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New results from CDMS II

Introduction

Non baryonic dark matter

WIMPs: a generic consequence of new physics at TeV scale

Situation: Summer 2009

New results

CDMS II blind analysis

Results

Discussion

What next?

Further exploitation of existing data

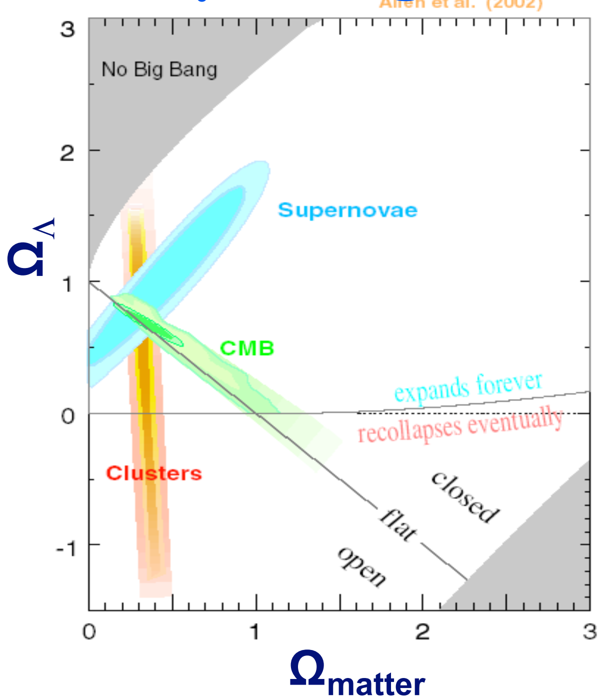
An opportunity for the field

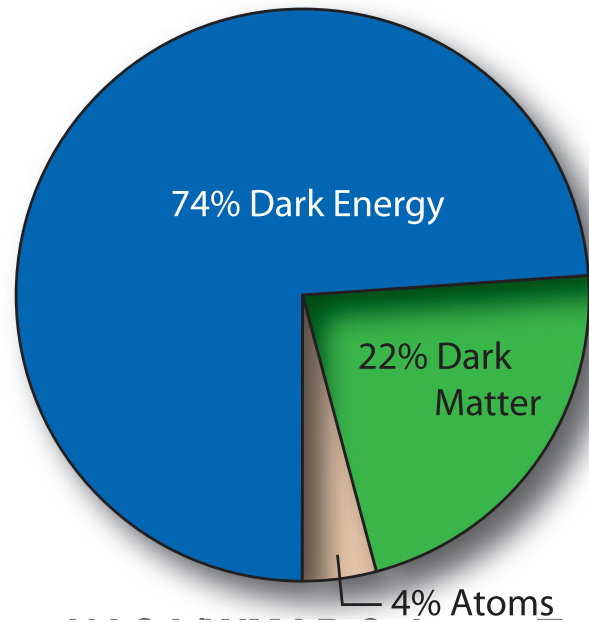
SCDMS @ Soudan, SCDMS @ SNOLAB, GEODM

Conclusions

Standard Model of Cosmology

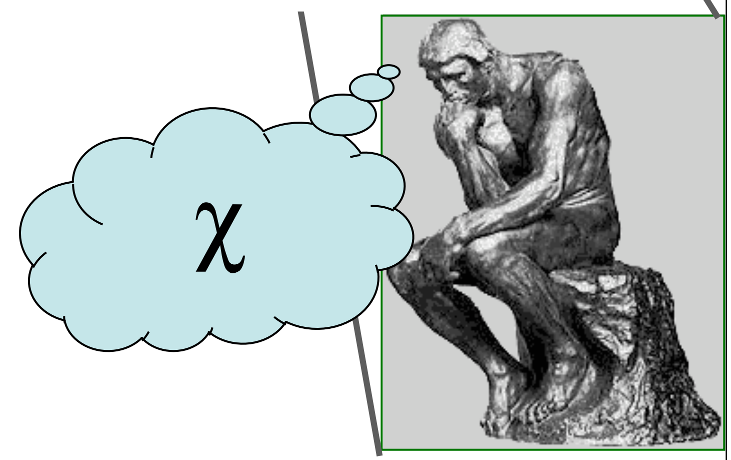
A surprising but consistent picture





Not ordinary matter (Baryons)

$$\Omega_m >> \Omega_b = 0.047 \pm 0.006 \text{ from } \left| \begin{array}{c} \text{Nucleosynthesis} \\ \text{WMAP} \end{array} \right.$$



Mostly cold: Not light neutrinos≠ small scale structure

Standard Model of Particle Physics

Fantastic success but Model is unstable

Why is W and Z at ≈100 M_p?

Need for new physics at that scale

supersymmetry

additional dimensions

In order to prevent the proton to decay, a new quantum number

=> Stable particles: Neutralino

Lowest Kaluza Klein excitation

Bringing both fields together: a remarkable concidence

Particles in thermal equilibrium
+ decoupling when nonrelativistic

Freeze out when annihilation rate ≈ expansion rate

$$\Rightarrow \Omega_x h^2 = \frac{3\cdot 10^{-27}\, cm^3/s}{\langle \sigma_A v \rangle} \Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$

Cosmology points to W&Z scale

Inversely standard particle model requires new physics at this scale

(e.g. supersymmetry or additional dimensions)

=> significant amount of dark matter

Weakly Interacting Massive Particles that can be detected by:
scattering, annihilation, production at LHC

Halo WIMP Scattering "Direct Detection"

Elastic scattering

Expected event rates are low

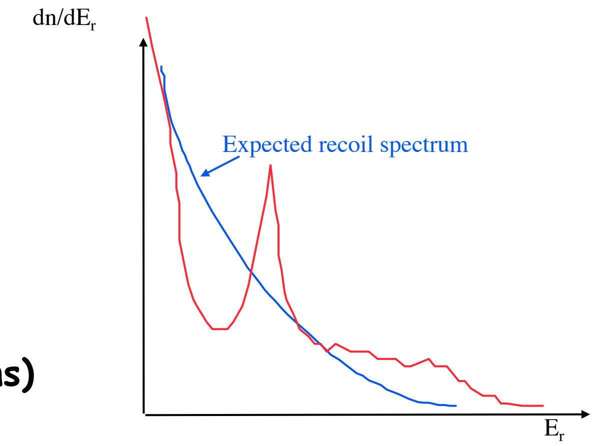
(<< radioactive background)

Small energy deposition (≈ few keV)

<< typical in particle physics

Signal = nuclear recoil (electrons too low in energy)

≠ Background = electron recoil **(if no neutrons)**



Signatures

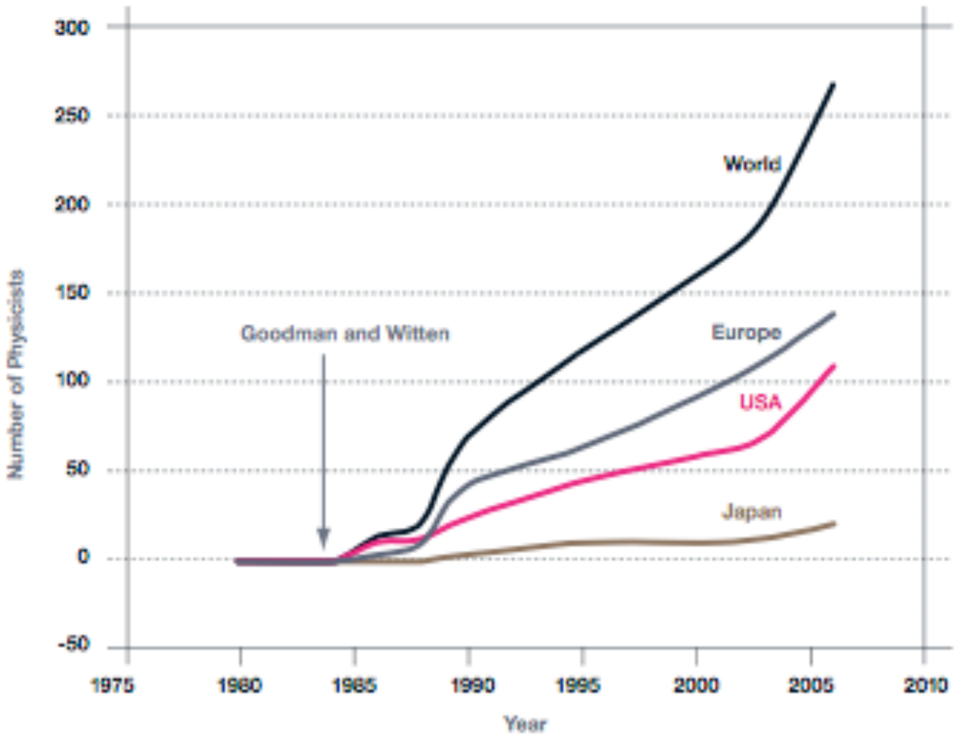
- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector

Linked to galaxy

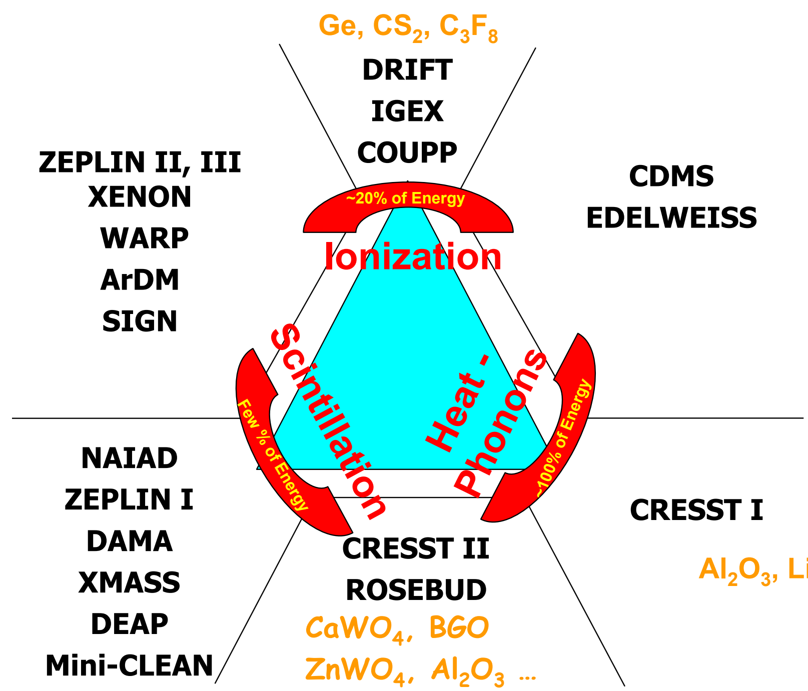
- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

Experimental Approaches

A blooming field



Direct Detection Techniques



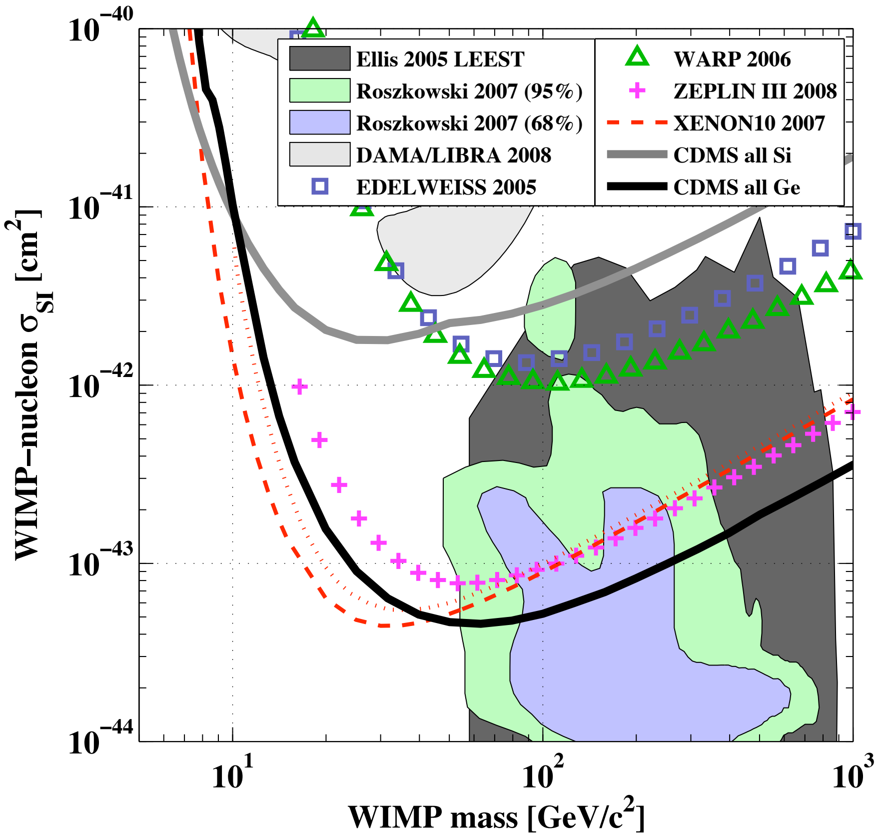
As large an amount of information and a signal to noise ratio as possible

At least two pieces of information in order to
- recognize nuclear recoil
- extract rare events from background (self consistency)
- + fiducial cuts (self shielding, bad regions)

Situation Summer 2009

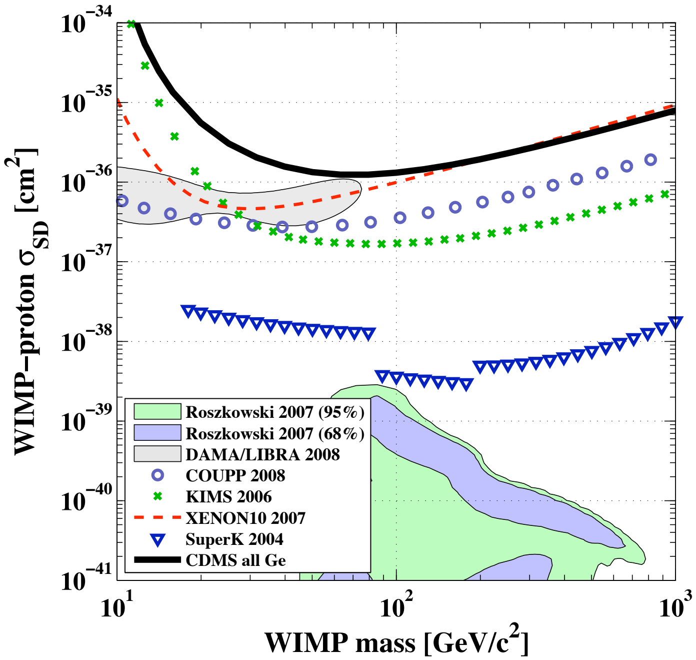
Scalar couplings: Spin independent cross sections

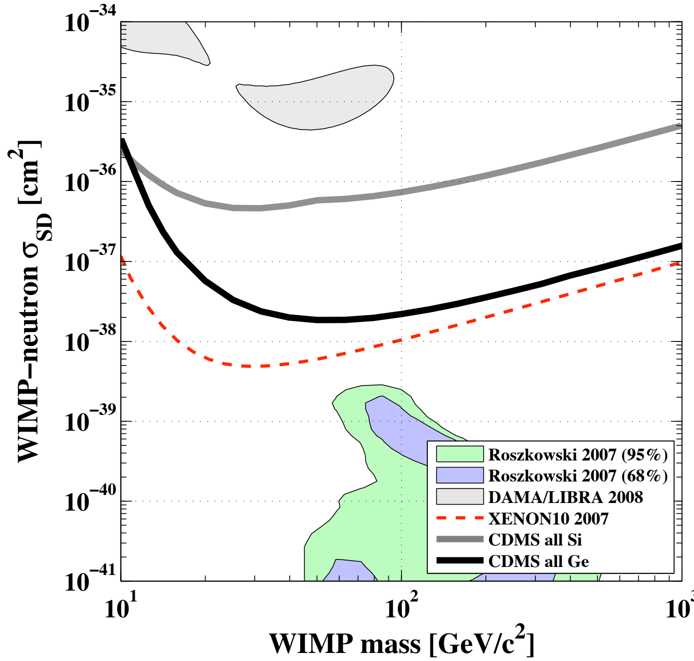
January 2009 compilation by Jeff Filippini
Gray=DAMA 2 regions(Na, I) from Savage et al.



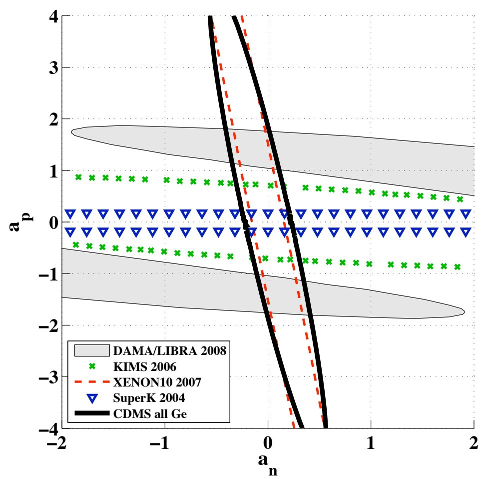
Situation Summer 2009

Spin dependent couplings





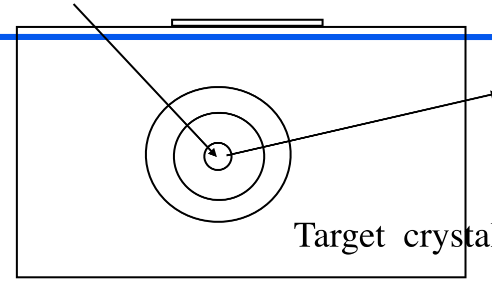
a_p vs a_n at mass of $60 GeV/c^2$



CDMS

Principle: Detect lower energy excitations

15 keV large by condensed matter physics standards



=> High signal to noise ratio

+ Several pieces of information
  - ionization (threshold ≈2keV ee)
  - arrival time of athermal phonons
  - rise time

cf EDELWEISS

- Higher ionization threshold
- only thermal phonons (Heat)
- New interdigitated geometry

=> multidimensional discrimination

Only technique so far with zero background!

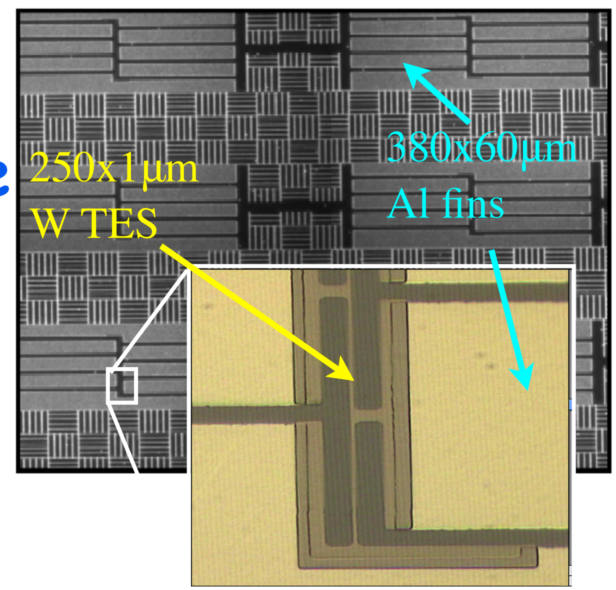
Xenon has to master contamination in liquid to be self shielding

Argon has to reduce/reject ^{39}Ar

Challenge: operation at low temperature

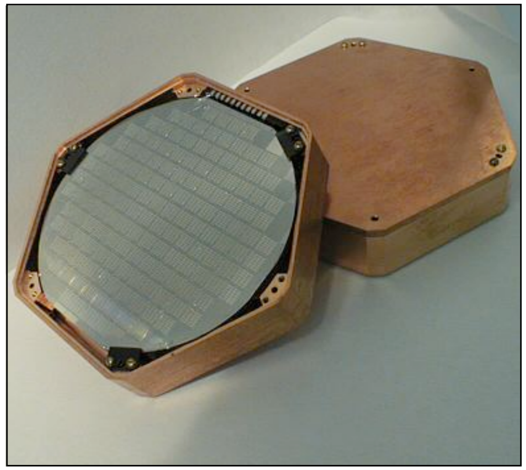
+ sophisticated technology

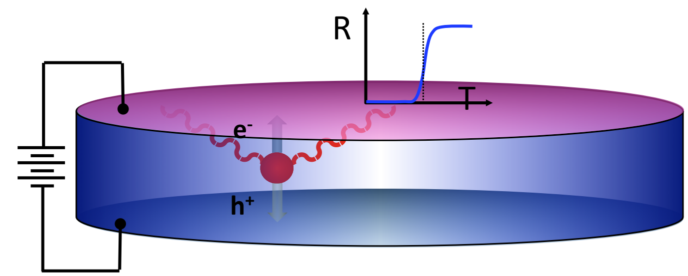
intensive in manpower for fabrication and testing



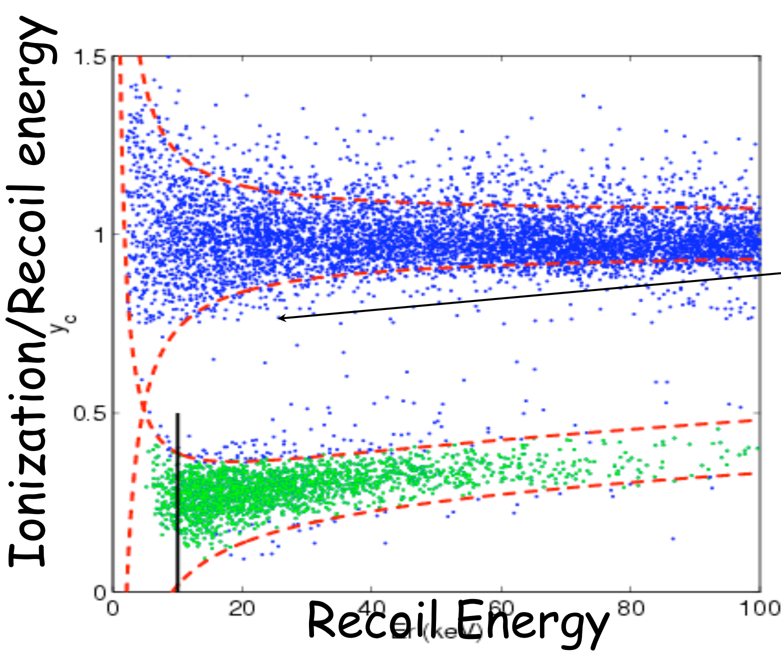
Multidimensional Discrimination

7.5 cmØ 1 cm thick ≈250g
4 phonon sensors on 1 face
2 ionization channel



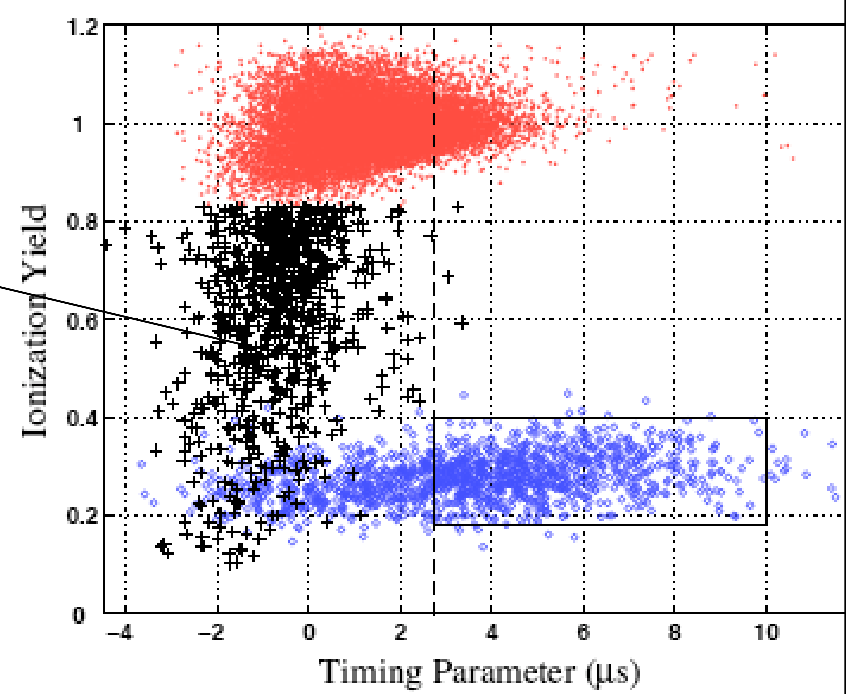


Ionization yield



Surface Electrons

Timing -> surface discrimination



(S)CDMS

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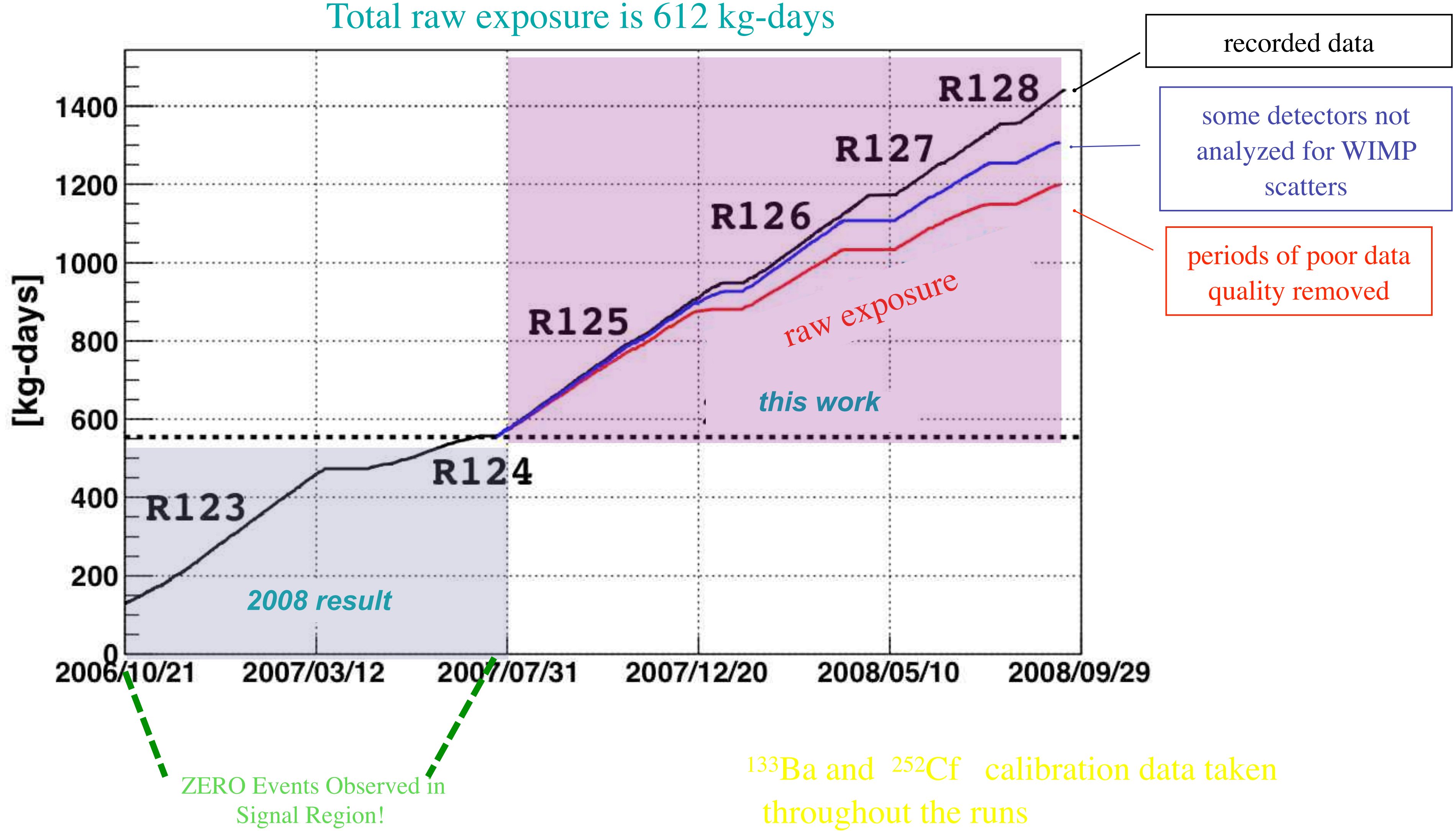
WIMP Search Exposure

4 runs separated by partial warmups of cryostat

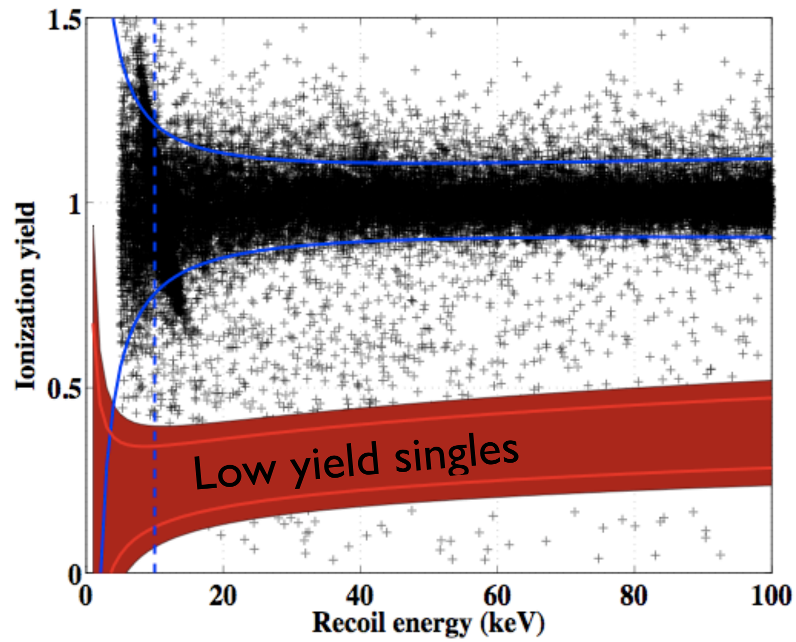
Dates of data taking: 7/2007 - 9/2008

Total raw exposure is 612 kg-days



^{133}Ba and ^{252}Cf calibration data taken throughout the runs

Analysis Overview

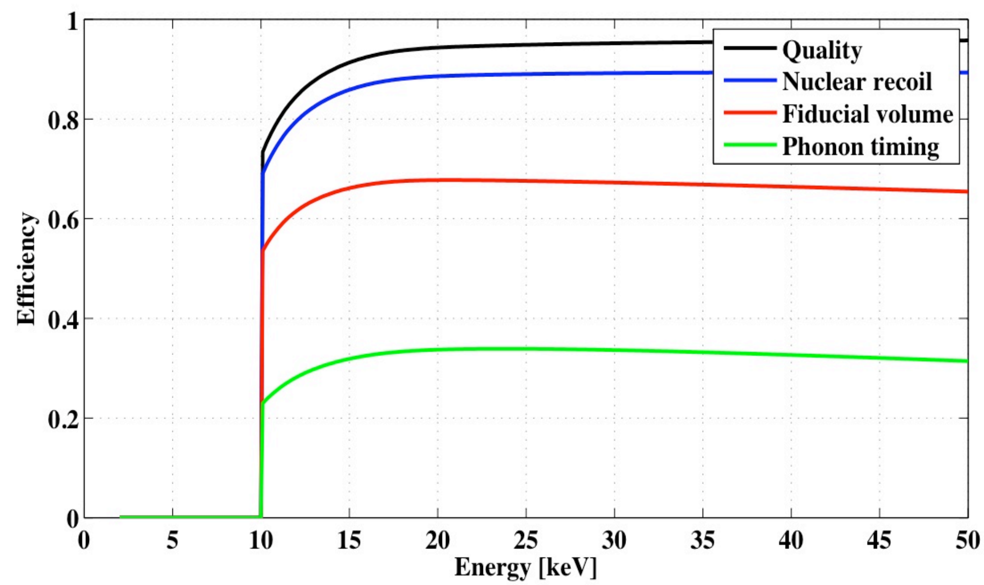


Blind analysis: Low yield singles masked

1. Reconstruction
   - pulse reconstruction (fits, etc.)
   - **position correction**
   - energy calibration

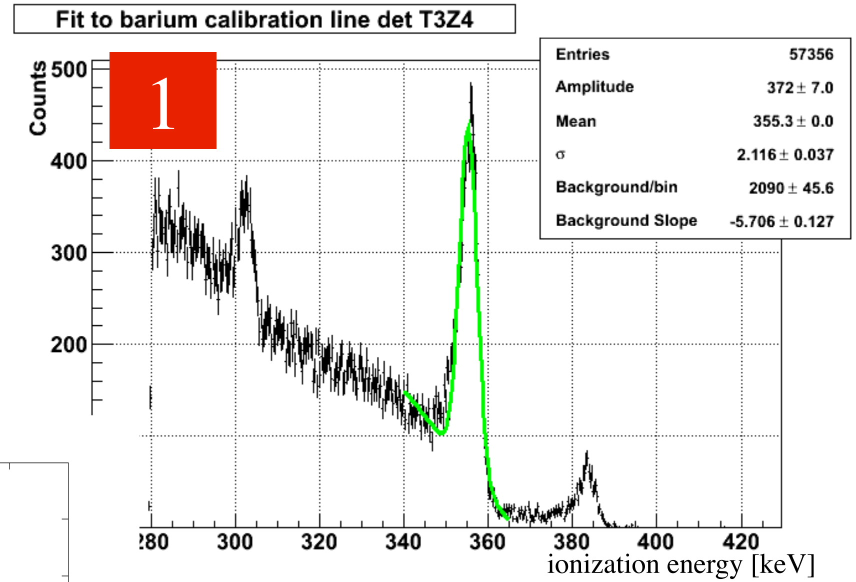
2. Data quality
   - cuts pile-up, period of poor noise or detector performance, bad neutralization
   - reconstruction failure

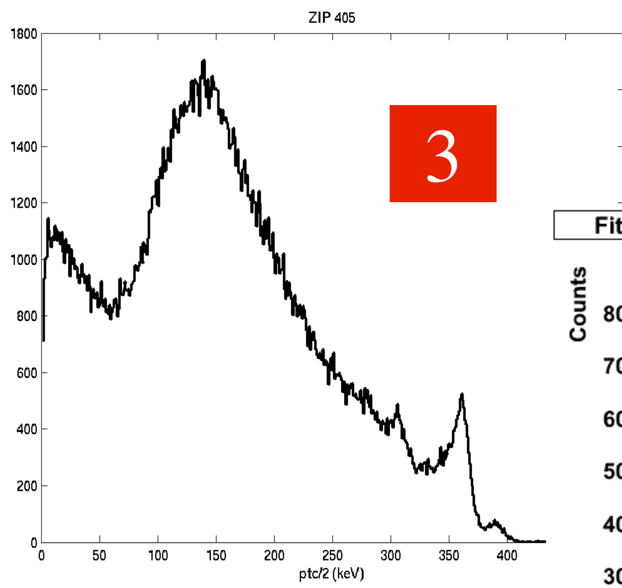
3. Physics
   - veto anti-coincidence cut
   - single scatter
   - Q_{inner} (fiducial volume)
   - ionization yield
   - Phonon timing

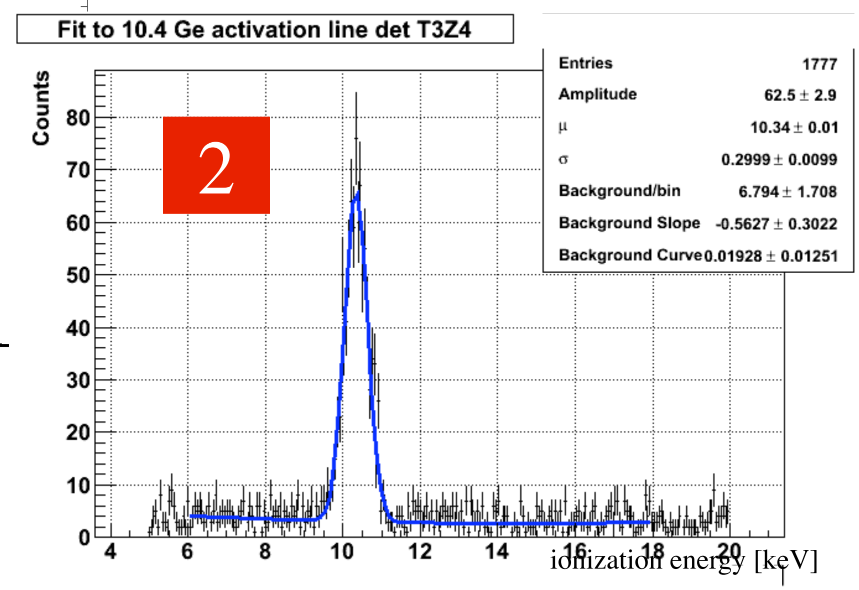


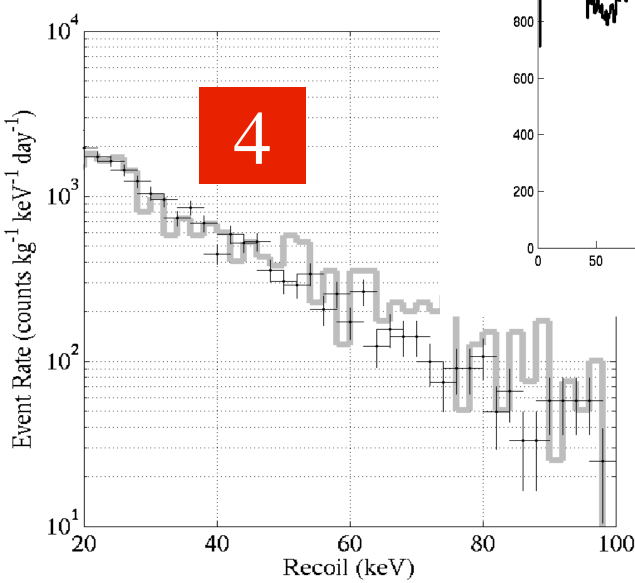
Energy calibration

1. Use 356 keV ^{133}Ba lines to calibrate Ionization
2. 10.4 keV (Ge activation), 303 keV, and 384 keV lines confirm linearity
3. Calibrate Phonons against Charge
4. =>Nuclear recoils (^{252}Cf) consistent with MC

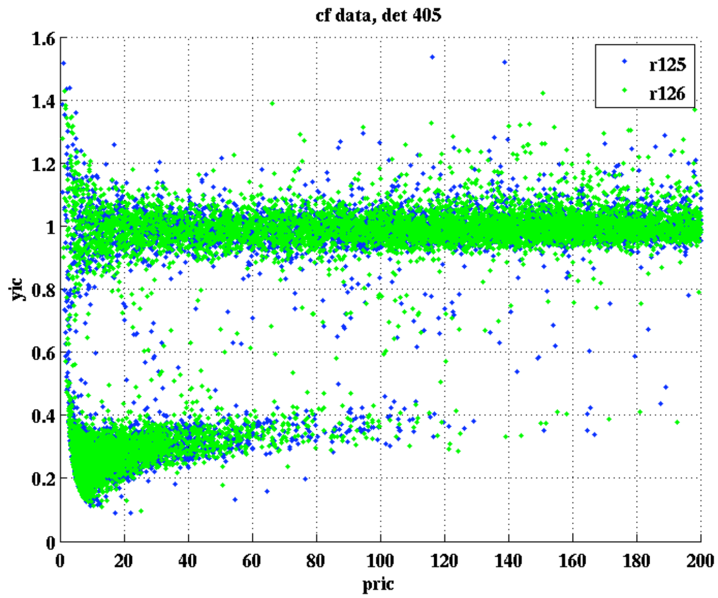


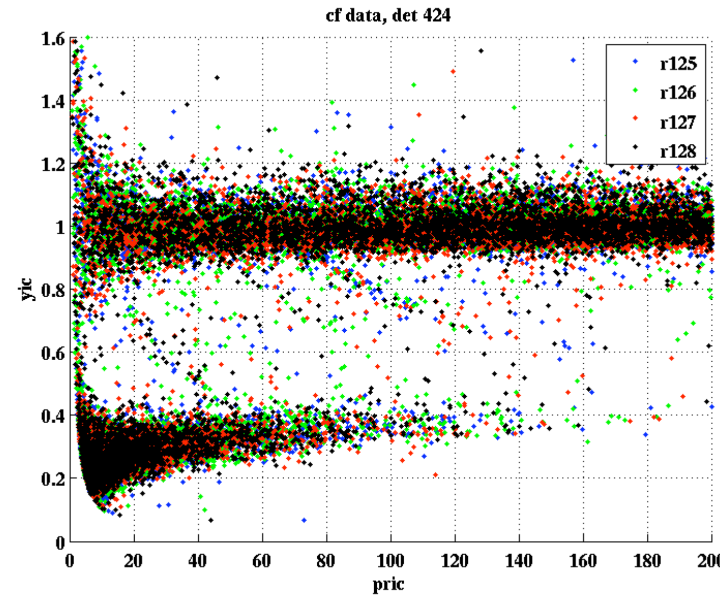


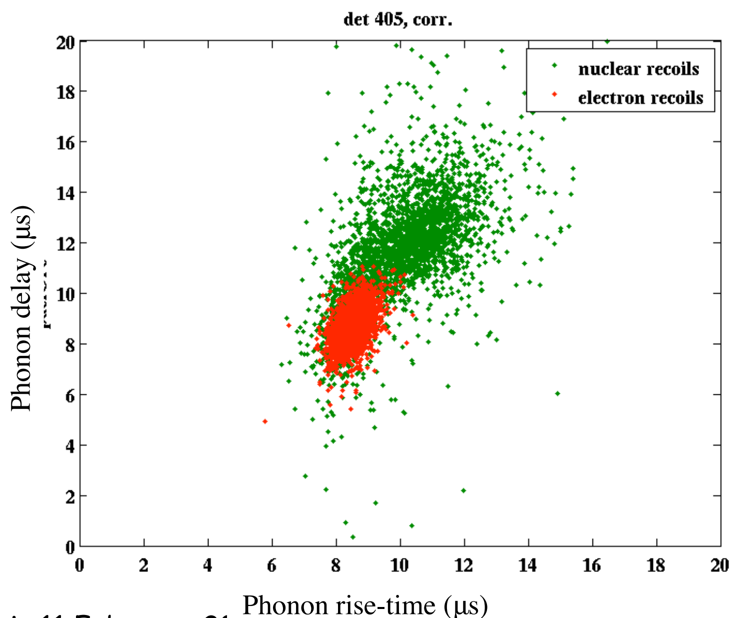


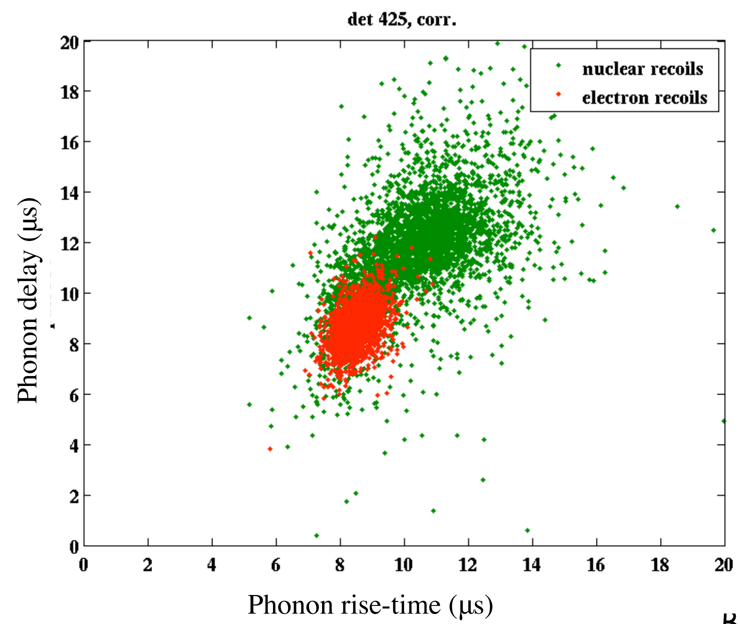


Calibration with sources



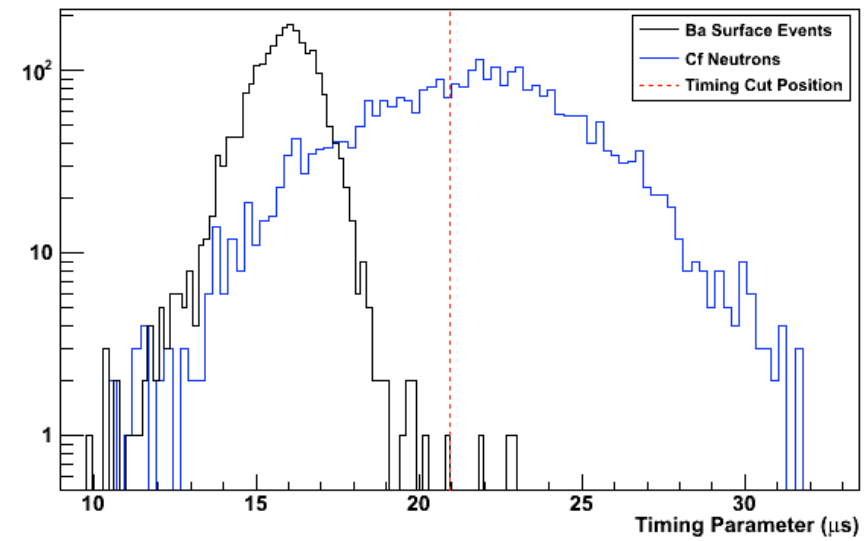


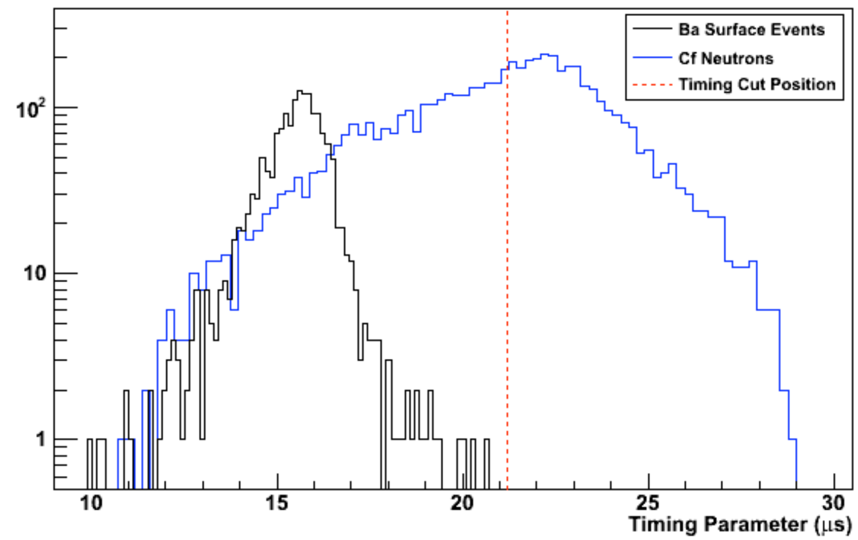




Surface Event Background

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





Timing parameter:

phonon delay + main phonon risetime

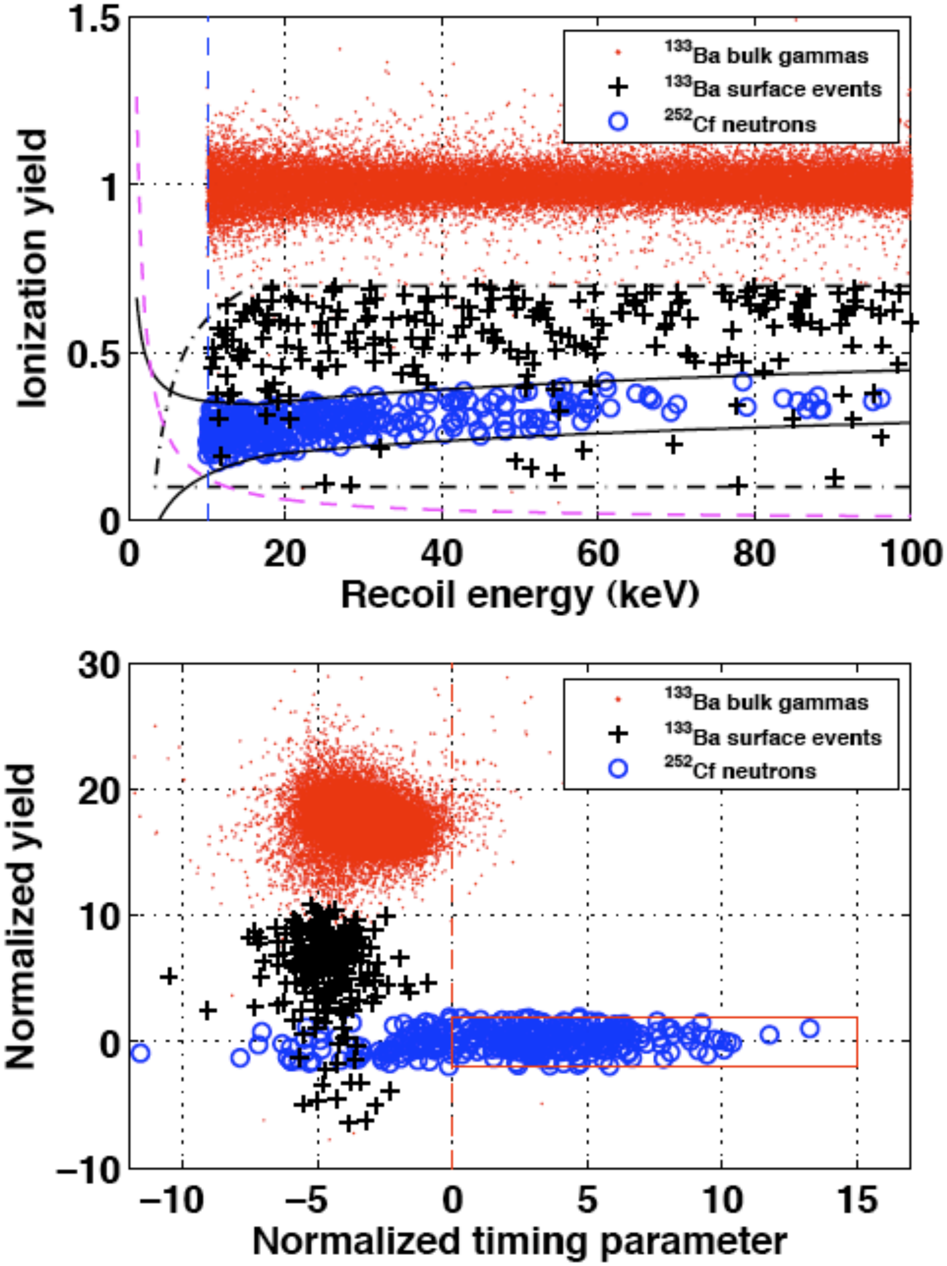
We optimized for the best sensitivity

(≈0.6 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

The bottom line (Sources)



Surface Event "Leakage" Estimate

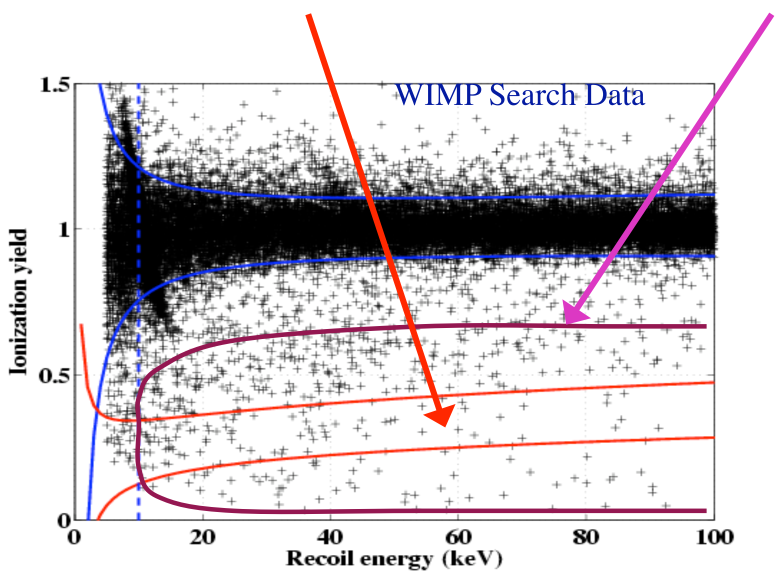
$$\text{Expected surface leakage} = \frac{N^{\text{sideband}}_{\text{passing cut}}}{N^{\text{sideband}}_{\text{failing cut}}} * N^{\text{data}}_{\text{failing cut}}$$

3 independent methods:

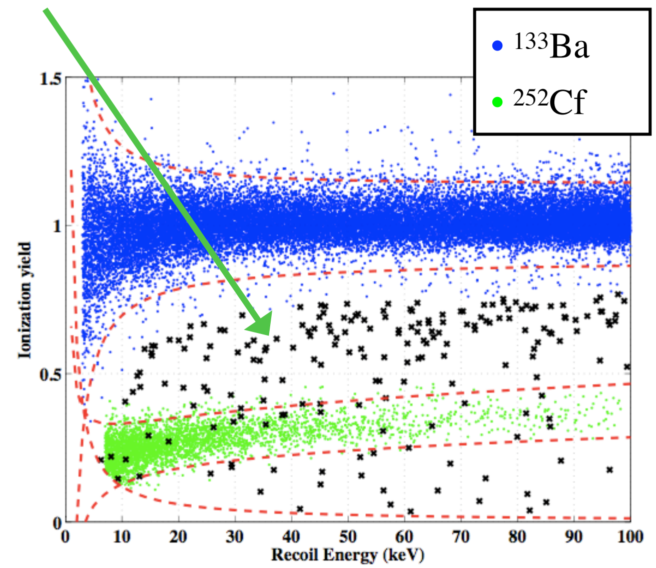
Method 1
Use multiple-scatters in NR band

Method 2
Use singles and multiples just outside NR band

Method 3
Use singles and multiples from Ba calibration in wide region



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



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

Estimated Neutron Background

- Cosmogenic Neutron Estimate:

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

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*

Total neutrons ≈ 0.1±0.05 event

=> Total pre-blind estimate of background 0.7 evt ±0.2

Blind Analysis Results

Rules of the game

Establish without looking in this region, a window in measurement space where signal efficiency is high and backgrounds strongly suppressed. √

Important to prevent bias: well defined efficiency

≠"I like or don't like this event"

No background subtraction (dangerous because we do not know background well)

Commitment to publish what you see

Check what you get: post-unblinding analysis

Check for obvious mistakes

High threshold to reject events:

The more you look, the more likely you are

bias against signal

difficulty to give an efficiency

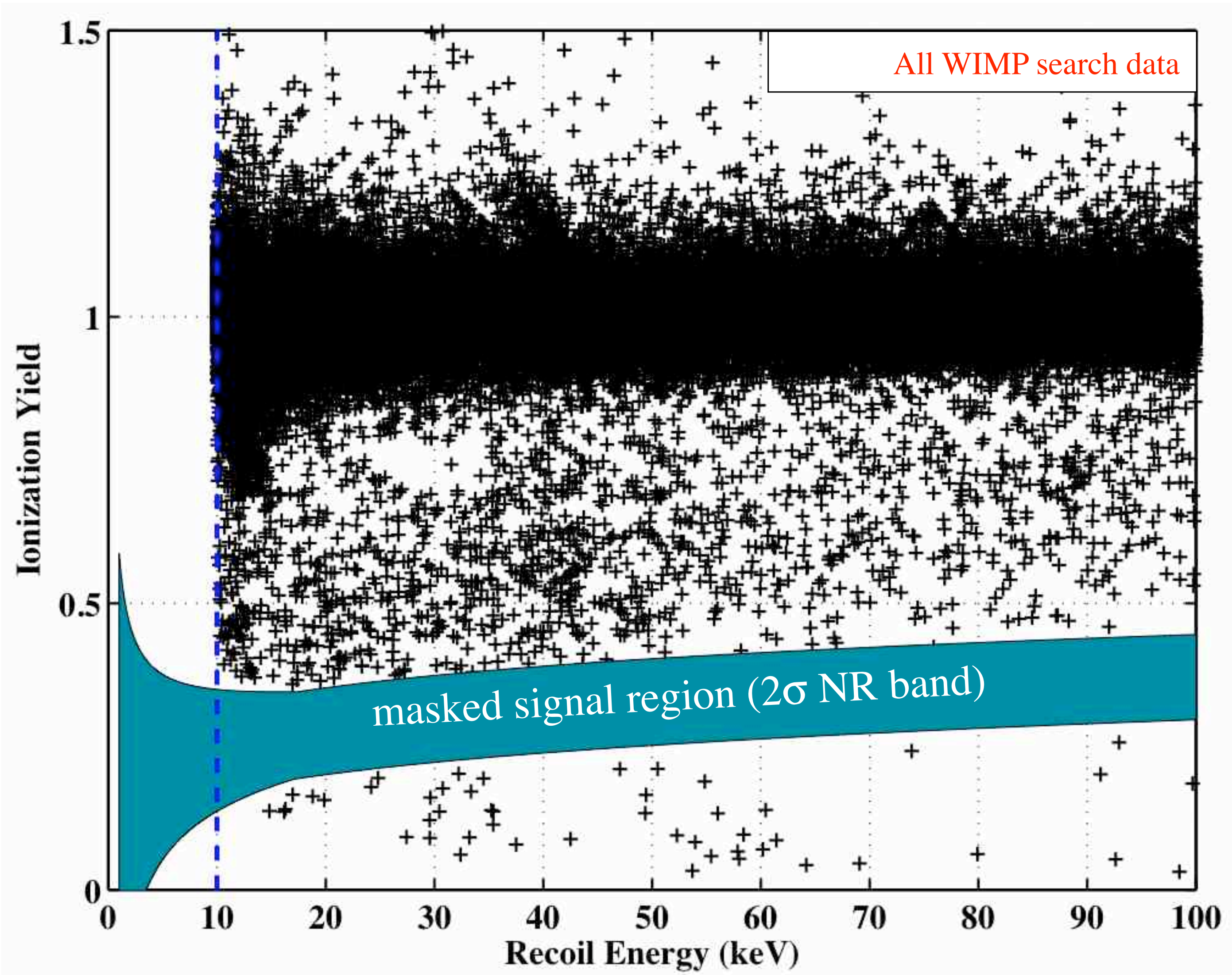
Obvious limits

You can be blind only once

Do not take into account the distribution of events in measurement space

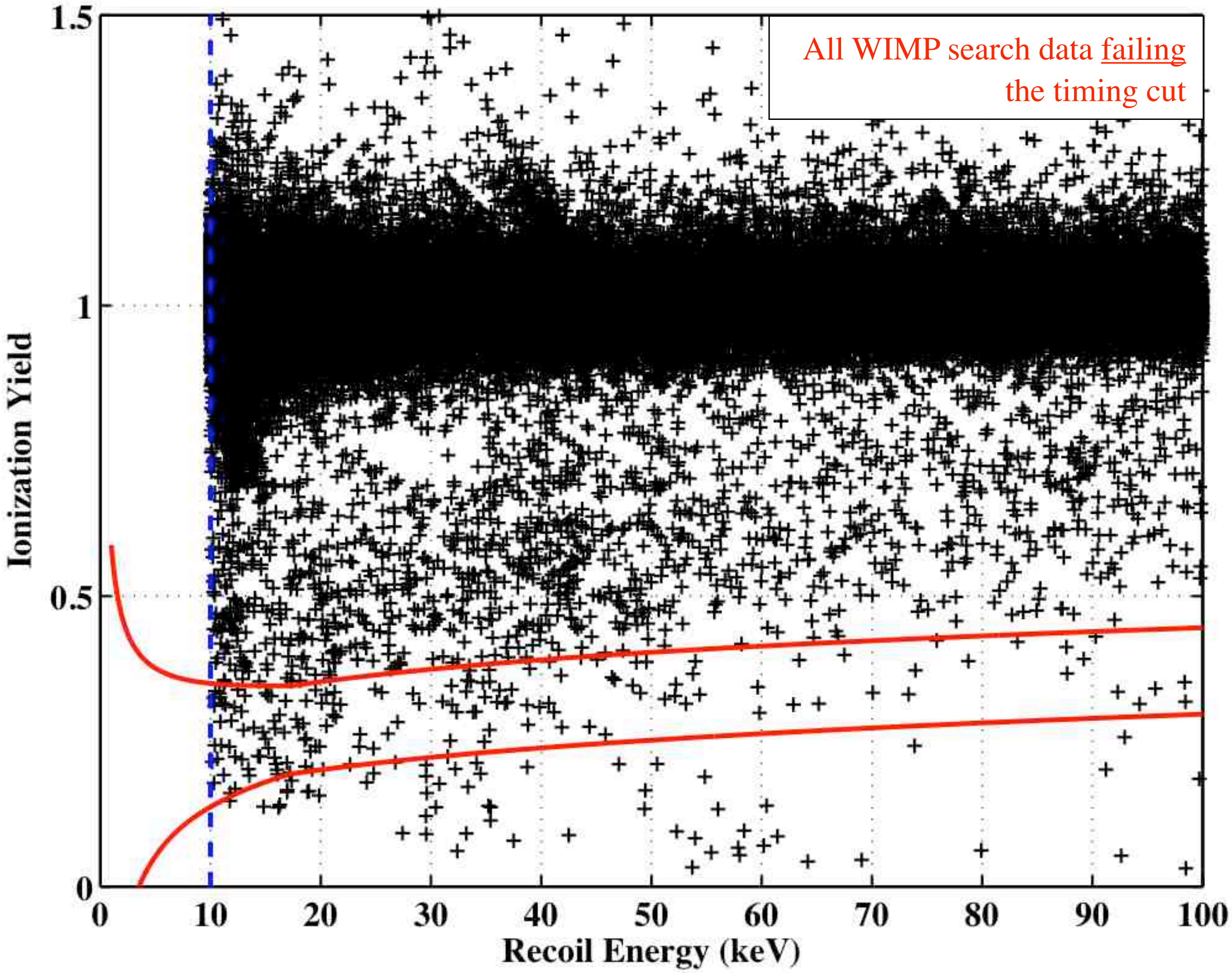
Likelihood methods but not blind and background subtraction

Unblinding



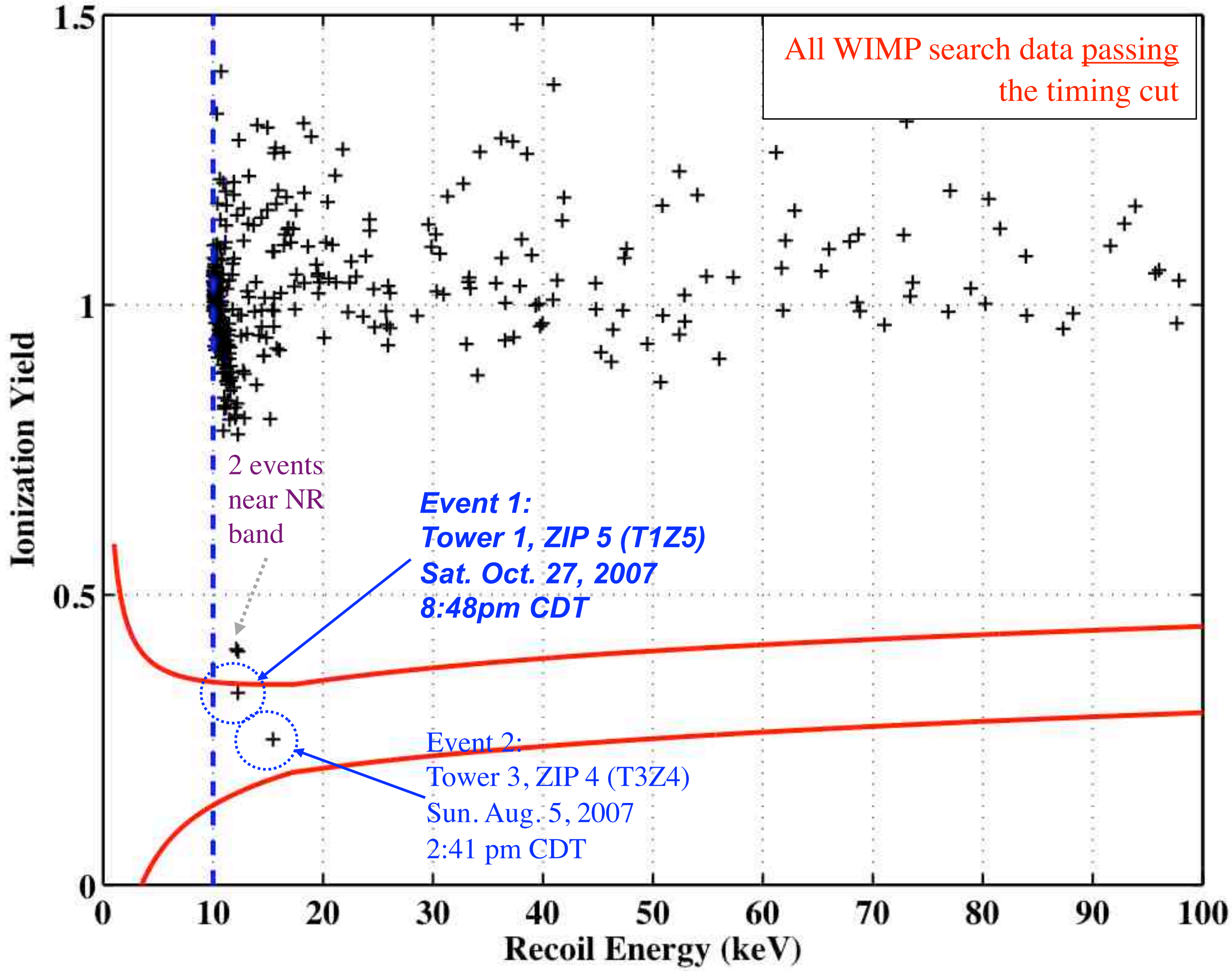
We unblinded the signal region November 5, 2009

Unblind Events Failing Timing Cut



150 events in the NR band fail the timing cut, consistency checks deemed ok

Unblind Events Passing Timing Cut

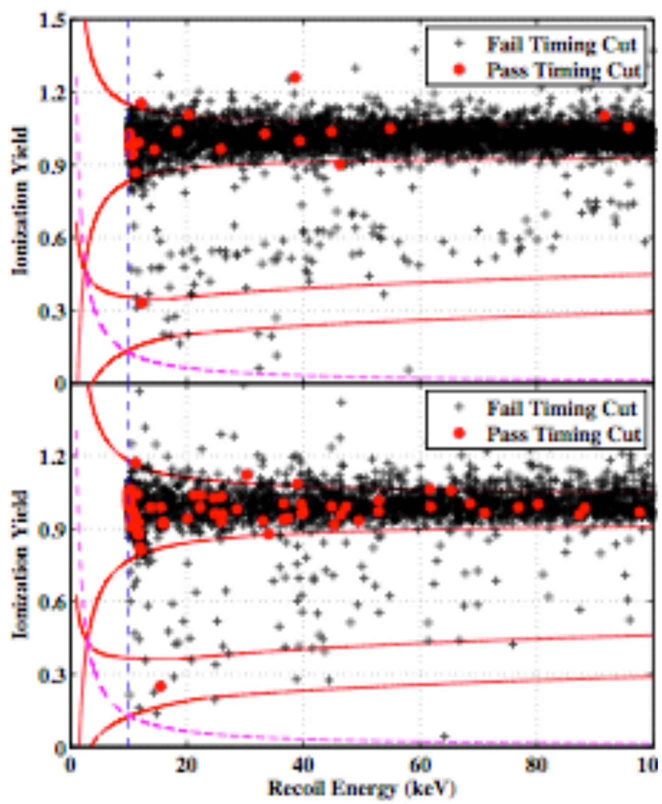


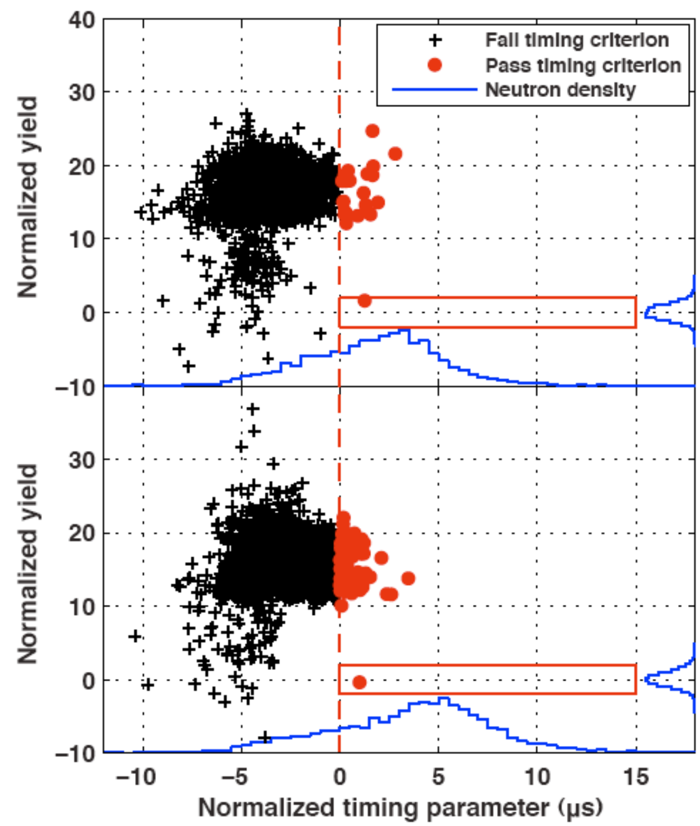
2 events in the NR band pass the timing cut!

Closer look at the 2 events

Saturday Oct, 27th 2007

Sunday Aug, 5th 2007





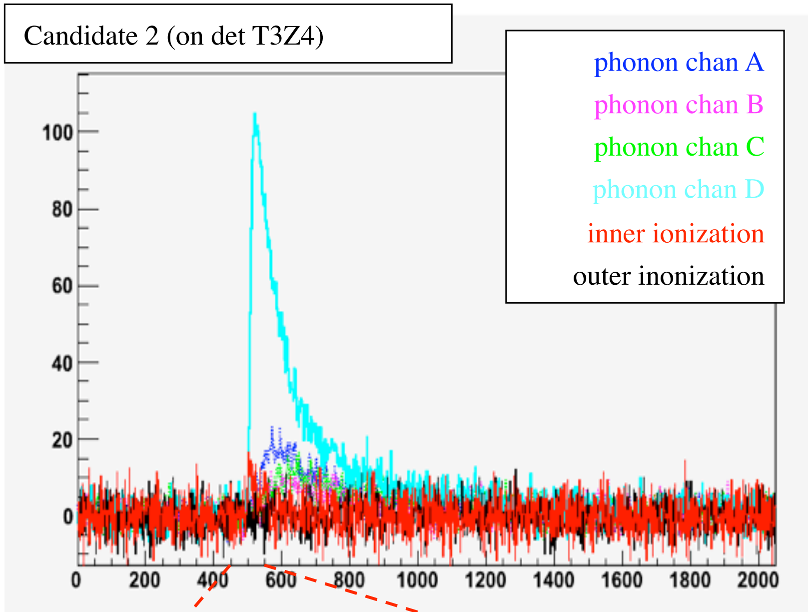
Events happened in two different detectors in two different towers at well separated times

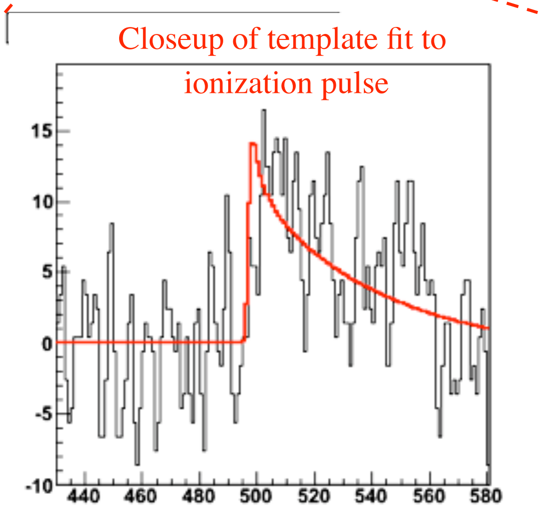
Post- blinding: Data Quality Re-checks

Data Quality Item	Result
muon veto performance	✓ *good*
neutralization	✓ *good*
KS tests	✓ *normal*
noise levels	✓ *typical*
pre-pulse baseline rms	✓ *typical*
background electron-recoil rate	✓ *typical*
surface event rate	✓ *typical*
radial position	✓ *well-contained*
single-scatter identification	✓ *good*
special running conditions	✓ *no*
operator recorded issues	✓ *no*

At the recorded time of both events, the experimental performance was excellent

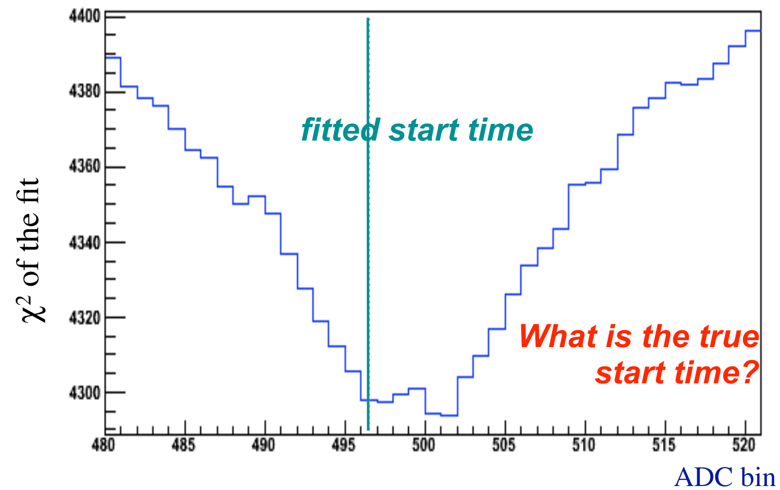
Reconstruction checks





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

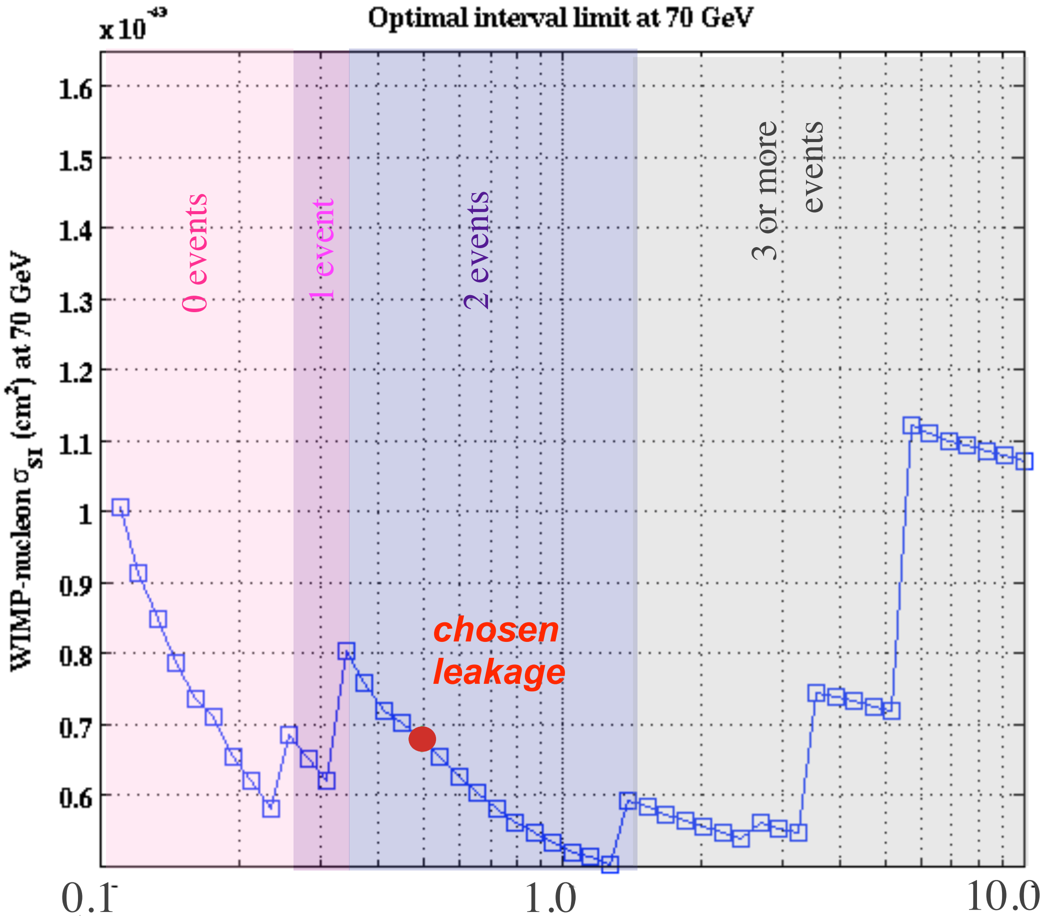
Could there be a problem with the start time of the charge pulse? (affects timing parameter)



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

To be sure, include conservative 0.2 correction in number of expected surface events

Cut Varying Study



estimated surface event leakage from ^{133}Ba
0.5->0.8 final estimate of surface evts

- Tightening cut to ~1/2 the expected leakage, removes all 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 calculated limit doesn't depend strongly on chosen surface-event rejection cut value

Signal or Background?

Taking this into account, our new estimate

0.8 ± 0.1 (stat) ± 0.2 (syst) surface events

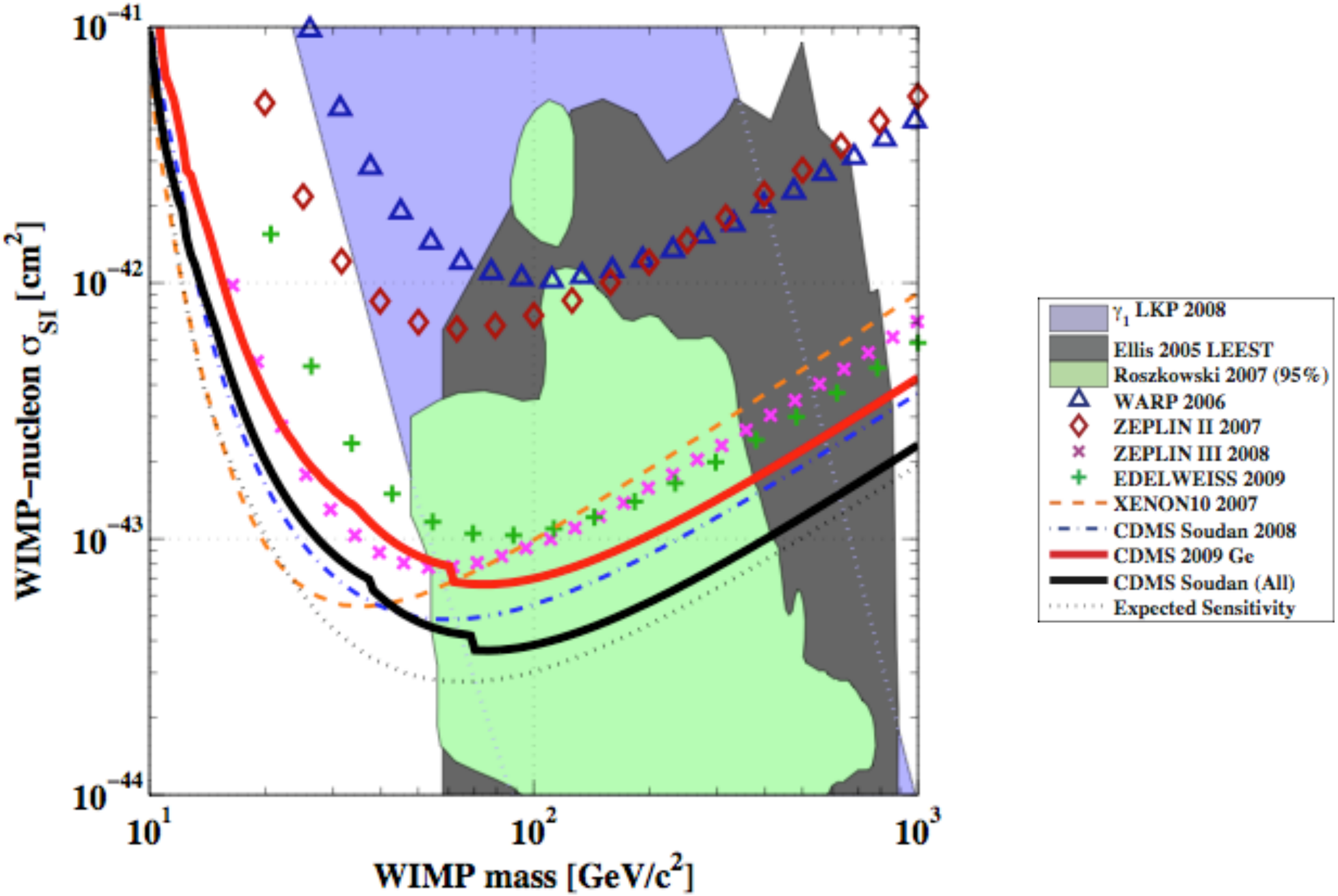
+ 0.1 ± 0.05 (syst) neutron

After including the neutron background, the probability to observe 2 or more events is 23%

These values indicate that the results of this analysis cannot be interpreted as significant evidence for WIMP interactions, but within the confine of a blind analysis we cannot reject either event as signal.

90% C.L. Spin-Independent Limit

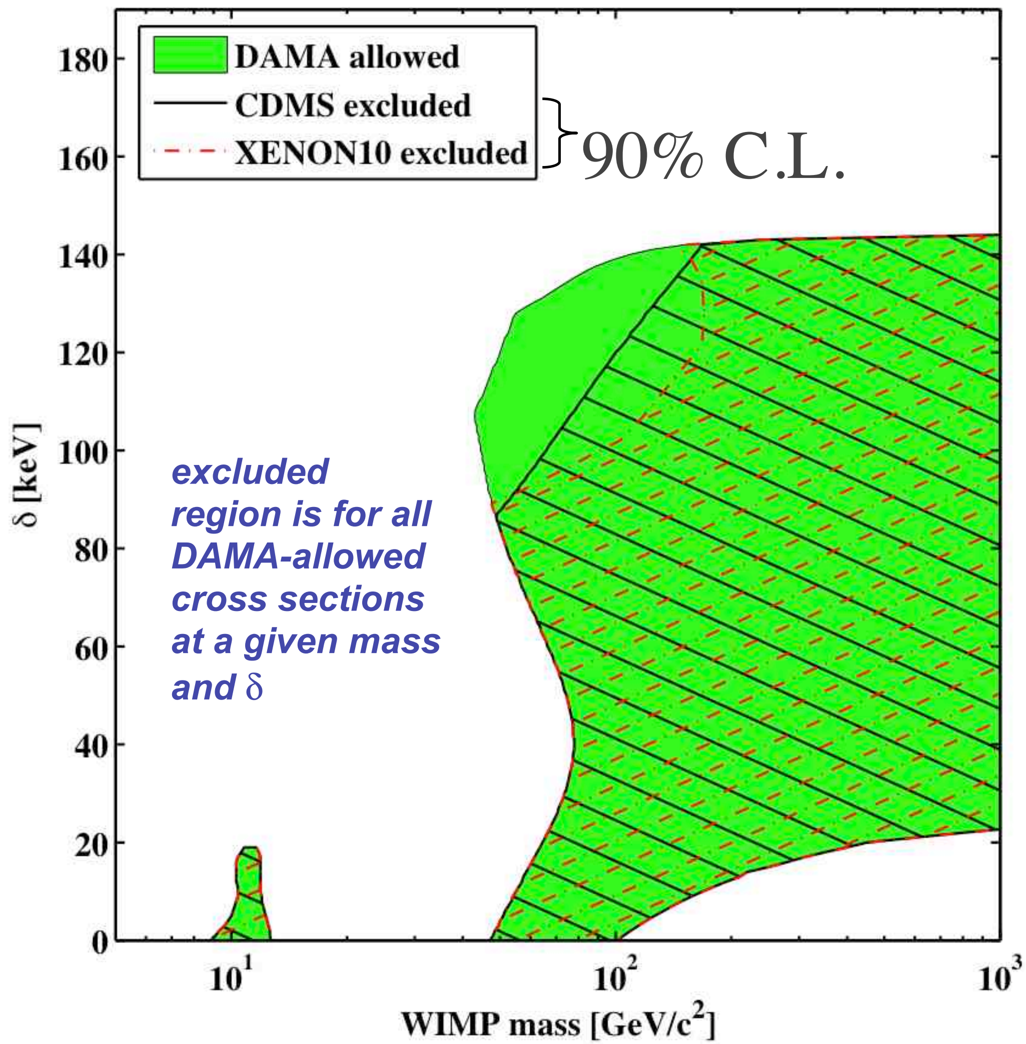
Science 12 February 2010



Upper limit at the 90% C.L. on the WIMP-nucleon cross section :

3.8×10^{-44} cm^2 for a WIMP of mass 70 GeV/c^2

Inelastic Dark Matter



No channeling

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]

What next?

Extract more from the current data: ≈ summer 2010

better algorithms

in particular better ionization fit (narrower distributions)

we can then reset our cuts with the same methods and background level

goals: no more formally blind, but quasi-blind

likely some movement of events in and out

take into account **the position of individual events in measurement space**

soon: probabilities to be as far from main distribution or that close t edges

summer: full likelihood analysis

An exciting time for the field

Xenon 100, EDELWEISS

LUX, WARP

Xmass

LHC and indirect detection

Next phase for CDMS

15kg installed at Soudan in winter 2011

100kg SNOLAB (strongly supported by PASAG)

GEODM 1.5 tons at DUSEL

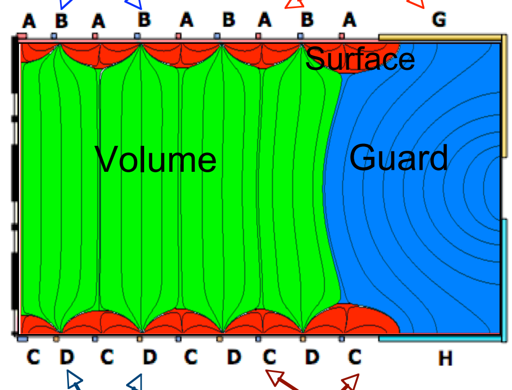
An important goal: maintain ≈0 background with increased exposure

Rejection has to increase proportionally with the mass

Interdigitated

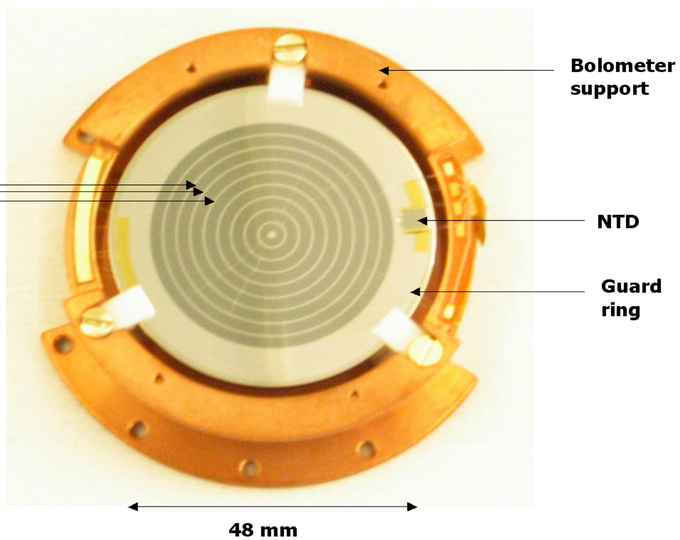
Breakthrough: Interdigitated detectors

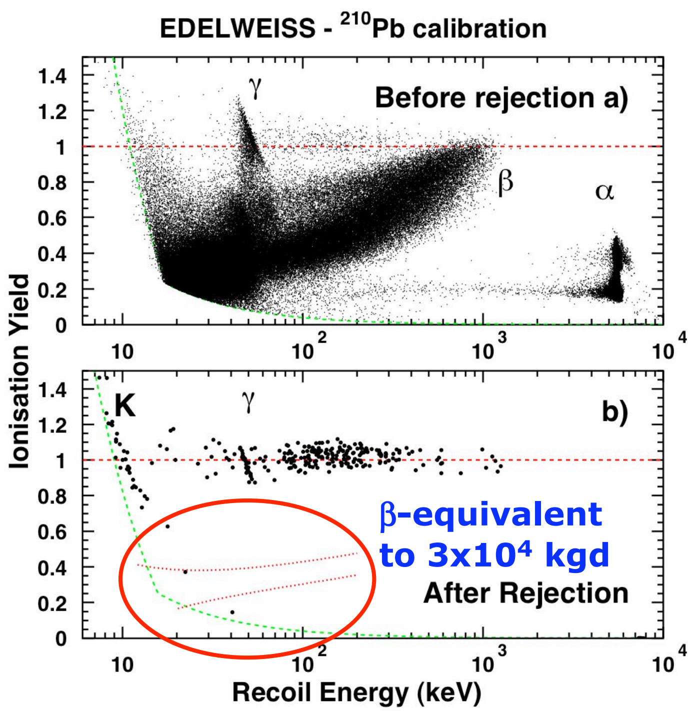
Positive and ground electrodes on top side
Negative and ground on negative
=> separate surface (asymmetric) from bulk (symmetric)
Initial demonstration with Si: CDMS LTD11 (2005)

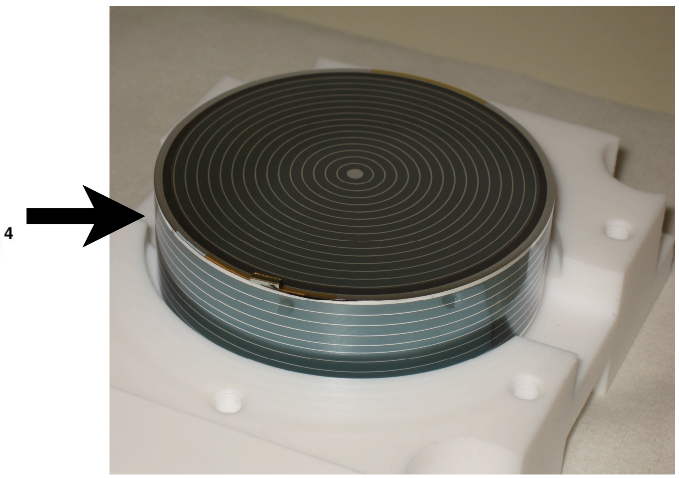


Underground demonstration EDELWEISS

Shows that low field regions are not a problem (Diffusion)



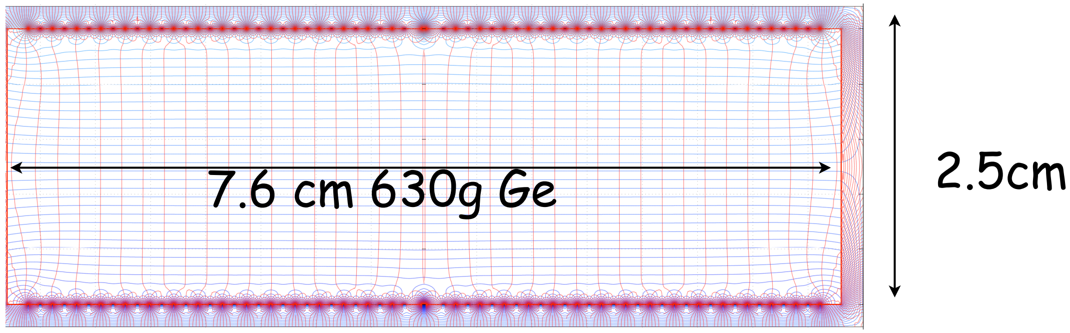




iZIP Rejection of surface

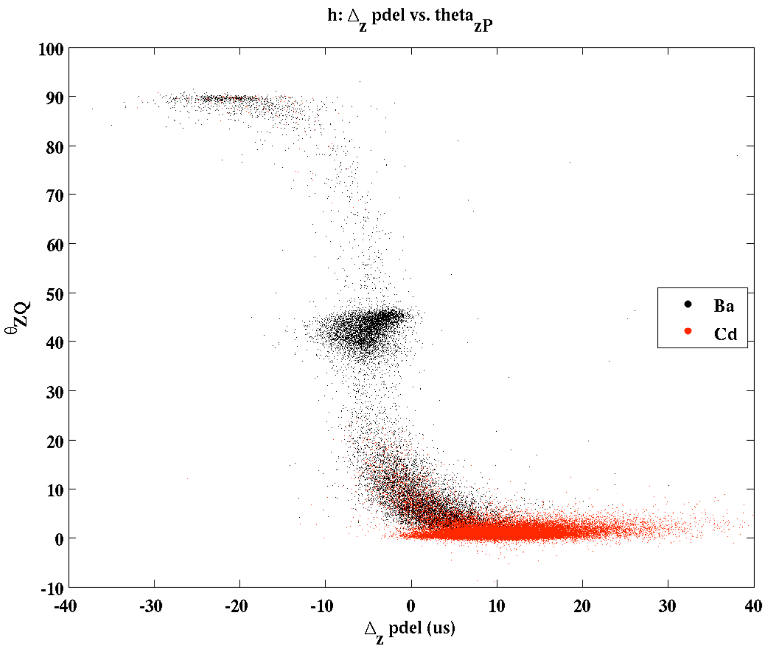
CDMS

Smaller rails
Athermal phonons sensors on both surfaces

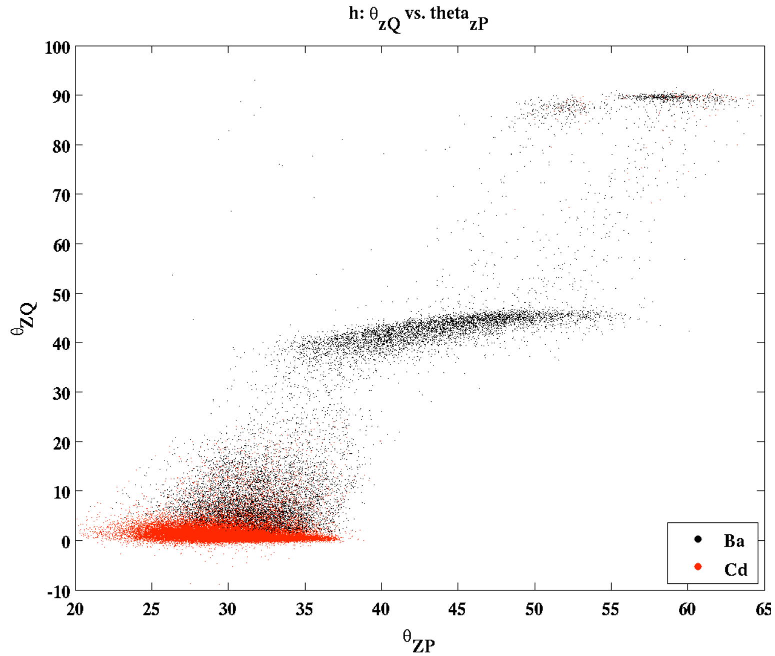


=>Real z measurement: **iZIP**

Ionization partition

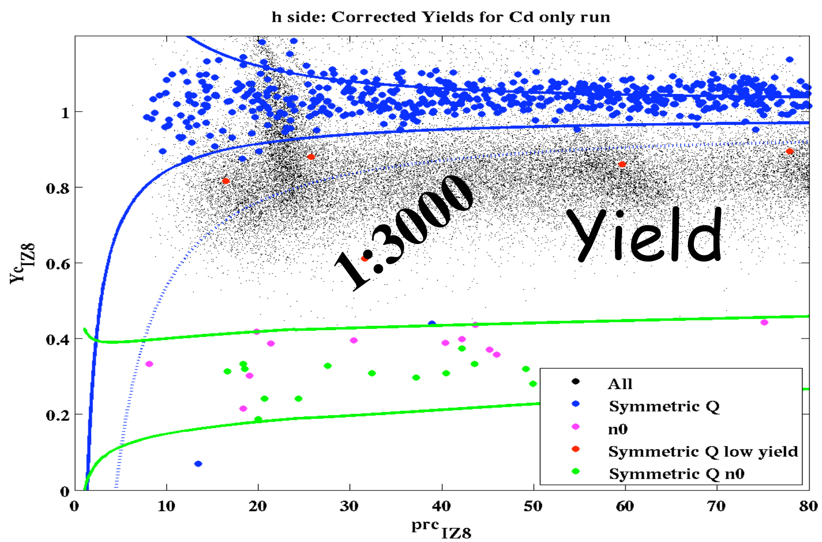


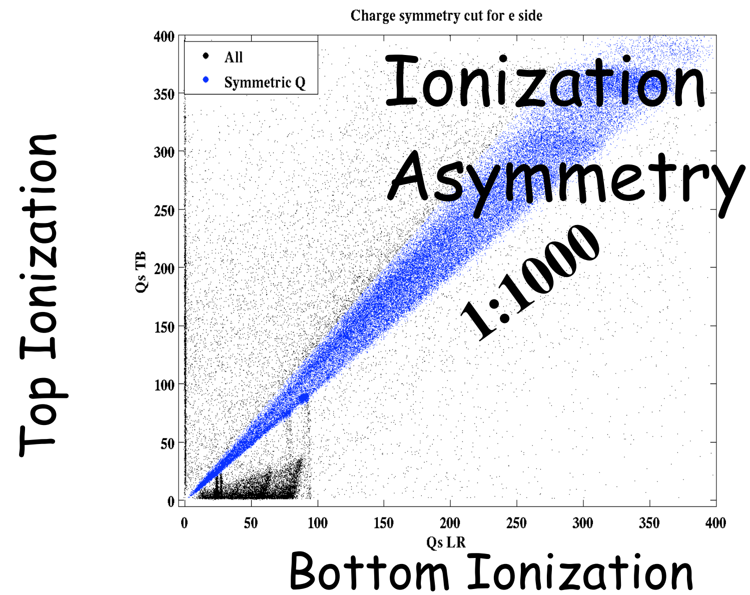
Phonon relative delay

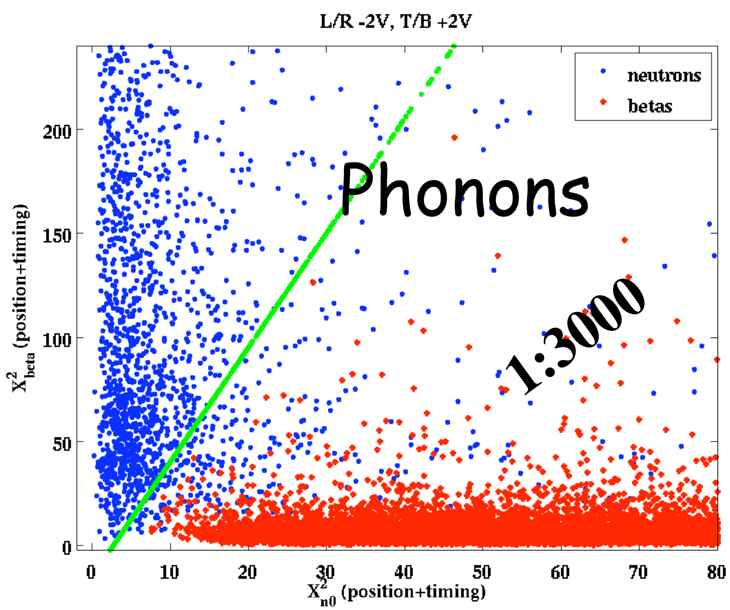


Phonon partition

iZIP Rejection performance







Of course likely correlations

But should have > $1/10^6$ rejection

Plenty of rejection for 100kg and 1 tonne scale

SuperCDMS Soudan 15kg

New 1 inch thick detectors : 0.64 kg

2.5 × bulk/surface

1 SuperTower: 5 × 1 inch detectors + 2 × 1 cm veto detectors

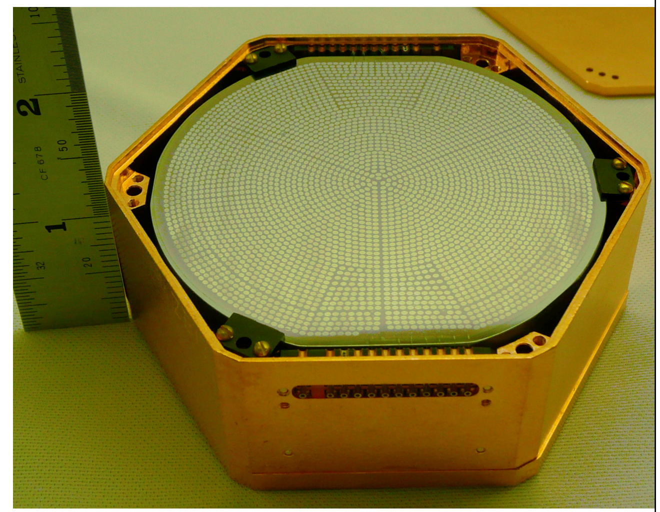
run June 2009-Jan 2010

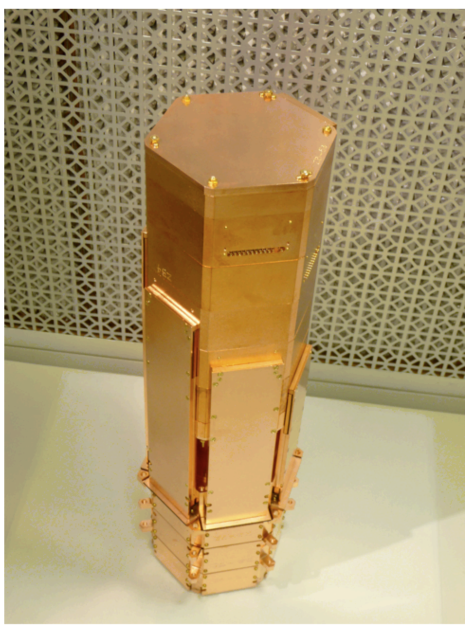
SuperCDMS 5 ST≈ 15kg: Approved

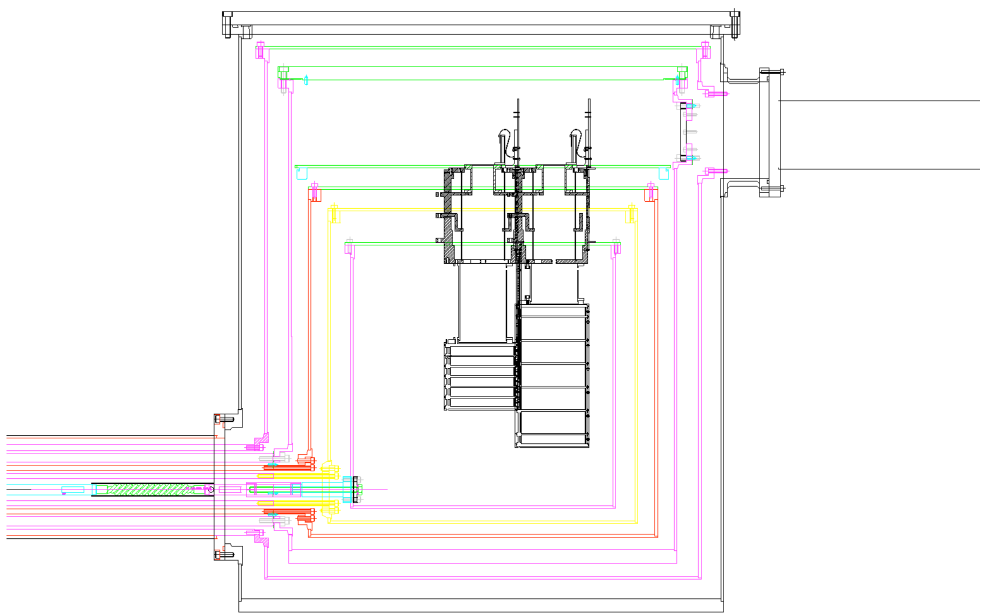
Choice between iZIP and mZIP about to be done

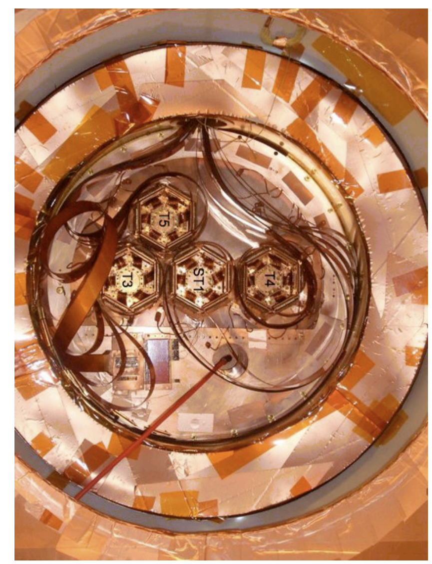
- inclined to go to iZIP because of much better rejection
- and easier analysi
- but require a bit more money

Depending on solution running end of 2010, or Spring 2010









Longer term

SCDMS Soudan 15kg

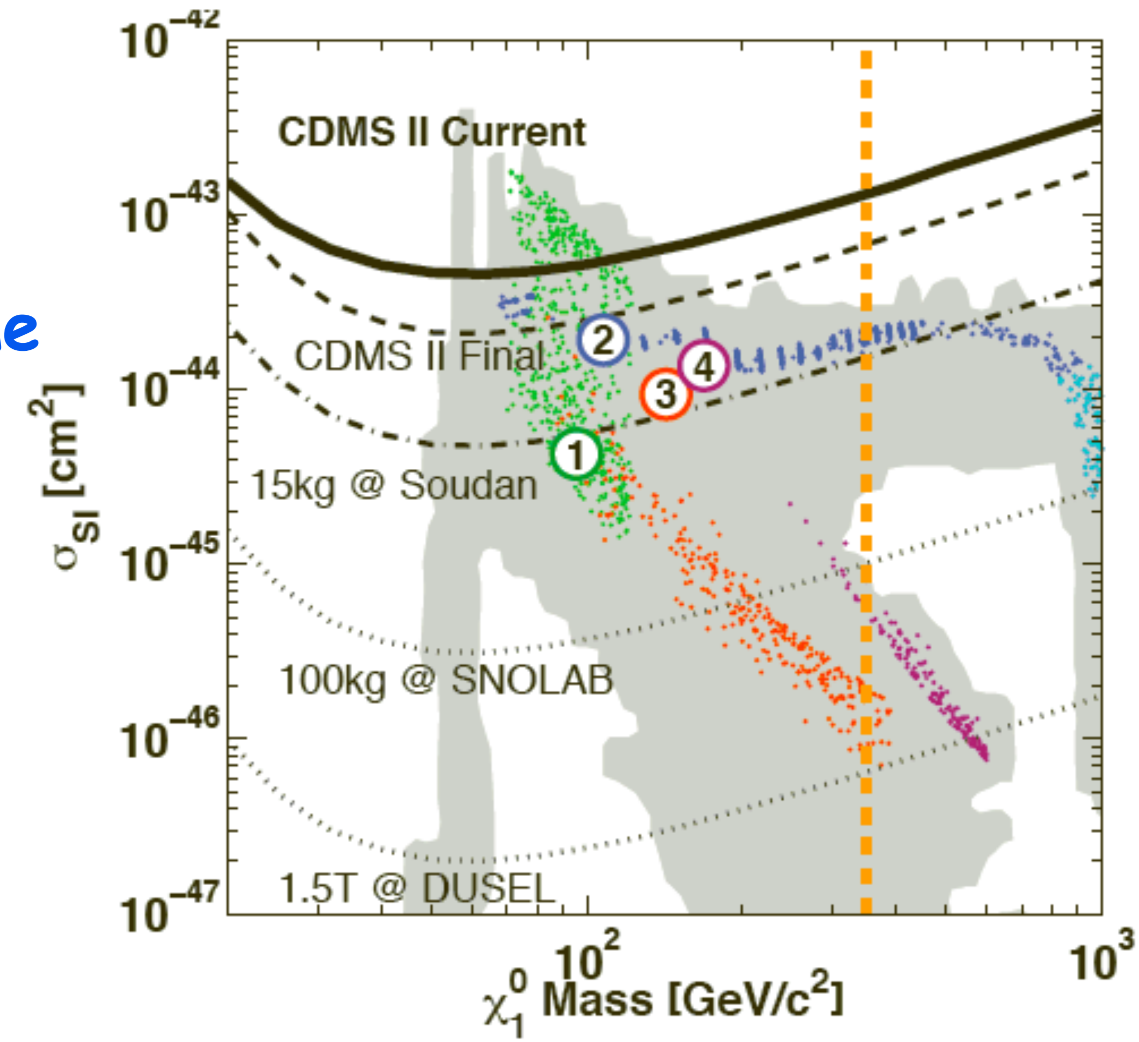
2011-2012: 5 10^{-45} cm^2

SCDMS SNOLAB 100kg

2014-2017 3 10^{-46} cm^2

GEODM DUSEL 1.5 tonne

2017-2021 2 10^{-47} cm^2



Conclusions

Result

We report two signal events, a number compatible at the 77% CL level with our expected background.

Two events are obviously insufficient to reach a statistically significant conclusion.

At this stage of the experiment, we cannot exclude that these events are WIMP signals.

A lot of noise about nothing?

The main piece of news is the interest of the community!

Our upper limits have not decreased as much as expected by our increase of exposure. This could be because of a fluctuation of the background or the emergence of signal.

What next?

Extract more from the current data: e.g. better algorithms and full likelihood analysis ≈ summer

Xenon 100, EDELWEISS, LUX, WARP, Xmass

SuperCDMS at Soudan and SNOLAB

LHC and indirect detection

Thanks to the US Department Of Energy and the National Science Foundation for their support