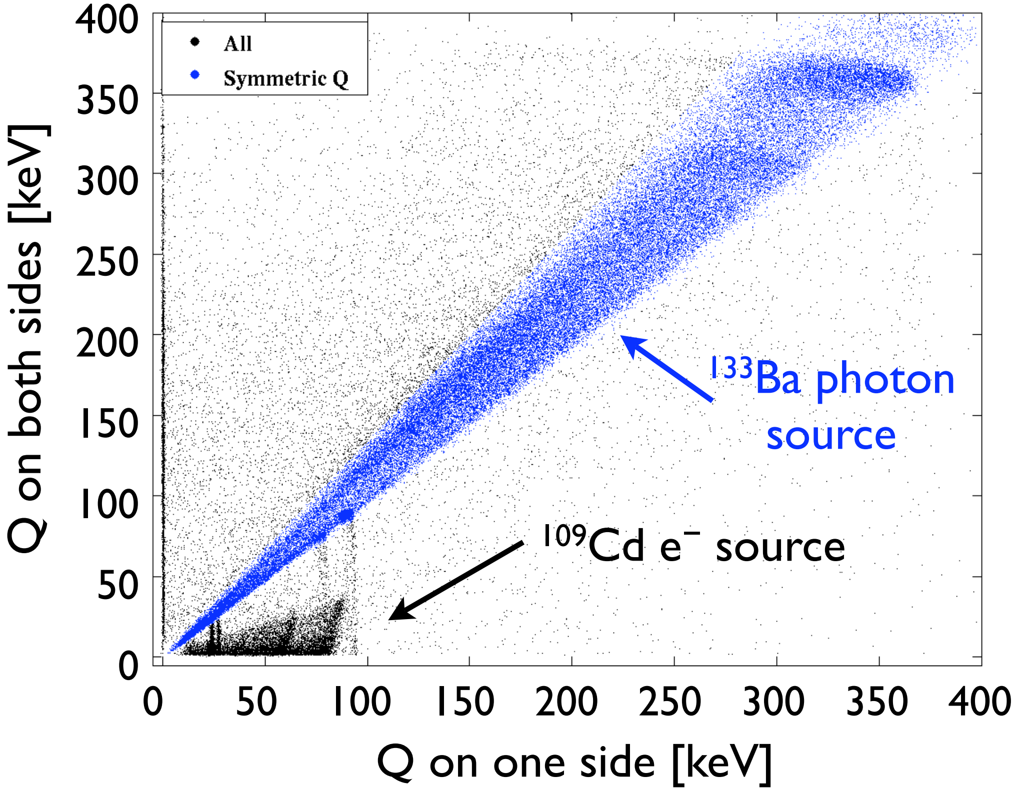
M. Pyle

- Interleaved ionization electrodes cause ionization to partition differently for surface and bulk events
- High field near surface increases ionization yield for surface events
- Top/bottom phonon sensors (ground rails) provide simpler, more direct z information



Improving Background Rejection

- Interdigitated ZIP (iZIP) design appears to meet needs of SuperCDMS SNOLAB and GEODM
  - Surface events share charge differently than bulk events: < 10^{-3} misid
  - High field at surfaces increases ionization yield: 0.2 misid → < 3 x 10^{-4} misid
  - Phonon partition and timing z position: < 10^{-3} misid



M. Pyle, B. Serfass

  - All measurements limited by neutron background in surface test facilities
  - Ionization yield and Q/P asymmetry likely uncorrelated; if true, then overall misid 10^{-4} → < 3 x 10^{-7}, far better than needed for GEODM

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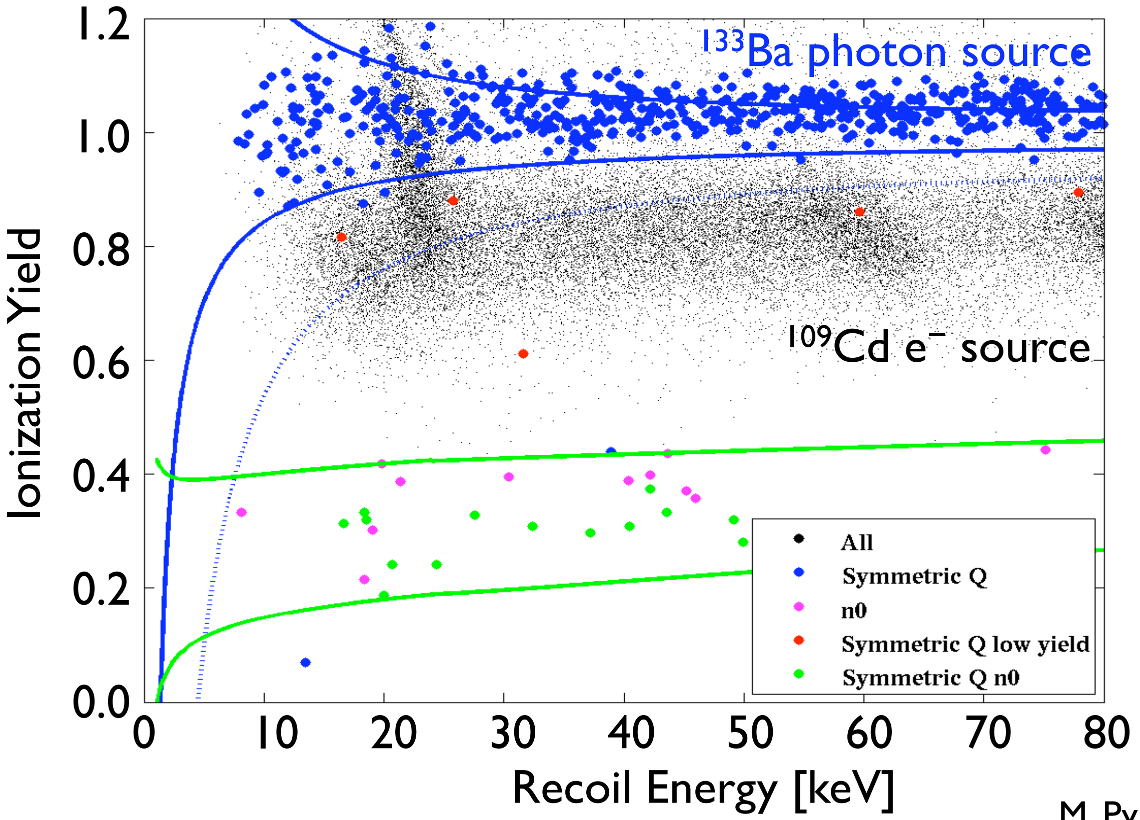

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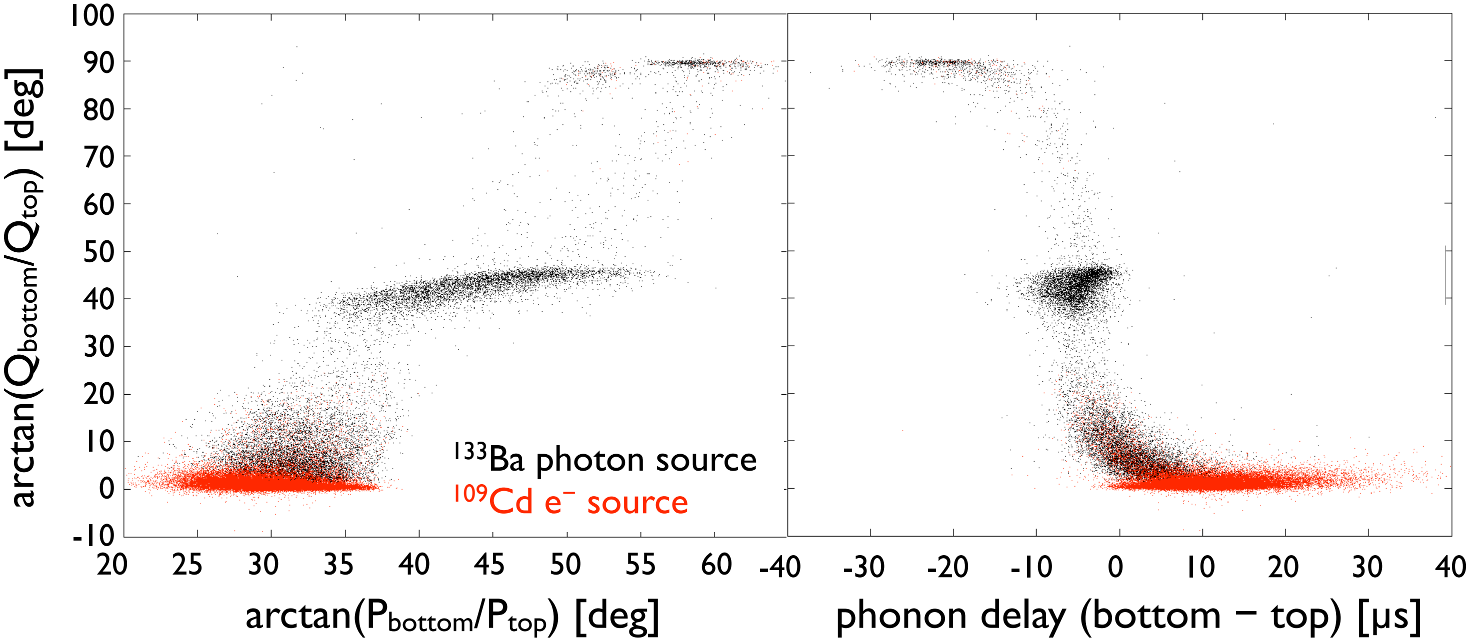

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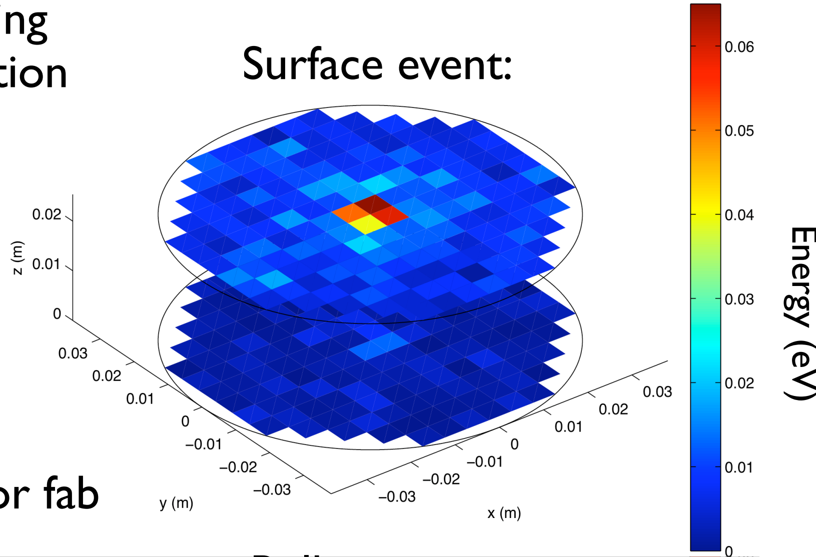
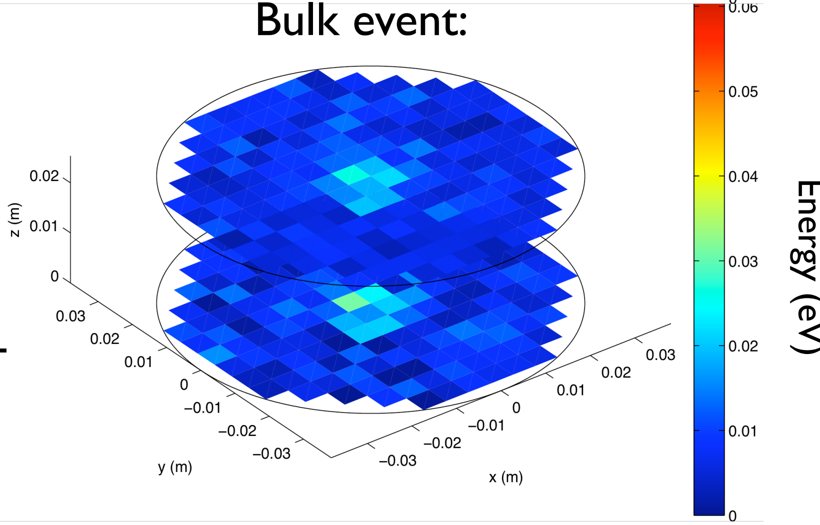
Phonon Detection Using MKIDs

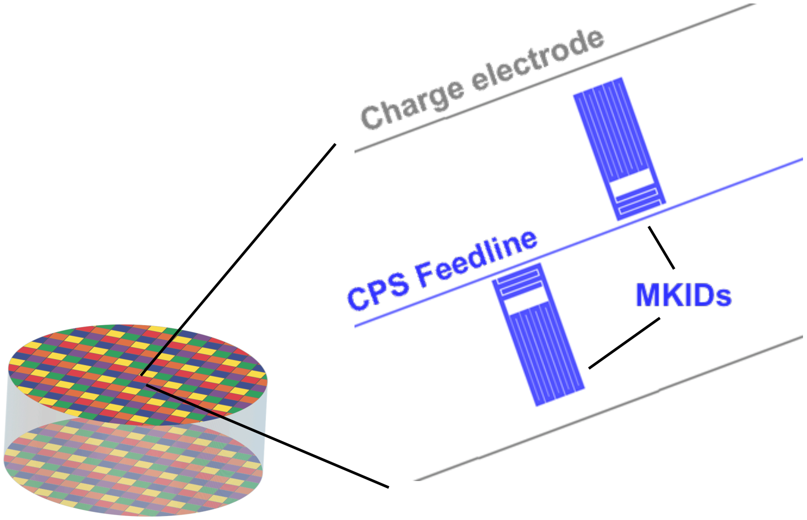
- Microwave kinetic inductance detectors (MKIDs, Zmuidzinas et al) can detect phonon energy: meV phonons break Cooper pairs, change L of superconductor
- Multiplexable: Form LC resonator w/single superconducting film. Readout like FM/AM radio with digital signal generation and demodulation.
- Recent development of lumped-element designs having low susceptibility to dielectric constant fluctuation noise and using large penetration depth materials enables large-area resonators for phonon sensing (Day, Gao, LeDuc, Noroozian, Zmuidzinas)
- Single film, 5 μm features would simplify GEODM detector fab
- Finer pixellization of phonon sensor provides additional surface event rejection

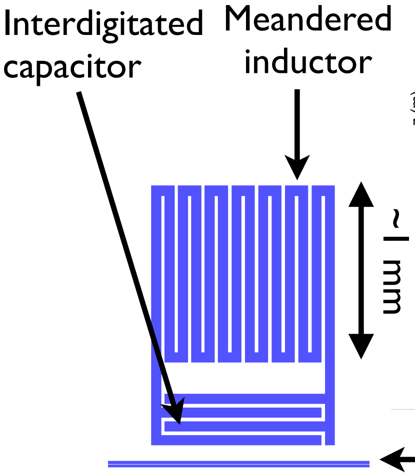
Surface event:



Bulk event:





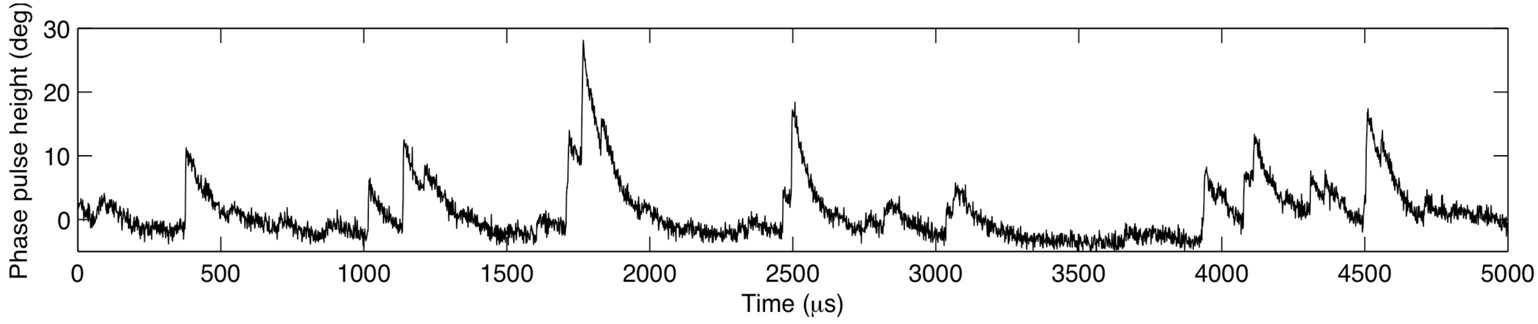


coplanar stripline (CPS) feedline to excite/probe resonator

Figures by D. Moore

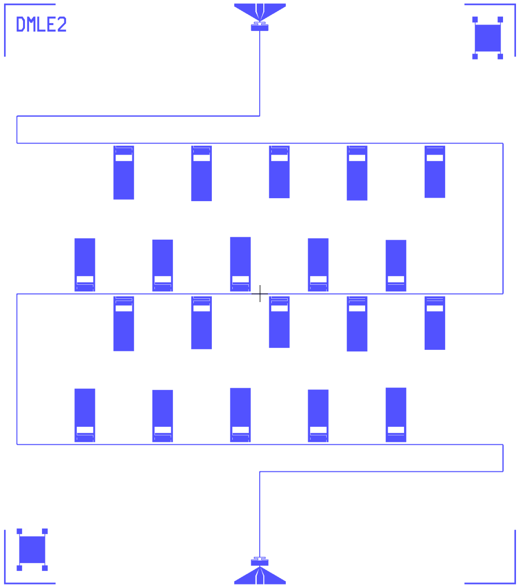
Expected Sensitivity

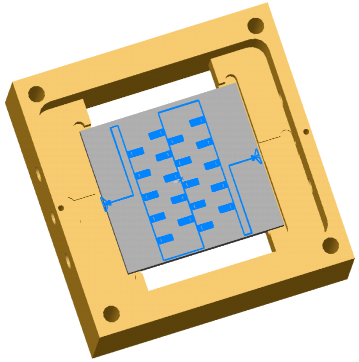
- Phonon-mediated 6 keV X-rays observed with ~100 μs lifetimes in mm^2 resonators:



D. Moore

- Using measured noise and responsivities, calculate a noise-equivalent power (NEP)
- Converting to an energy resolution gives: $\sigma_E = 46$ eV for A = 1.5 mm^2 and $\sigma_E = 14$ eV for A = 0.64 mm^2 (single-resonator resolution)
- Numbers agree with measured resolution for 5 eV photons in ~0.1 mm^2 resonators, scaled by responsivity
- An MKID-based detector with 500 one mm^2 resonators would have similar energy resolution as current designs, but would be much easier to fabricate and read out
- 12 mm x 16 mm array of 20 resonators soon to be tested with collimated source to demonstrate position reconstruction!





Project(s) Status

- SuperCDMS Soudan
  - Fully approved (review Aug 2009); preparing final project execution plan
  - First detectors running underground since mid-2009, installing new detectors this year/next year, interesting exposure by end 2011
- SuperCDMS SNOLAB
  - iZIP + 100 kg total mass received substantial endorsement from PASAG
  - SLAC has joined experiment
  - requesting R&D funds this year, project proposal next year, hope for FY13 construction start
  - SNOLAB test facility being assembled to demo iZIP rejection underground ASAP
- GEODM DUSEL
  - iZIP + 15 cm x 5 cm to provide 1.5 T detector mass
  - "S4" DUSEL engineering study proposal funded
  - Working on production of large crystals and automation of fab using evolution of current detector design
  - Caltech working on simplified phonon sensors using MKIDs
  - SNOLAB test facility will provide underground demonstration of rejection

Exciting Times!

- Remarkable progress
  - 2 orders of mag in ~10 yrs
  - Predictions for larger gains in next decade
- LHC data soon!
  - perhaps a prediction based on detecting SUSY; perhaps a confirmation of a DD signal