Low-Energy Analyses of Data from SuperCDMS at Soudan

Adam Anderson

COSMO 2014
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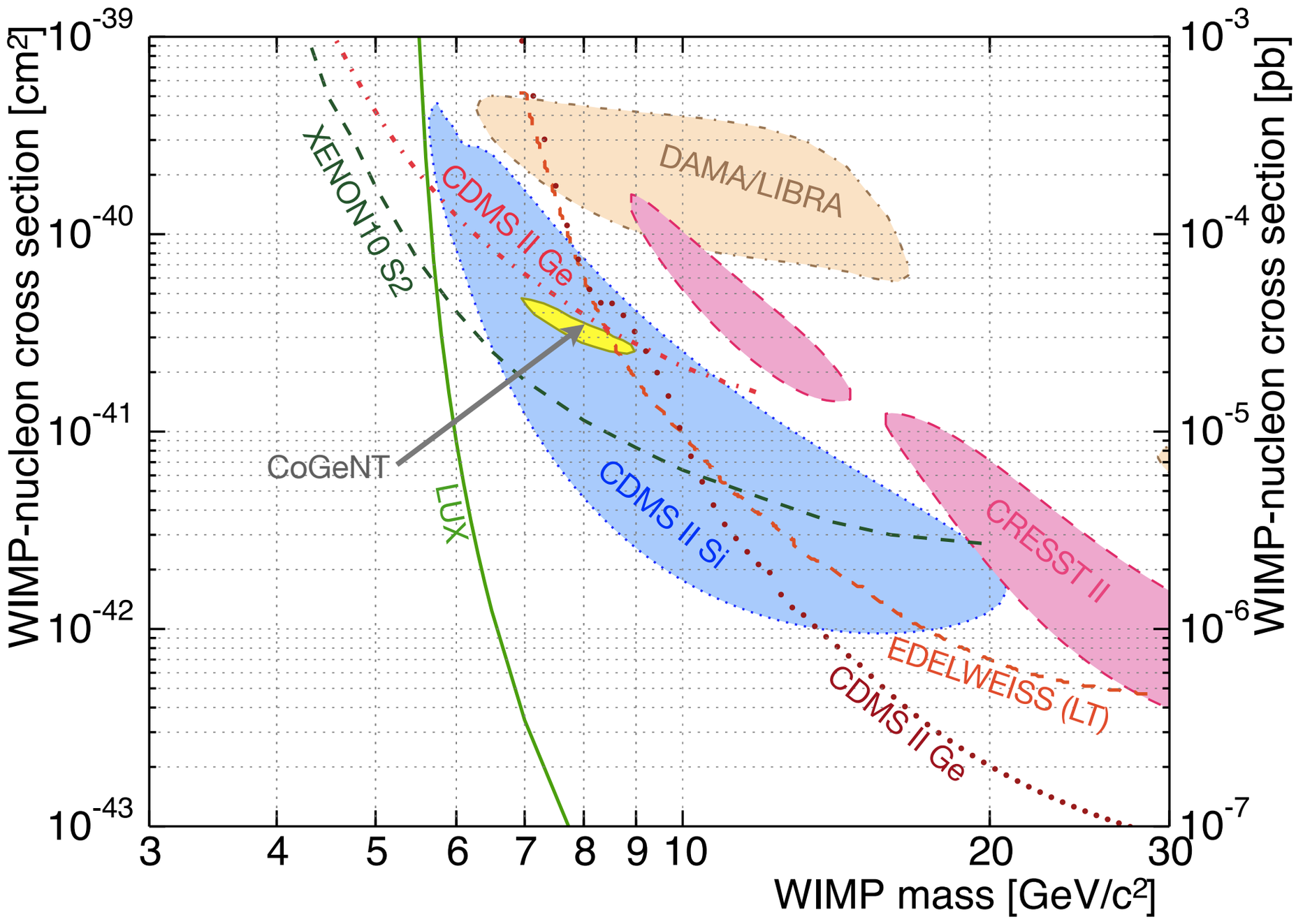
Massachusetts Institute of Technology

Motivation for Light WIMPs

Important to better constrain existing and future anomalies



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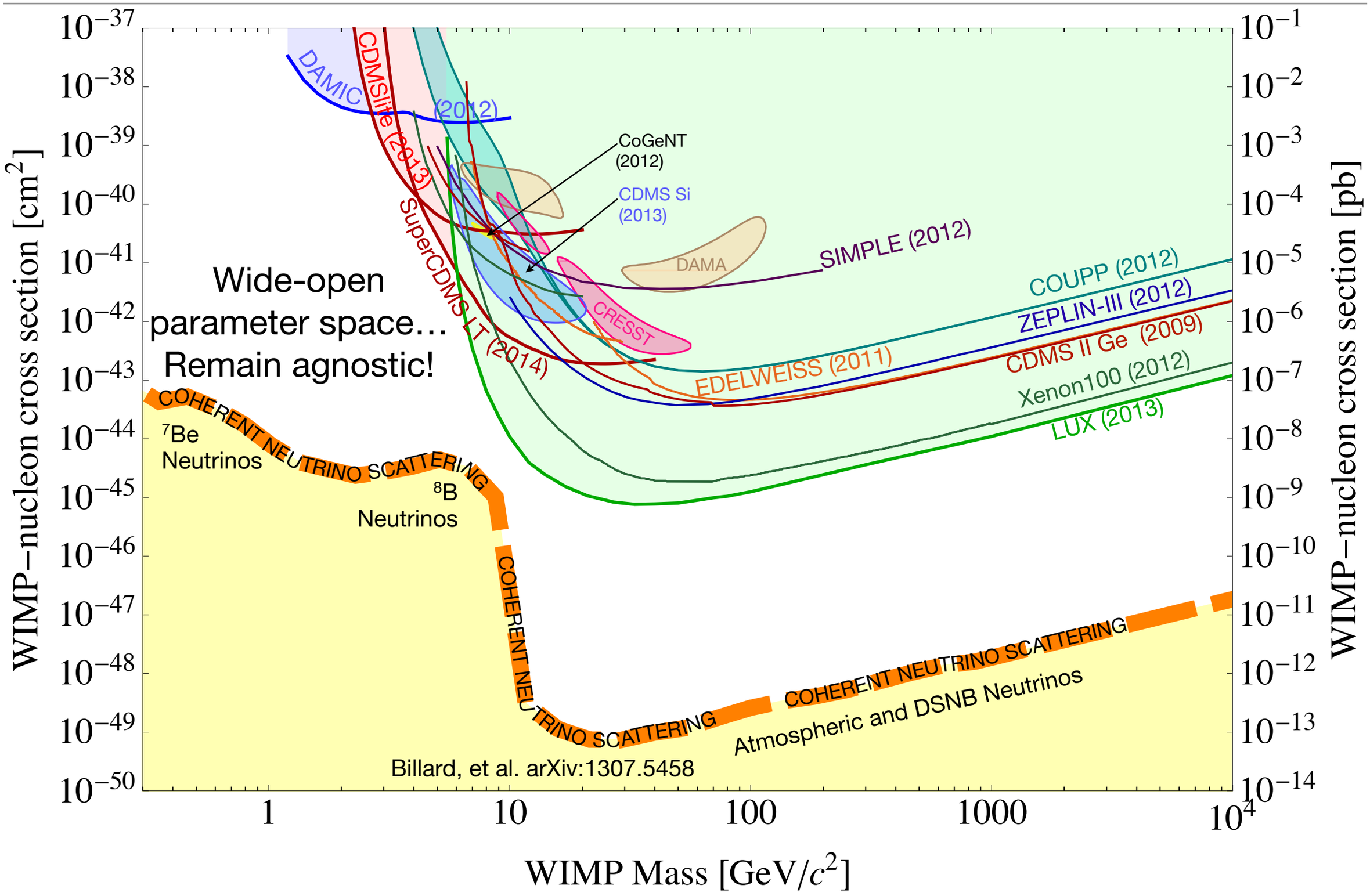
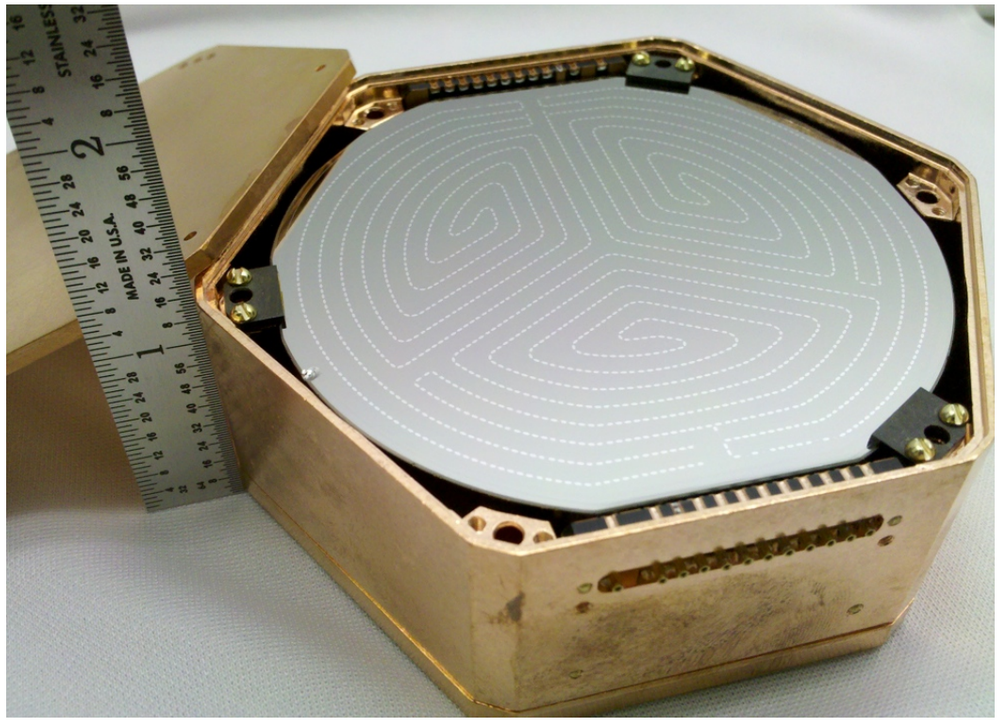


SuperCDMS Overview

- Upgrade to CDMS II experiment
- Ge detectors measure both ionization and phonons

0.6 kg Ge crystals



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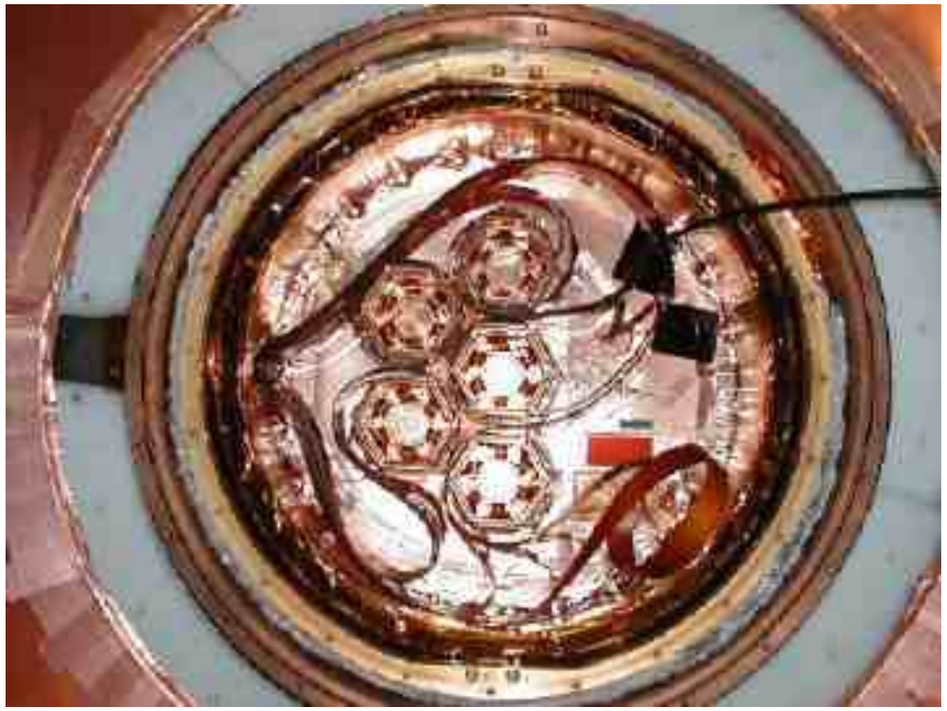
icebox



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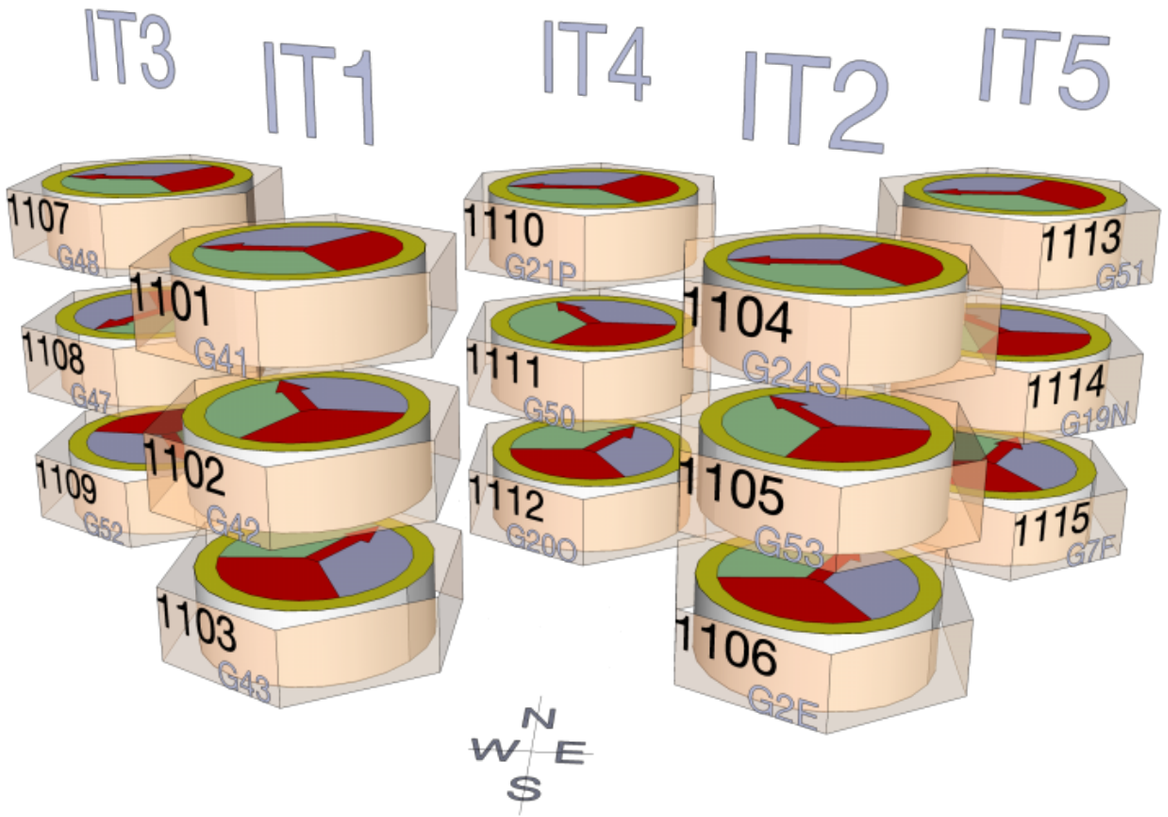

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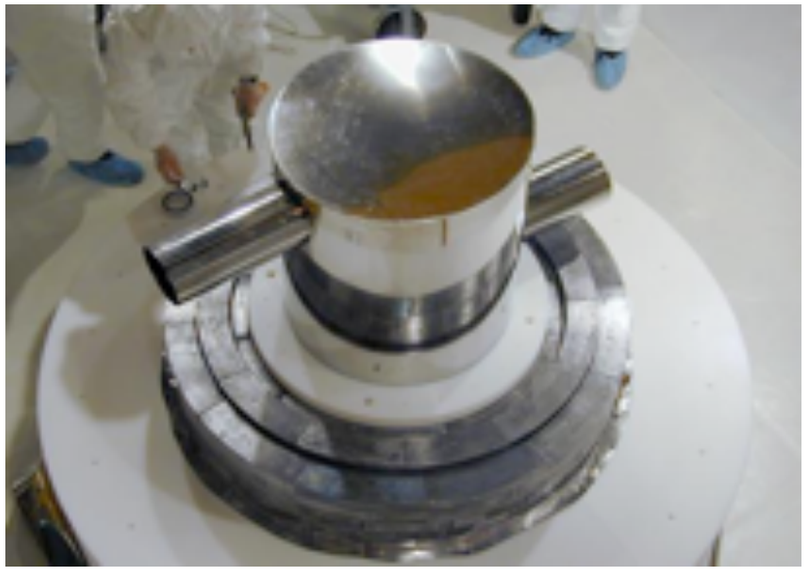
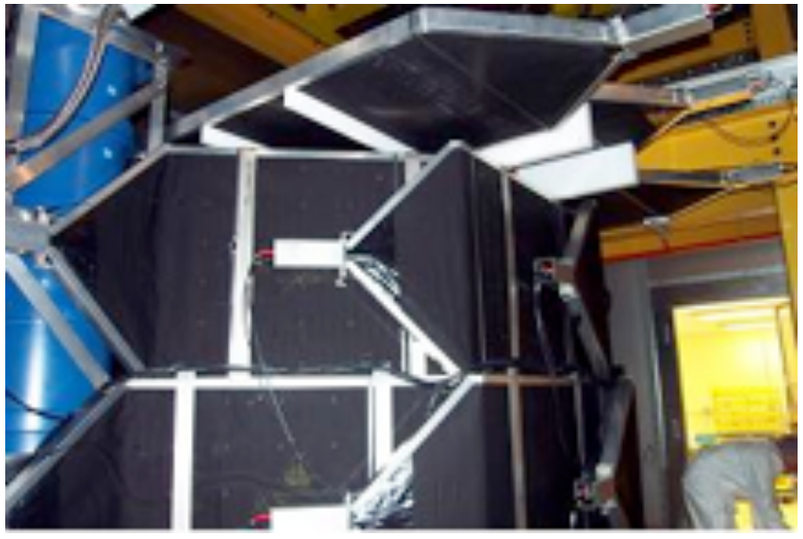
- Active and passive shielding surround detectors

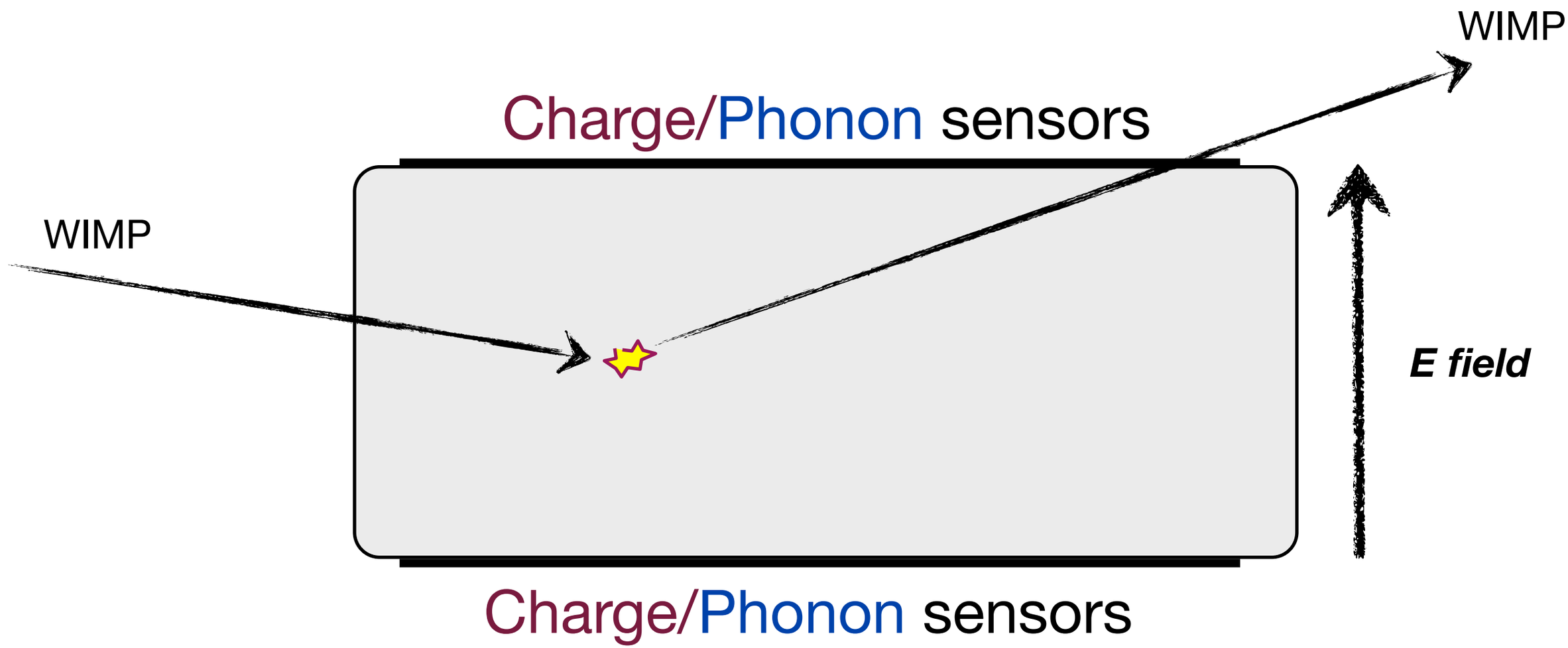
poly and lead shielding



muon veto



iZIP Detectors



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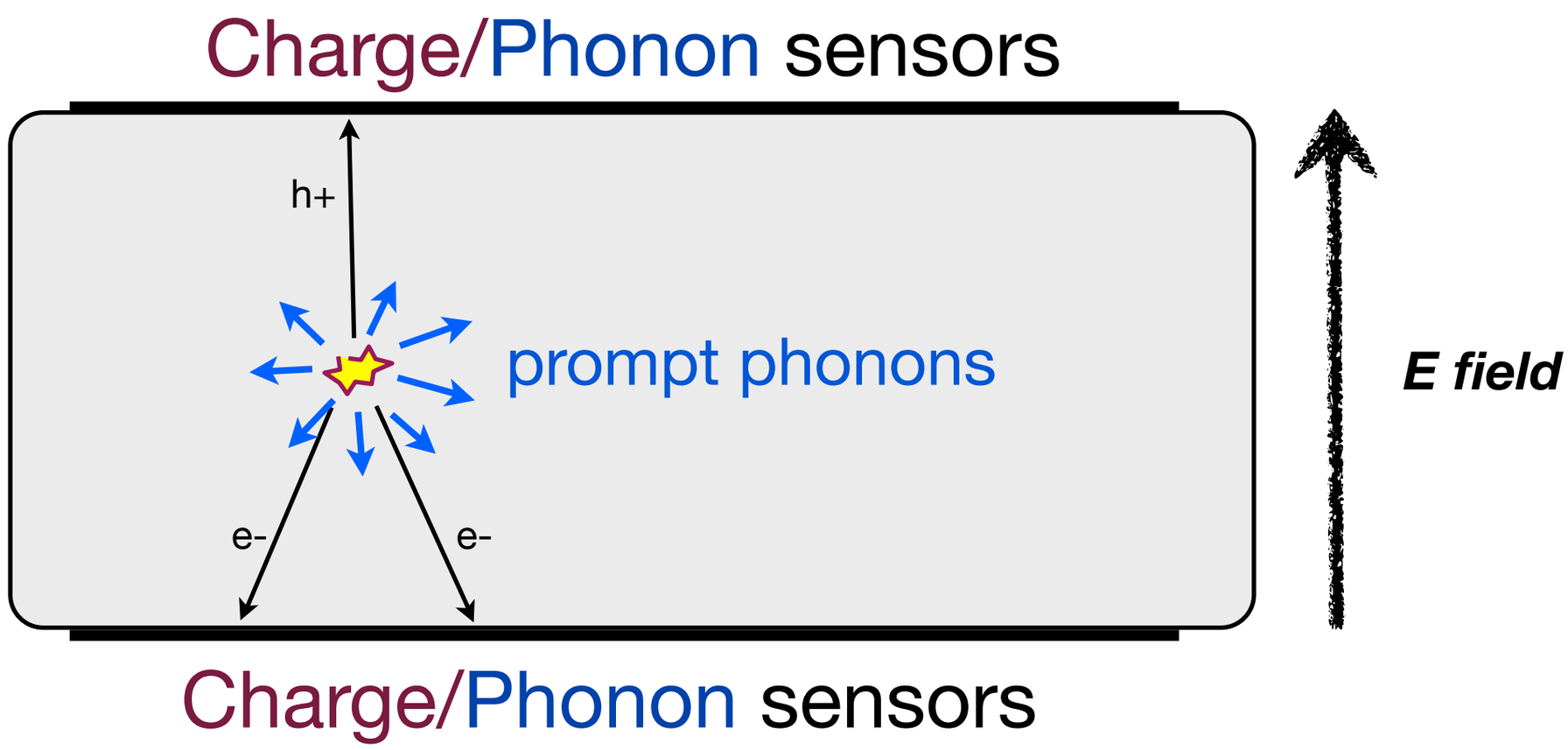

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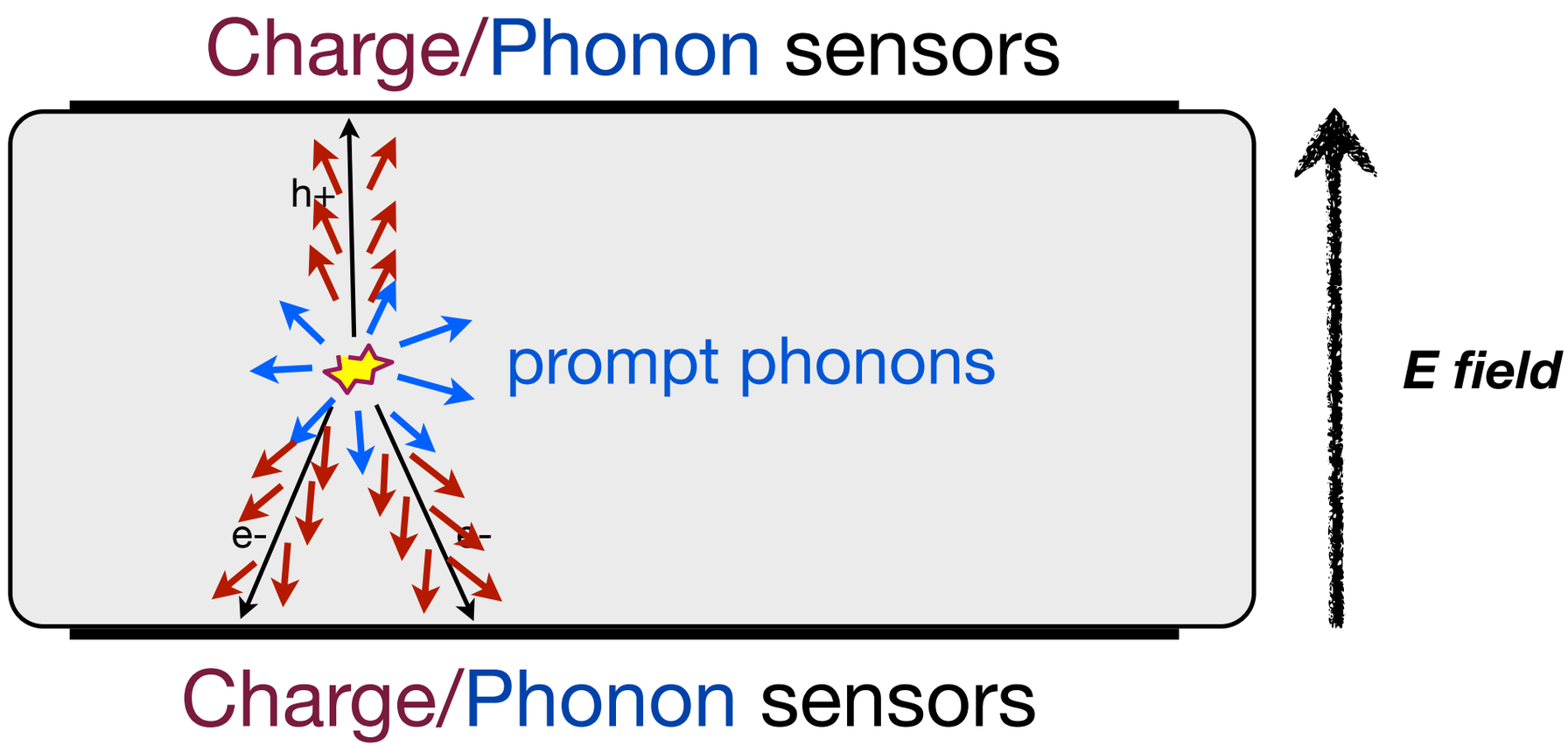
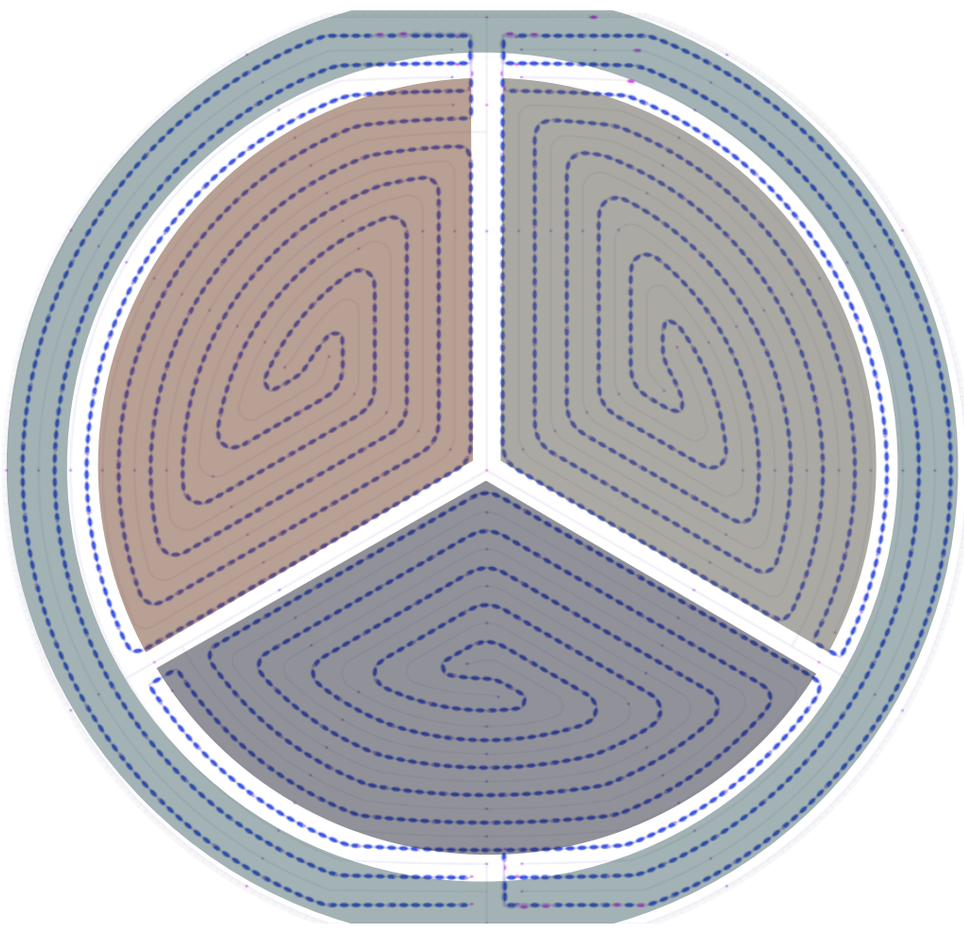


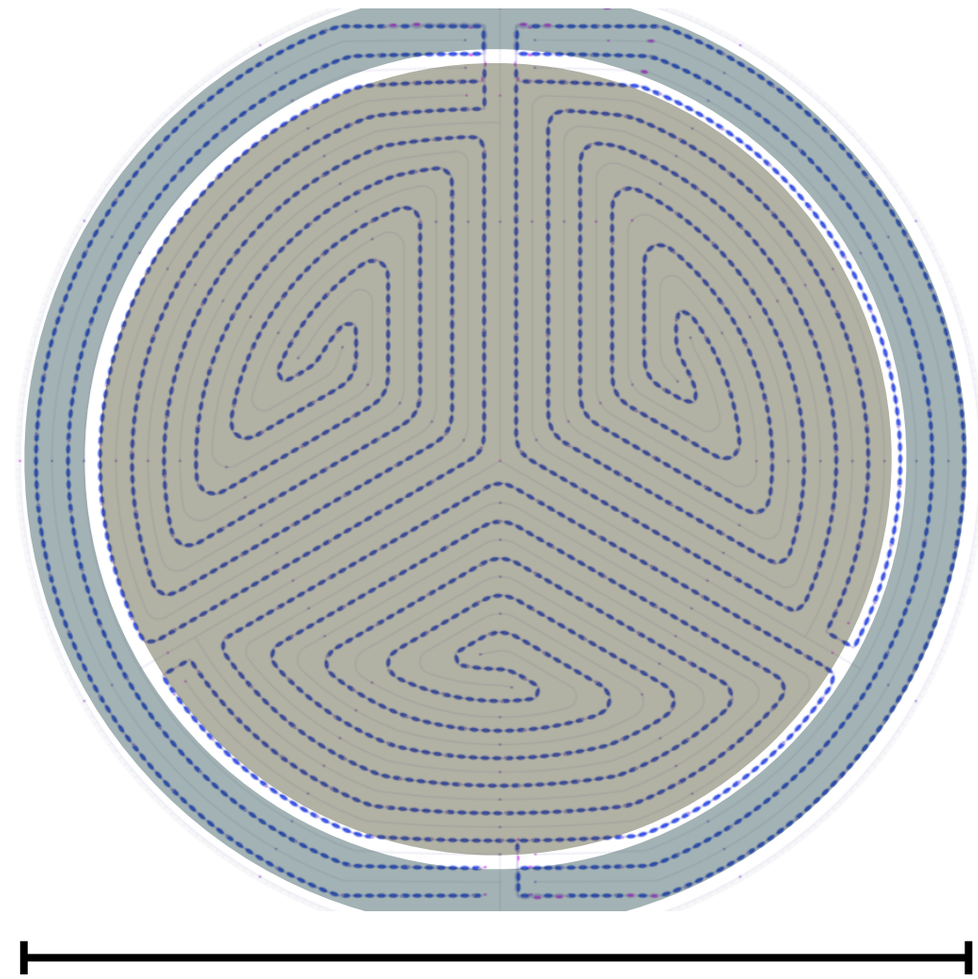
Phonon energy = E_{recoil} + E_{Luke}

Position Sensitivity

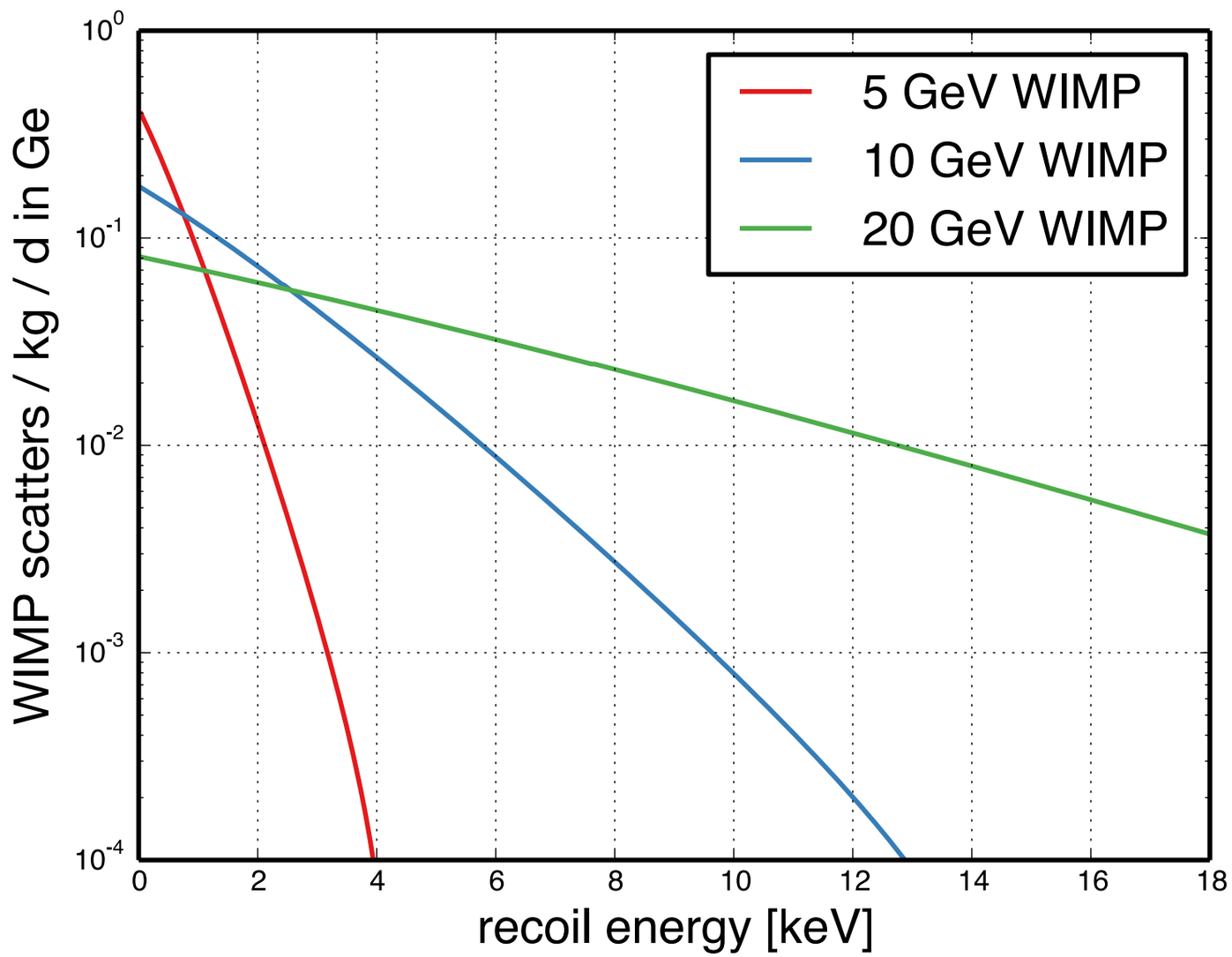
phonon channels



ionization channels

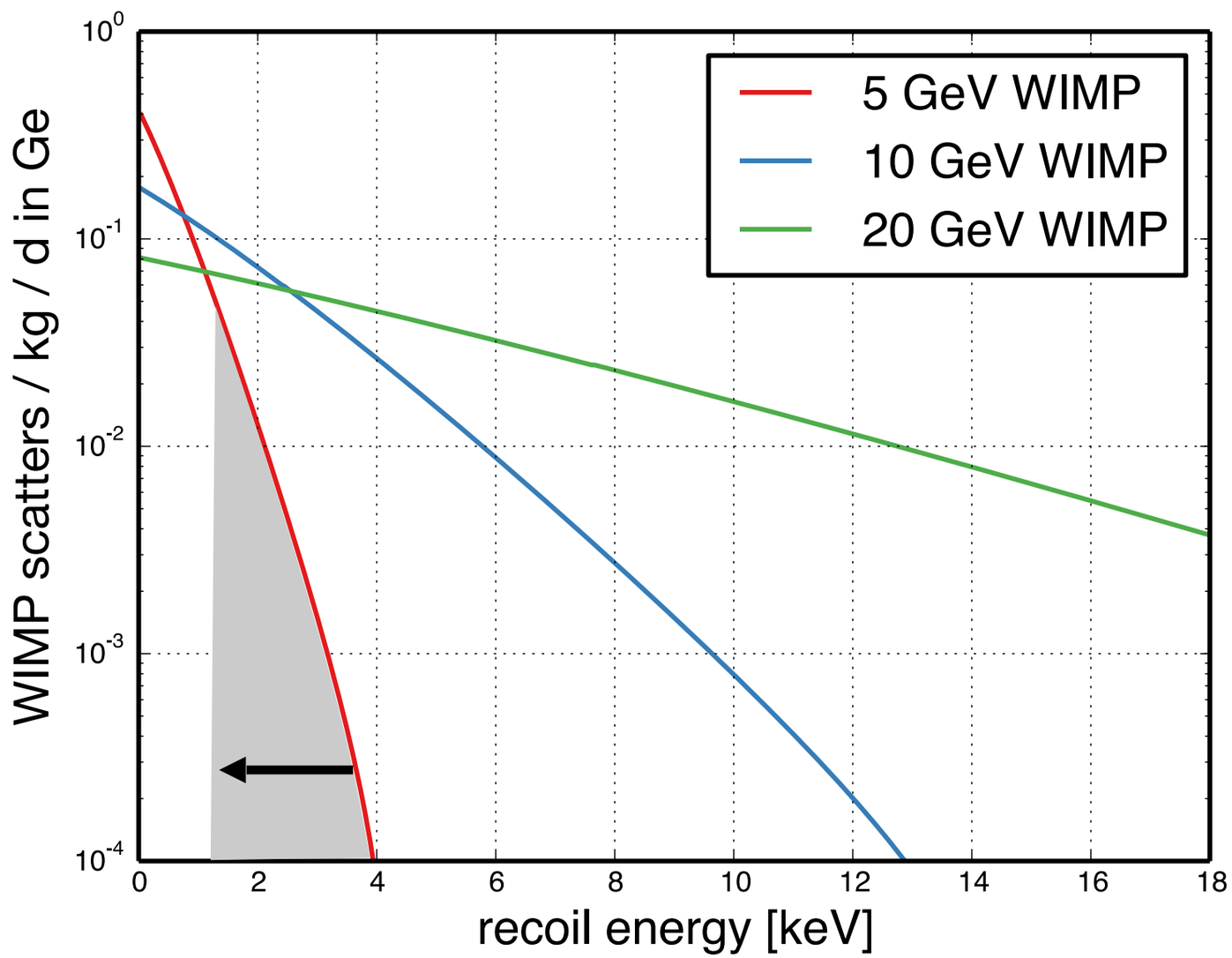


Probing Lighter WIMPs



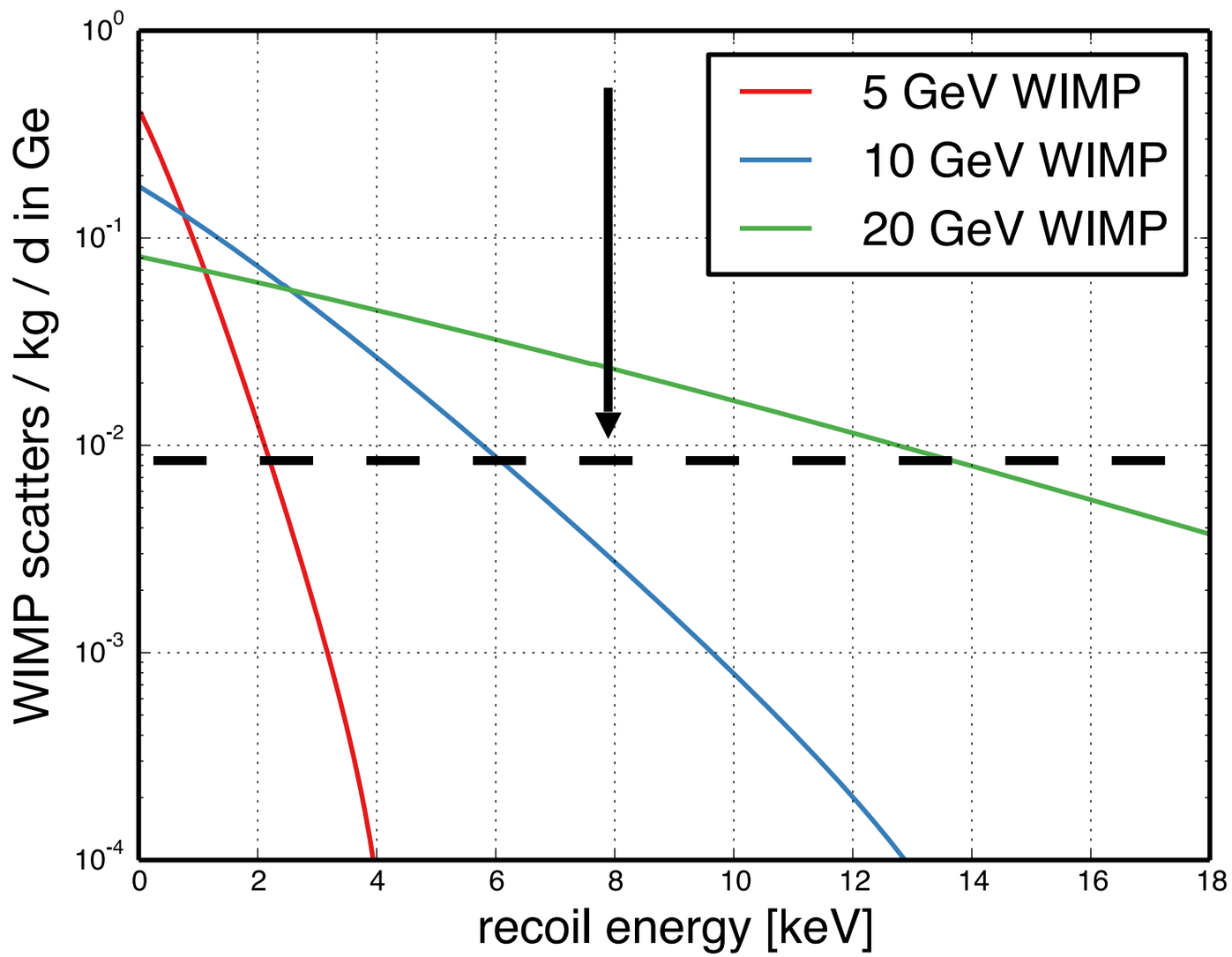
Probing Lighter WIMPs

lower “effective” threshold



Probing Lighter WIMPs

reduce “effective” background

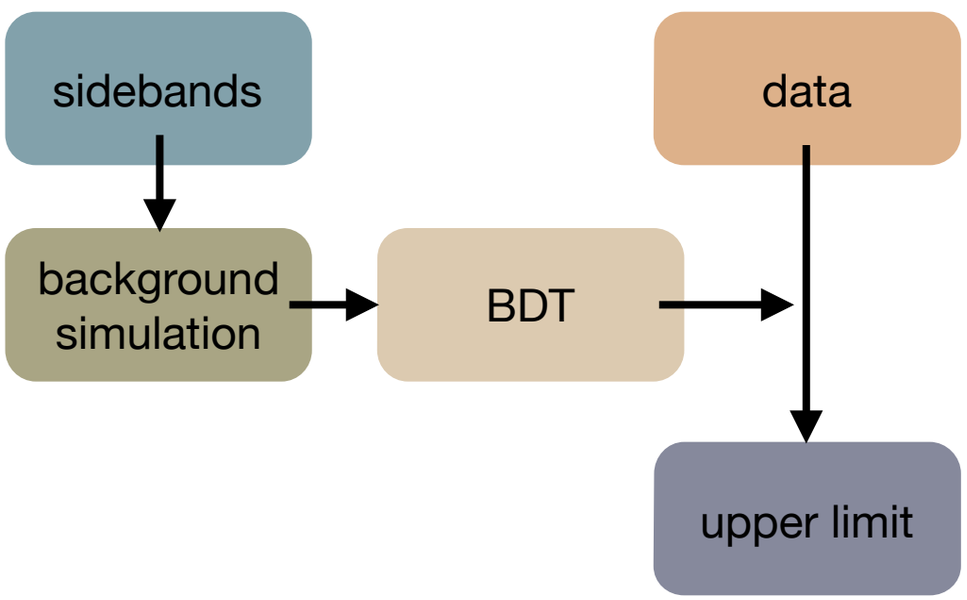


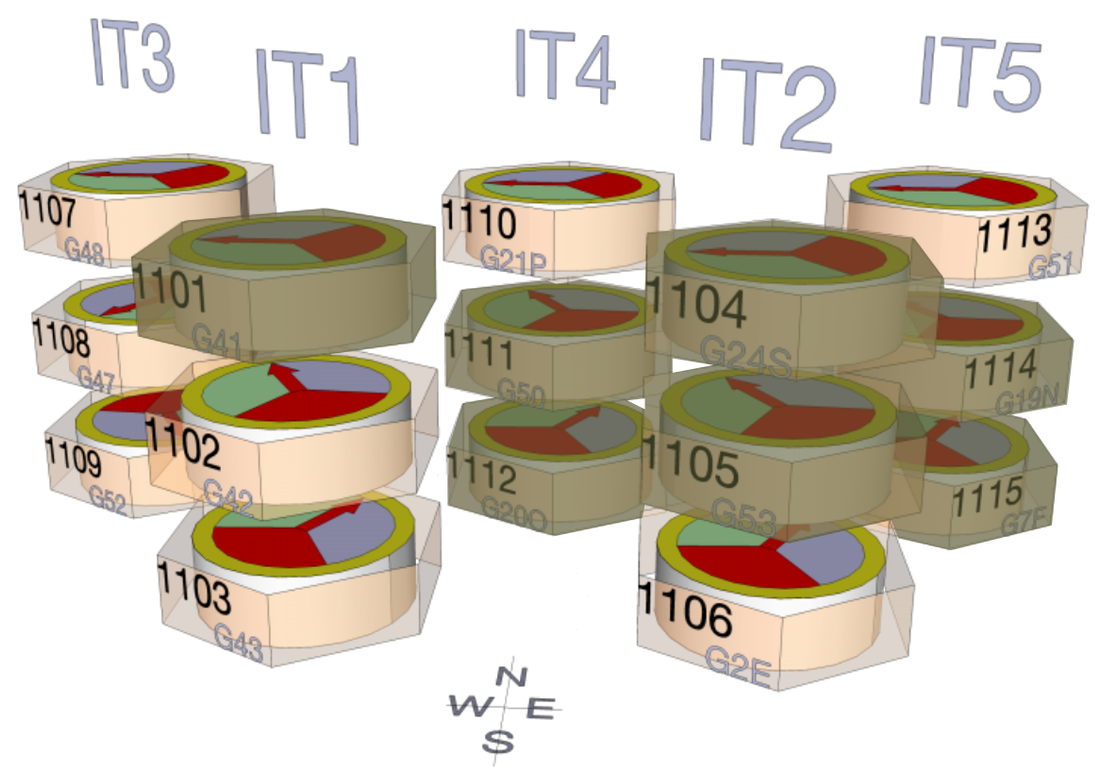
Two Approaches

1.) Improve exposure and background ID:
Low-energy analysis of SuperCDMS data

Low-energy Analysis

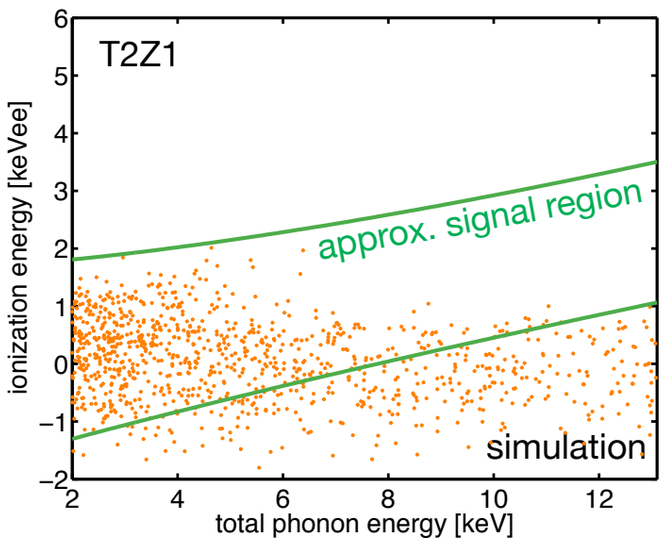
- Use 7 detectors with lowest trigger thresholds (~1.6 keV - 5 keV)
- 577 kg-d of exposure (Oct. 2012 - July 2013)
- **Background discrimination still possible near threshold!!**
- **Blind** analysis optimized for exclusion



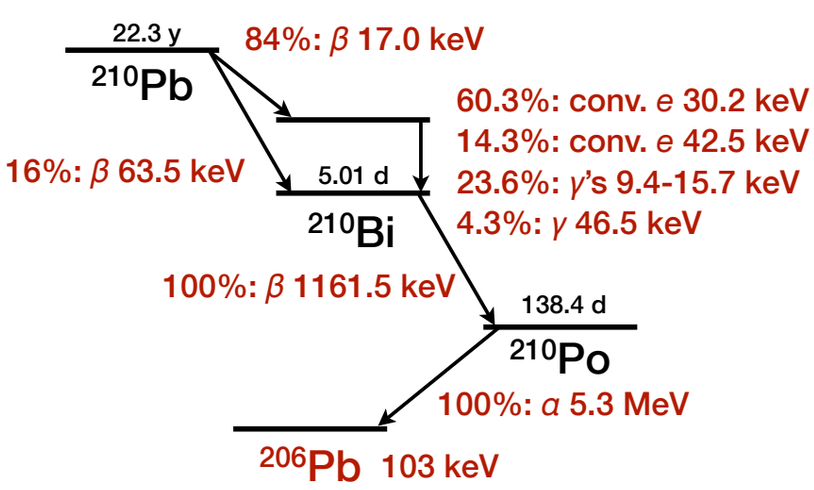


Dominant Backgrounds at Low Energy

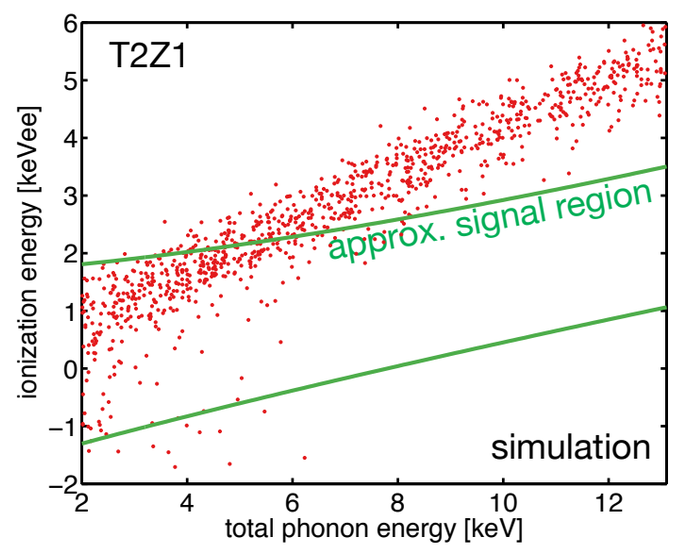
^{210}Pb "surface events"



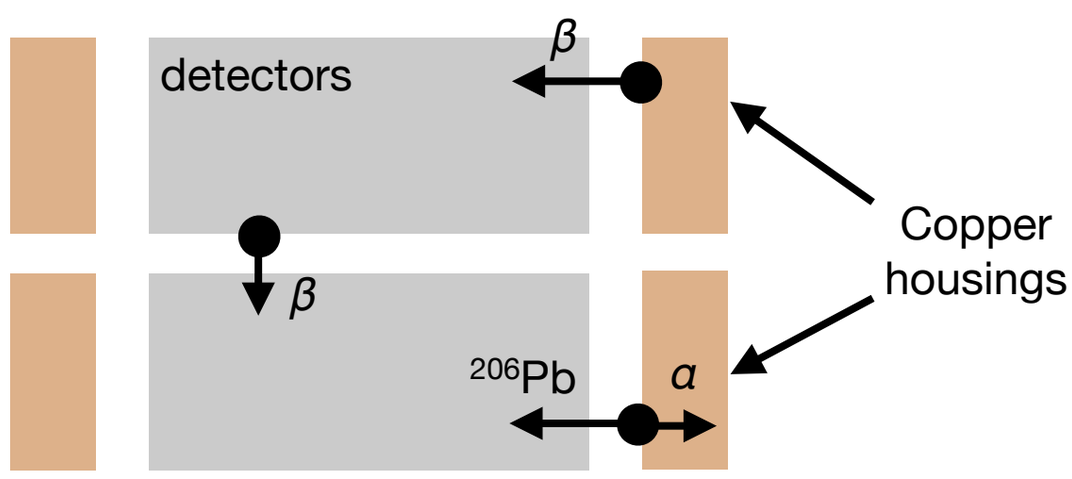
- betas and ^{206}Pb nuclei from ^{210}Pb decay chain
- events are located on detector face and sidewall ***surfaces*** from ^{222}Rn contamination



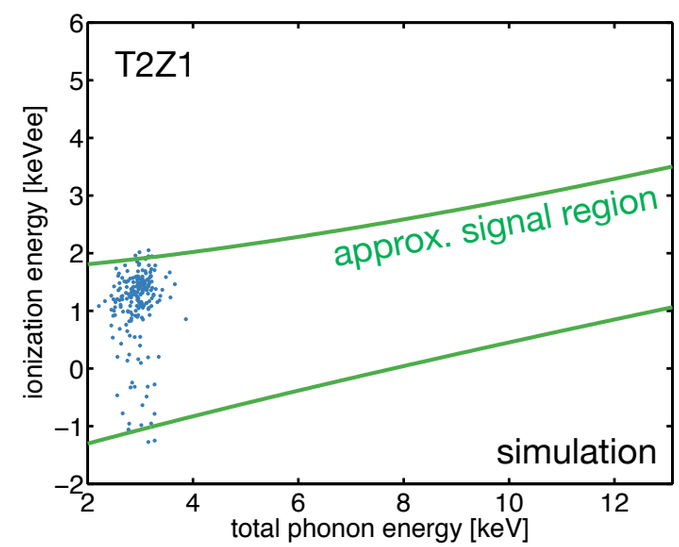
External gammas



- from radioactivity in shielding and cryostat



Internal activation lines



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

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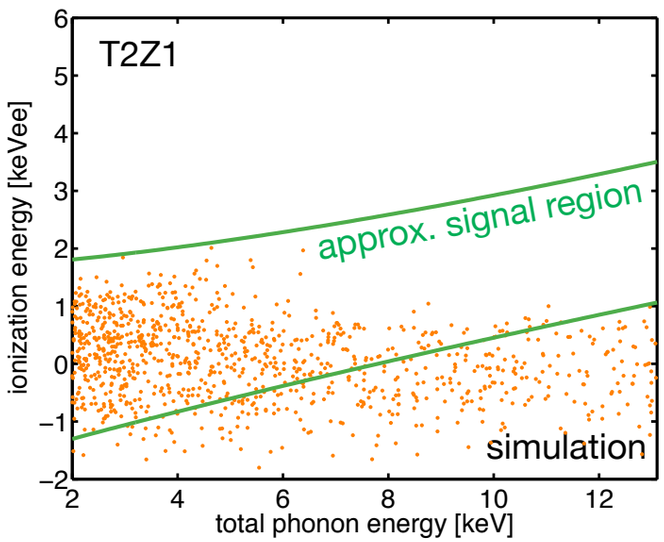

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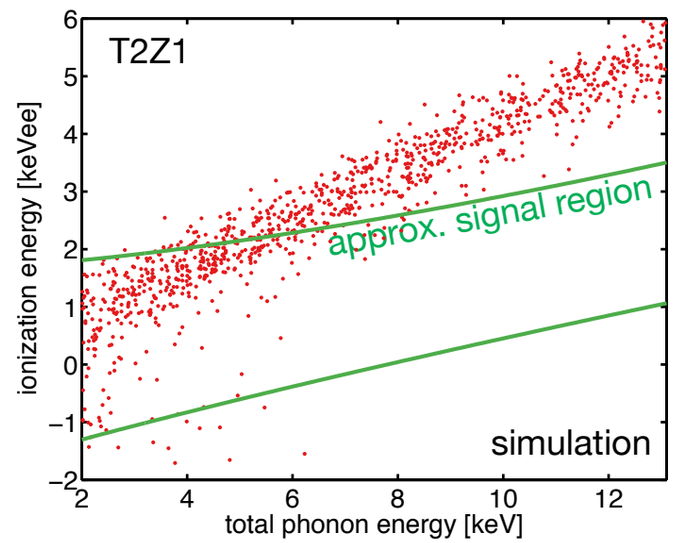

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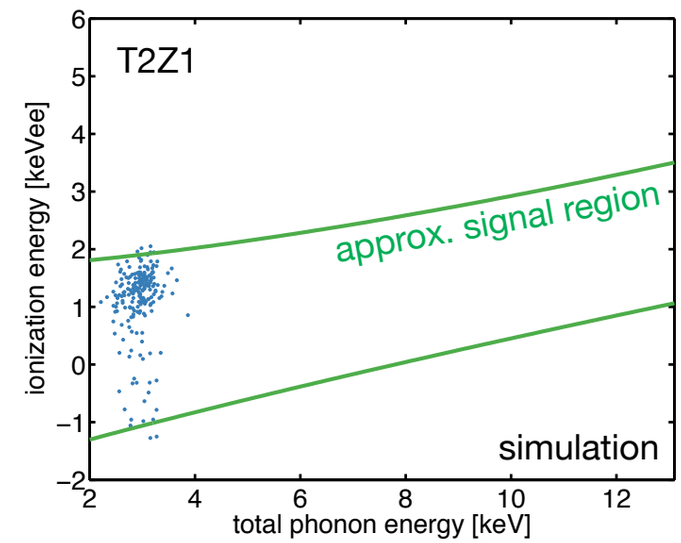

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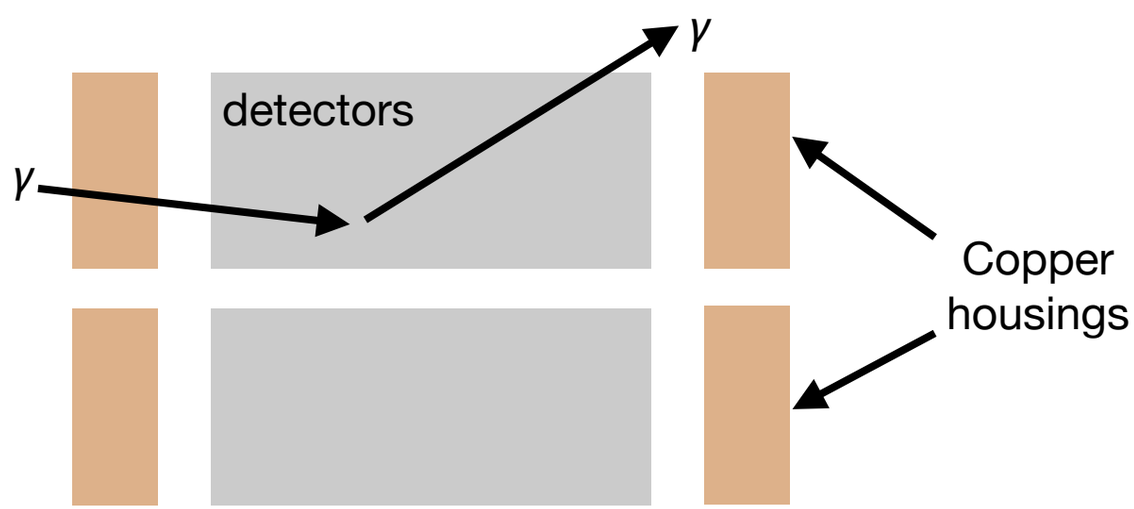

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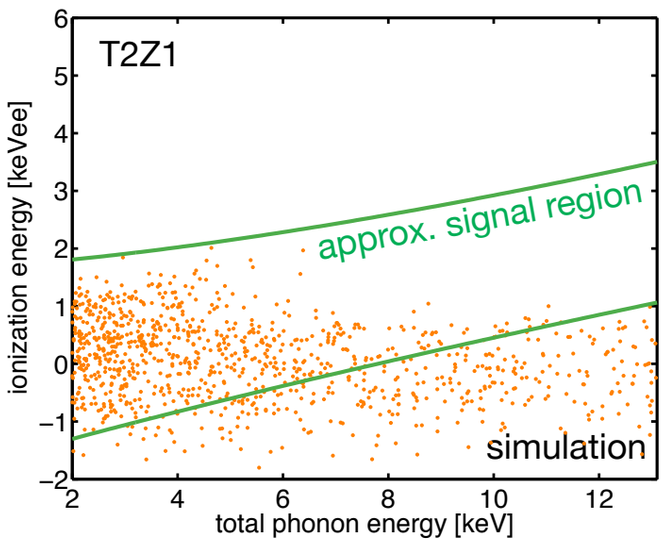

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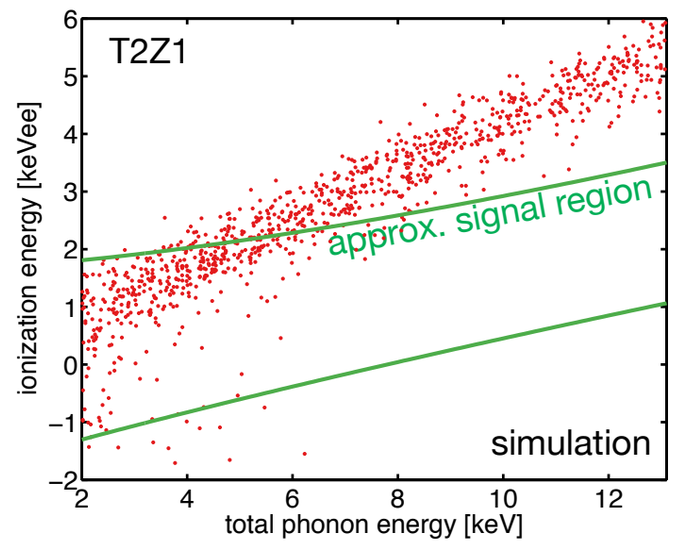

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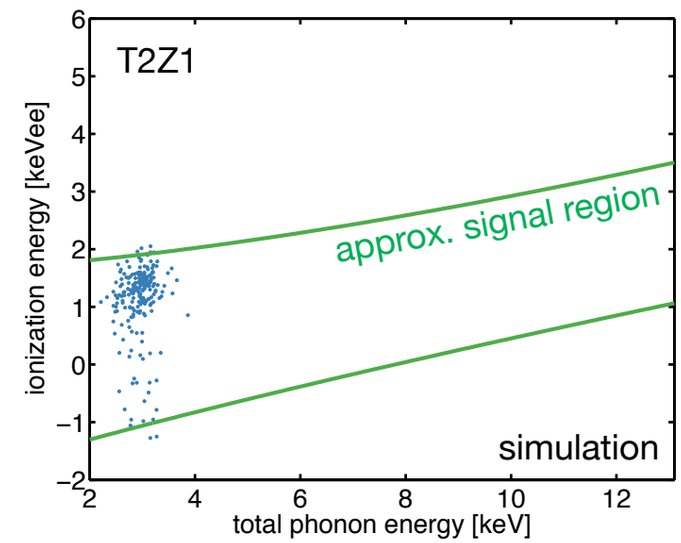

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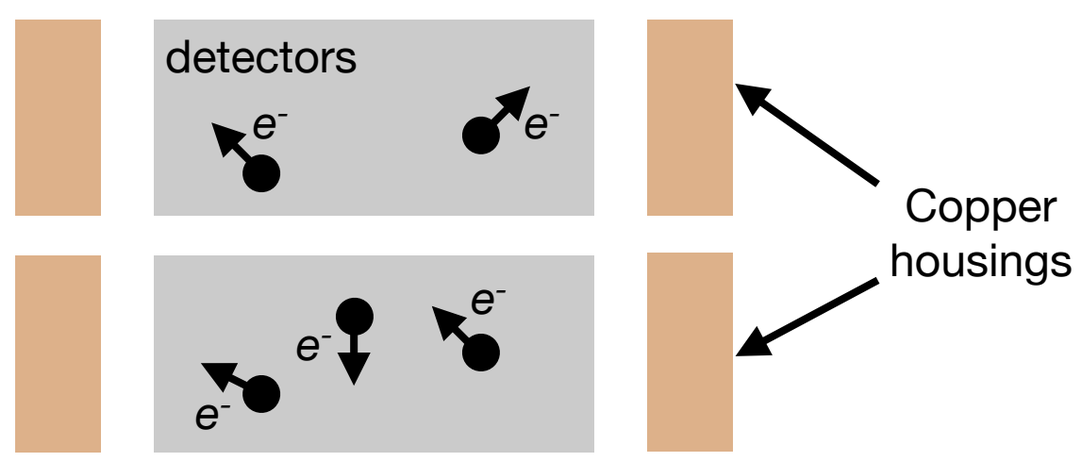
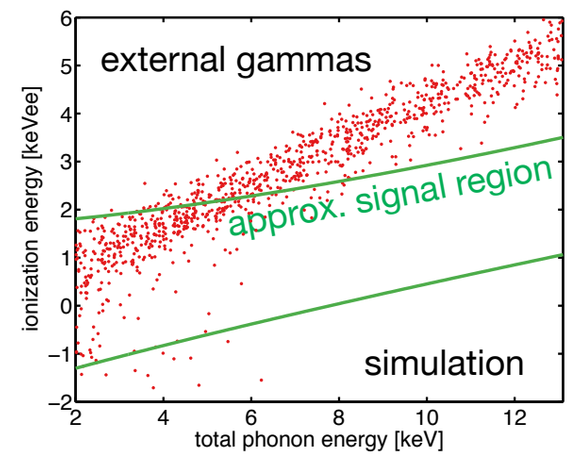


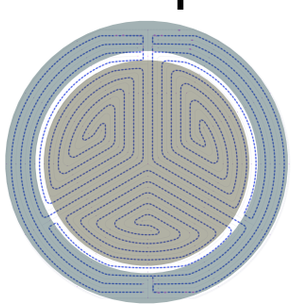
Discriminators

ionization yield
+
total phonon energy

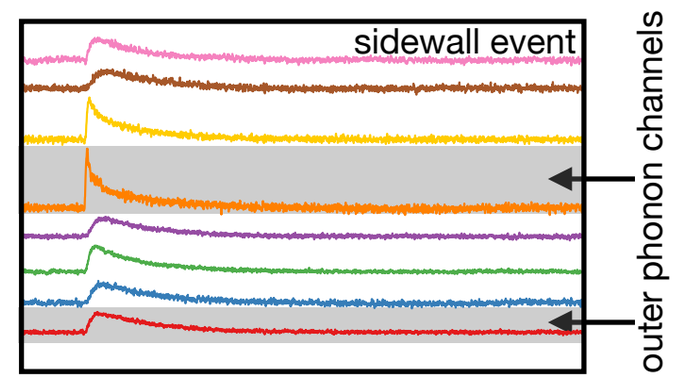
Bulk electron recoils



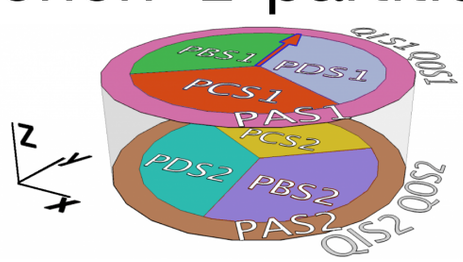
phonon "*r*-partition"



Low energy
sidewall events



phonon "*z*-partition"



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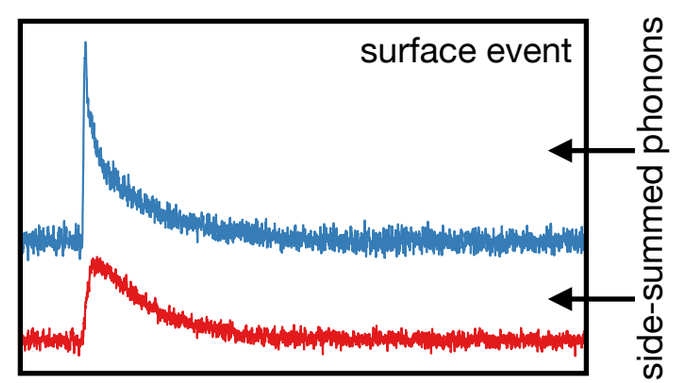
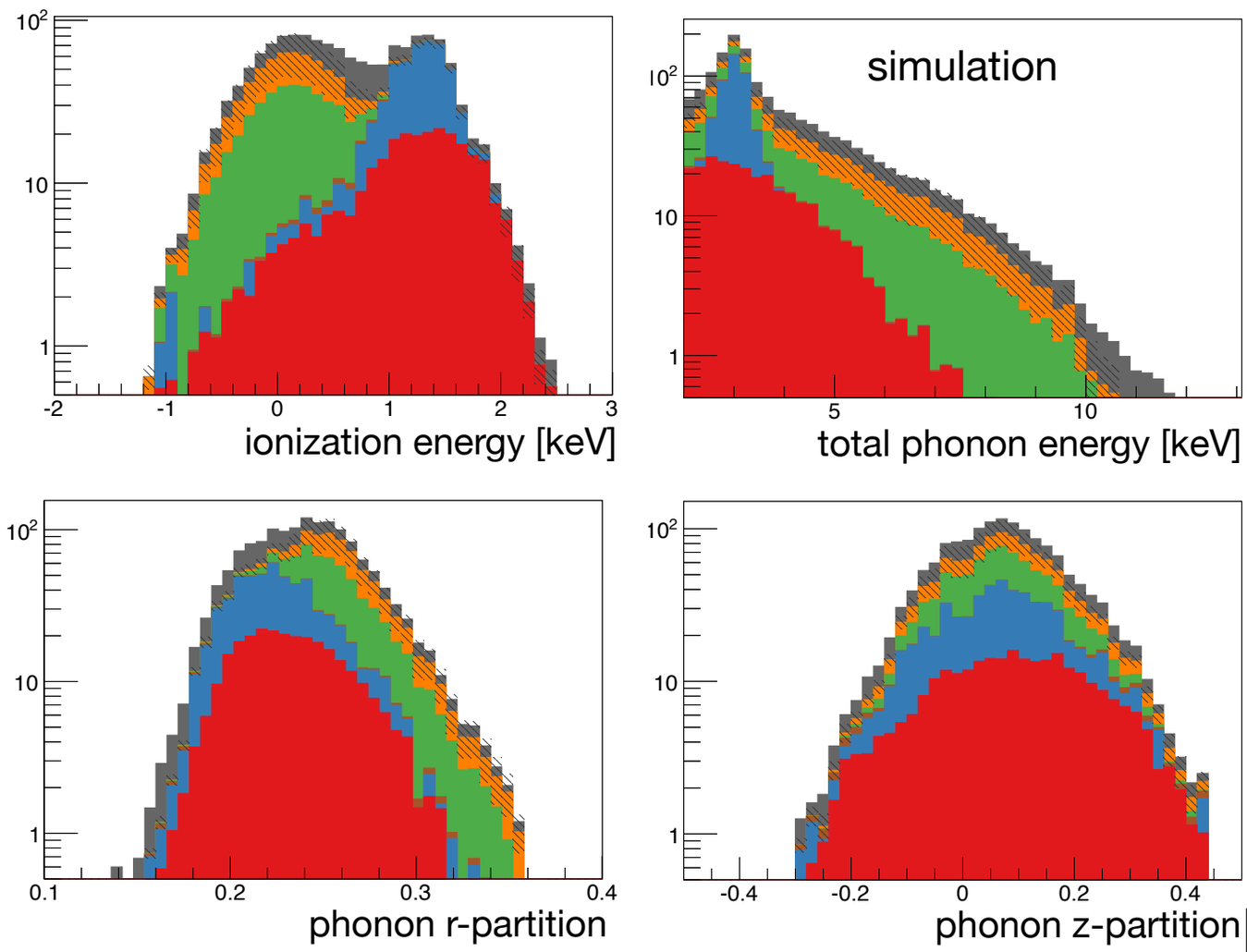


Boosted Decision Tree

BDT inputs



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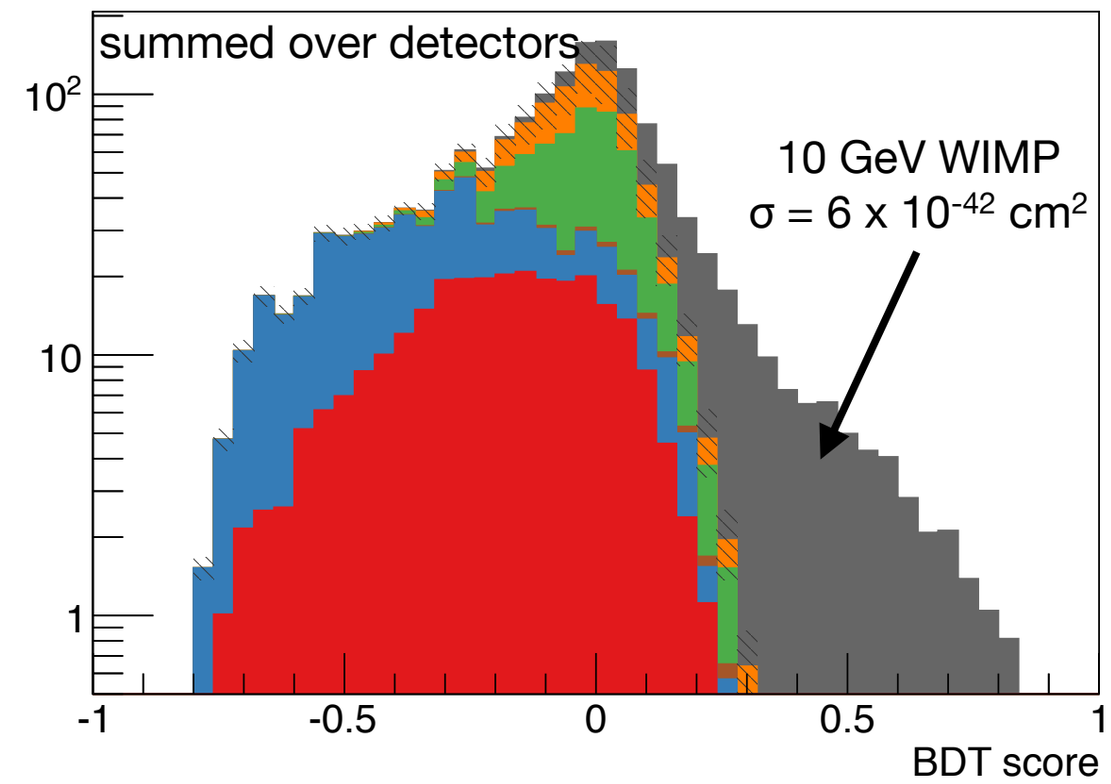

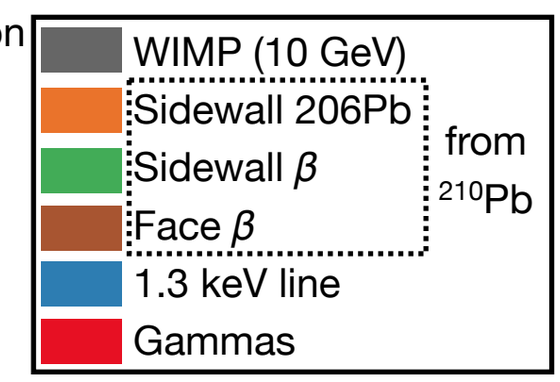

Construction: 1 BDT per detector
Optimization: set cuts simultaneously to minimize expected 90% CL upper limit on WIMP-nucleon cross section

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

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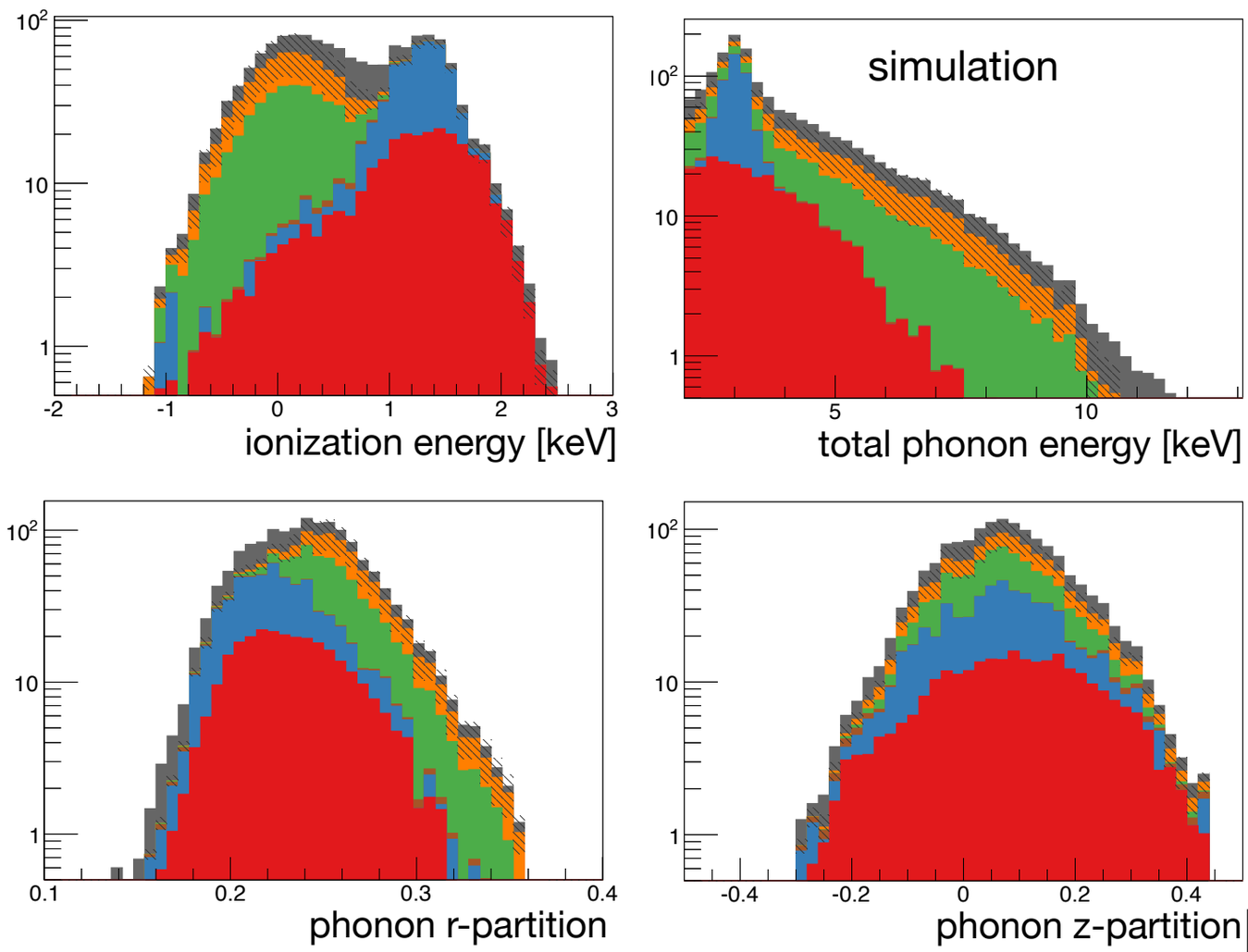

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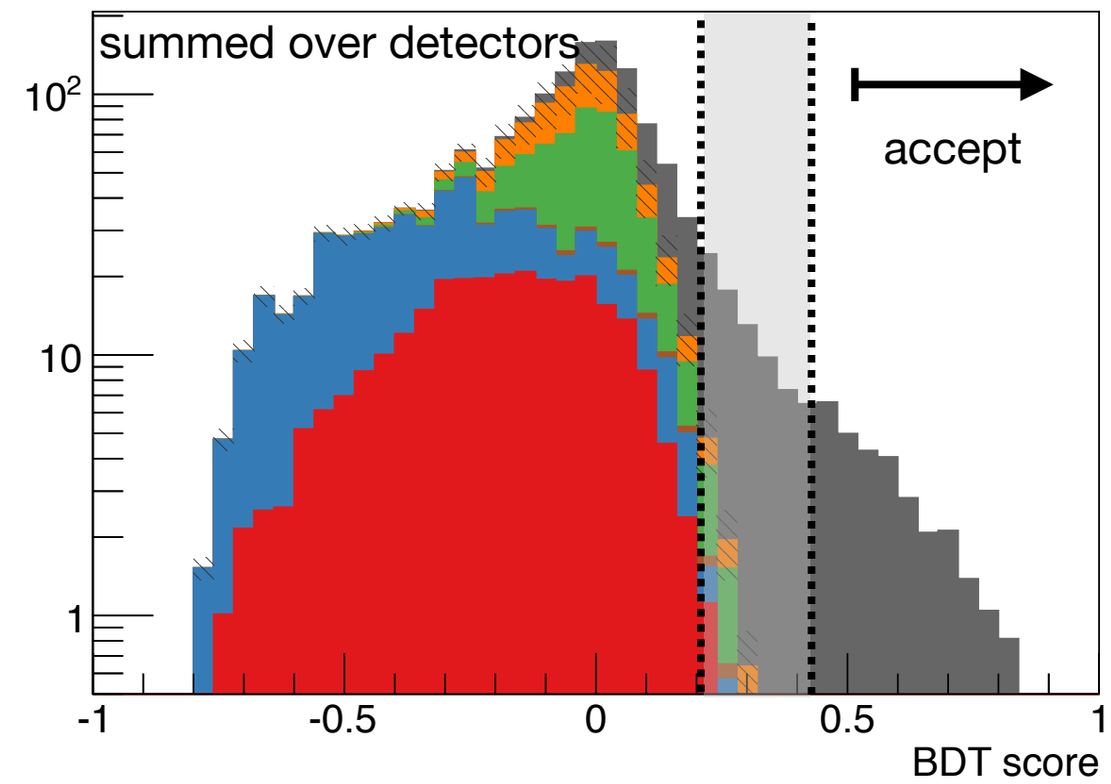

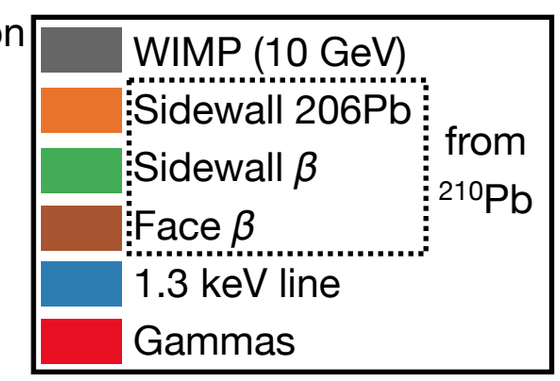

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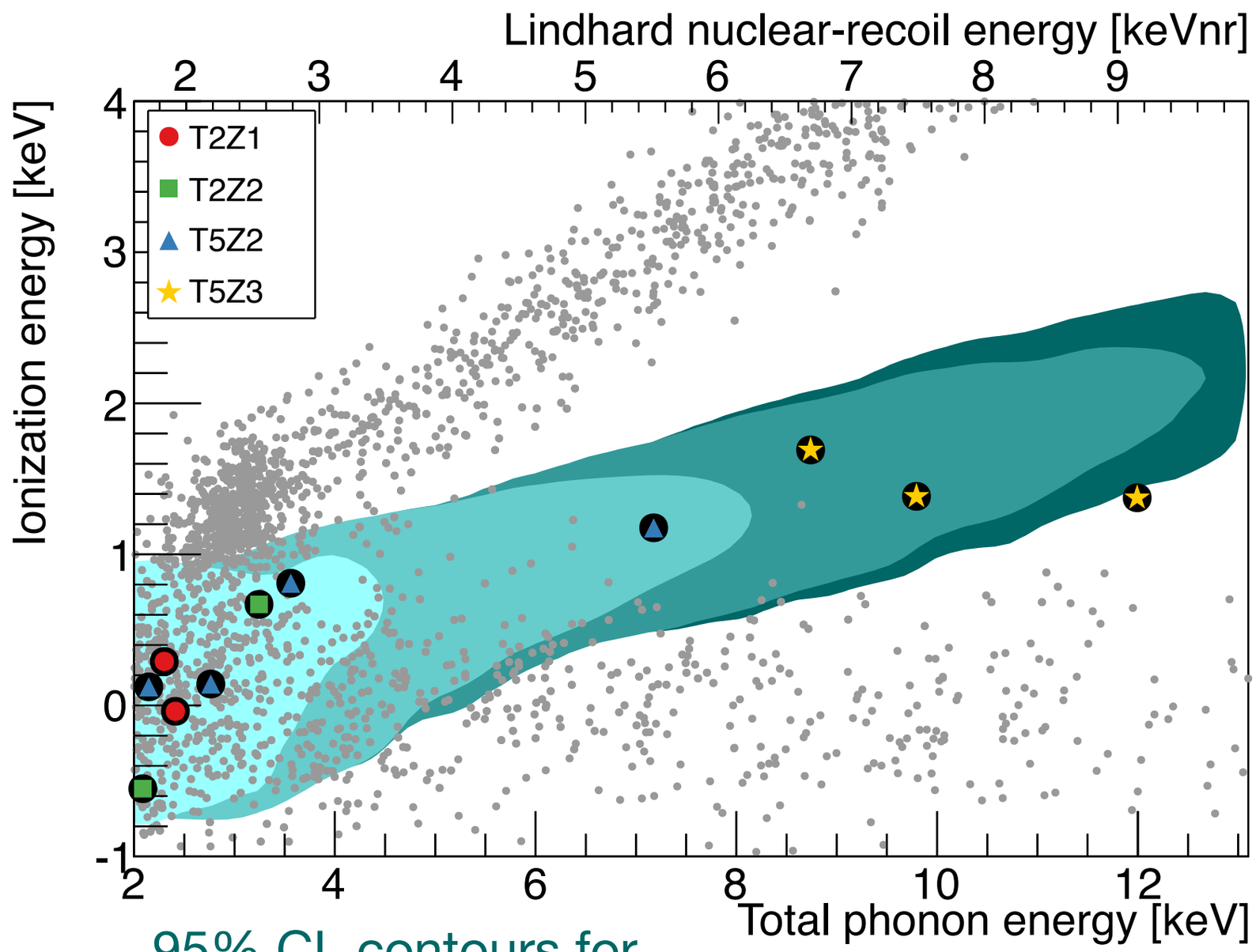
Unblinding: After BDT

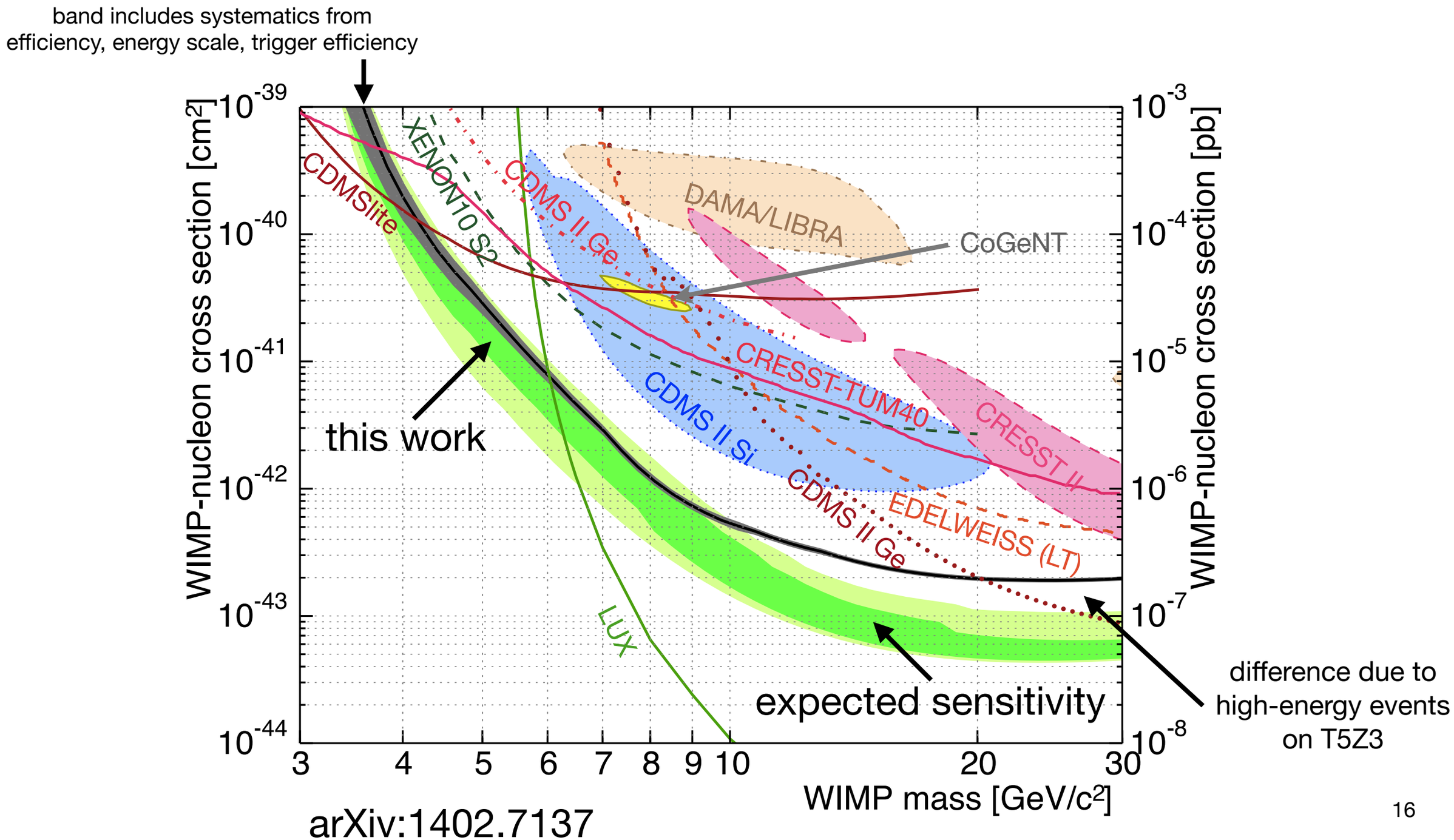
11 events observed passing BDT (expected $6.2^{+1.1}_{-0.8}$)



95% CL contours for
5, 7, 10, 15 GeV WIMP

Limit

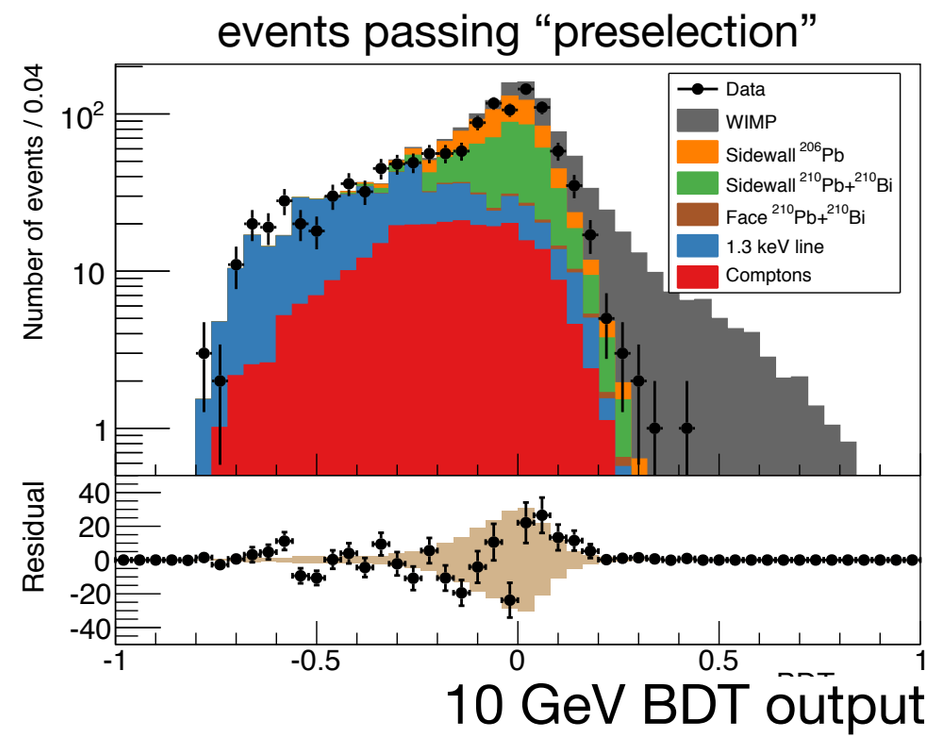
set 90% CL upper limit with optimal interval method (no background subtraction)

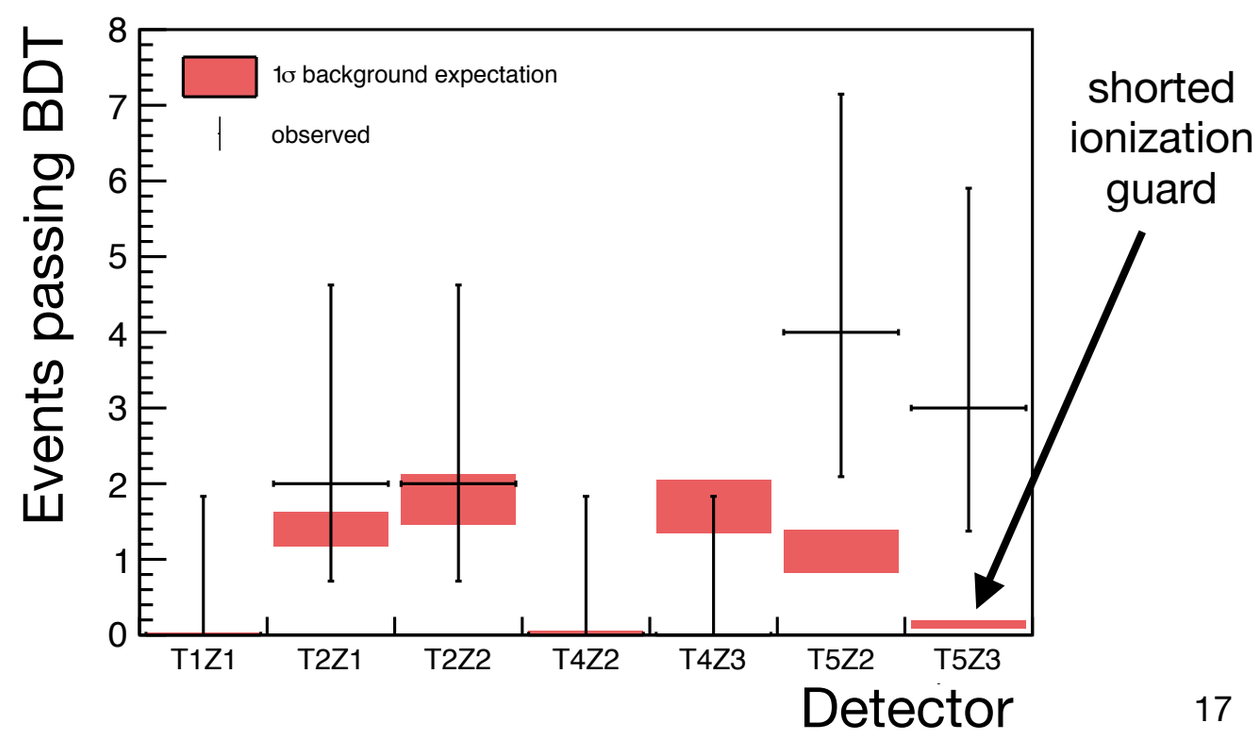


arXiv:1402.7137

Post-Unblinding Follow Up

- Background model **accurate in full preselection region**
- Shorted ionization guard on T5Z3 may have affected background model performance (p-value is 0.04%)
- Now calibrating detector response to sidewall events with sidewall ^{210}Pb source





Two Approaches

1.) Improve exposure and background ID: **Low-energy analysis of SuperCDMS data**

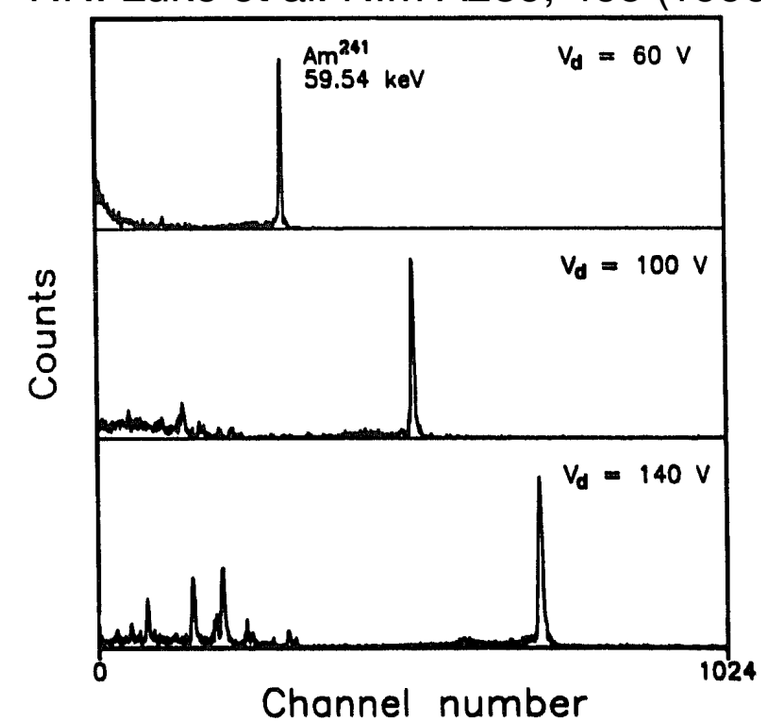
2.) Lower energy threshold: **CDMSlite**

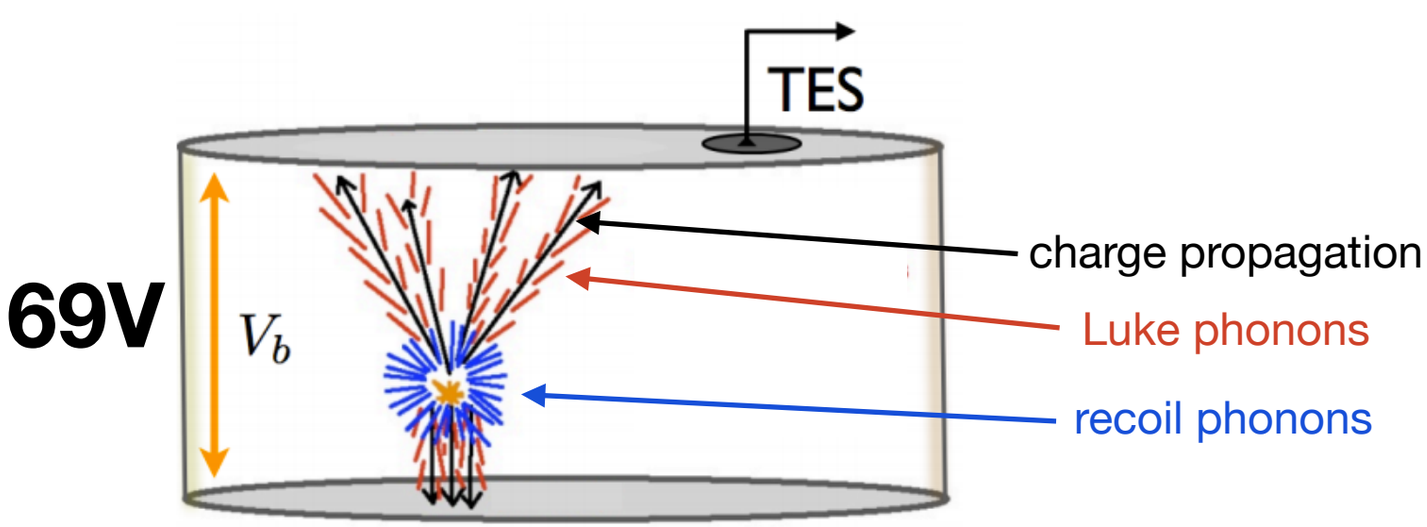
CDMSlite: “low ionization threshold experiment”

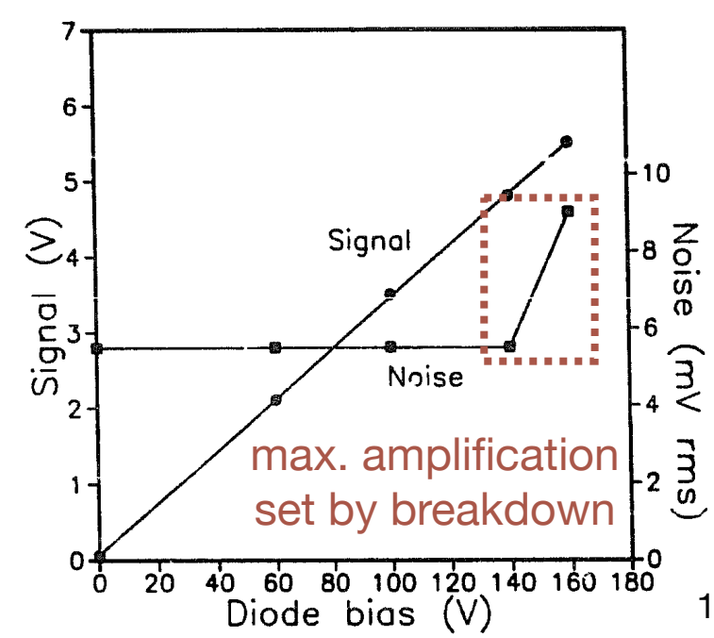
$$E_{total} = E_{recoil} + E_{luke}$$
$$= E_{recoil} + \frac{1}{3\ eV} E_Q \Delta V$$

- Measure charge with phonons, and increase voltage to amplify signal
- Lose background discrimination, but achieve lower ionization energy threshold

P.N. Luke et al. NIM A289, 405 (1990)

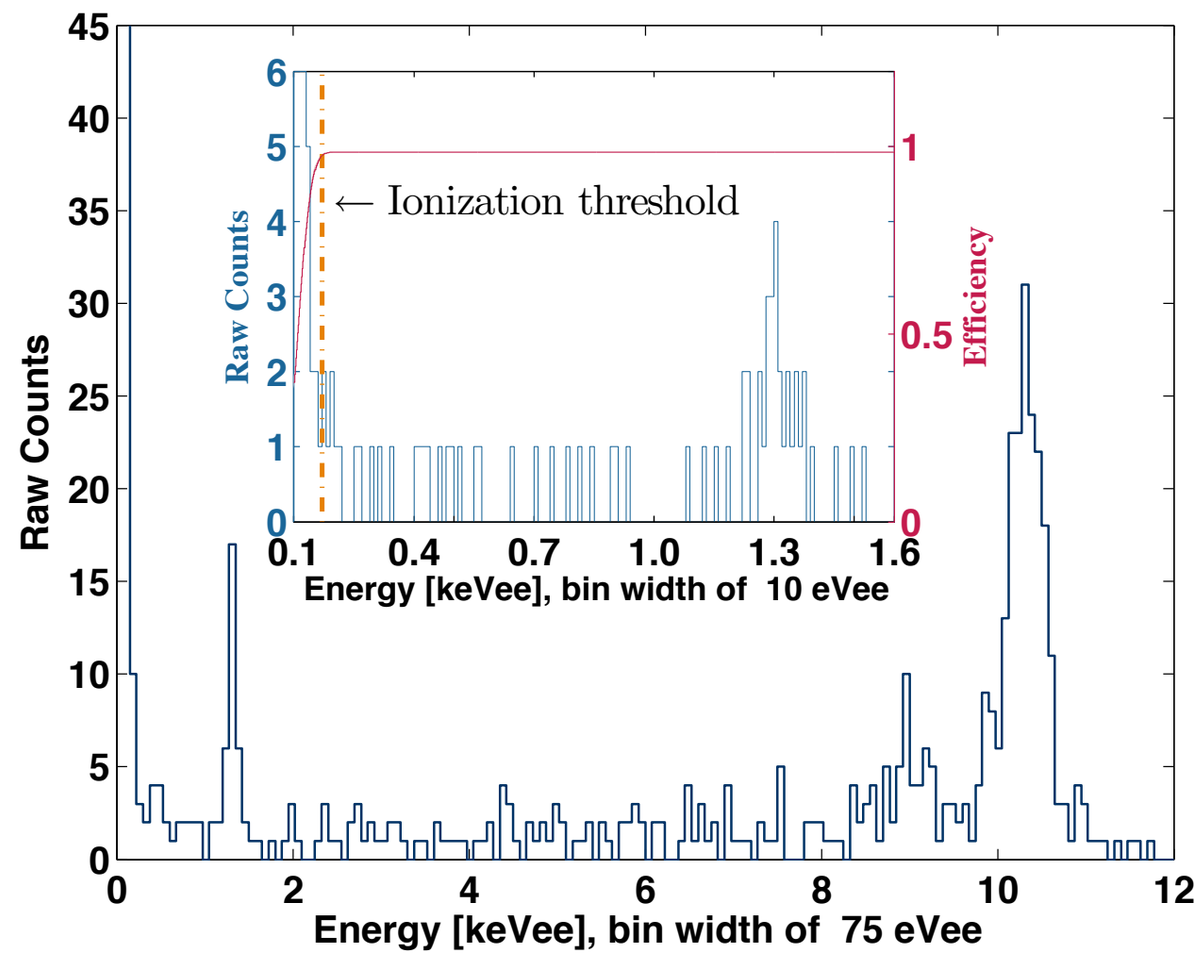




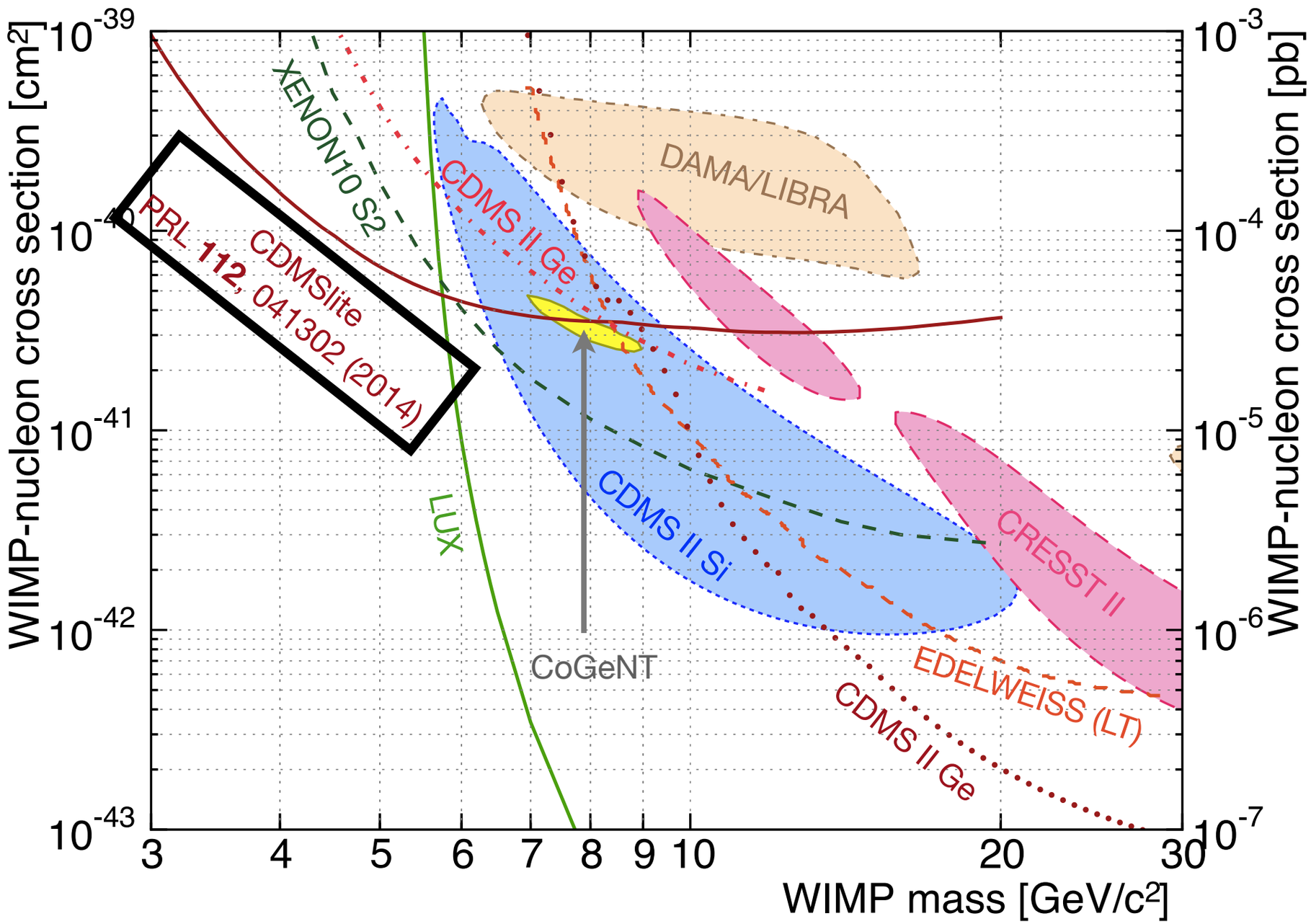


CDMSlite: Run 1

- Acquired 6 kg-d of exposure on detector with best combination of breakdown voltage and threshold
- Ionization energy calibration with EC lines at 1.3 keVee and 10.4 keVee
- Operated stably at 69V or **24x** amplification (only 12x due to electronics limitations)
- 860 eVnr => 170 eVee threshold
- **Must assume NR energy scale**



CDMSlite: Run 1 Results



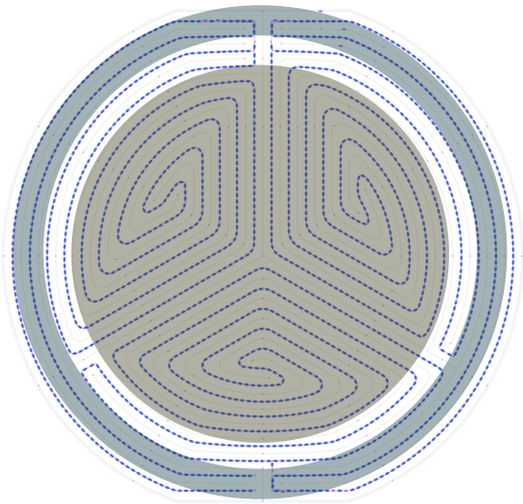
CDMSlite: Run 2 Outlook

	Run 2	Run 1
raw exposure	4 months	15 days
baseline noise	8.3 eVee	13.3 eVee
resolution @ 1.3 eVee	30 eVee	50 eVee
threshold	80 eVee (preliminary)	170 eVee
background discrimination	reject sidewall surface events	none

Backgrounds for low-threshold analysis also affect CDMSlite

↓

CDMSlite can also use radial phonon info to reject backgrounds!



Conclusion

- Limits from low-energy analysis and CDMSlite significantly constrain low-mass anomalies
- First science results from SuperCDMS iZIP detectors
- Major improvements to CDMSlite performance and analysis will significantly improve future sensitivity
- Better simulations and sidewall event calibration will improve understanding of systematics at low energies
- 2.5 years of data from SuperCDMS at Soudan: more limits soon!

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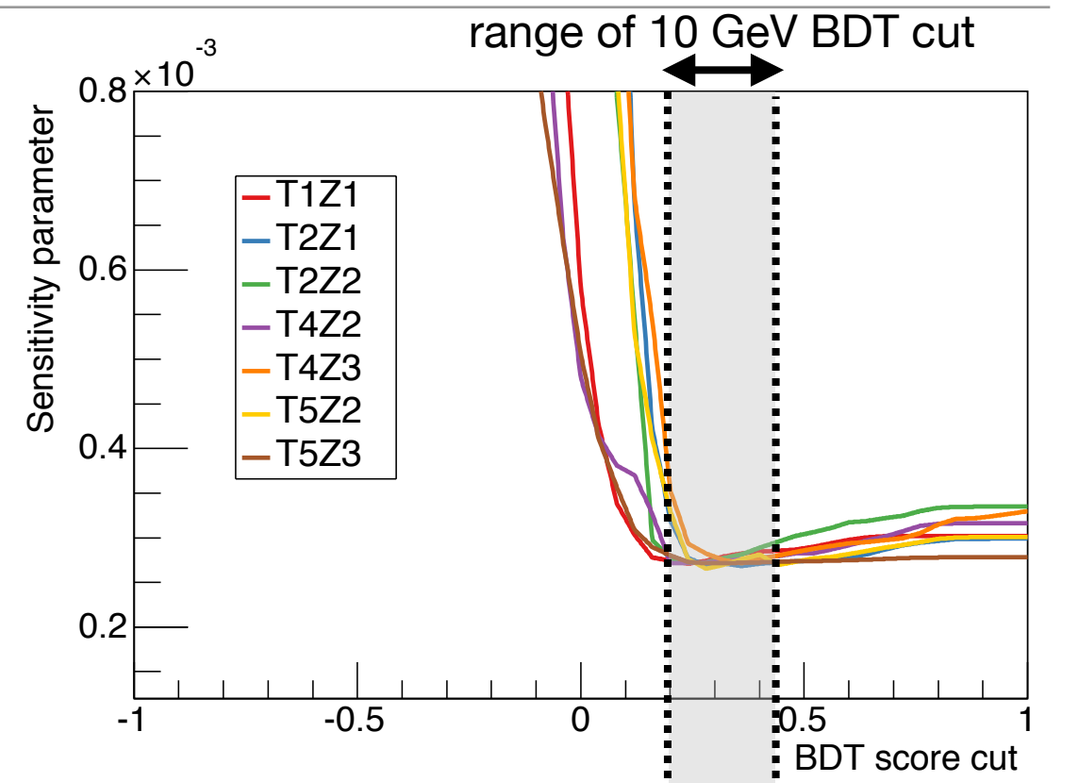
J. Sander

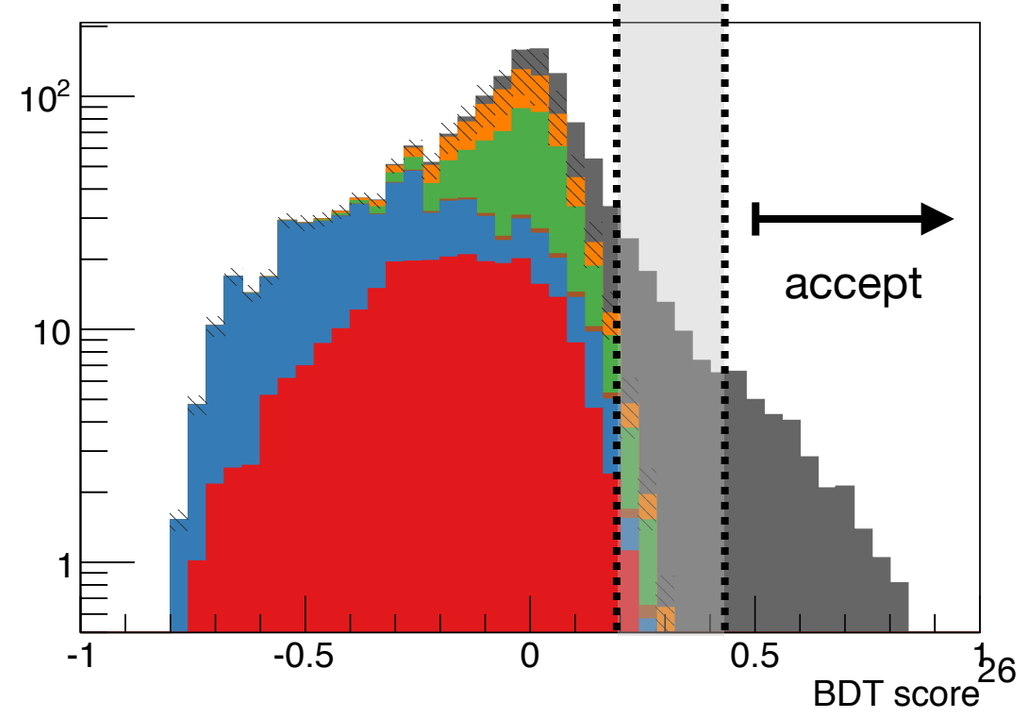
*Emeritus Professor at U.C. Santa Barbara

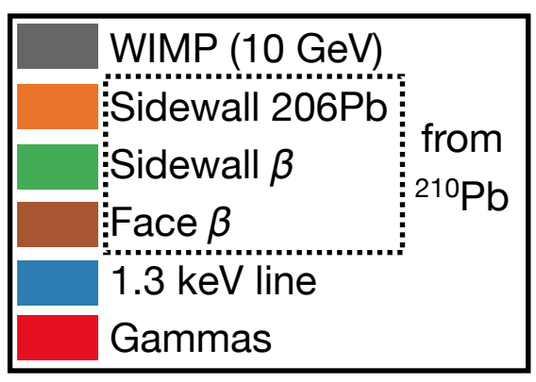
Backup

Cut Optimization

- 1 BDT classifier per detector
- Each detector has a BDT cut that has to be optimized
- Set detector BDT cuts simultaneously to minimize expected 90% CL upper limit on WIMP nucleon cross section
- Final cut is the logical OR of all the BDT cuts optimized for WIMPs of 5, 7, 10, and 15 GeV





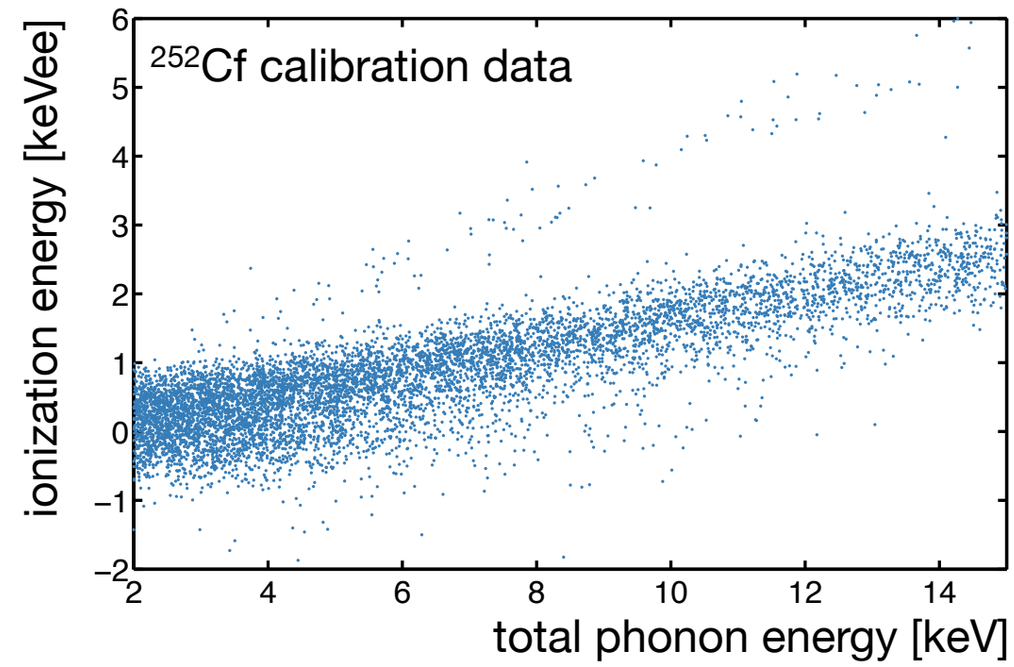


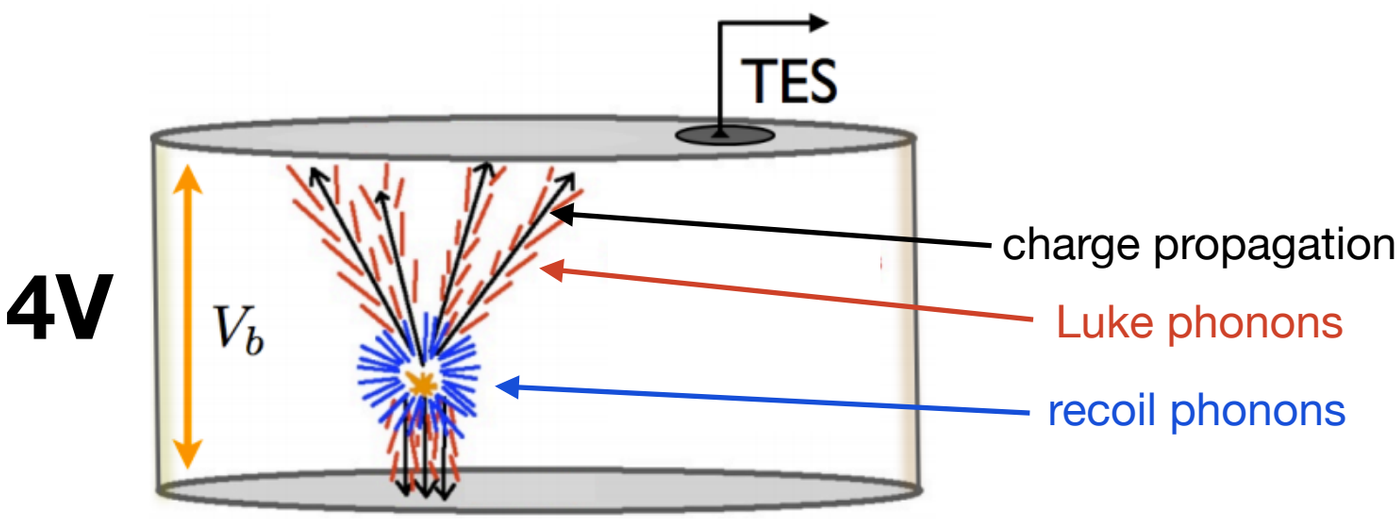
Calibration and Energy Scale

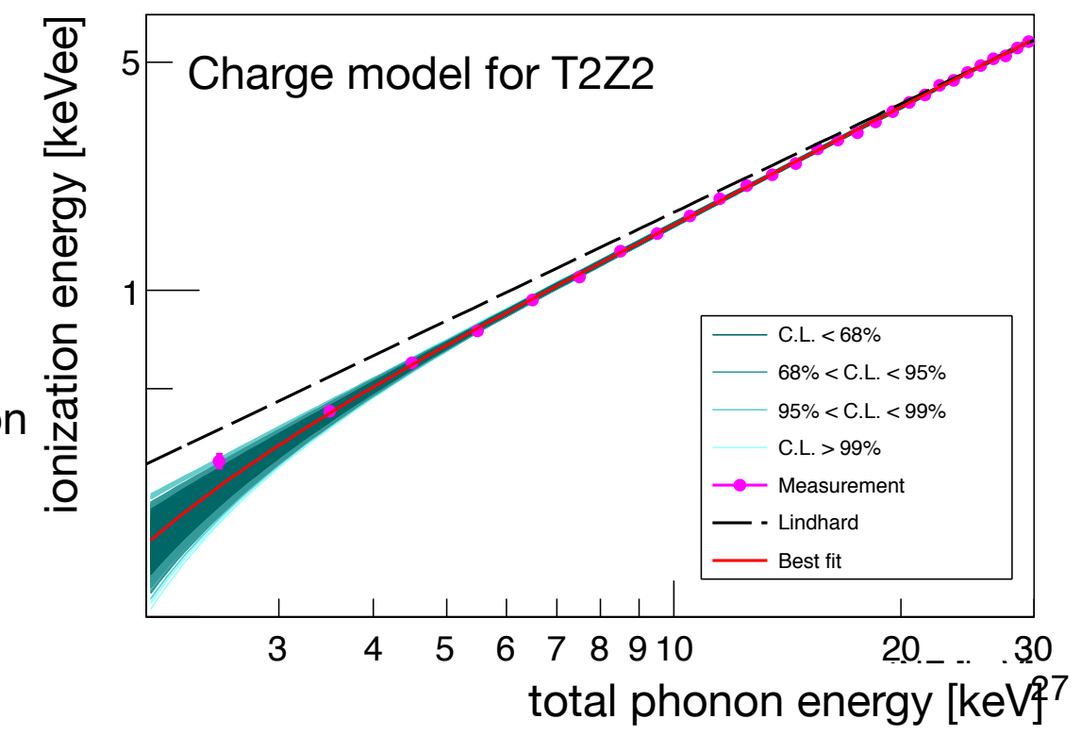
$$E_t = E_r + E_L$$

$$E_r = E_t - \frac{1}{3\,eV} E_Q(E_t)\Delta V$$

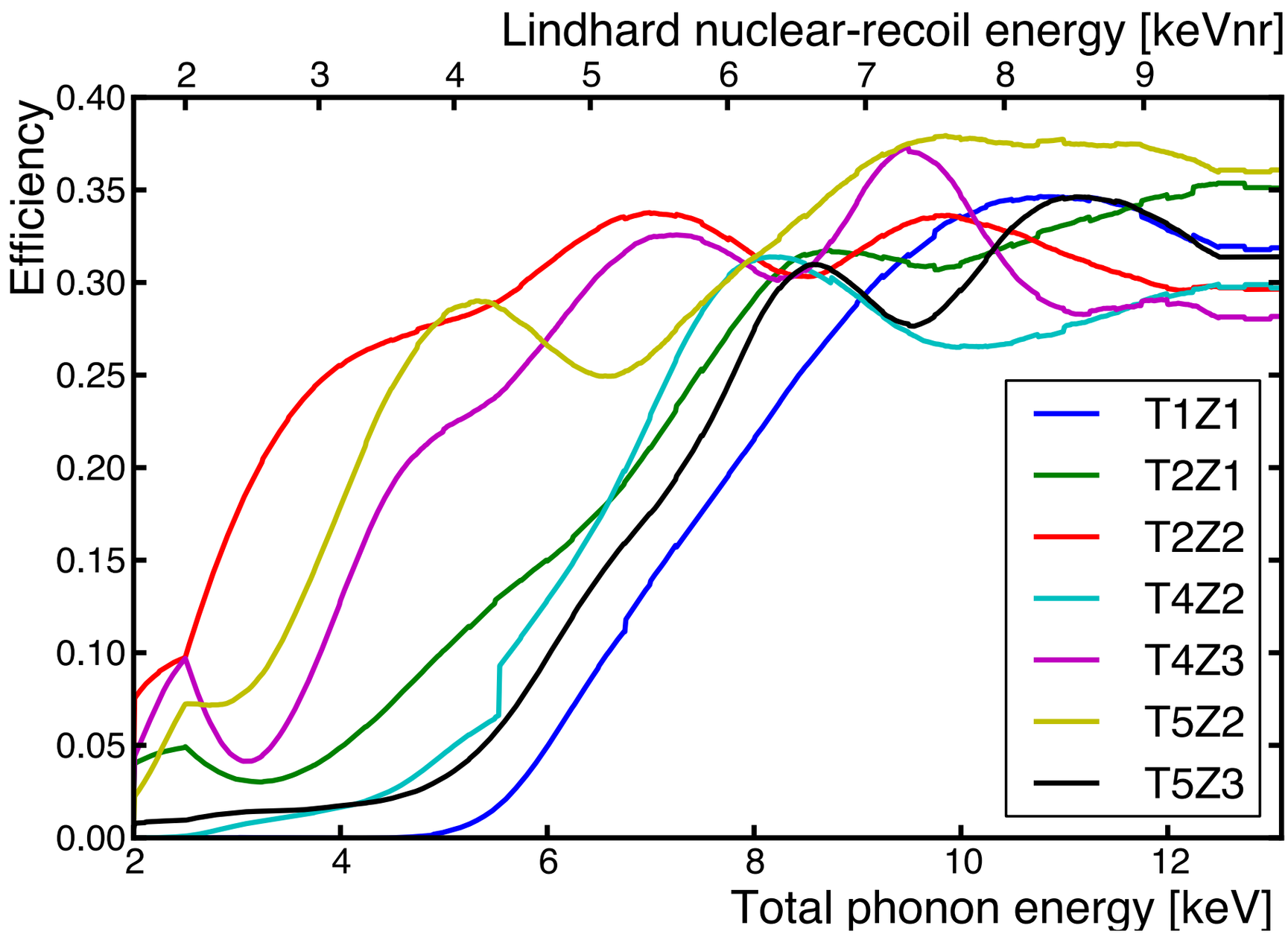
- Since signal-to-noise is poor, fit mean ionization energy for nuclear recoils
- Systematic uncertainties propagated into final limit
- Most detectors consistent with or slightly below Lindhard



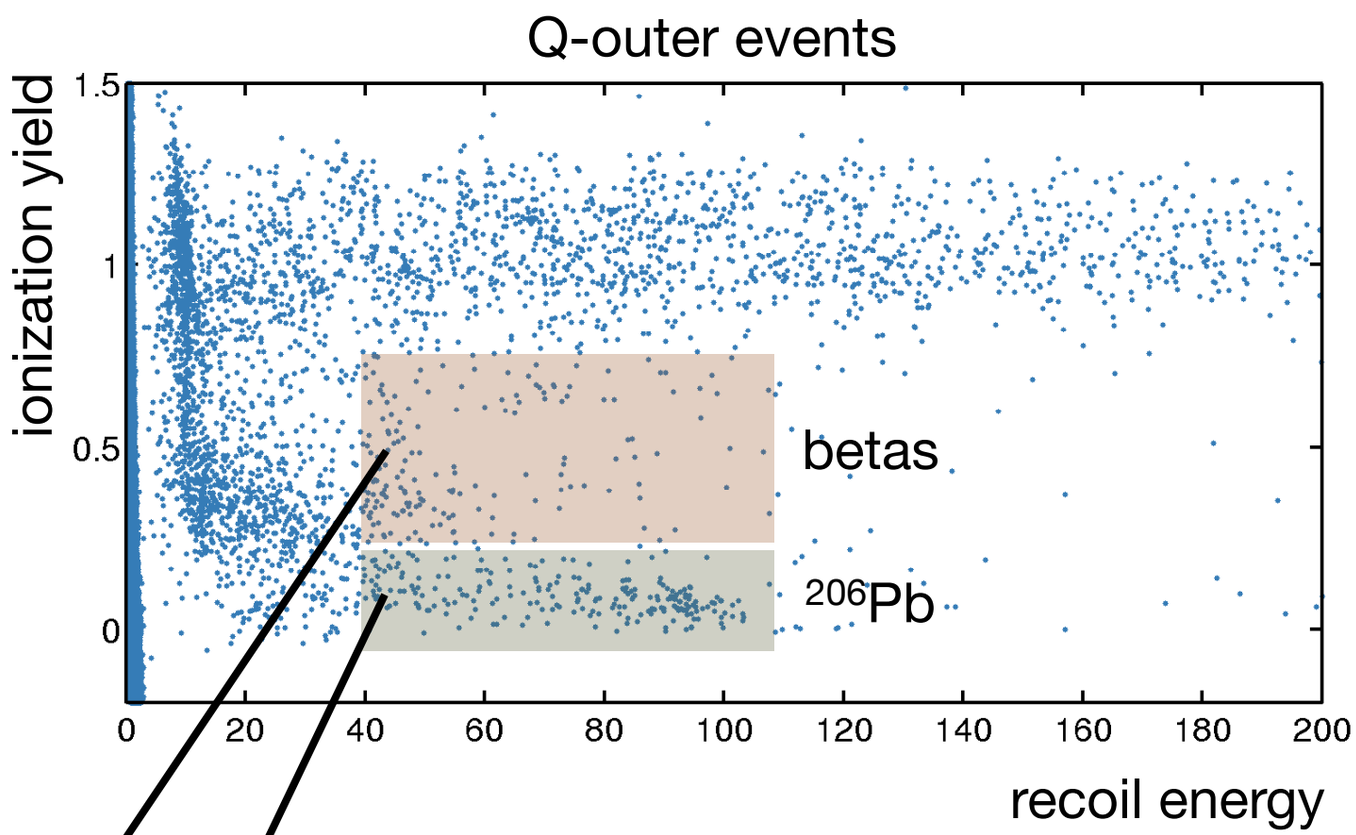




Efficiencies by Detector

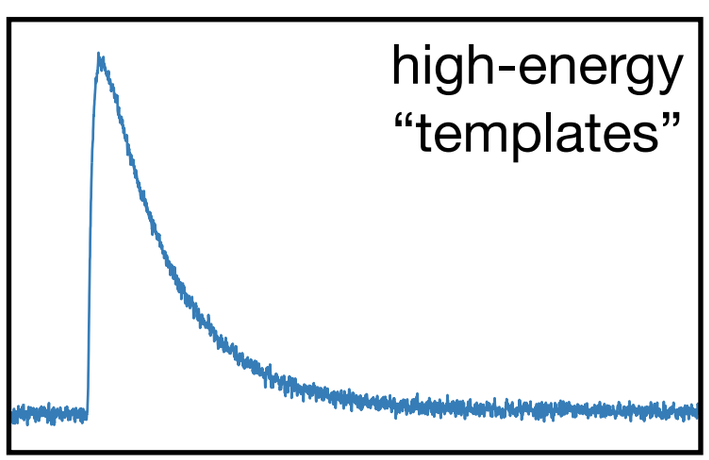


Detector Pulse Simulation



background type	*template source*
210	WIMP-search data (~40-100 keV)
External gammas	133 (~100 keV)
L-shell lines (~1 keVee)	K-shell decays (~10 keVee)

High-E events as templates for low-E events: **preserves pulse shape info**



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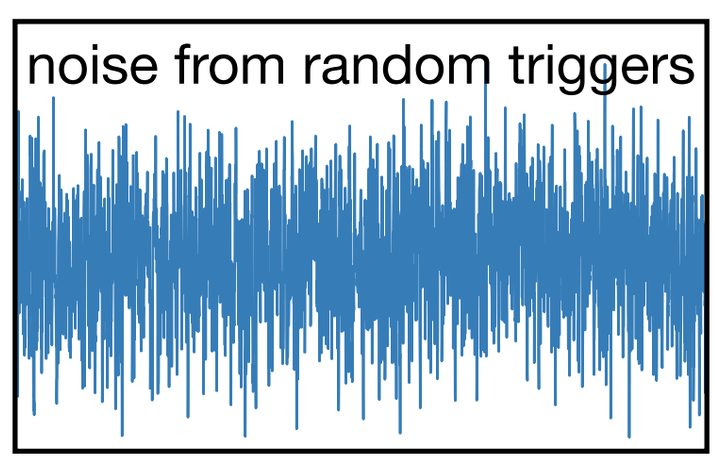

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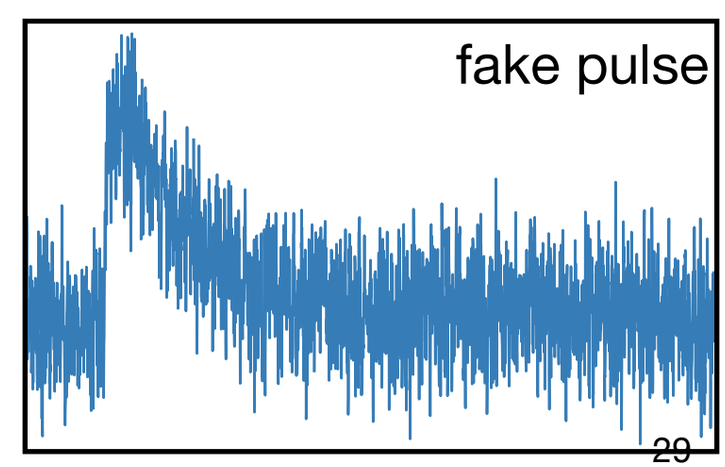
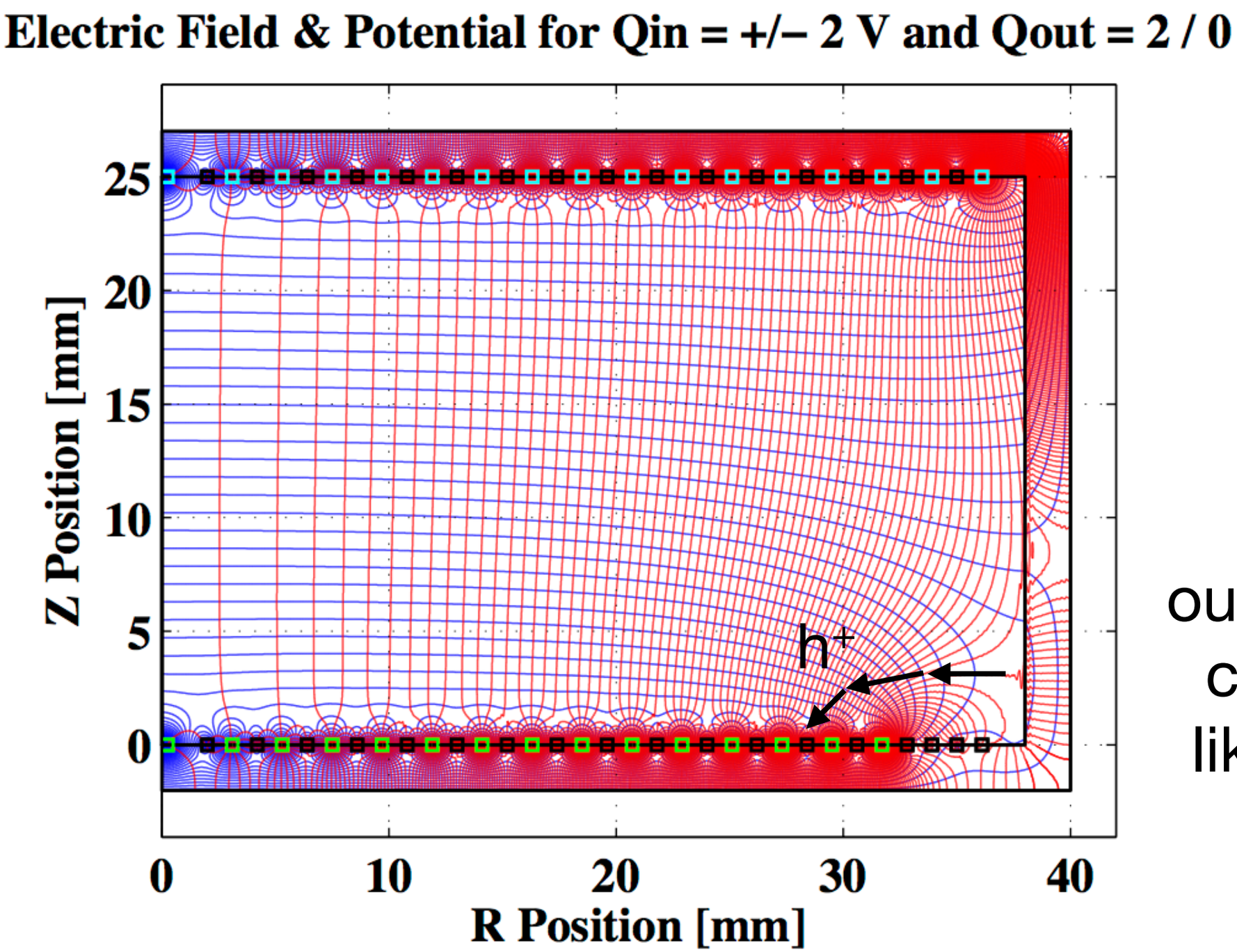
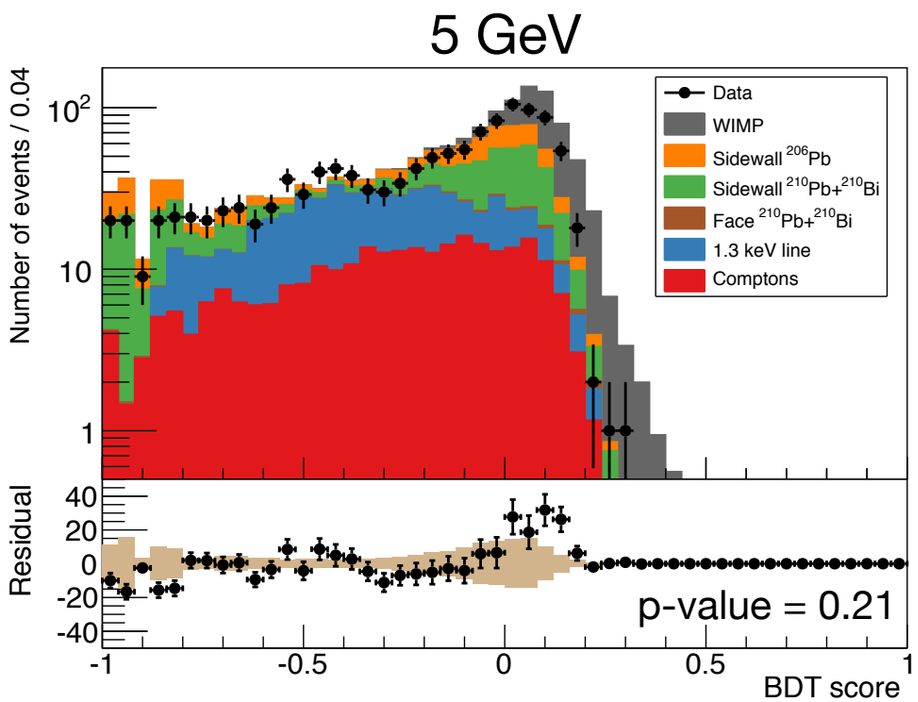


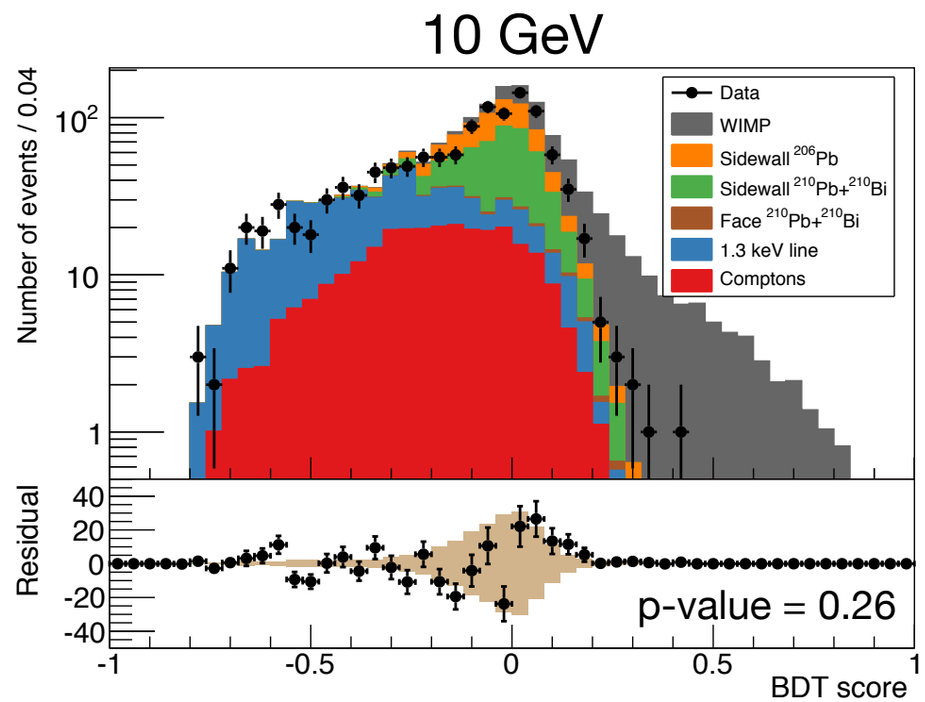
Electric Field in T5Z3

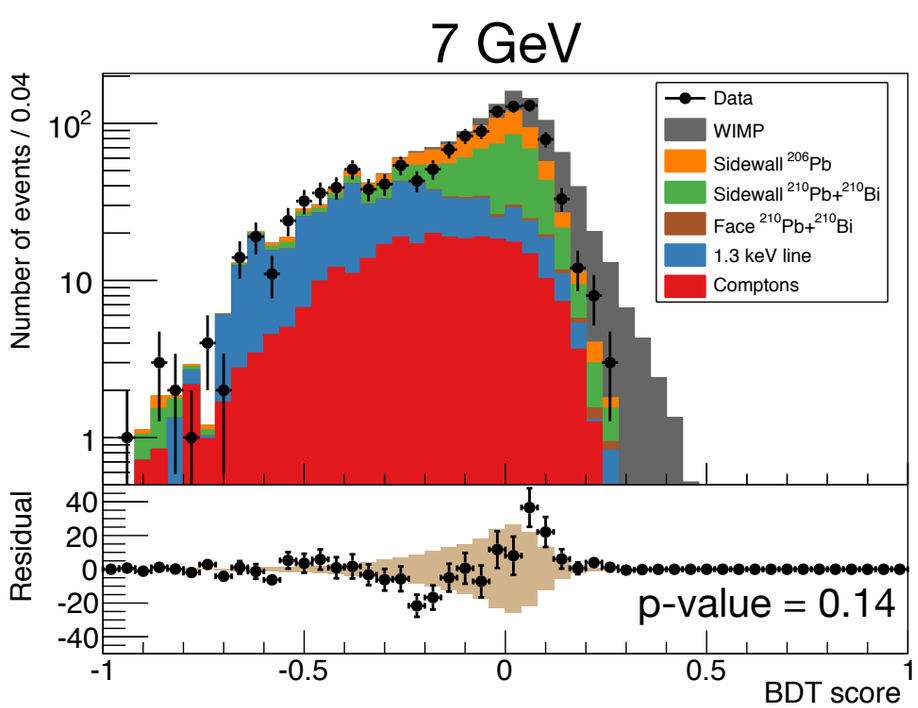


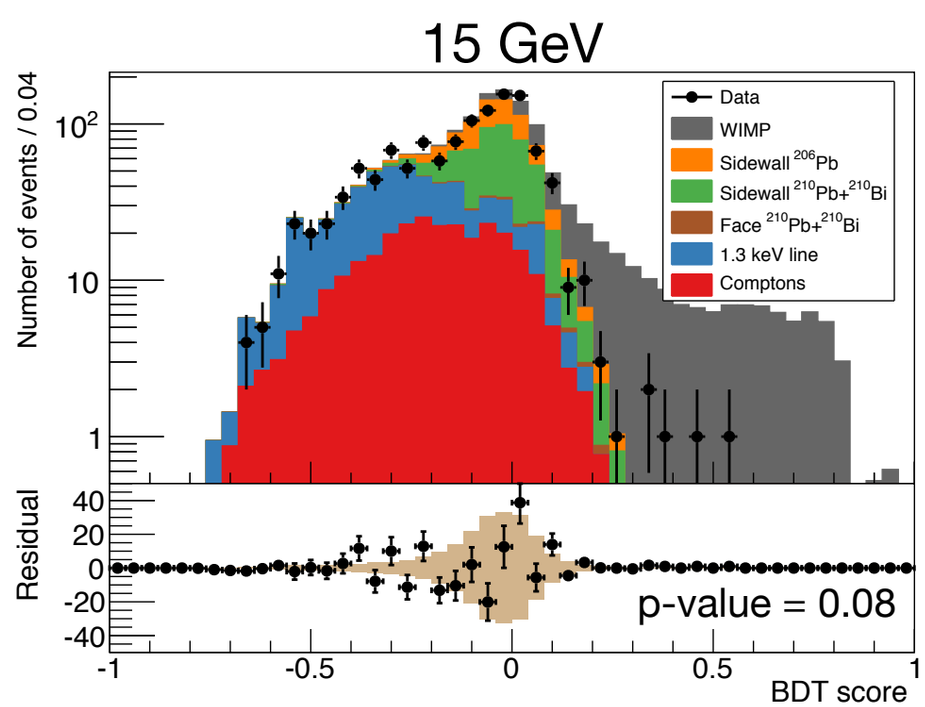
outer event can look like inner!

BDT Distributions

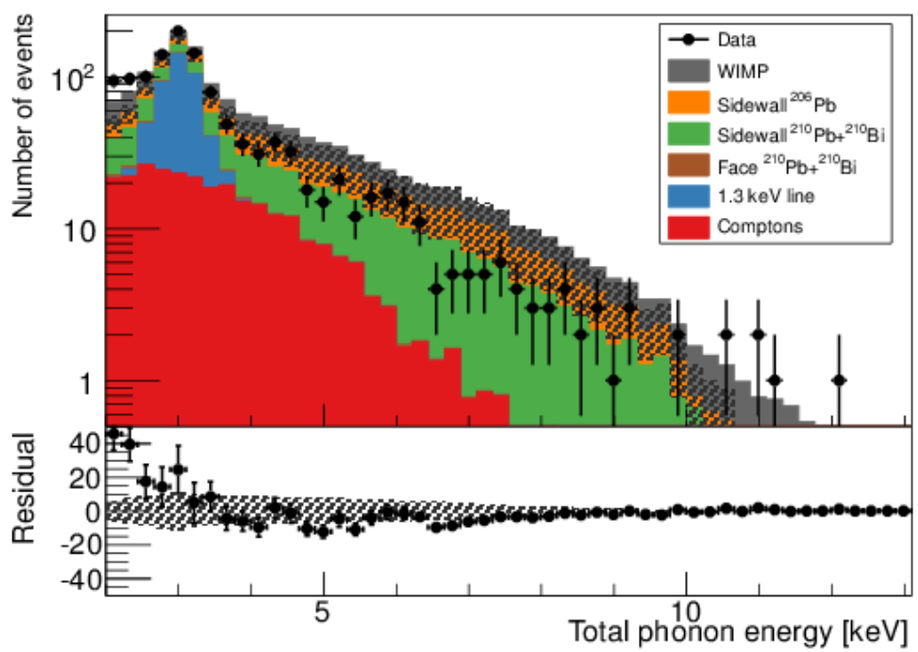


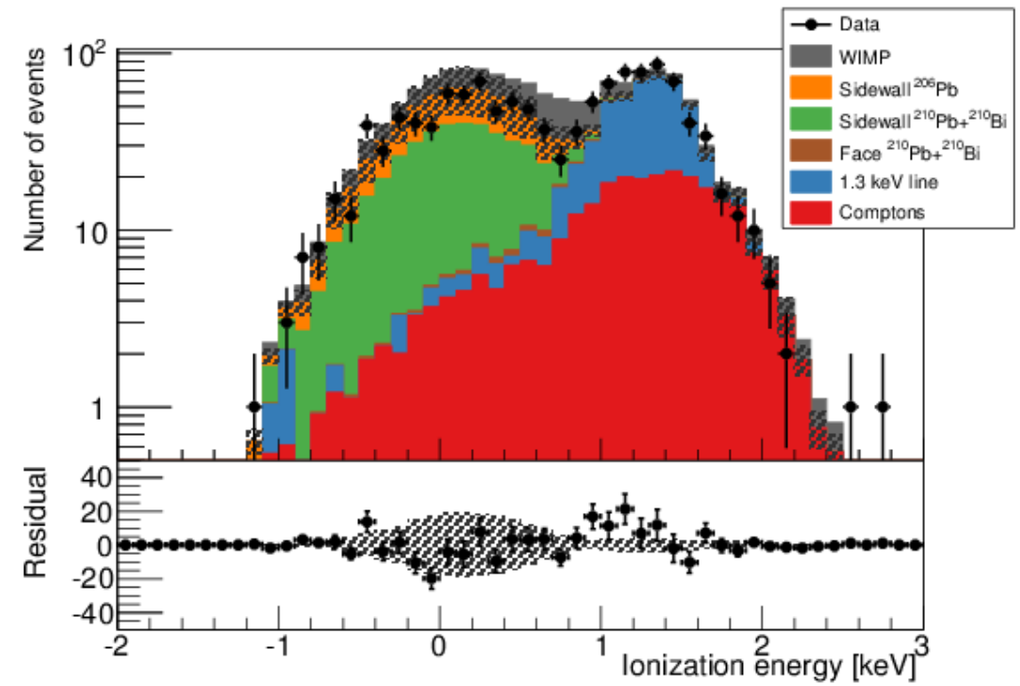


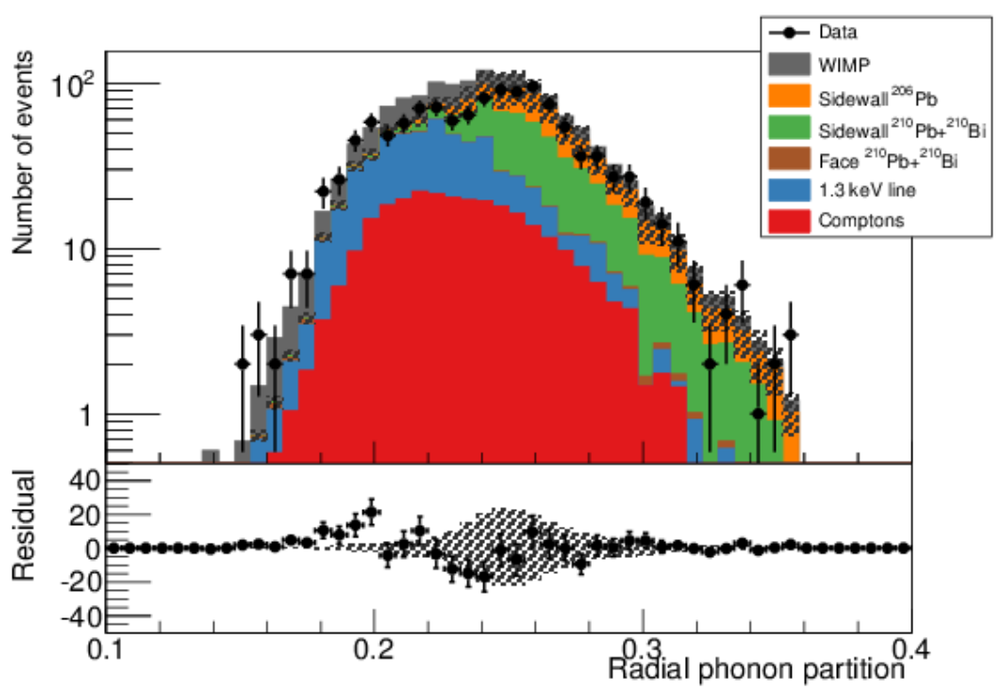


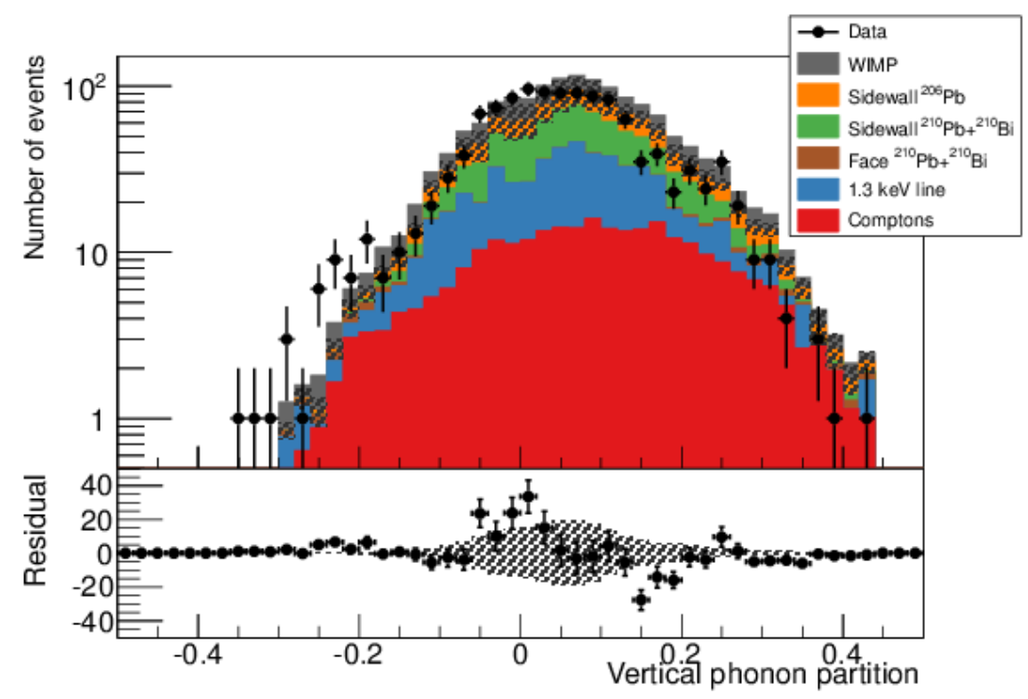


BDT Input Distributions

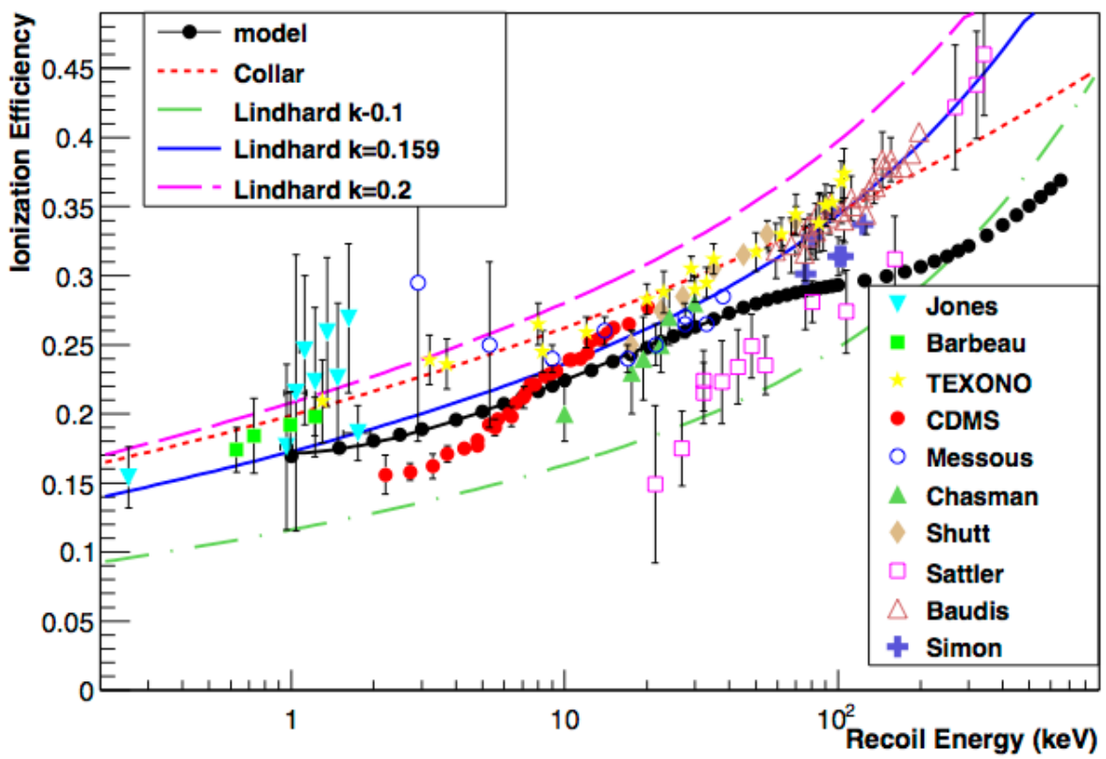


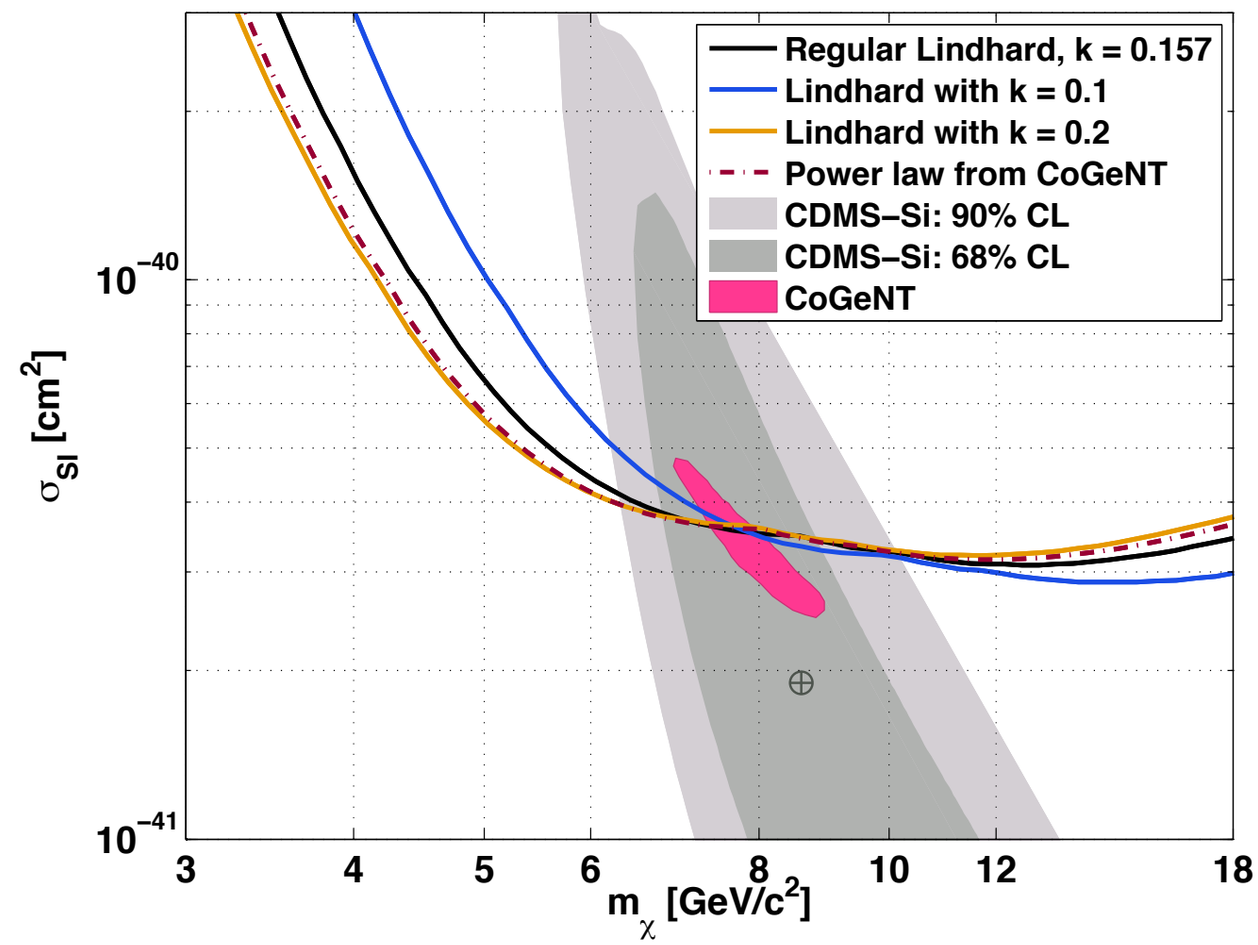






CDMSlite: Effect of Nuclear Recoil Energy Scale





Selection Criteria and Efficiencies

Quality

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

Thresholds

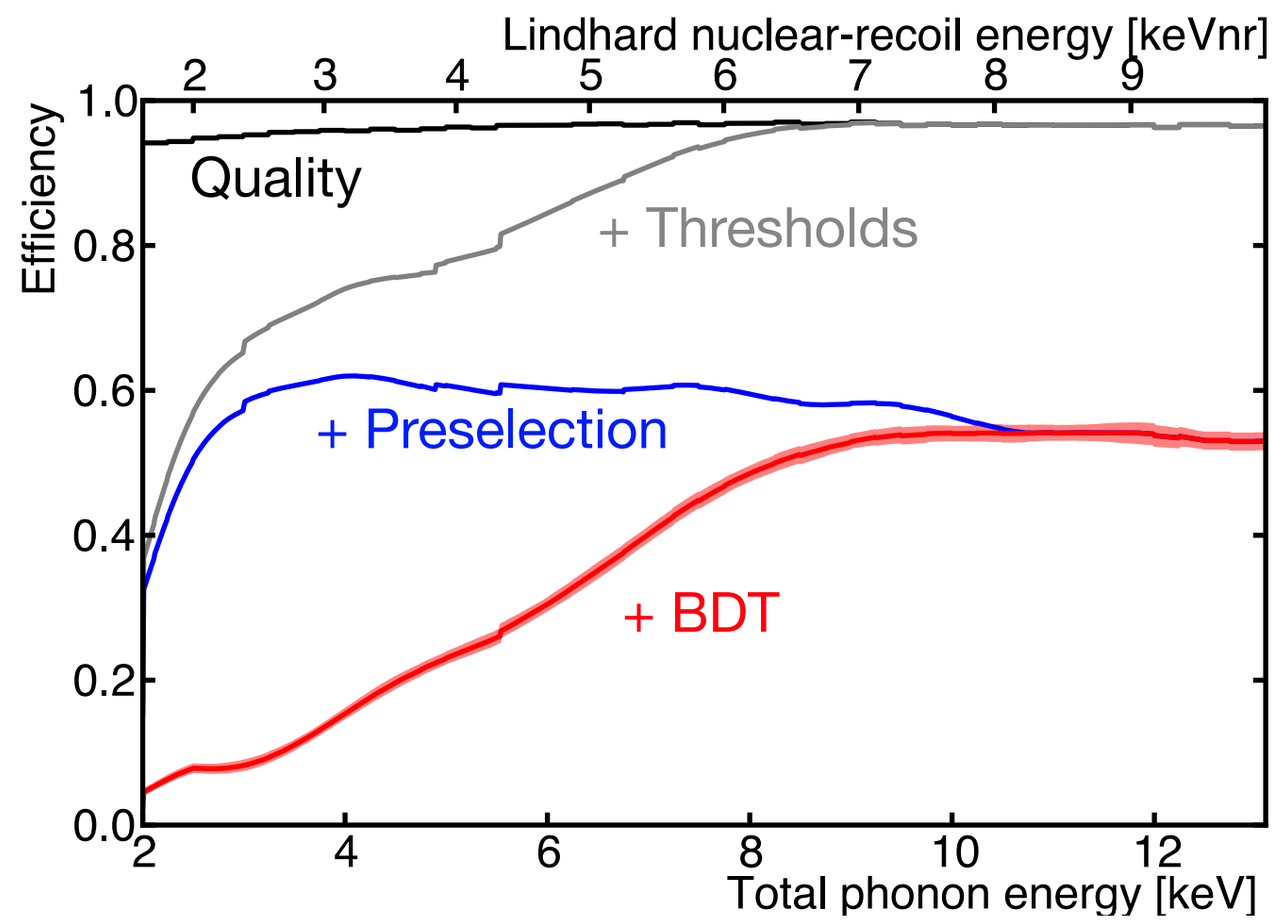
- Trigger and analysis thresholds 1.6-5 keVnr
- Measure efficiency using ^{133}Ba calibration data

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

Follow-Up Studies

- Validation and refinement of background models on unblinded data
- Investigating full detector simulation as replacement for pulse simulation
- Calibrate detector response to sidewall events with sidewall ^{210}Pb source
- Use calibration to validate modeling of detectors with shorted channels (e.g. T5Z3)
- Follow-up likelihood analysis to incorporate improved simulations