Recent Results from SuperCDMS for Low-Mass WIMPs

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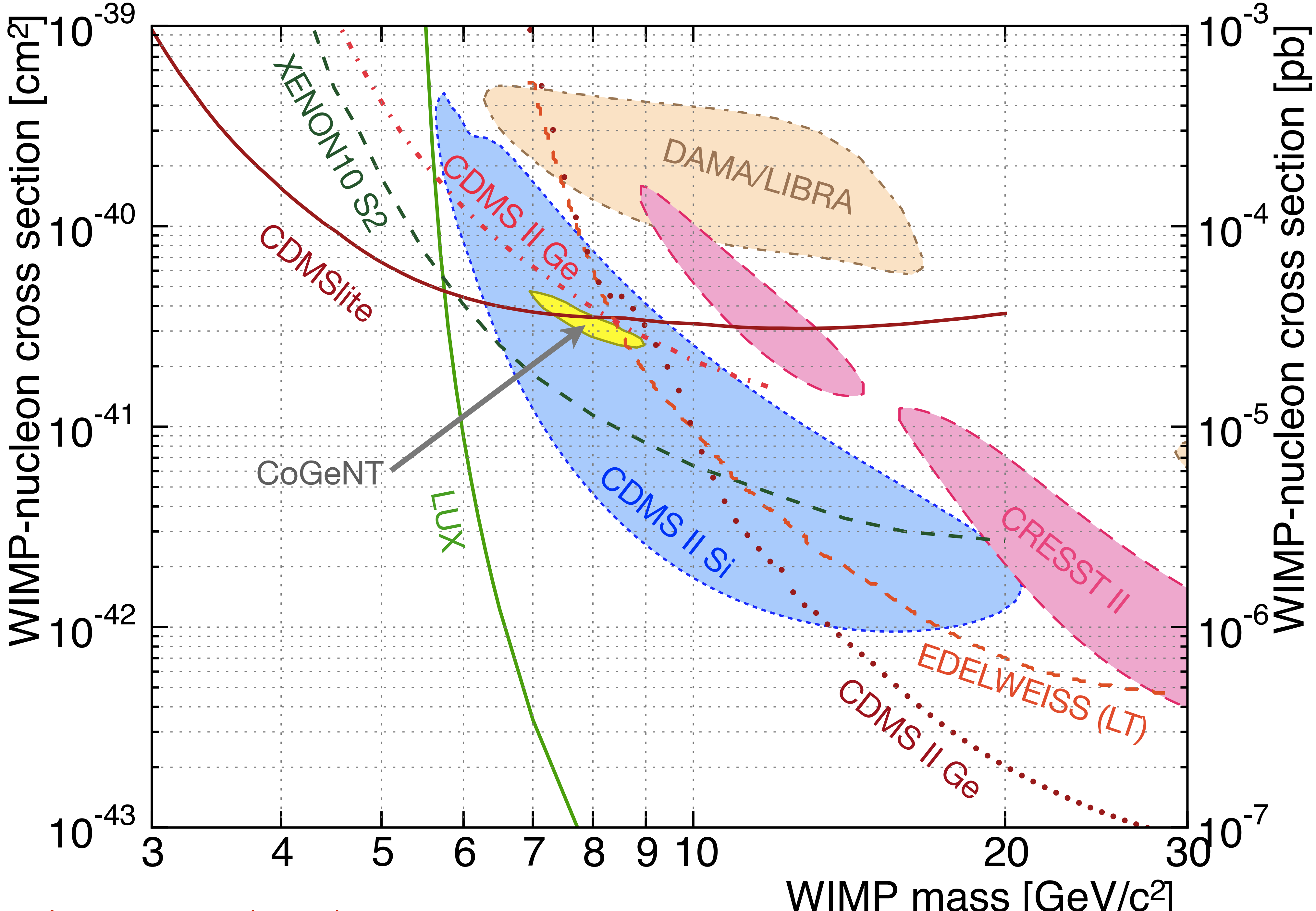
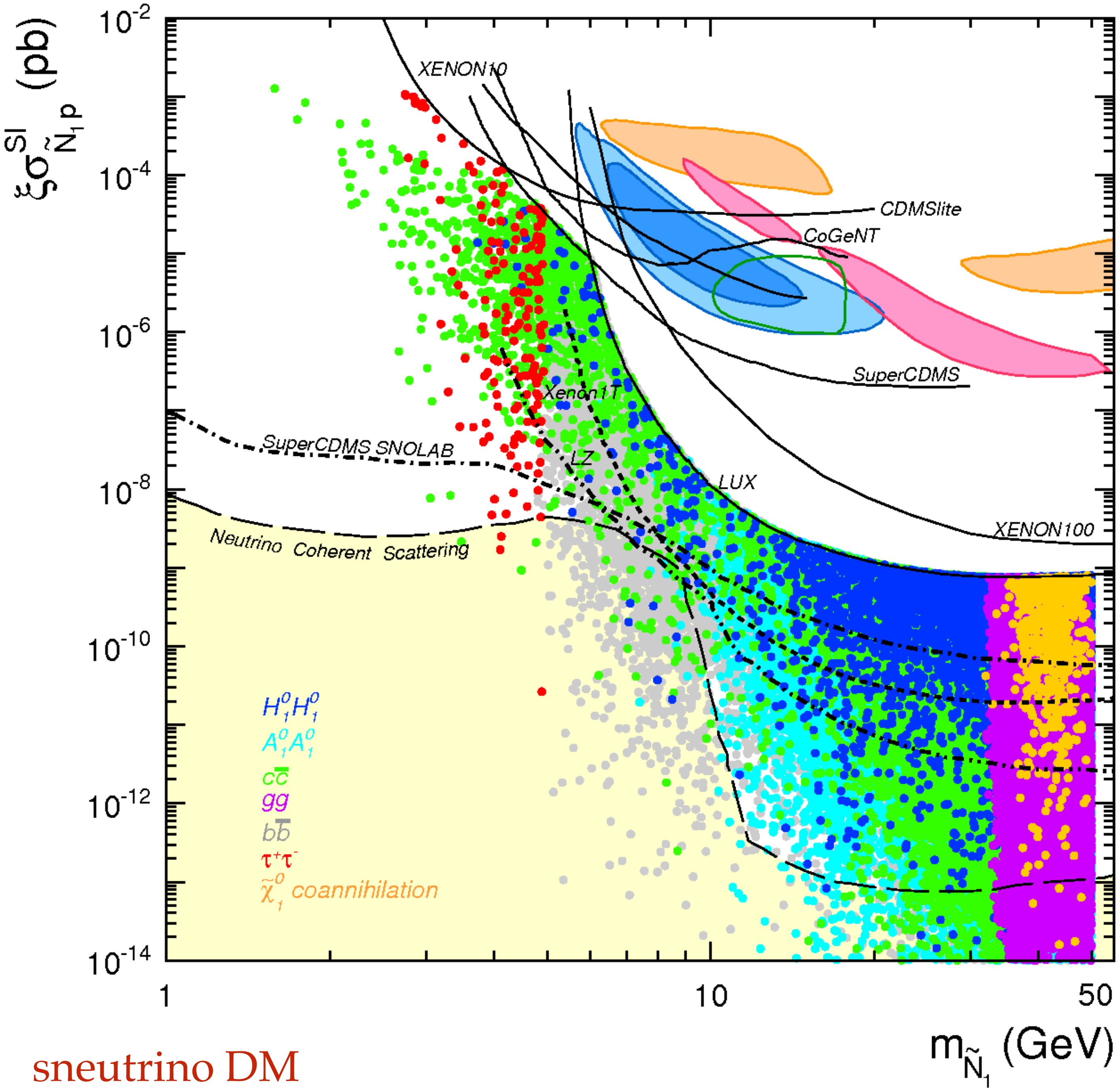
“Hints” for Low-Mass WIMPs



CDMS II Si: PRL 111 (2013) 251301

CDMSlite: PRL 112 (2014) 041302

Motivation



sneutrino DM
arXiv:1404.2572 (Cerdeno, Peiro, Robles)

- No signal has so far been seen at higher mass by direct detection experiments or at the LHC
- Particle Physics models provide candidates for light dark matter including (but not limited to):
  - Supersymmetry (neutralino in the MSSM or NMSSM, neutrino in extended models)
  - Asymmetric Dark Matter
  - others
- **This parameter space is largely unexplored and must also be advanced!**

Challenges & Strategy

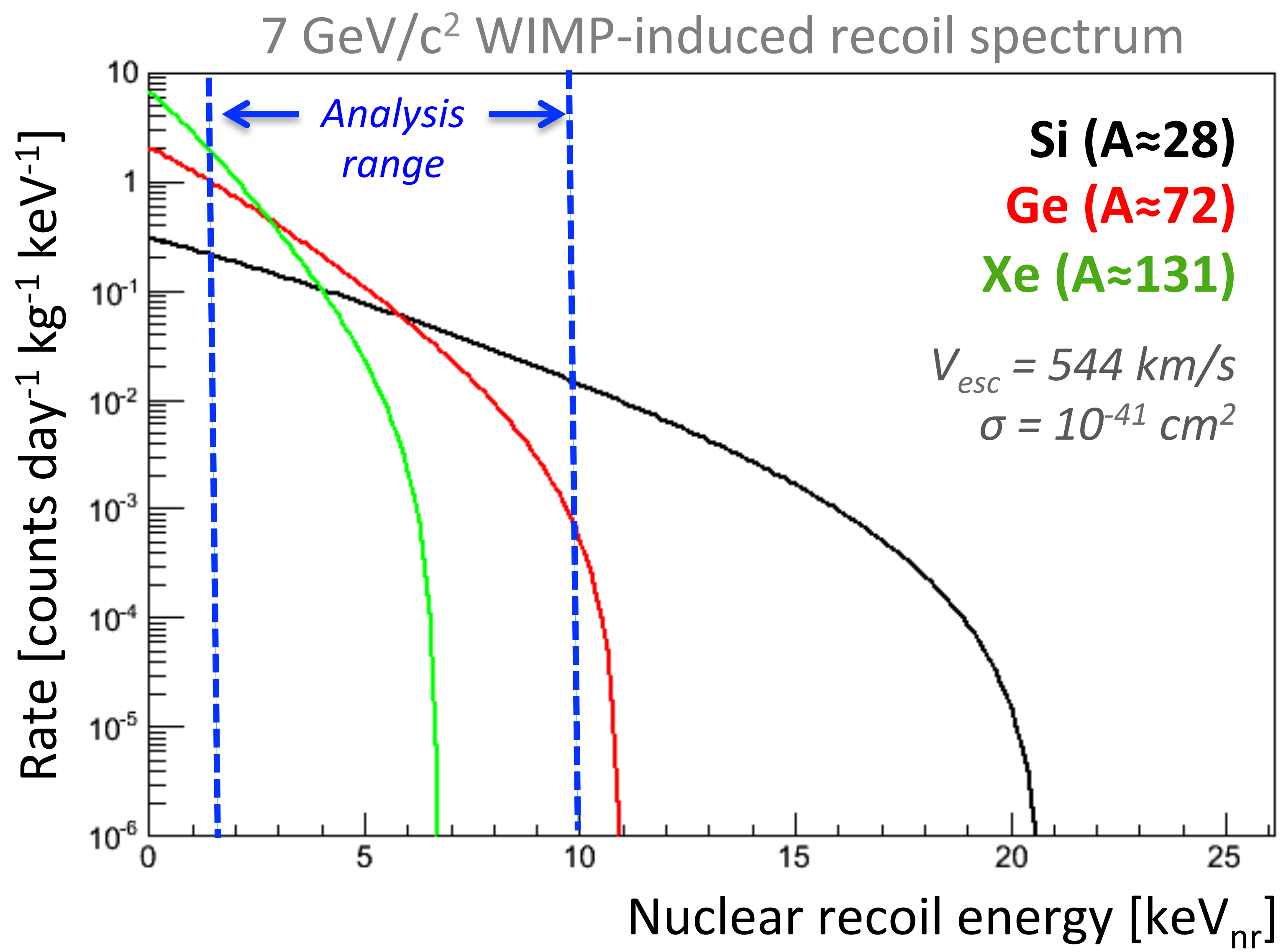
Challenges:

- Signal is at very low recoil energies.
- Ge is a relatively heavy target
- Backgrounds are difficult to discriminate

Strategy:

Lower the threshold as much as possible

➡ 1.6 keV_{nr} trigger threshold



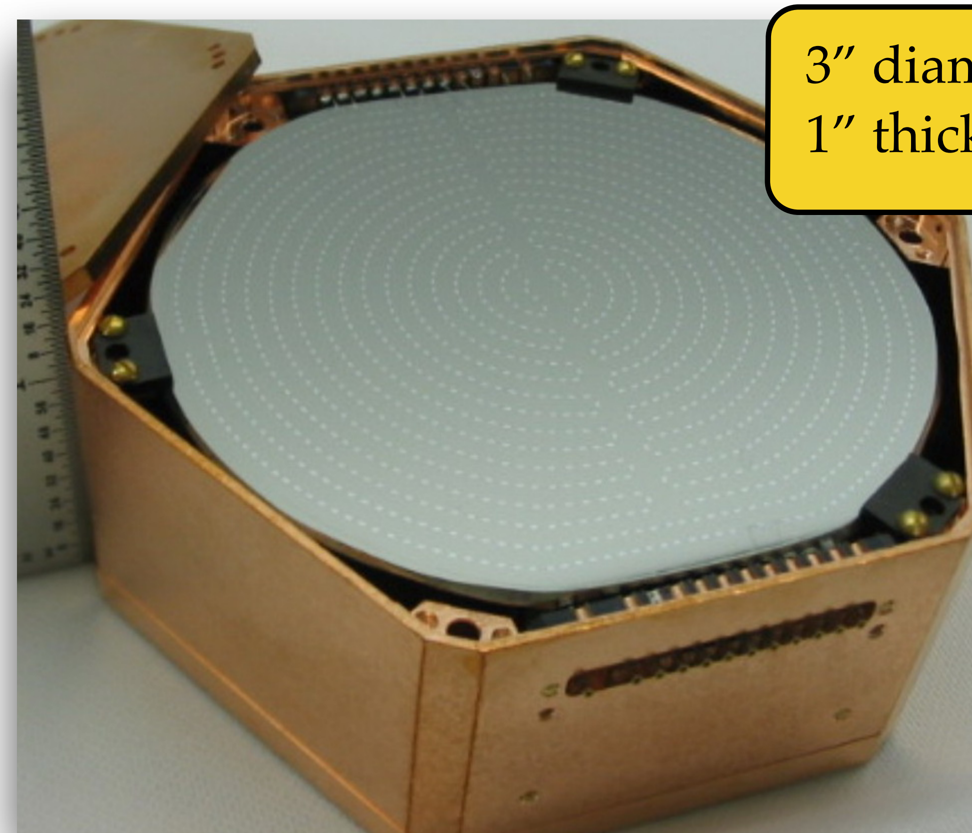
Trade-off:

Background is difficult to reject below 10 keV_{nr}. Try to reject as much background as possible.

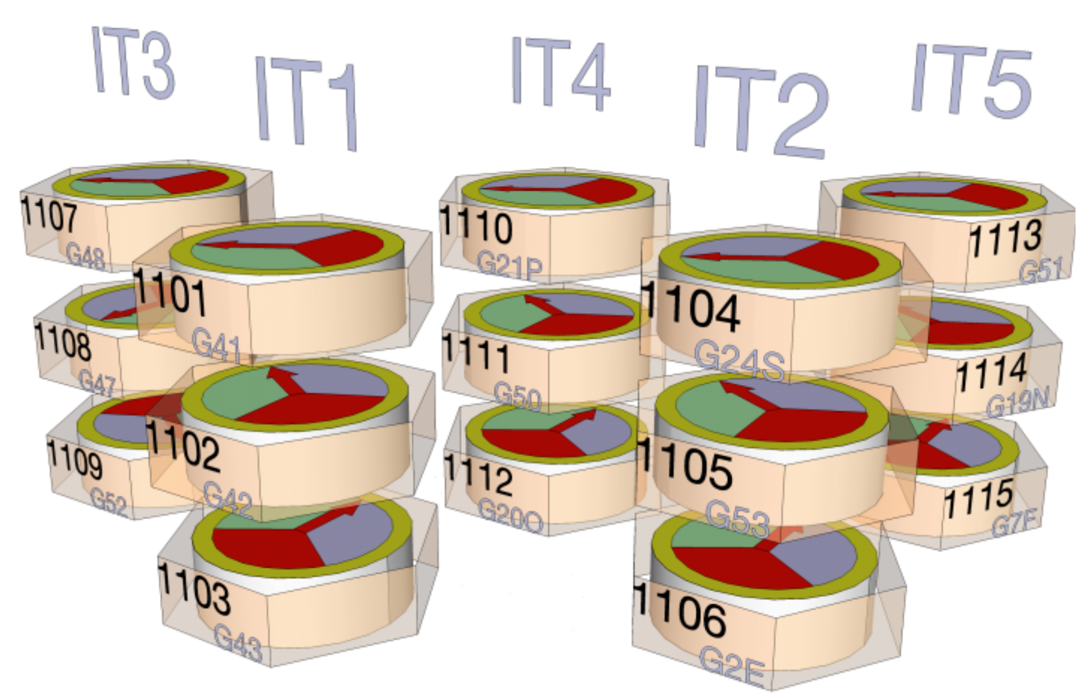
We expect background events in the signal region!

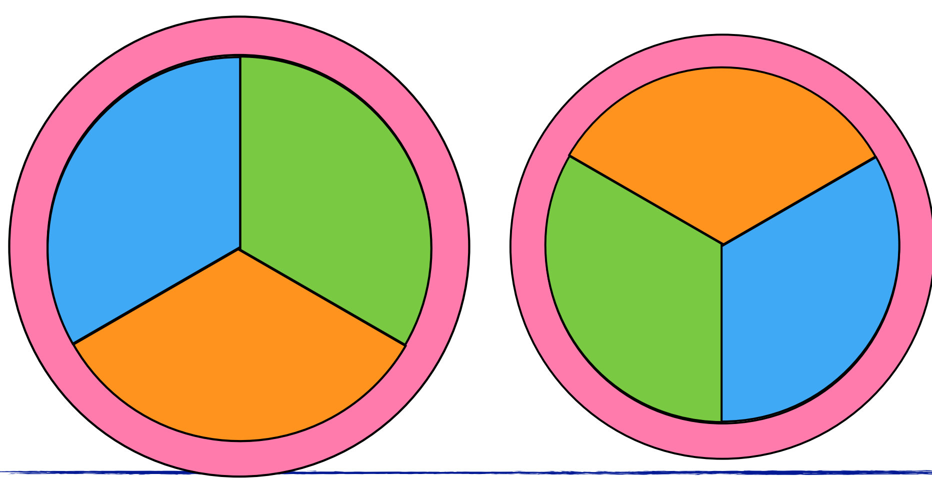
SuperCDMS Detectors

- **interleaved Z-sensitive Ionization and Phonon detectors (iZIP)**
- Each side instrumented with 2 charge + 4 phonon sensors
- Experiment contains 15 iZIPs, stacked into 5 towers, science operations since Mar. 2012
- Location: Soudan Underground Laboratory, Minnesota, USA
- Data for this analysis: 577 kg-days taken from March 2012- July 2013 using 7 iZIPs with lowest trigger threshold.



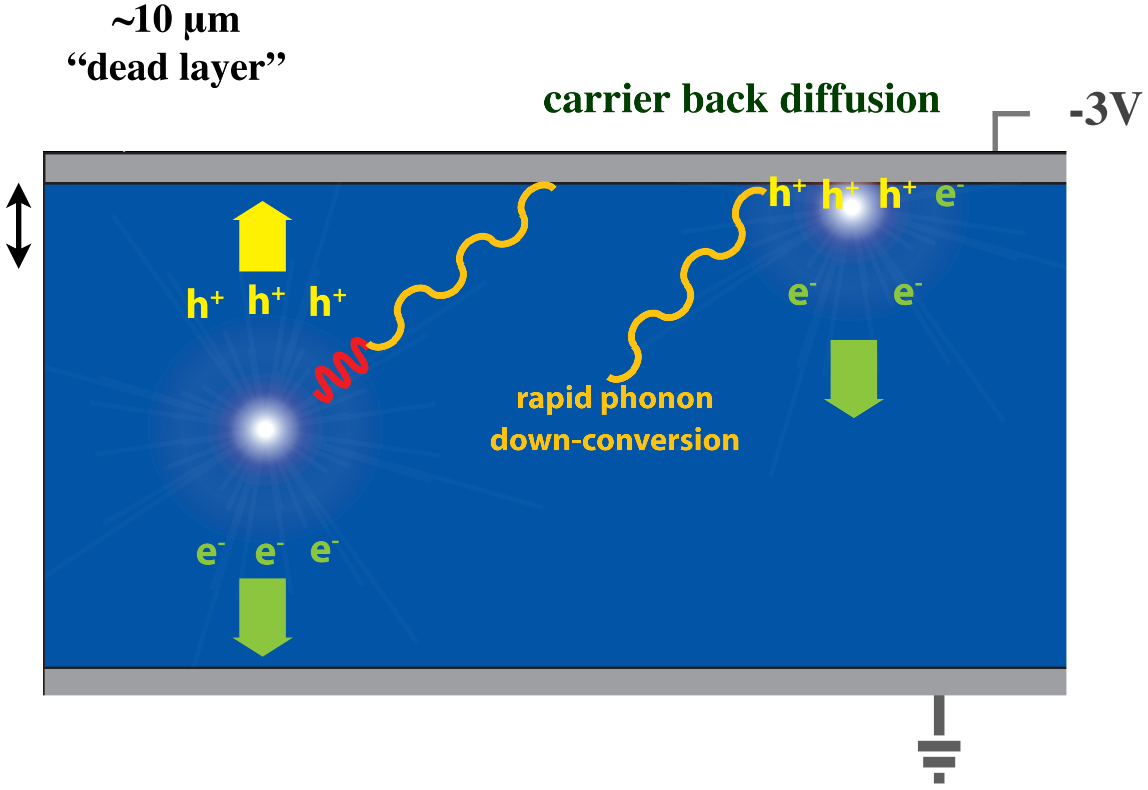
3″ diameter
1″ thick

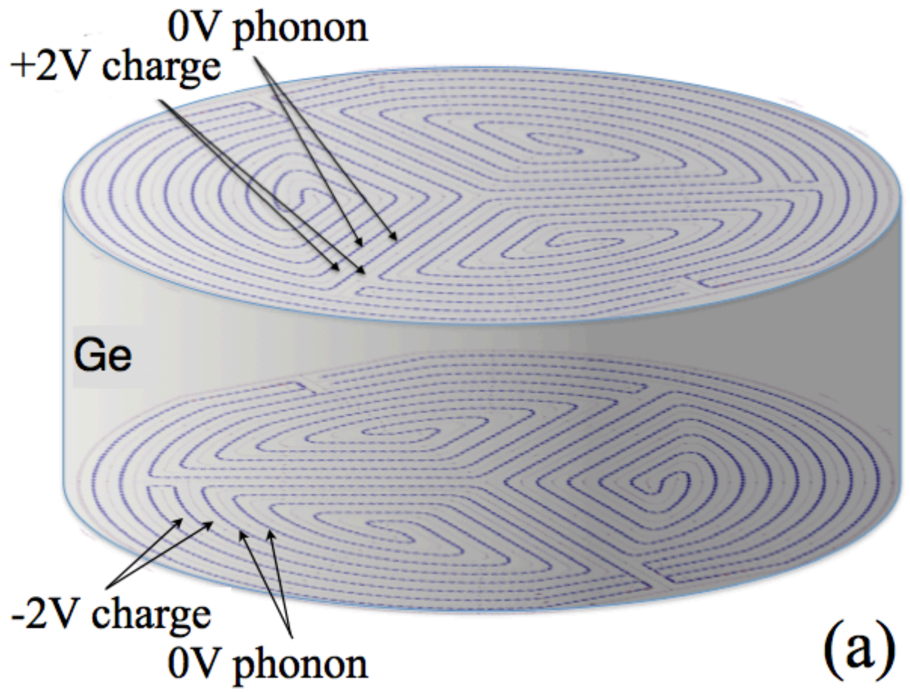




iZIP Discrimination of Surface Events

- In the CDMS II detectors the main background of concern was from surface events.
- The ratio of ionization-to-phonon energy and pulse shape yielded a surface misID ratio of 1:1200 with fiducial volume of ~35%.
- In the new iZIP detectors the ionization lines (±2V) are interleaved with phonon sensors (0V).





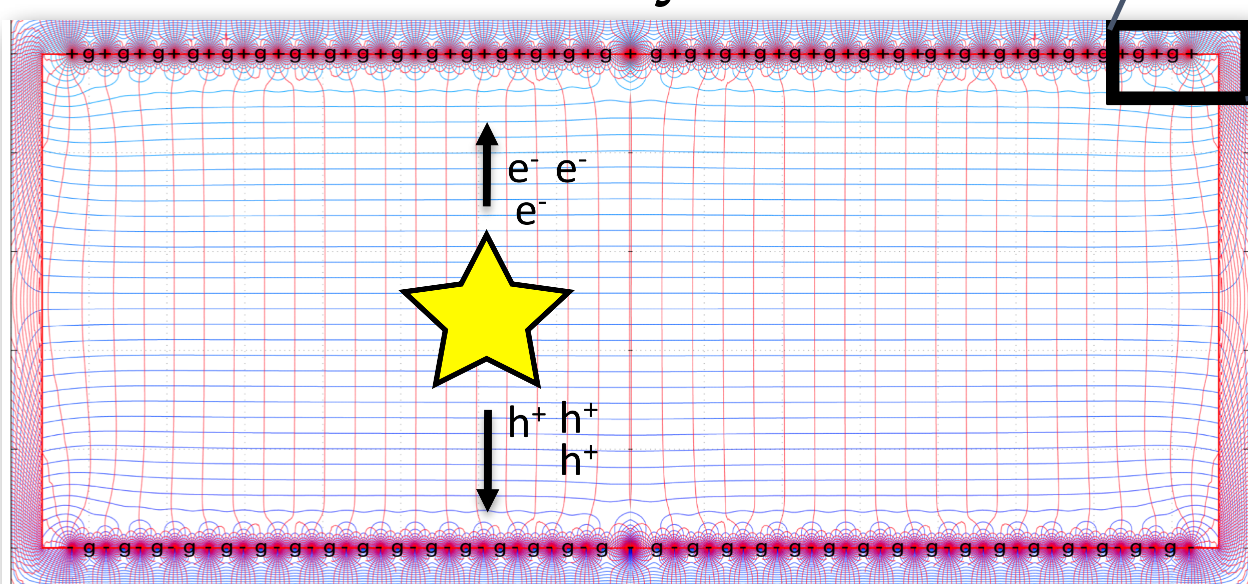
SCDMS iZIPs: Charge Signal

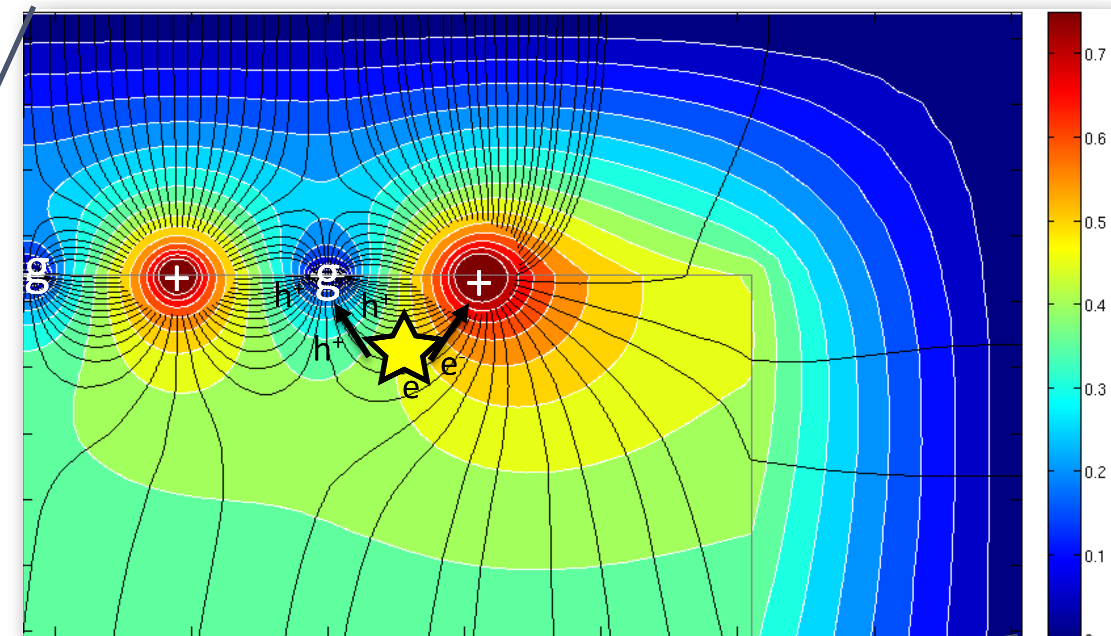
Bulk Events:

Equal but opposite ionization signal appears on both faces of detector (symmetric)

Surface Events:

Ionization signal appears on one detector face (asymmetric)





APL 103, 164105 (2013)

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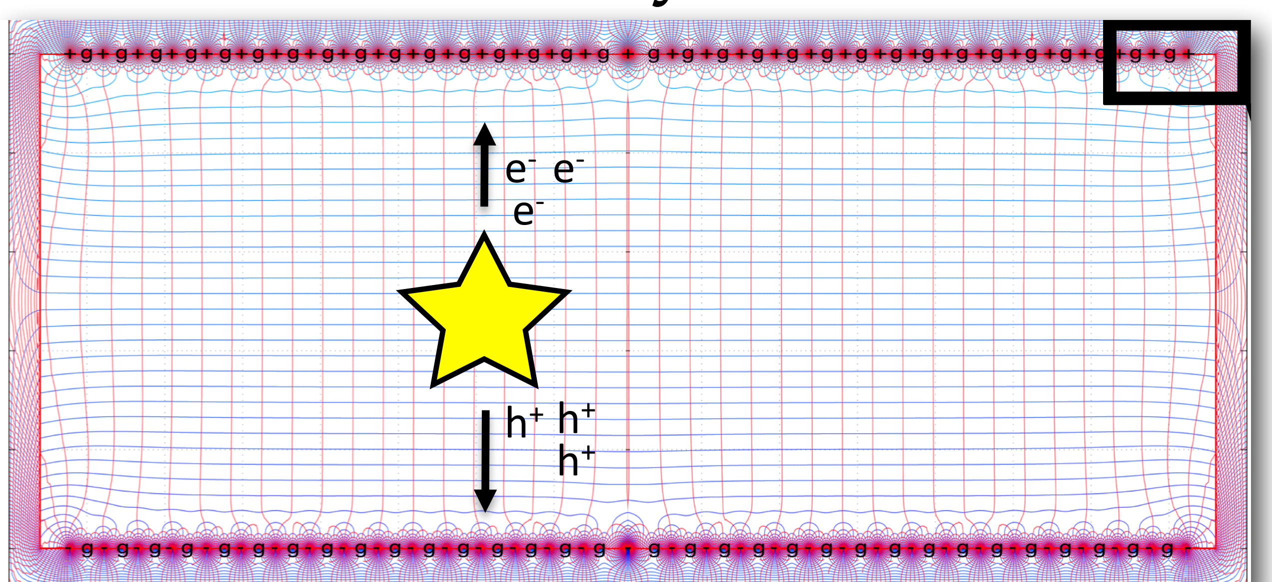
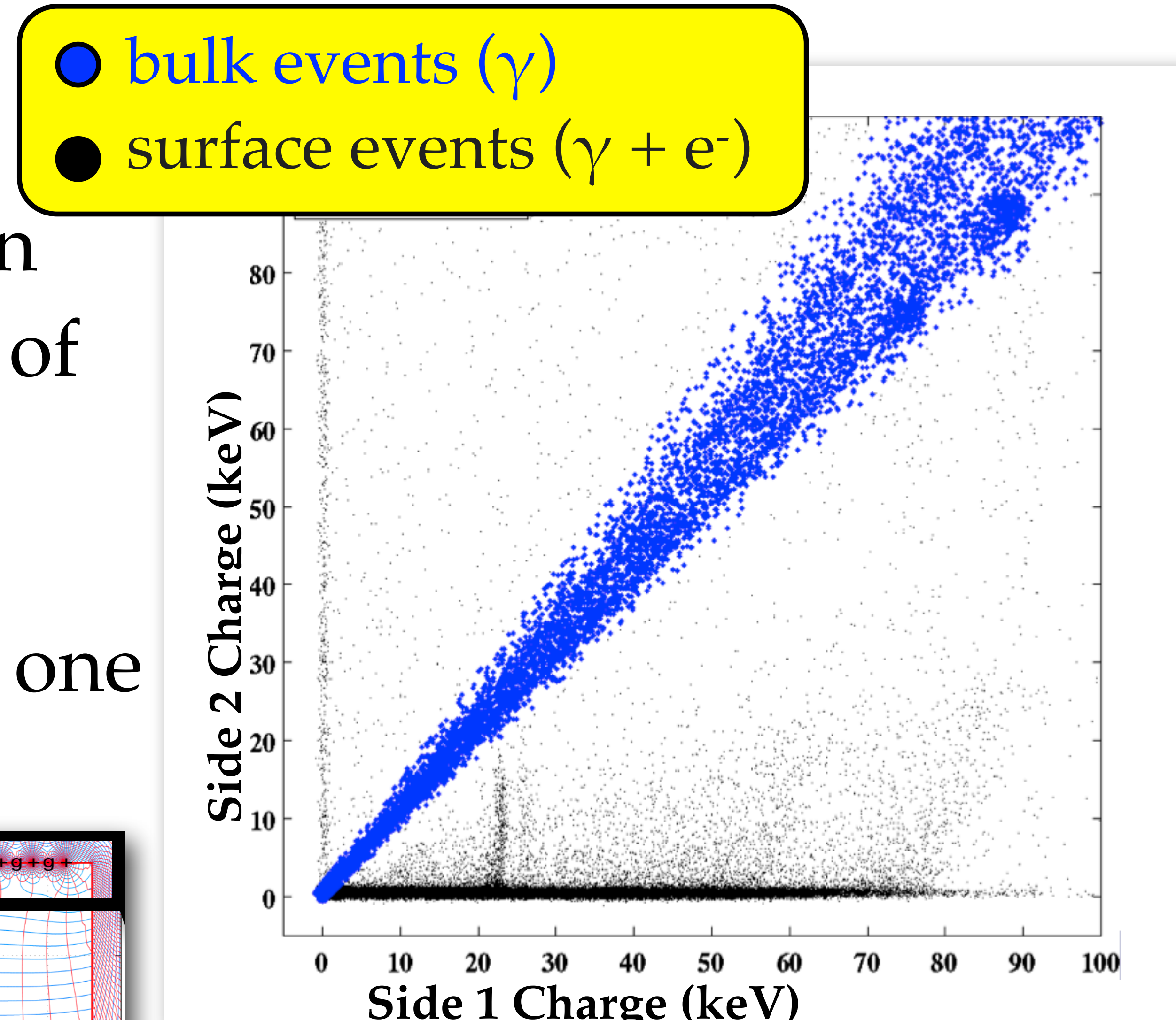


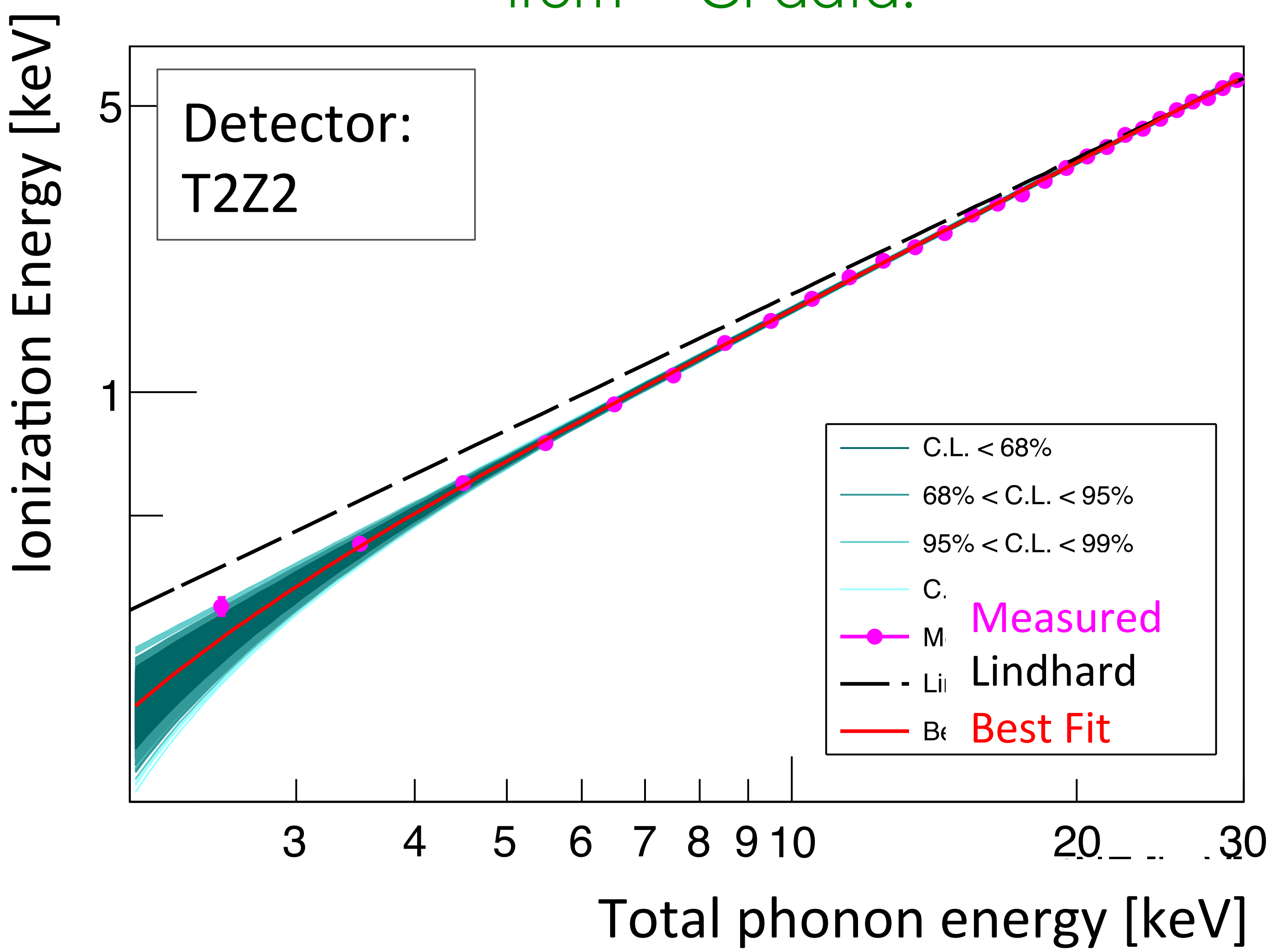
APL 103, 164105 (2013)



- ~50% fiducial volume (8-115 keVr) with misID fraction of 1.7 x 10^{-5}.
- < 0.6 events in 0.3 ton-years
- **Good enough for a 200 kg experiment run for 4 years at SNOLAB!**

Nuclear 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
E_{luke} is the energy from propagating the charges

NR equivalent energy =

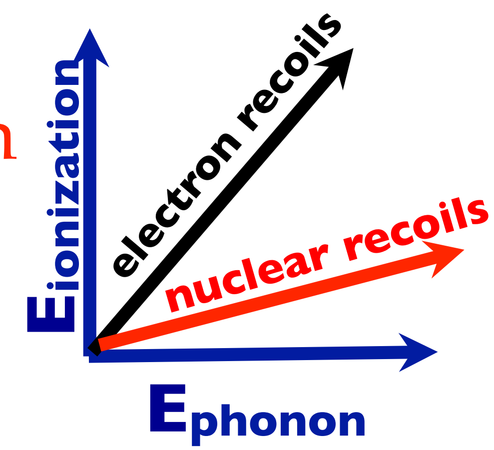
$$E_{total} - E_{luke\ NR}$$

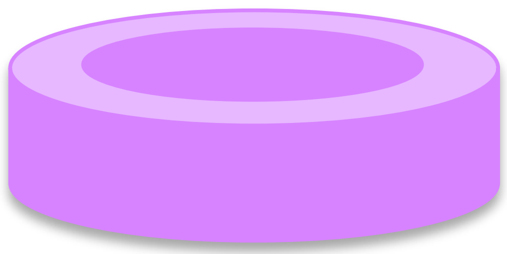
$E_{luke\ NR}$ is estimated from the mean NR ionization. It varies with E_{total}

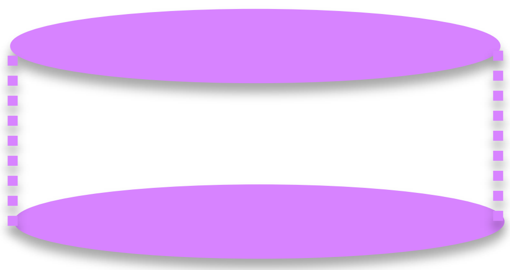
Background Sources

Bulk Electron Recoils:

- Compton background and 1.3 keV activation line
- *Use ionization and phonon energy to discriminate NR from bulk ER*







Sidewall and Surface Events:

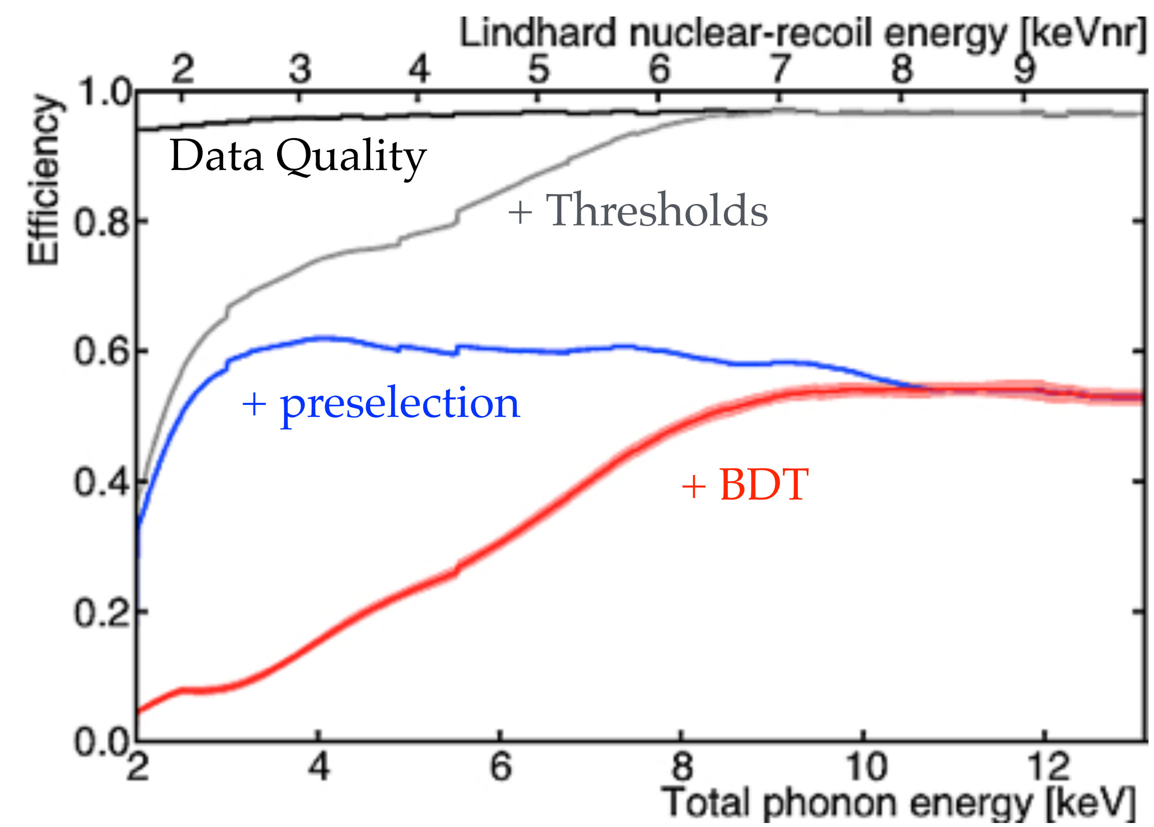
- betas and x-rays from ^{210}Pb, ^{210}Bi, ^{206}Pb recoils, outer radial Compton background and ejected electrons from Compton scattering
- *Use division of energy between inner and outer electrodes AND division of energy between sides 1 and 2.*

Cosmogenic and Radiogenic Neutrons:

Use active and passive shielding to eliminate AND the fact that neutrons tend to scatter in multiple detectors.

Analysis Details

Blind Analysis:
All single-detector scatter events in energy range removed from study, except data following ^{232}Cf calibration due to activation.



Data Quality:
Reject periods with poor detector performance.
Remove misreconstructed and noisy pulses

Trigger and Analysis Threshold:
Select periods w/ stable well-defined trigger threshold

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

Boosted Decision Tree:
Optimized cut on the phonon fiducial volume and ionization yield at low energy.

Efficiencies:
measured for neutrons from ^{252}Cf.
Corrected for multiple scatter with Geant4.

Background Estimates

- Prior to unblinding, background estimates were finalized, including known systematic effects.

- The background model was used to tune selection criteria. Unknown systematics preclude background subtraction for this blind analysis.

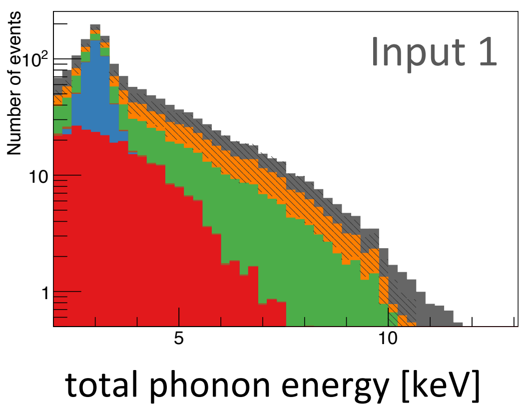
  We decided prior to unblinding to only set an upper limit.

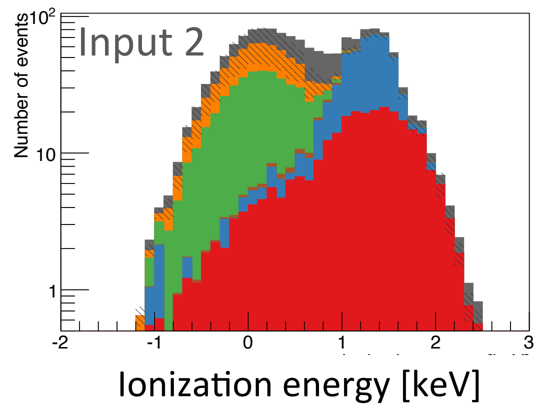
- 4 BDT cuts were optimized for 5, 7, 10 and 15 GeV/c^2 WIMPs. Accept events that pass any of the four cuts. Each cut was simultaneously tuned on all detectors, maximizing 90% C.L. poisson sensitivity for that mass.

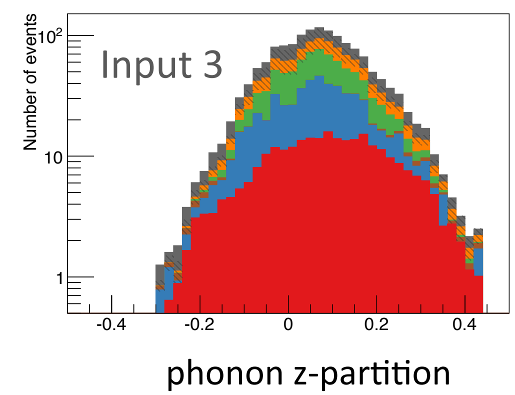
Background model expectation: $6.1^{+1.1}_{-0.8}$ events

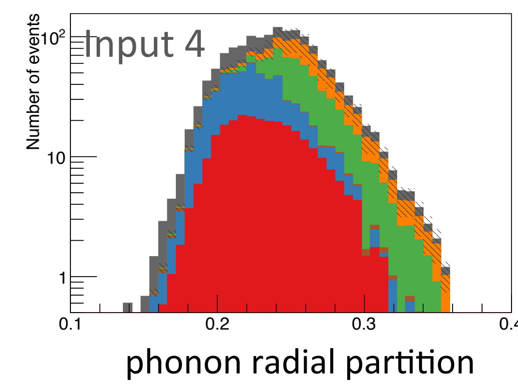
Neutron estimate: 0.1 ± 0.02 events

Boosted Decision Tree (BDT)

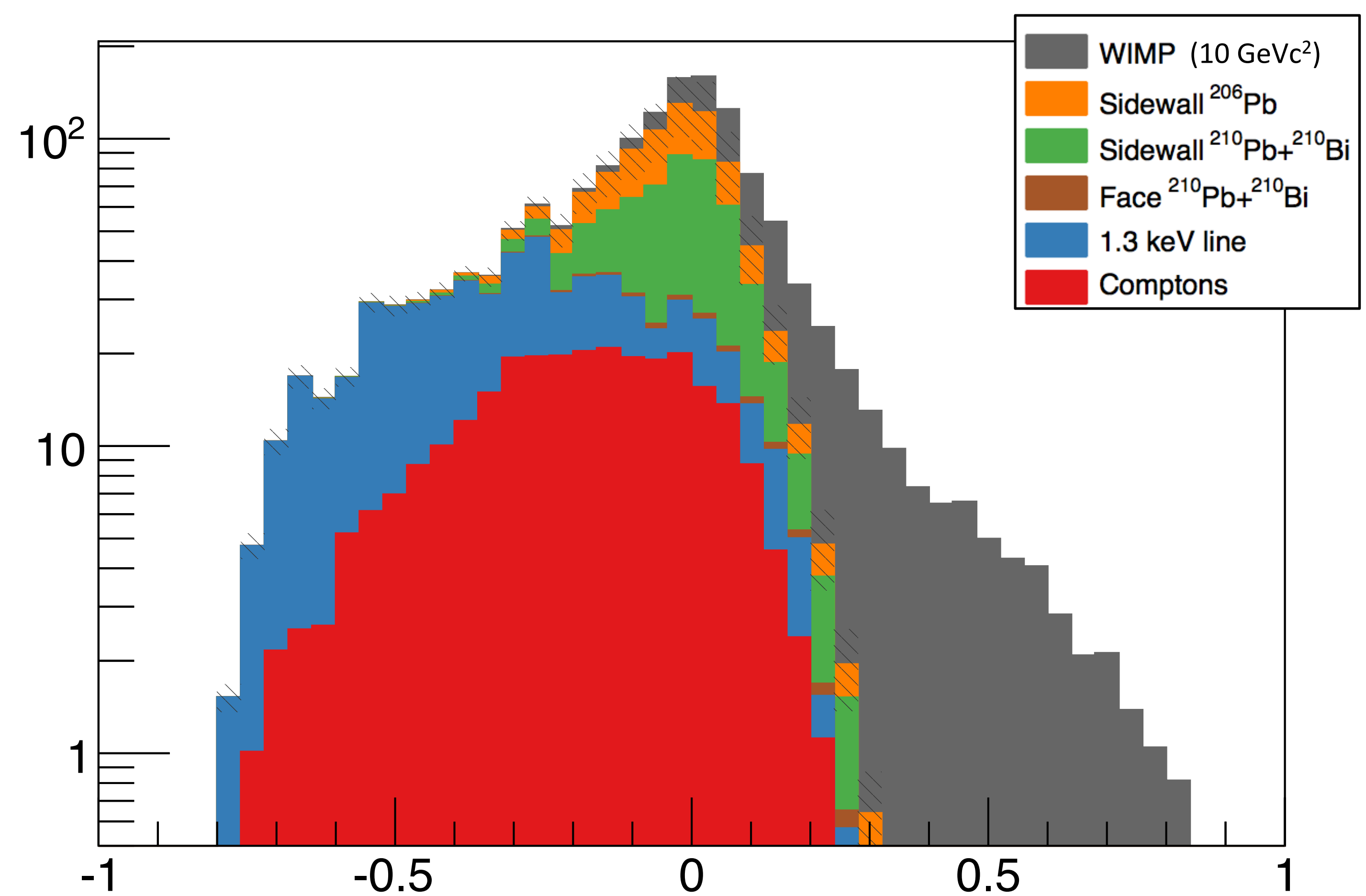






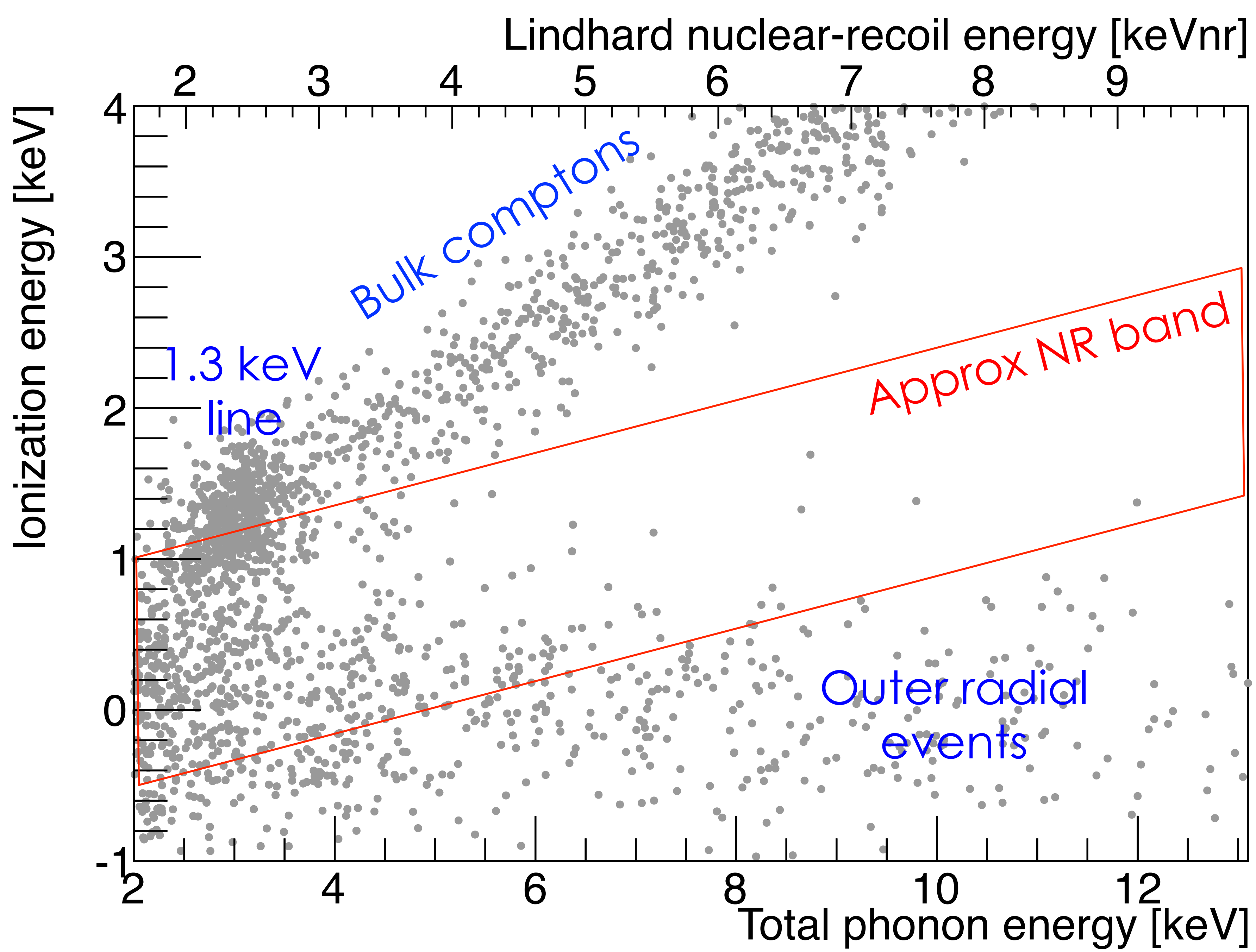


- **Backgrounds modeled with simulated data based on sidebands and calibration data.**
- **Signal modeled with nuclear recoils from ^{252}Cf calibration data rescaled for 10 GeV/c^2 WIMP.**



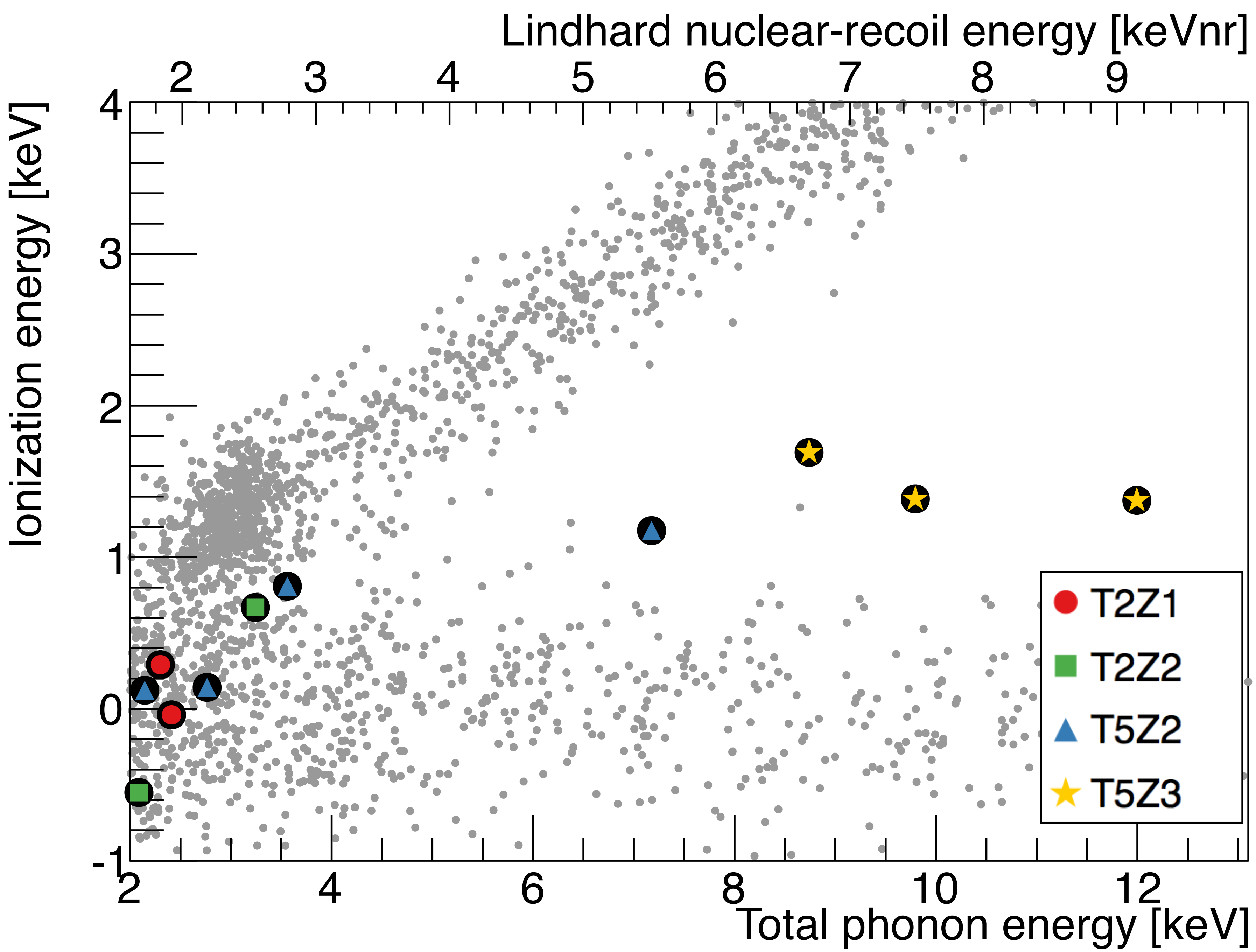
Unblinding: Before BDT Cut

Events passing all cuts prior to applying BDT

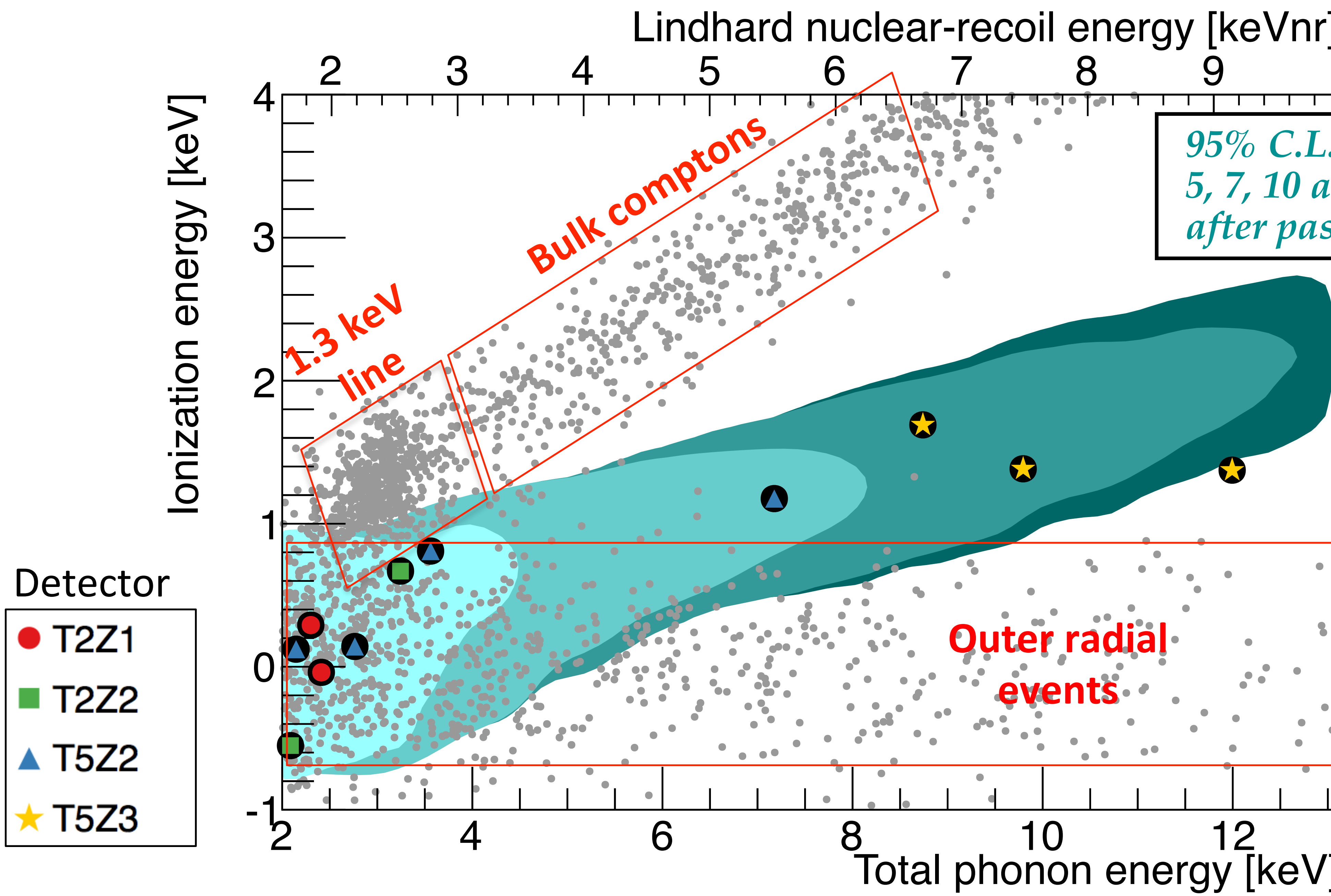


Unblinding: After BDT cut

11 candidates observed, $6.2^{+1.1}_{-0.8}$ expected



95% Confidence Intervals

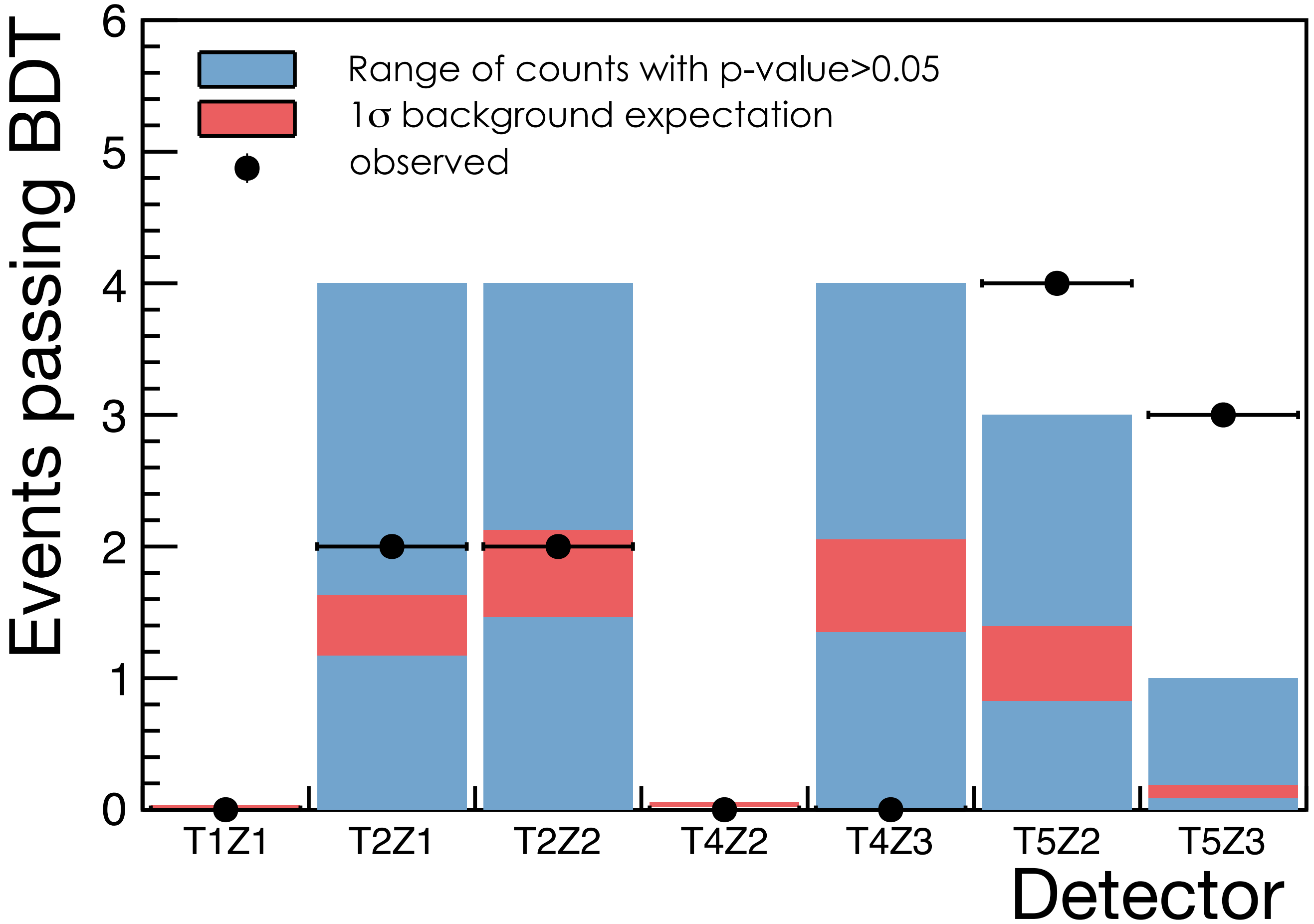


95% C.L. interval for a 5, 7, 10 and 15 GeV/c² WIMP after passing BDT selection

Detector	Energy [keVnr]	Bkgd
T1Z1	—	0.03 $^{+0.01}_{-0.01}$
T2Z1	1.8, 1.9	1.4 $^{+0.2}_{-0.2}$
T2Z2	1.7, 2.6	1.8 $^{+0.4}_{-0.3}$
T4Z2	—	0.04 $^{+0.02}_{-0.02}$
T4Z3	—	1.7 $^{+0.4}_{-0.3}$
T5Z2	5.8, 1.7, 2.8, 2.2	1.1 $^{+0.3}_{-0.3}$
T5Z3	7.5, 9.2, 6.7	0.13 $^{+0.06}_{-0.04}$

Post-unblinding Discussion

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

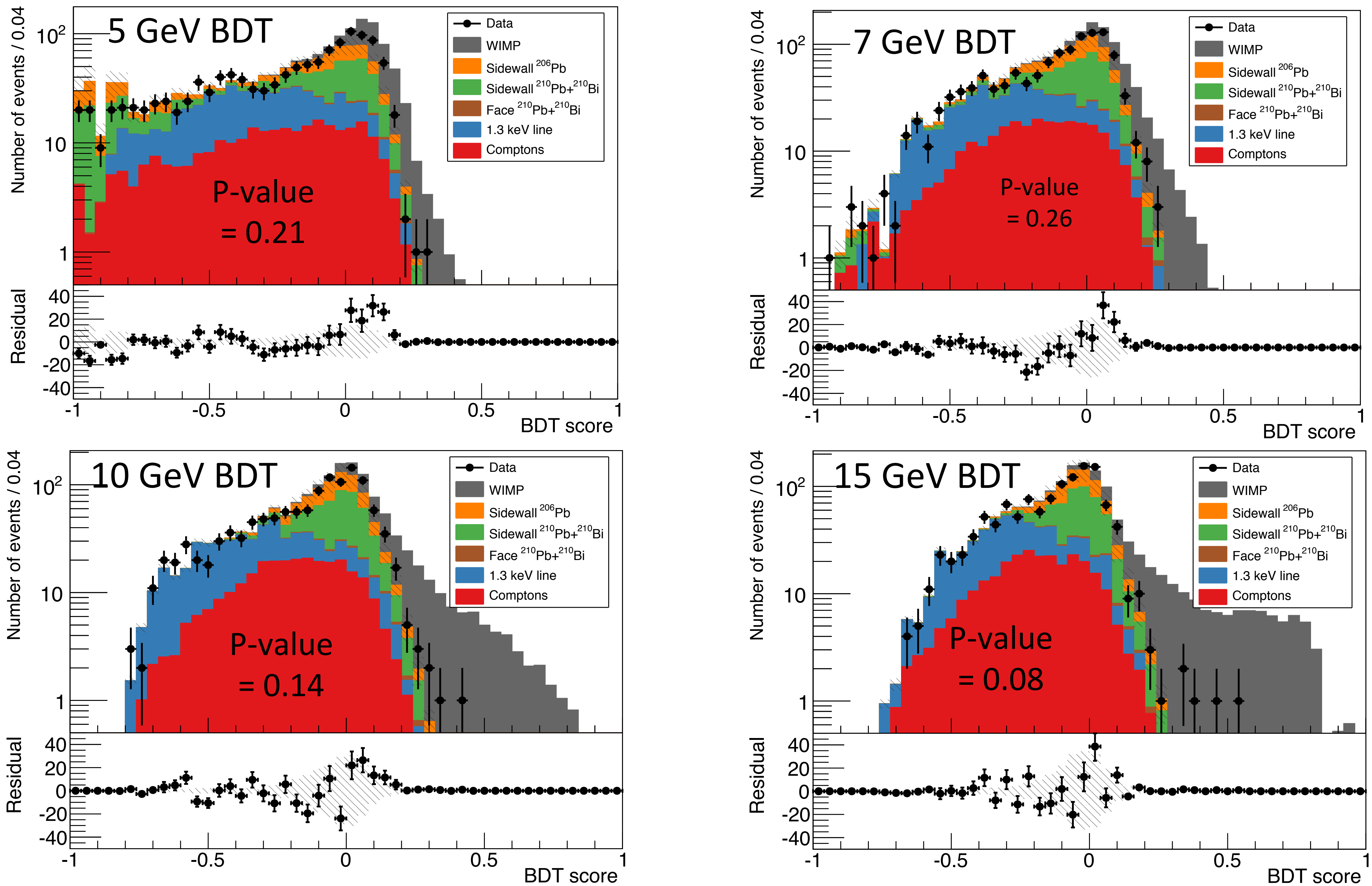


- Good agreement with predicted background on most detectors.

- T5Z3 observes the 3 highest-energy events. (Poisson p-value is 0.04%).

T5Z3 detector has a shorted ionization guard which may have affected the background model performance. Additional studies underway.

Model to Data Comparison

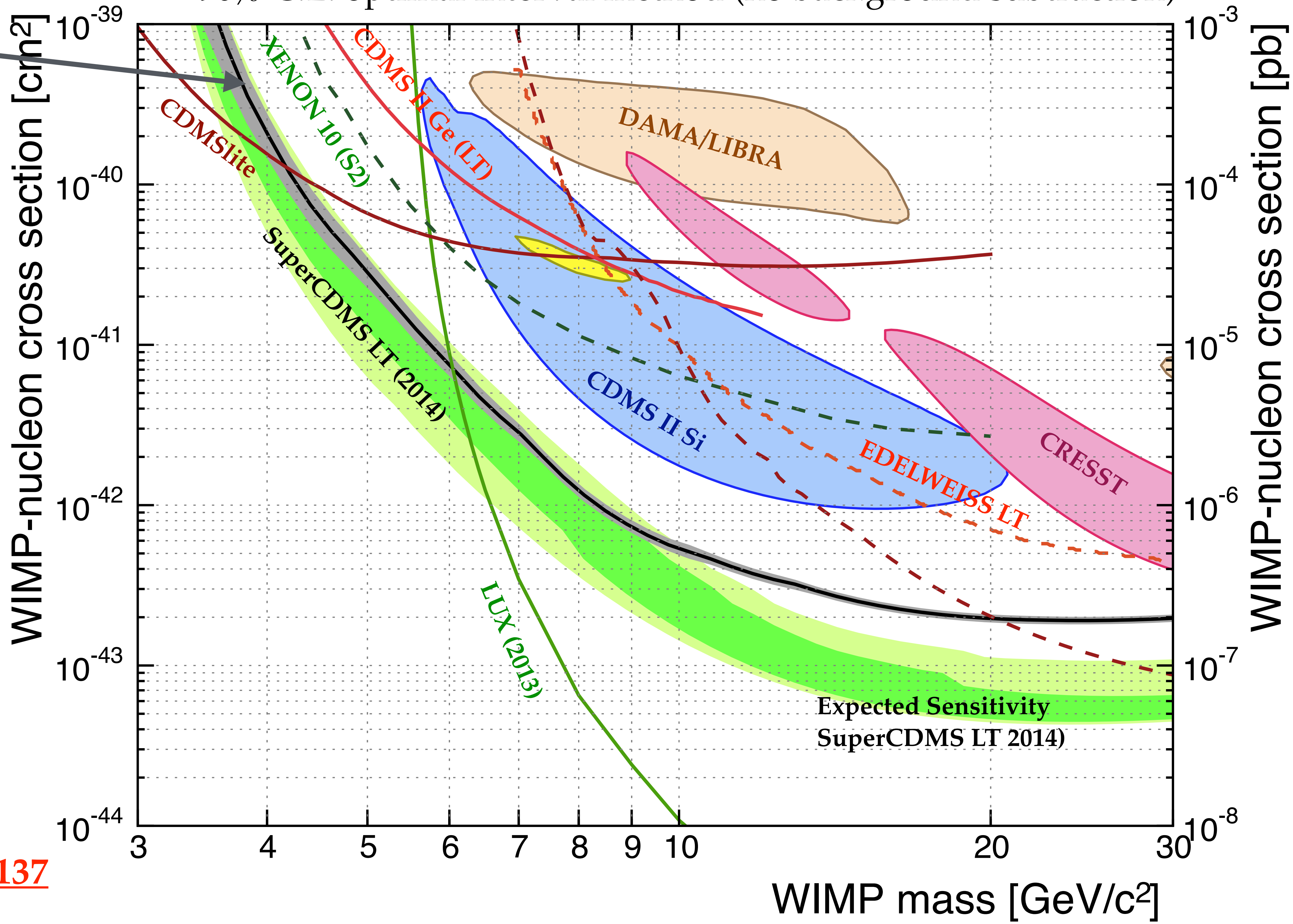


For most detectors, there is good agreement with predicted background.

New Limit for Low Mass WIMPs

Note: Assumes SHM, Spin-Independent Couplings: This plot changes if we change assumptions!

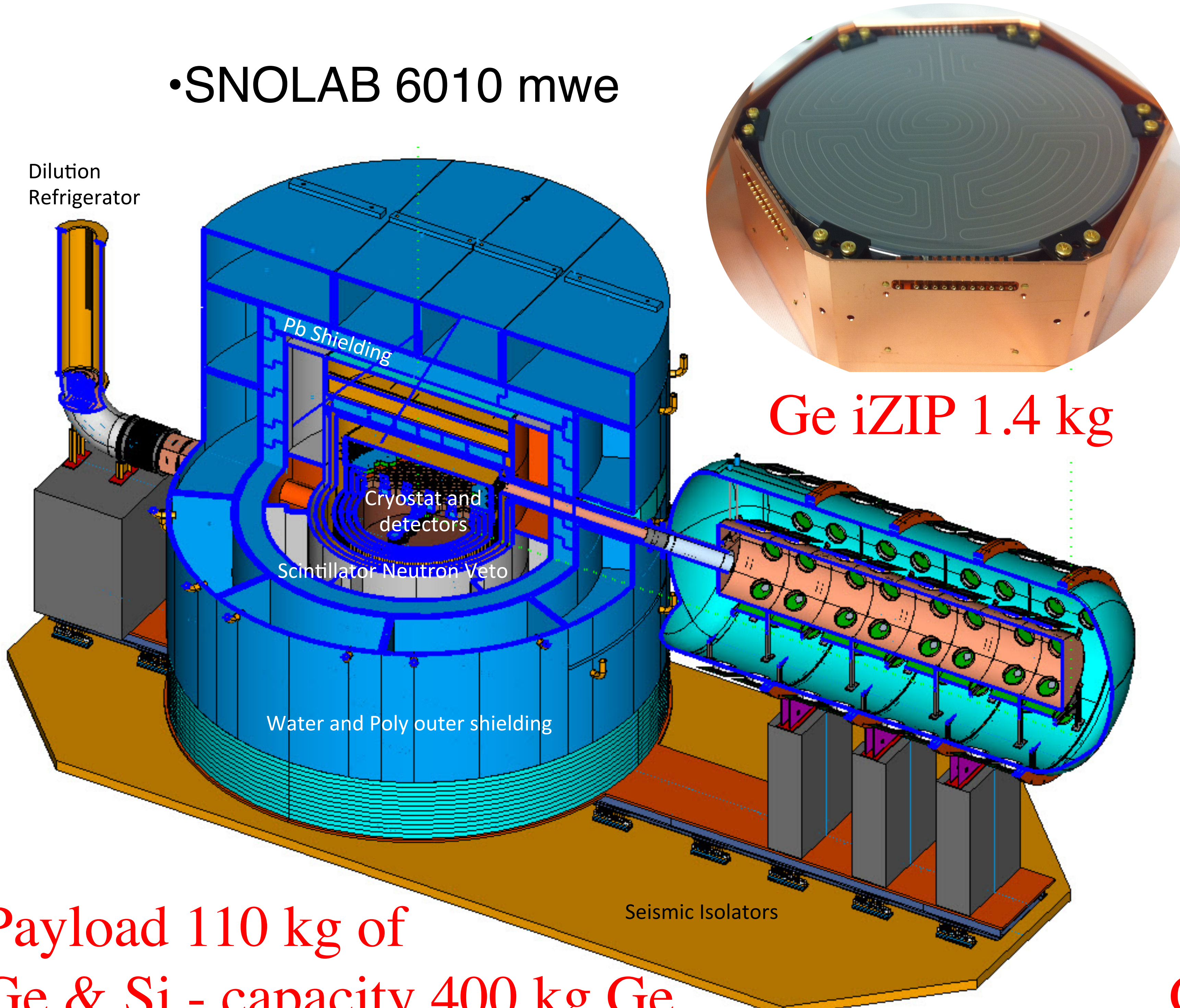
systematics (efficiency, energy scale, trigger efficiency)



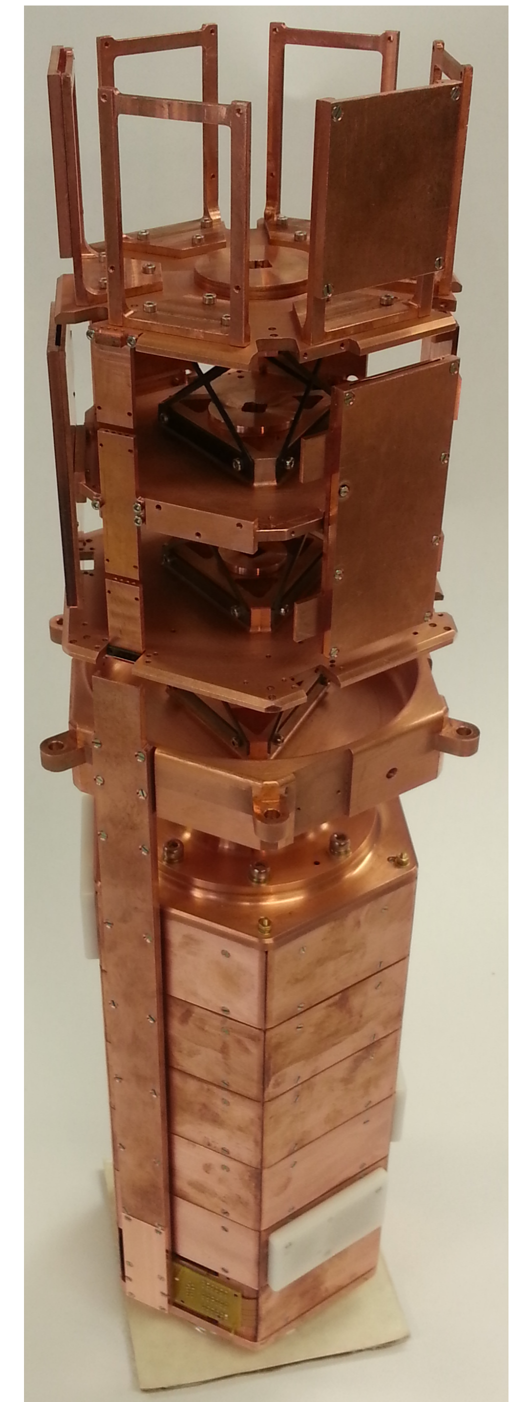
arXiv: 1402.7137

Future: SuperCDMS @ SNOLAB

- SNOLAB 6010 mwe



Ge iZIP 1.4 kg



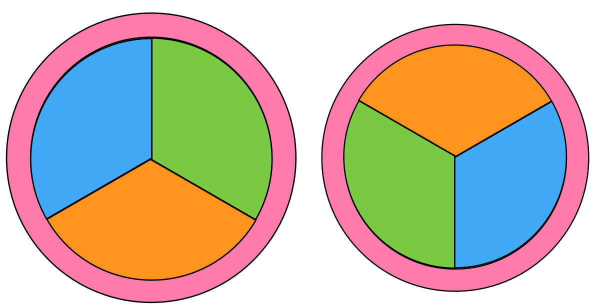
Payload 110 kg of
Ge & Si - capacity 400 kg Ge

Ge Tower 8.4 kg

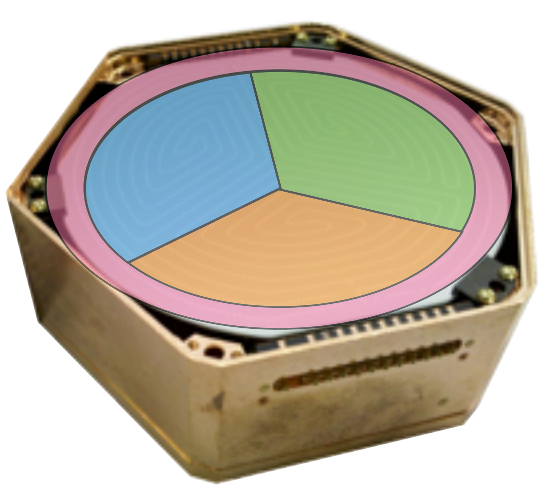
From Soudan to SNOLAB

<u>SuperCDMS Soudan</u>

9.0 kg Ge (15 x 600g)
3” Diameter
2.5 cm Thick

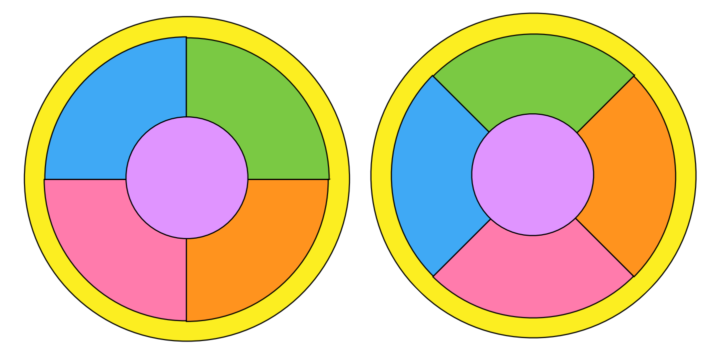


2 charge + 2 charge
4 phonon + 4 phonon

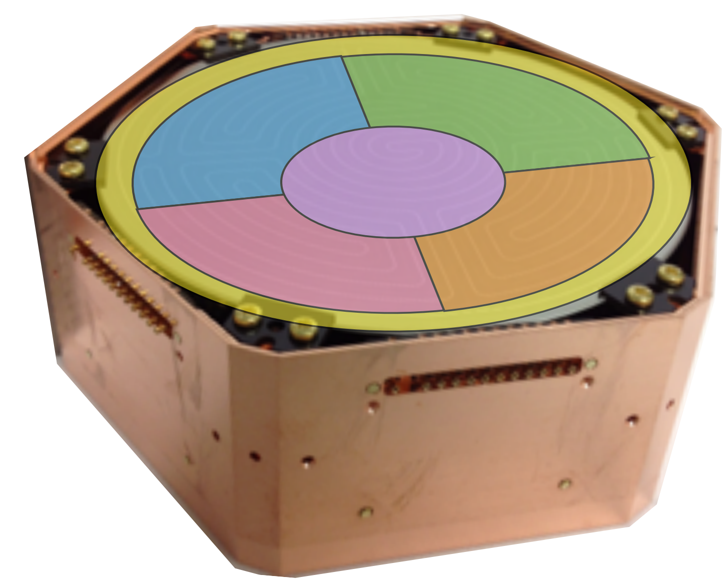


<u>SuperCDMS SNOLAB</u>

98 kg Ge (70 x 1.4 kg)
12 kg Si (20 x 0.6 kg)
4” Diameter
3.3 cm Thick

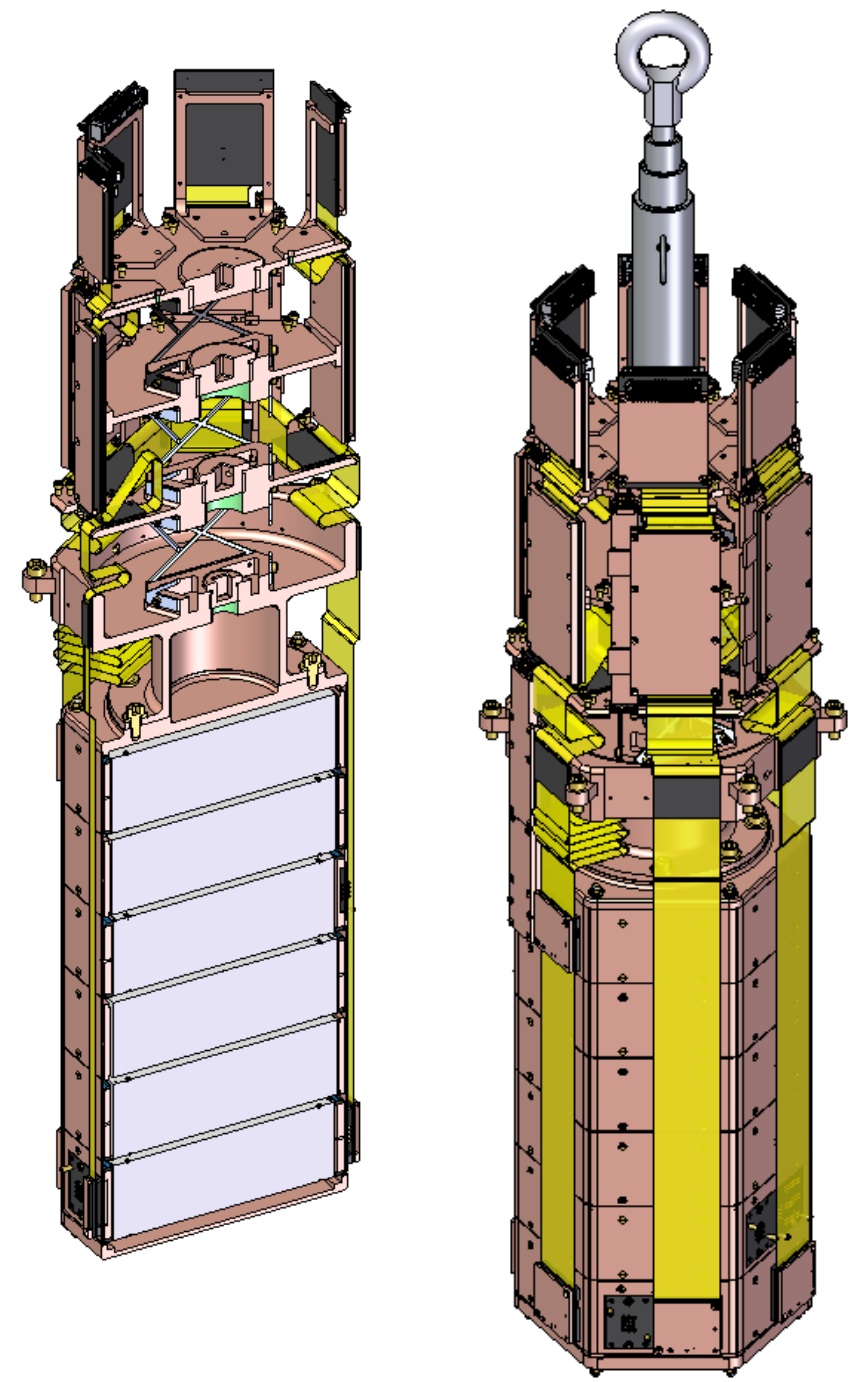


2 charge + 2 charge
6 phonon + 6 phonon

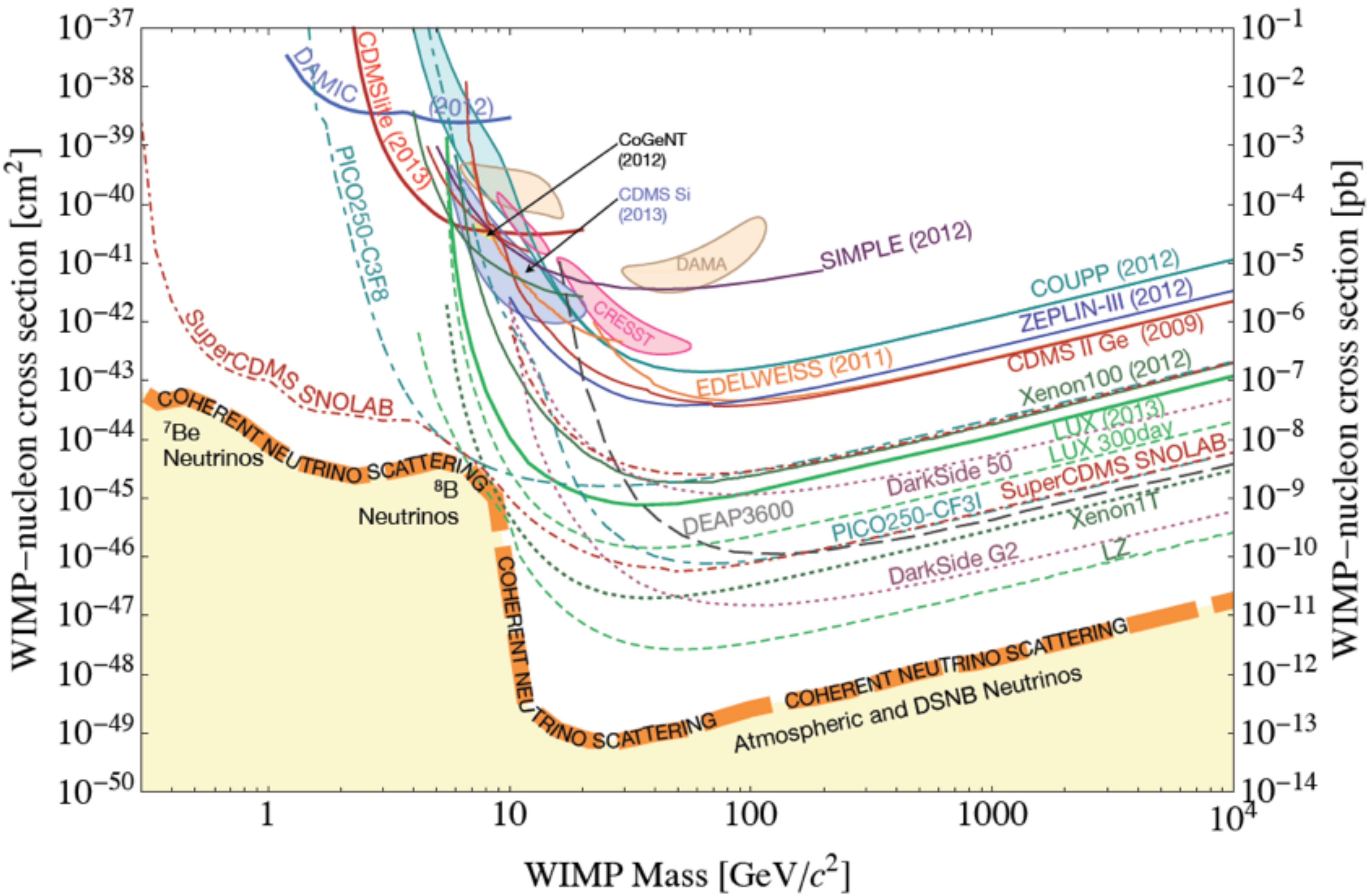


SuperCDMS SNOLAB Towers

- 70 Ge Detectors in 18 Towers
  (66 detectors @ nominal voltage + 4 in HV mode)
- 20 Si Detectors in 6 Tower
  (18 detectors @ nominal voltage + 2 in HV mode)
- Lower operating temperature = better phonon resolution
- Improved charge resolution with HEMT readout
- Better phonon resolution + more phonon channels = better fiducialization = better surface event rejection



Expected Sensitivities

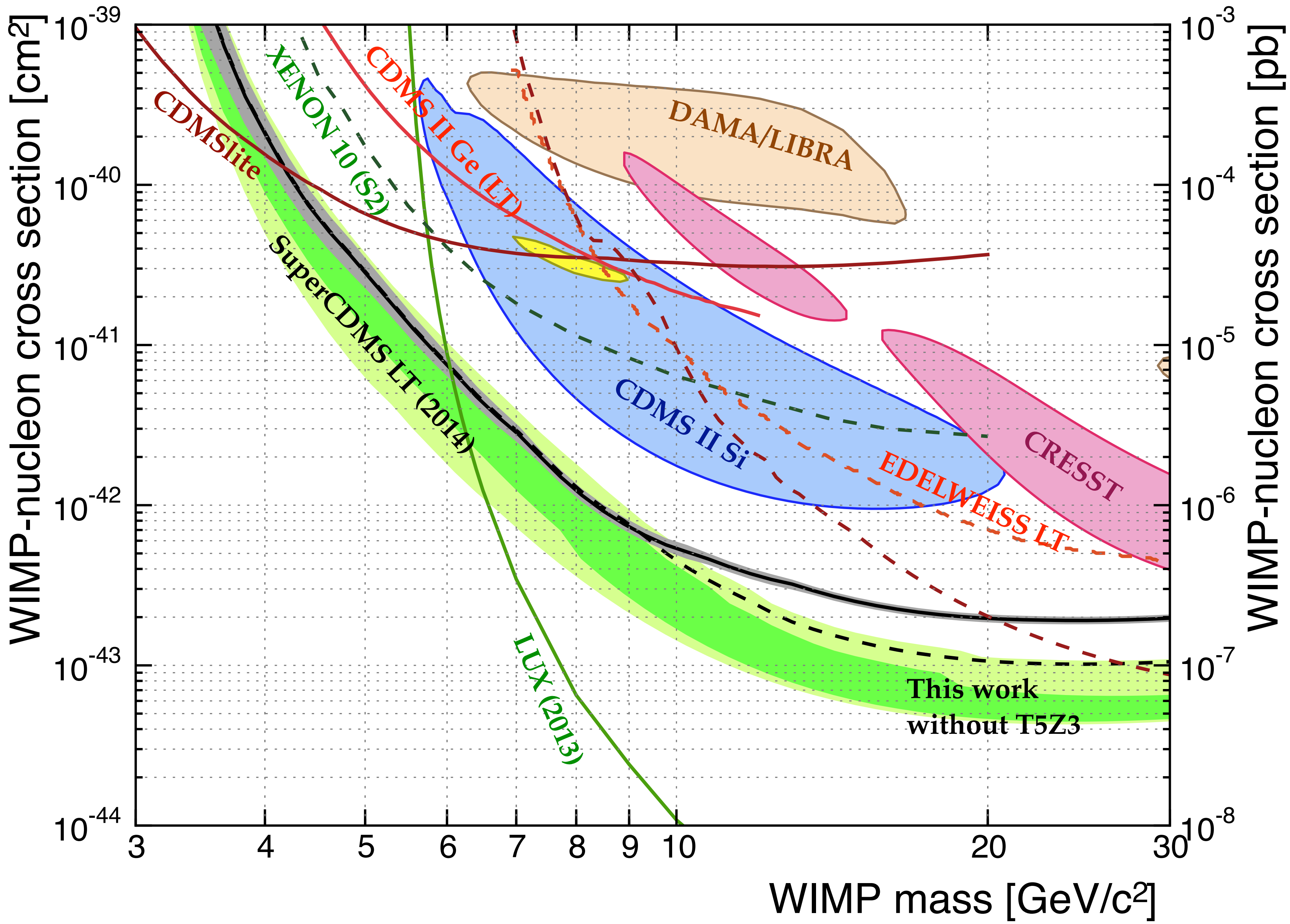


Conclusions

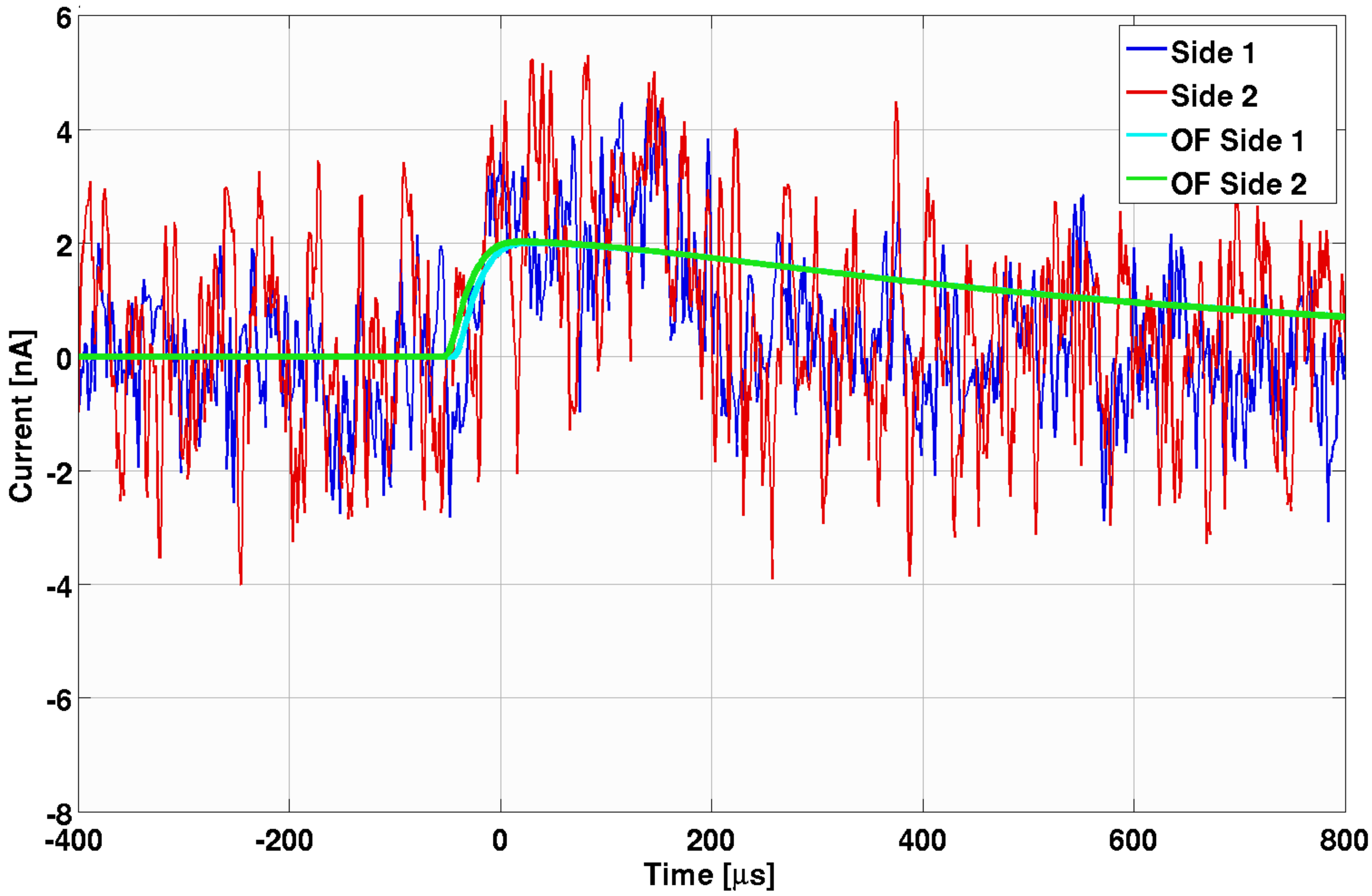
- First science results using the background rejection capability of the new SuperCDMS iZIP detectors.
- Seven iZIPs were analyzed resulting in a 557 kg-day exposure in the 1.6 keV_{nr} - 10 keV_{nr} energy range. This analysis yielded an upper limit on the spin-independent WIMP- nucleon cross section of less than 1.2 x 10^{-42} cm^2 for WIMPs of mass 8 GeV/c^2.
- New phase space was explored for WIMPs in the mass range 4 - 6 GeV/c^2.
- The interpretation of the excess events seen by CoGeNT as a WIMP signal is disfavored. CDMS II (Si) disfavored assuming standard WIMP interactions and a standard halo model.
- The standard high threshold analysis of SuperCDMS is ongoing and aims for a background of less than 1 event.
- Plans for a 110 kg SuperCDMS SNOLAB experiment are well underway. If funded, the SuperCDMS SNOLAB experiment will have unprecedented sensitivity to low mass WIMPs.

Backup Slides

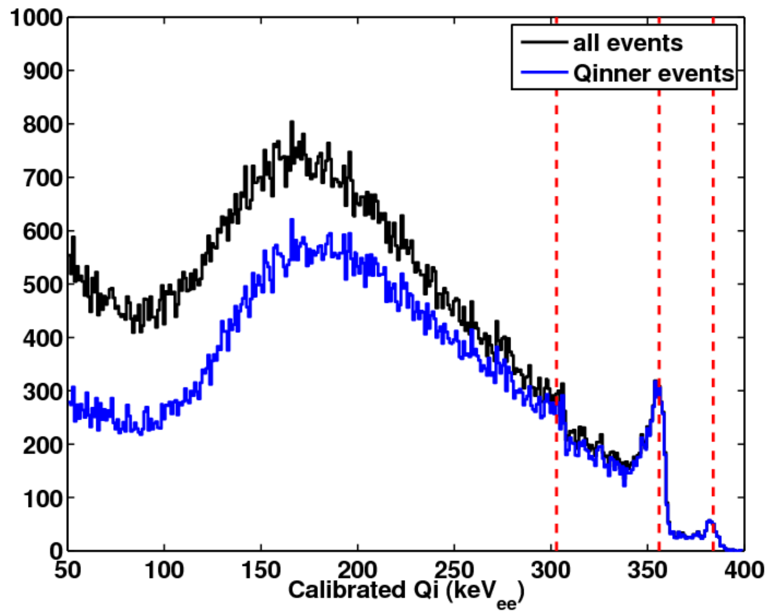
SuperCDMS Limit w/o T5Z3



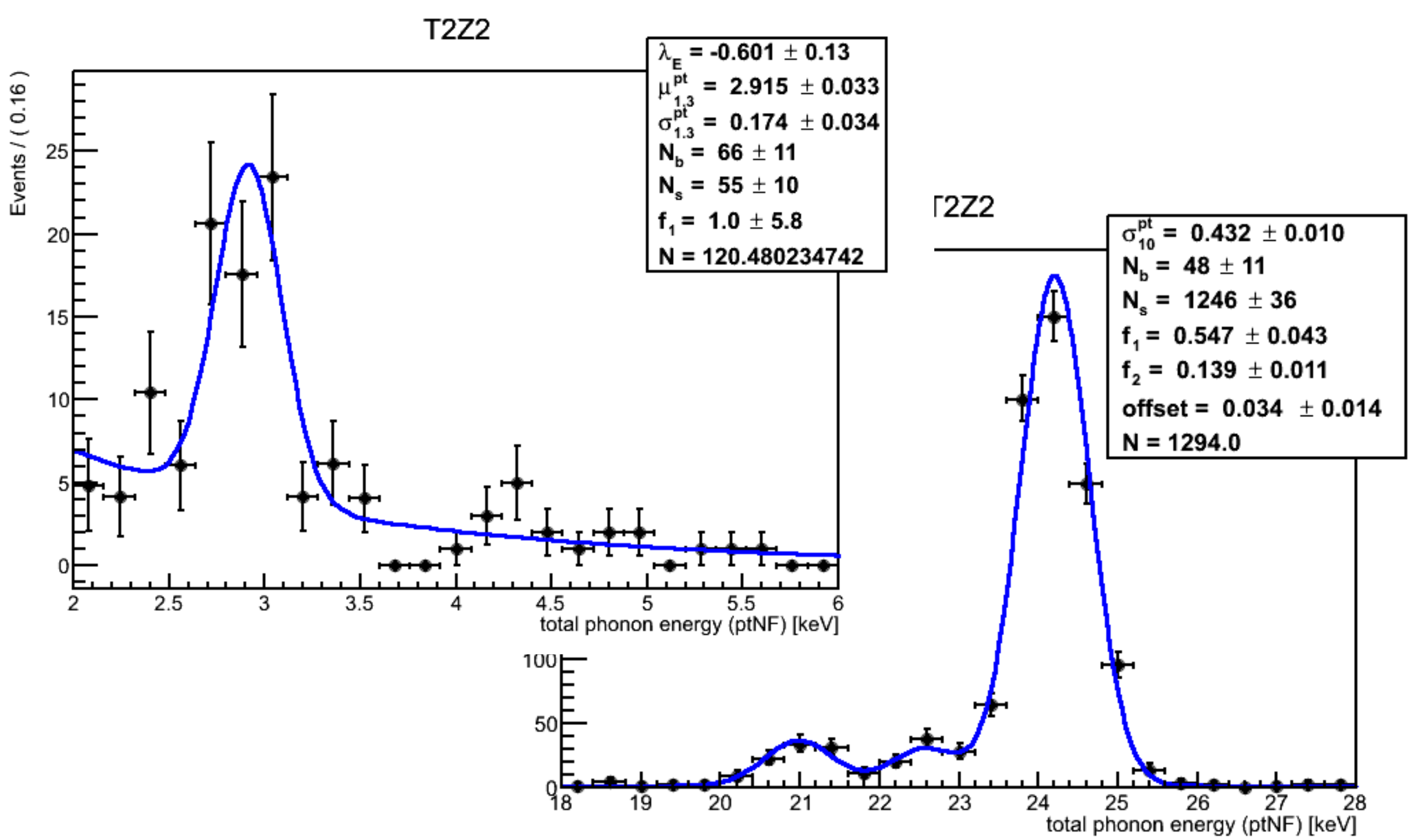
T2Z2 Low Energy Candidate



Electron Recoil Calibration

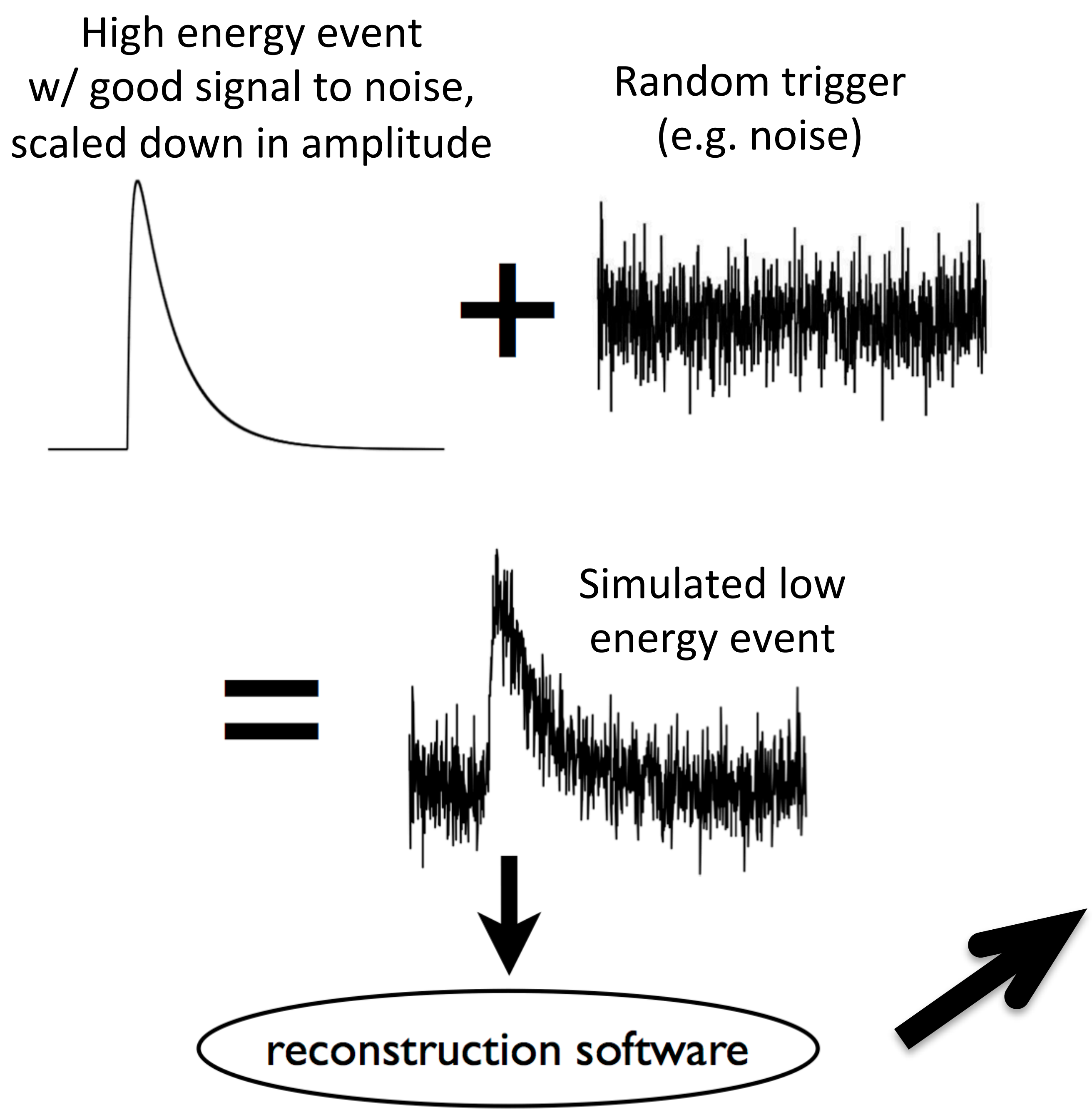


- Electron recoil ionization energy scale calibrated with ^{133}Ba lines.
- Phonon energy calibrated to give ionization yield of 1.



- Linearity at low energies checked with 10.3 (k-shell) and 1.3 (l-shell) keV lines.

Background Model w/ Pulse Simulations



Backgrounds at low energy are more difficult to separate from signal region due to poor signal to noise

Study directly with a pulse simulation; using high energy events in sidebands and calibration data

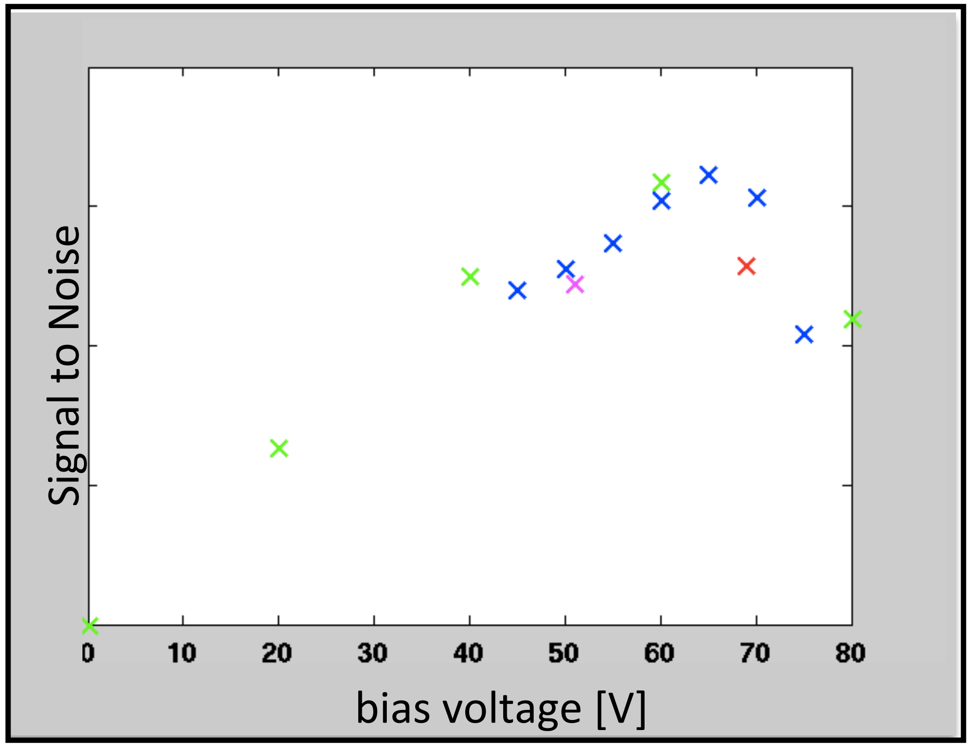
weight events as a function of energy to match low energy spectrum

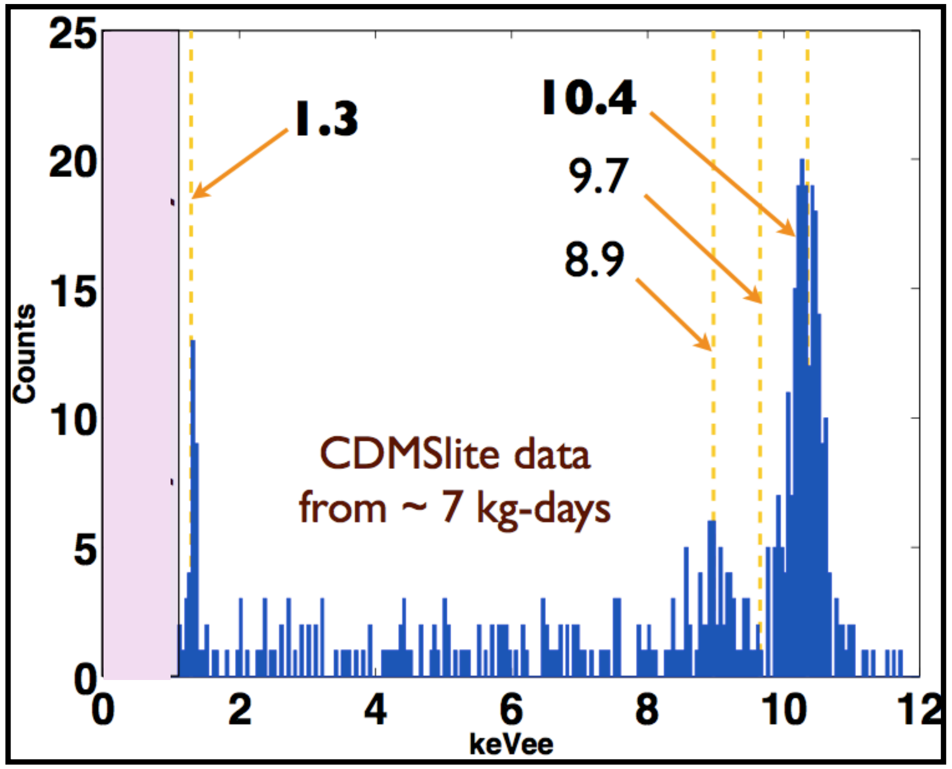
CDMSlite: Principles

- Custom electronics were installed to allow biases above 10V
  - Disable one side of iZIP and raising that entire side to the bias voltage.
- A voltage scan indicated 69 V was the optimal operating voltage.

$$G^* = \frac{E_t(V=69)}{E_t(V=0} = \frac{1+qN_eV}{1} = 24$$

- Voltage assisted calorimetric ionization detection can improve energy resolution and threshold of bolometric devices.
- Resulting Luke amplification has excellent energy resolution down to 170 eeV$_{ee}$.





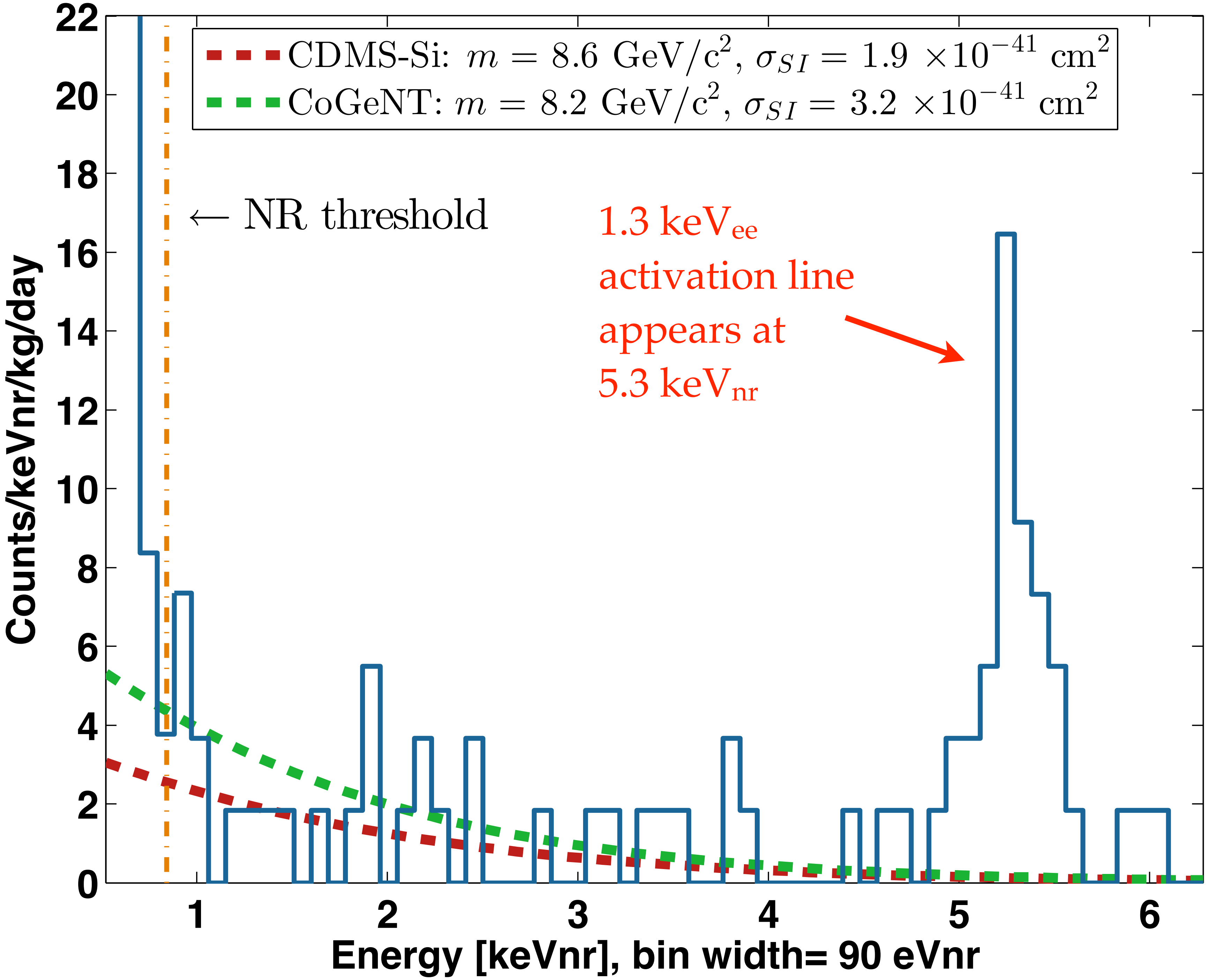
CDMSlite: The Data

- Data were taken during three periods in 2012
- One iZIP was used, IT5Z2 – 0.6 kg
  - Selected for its low trigger threshold and low leakage current
- There were two neutron exposures (^{232}Cf)
  - Activation of Ge (^{70}Ge + n --> ^{71}Ge) allowed determination of energy scale and monitoring of stability (10.36 keV_{ee} and 1.29 keV_{ee} lines).
- Raw exposure was 9.6 kg days (16 live days)
  - Optimized based on a flat extrapolation of known electron recoil backgrounds in the 2-7 keV window

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

CDMSlite: Results

PRL 112, 041302, 2014



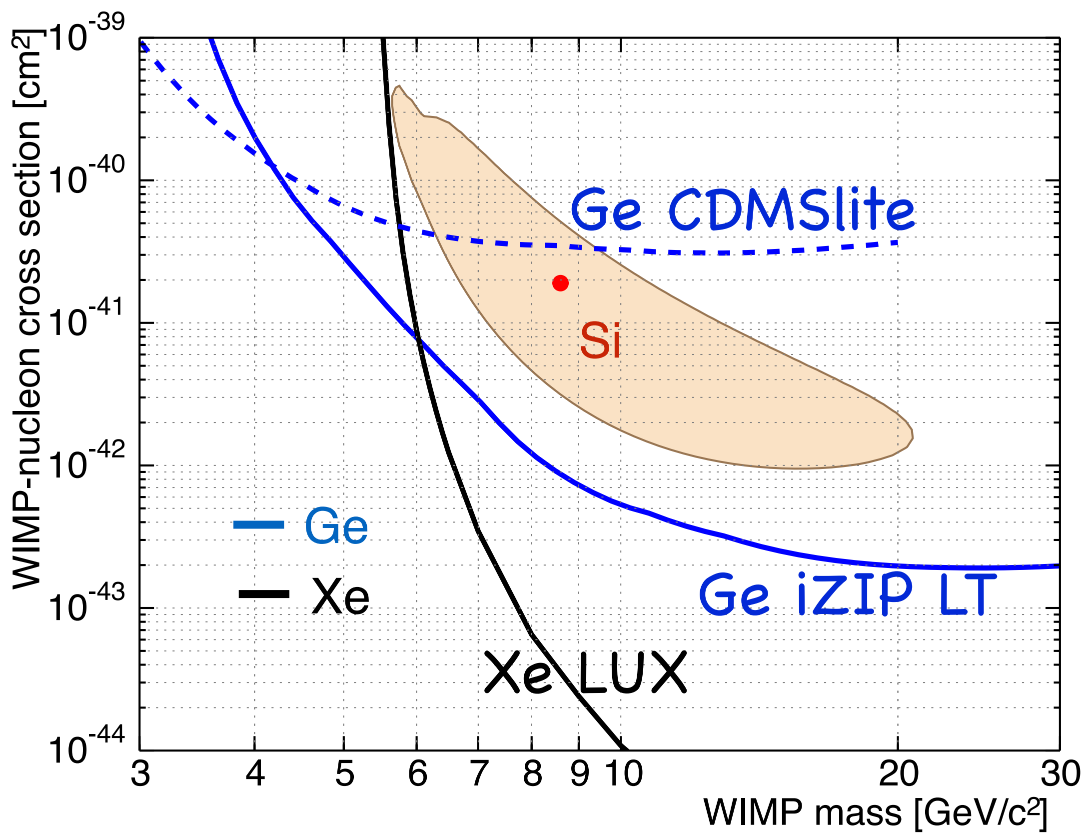
Nuclear recoils create fewer charges than electron recoils.

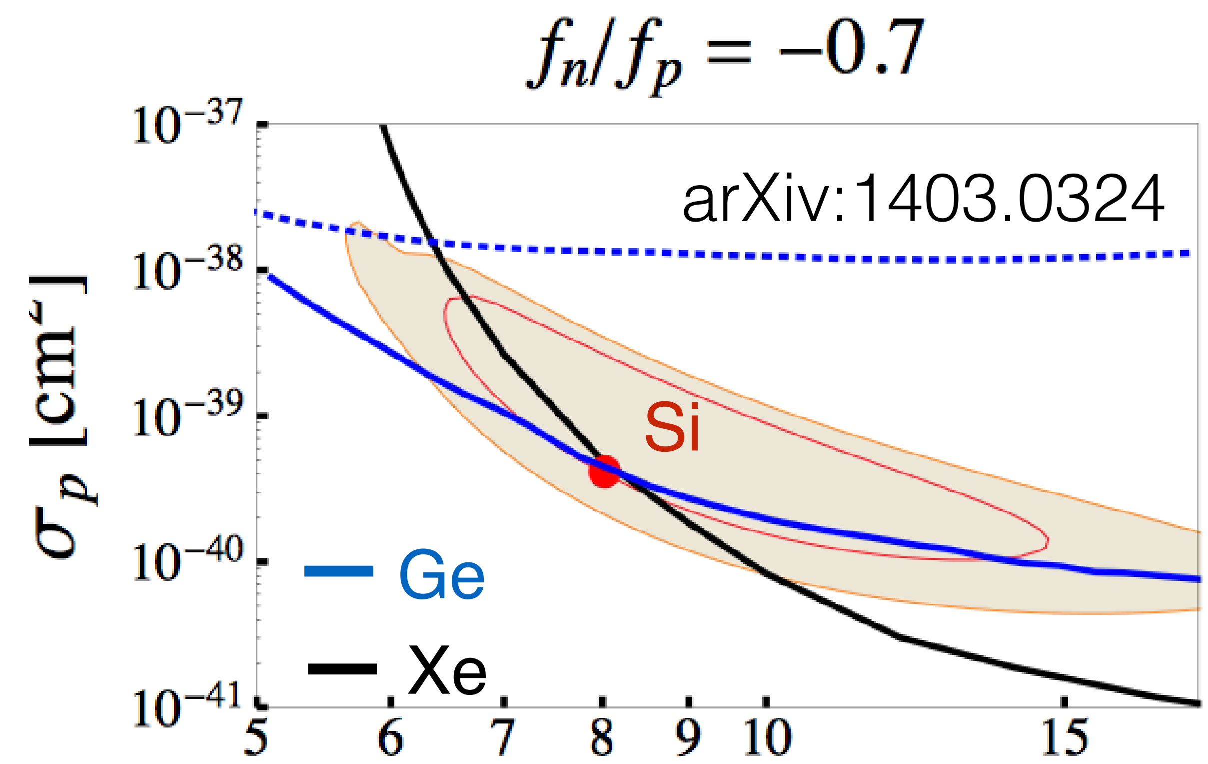
Conversion keVee to keVnr

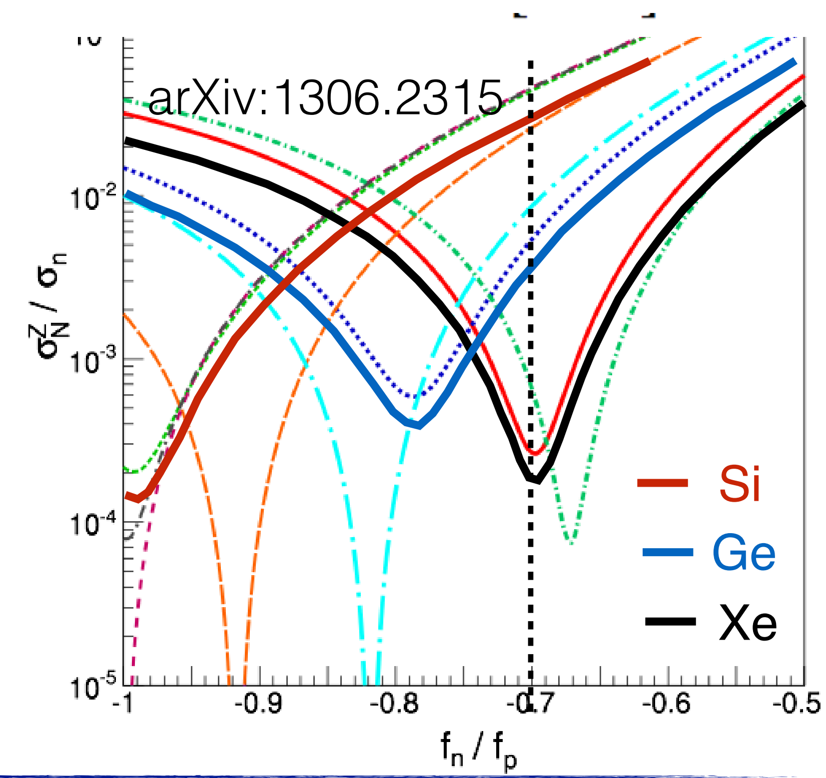
$$E_{nr} = E_{ee} \frac{1 + \frac{eV_b}{\epsilon}}{1 + \frac{eV_b}{\epsilon} Y(E_{nr})}$$

where Y is the ionization yield, defined to be unity for electron recoils.

Isospin Violating Dark Matter







As an example, changing the ratio of f_n/f_p changes the interpretation of the results.