SuperCDMS: Results for low-mass WIMPS

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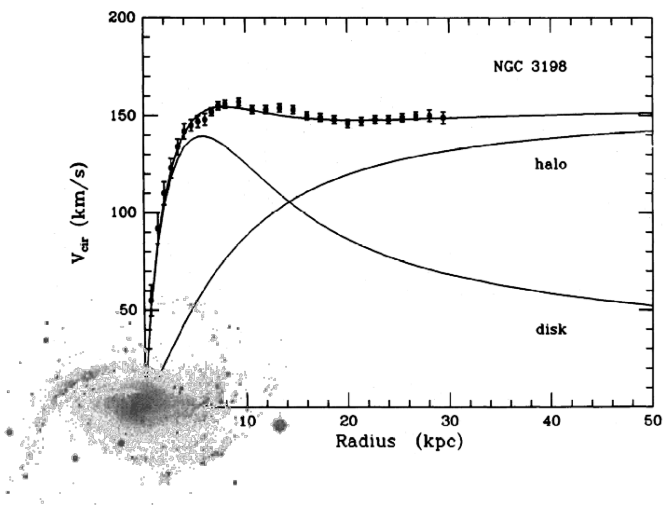
Dark Matter is a necessary (and abundant) ingredient in the Universe

It is one of the clearest hints of Physics Beyond the SM

Galaxies

- Rotation curves of spiral galaxies
- Gas temperature in elliptical galaxies



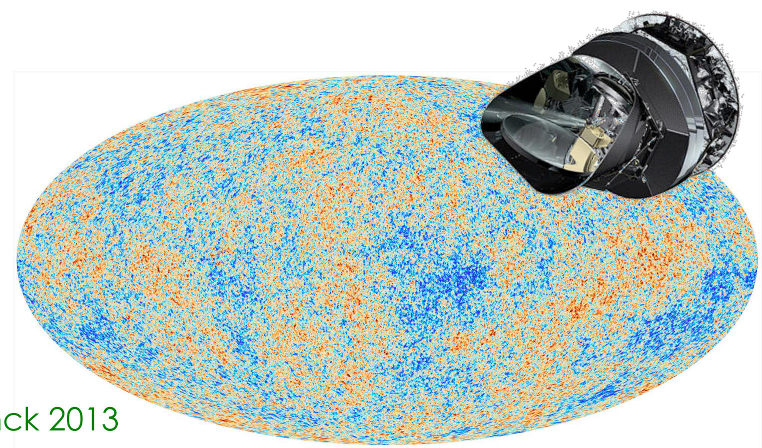
Clusters of galaxies

- Peculiar velocities and gas temperature
- Weak lensing
- Dynamics of cluster collision
- Filaments between galaxy clusters

Cosmological scales

Anisotropies in the Cosmic Microwave Background

$$\Omega_{CDM}\, h^2 = 0.1196 \pm 0.003$$



Planck 2013

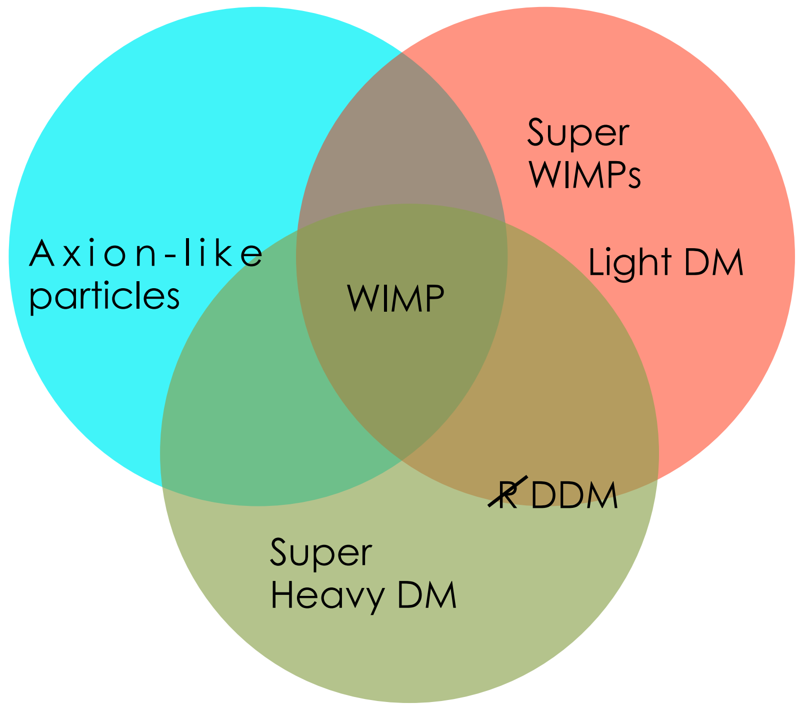
Dark Matter can be searched for in different ways...

Accelerator Searches (DM production) LHC (ILC)

Direct Detection

(DM-nuclei scattering)

DAMA/LIBRA
SuperCDMS
XENON
LUX
CoGeNT
KIMS
COUPP
PICASSO
ZEPLIN
CRESST
SIMPLE
ZEPLIN
ANAIS
XMASS
...



Indirect Detection

(DM annihilation)

PAMELA
Fermi
MAGIC
AMS

ANTARES
IceCube
CTA
...

… probing different aspects of the DM interactions with ordinary matter

Accelerator Searches (DM production) LHC (ILC)

Direct Detection

(DM-nuclei scattering)

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SuperCDMS
XENON
LUX
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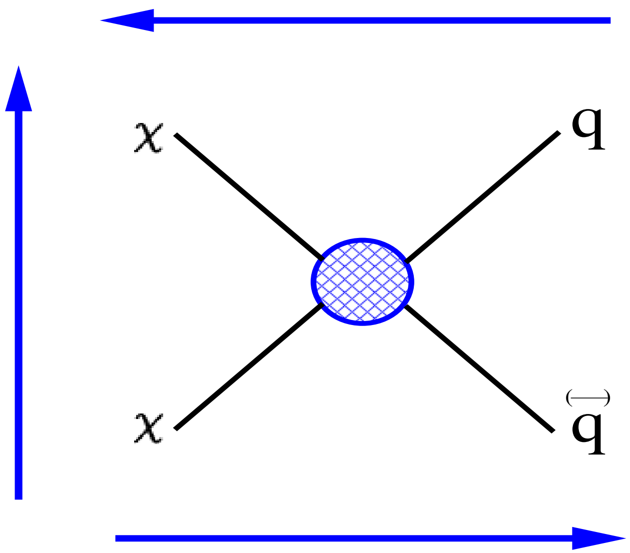
…



Constraints in one sector might affect observations in the other two.

"Redundant" detection can be used to extract DM properties.

COMPLEMENTARITY of DM searches

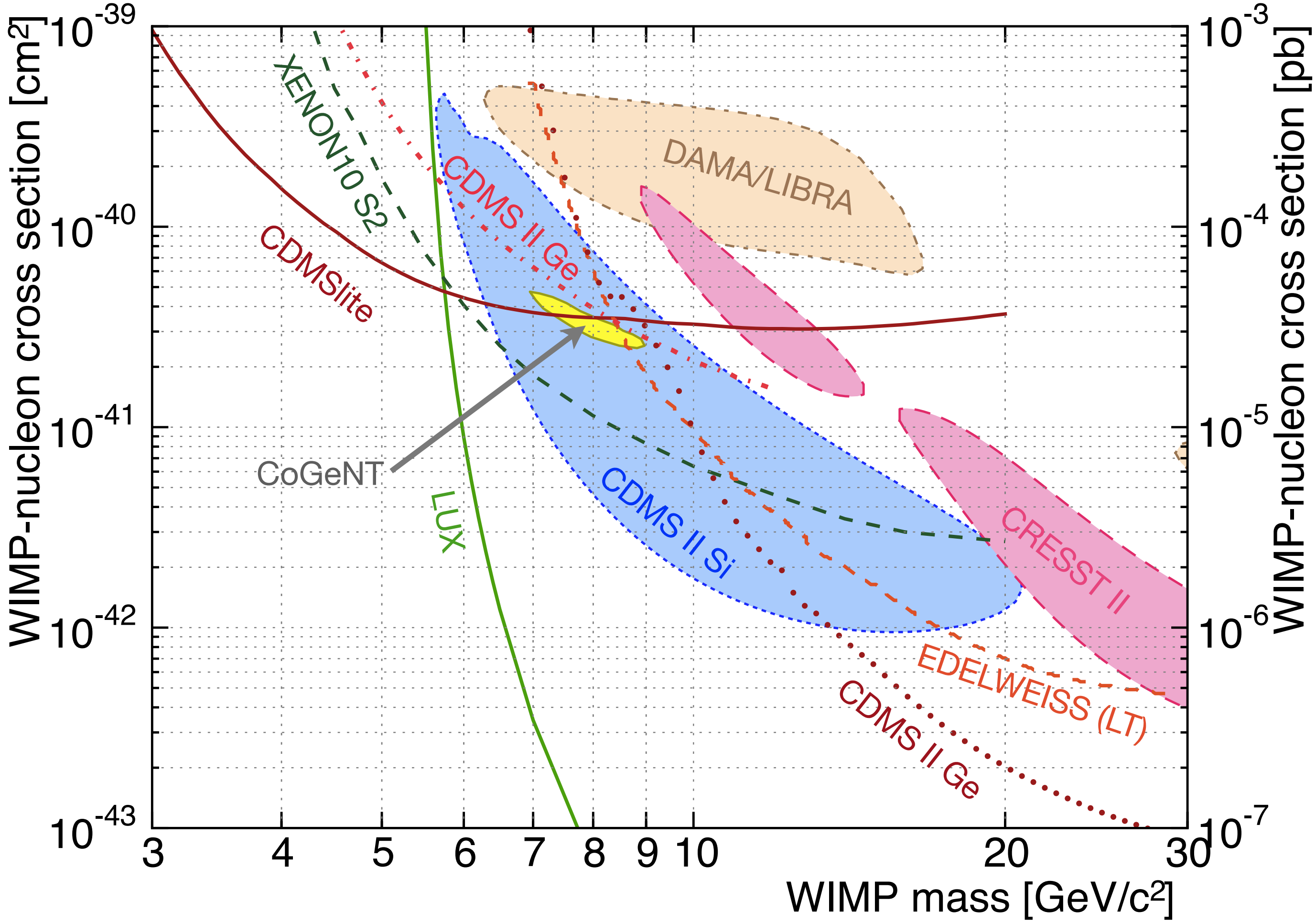
Indirect Detection

(DM annihilation)

PAMELA
Fermi
MAGIC
AMS

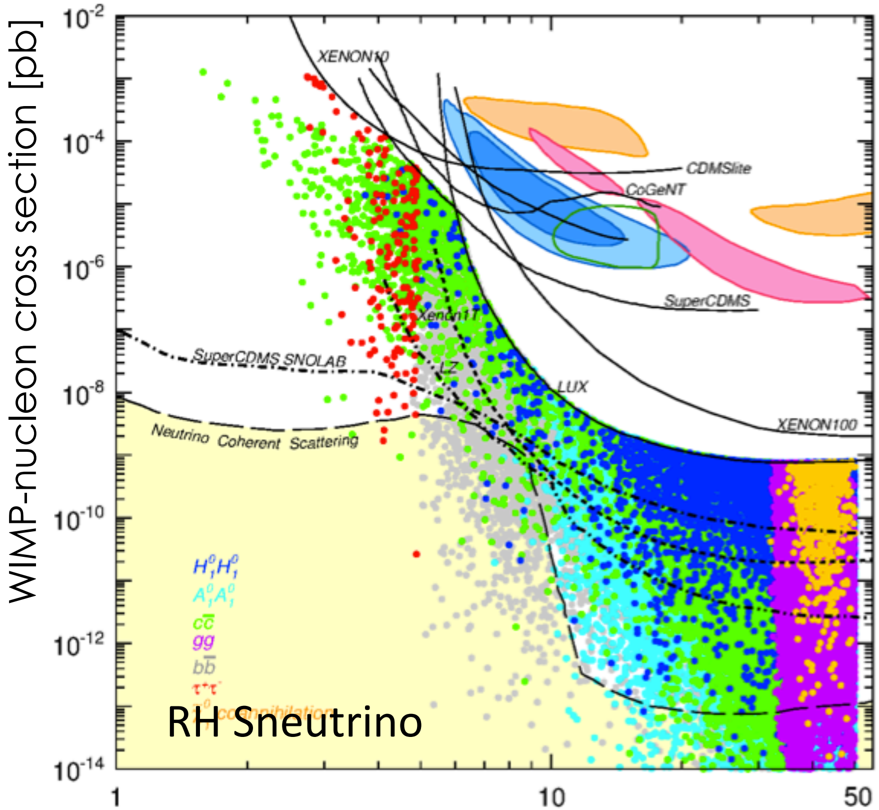
ANTARES
IceCube
CTA
…

“Hints” for low-mass WIMPs in direct detection experiments



CDMS II Si: Phys.Rev.Lett. 111 (2013) 251301
CDMSlite: Phys.Rev.Lett. 112 (2014) 041302

Particle Physics models provide candidates for light DM



Cerdeño, Peiró, Robles
JCAP 08 (2004) 005

WIMP mass [GeV/c^2]

Among other possibilities:

- Supersymmetry neutralino in the NMSSM or sneutrino in extended models
- Asymmetric DM

Are these theoretical predictions within the reach of our detectors?

It is an appealing window of the DM parameter space that is essential to explore

The search for low-mass WIMPs is challenging

- The signal is expected at very low recoil energies

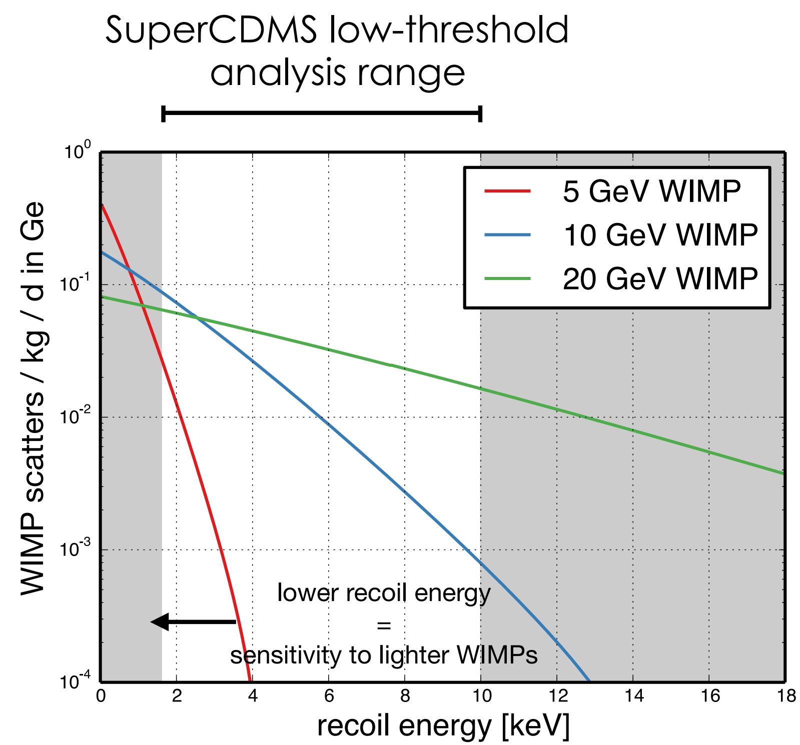
  Favours light targets

  Low-threshold searches

- Ge is relatively heavy so the threshold has to be just above the noise to be sensitive to 5 GeV WIMPs

  trigger threshold 1.6 keVnr

- Backgrounds are more difficult to discriminate (this is not a background-free search)

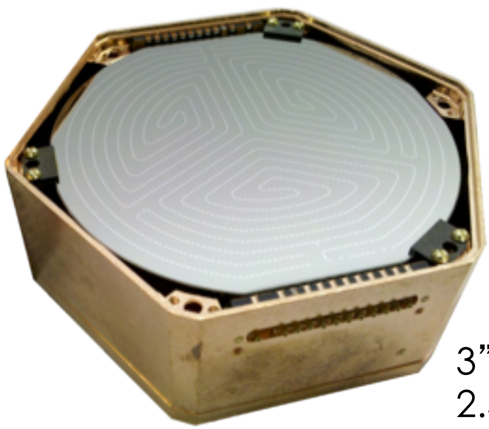


SuperCDMS at SOUDAN

Operational since March 2012

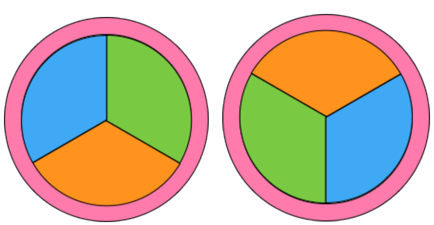
iZIP

interleaved Z-sensitive
Ionization & Phonon detectors

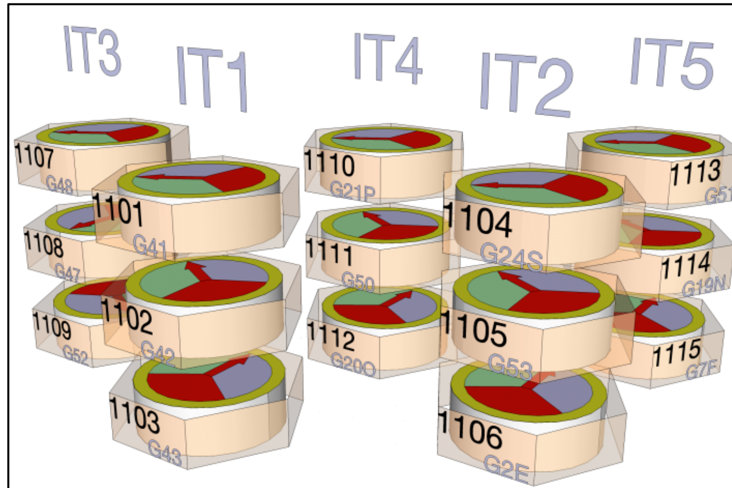


3" Diameter
2.5 cm Thick

Instrumented on both sides with
2 charge+ 4 phonon sensors



Side 1 Side 2



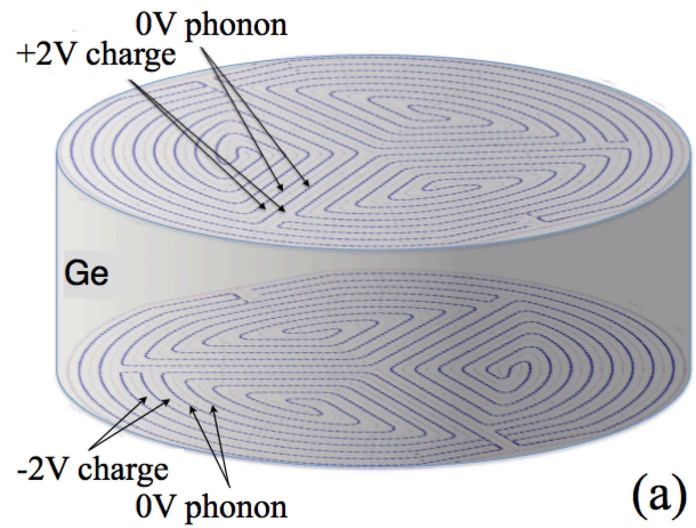
9.0 kg Ge (15 iZIPs x 600g)

Data for this analysis:

577 kg-days
taken from March 2012 – July 2013
using the 7 lowest threshold iZIPs

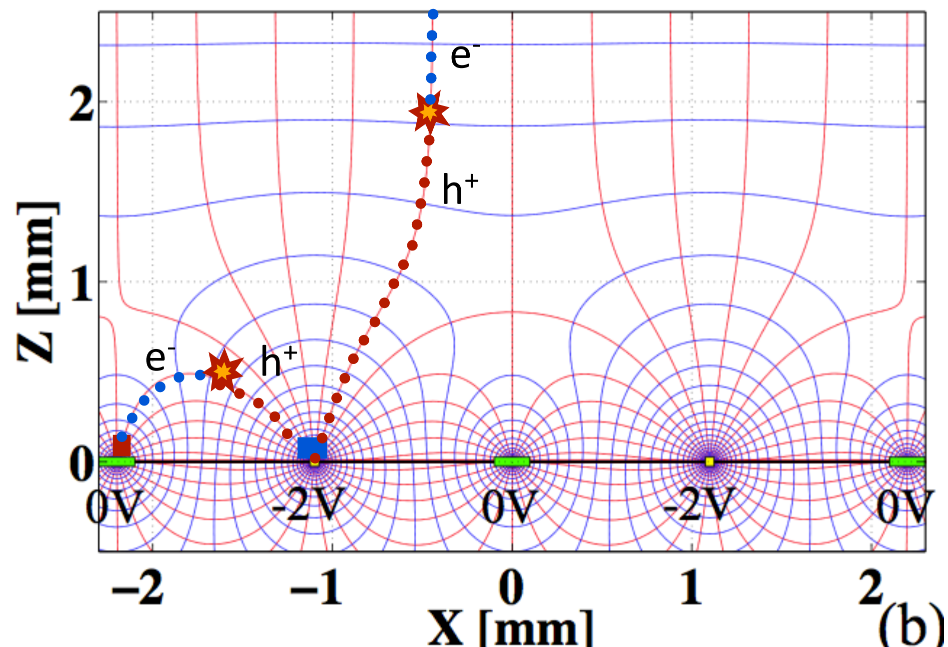
iZIP discrimination of surface events

In the new iZIPs the ionization lines (±2V) are interleaved with phonon sensors (0V) on a ~1mm pitch



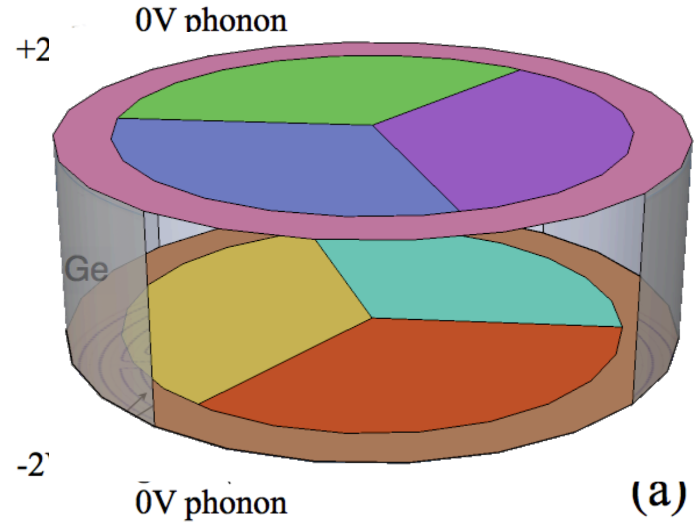
Bulk events:
charges (e,h) drift to **both sides** of the crystal

Surface events:
charges (e,h) drift to **only one side** of the crystal



Z-PARTITION:
The resulting **symmetry**/**asymmetry** on charge collection in sides 1 and 2

iZIP discrimination of surface events



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Z-PARTITION:
The resulting **symmetry**/**asymmetry** on charge collection in sides 1 and 2

Sidewalls

Surface events on the sides of the detector leave more energy in the outer sensors.

RADIAL PARTITION:
division of energy between inner and outer sensors

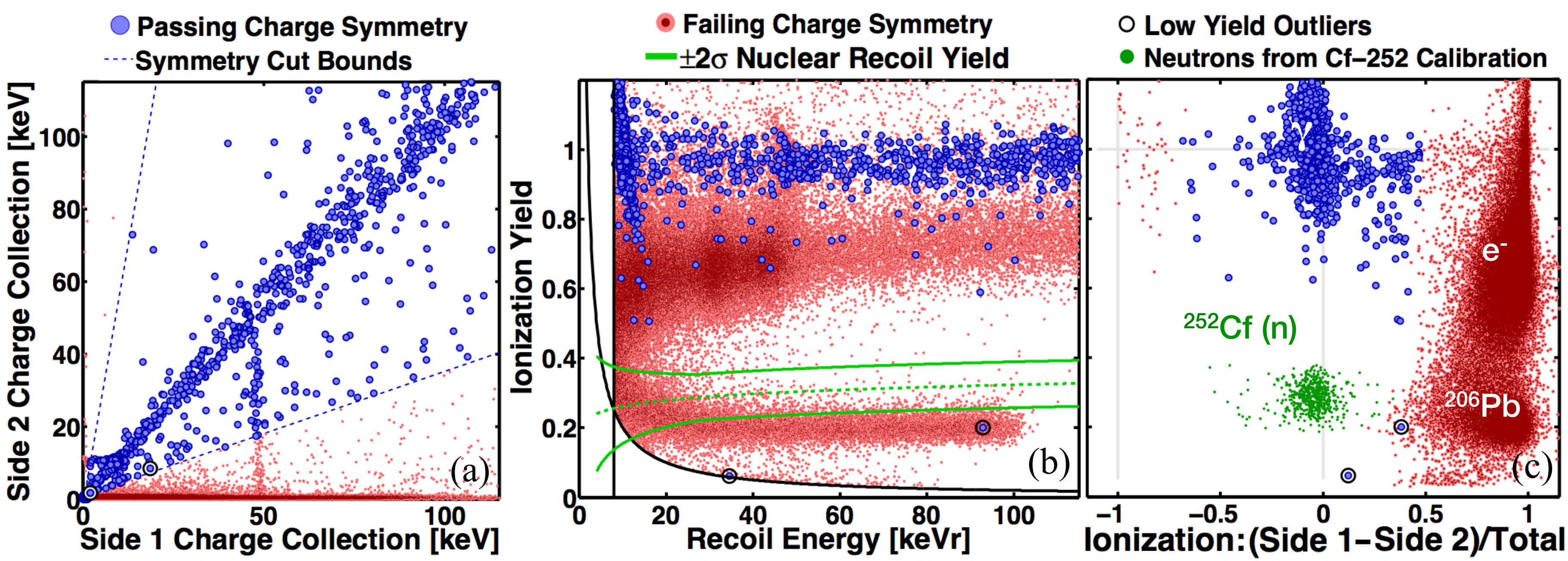
The rejection of surface events with the new iZIPs using Z-partition has been demonstrated with data from exposure to betas from ^{210}Pb sources

In ~800 live hours, no events leaked into the 8-115 keV signal region

Leakage < 1.7×10^{-5}

This could allow a background free search for 5 yr of operation in SuperCDMS @ SNOLAB (~100 kg)

Appl.Phys.Lett. 103 (2013) 164105



(the low threshold analysis corresponds to smaller energies and some leakage is expected)

Background		Rejection
• Bulk electron recoils Compton background 1.3 keV activation line	→	Yield = Ionization/phonon helps discriminating NR from ER
• Sidewall & surface events betas and x-rays from ^{210}Pb, ^{210}Bi, recoils from ^{206}Pb, outer radial Comptons, ejected electrons from Compton scattering	→	Z-Partition and Radial partition define a fiducial volume
• Neutrons (cosmogenic & radiogenic)	→	Use active and passive shielding. Cut on multiple hits. Simulation determines remaining irreducible rate

Analysis: Selection criteria and efficiencies

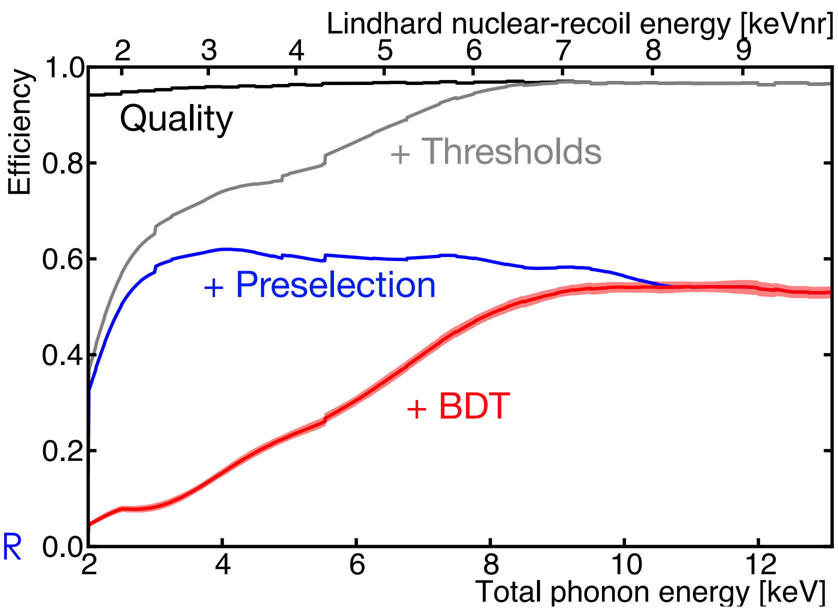
We carry out a blind analysis, with cuts set by examining only events that will never be accepted as WIMP candidates (multiple scatters, calibration events, and periods following high activation from ^{252}Cf calibration)

Data Quality:
Reject periods with poor detector performance
Remove misreconstructed and noisy pulses
Measure efficiency with pulse MC

Trigger and analysis threshold:
Select periods with stable well-defined trigger threshold
Measure efficiency from ^{133}Ba calibration data

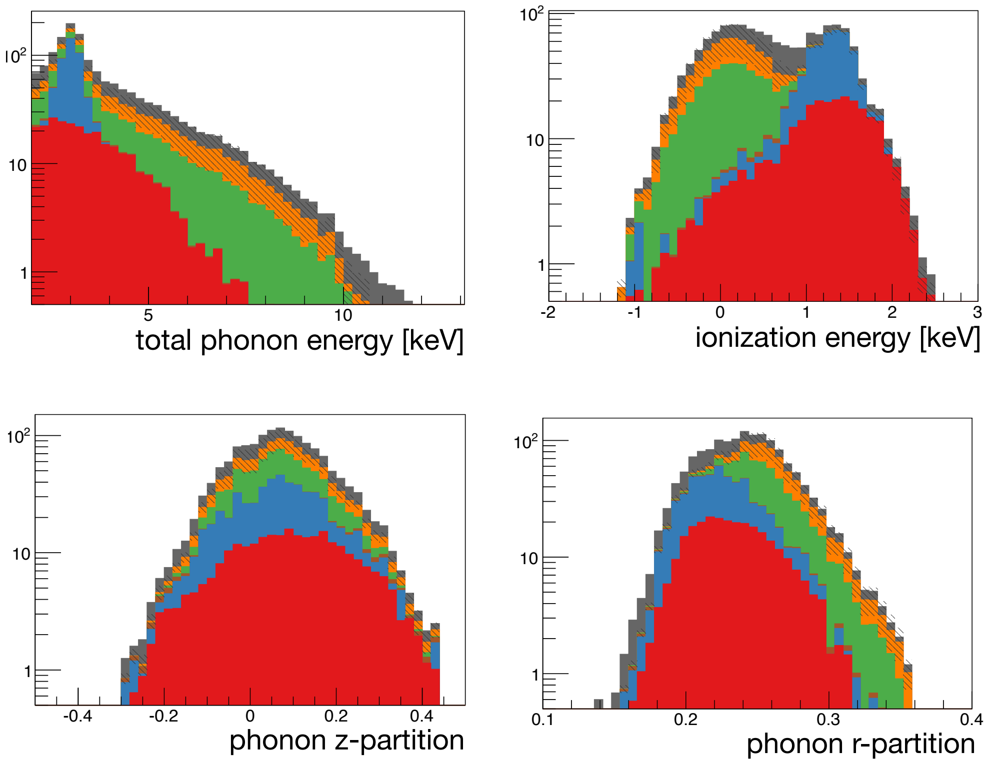
Preselection:
Single-detector scatter
Remove events coincident with muon veto
Ionization fiducial volume
Ionization and phonon partitions consistent with NR

Boosted Decision Tree:
Optimised cut on the phonon fiducial volume and ionization yield at low energy
Efficiency estimated from fraction of ^{252}Cf passing

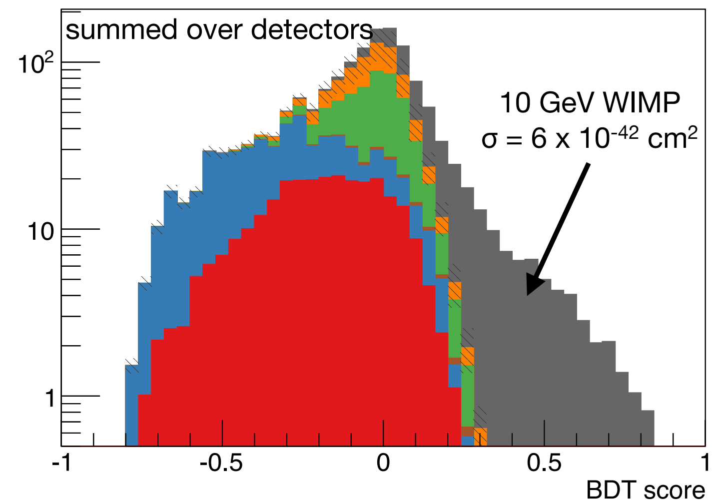


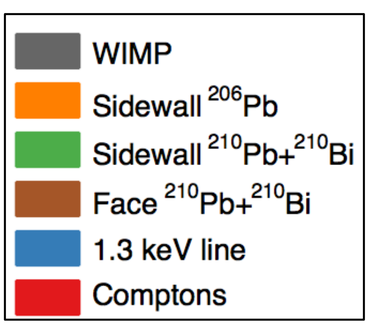
Boosted Decision Tree (BDT)

Inputs (per detector)



Output



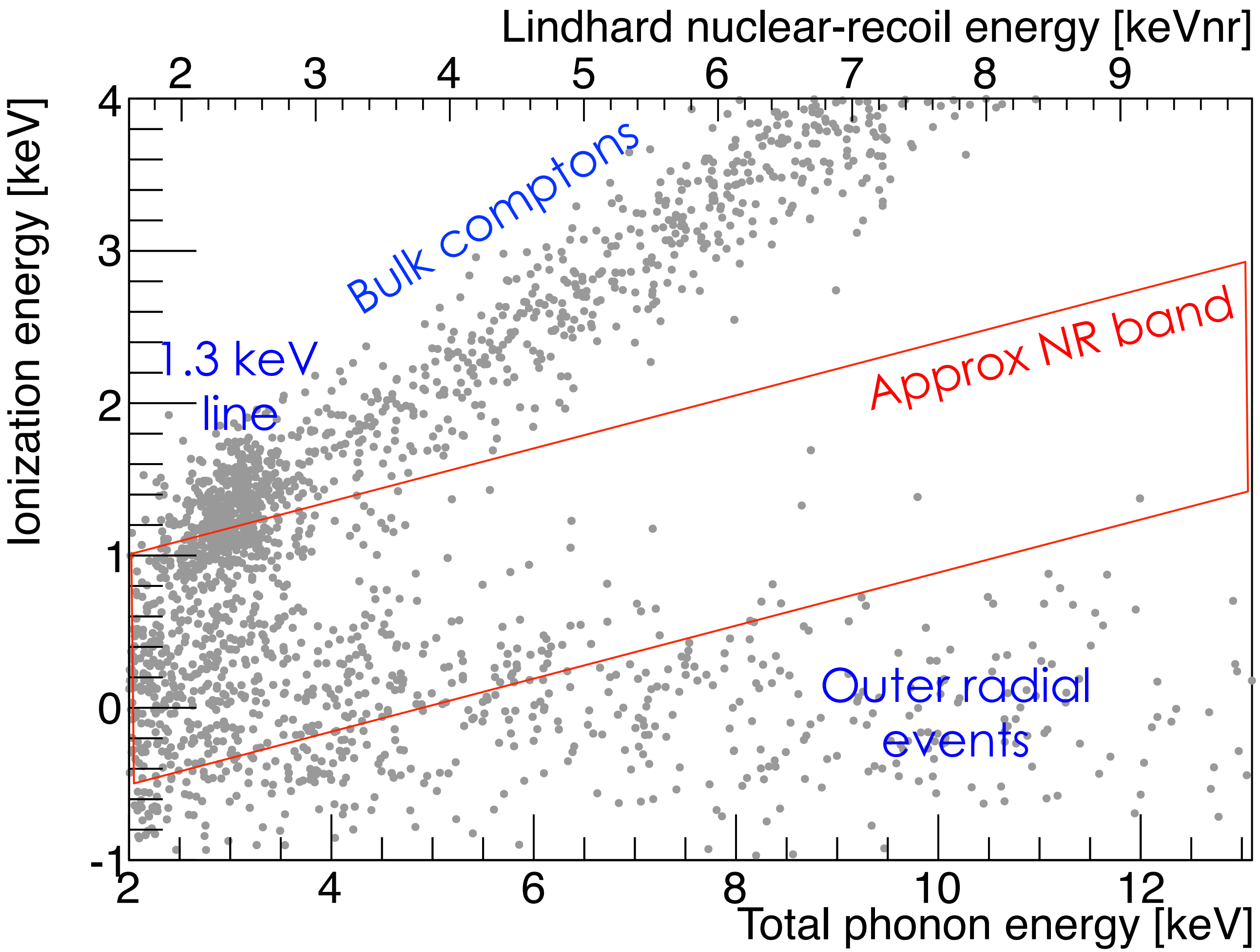


Background: Modelled with simulated data on sidebands and calibration.

WIMP Signal: Modelled with NR data from ^{252}Cf, then rescaled for WIMPs with mass 5, 7, 10, 15 GeV

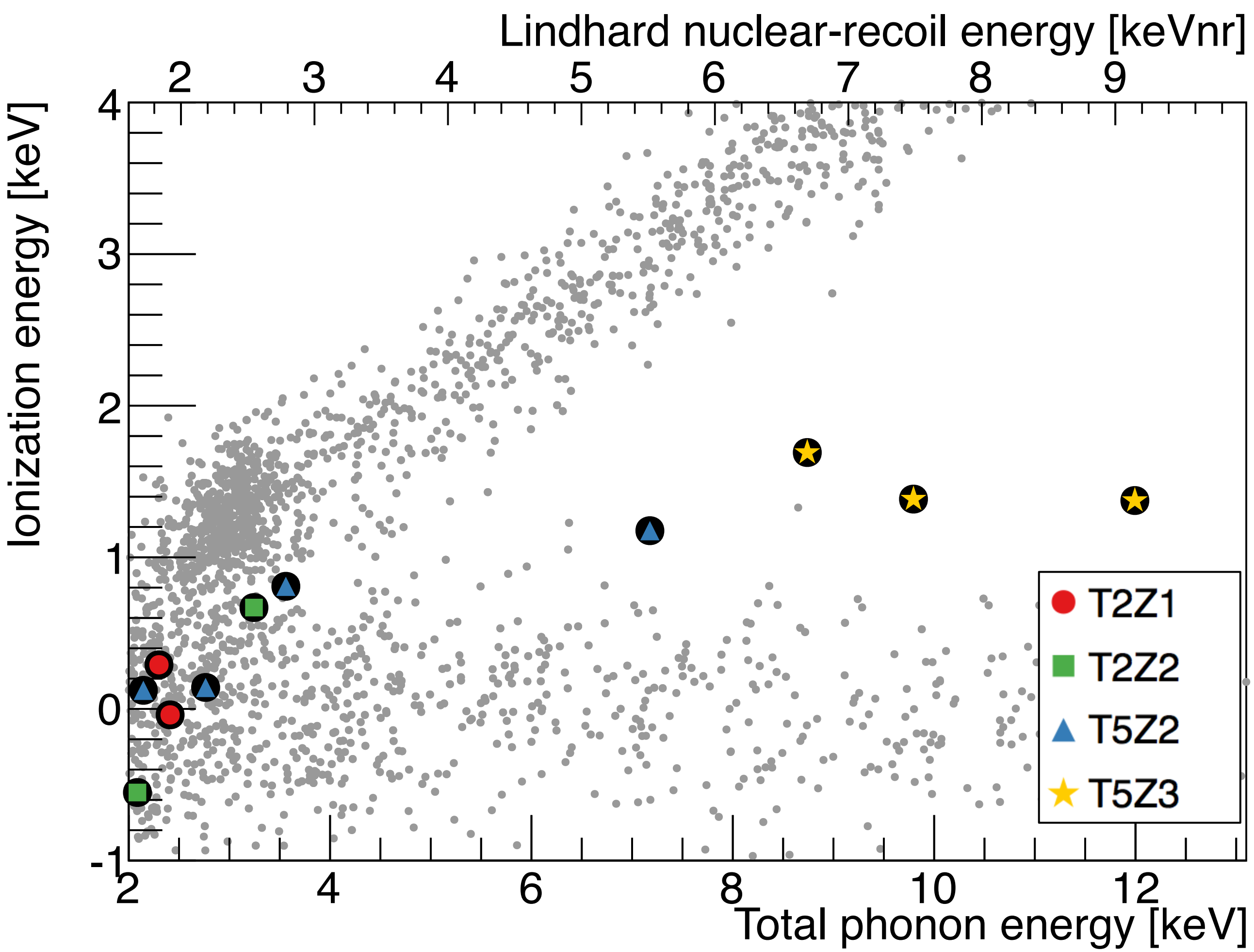
Unblinding: Before BDT cut

Events passing all the cuts prior to applying BDT



Unblinding: After BDT cut

11 candidates (6.2 +1.1 -0.8 expected)



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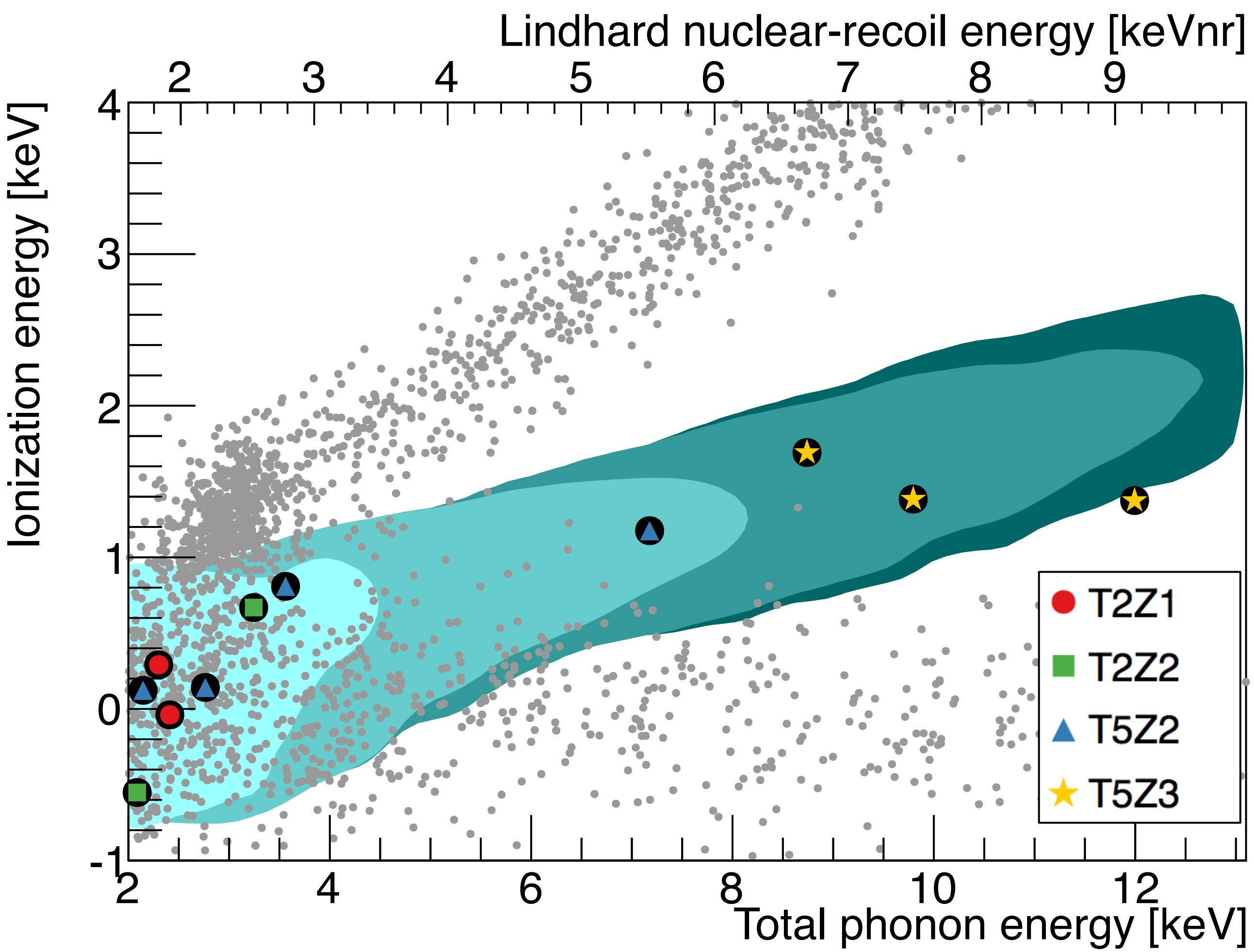
11 candidates (6.2 +1.1 -0.8 expected)



95% CL intervals for WIMPS with

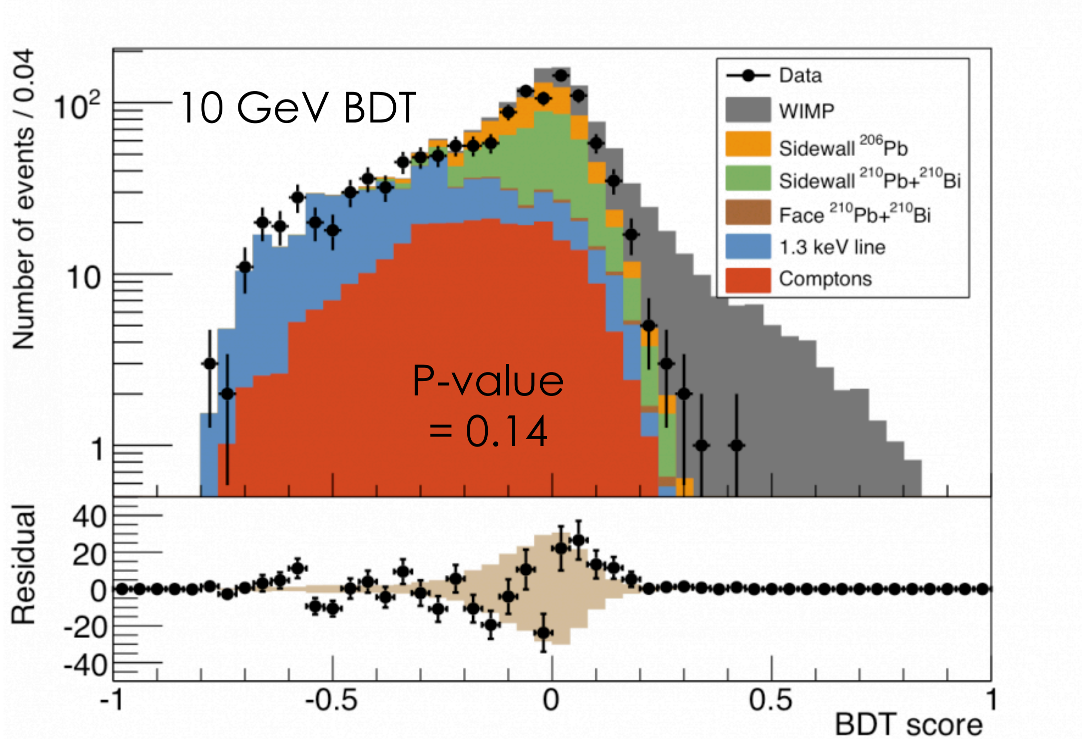
m=5 GeV
m=7 GeV
m=10 GeV
m=15 GeV

The three highest energy events were all found in T5Z3, which was not functioning fully

Post-unblinding discussion

Events are high in quality. Only the lowest energy candidate looks like spurious noise

- For most of the detectors there is good agreement with predicted background



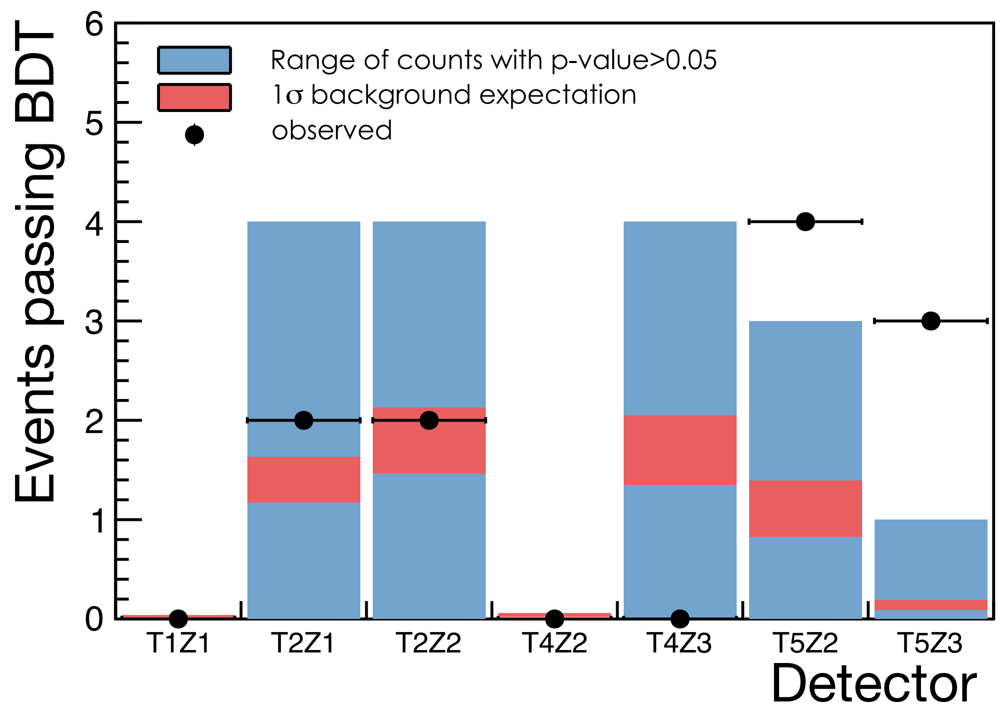
Post-unblinding discussion

Events are high in quality. Only the lowest energy candidate looks like spurious noise

- For most of the detectors there is good agreement with predicted background

- However, T5Z3 observes the 3 highest-energy events

  (Poisson p-value is 0.04%)

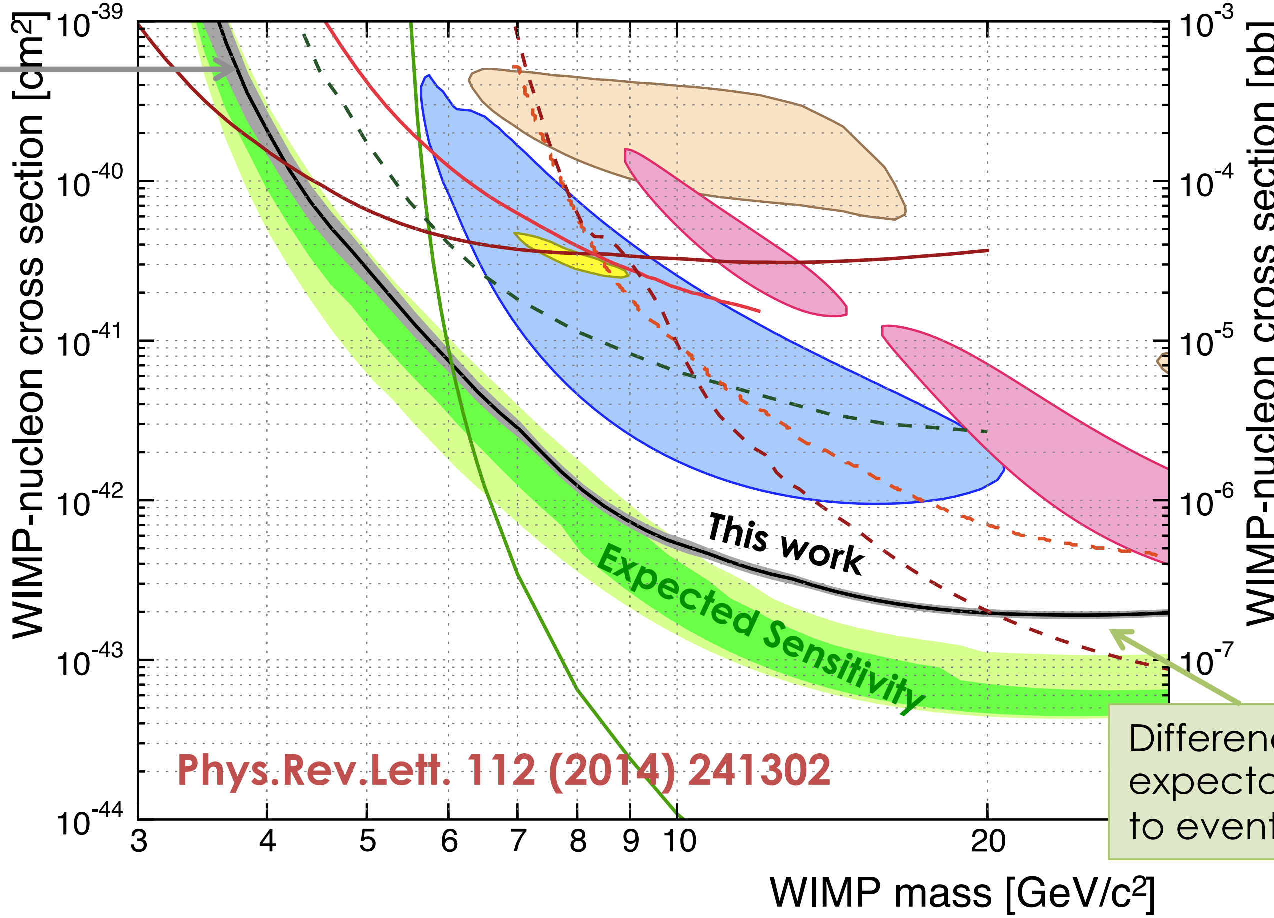


T5Z3 has a shorted ionization guard. This may have affected the background model performance. Additional studies are ongoing.

New limit for low-mass WIMPs

90% C.L. optimal interval method
(no background subtraction)

systematics (efficiency, energy scale, trigger efficiency)



Difference with expectation due to events in T5Z3

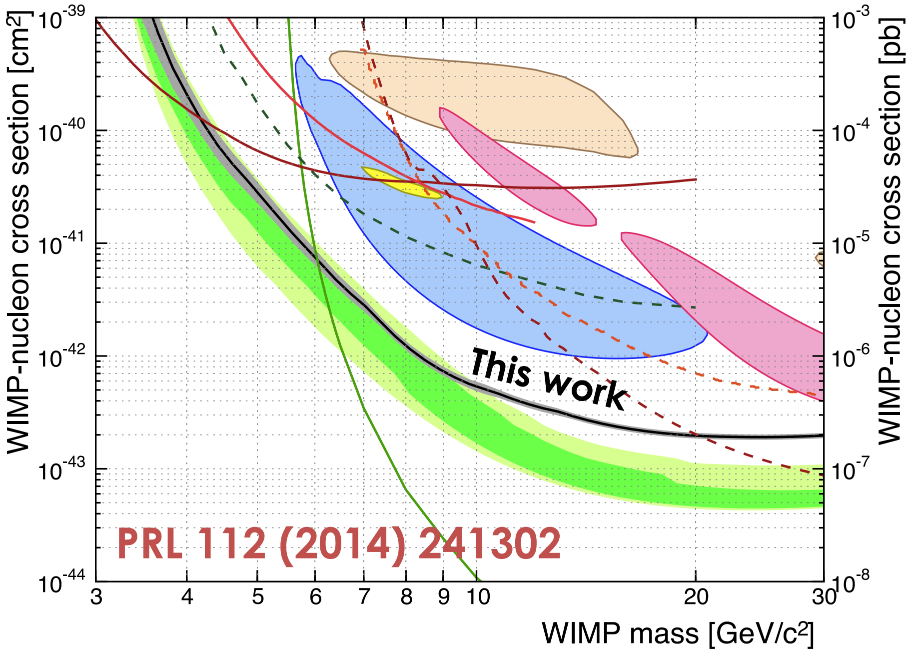
Conclusions

- First result using the background rejection capability of SuperCDMS

  7 iZIPs analysed (threshold 1.6 keV_{nr})
  Exposure: 577 kg day
  $\sigma^{SI} > 1.2 \times 10^{-6}$ pb at 8 GeV

  New limit for WIMPs with masses in the range 4 - 6 GeV

  (below 4 GeV CDMSlite dominates)

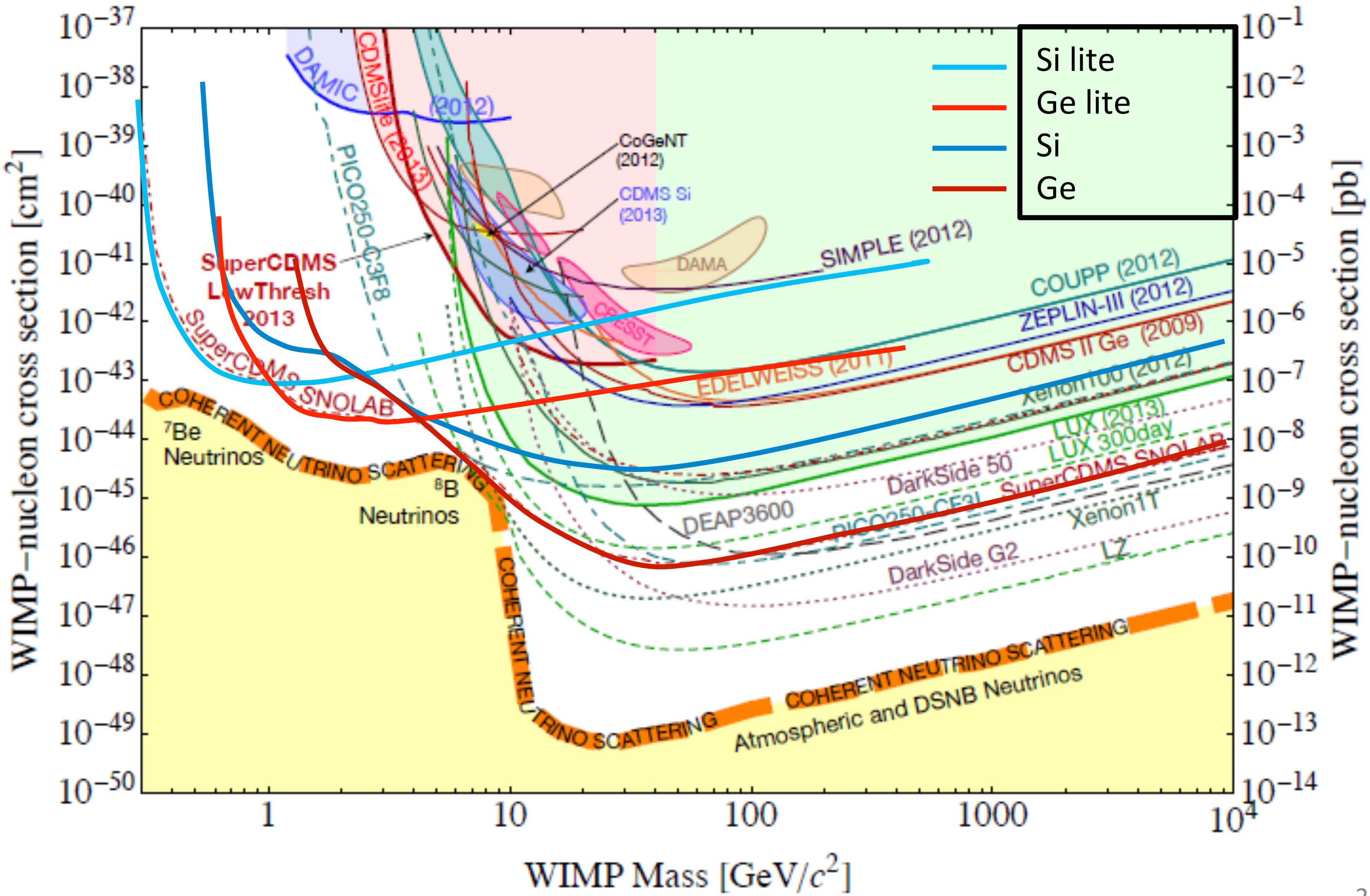


- CoGeNT interpretation of WIMP signal disfavoured in model-independent way

  CDMS-II (Si) disfavoured assuming standard WIMP interactions and for the standard halo model.

- High threshold analysis of SuperCDMS ongoing
  SuperCDMS Soudan detectors are a vast improvement over CDMS II

- SuperCDMS-SNOLAB (with ~100 kg Ge and ~10kg Si) will extend the sensitivity by over an order of magnitude with an excellent coverage of the light mass window.



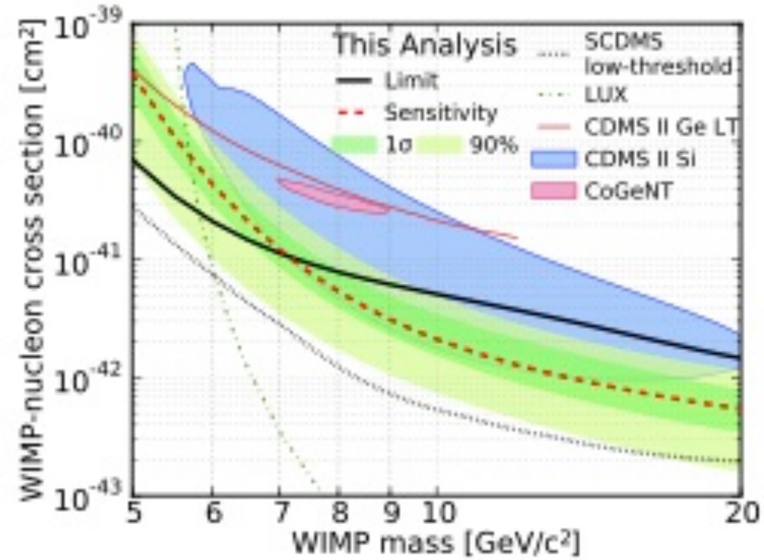
The SuperCDMS collaboration

California Inst. of Tech.
CNRS-LPN
FNAL
Mass. Inst. of Tech.
NIST Inst. of Tech.
PNNL
Queen's University
SLAC
Southern Methodist U.
Santa Clara University
South Dakota SM&T
Stanford University
Texas A&M University
U. Autónoma de Madrid
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Minnesota
U. South Dakota

Extra material & Backup slides

Maximum Likelihood fit for CDMS II (Ge)

Limit derived from singles data

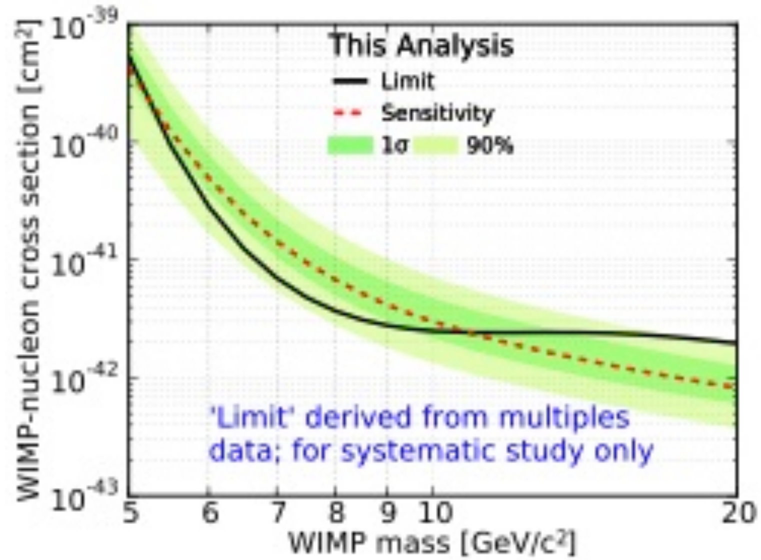


Using a background model derived from detector simulations and calibration data.

No significant evidence for Nuclear Recoils in the data

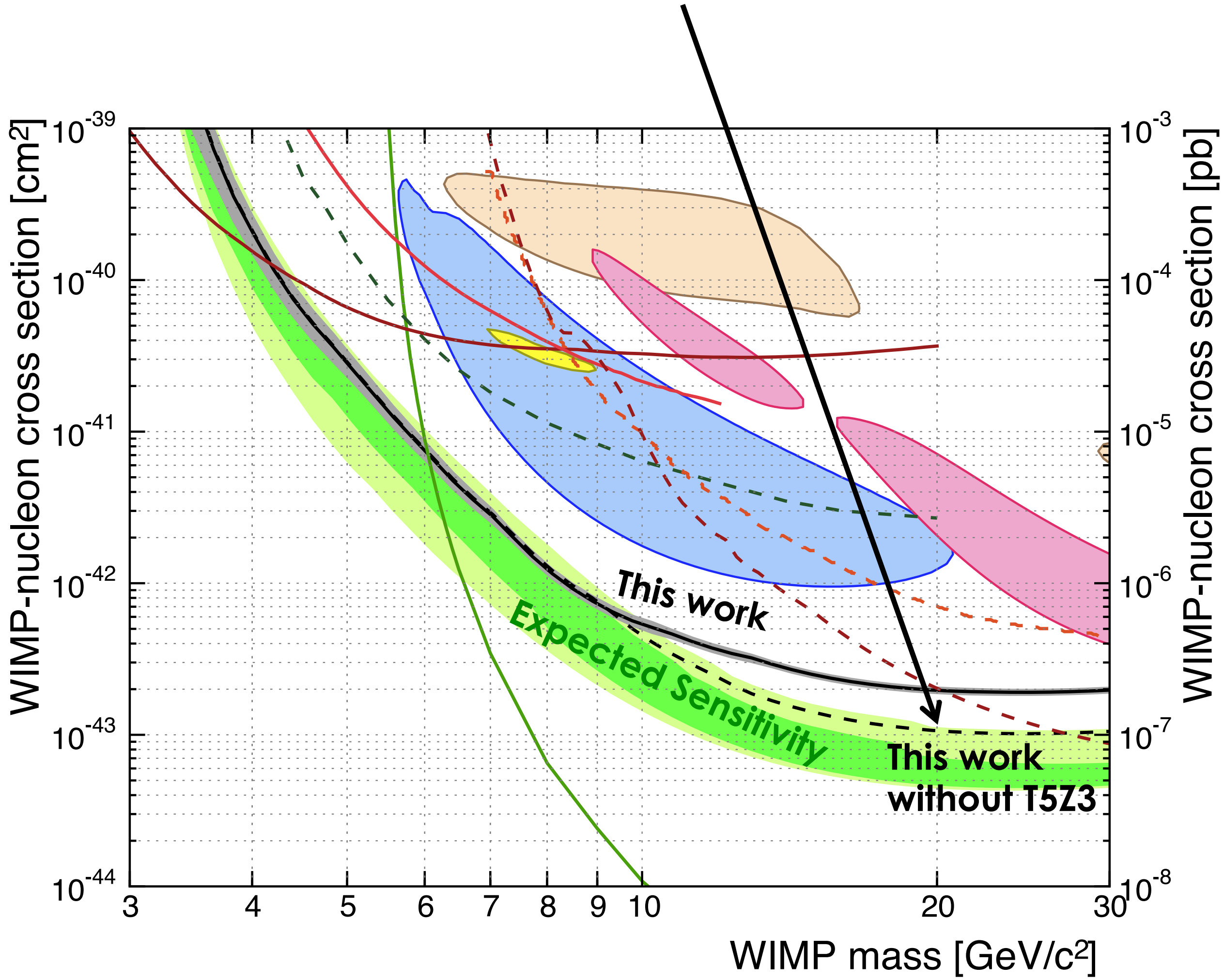
The resulting limit is approximately **5 times stronger** than previous analysis wihtout background subtraction

arXiv:1410.1003



Limit without T5Z3

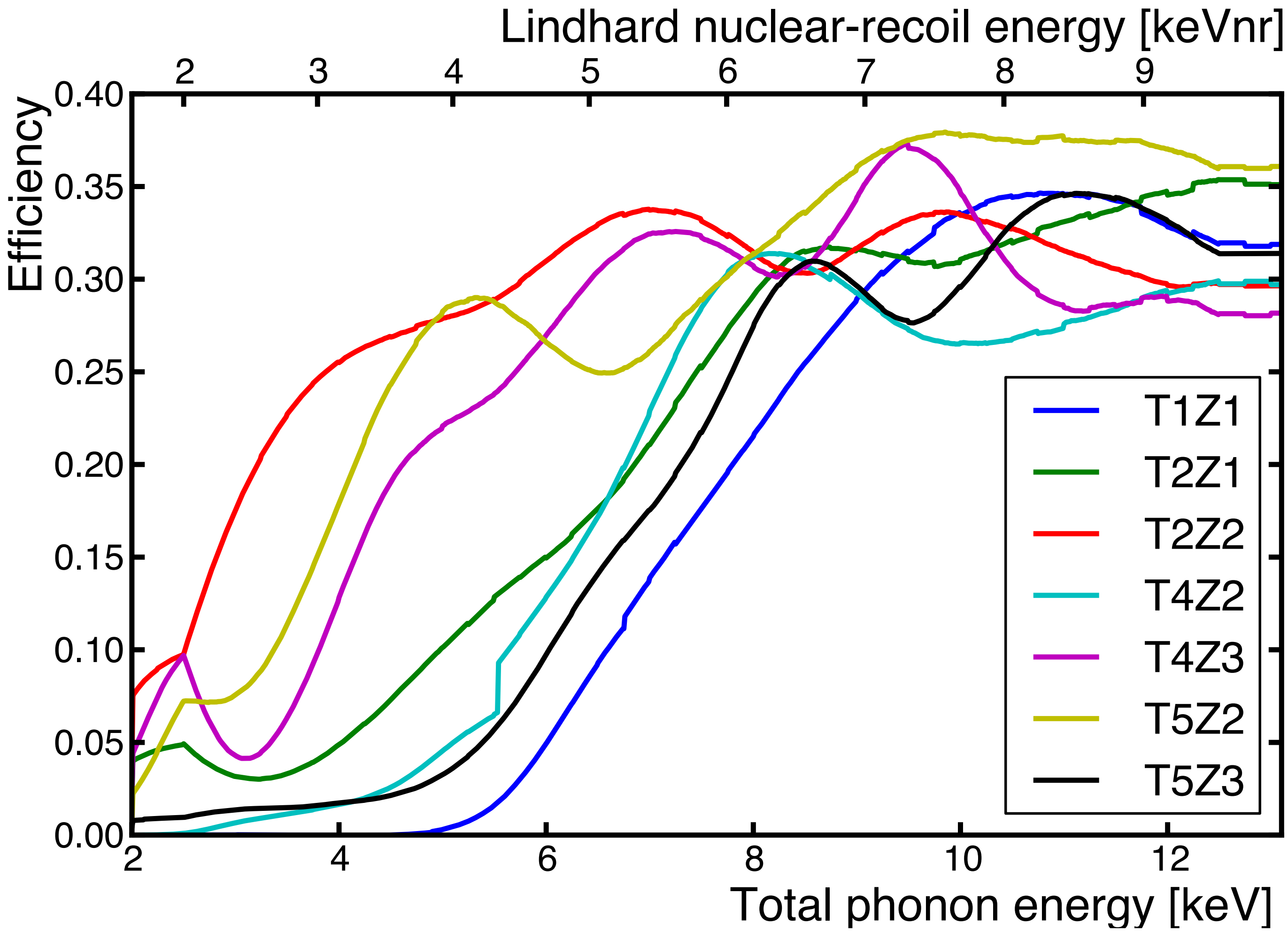
The limit extracted without T5Z3 only differs for m>10 GeV and is approx. a factor 2 better



11 candidates that pass all the cuts

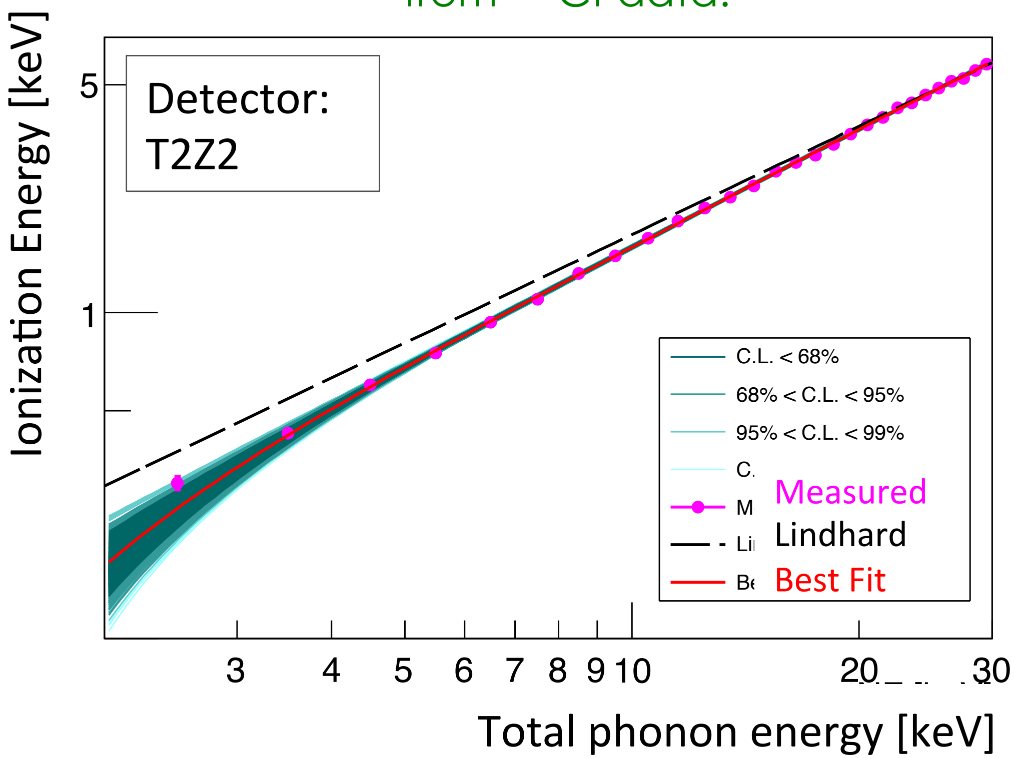
Detector	Candidate energies [$\mathrm{keV_{nr}}$]	Expected background
T1Z1	—	$0.03^{+0.01}_{-0.01}$
T2Z1	1.7, 1.8	$1.4^{+0.2}_{-0.2}$
T2Z2	1.9, 2.7	$1.8^{+0.4}_{-0.3}$
T4Z2	—	$0.04^{+0.02}_{-0.02}$
T4Z3	—	$1.7^{+0.4}_{-0.3}$
T5Z2	5.8, 1.9, 3.0, 2.3	$1.1^{+0.3}_{-0.3}$
T5Z3	7.8, 9.4, 7.0	$0.13^{+0.06}_{-0.04}$

Efficiencies



Measurement of the recoil energy

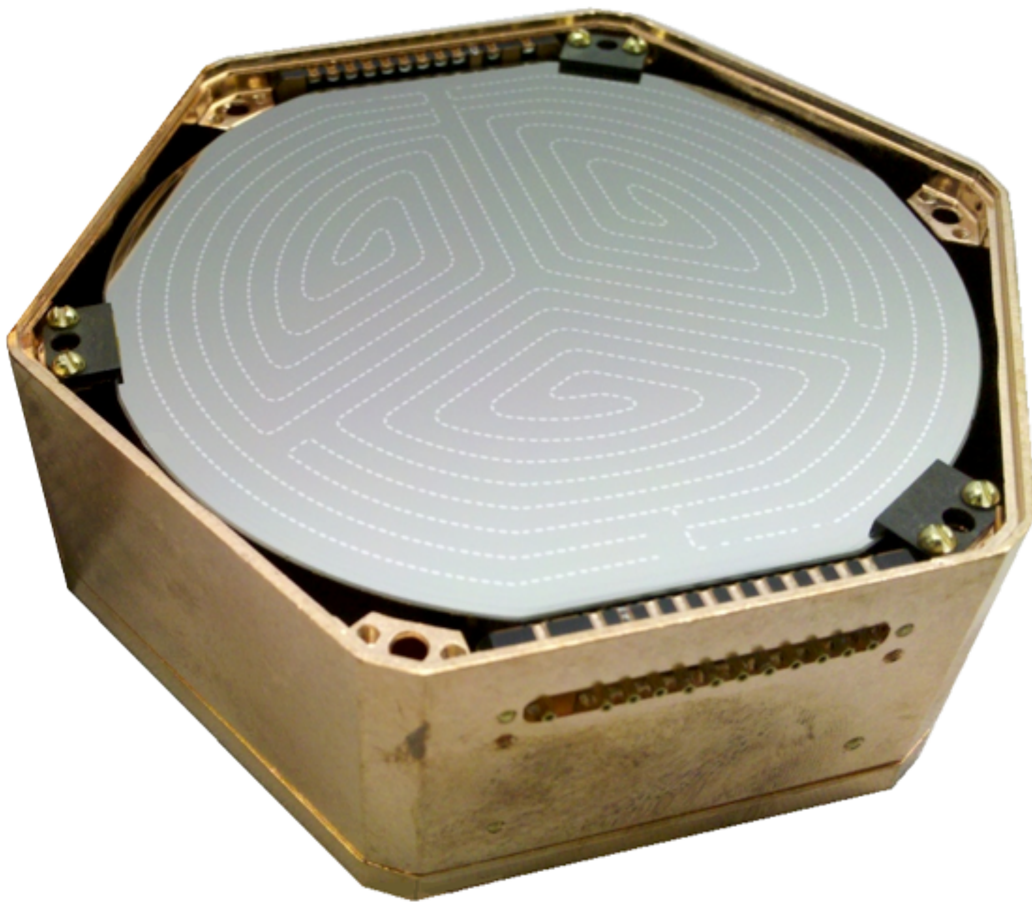
Ionization for nuclear recoils, measured from ^{252}Cf data:



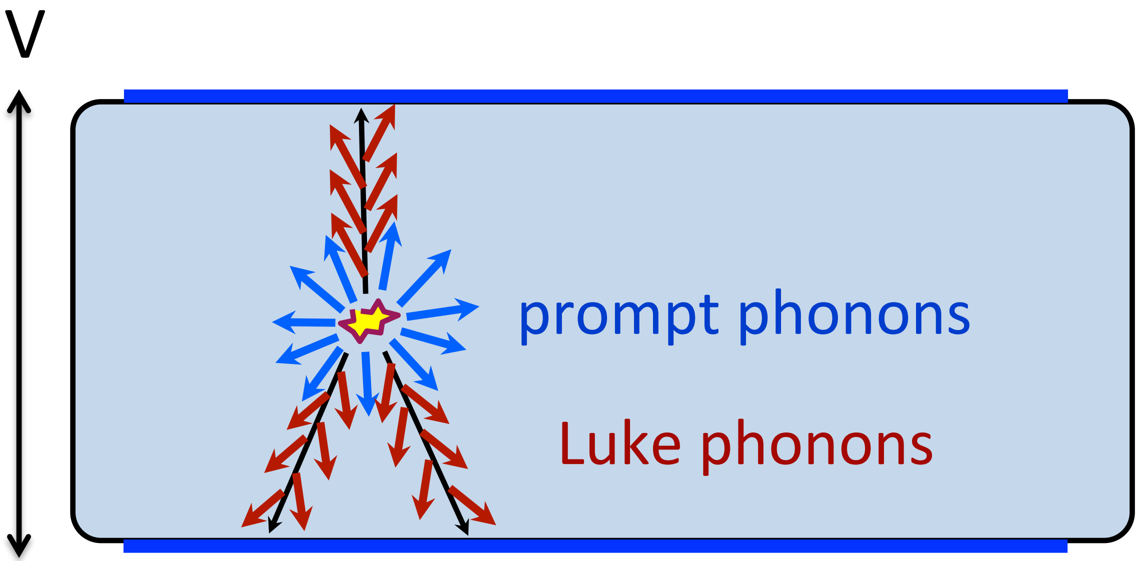
Total phonon energy =
$E_{total} = E_{luke} + E_{recoil}$
E_{total} is measured with phonons

NR equivalent energy =
$E_{total} - E_{Luke\ NR}$
$E_{Luke\ NR}$ estimated from mean NR ionization, varies with E_{total}

SuperCDMS Soudan



CDMSlite – Amplification of the Luke-Neganov phonons



$E_Q = N_{eh}\varepsilon$ = Ionisation energy

ε = 3 eV (in Ge) =
(e-h) pair creation mean energy

E_{recoil} = E. of prompt phonons

$E_{Luke} = V\,e\,N_{eh}$

$$P_{tot} = E_{recoil} + E_{Luke}$$

If the bias voltage is increased, the work done in drifting charge carriers, E_{Luke}, increases

The signal is amplified, allowing a substantial reduction in energy threshold and a better energy resolution

The phonon instrumentation thus measures the ionization energy (no signal is used from the ionization channels) → No Yield-based discrimination of electron and nuclear recoils

CDMSlite – data taking

- Data were taken in three periods in 2012
  - with ^{133}Ba calibration data interspersed throughout
- There were two neutron exposures (^{252}Cf)
  - to determine energy scale and monitor stability
  - August 22, and August 31

Run Period	Starting Date	Ending Date	Raw Livetime [h]
1	August 18	August 29	166.5
2	September 7	September 14	111.2
3	September 18	September 25	105.9

- One iZIP was used, IT5Z2 – 0.6 kg
  - Selected for its low trigger threshold and low leakage current
  - Signal gain at operating voltage of 69 V was 24

$$E_T = E_r \times \left(1 + \frac{eV_b}{\varepsilon_\gamma}\right)$$

Average excitation energy per charge pair $\varepsilon_\gamma = 3\ \mathrm{eV}$

- Raw exposure is 15 live days, 9.6 kg days
  - Optimized based on a flat extrapolation of known electron recoil backgrounds in the 2-7 keV window

CDMSlite – low-energy spectrum and efficiency

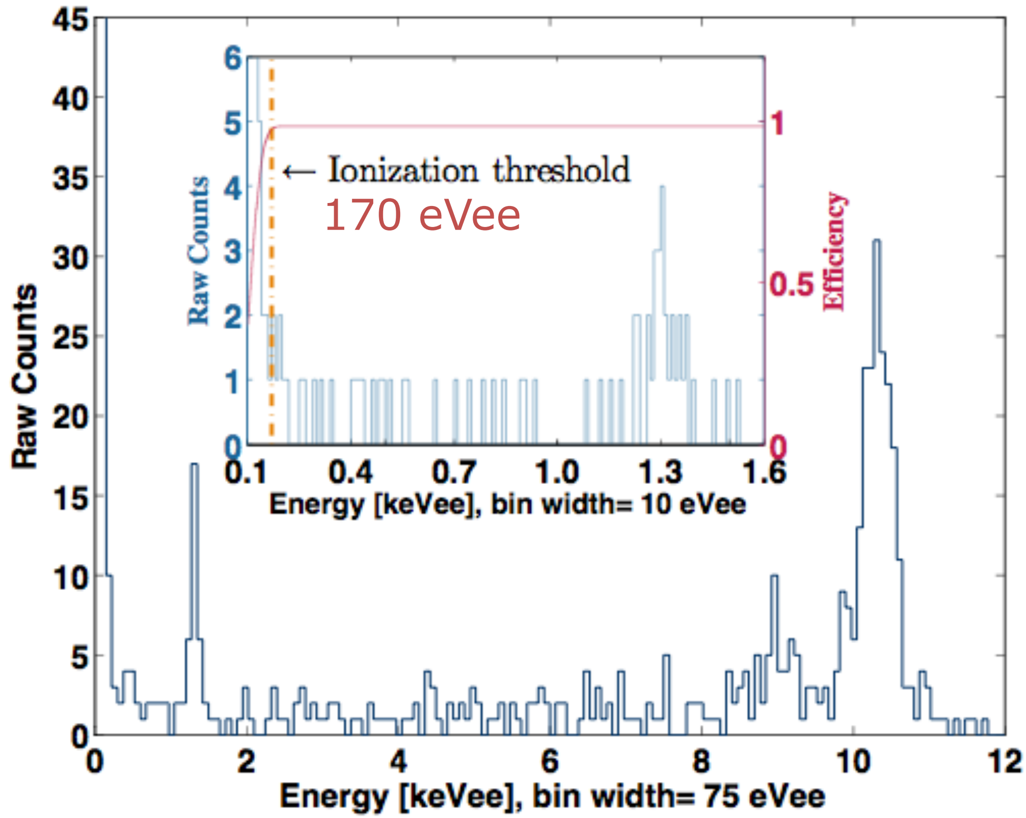
Event selection criteria

- Not coincident with signals in the muon veto
- Single detector energy depositions
- Not consistent with high frequency noise ("glitches")
- Not consistent with low frequency noise (microphonics)

Time periods selected with low leakage and where the gain could be well calibrated

Exposure = 10.3 live days
= 6.3 kg day

Recoil spectrum of WIMP search events

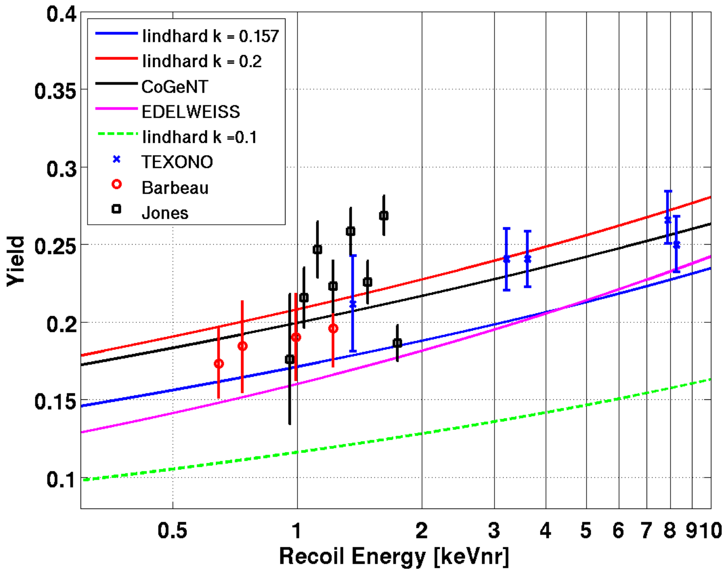


The spectrum shows features at 10.36 keV and 1.3 keV due to K- and L- shell electron captures in ^{71}Ge. The energy resolution of the 1.3 keV line is 43 eV (1σ).

CDMSlite – Spectrum of nuclear recoils

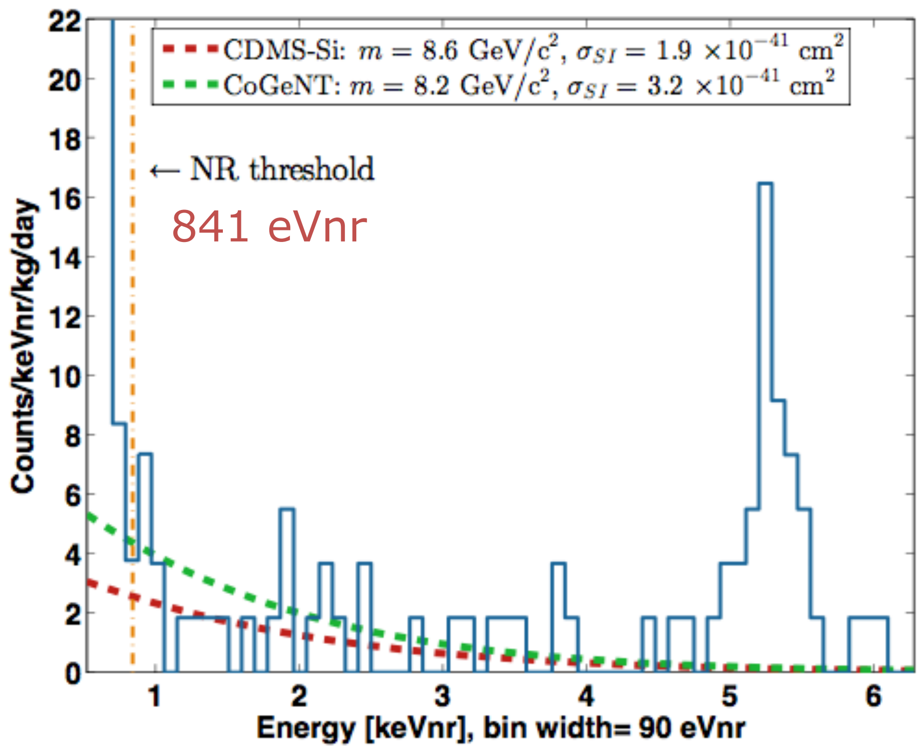
$$E_{\mathrm{nr}} = E_{\mathrm{ee}} \frac{\left(1 + \frac{eV_{\mathrm{b}}}{\varepsilon_\gamma}\right)}{\left(1 + \frac{eV_{\mathrm{b}}}{\varepsilon_\gamma} Y(E_{\mathrm{nr}})\right)}$$

The yield is not measured: use theoretical (Lindhard) model



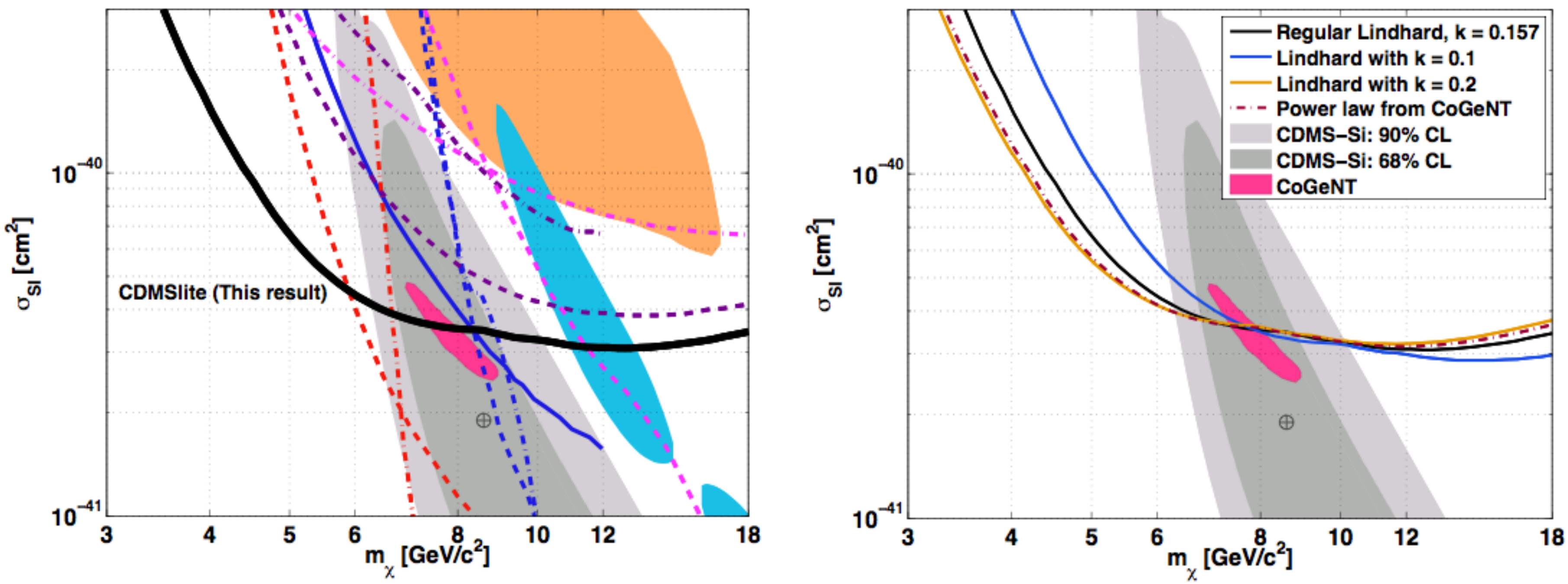
A number of experiments have measured nuclear recoils in germanium over the relevant energy range.

Resulting NR spectrum



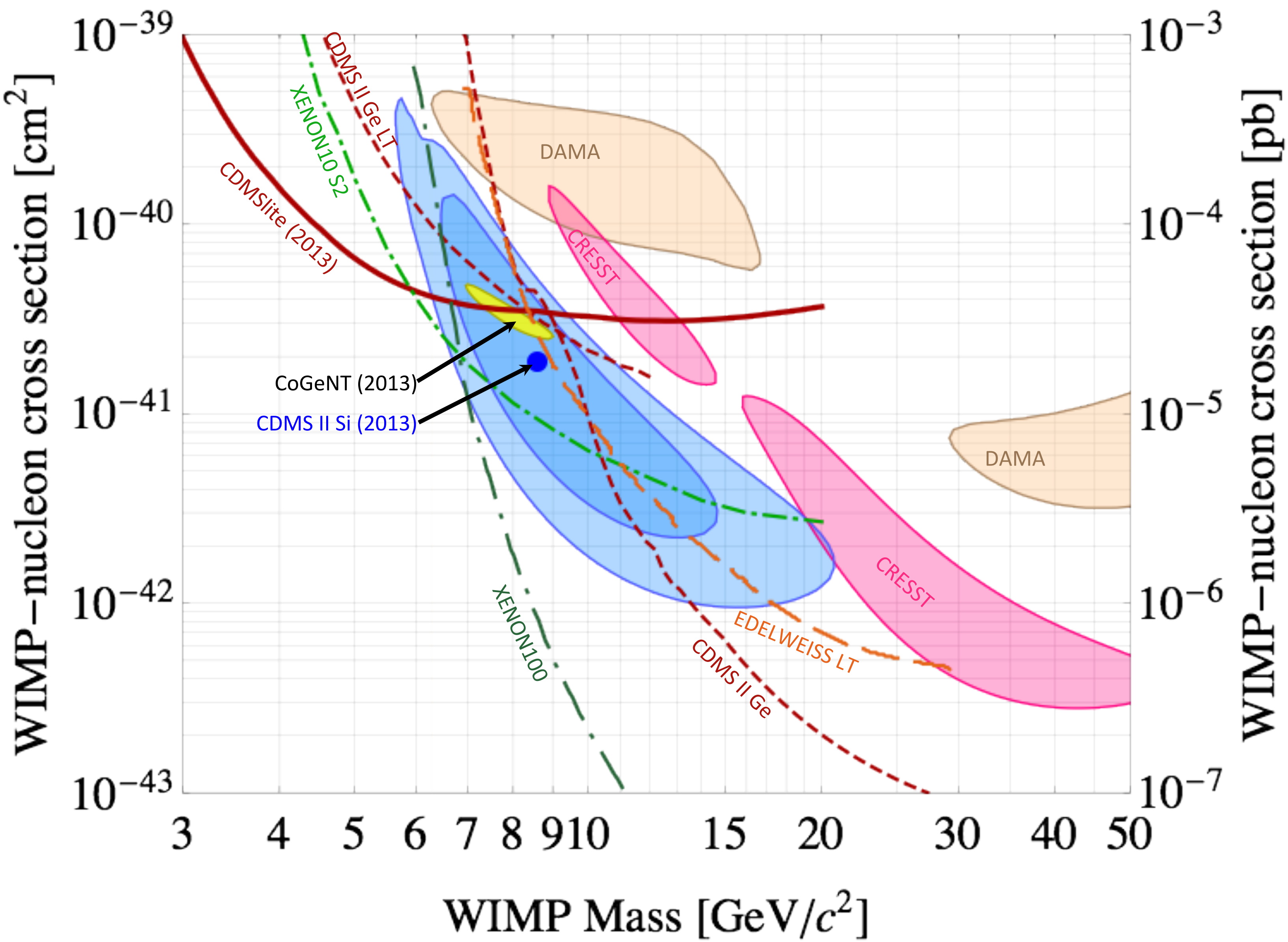
CDMSlite – Results

This analysis limits new WIMP parameter space for low masses and rules out portions of CDMS II and CoGeNT contours



The choice of a different model for the yield affects the reconstruction of the nuclear recoil energy and thus the interpretation as a limit on the WIMP-nucleon cross-section

Resulting experimental situation for low-energy WIMPs



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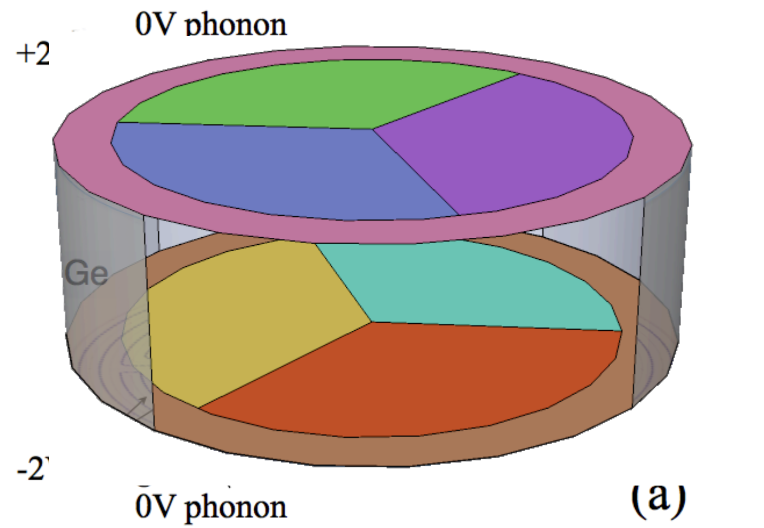

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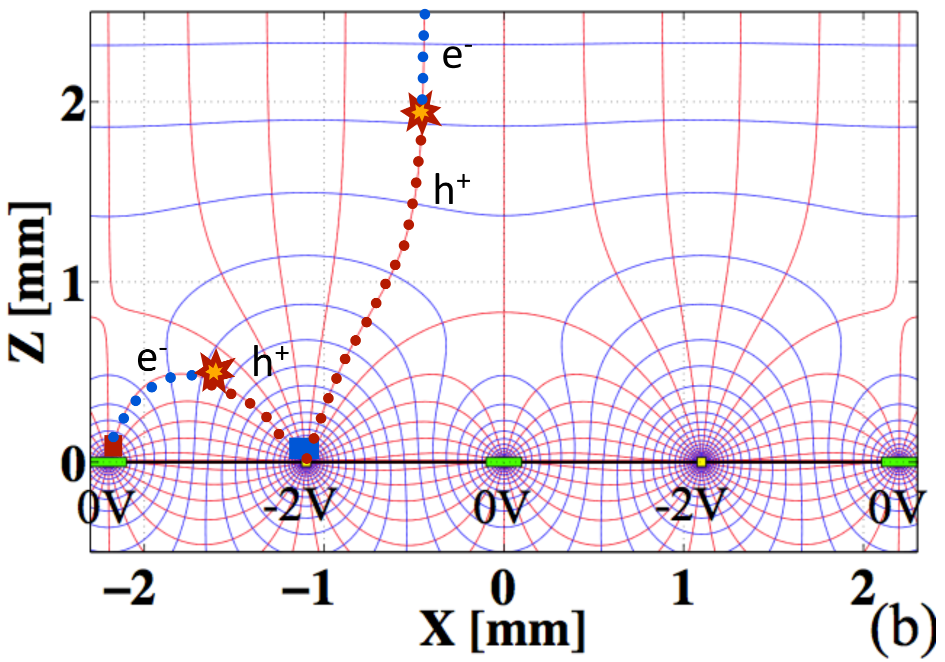


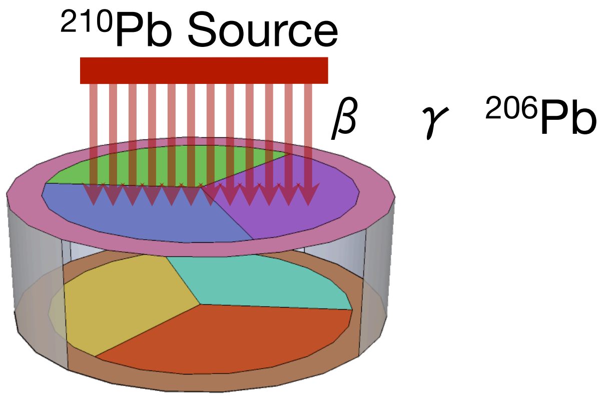
The resulting symmetry/asymmetry in charge collection is an extremely effective discriminant for surface events

iZIP calibration

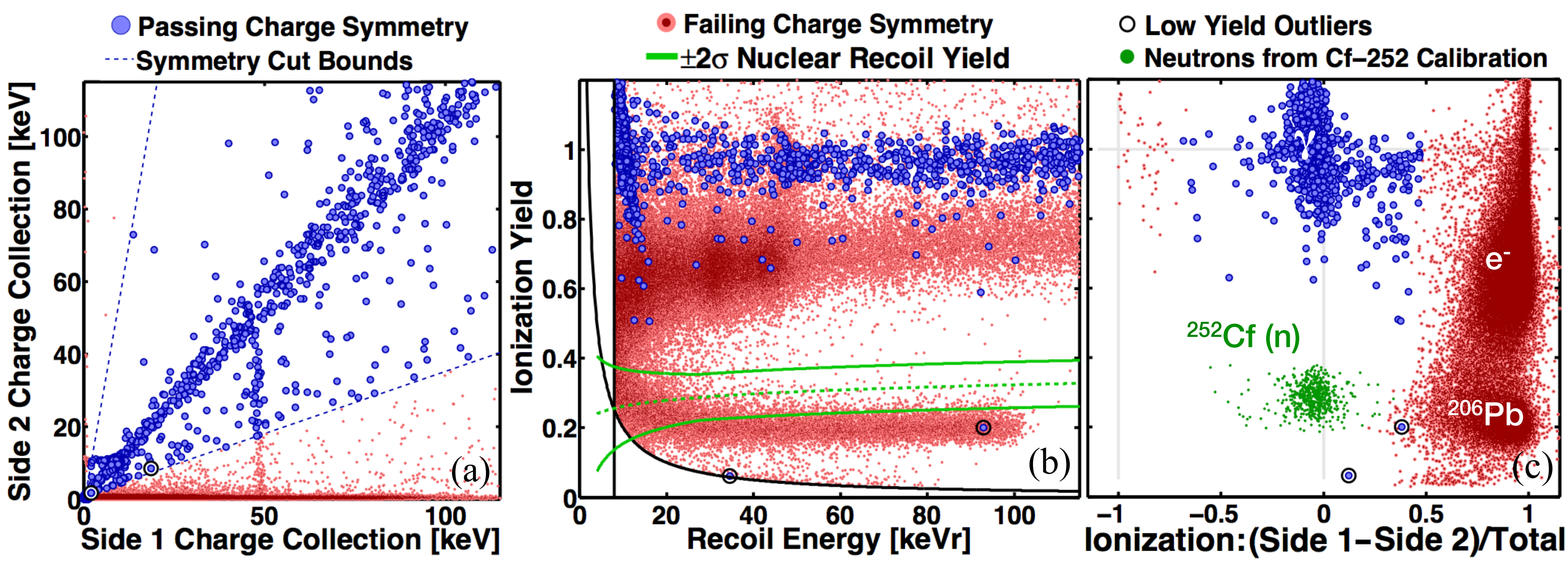
~900 live hours in T3Z1 with a ^{210}Pb source on side 1

71,525 electrons
16,258 ^{206}Pb recoils

No events leaking into the signal region (8-115 keV)



For 300 kg yr (200 kg Ge SNOLAB) the estimated leakage is < 0.6 events 90% cl



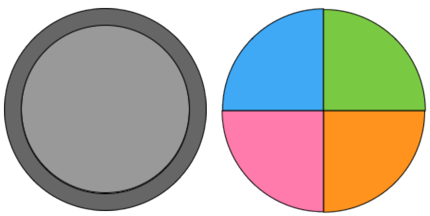
(Ionization threshold 2 keVee)

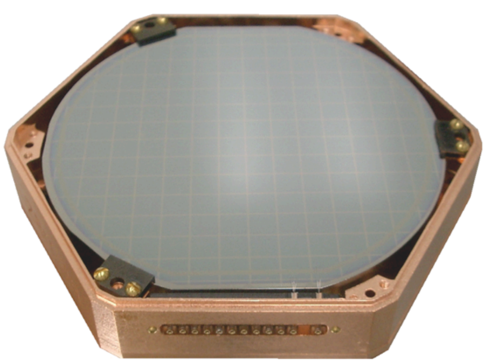
CDMS II

4.6 kg Ge (19 x 240 g)
1.2 kg Si (11 x 106g)

3" Diameter
1 cm Thick

2 charge + 4 phonon



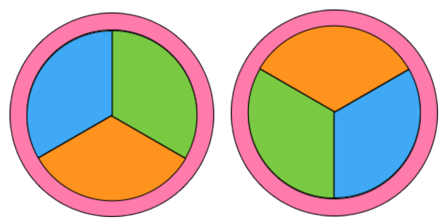


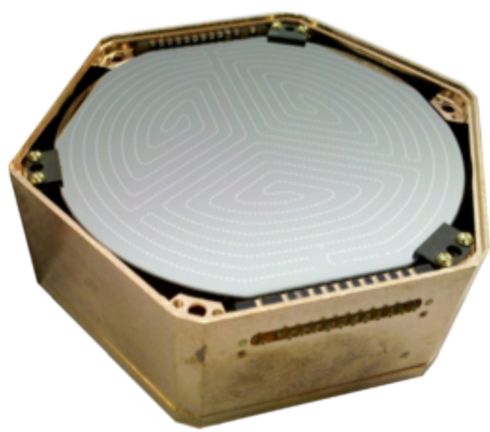
SuperCDMS Soudan

9.0 kg Ge (15 x 600g)

3" Diameter
2.5 cm Thick

2 charge + 2 charge
4 phonon + 4 phonon





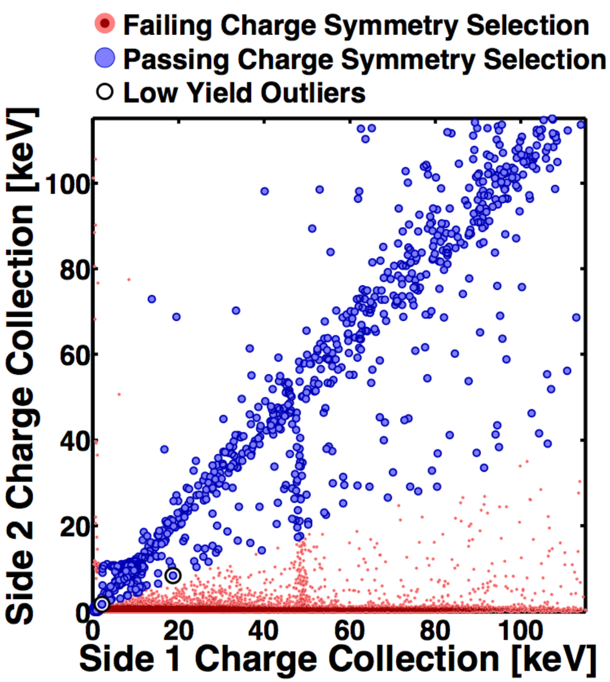
The rejection of surface events with the new iZIPs using Z-partition has been demonstrated with data from exposure to betas from ^{210}Pb sources

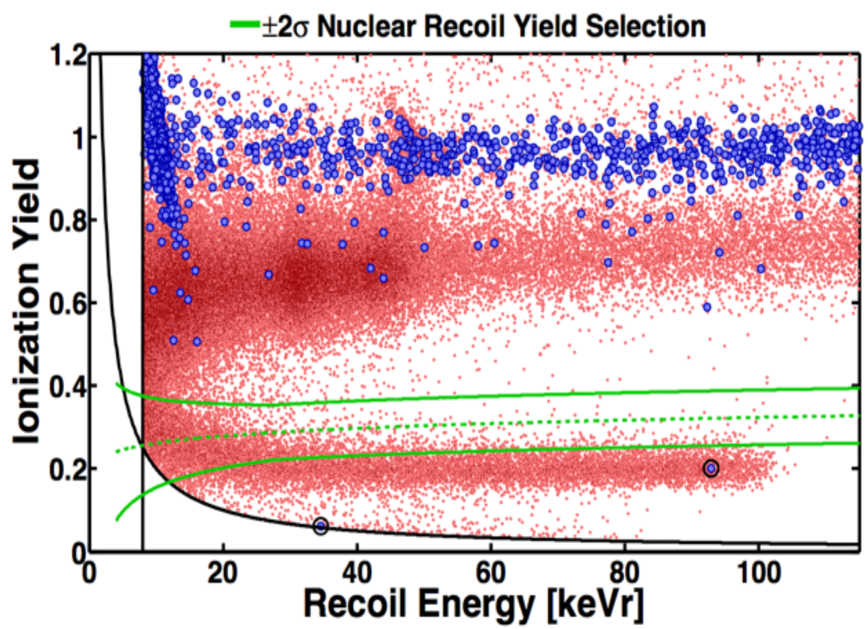
In ~800 live hours, no events leaked into the 8-115 keV signal region

Leakage < 1.7×10^{-5}

This could allow a background free search for 5 yr of operation in SuperCDMS @ SNOLAB (~100 kg)

Appl.Phys.Lett. 103 (2013) 164105





(the low threshold analysis corresponds to smaller energies and some leakage is expected)