Recent Constraints on Light WIMPs from SuperCDMS

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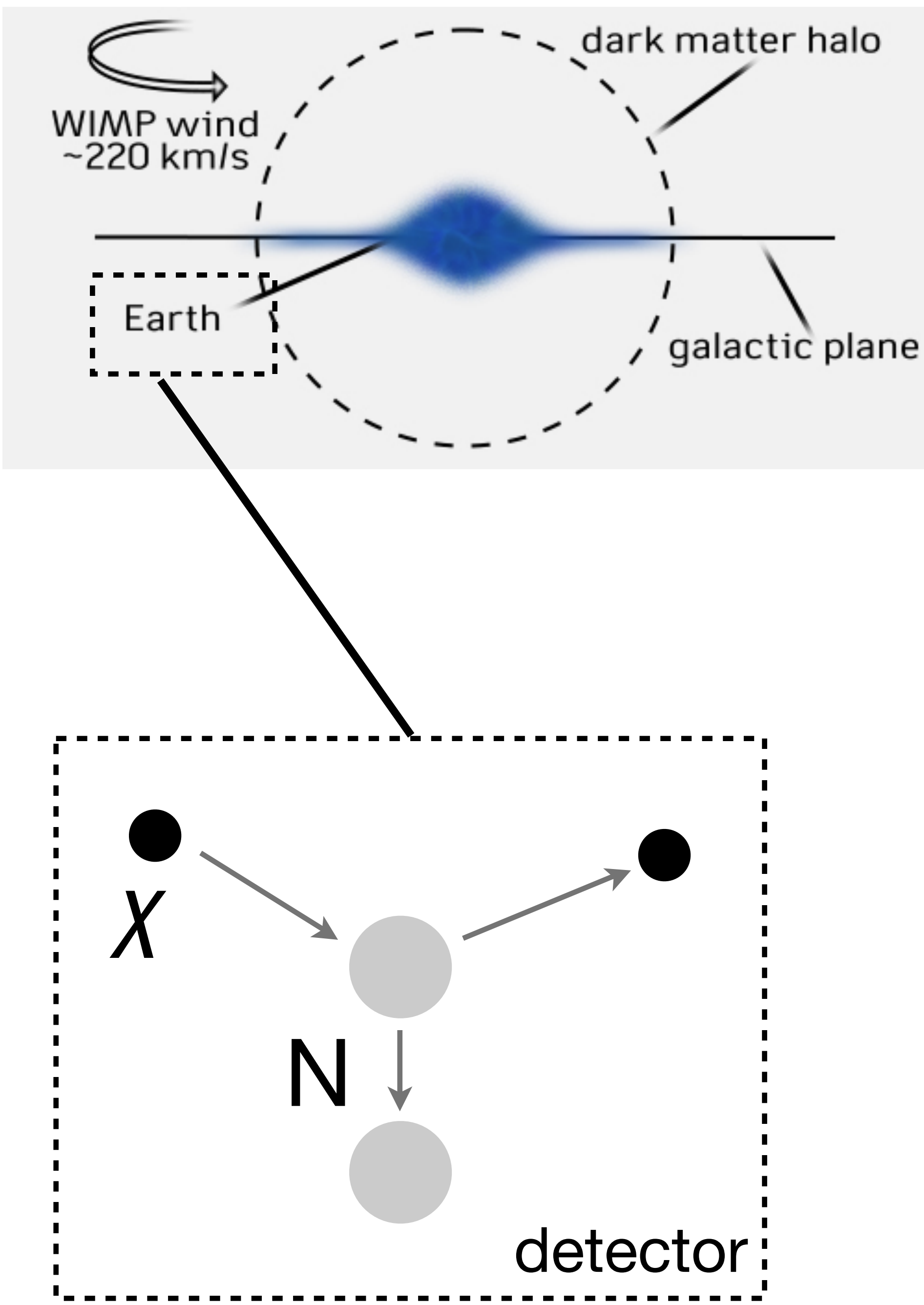
for the SuperCDMS Collaboration

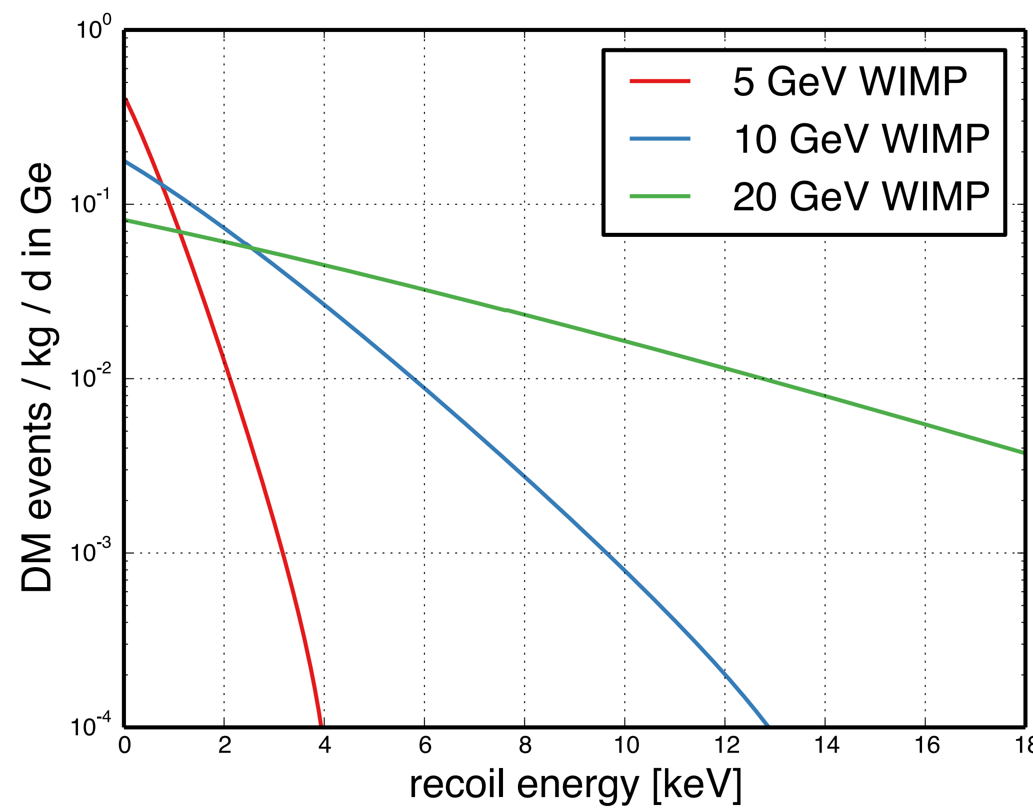
Moriond Electroweak
18 March 2014

Massachusetts Institute of Technology

Direct Detection of WIMP Dark Matter

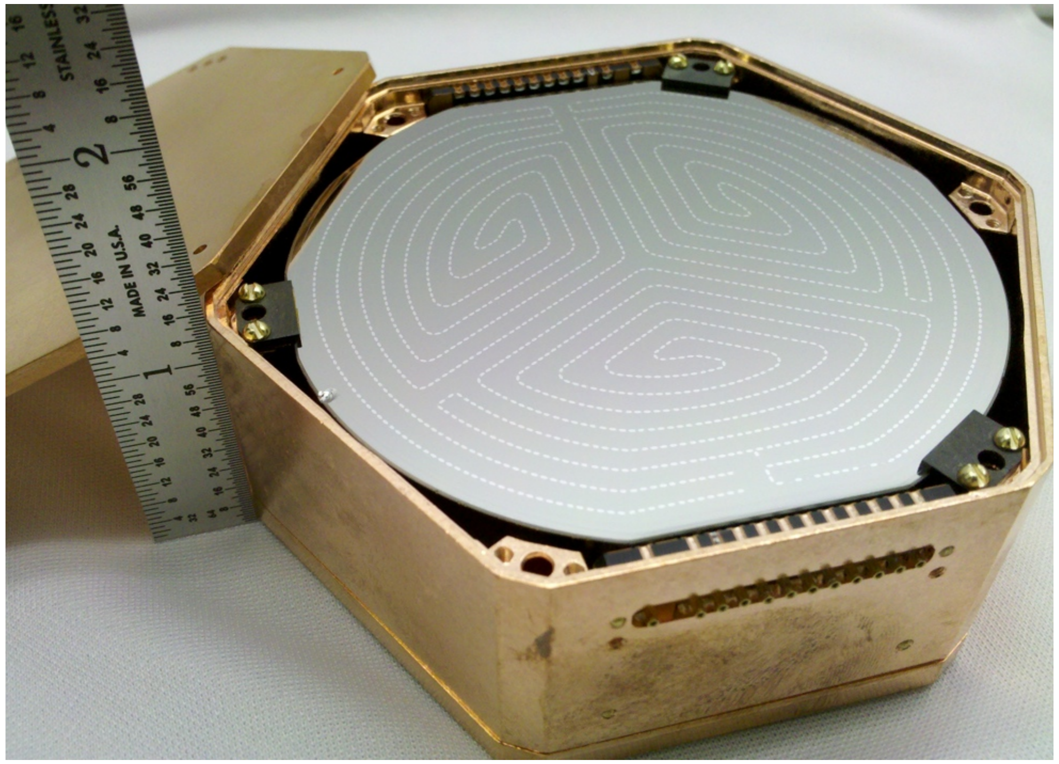


- Earth passing through dark matter halo
- WIMPs have weak-scale cross-section for elastic scattering on nuclei
- Search for low-energy exponential in nuclear recoil energy spectrum



SuperCDMS Overview

- Upgrade to CDMS II, in continuous operation since spring 2012 at Soudan Underground Laboratory
- 600g Germanium detectors measure ionization and non-equilibrium phonons



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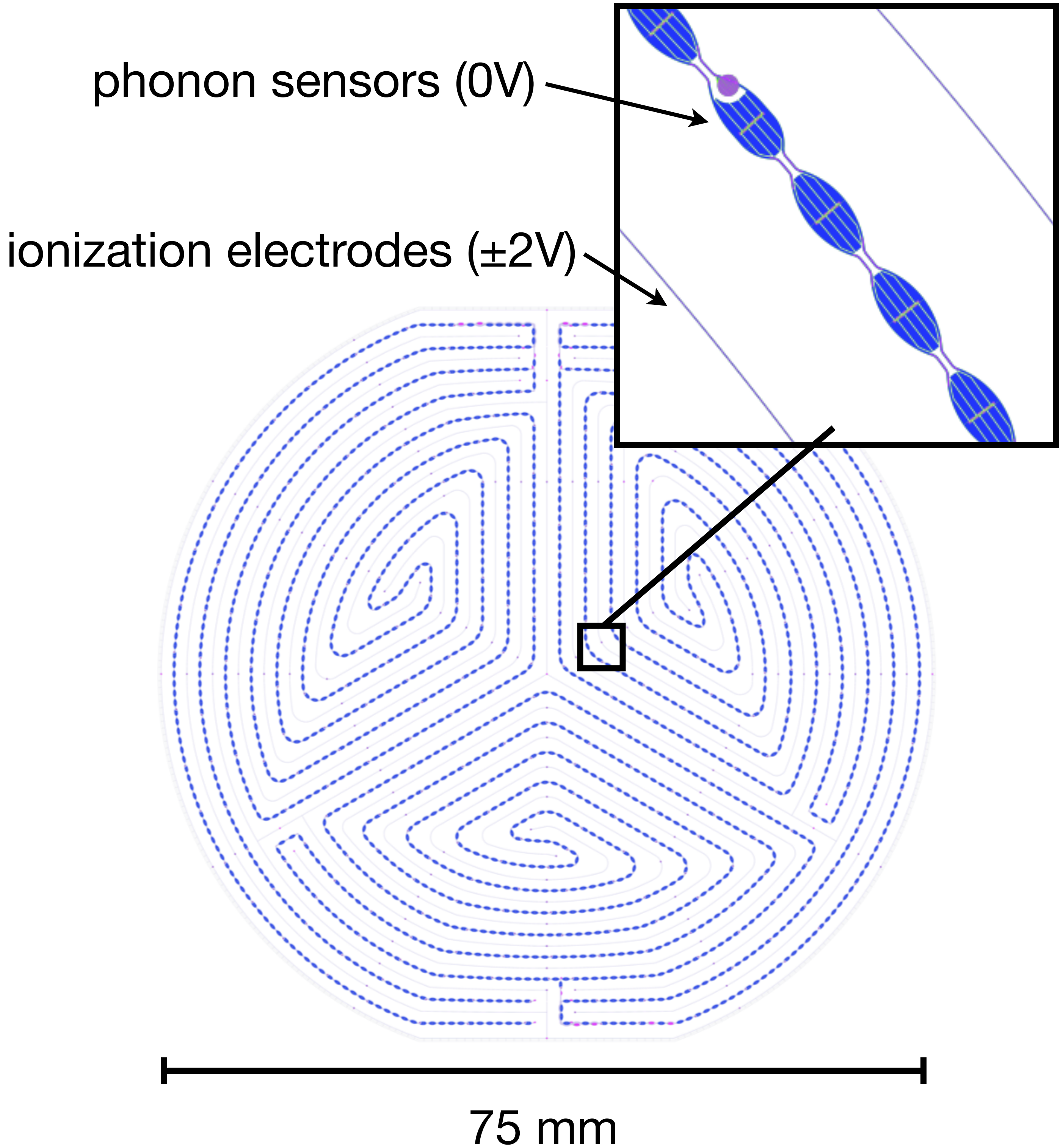

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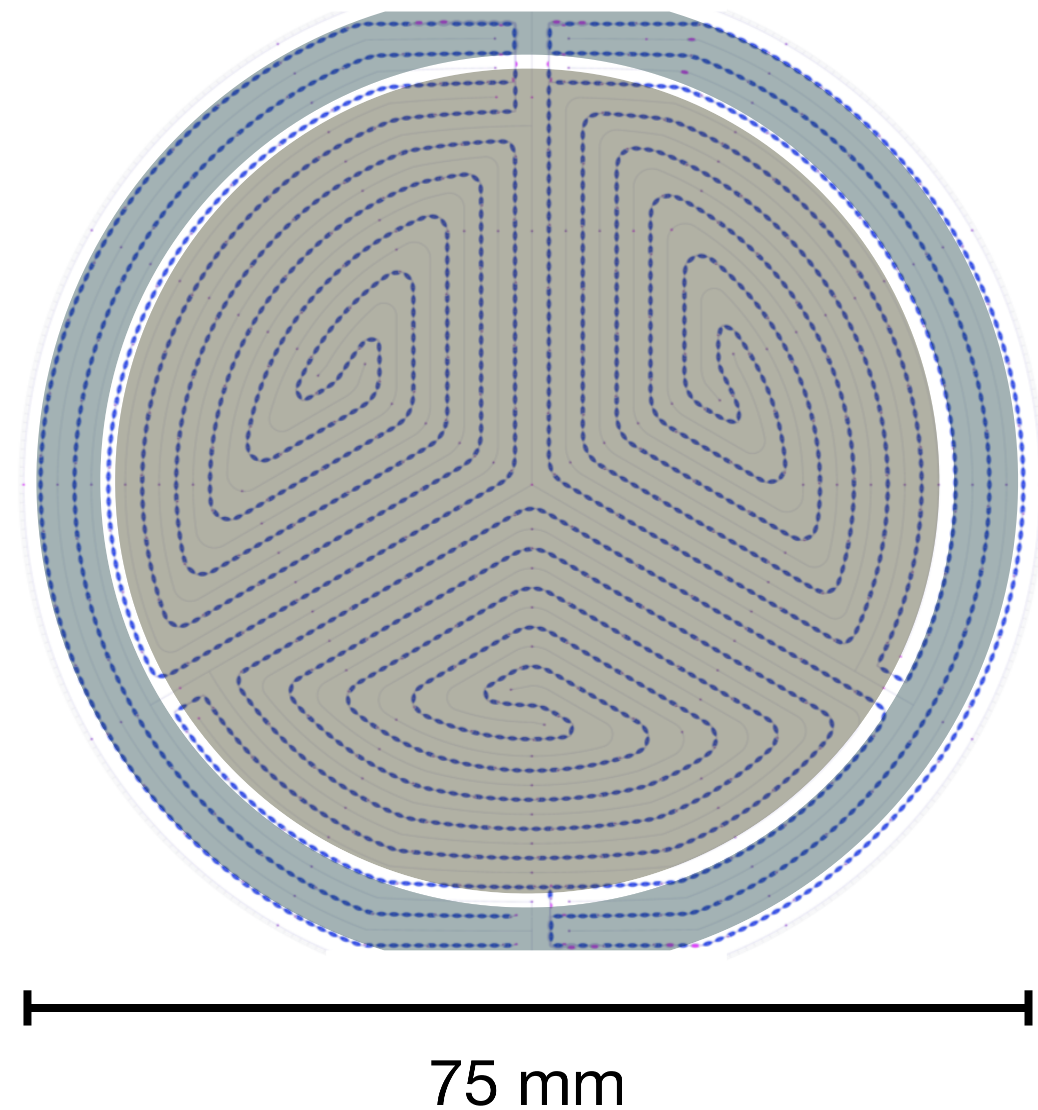
- ionization guard rejects sidewall events



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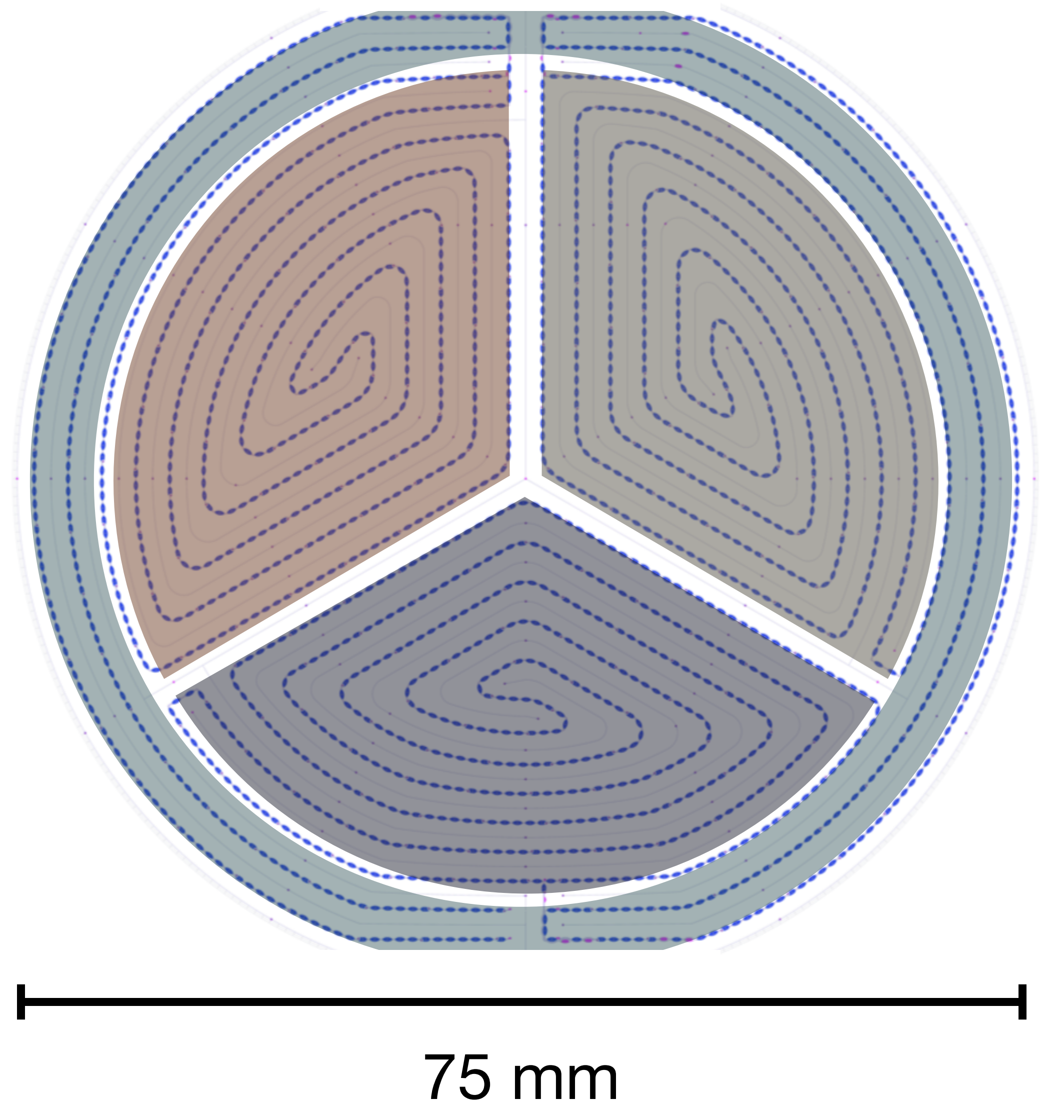

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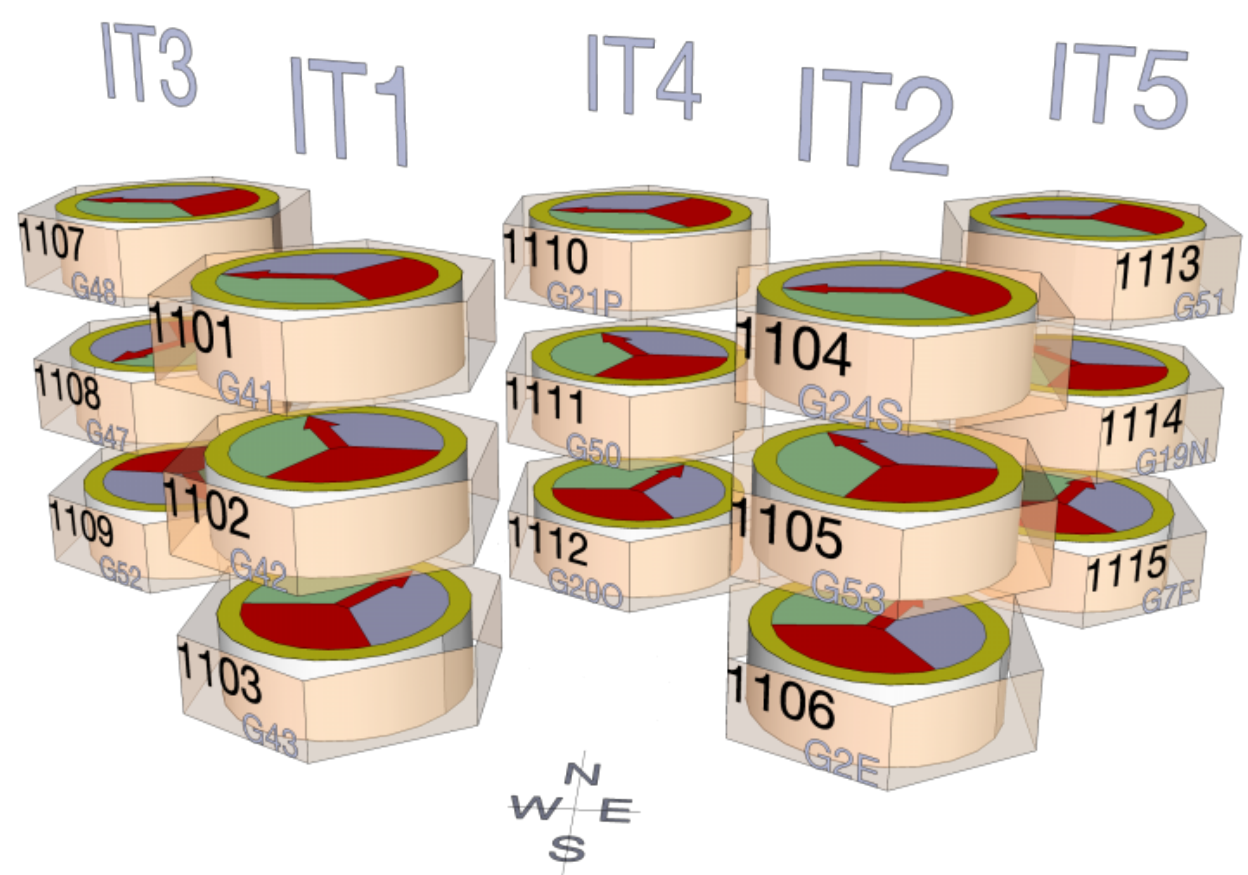
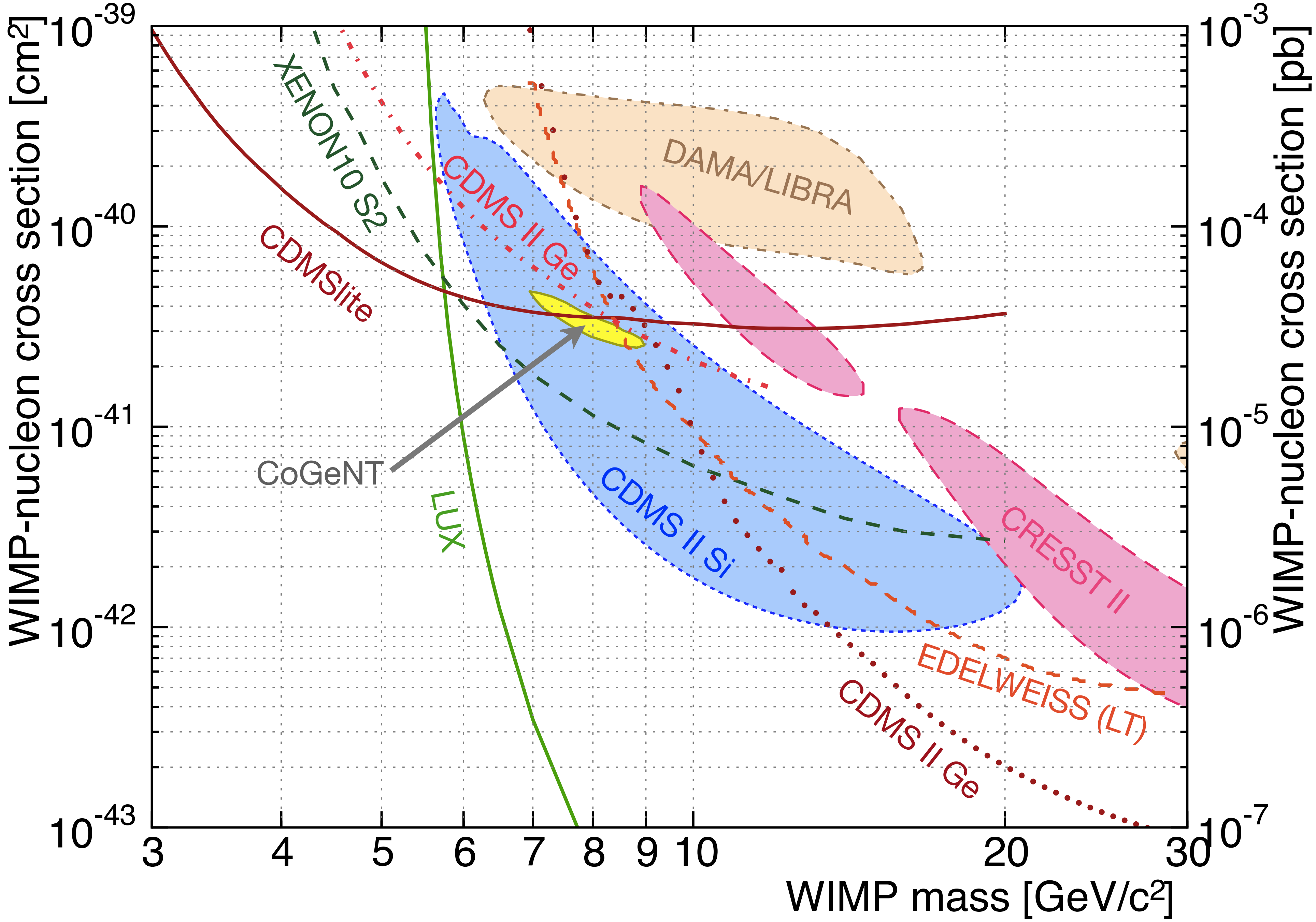
- phonon channels reject sidewall events, provide 3D position estimators
- 15 detectors = 9 kg target mass



Low-mass Region

What can we say about low-mass dark matter “hints”?



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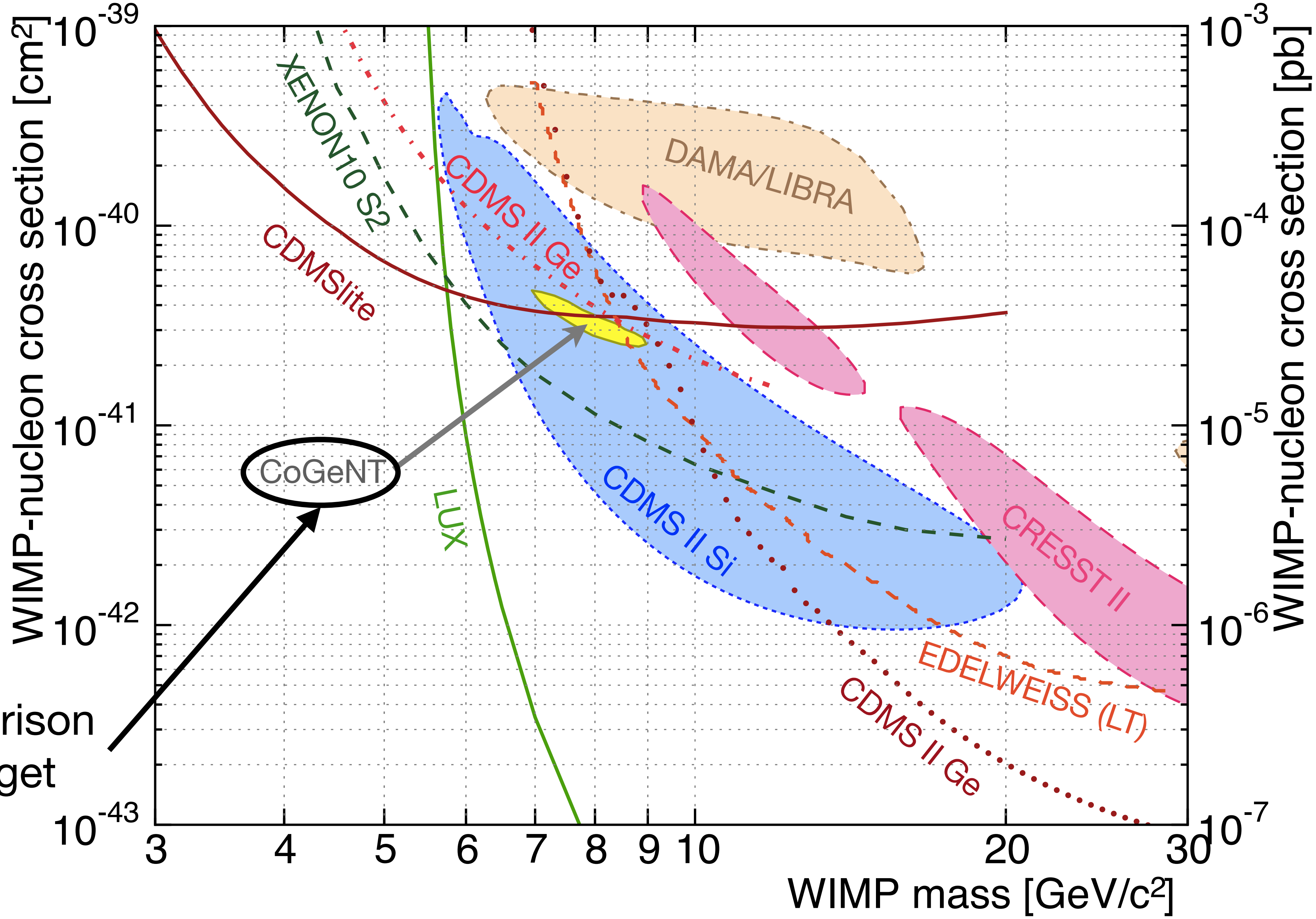


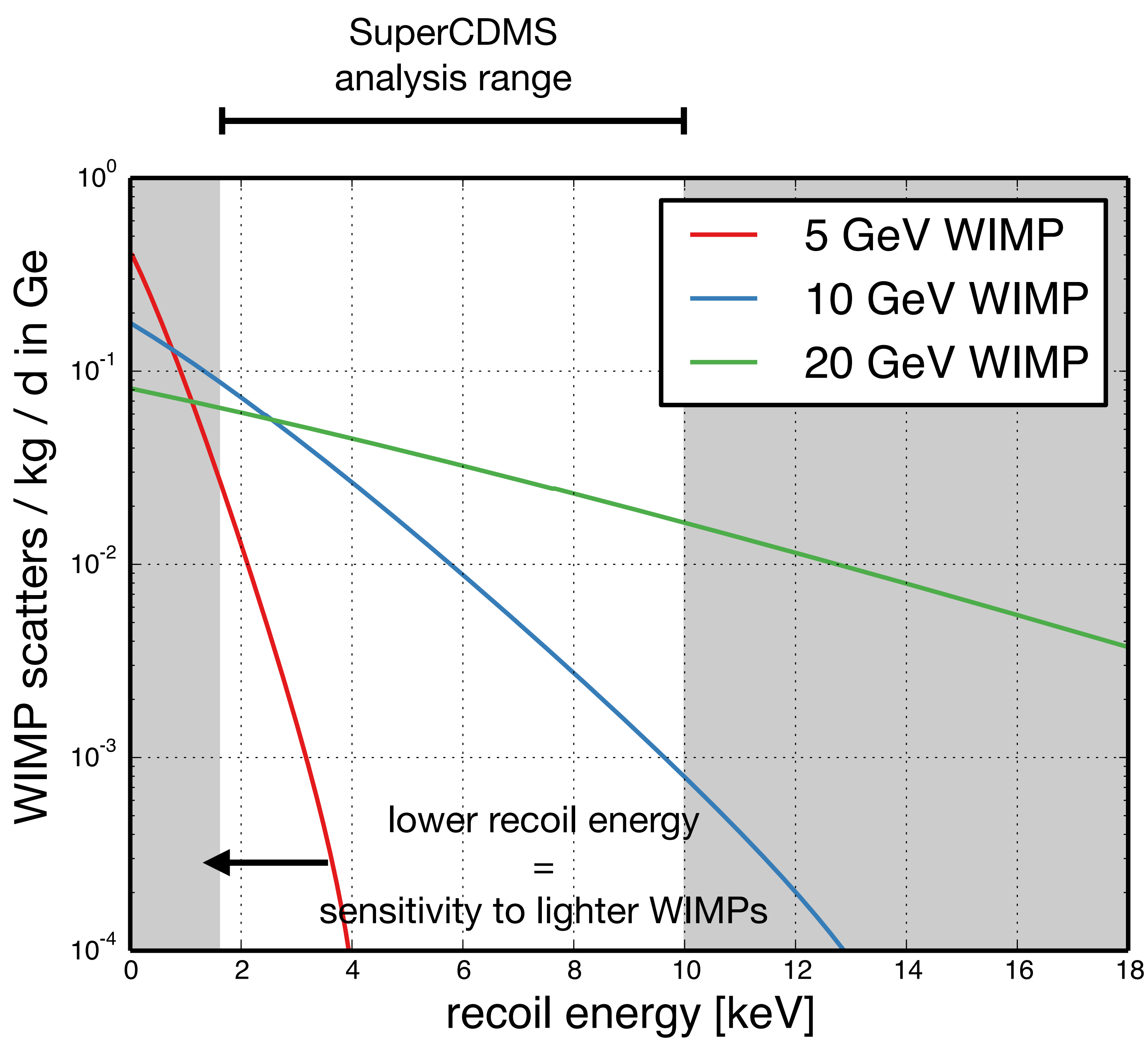
direct comparison with Ge target

SuperCDMS Approaches to Light WIMPs

1. CDMSlite

2. Low-energy analysis

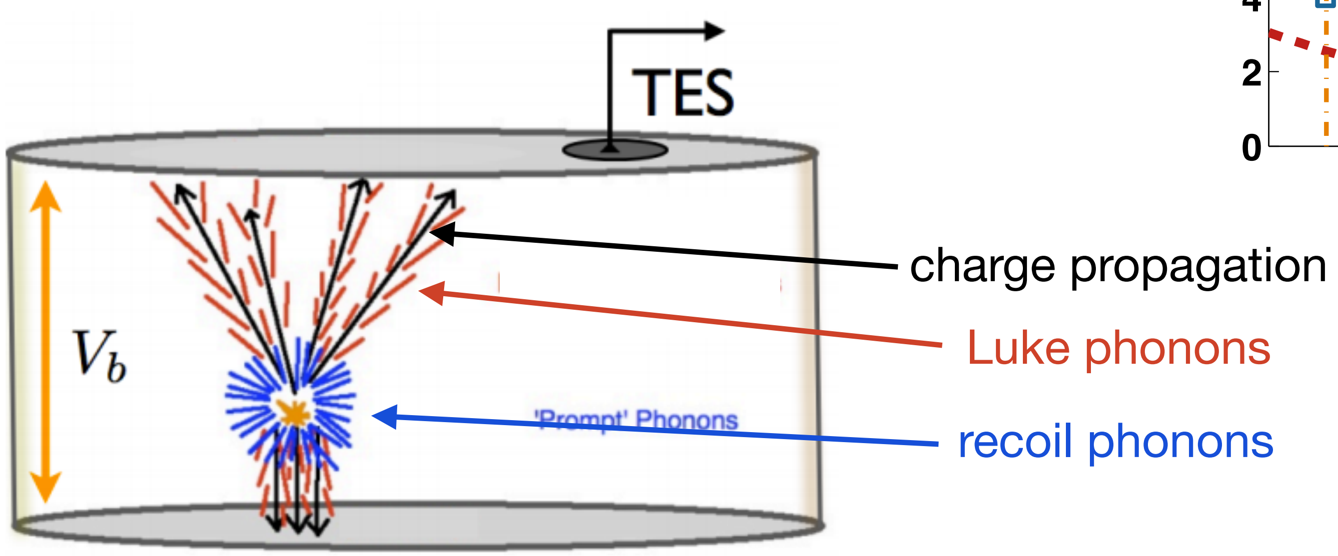
Strategy for Light WIMP Searches

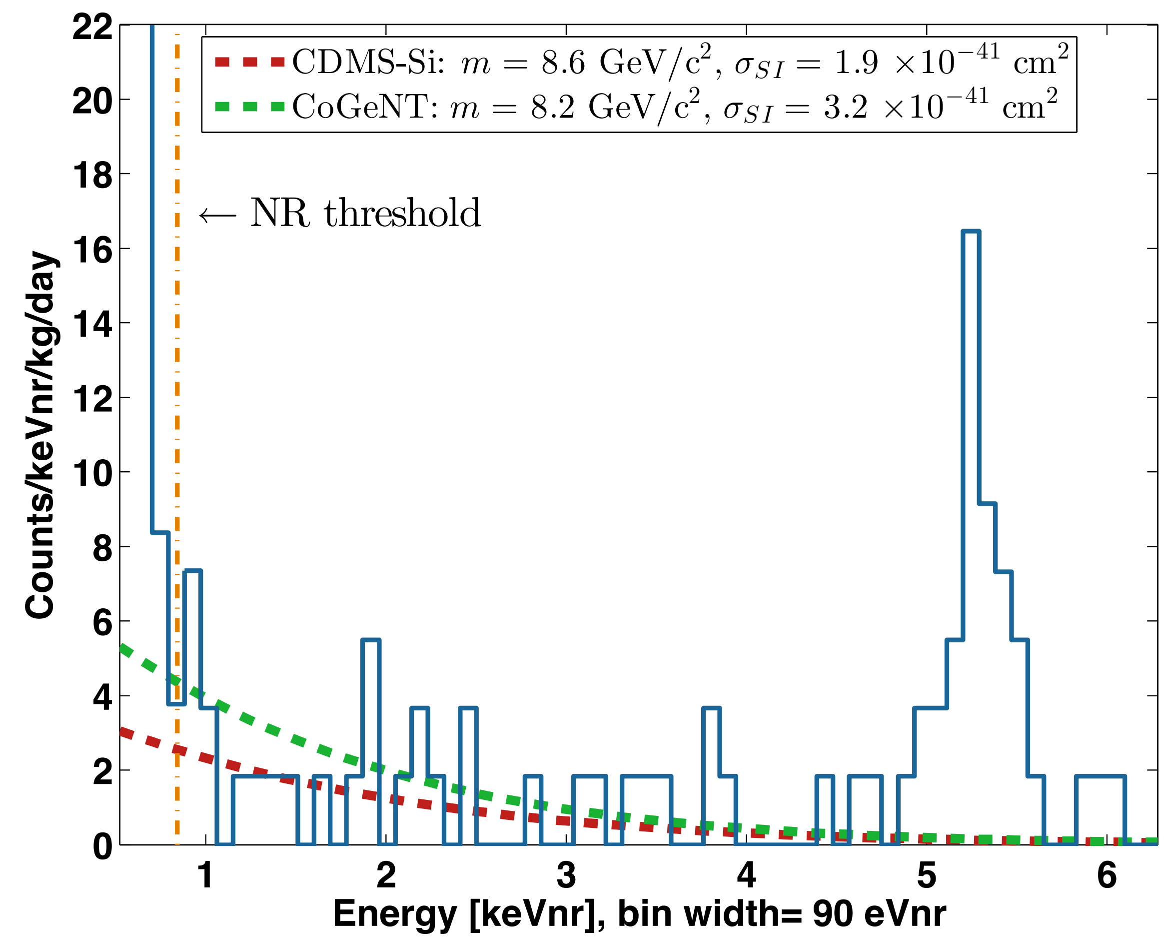


1. CDMSlite

- Use Luke phonons to amplify ionization signal *only*
- Factor of 24 amplification of ionization energy achieved in “CDMSlite” mode
- No event-by-event discrimination, since phonons used to read charge
- 170 eVee (ionization) threshold

$$E_{total} = E_{recoil} + E_{luke}$$





1.2 ± 0.2 events / keVnr / kg-d
(below 4 keVnr)

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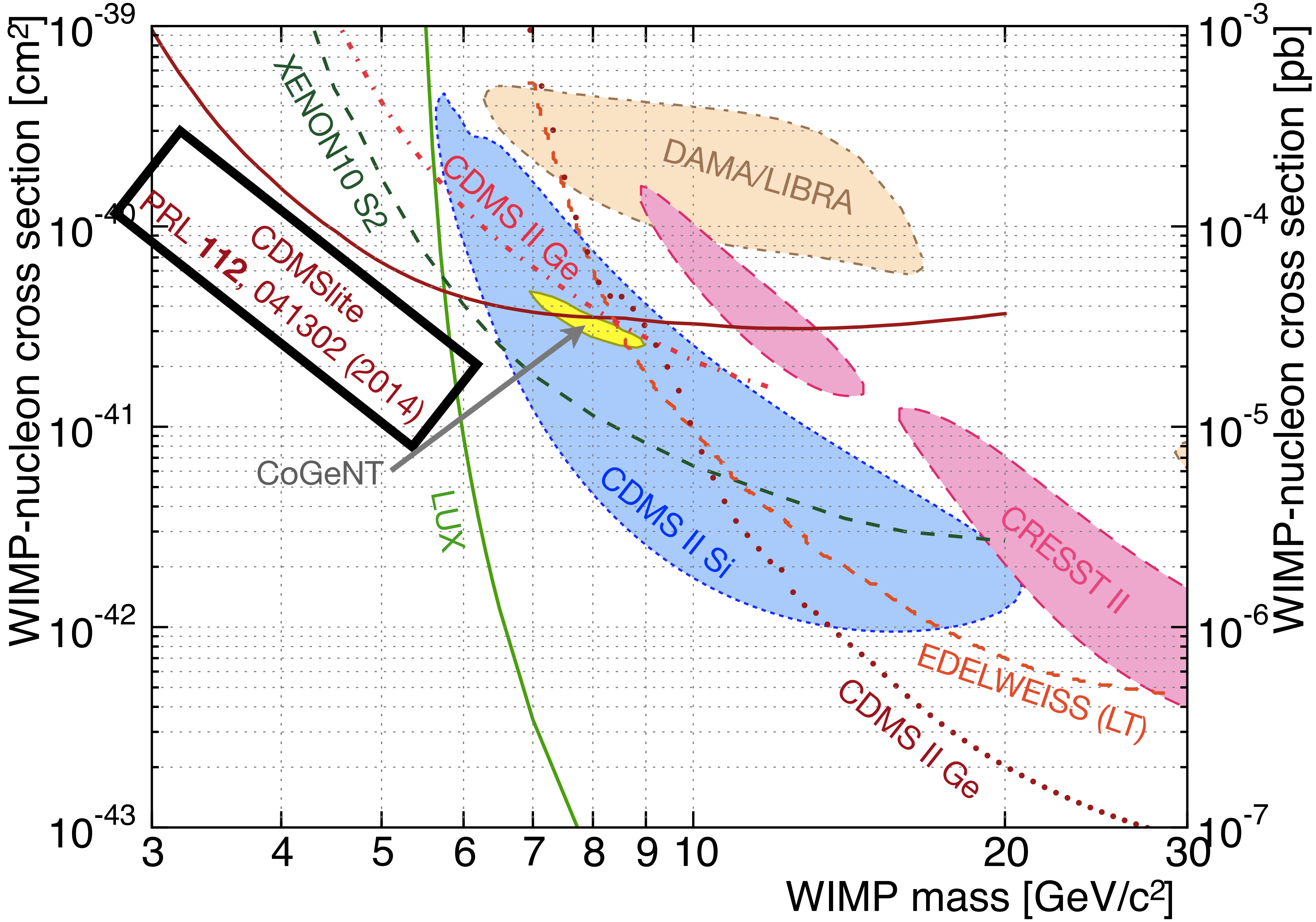
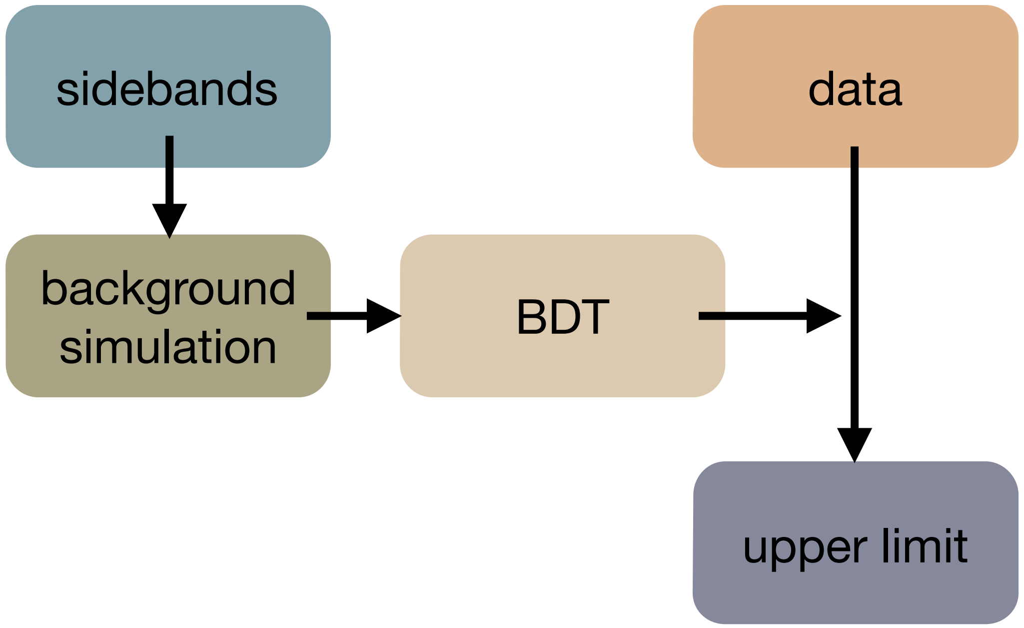


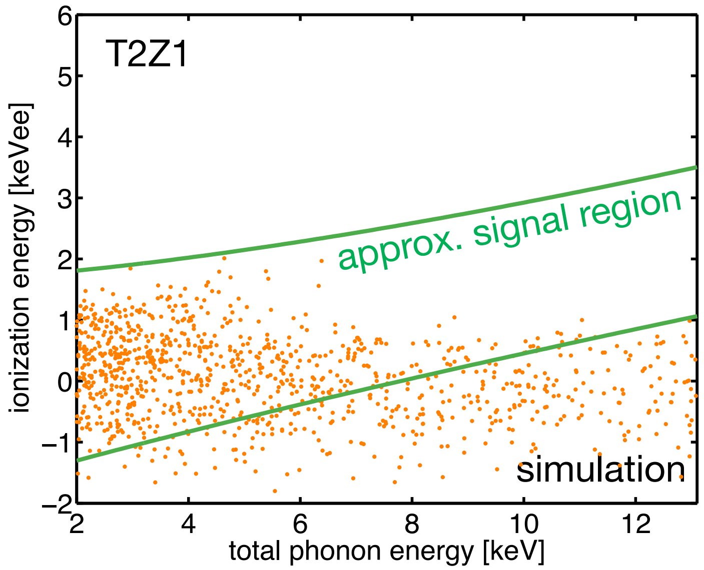
2. Low-energy Analysis

- Use 7 detectors with lowest trigger thresholds (~1.6 keV - 5 keV)
- 577 kg-d of exposure (Oct. 2012 - July 2013)
- **Background discrimination still possible near threshold!!**
- **Blind** analysis optimized for exclusion:

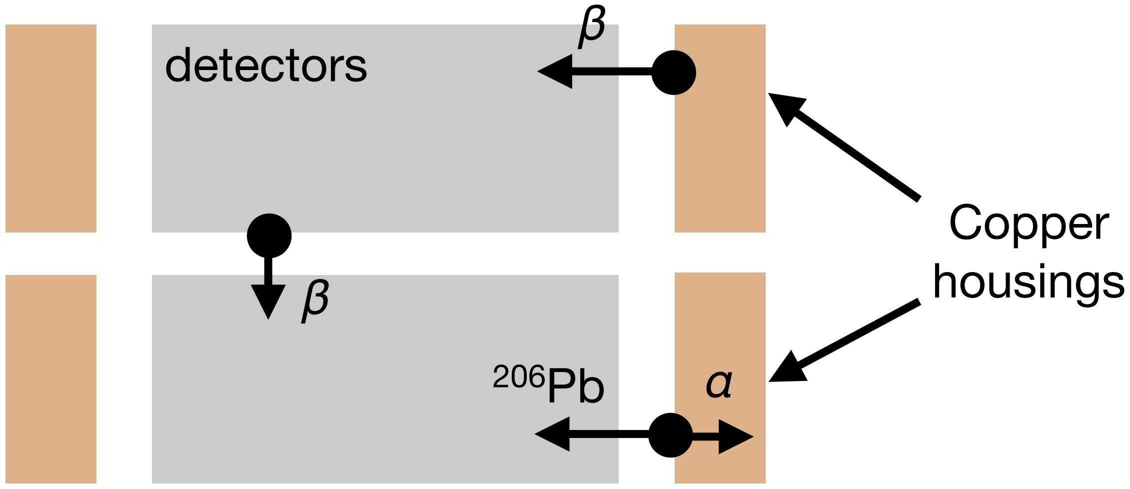


Dominant Backgrounds at Low Energy

^{210}Pb "surface events"



- betas and ^{206}Pb nuclei from ^{210}Pb decay chain
- events are located on detector face and sidewall ***surfaces*** from ^{222}Rn contamination



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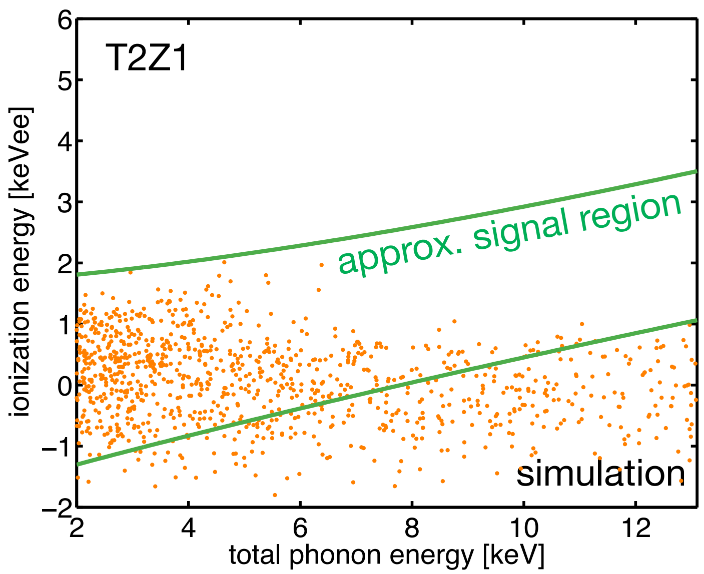

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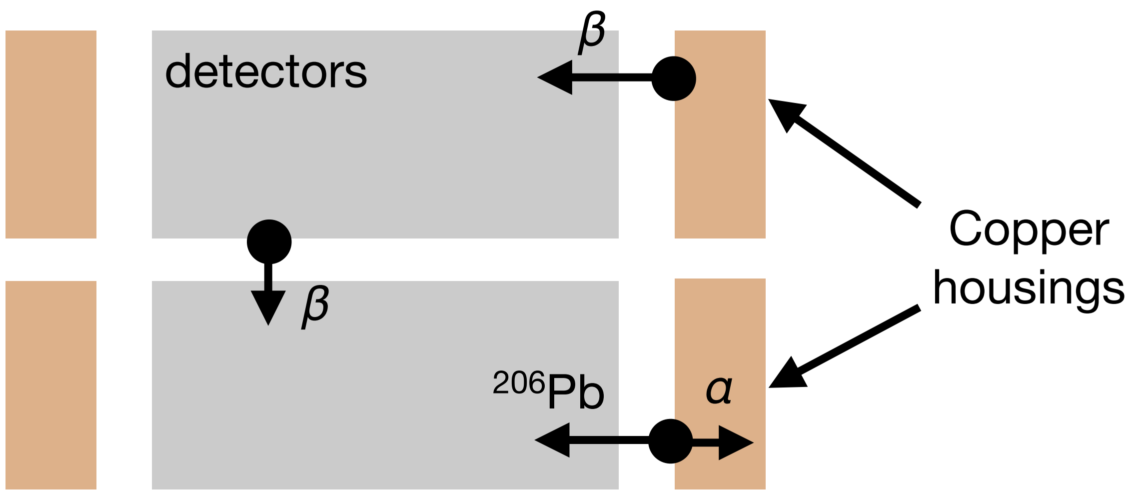
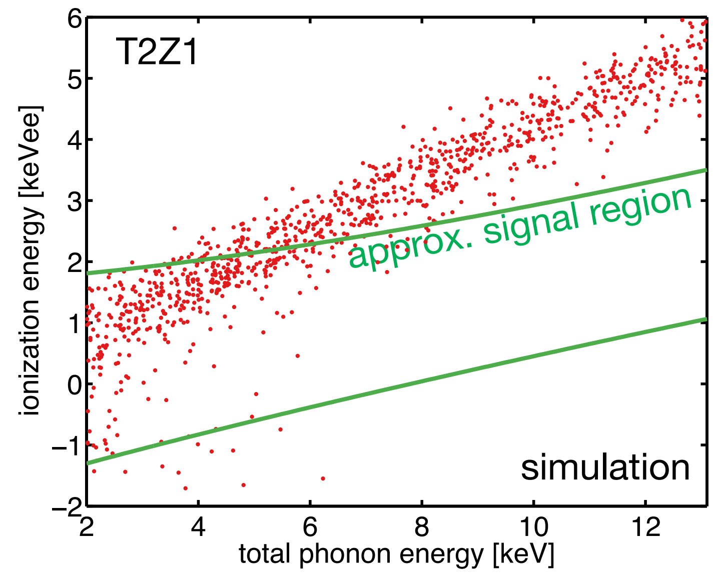


External gammas



- from radioactivity in shielding and cryostat

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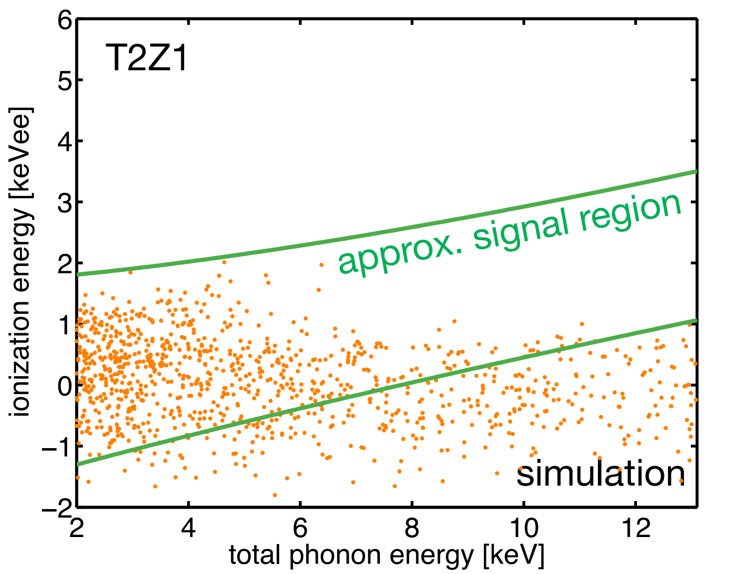

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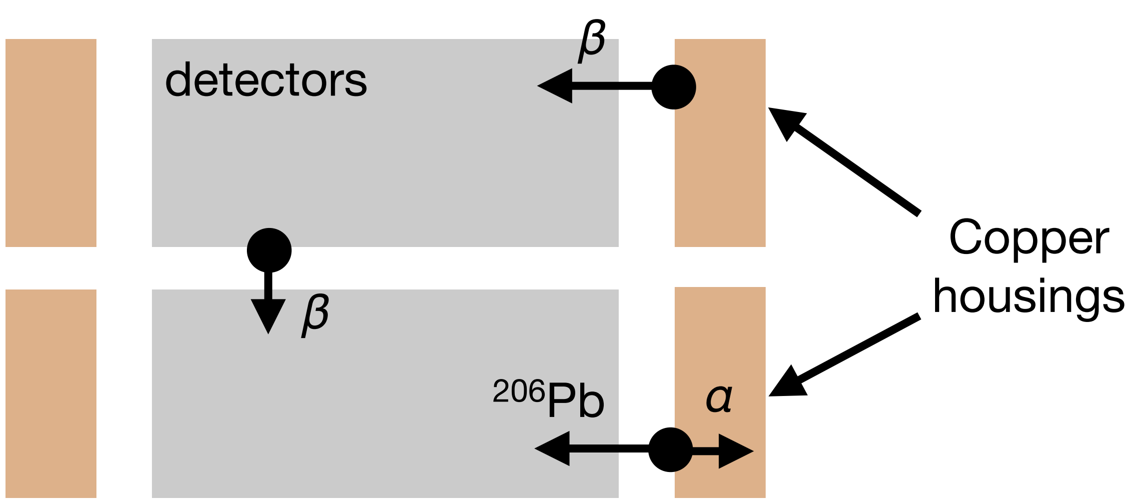

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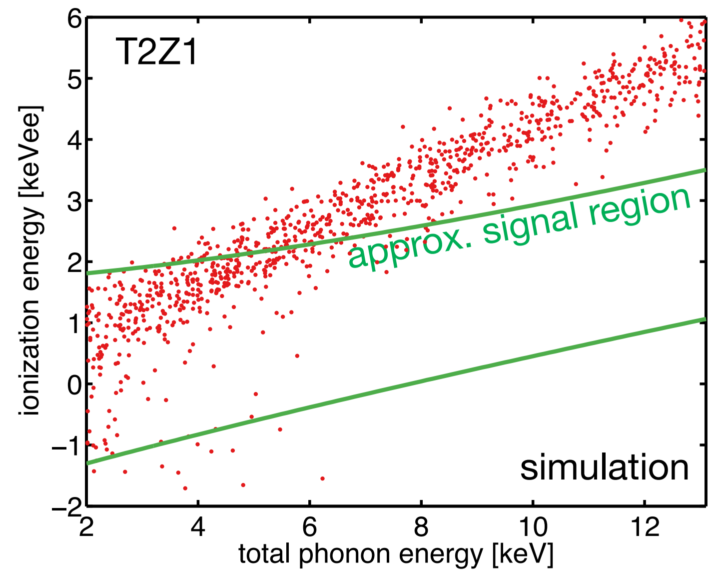

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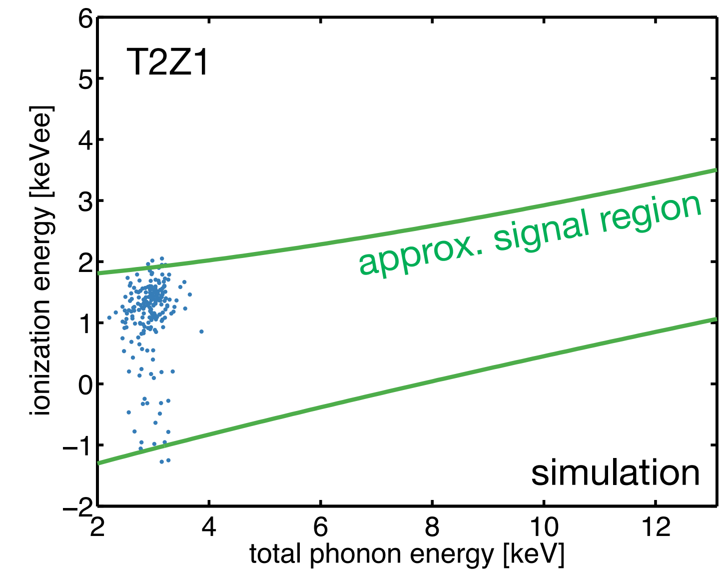
Internal activation lines



- L-shell capture from ^{68,71}Ge, ^{65}Zn, ^{68}Ga

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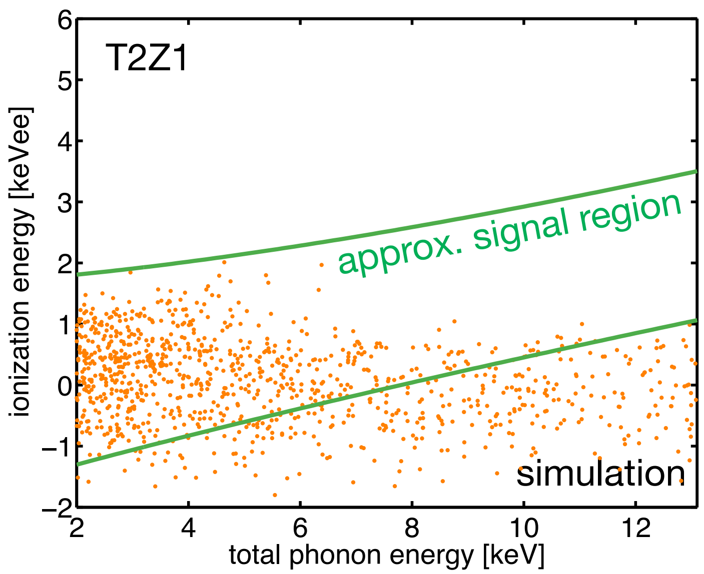

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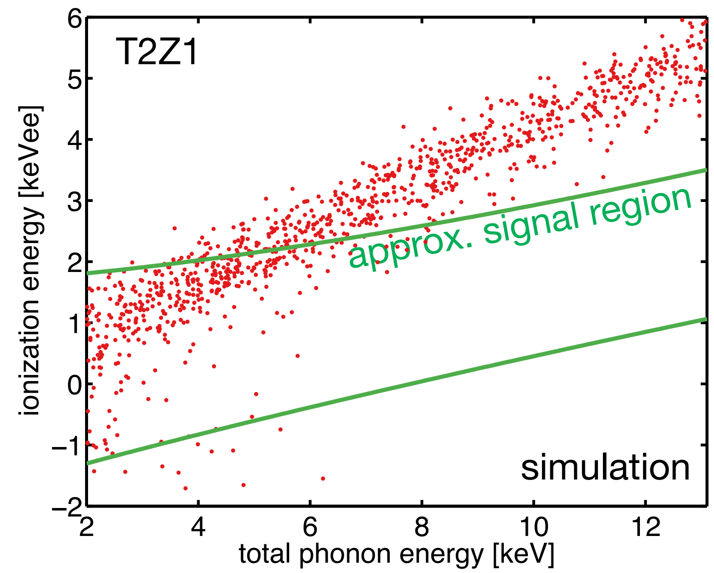

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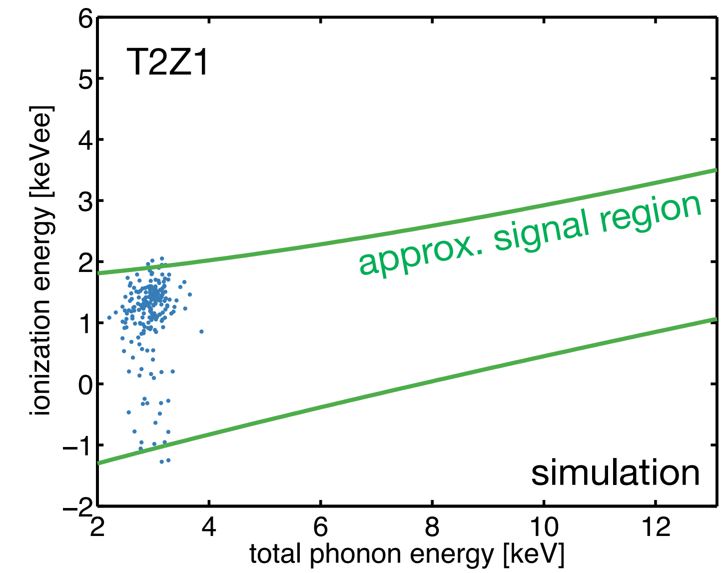

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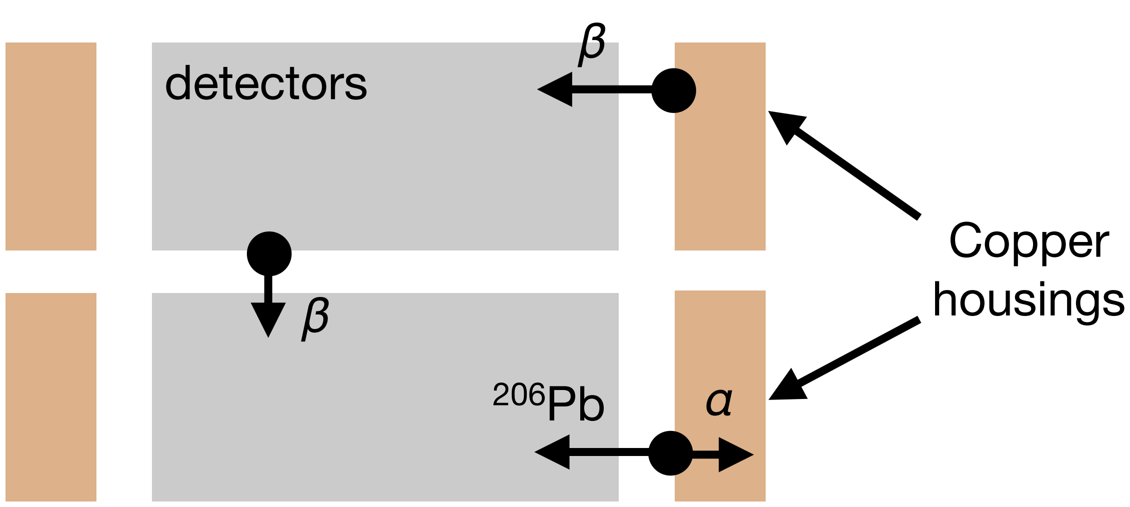
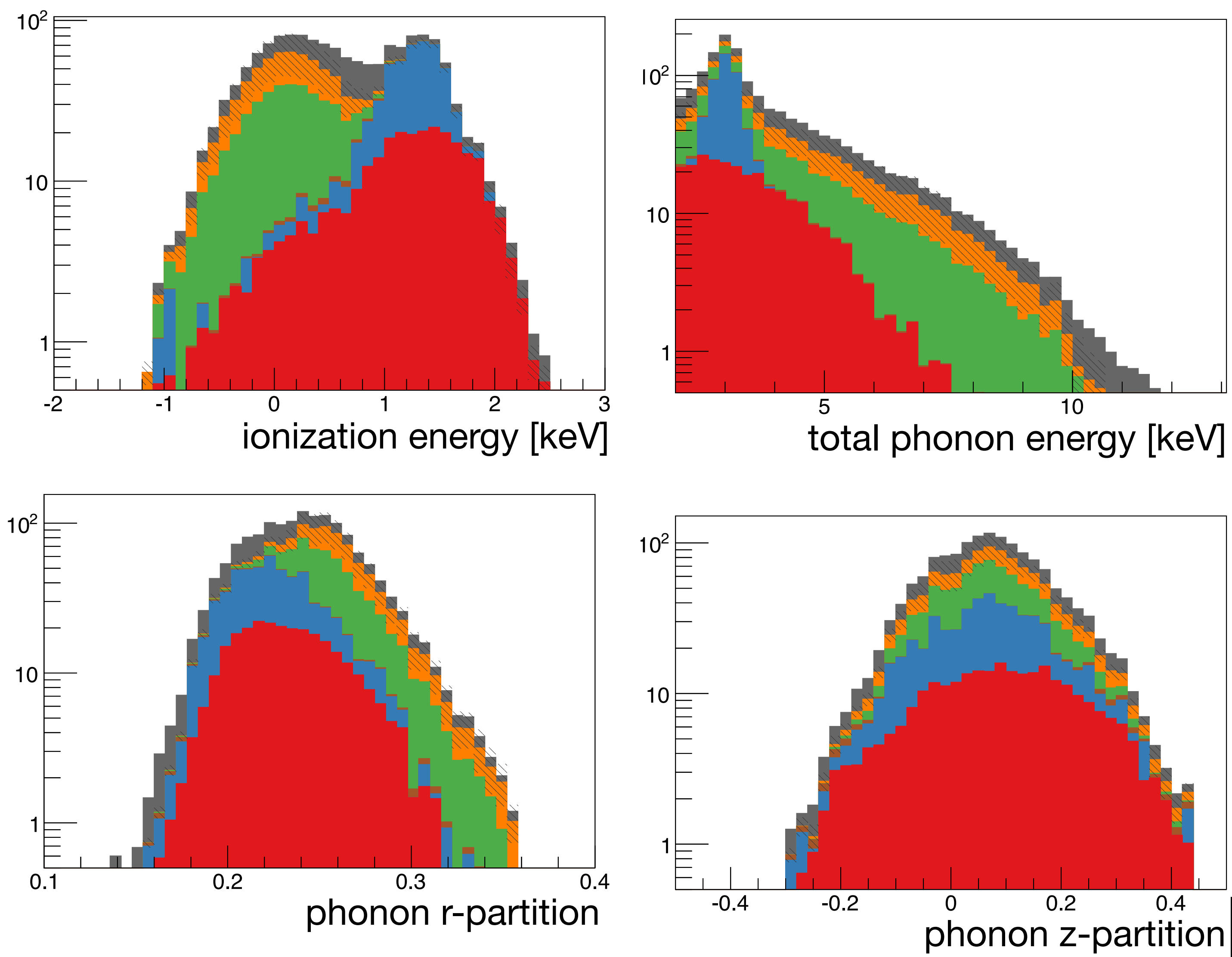


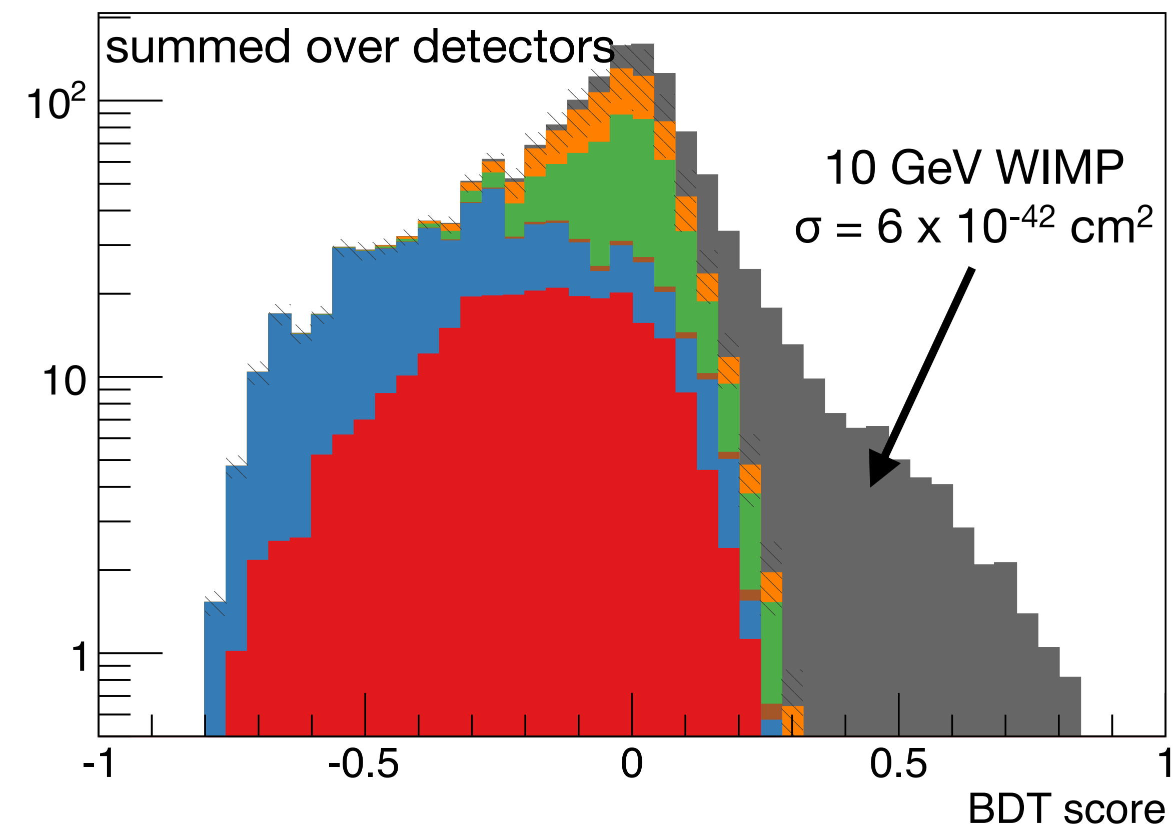
- Signal region **blinded** & **no calibration** data for dominant ^{210}Pb sidewall background
- Systematics from ^{210}Pb simulation not understood in detail, so chose before unblinding to set **upper limit**

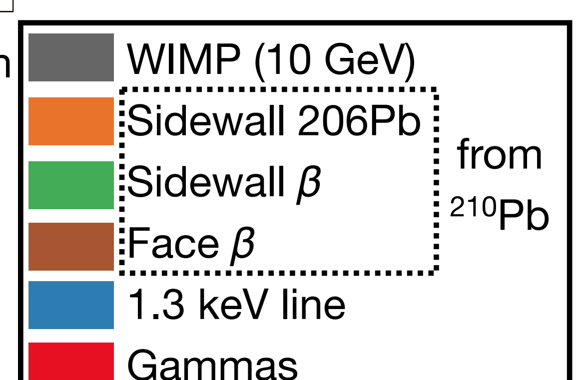
Boosted Decision Tree

BDT inputs



BDT output





Background model: pulse simulation
Signal model: ^{252}Cf NR events reweighted to match 5, 7, 10, and 15 GeV WIMP

Construction: 1 BDT per detector
Optimization: set cuts simultaneously to minimize expected 90% CL upper limit on WIMP-nucleon cross section

Selection Criteria and Efficiencies

Quality

- Remove periods of poor detector performance
- Remove misreconstructed and noisy pulses
- Measure efficiency with pulse Monte Carlo

Thresholds

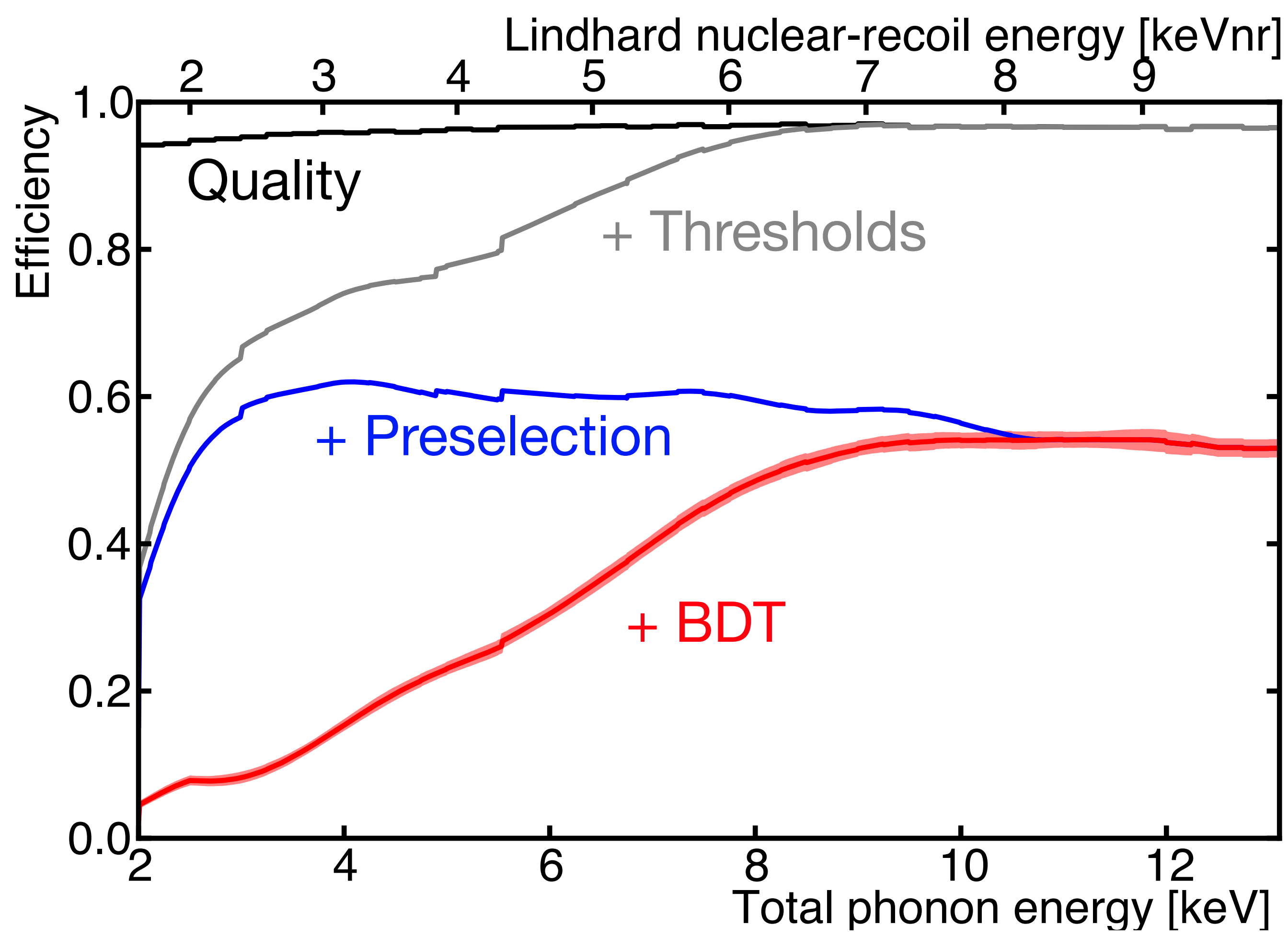
- Trigger and analysis thresholds 1.6-5 keVnr
- Measure efficiency using ^{133}Ba calibration data

Preselection

- Ionization consistent with nuclear recoils
- Ionization-based fiducialization
- Remove multiple-detector hits
- Remove events coincident with muon veto

BDT

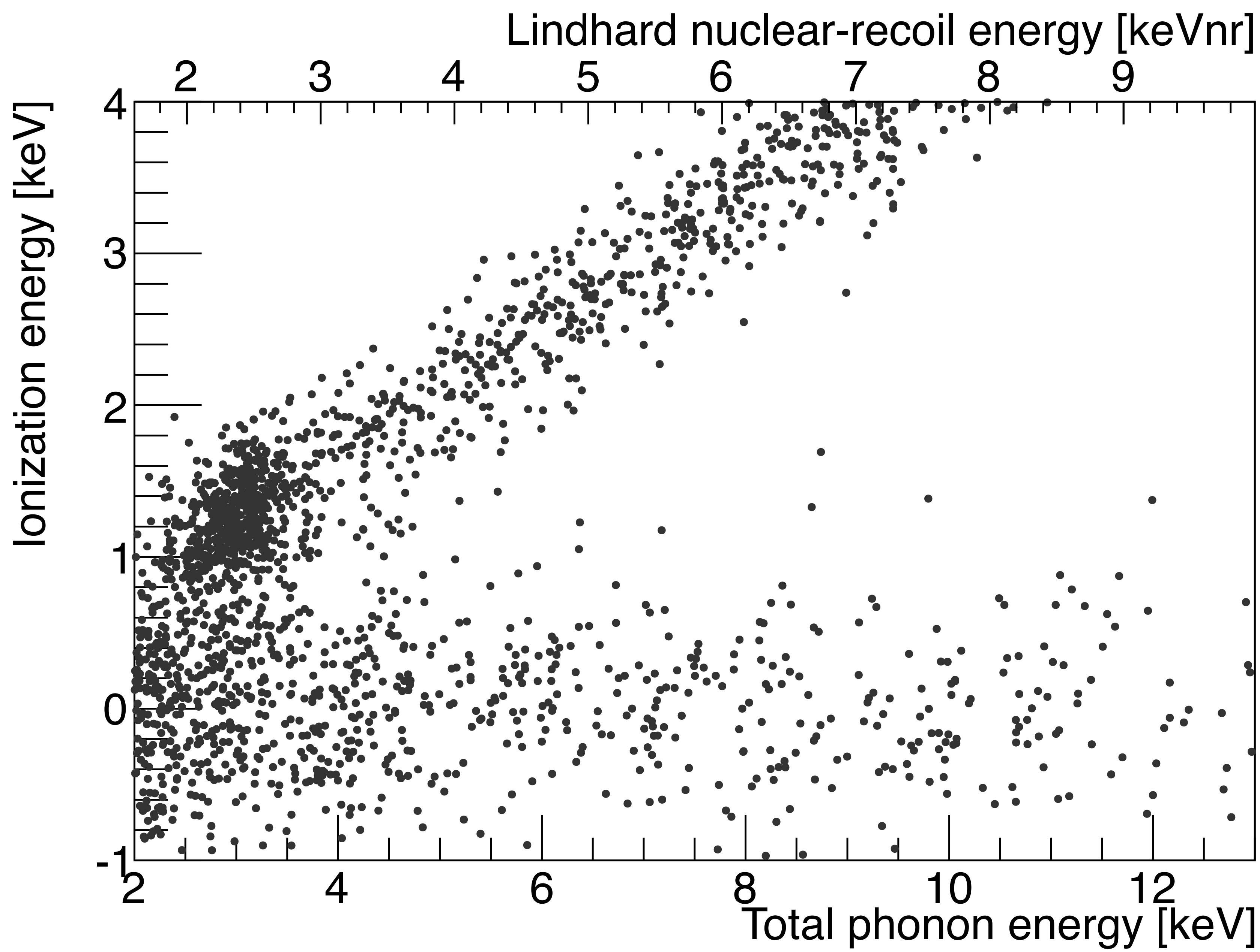
- Optimized cut on energy and phonon position estimators
- Estimate BDT+preselection efficiency using fraction of 252Cf passing



Includes ~20% correction, from Geant4 simulation, for multiple scattering in single detector

Unblinding: Before BDT

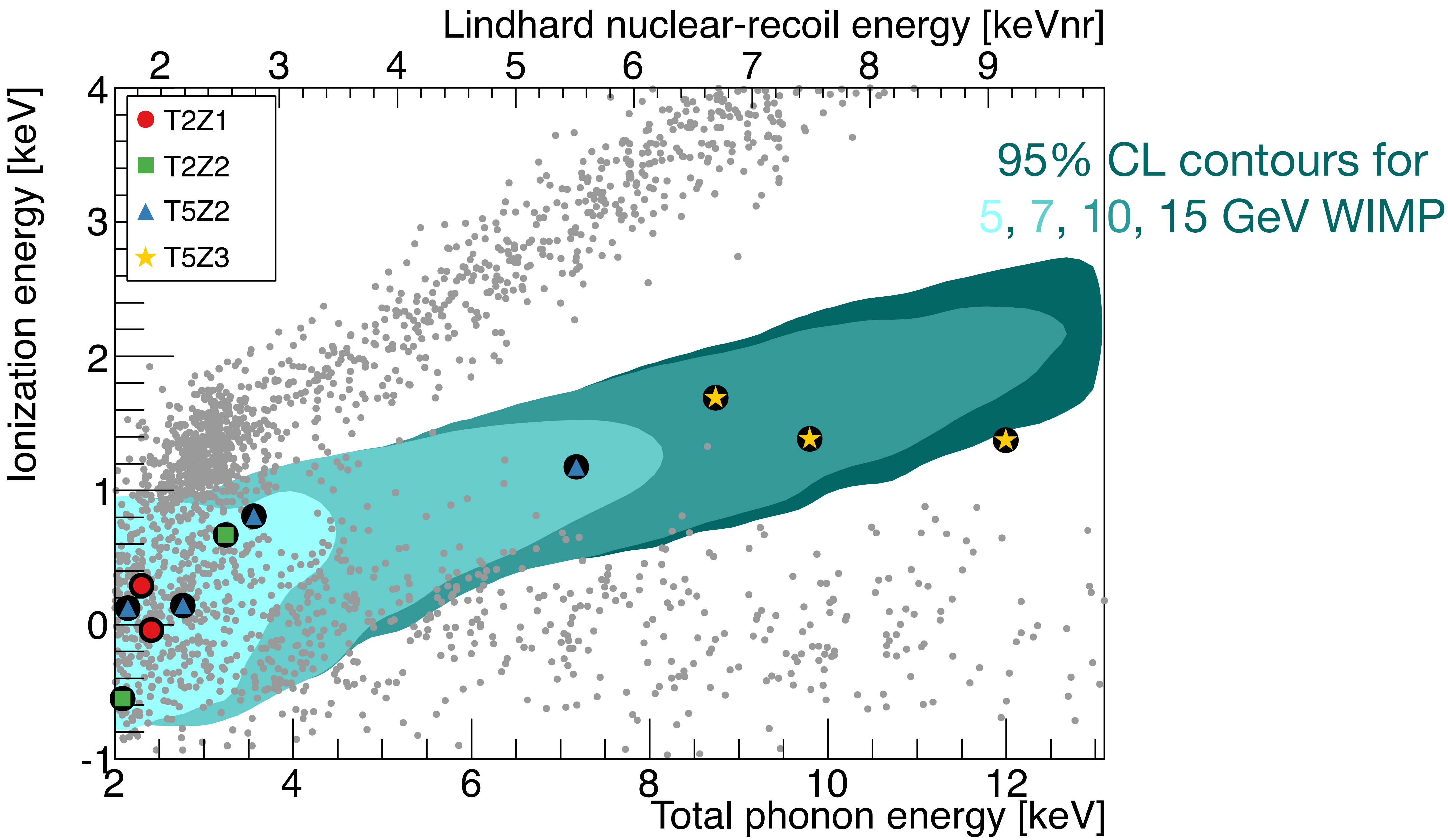
Expected background after BDT: **$6.1^{+1.1}_{-0.8}$ + (0.10 ± 0.02 neutrons)**



Passing data quality &
ionization fiducialization cuts

Unblinding: After BDT

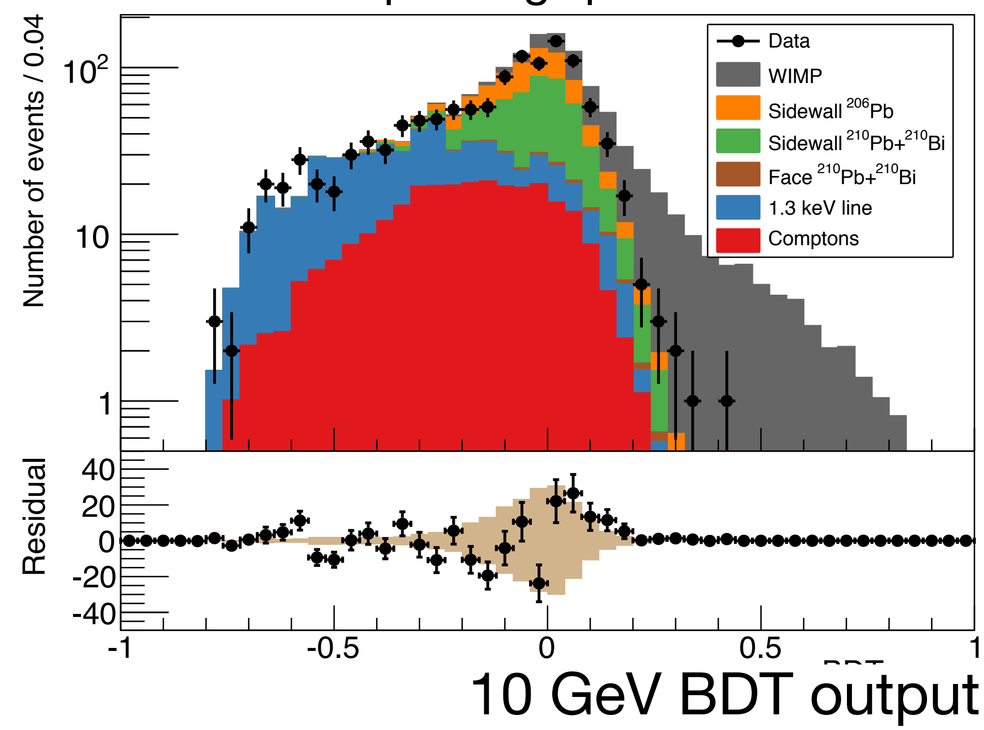
11 events observed passing BDT (expected $6.2^{+1.1}_{-0.8}$)

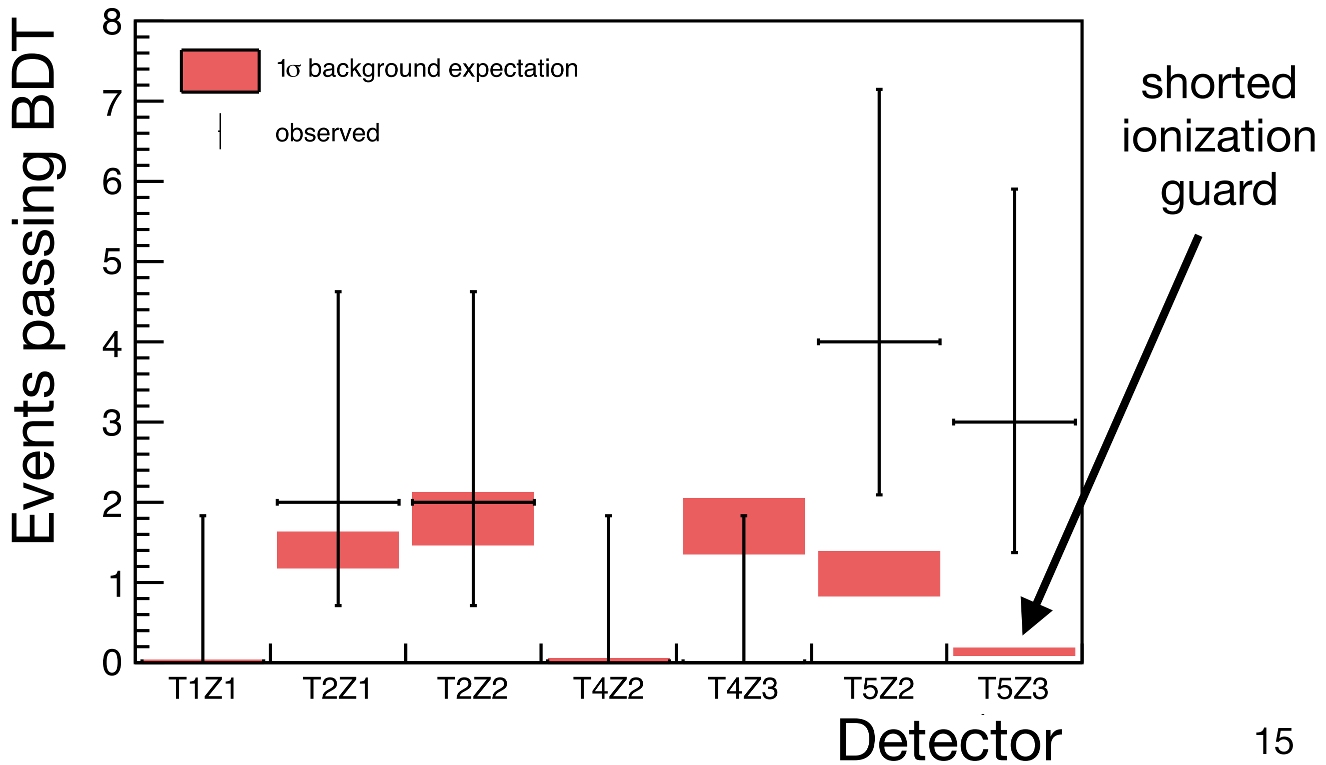


Post-Unblinding Comparison

- Background consistent with expectations overall and on most individual detectors
- Background model **accurate in full preselection region**
- Shorted ionization guard on T5Z3 may have affected background model performance—*further study ongoing*
- Poisson p-value for T5Z3 is 0.04%, and even lower considering only high event energies

events passing “preselection”

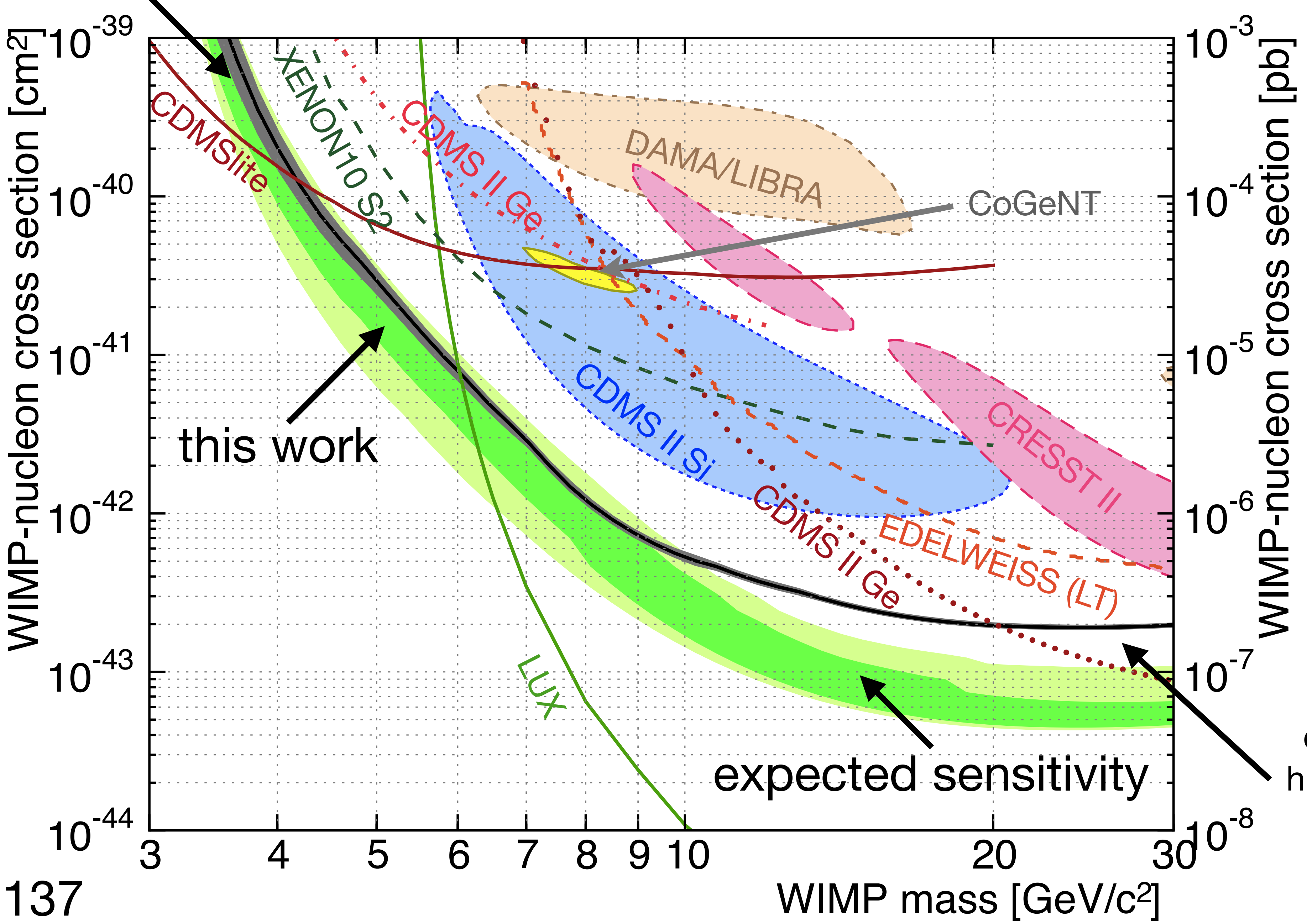




Limit

set 90% CL upper limit with optimal interval method (no background subtraction)

band includes systematics from
efficiency, energy scale, trigger efficiency



difference due to
high-energy events
on T5Z3

arXiv:1402.7137

Conclusions

- CDMSlite demonstrates power of Luke amplification to probe very low WIMP masses
- Low-energy analysis is first science result from SuperCDMS using background rejection capabilities of iZIP detectors
- Exposure of 577 kg-d sets limit of 1.2×10^{-42} cm^2 at 8 GeV
- Strong tension with existing light WIMP “hints”, under standard halo assumptions
- Model-independent test strongly disagrees with WIMP interpretation of CoGeNT
- Future improvement possible through refined reconstruction algorithms, likelihood analysis, and reduction of background on Cu housings
- Plus upgraded 100 kg experiment at SNOLAB!

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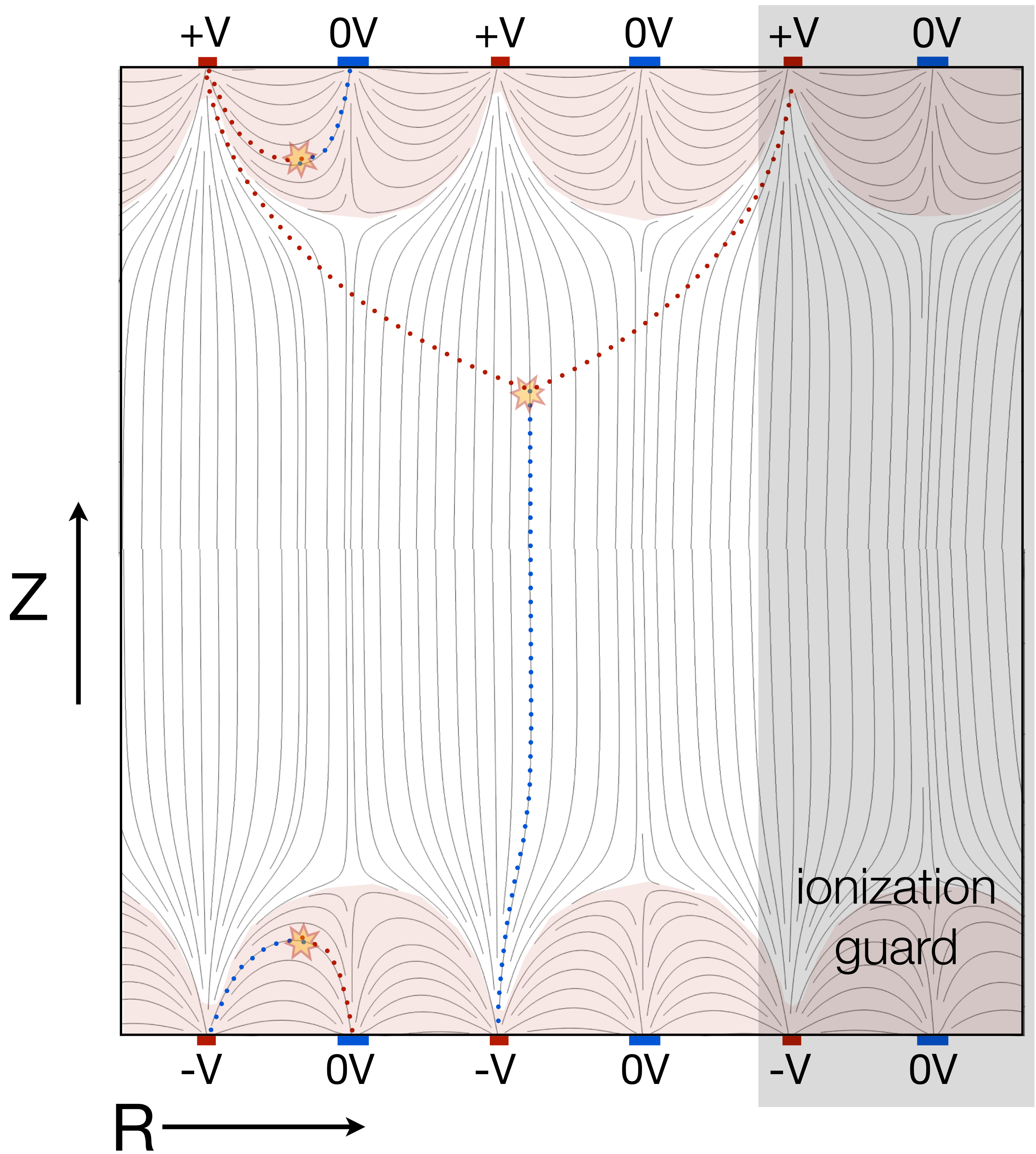
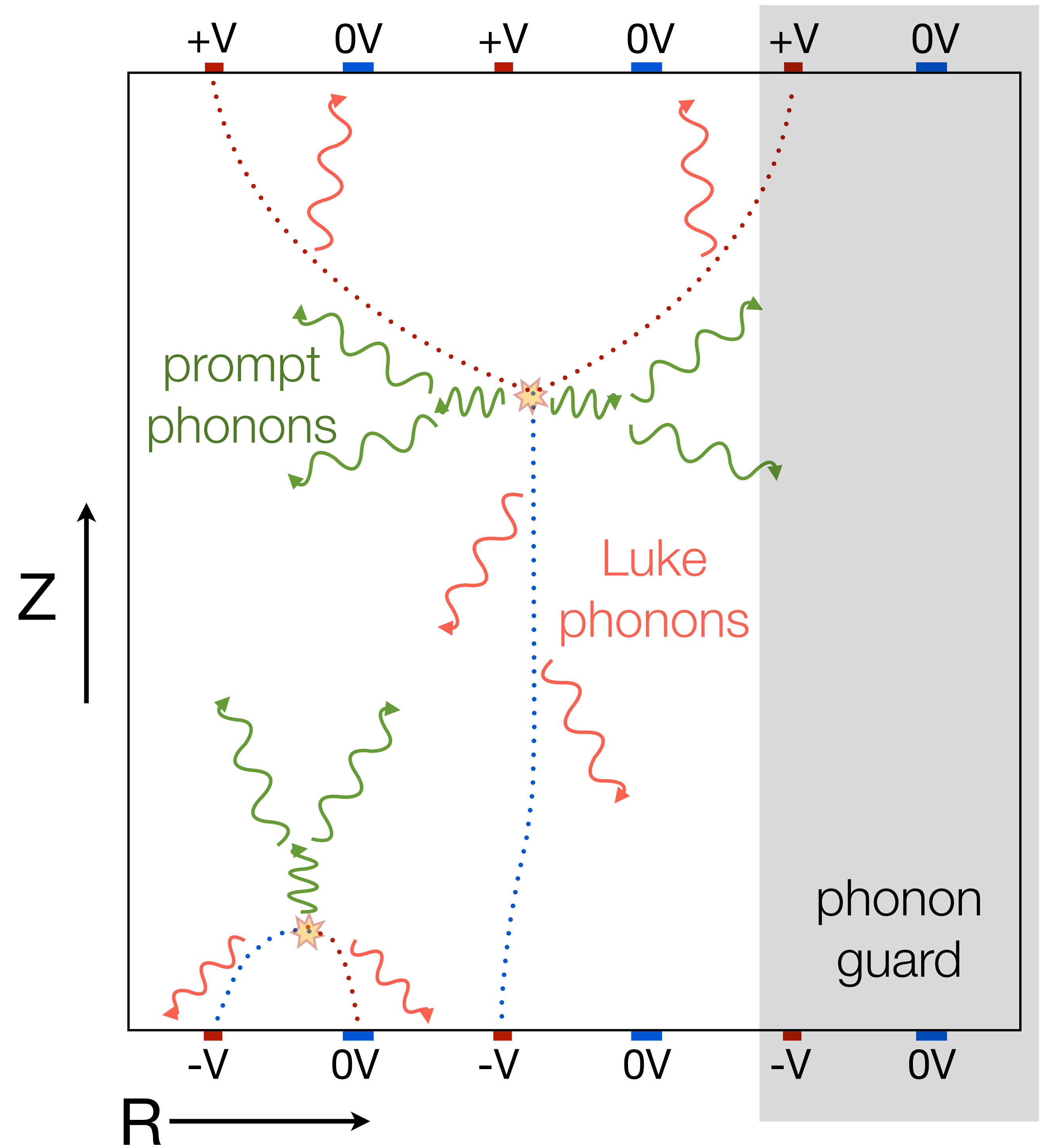
J. Sander

Backup

iZIP Fiducialization





Appl. Phys. Lett. **103**, 164105 (2013)

Calibration and Energy Scale

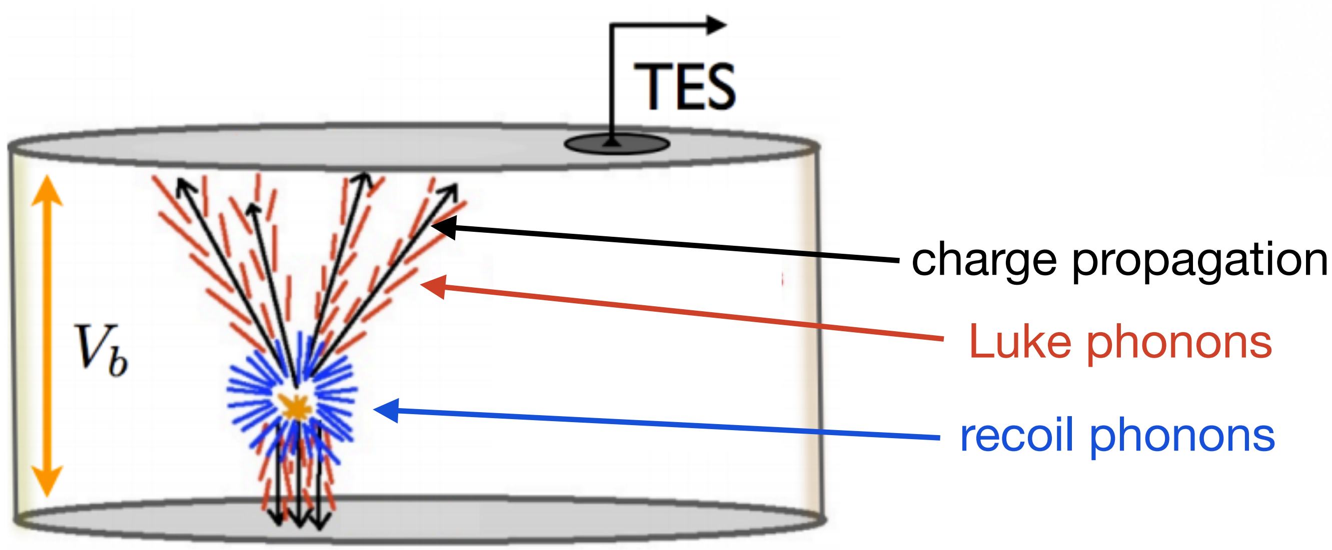
- Measure "total" phonon energy:

$$E_{total} = E_{recoil} + E_{luke}$$

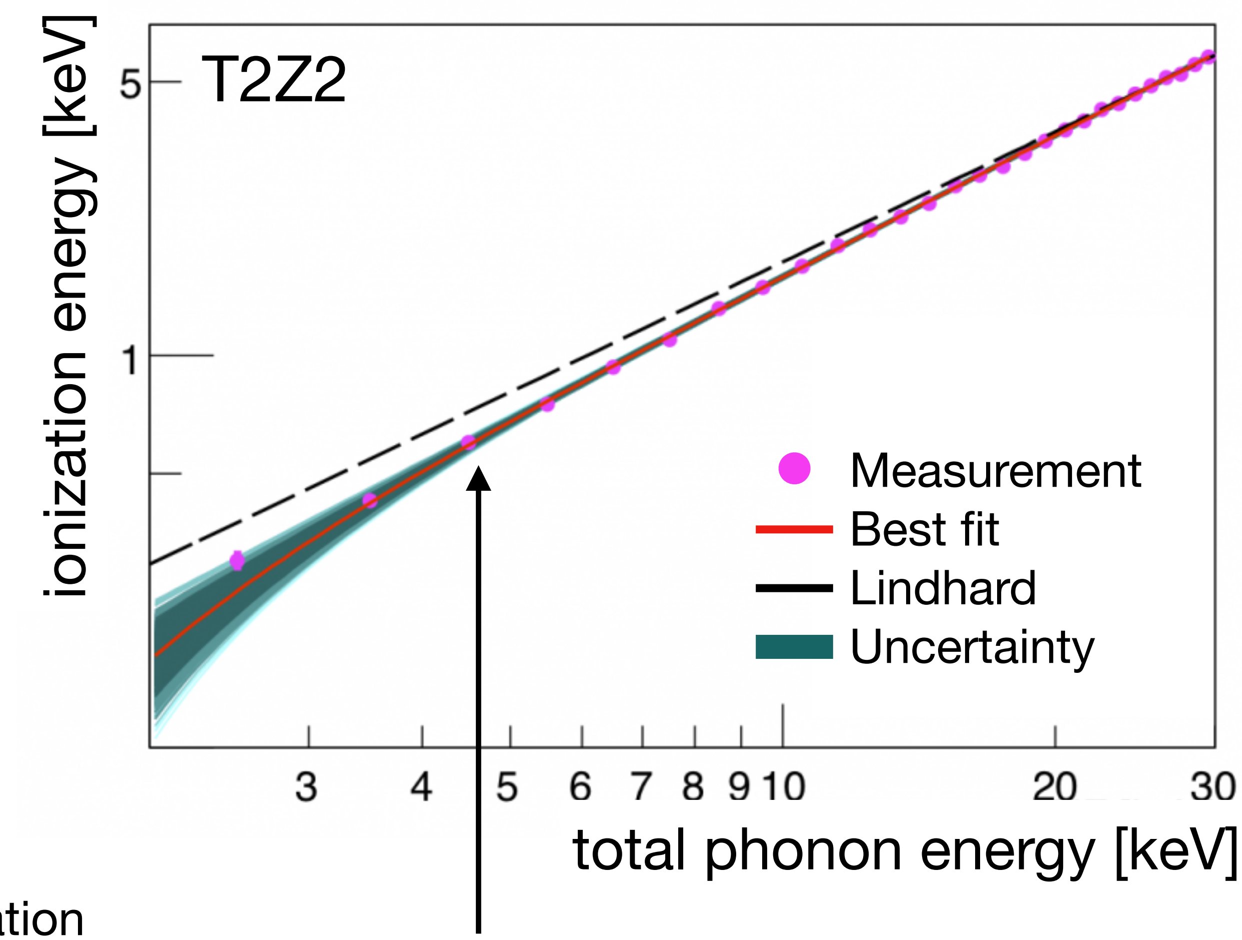
- Use mean ionization energy for nuclear recoils to convert to NR-equivalent recoil energy:

$$E_{recoil,NR} = E_{total} - E_{luke,NR}$$

Luke phonon energy assuming mean ionization energy for NRs

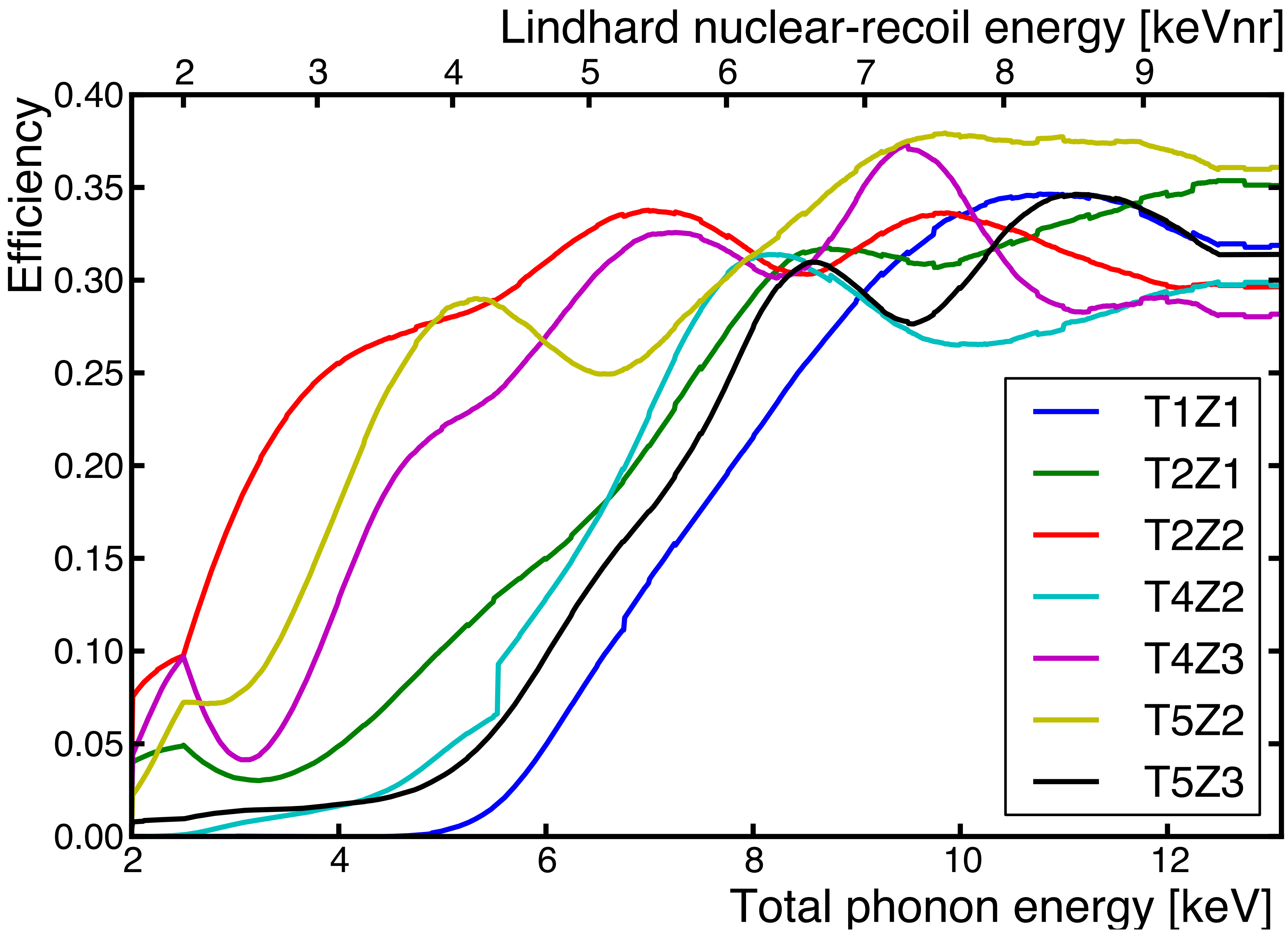


Mean ionization energy from ^{252}Cf neutron calibration data

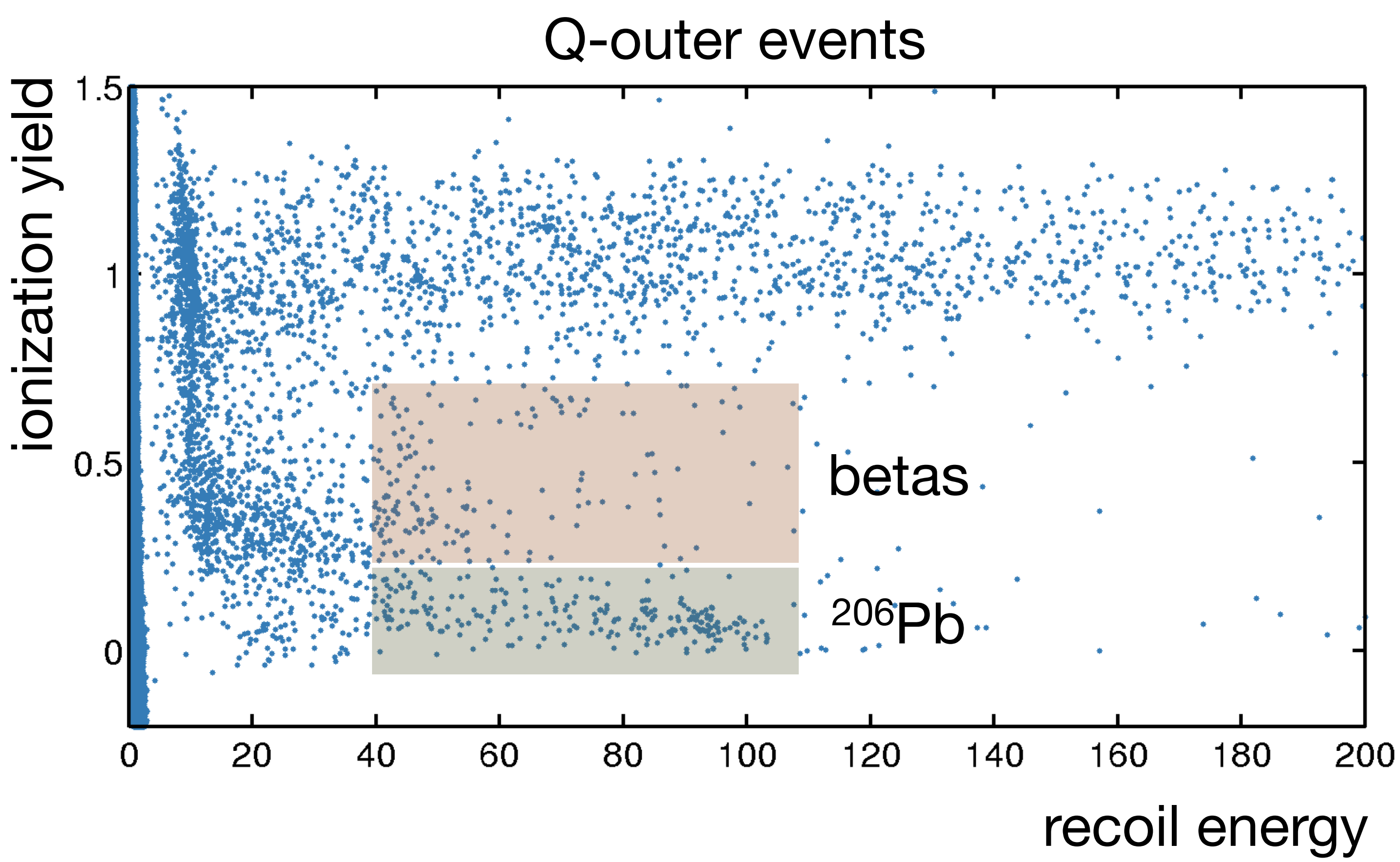


most detectors similar to or slightly below Lindhard

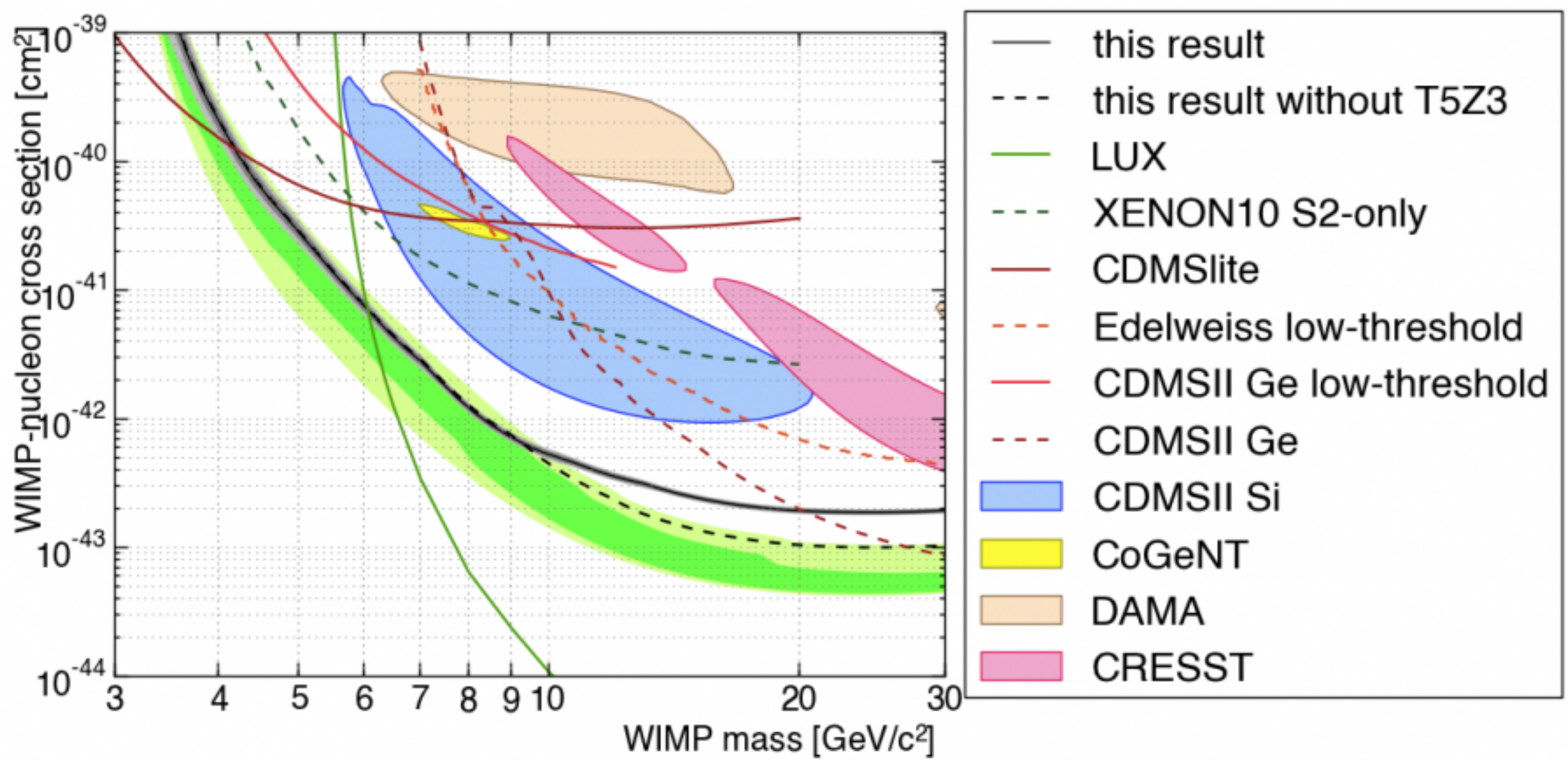
Efficiencies by Detector



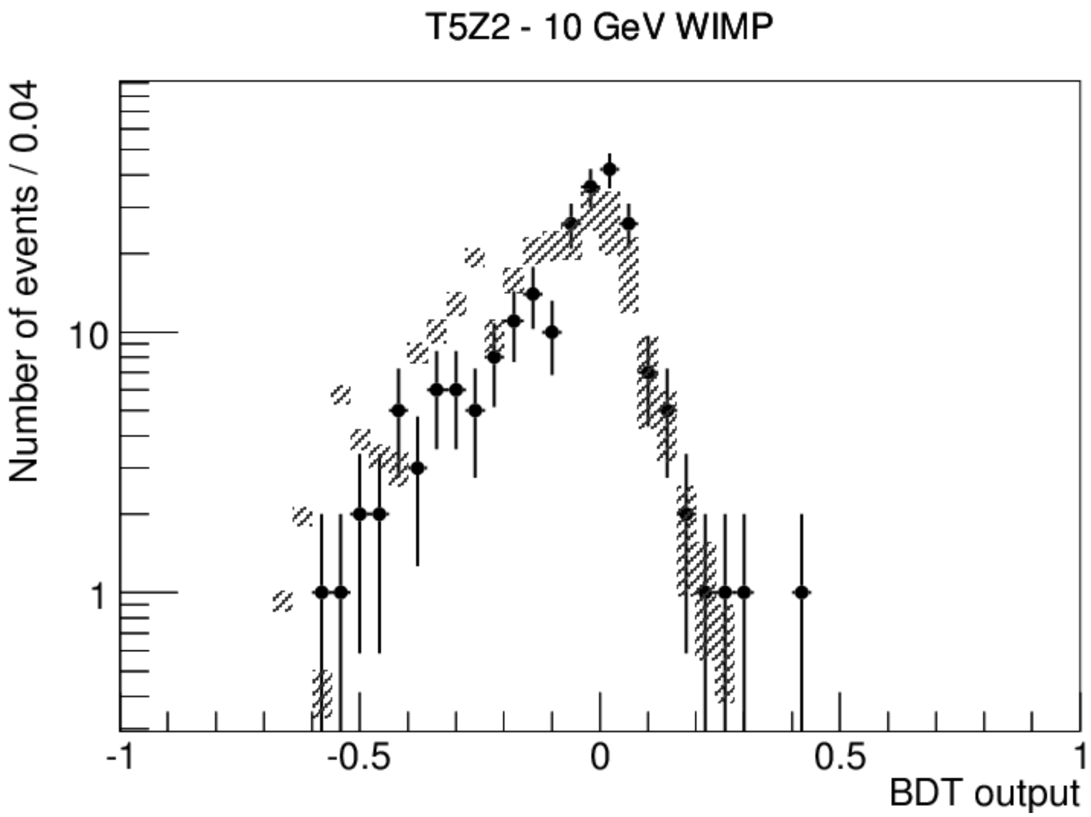
Background Simulation

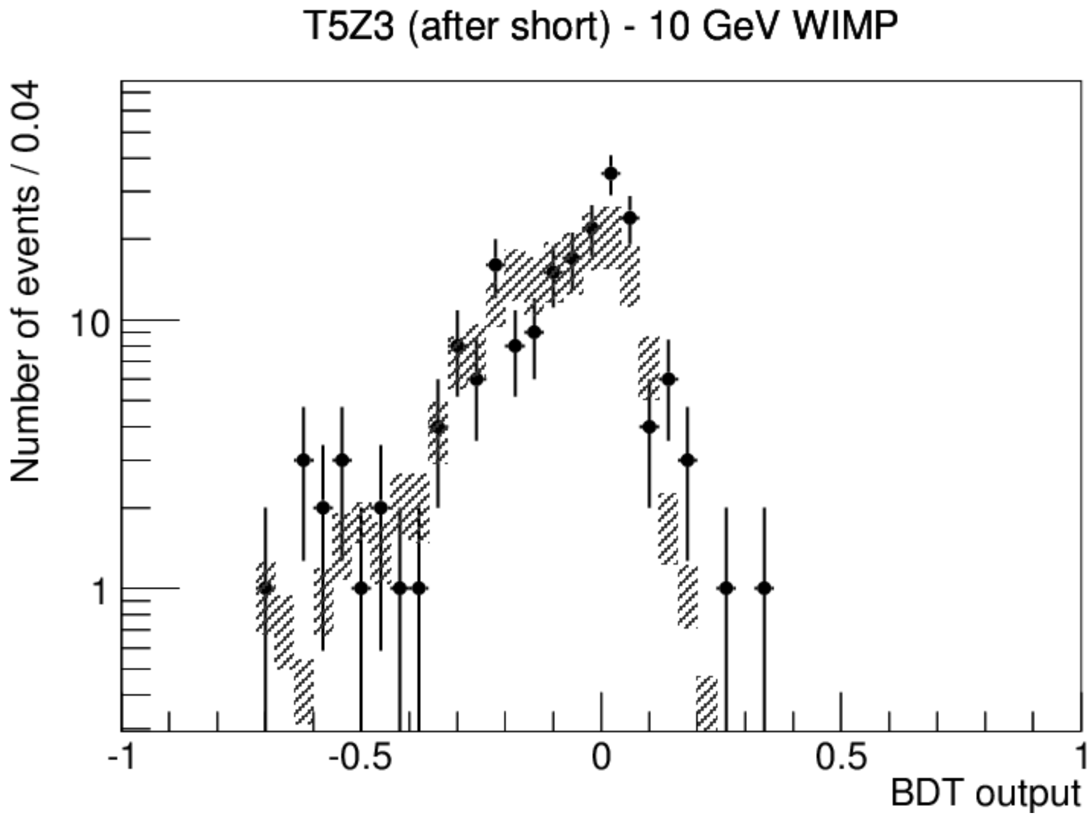


Limit without T5Z3

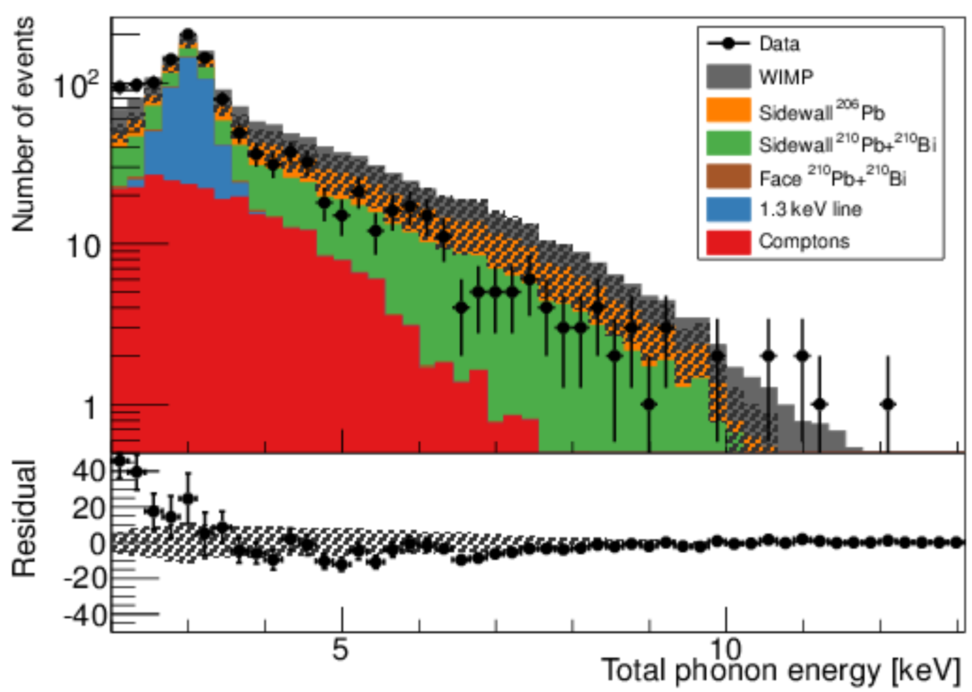


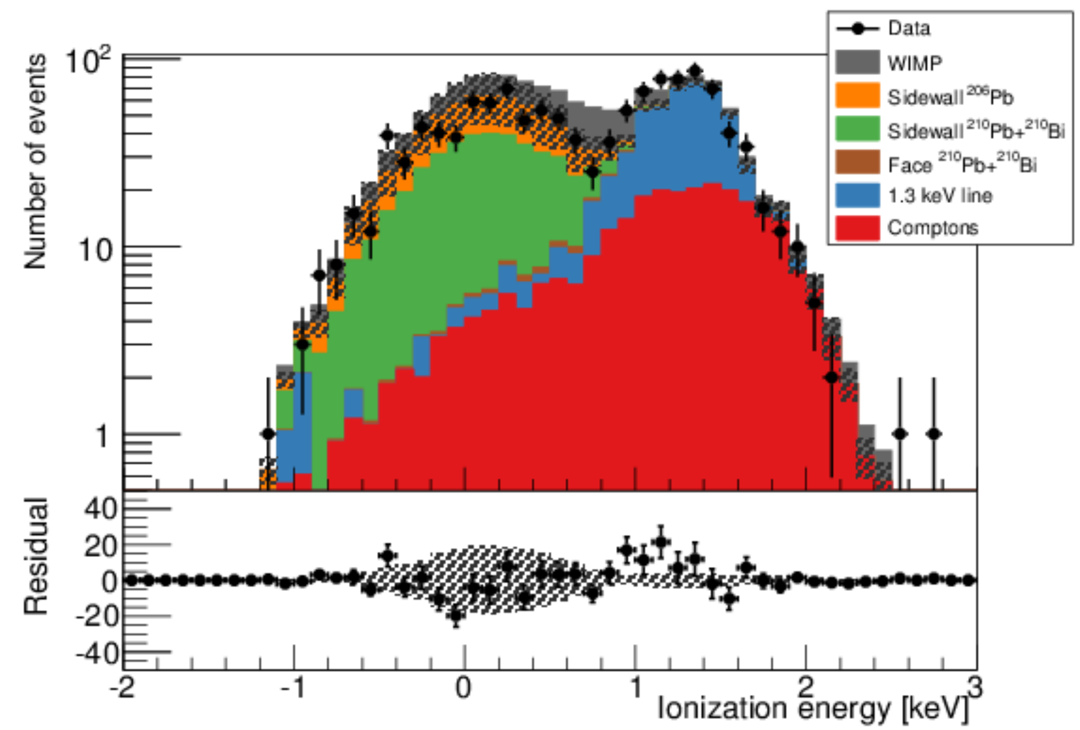
Tower 5 Data

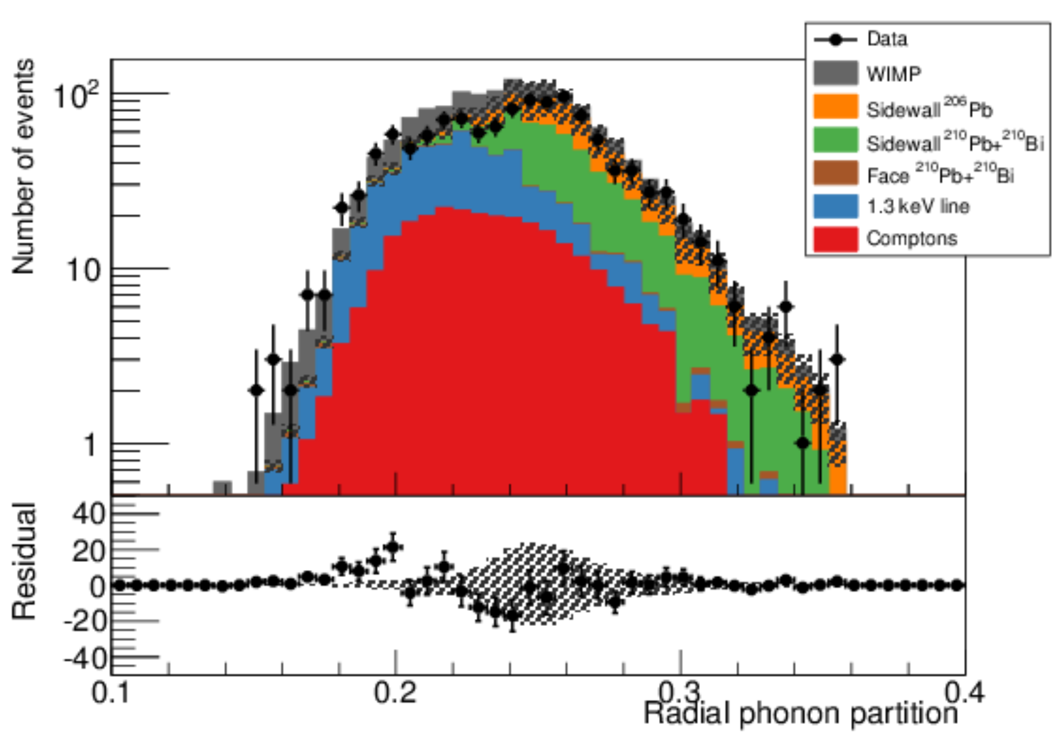

T5Z2 - 10 GeV WIMP
Number of events / 0.04
10
1
-1
-0.5
0
0.5
1
BDT output

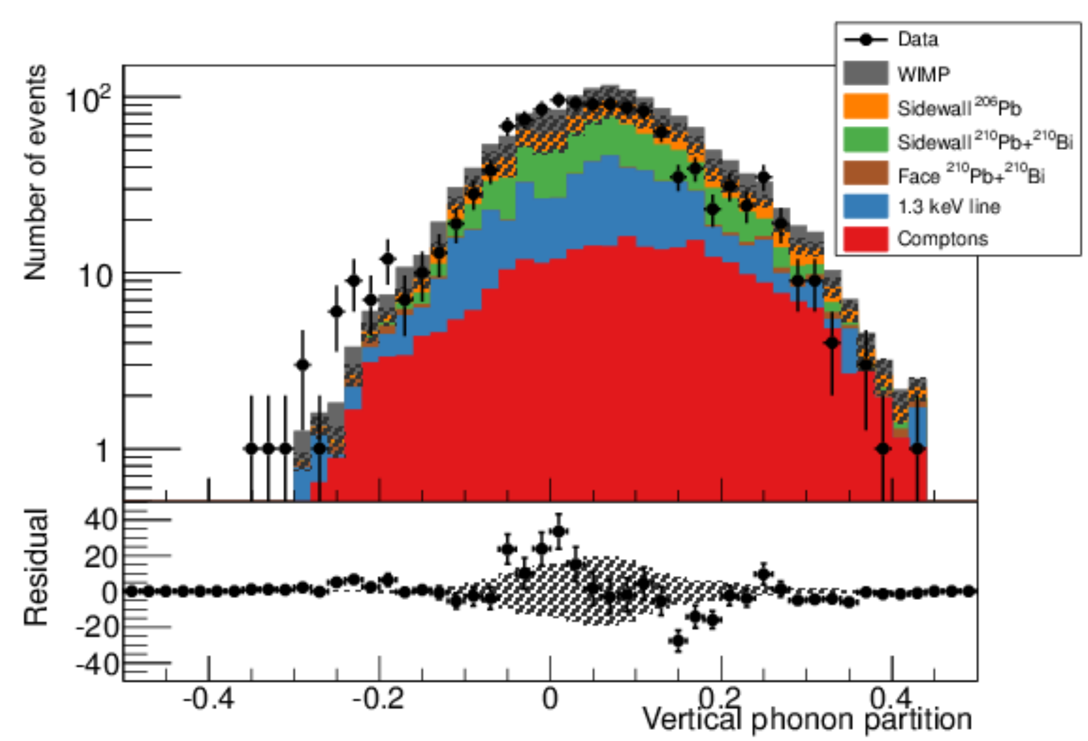

T5Z3 (after short) - 10 GeV WIMP
Number of events / 0.04
10
1
-1
-0.5
0
0.5
1
BDT output

BDT Input Distributions



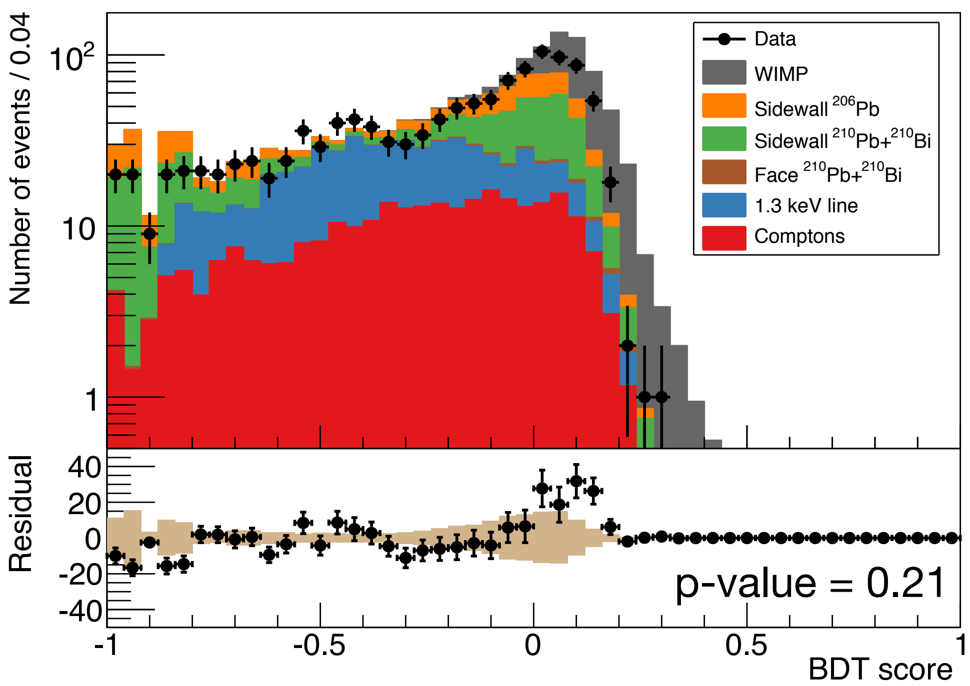




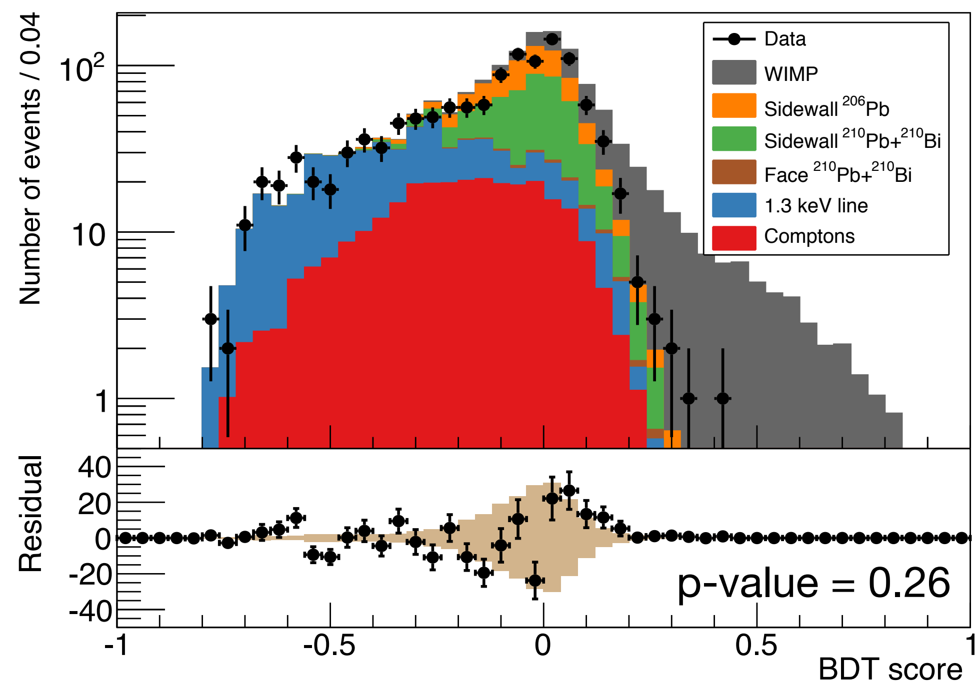


BDT Distributions

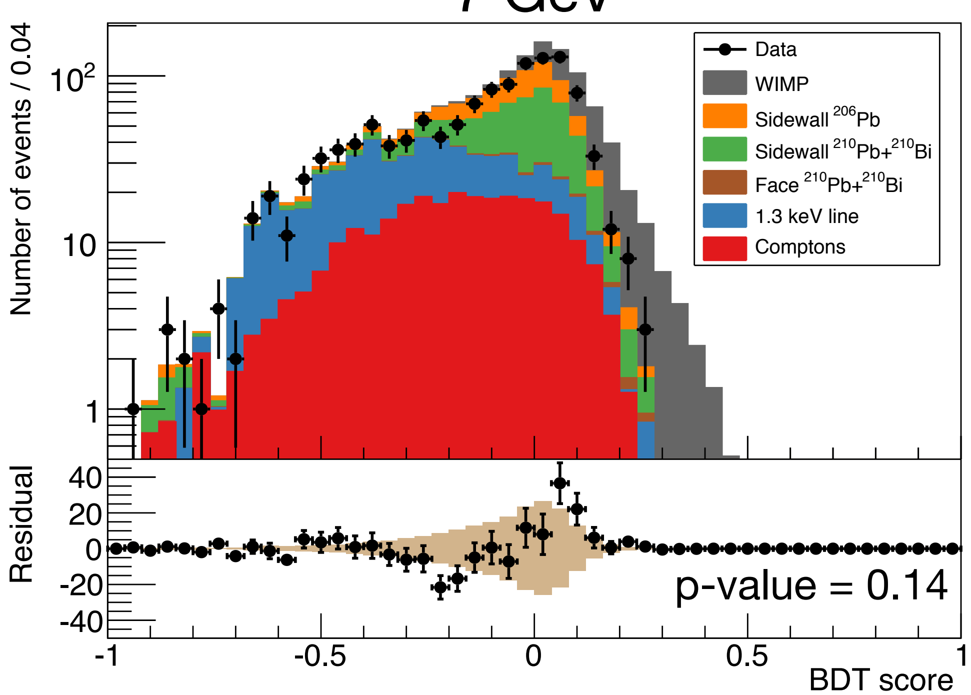
5 GeV



10 GeV



7 GeV



15 GeV