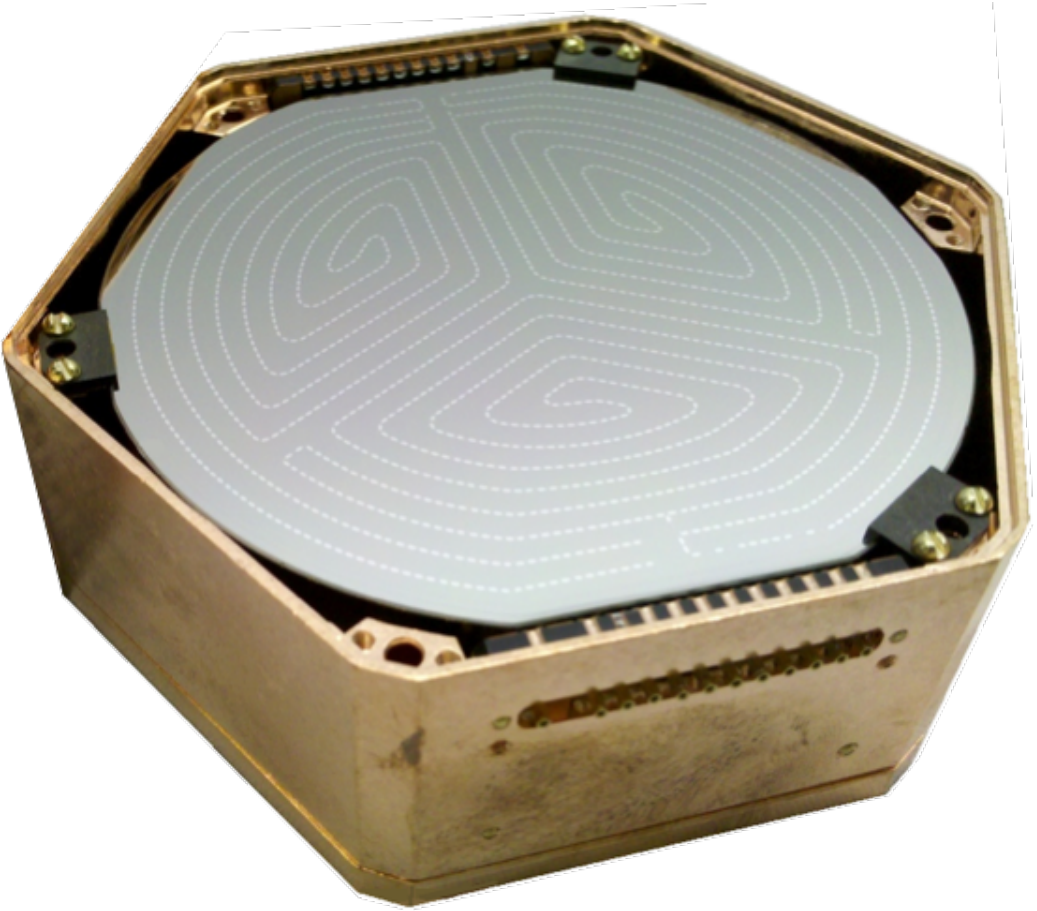
SuperCDMS:
Current and Future Prospects



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University of California Berkeley

INPA Dark Matter Workshop
May 8 2014

The SuperCDMS Collaboration

http://cdms.berkeley.edu

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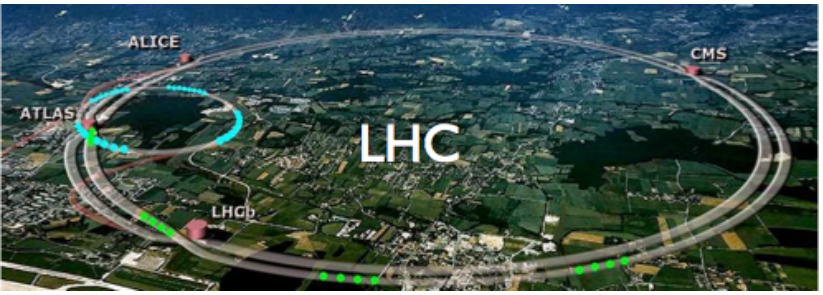
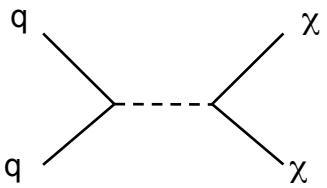
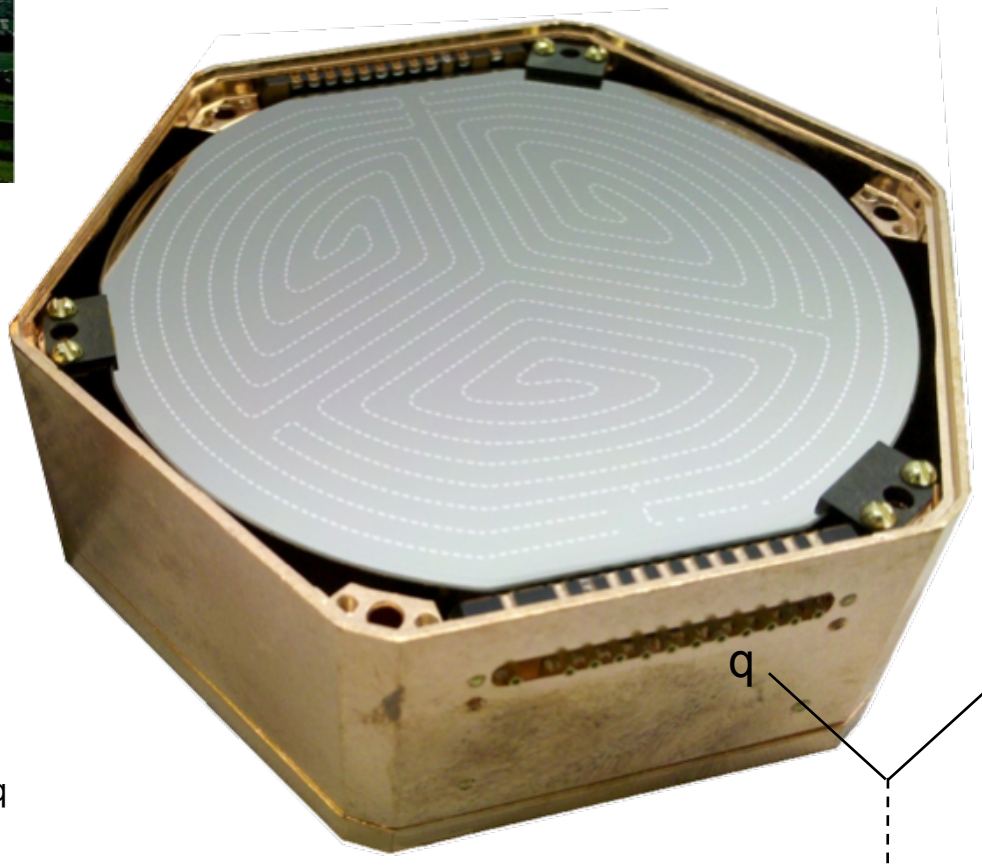
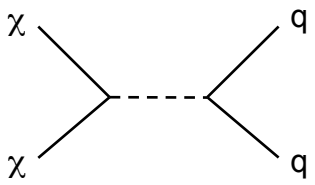
U. South Dakota
J. Sander

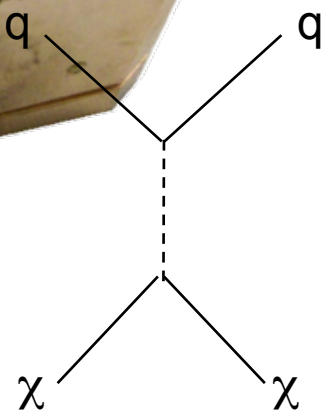
Dark Matter Search Techniques



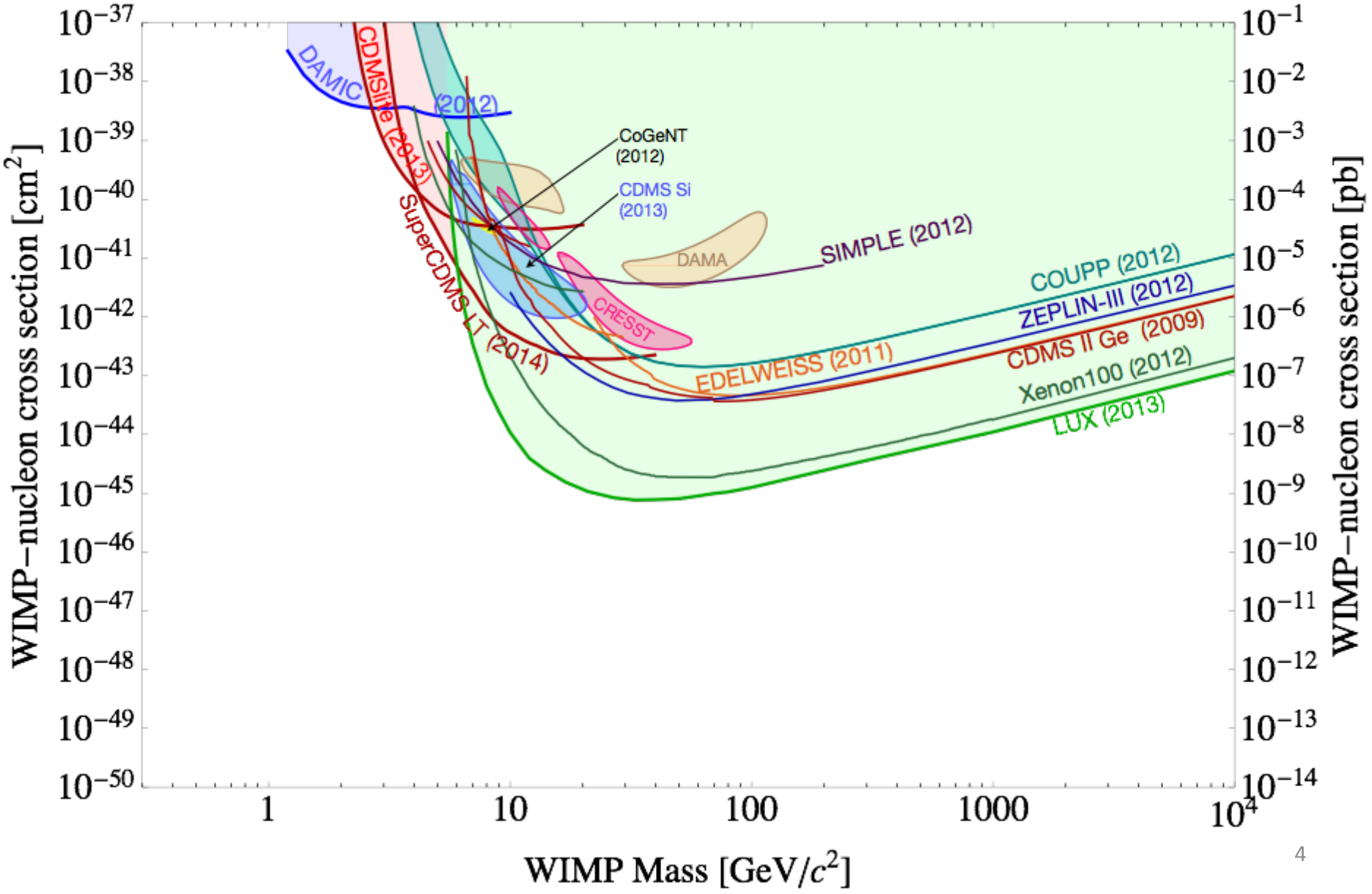




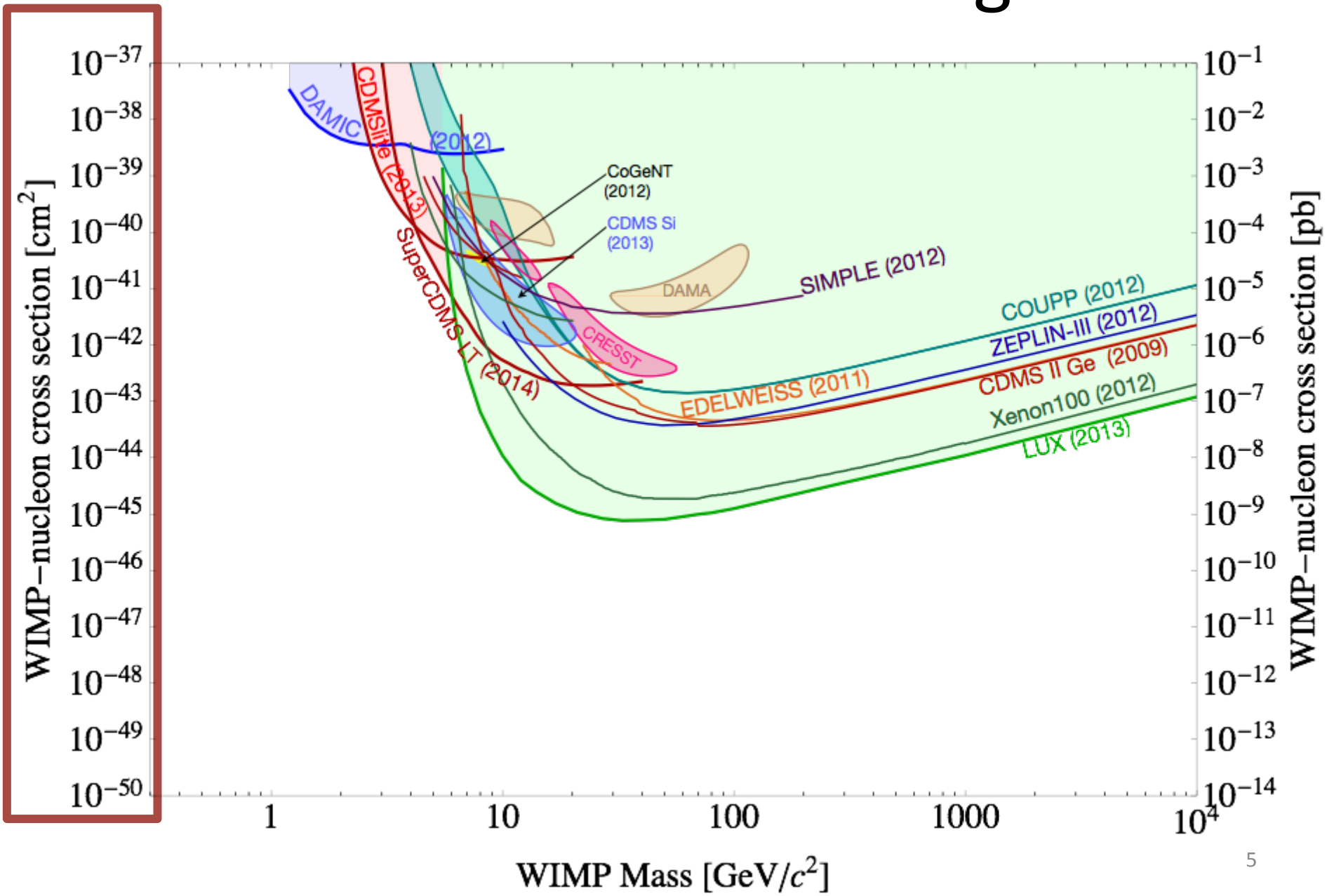




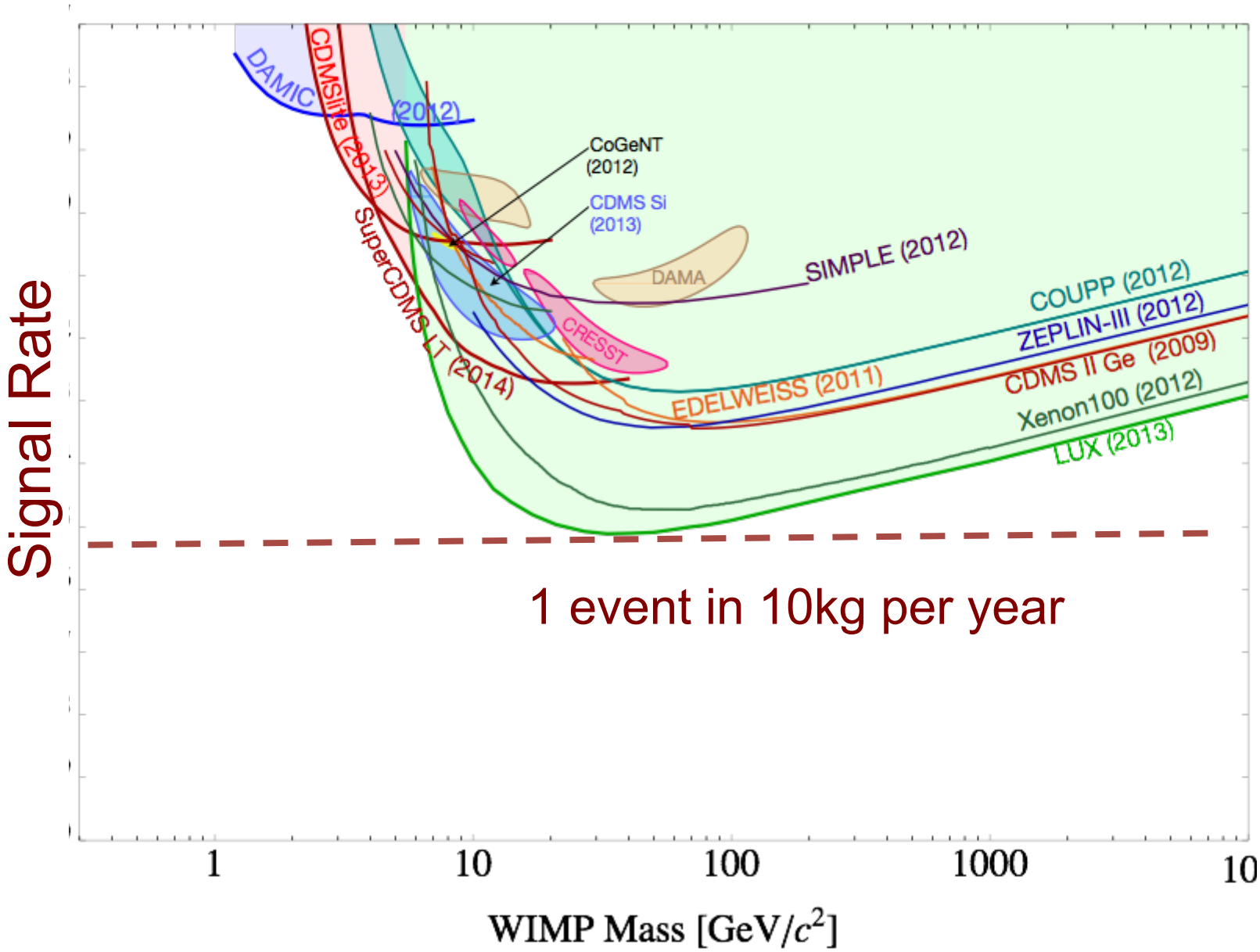
Direct Detection Sensitivities



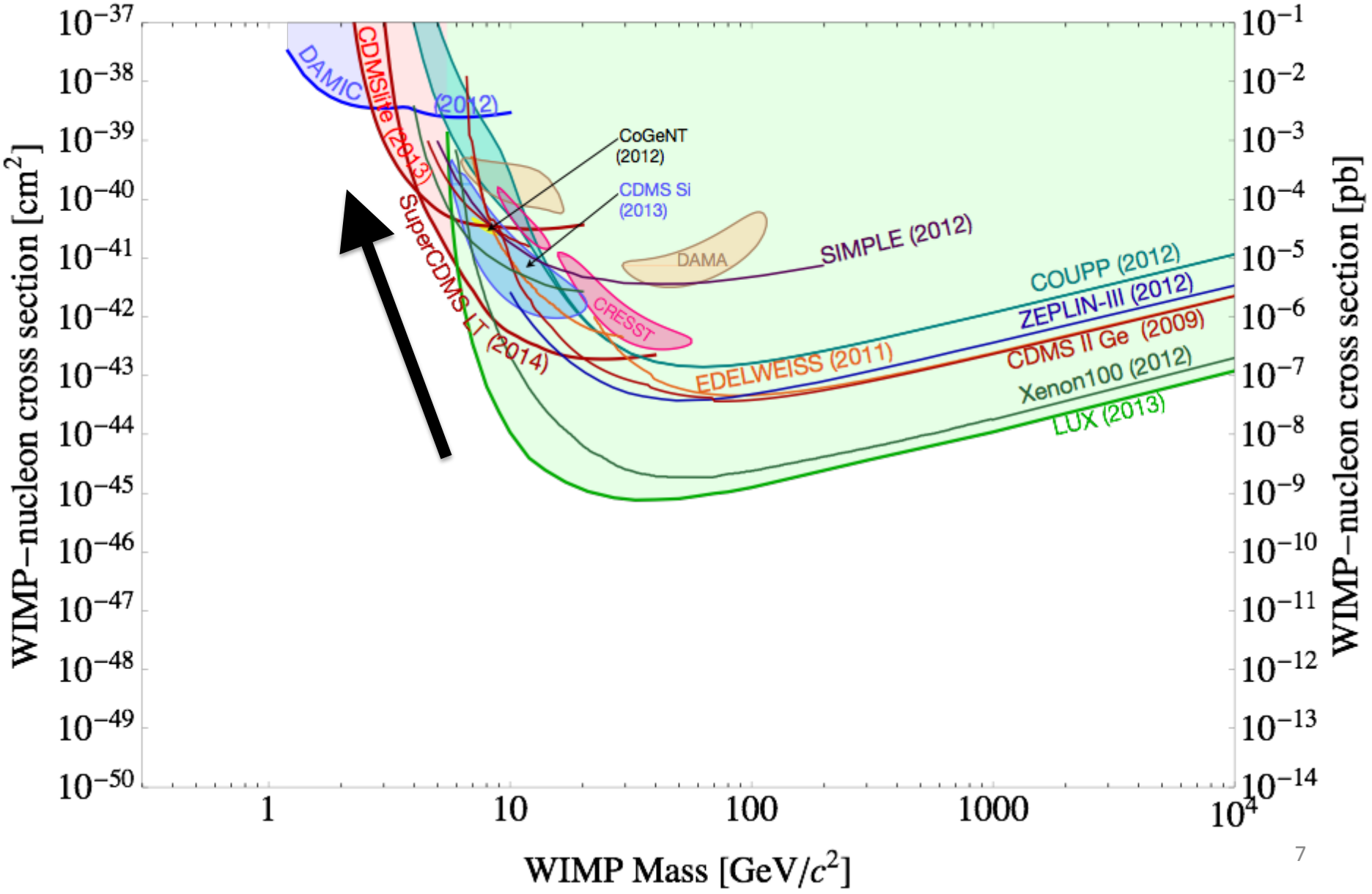
Direct Detection Challenge #1



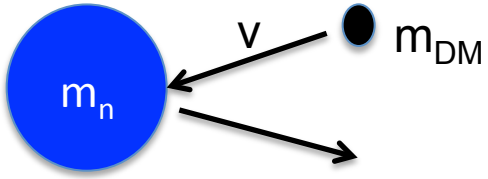
Direct Detection Challenge #1



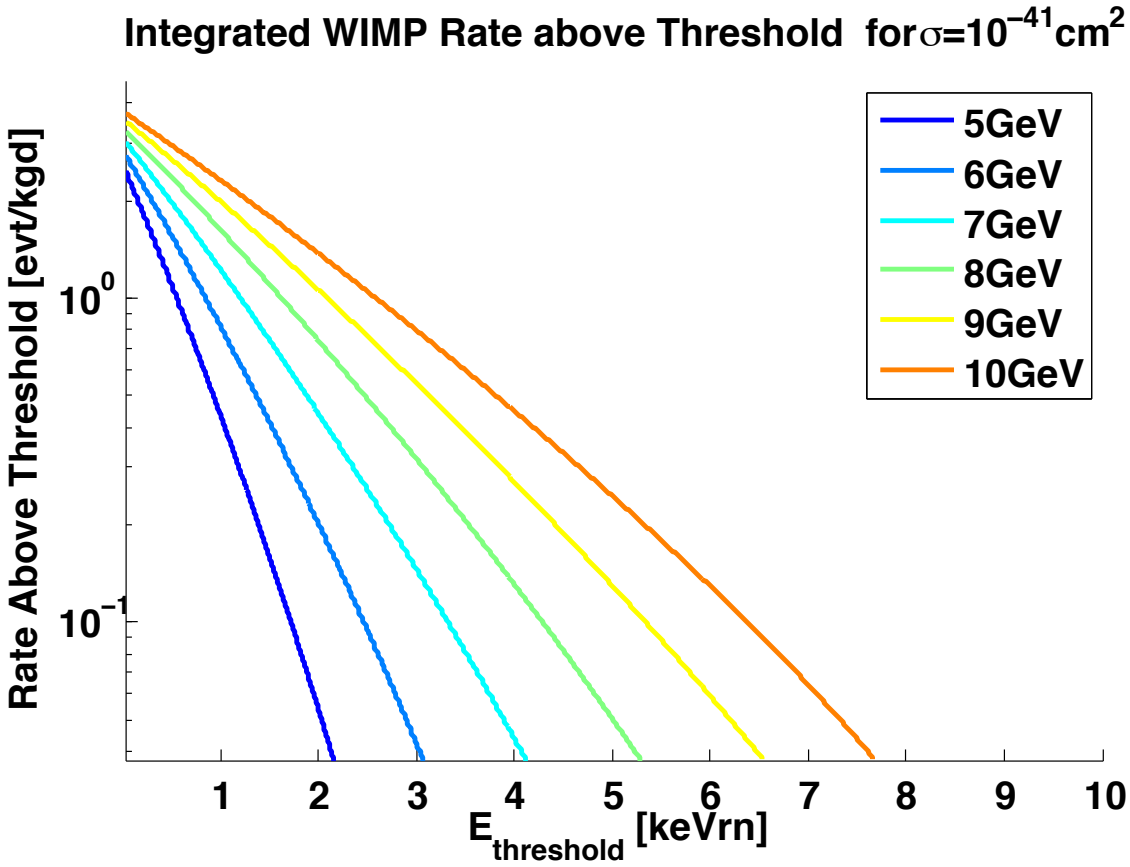
Sensitivity Loss at Low Mass



Direct Detection Challenge #2
Small Recoil Energy

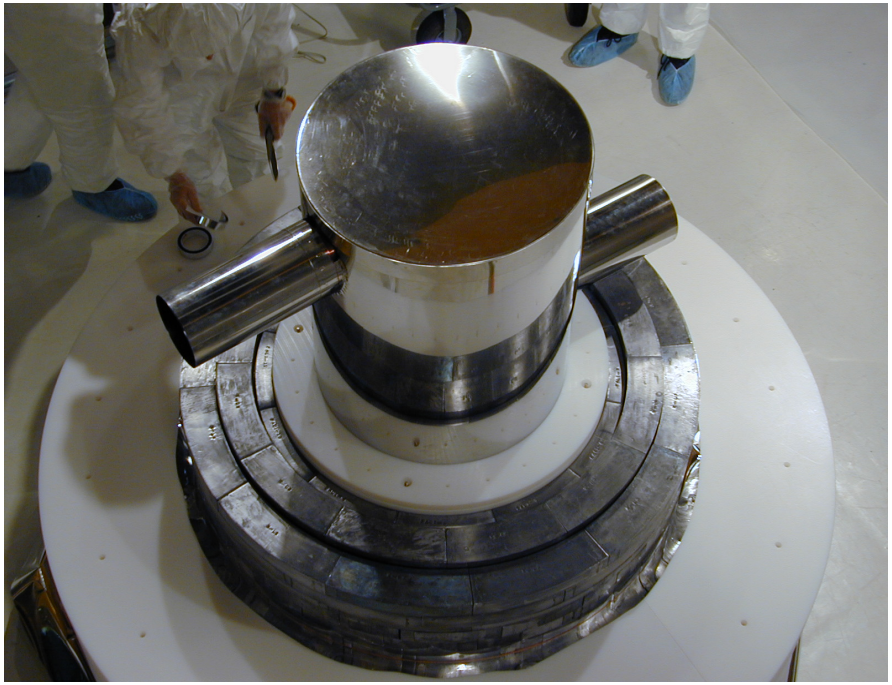


$$\Delta E = \frac{\Delta P^2}{2M_n} \lesssim \frac{2M_{DM}^2 v^2}{M_N}$$

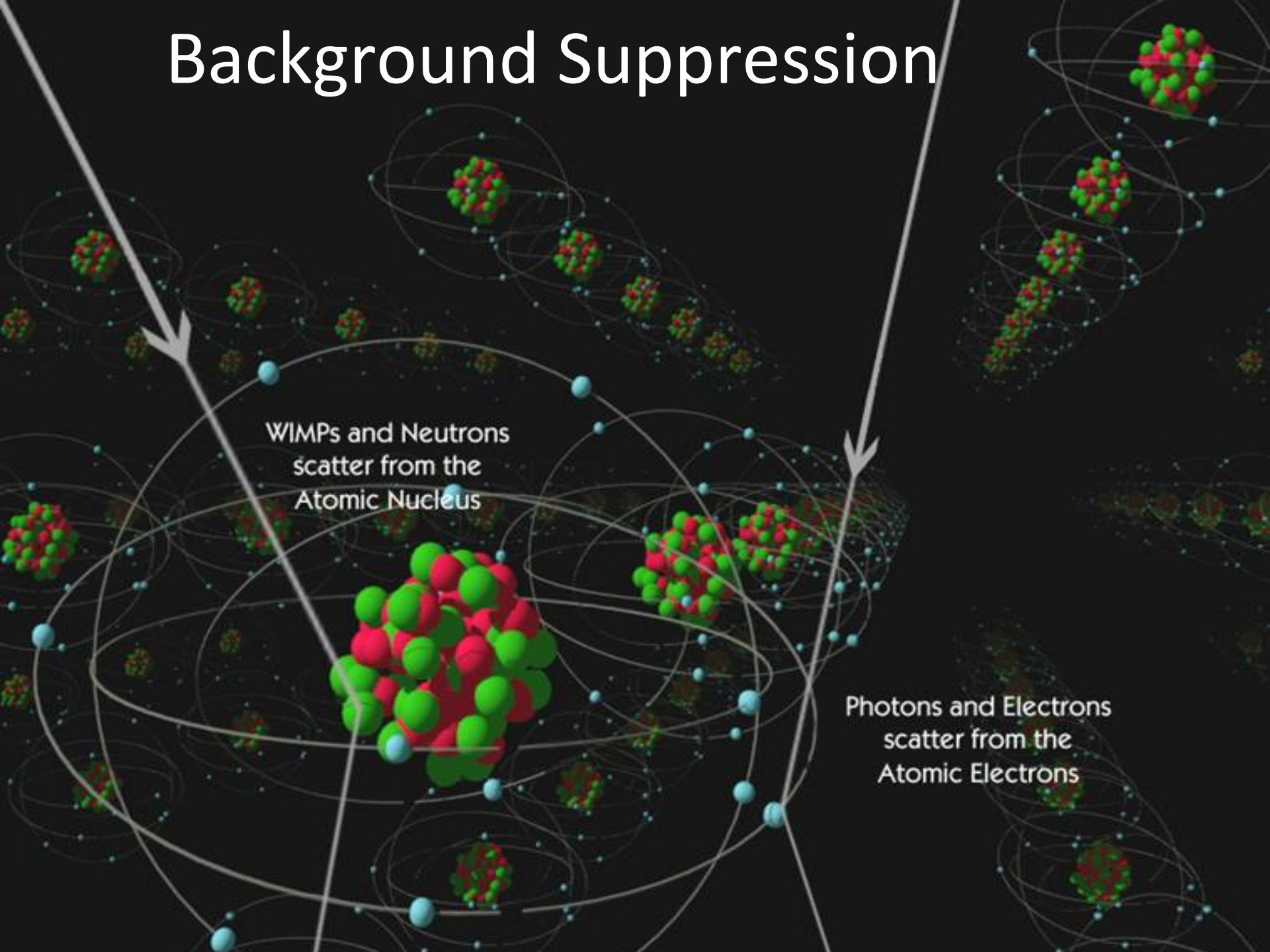


Background Suppression

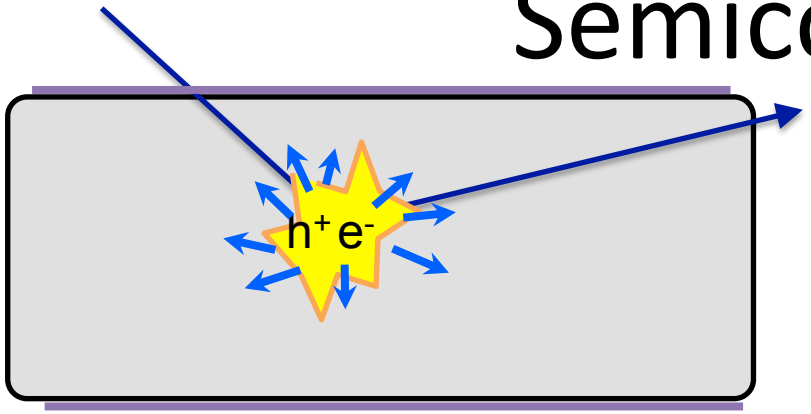
- Go underground
- Use radiopure materials
  - onion principle



Background Suppression

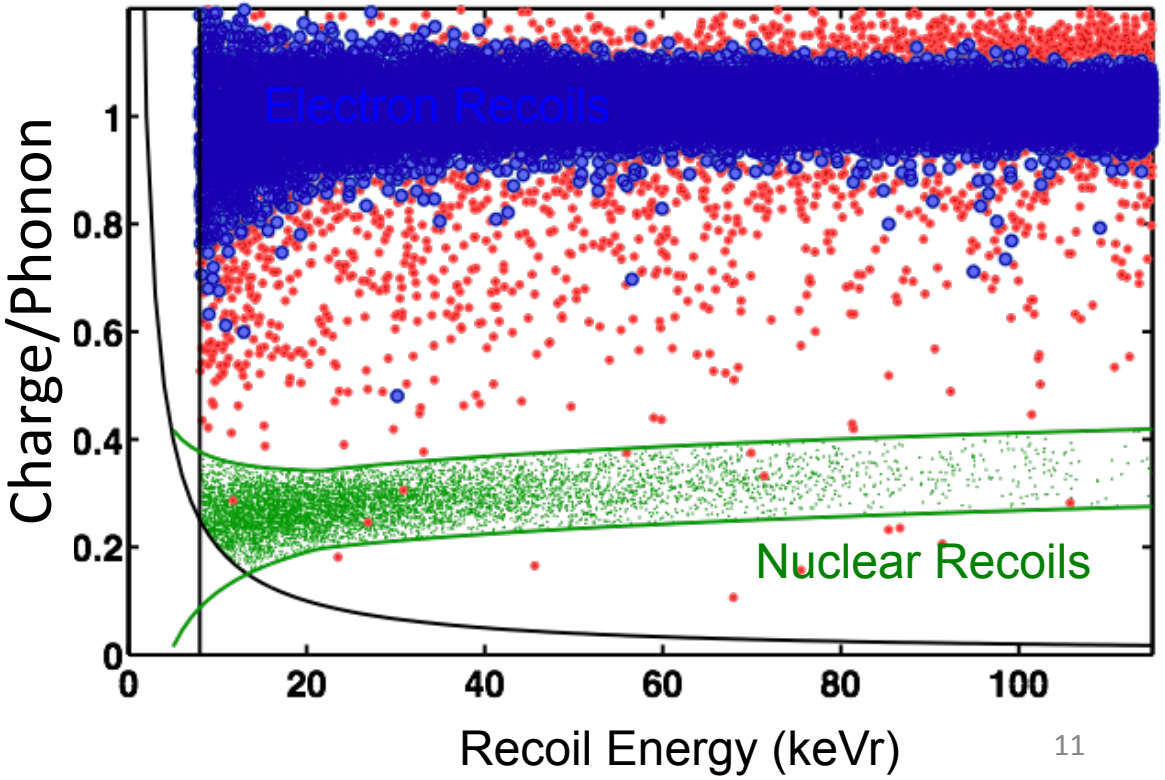


Interaction Products in Semiconductors



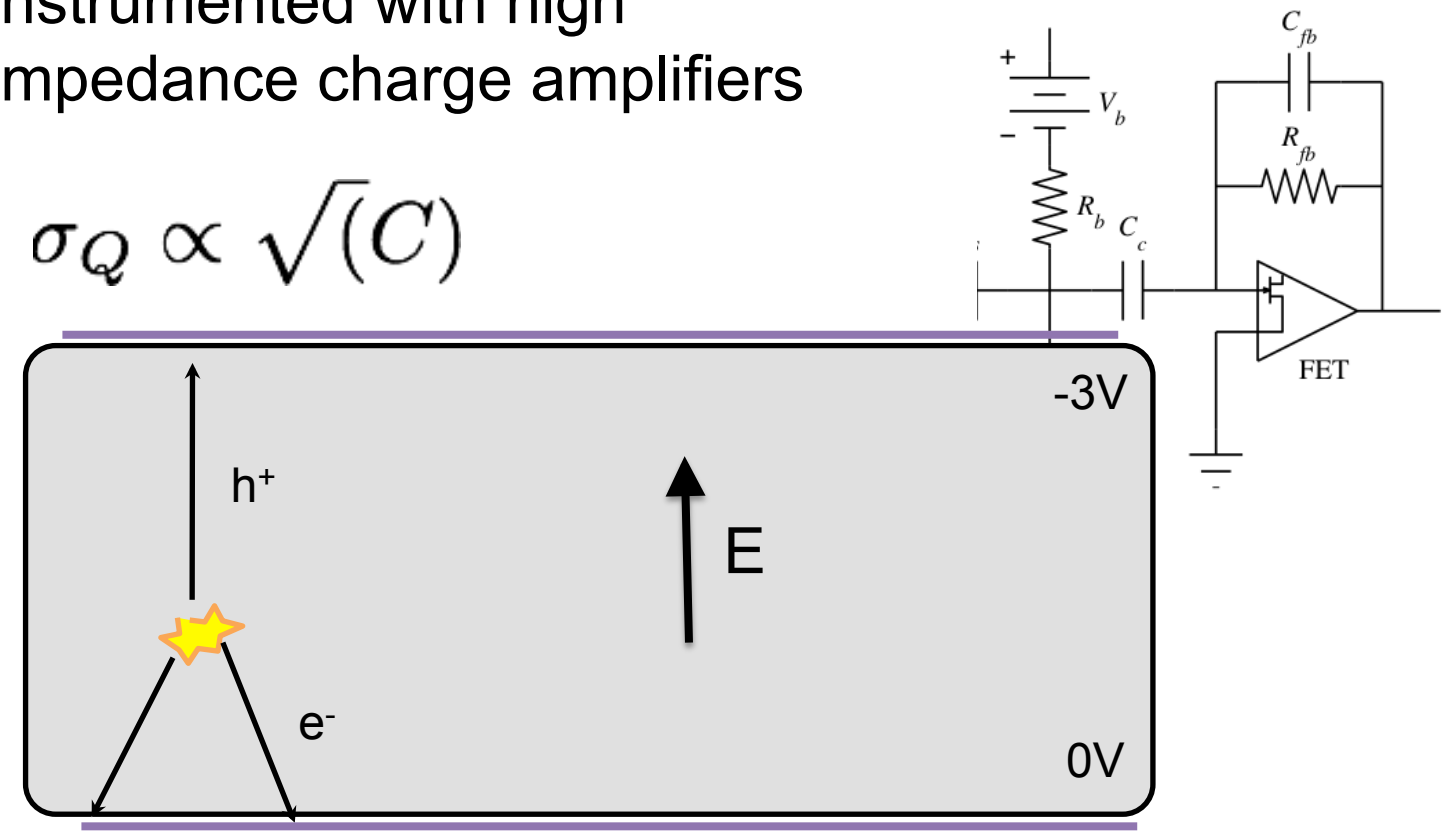
Nuclear Recoils (NR)
- 8% e^-/h^+
- 92% phonons

Electron Recoils (ER)
- 25% e^-/h^+
- 75% phonons



Standard Charge Measurement

- Drift charges with an externally applied E-field to electrodes instrumented with high impedance charge amplifiers
- $\sigma_Q \propto \sqrt{(C)}$



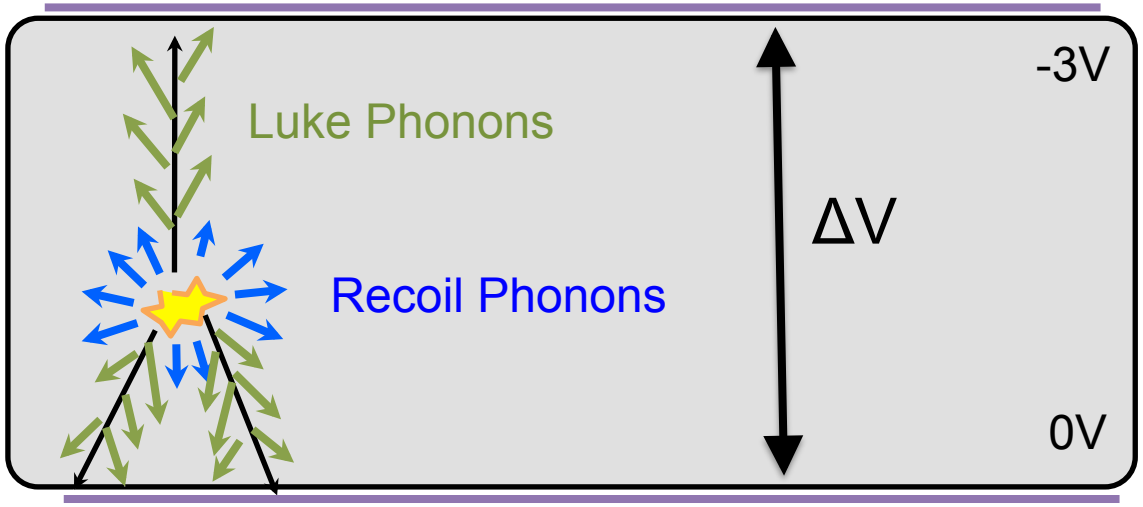
Luke-Neganov Phonon Production

- Drifting charges release kinetic energy via Luke-Neganov Phonon Production
- $$E_{total} = E_{recoil} + E_{luke}$$
$$= E_{recoil} + QeΔV$$

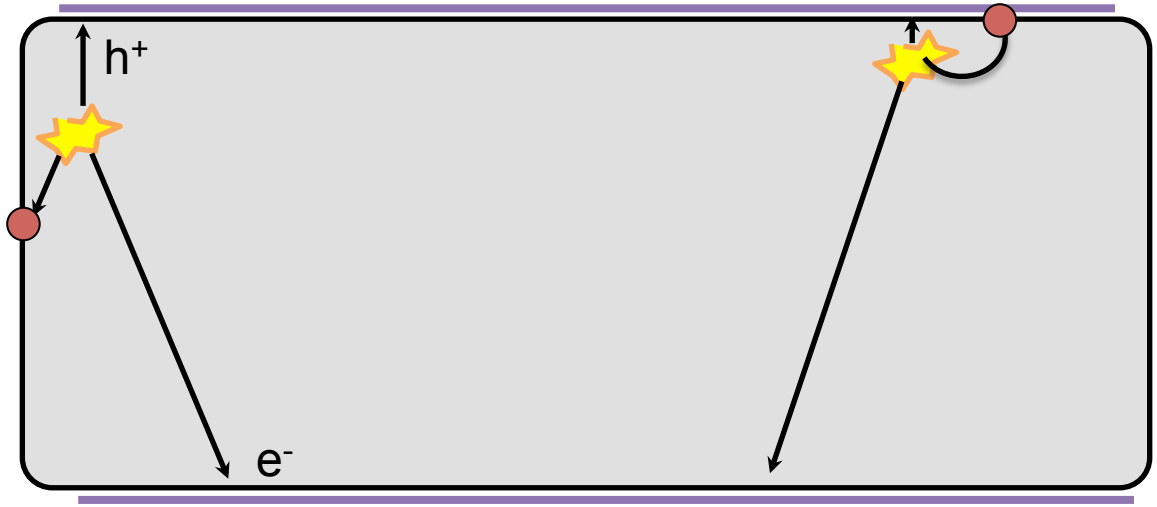
Warning:

$$\lim_{\Delta V \to \infty} E_{total} \propto Q$$

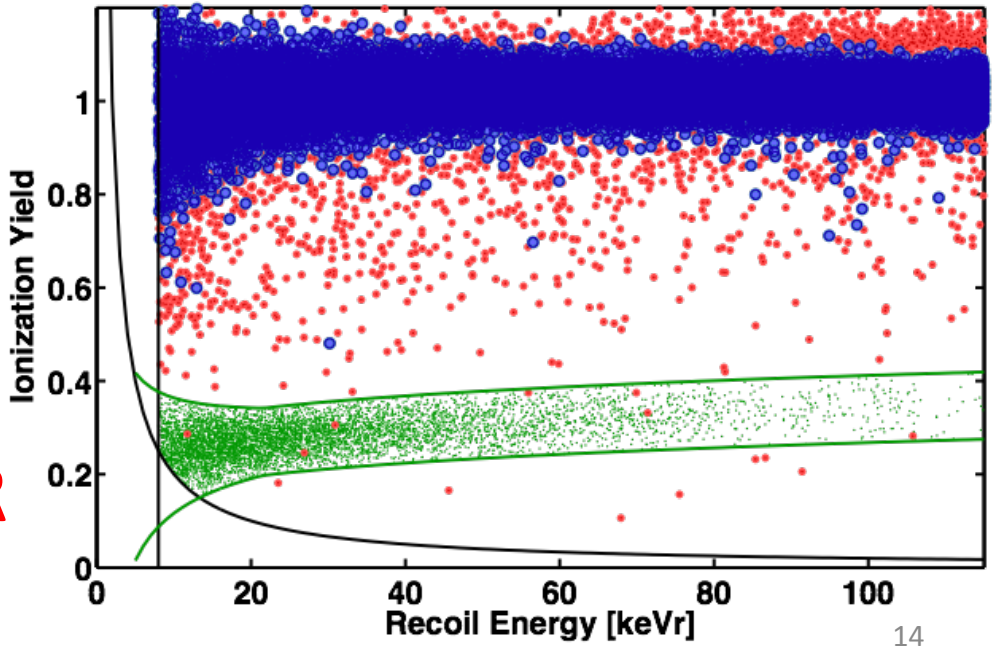
Q/E_{total} has no ER/NR Sensitivity. Must use small ΔV



Surface Trapping of Charges

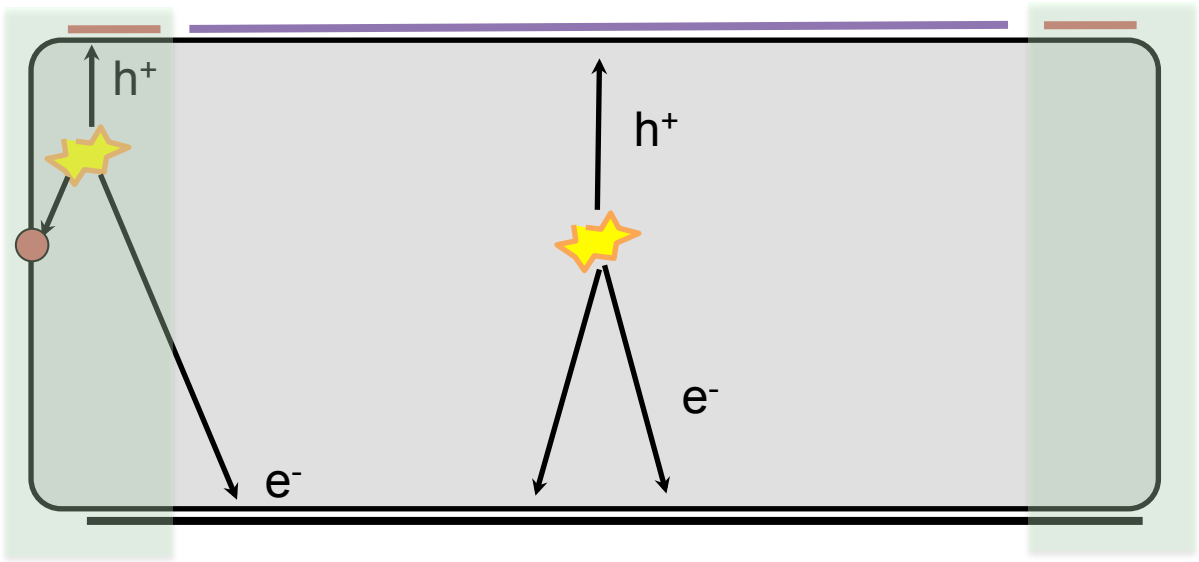


- Charges that hit a crystal surface during transport get stuck
- Reduced charge signal : ER look like NR



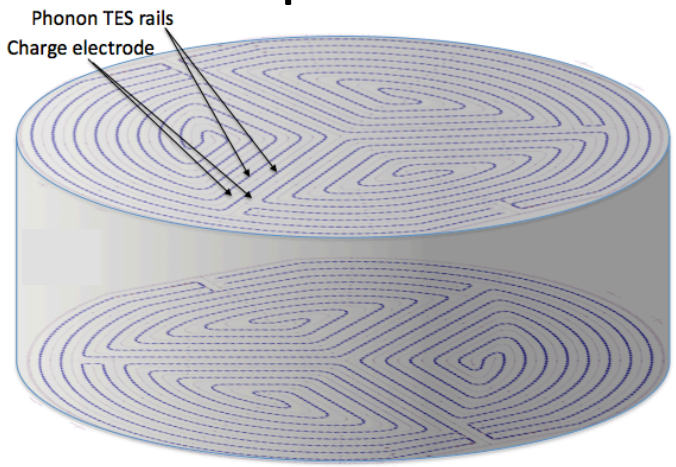
Position Information in Charge

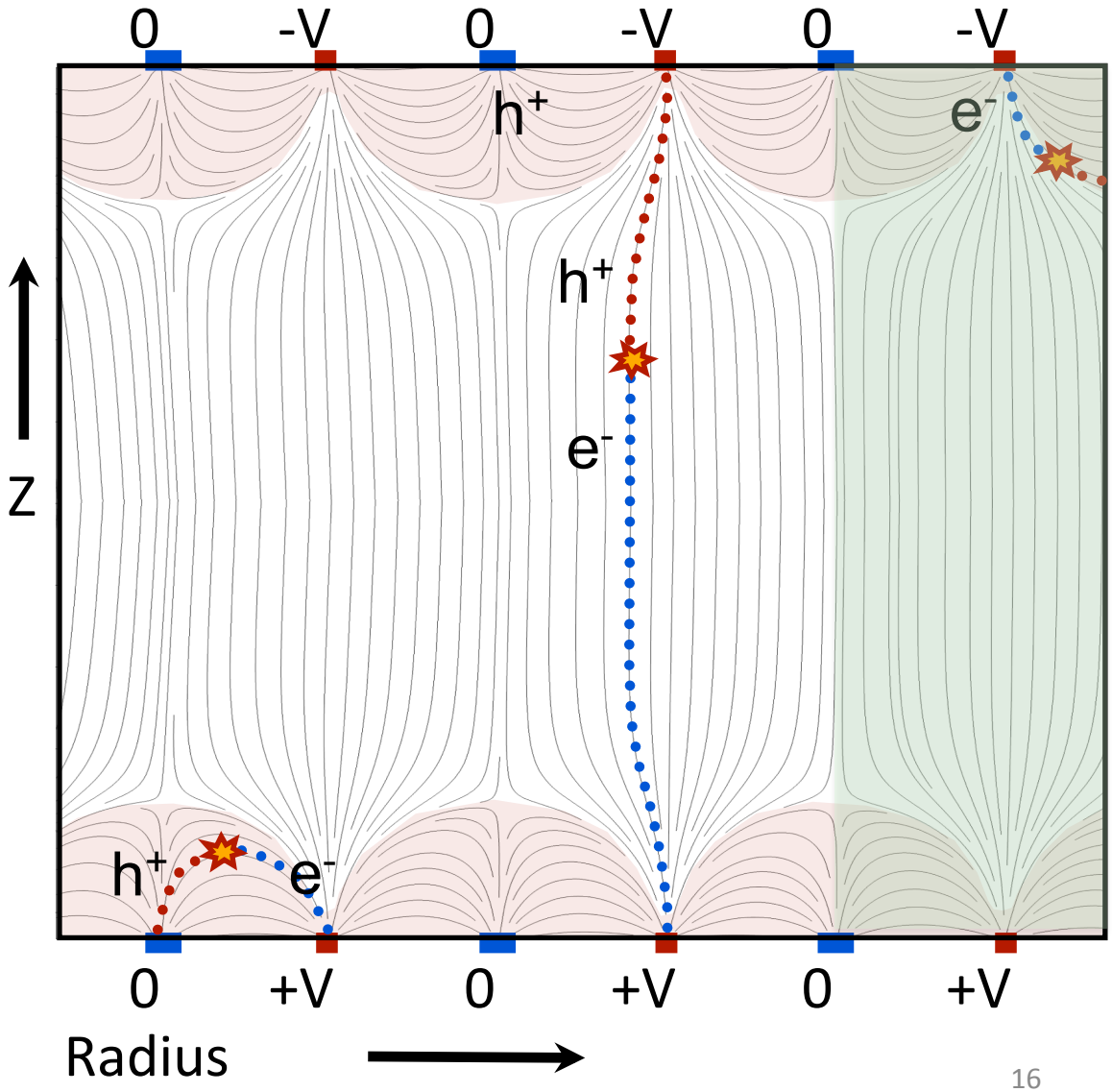
Multi-Channel Readout



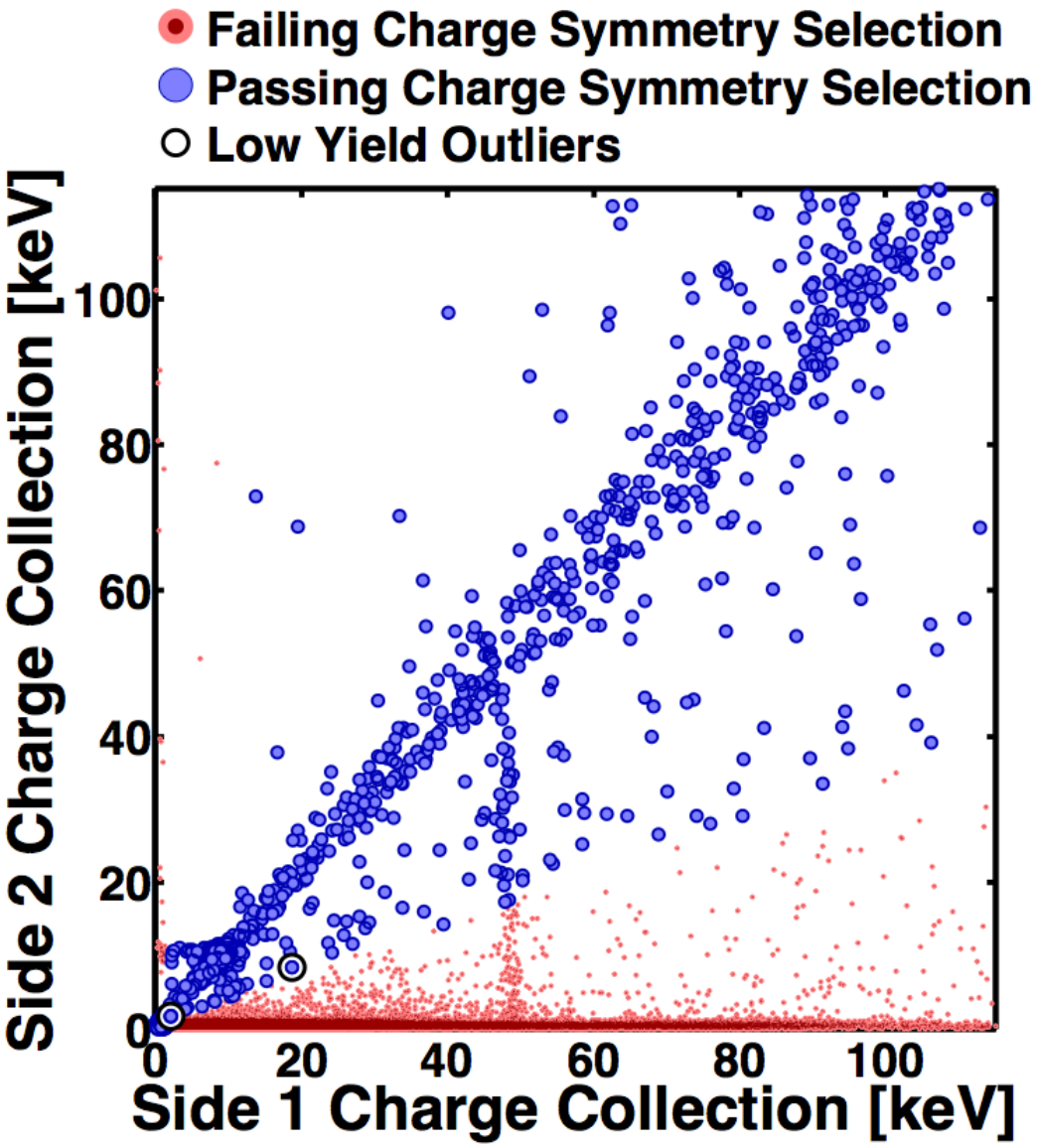
3D Position in Charge

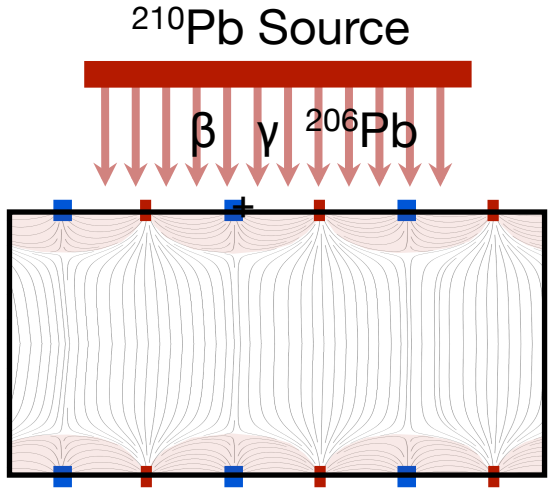
- Complex E-Field Geometries Encode 3D Position
- iZIP: 4 charge channels
- C ~125pf





Studying Charge Fiducial Volume

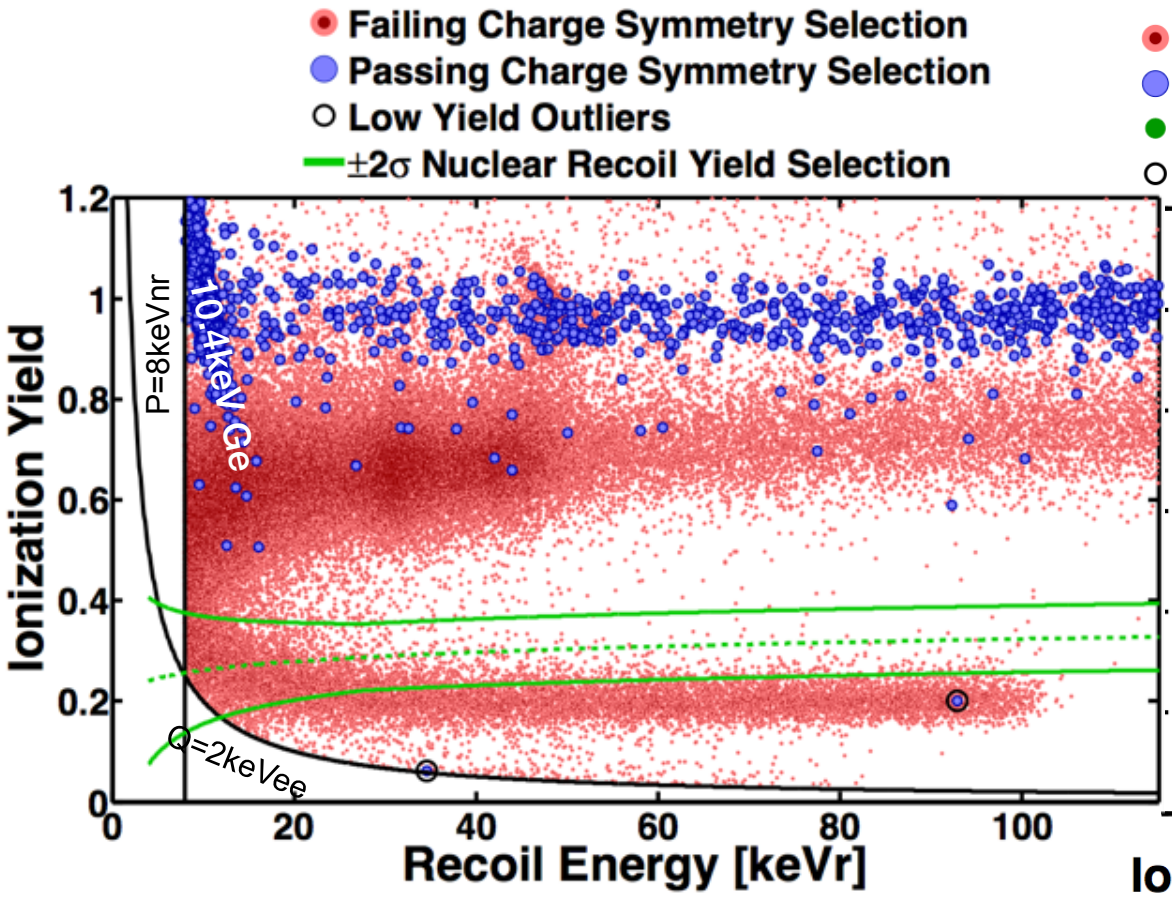


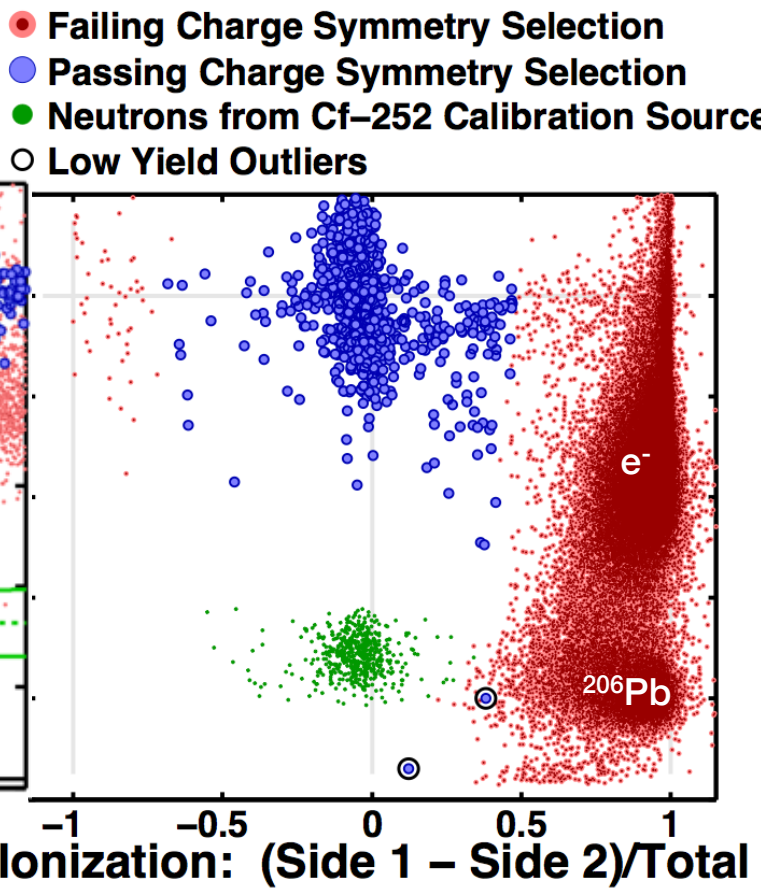


APL 103, 164105 (2013)

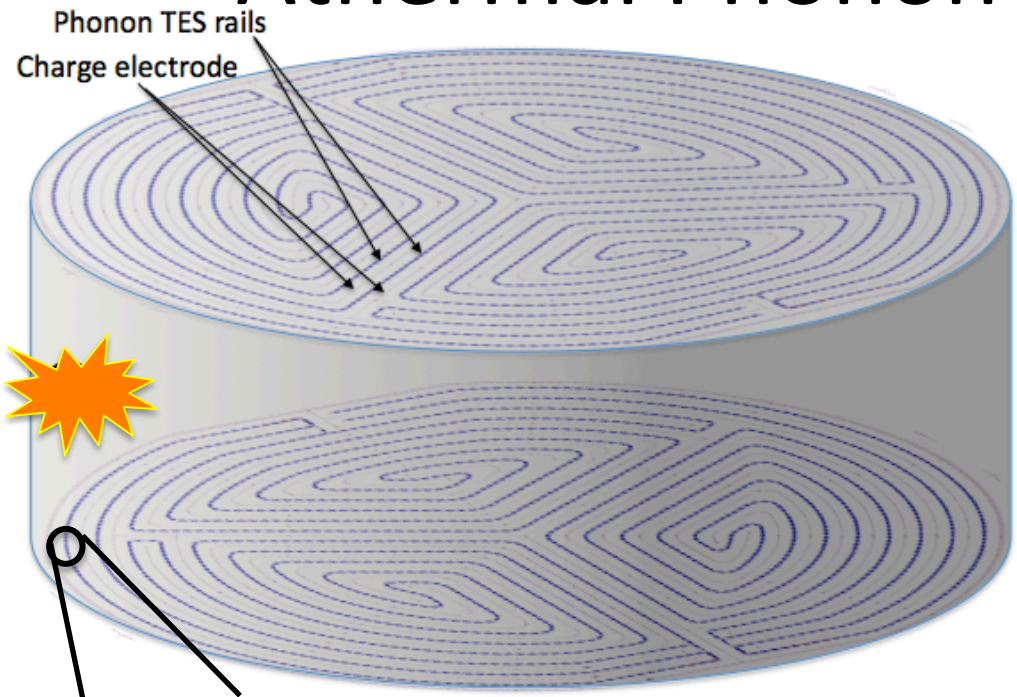
Studying 3D Charge Fiducial Volume

- 71,525 e^- / 16,258 ^{206}Pb recoils
- Rejection > 1.7×10^{-5} (8-100keV 50% NR Passage)

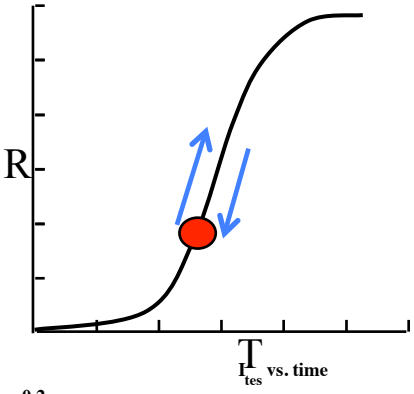


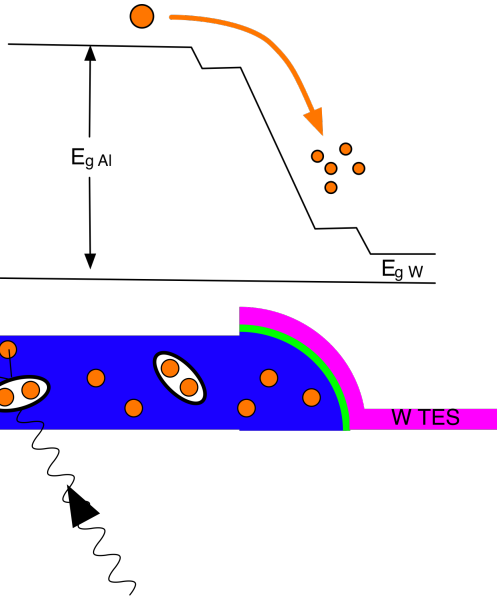


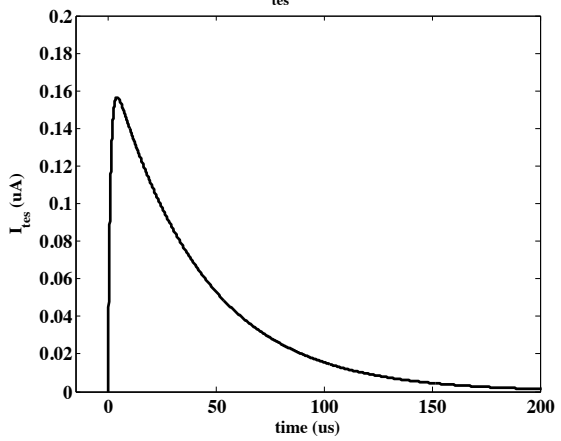
Athermal Phonon Measurement



Collect and Concentrate Phonon Energy into W TES (Transition Edge Sensor)

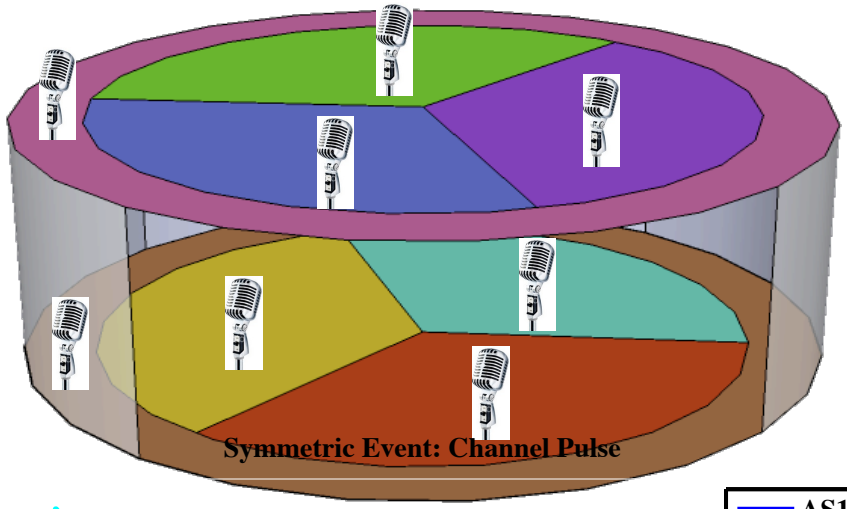


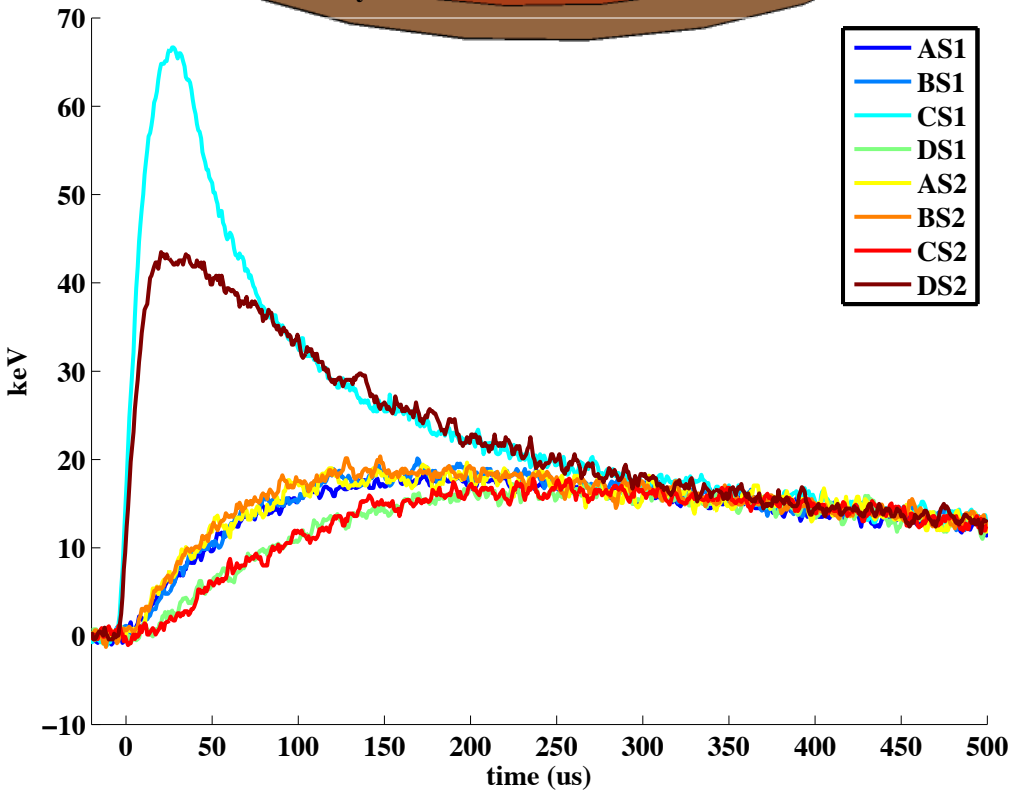




Athermal Phonon Advantages

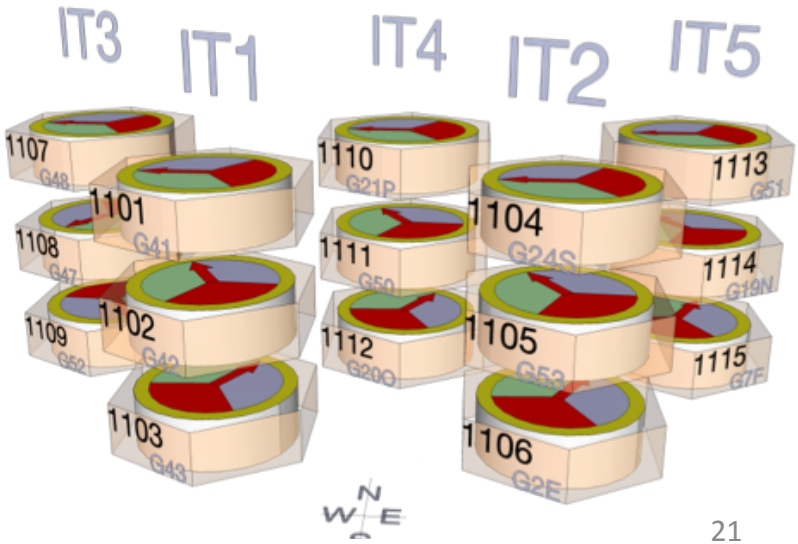
- Athermal phonons carry position information: 3D fiducialization possible in phonons as well
- insensitive to crystal heat capacity



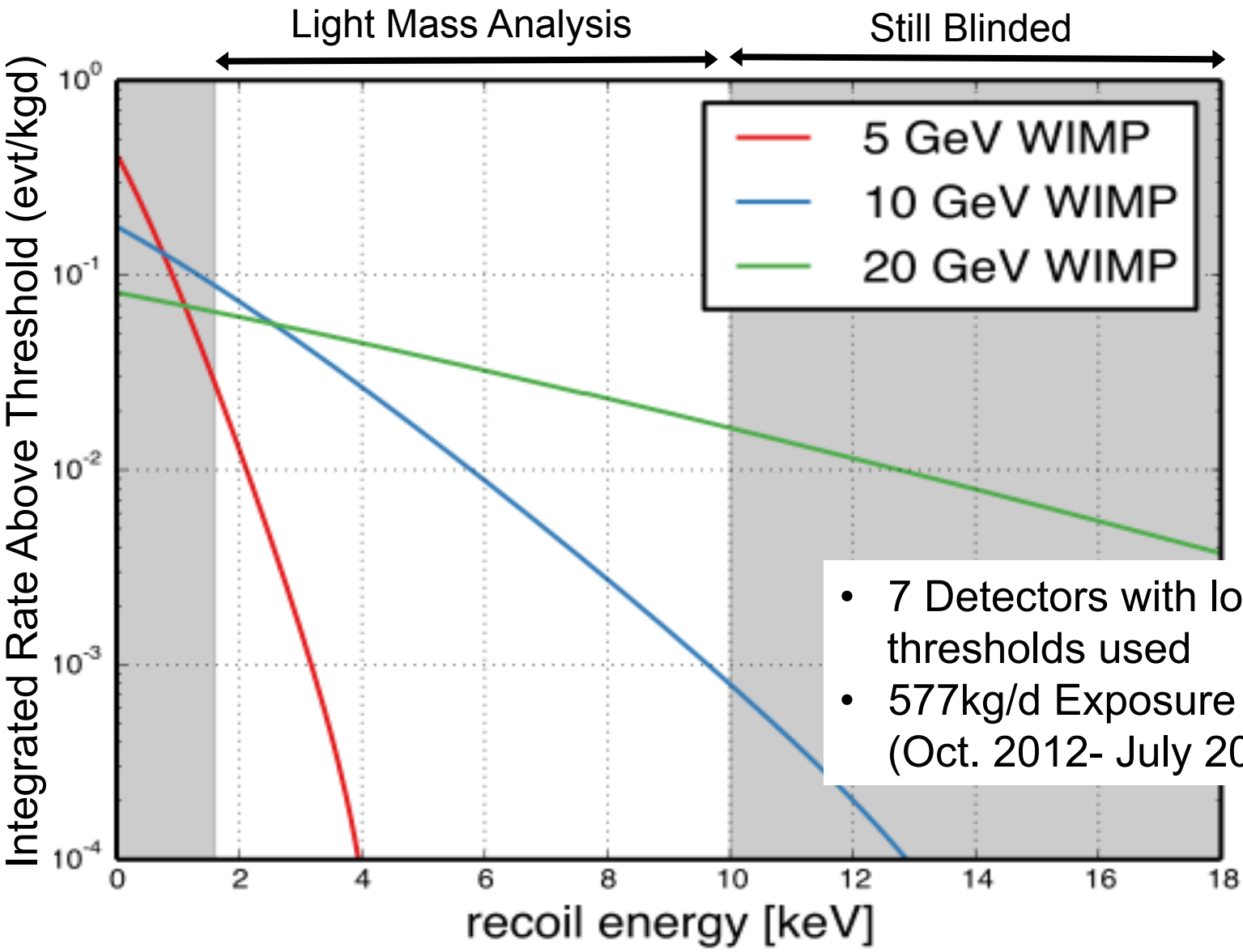


SuperCDMS Soudan: 1st iZIP WIMP Search

- 15 Ge iZIP running in Soudan since 2012
- 9kg total detector mass
- High WIMP Mass Analysis Ongoing
- 1st Light WIMP Mass Analysis Complete (1402.7137)



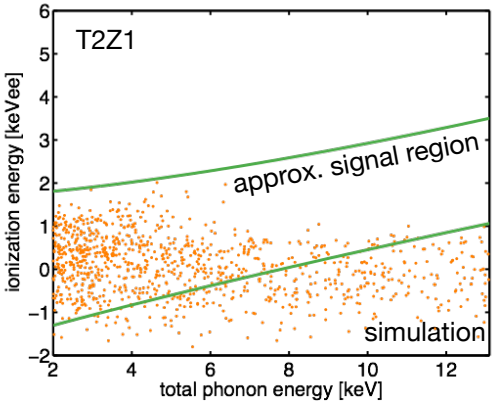
Analysis Strategy



- 7 Detectors with lowest thresholds used
- 577kg/d Exposure (Oct. 2012- July 2013)

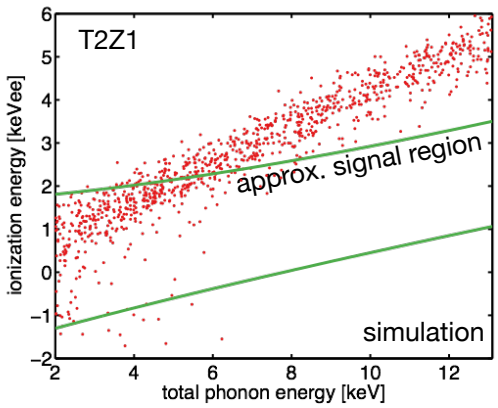
Understanding Backgrounds

^{210}Pb "surface events"



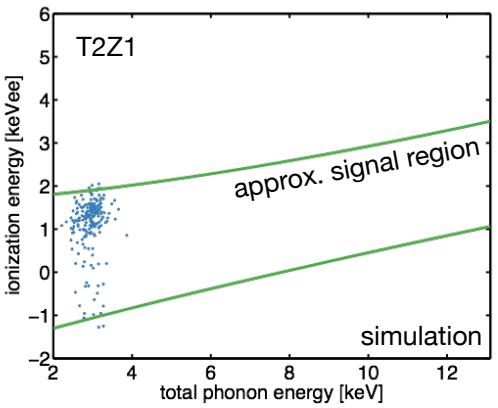
- betas and ^{206}Pb nuclei from ^{210}Pb decay chain due to surface ^{222}Rn contamination
- Q & P Fiducial Volume Cuts
- Most difficult background to understand (no calibration data only sidebands)
- Before unblinding chose to set upper limit

External gammas

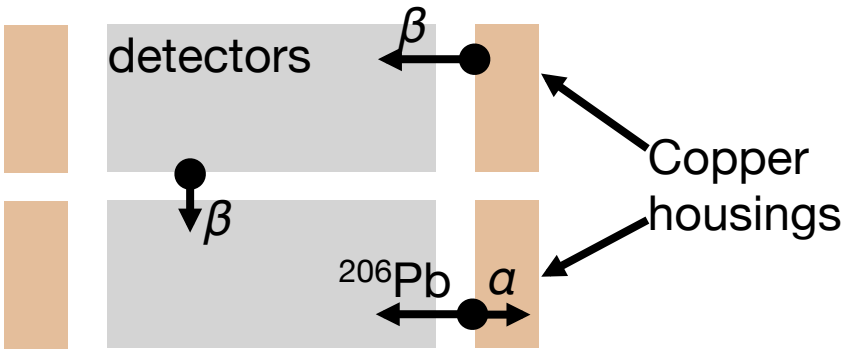


- Radioactivity in shielding and cryostat
- Ionization Yield

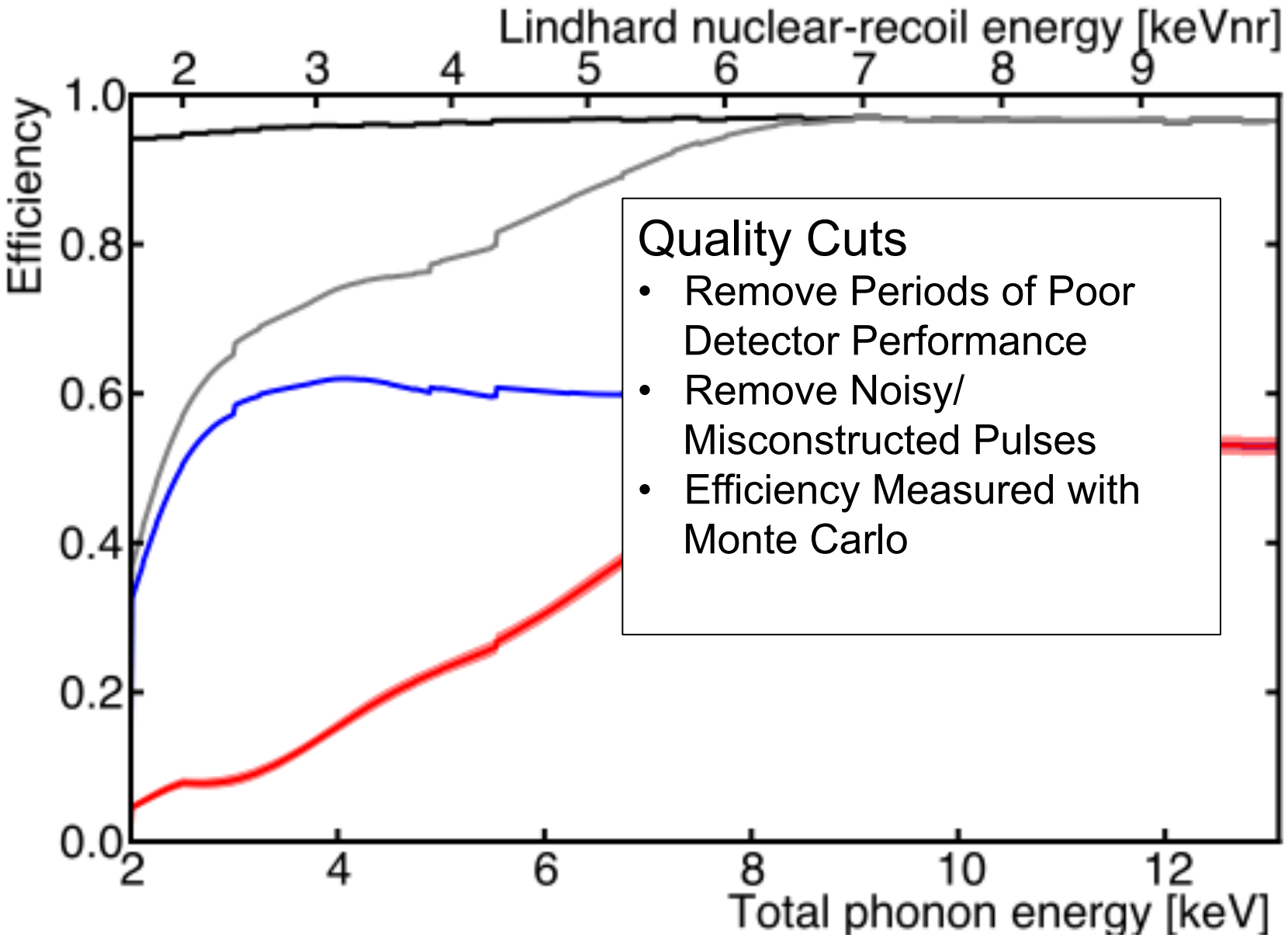
Internal activation lines



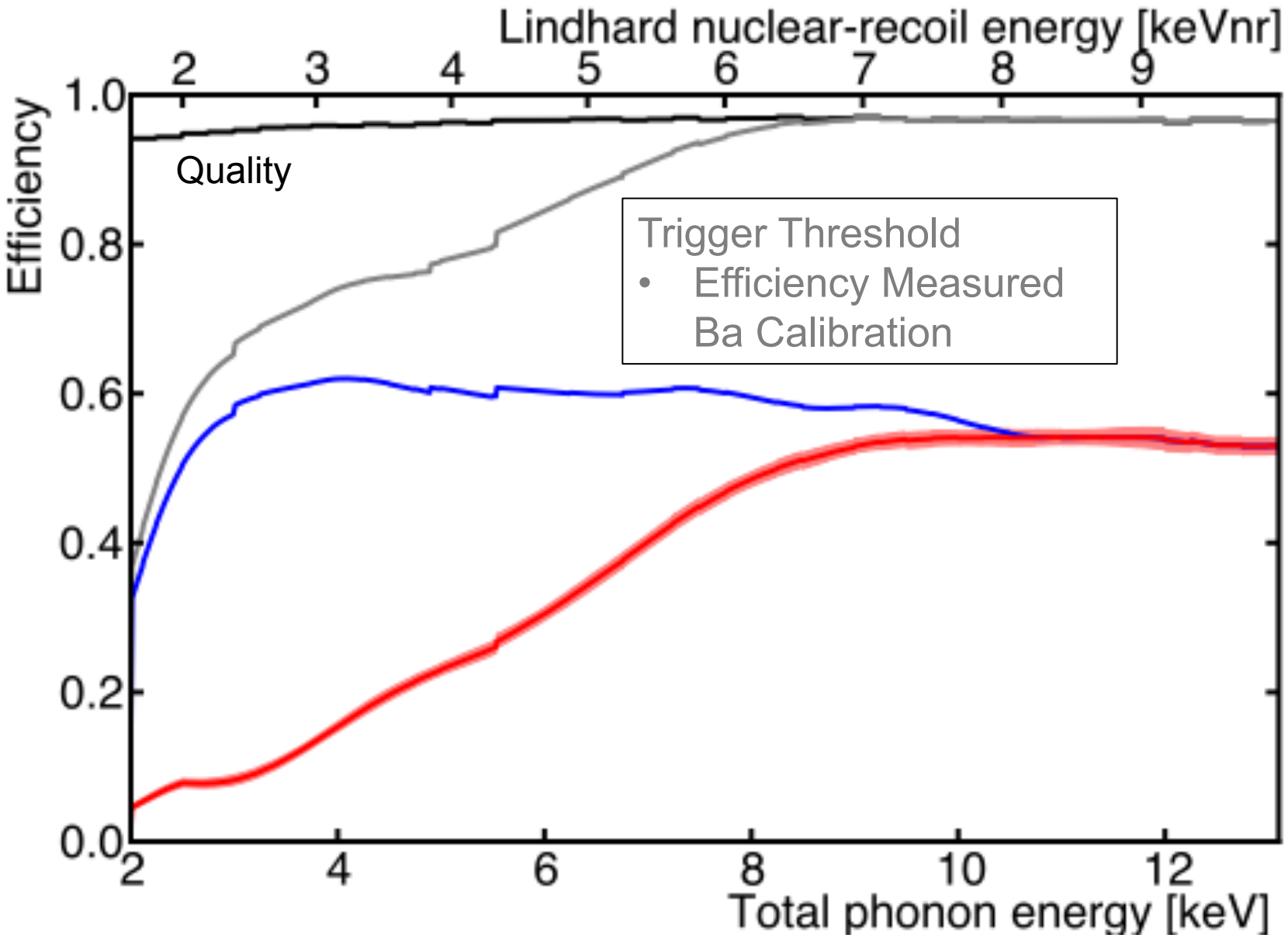
- Cosmogenic Activation
- Ionization Yield



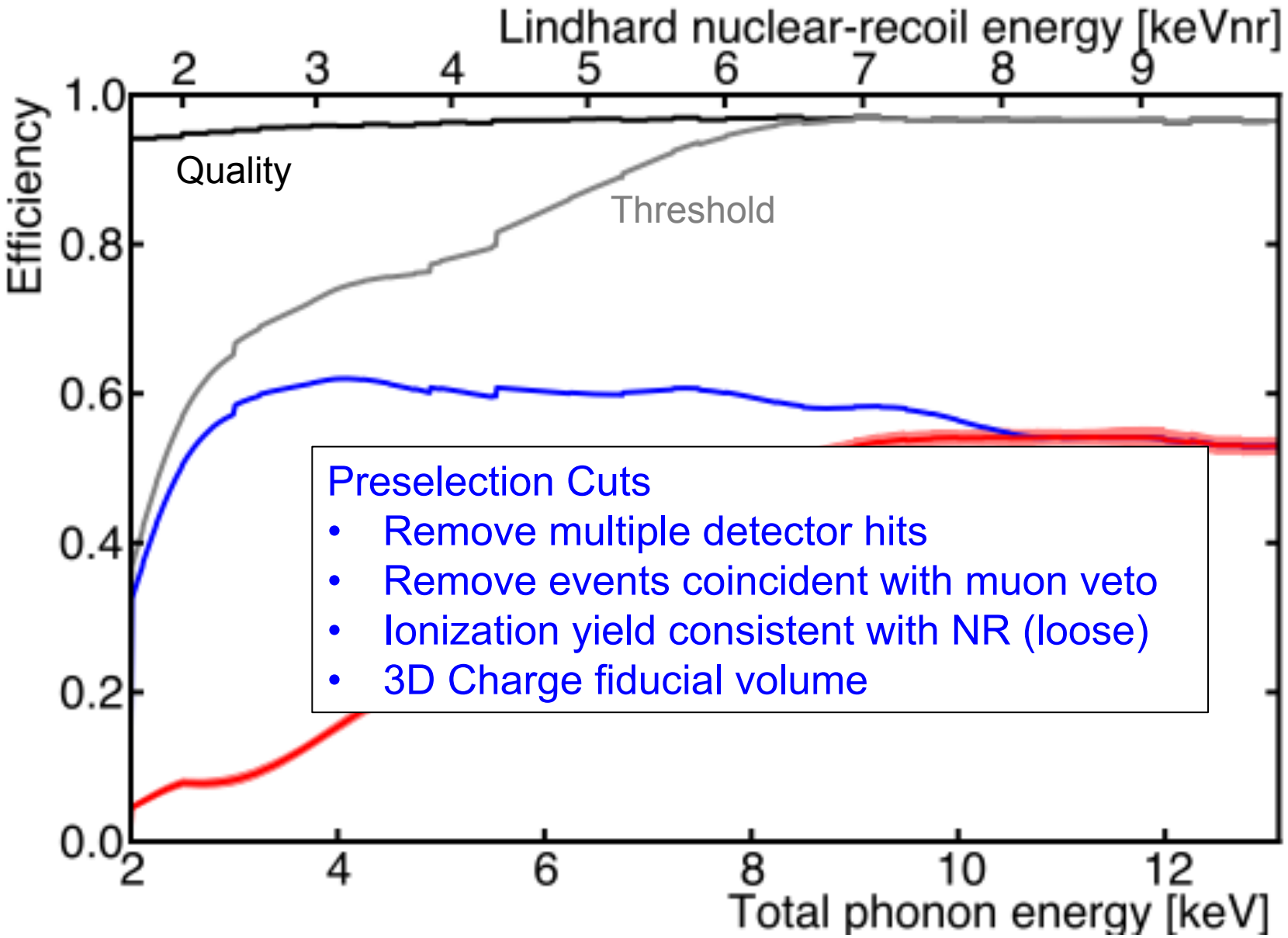
Event Selection



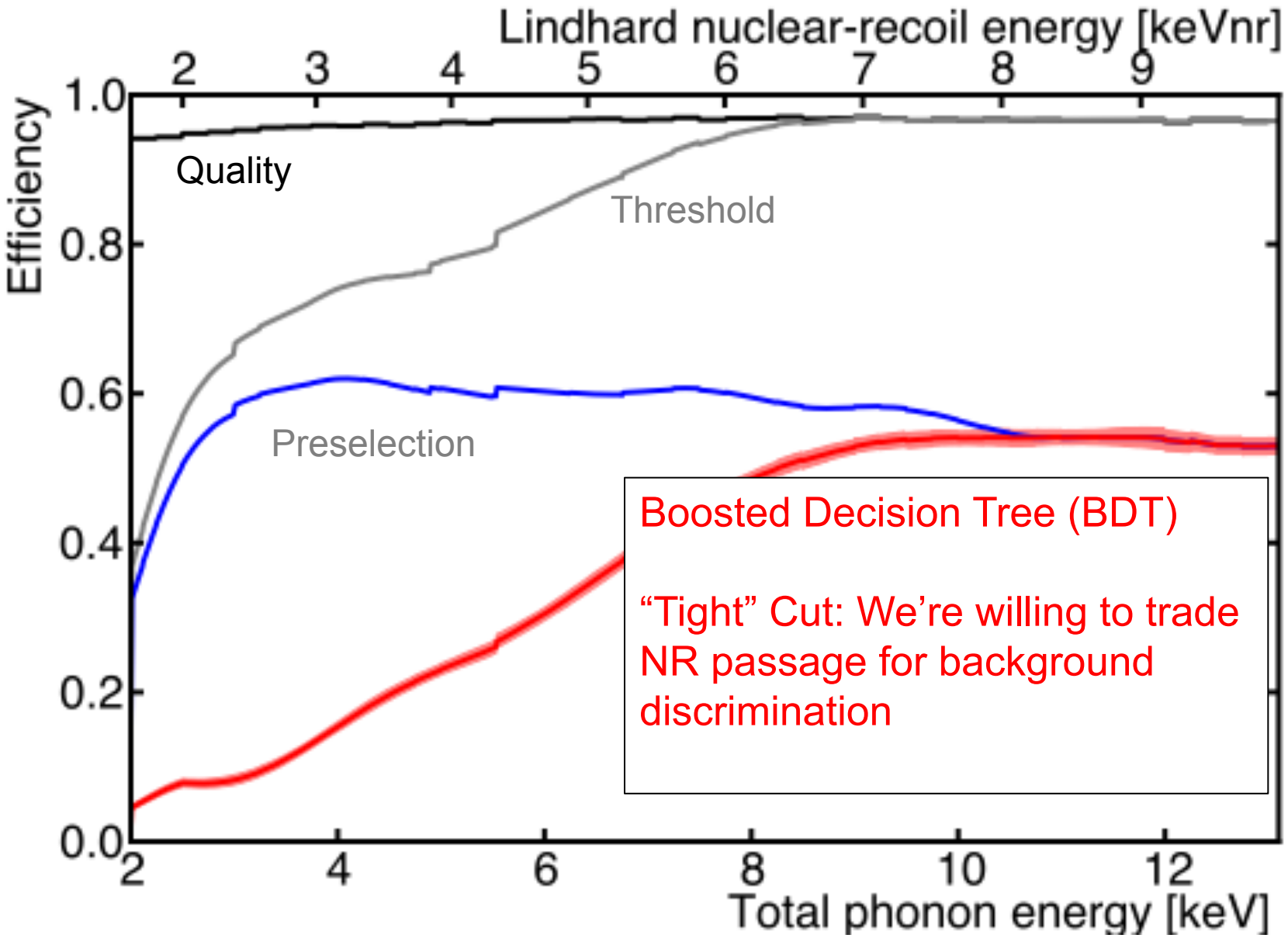
Event Selection



Event Selection

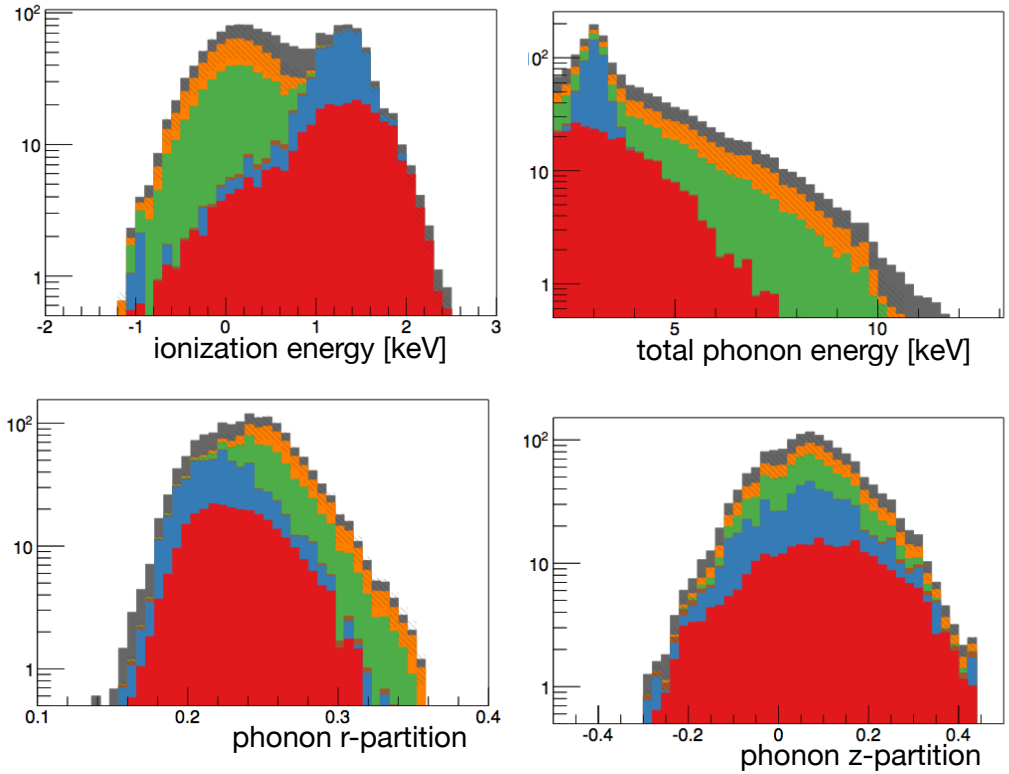


Event Selection

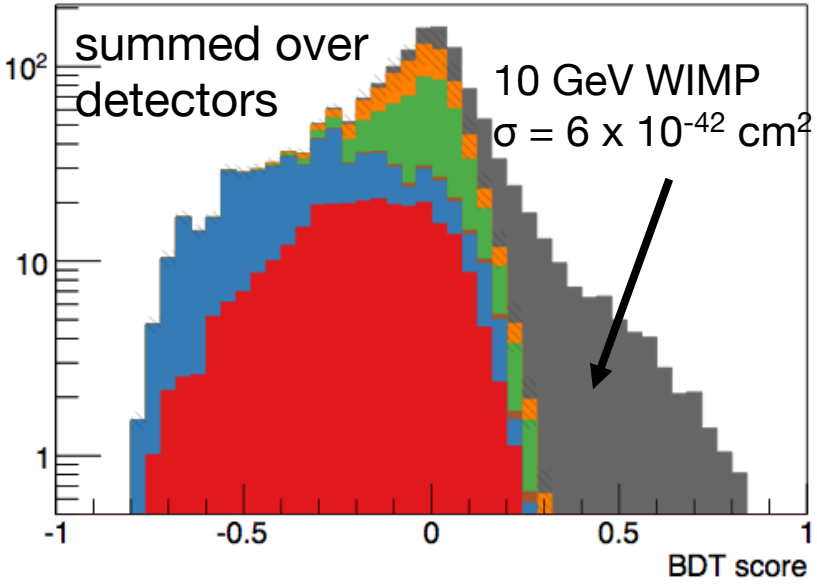


Boosted Decision Tree

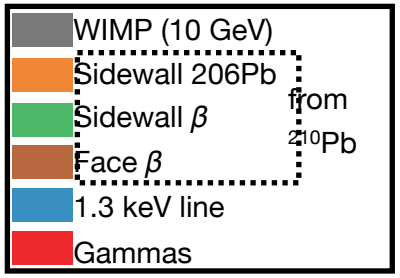
BDT inputs



BDT output

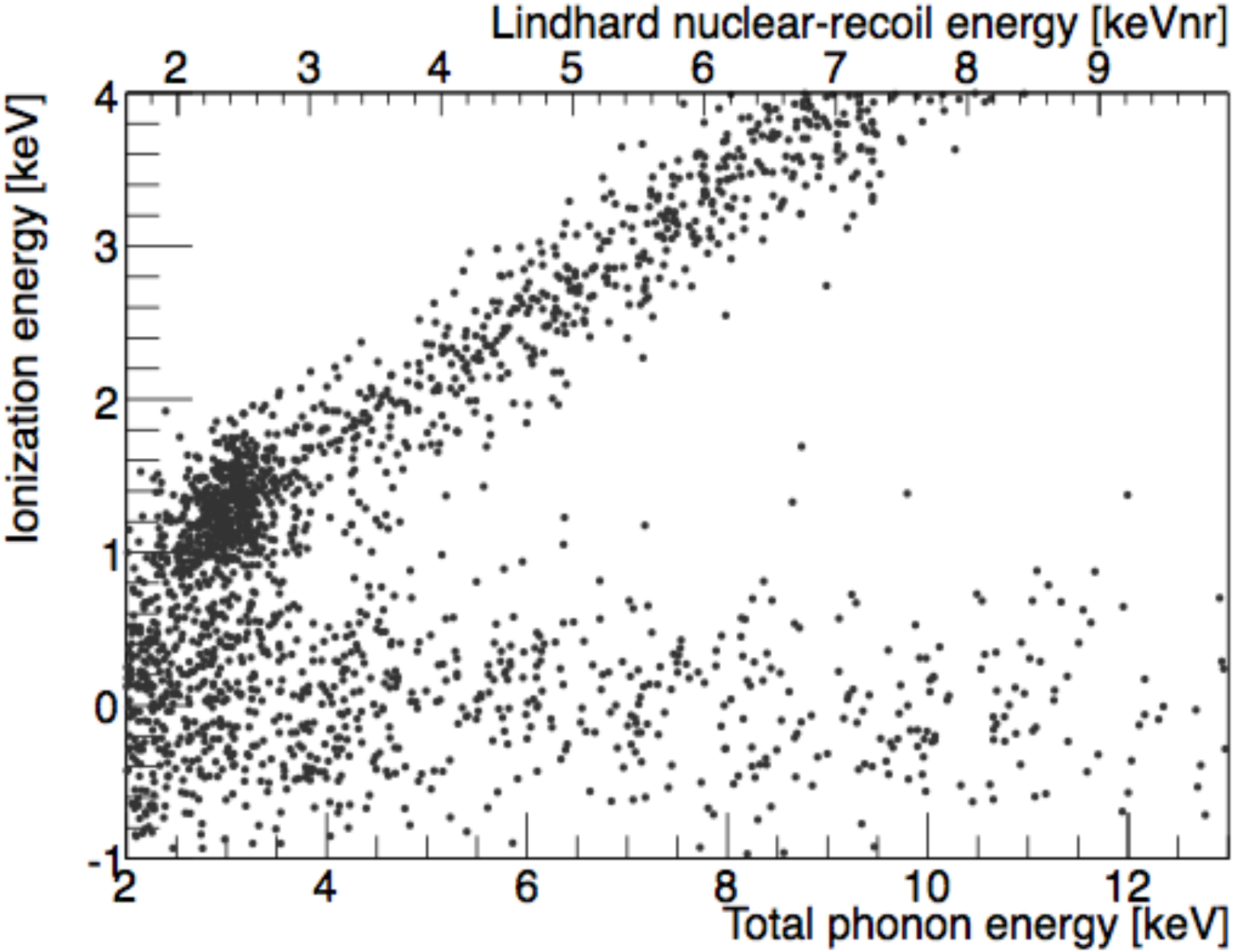


Background model: pulse simulation
Signal model: ^{252}Cf NR events reweighted to match 5, 7, 10, and 15 GeV WIMP

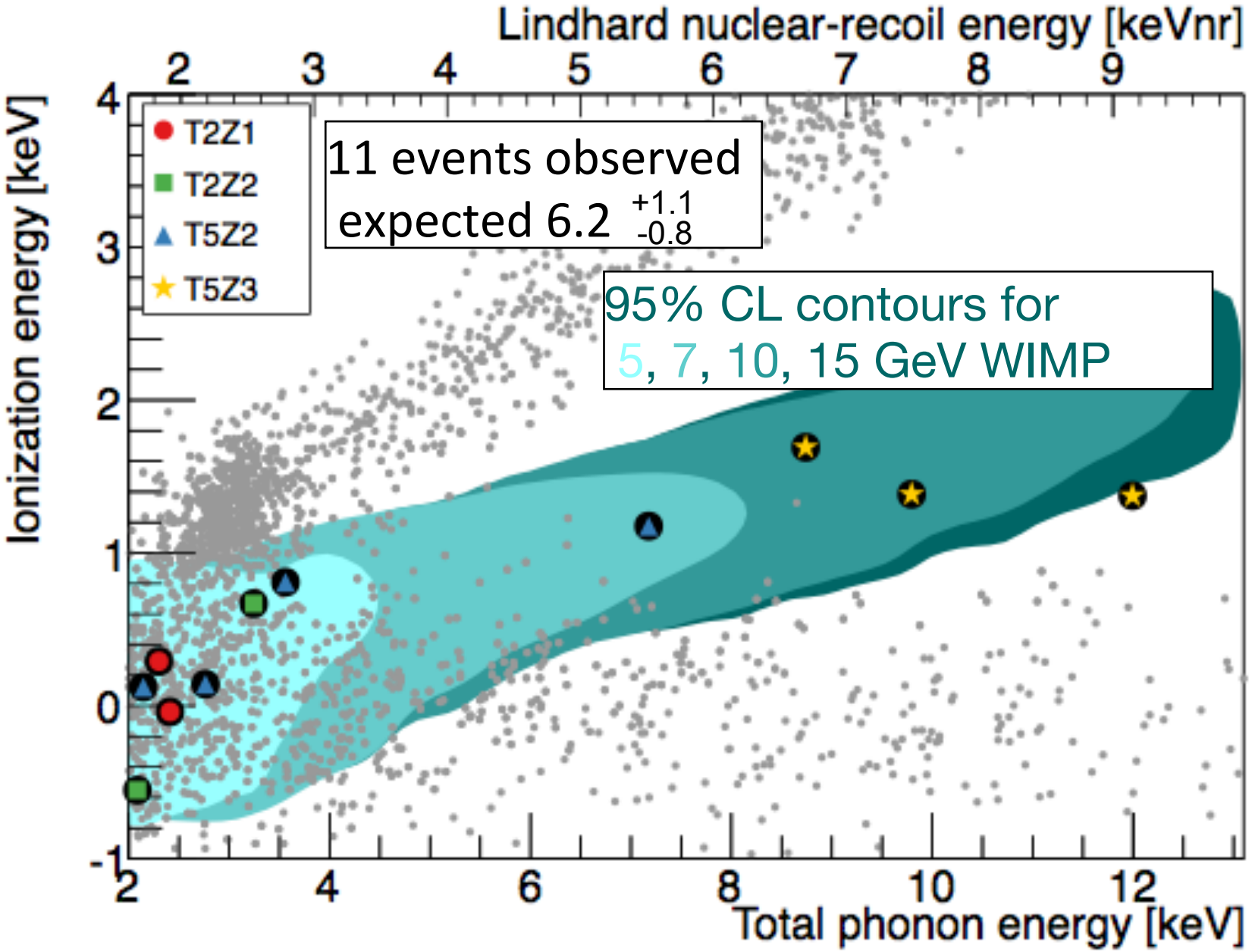


Construction: 1 BDT per detector
Optimization: set cuts simultaneously to minimize expected 90% CL upper limit on WIMP-nucleon cross section

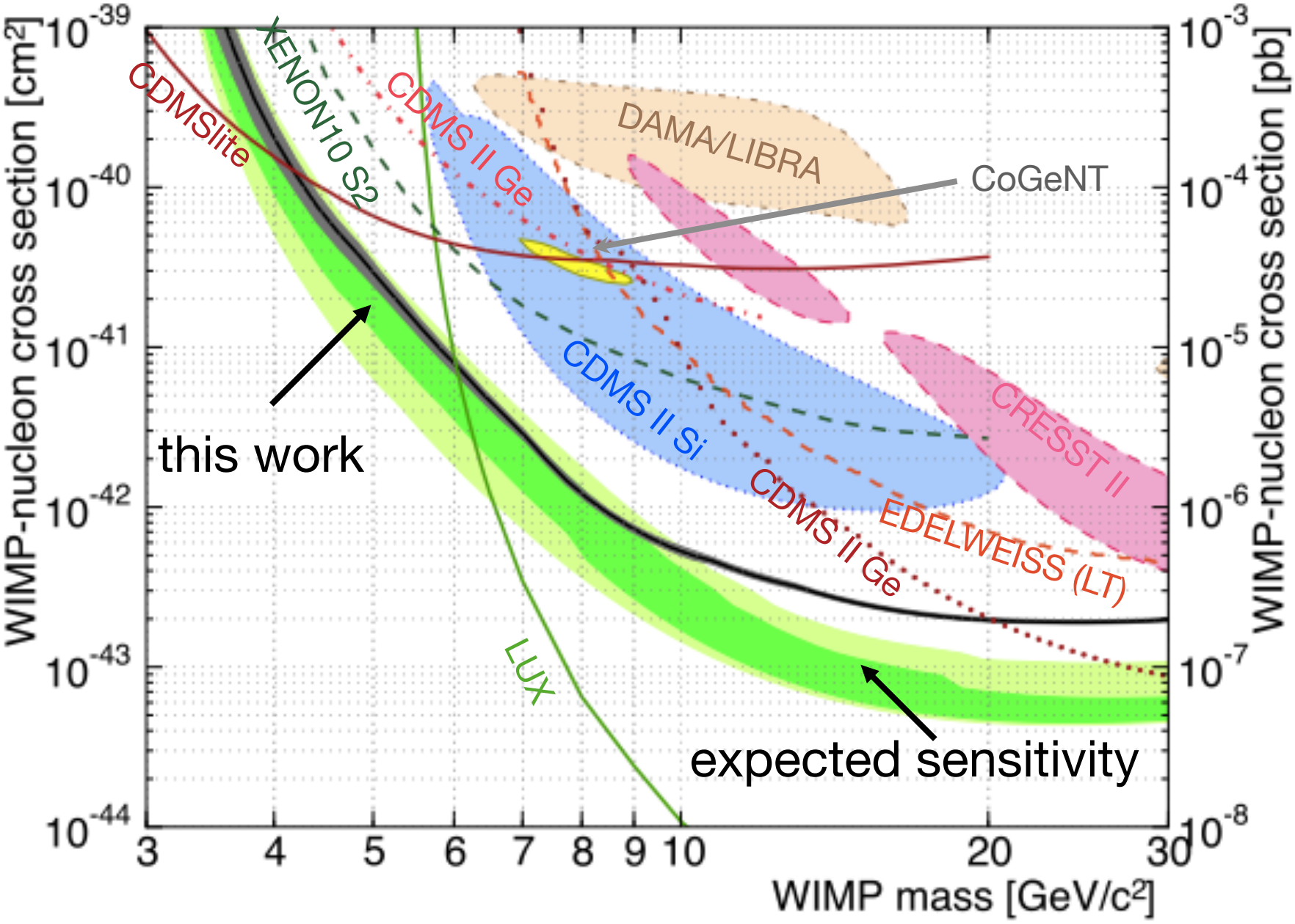
Before BDT & Ionization Yield



After All Cuts



SuperCDMS Light Mass Sensitivity



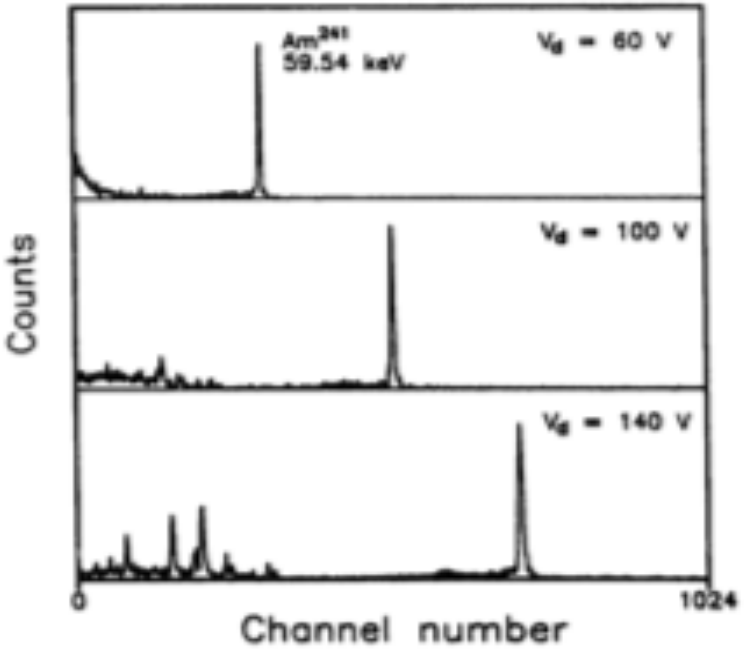
Luke-Neganov Phonons: Reprised

$$E_{total} = E_{recoil} + E_{luke}$$
$$= E_{recoil} + QeV$$
$$= E_{recoil}\left(1 + \frac{YeV}{< E_{eh} >}\right)$$

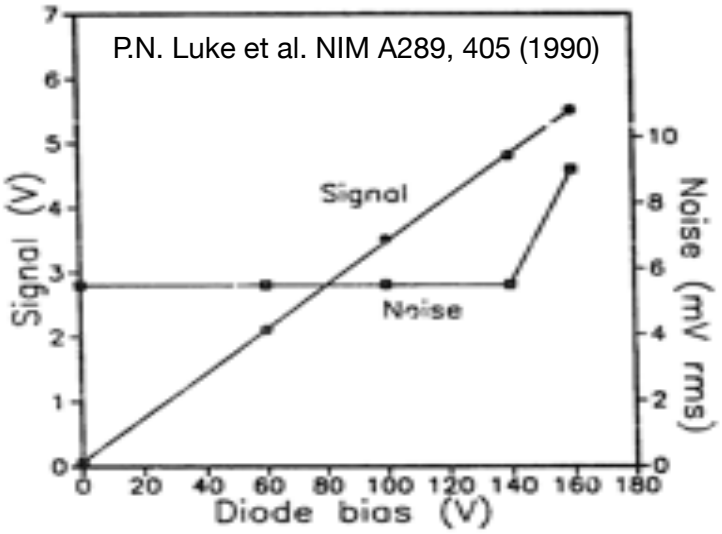
At high voltage, total phonon signal becomes a measure of the amount of charge produced

- Bad: No ER/NR discrimination through Ionization Yield
- Good: You've made a phonon amplifier for charge

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

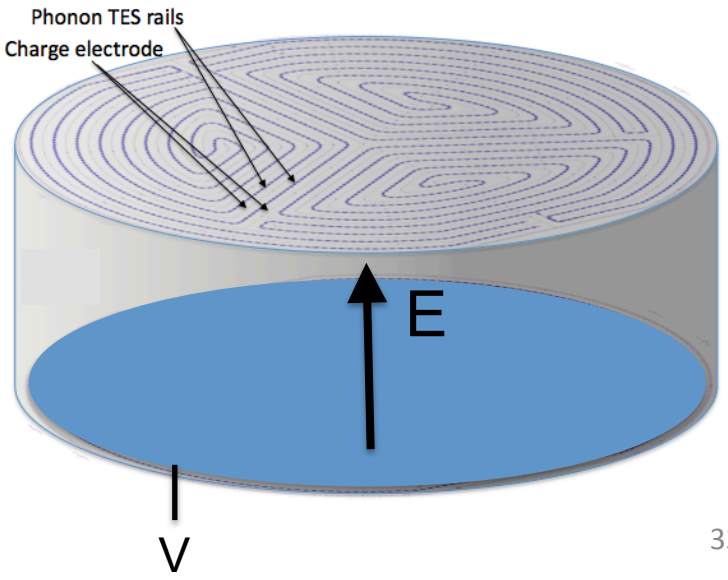


∞ Luke-Neganov Gain?



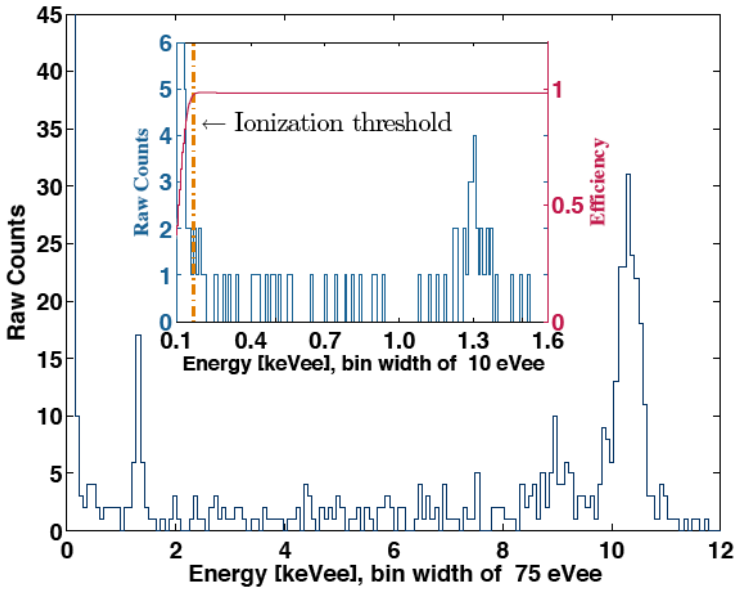
- Charge Breakdown Limits Luke-Neganov Gain
- What's $V_{breakdown}$ for our detectors?
- Test Setup: Unplug 1 side of an iZIP

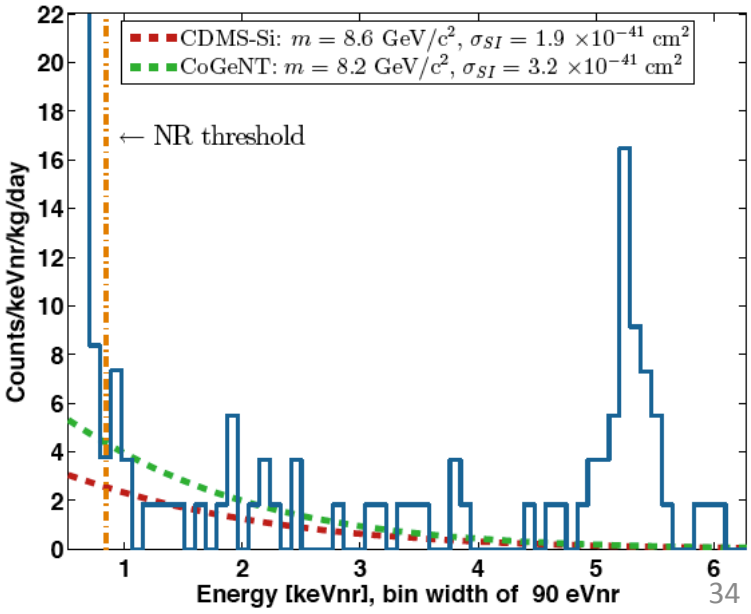
- $E_{breakdown}$ 27V/cm (69V)
- This is a really low breakdown field
- Luke Gain:
  - ER = 24
- Charge Resolution: 14eVee
  4.7 e^-/h^+ pair
  - CoGENT: 50eVee
  - We lose ½ our phonon signal
  - noise in electronics setup not ideal



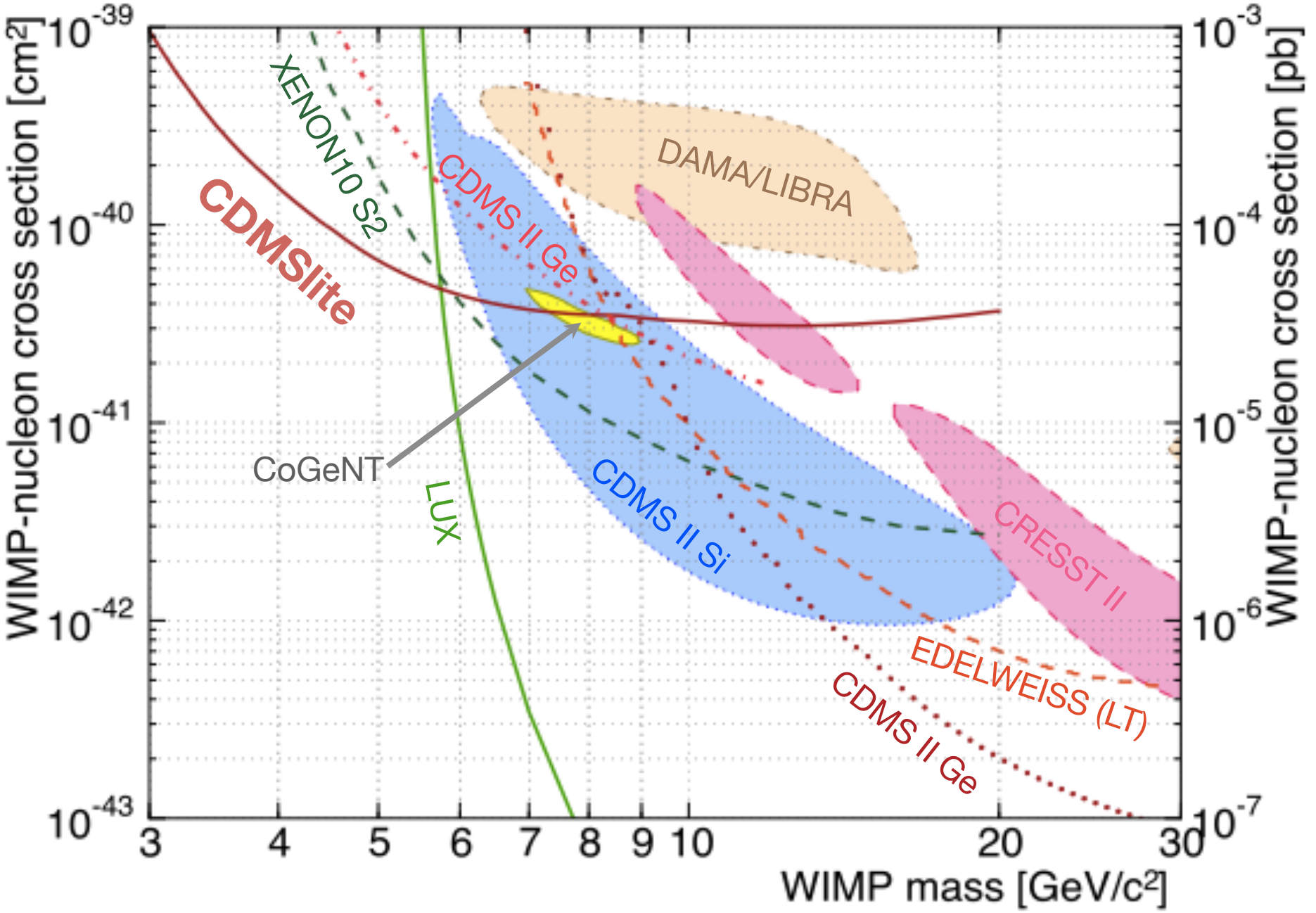
CDMSlite: “low ionization threshold experiment”

- 6kgd Exposure
- Threshold:
  - 170eVee
  - 12 σ (yikes!)
- Only Quality Cuts
- PRL **112**, 041302 (2014)



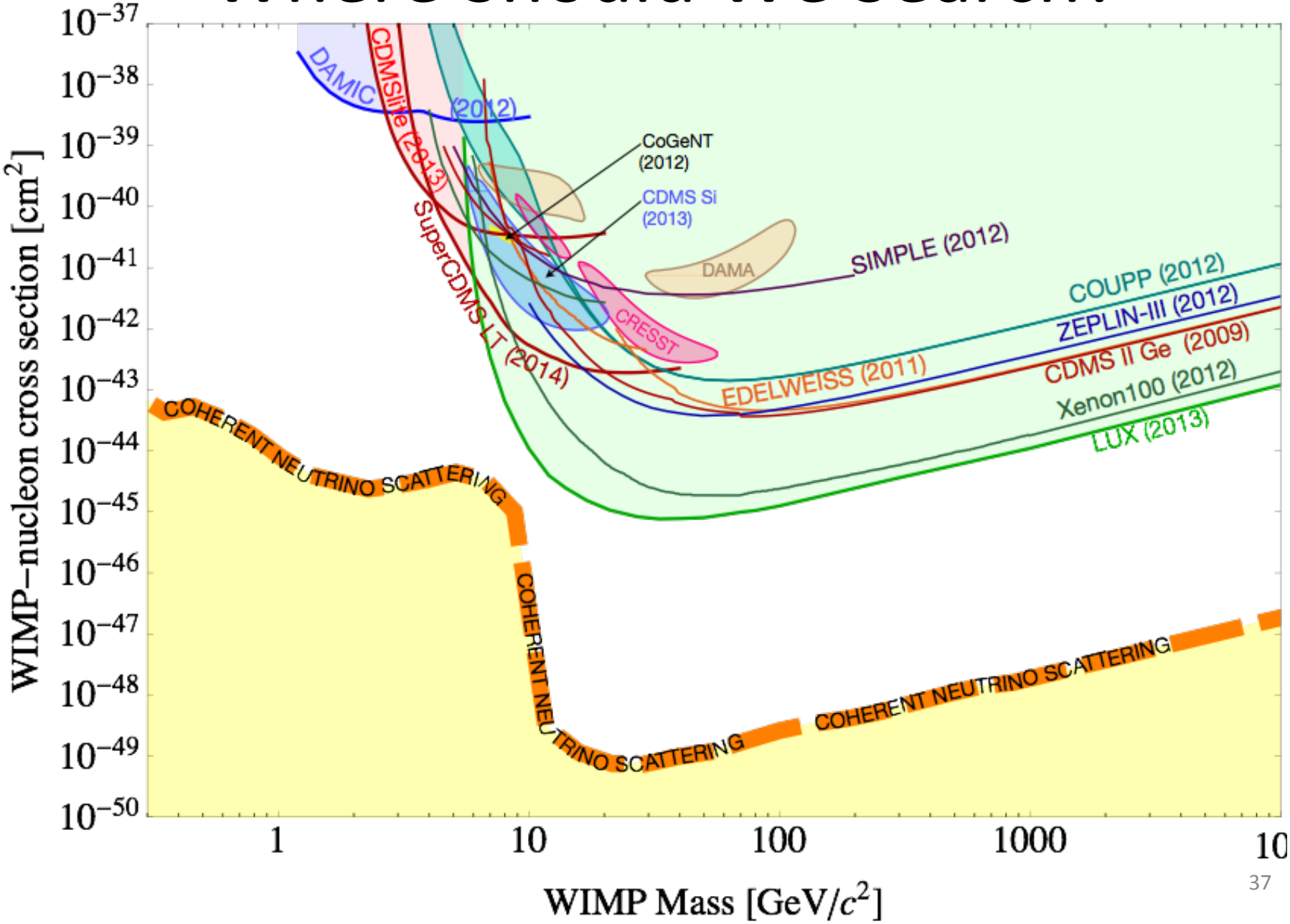


CDMSlite WIMP Sensitivity

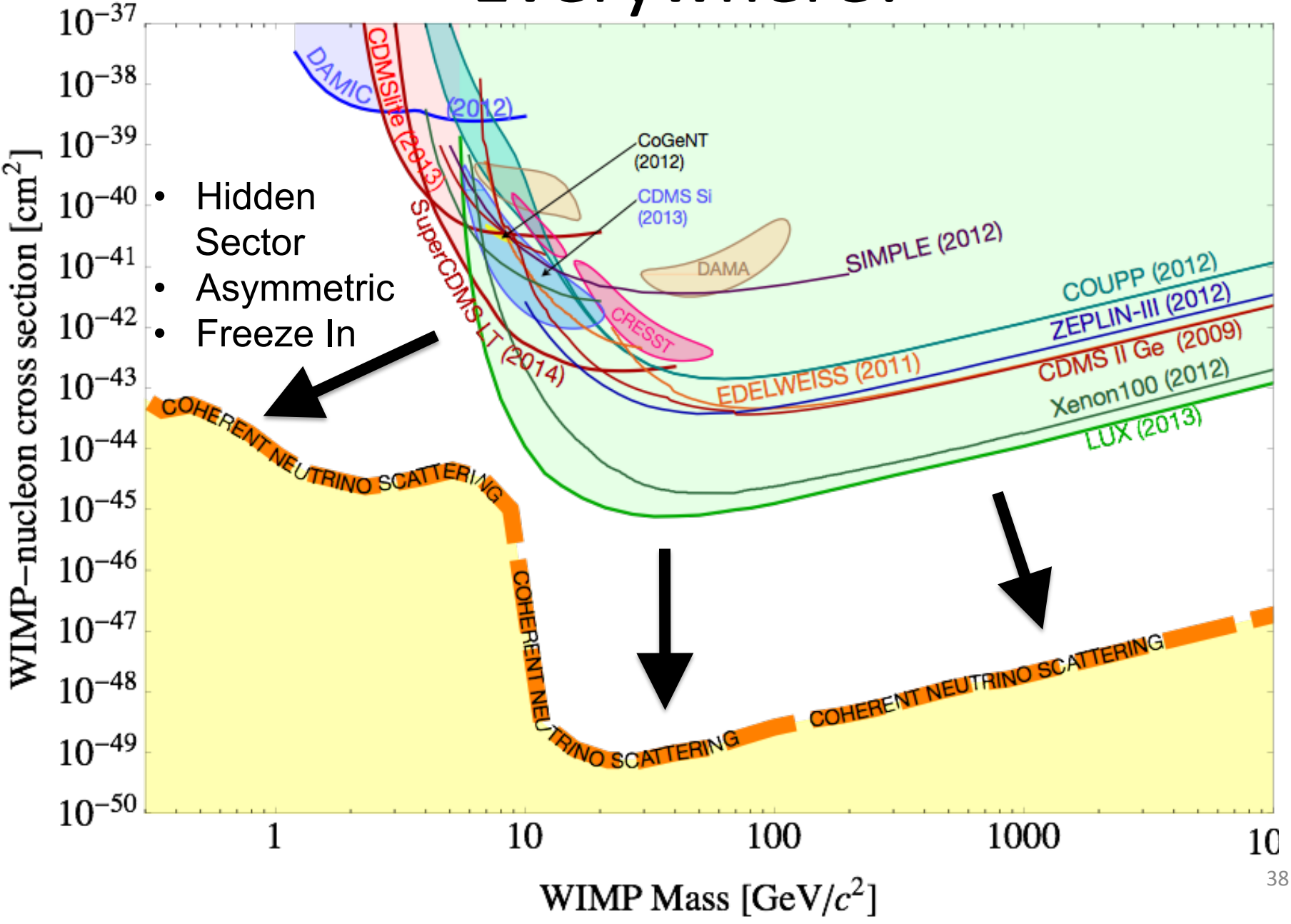


FUTURE

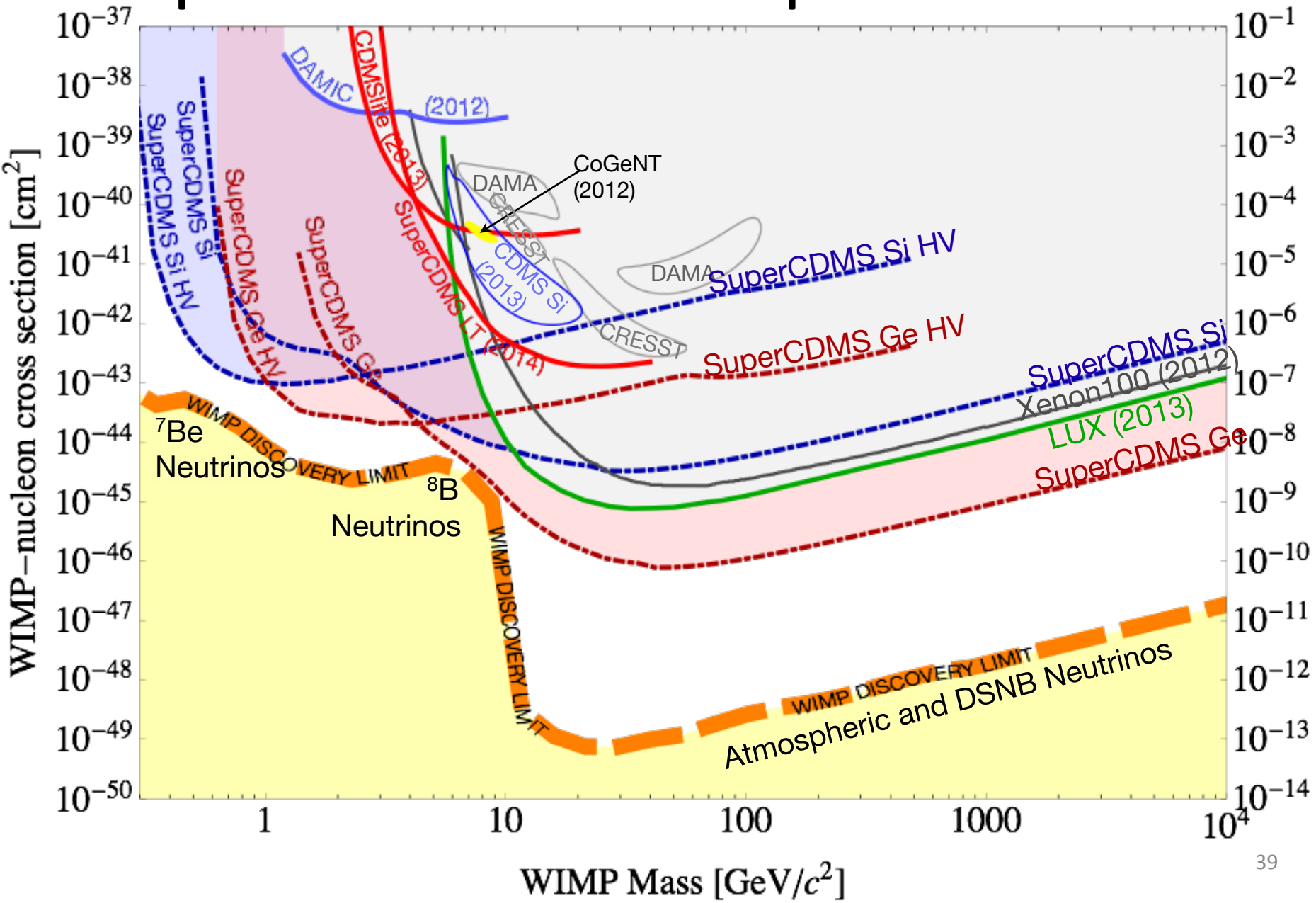
Where Should We Search?



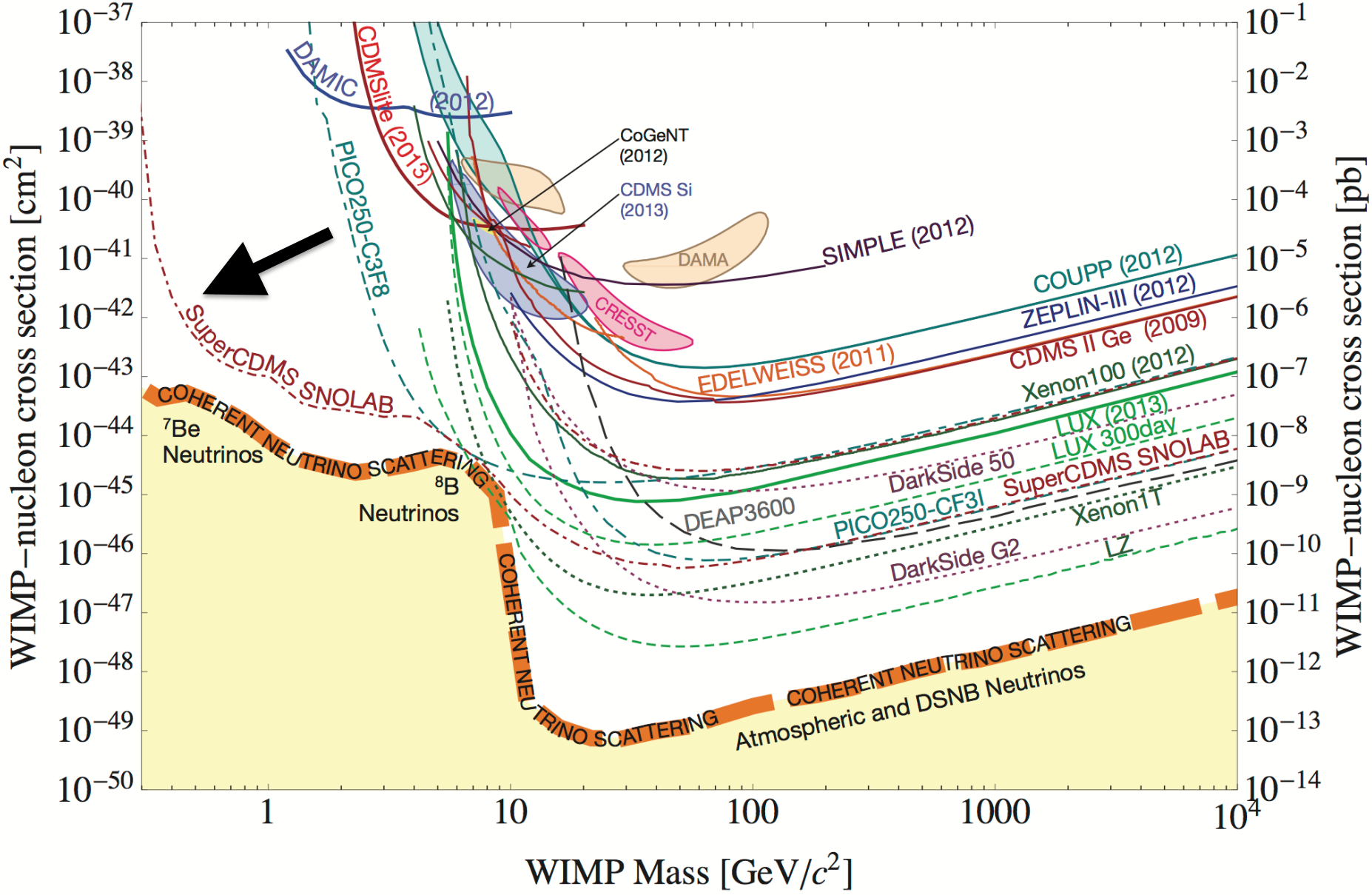
Everywhere!


• Hidden Sector
• Asymmetric
• Freeze In
DAMIC
CDMSlite (2013)
(2012)
SuperCDMS LT (2014)
CoGeNT (2012)
CDMS Si (2013)
DAMA
CRESST
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
Xenon100 (2012)
LUX (2013)
COHERENT NEUTRINO SCATTERING
COHERENT NEUTRINO SCATTERING
COHERENT NEUTRINO SCATTERING
WIMP–nucleon cross section [cm^2]
WIMP Mass [GeV/c^2]
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
1
10
100
1000

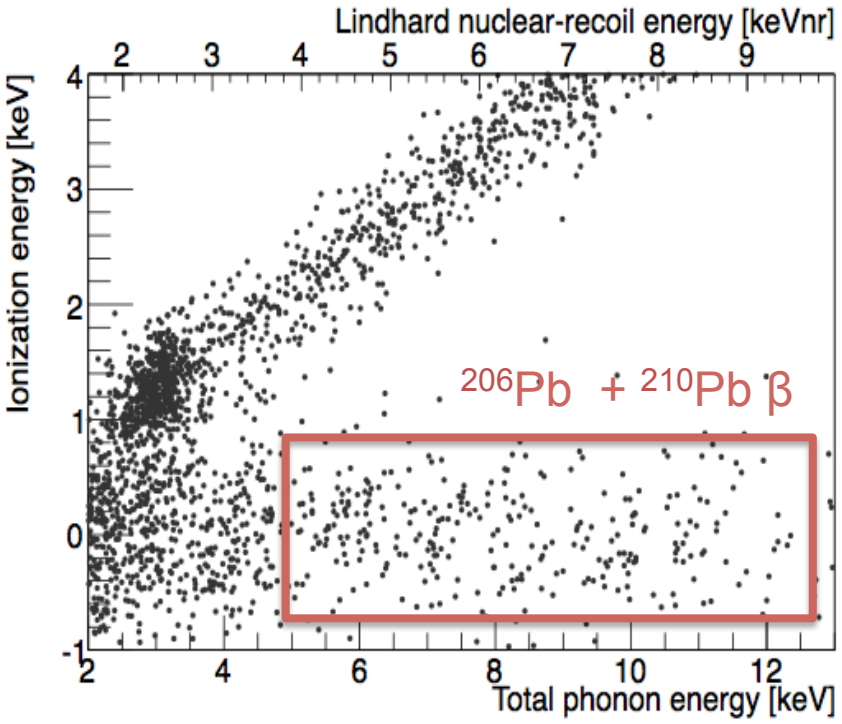
SuperCDMS G2: 4 Experiments in 1

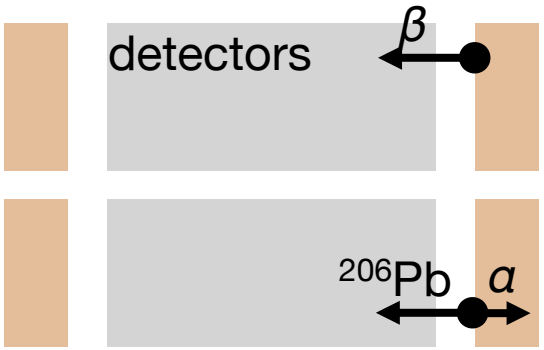


G2: The Entire Community



SuperCDMS G2: Improving Backgrounds





Soudan 210Pb Surface Contamination	α Rate (evt/cm^2/d)	^{206}Pb Singles Rate (evt/kgyr)
Ge/Si	2.2×10^{-3}	7
Cu Housing	4.8×10^{-2}	900

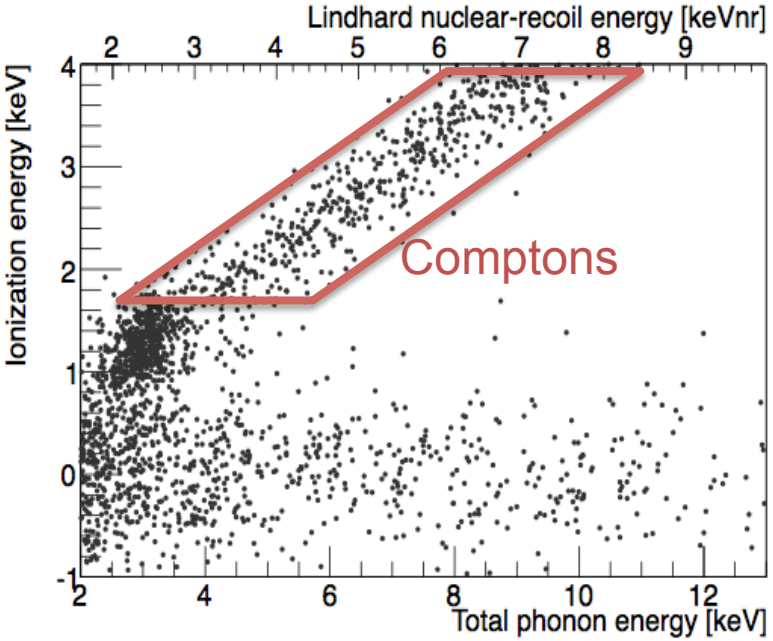
We need cleaner copper

- G. Zuzel and M. Wojcik NIM A 676 (2012)
- Electro-polishing Cu: x346 reduction in ^{210}Pb

G2 assumptions:

- x22 reduction in Cu contamination ($R_{singles}$ 40 evt/kgyr)
- No reduction in Ge/Si contamination

SuperCDMS G2: Improving Backgrounds



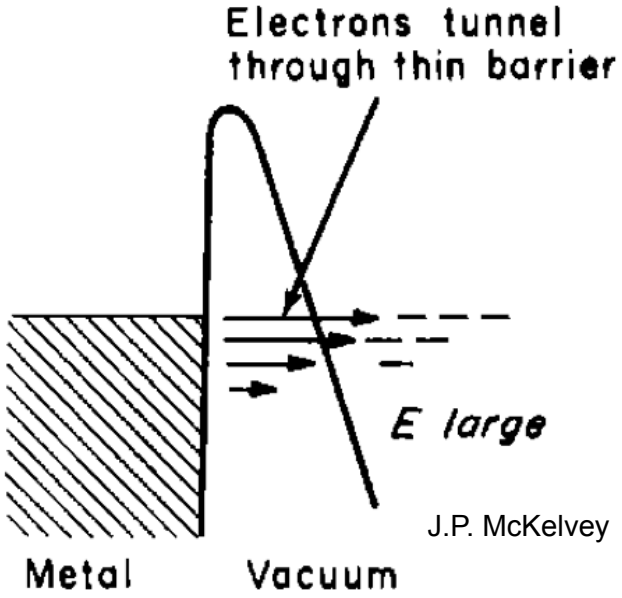
- Soudan Photon Rate: 1100 evt/keVr/kgyr
- Wasn't a priority for CDMS II Soudan. We had ER/NR Discrimination at high energies

SNOLAB: 5evt/keVr/kgyr (x 220)

		U (mBq/kg)	Th (mBq/kg)	K (mBq/kg)
Polyethylene	DEAP/CLEAN (unpublished)	0.03	0.02	0.1
Cu	Xenon 100 (arXiv: 1103.5831)	0.07	0.02	0.03
Pb	Xenon 100	0.8	0.5	1.5

SuperCDMS G2: Charge Breakdown

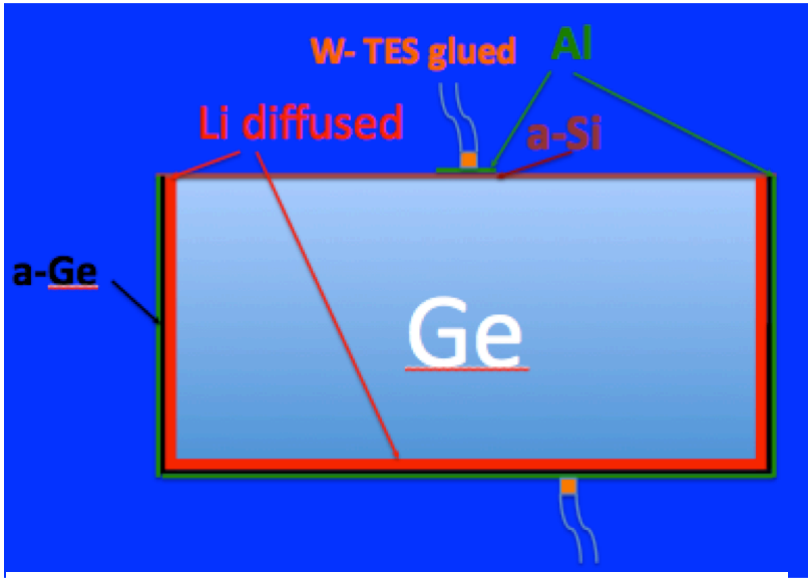
- CDMS $E_{breakdown} < 25V/cm$
- 77K Ge diodes: $E_{breakdown} > 1000V/cm$
- Why so low?
  - Impact Ionization?
  - Leakage through electrodes?
  - Conduction along the bare Ge Surface?
  - ?
- UCB / TAMU / LBNL: Active Research Effort

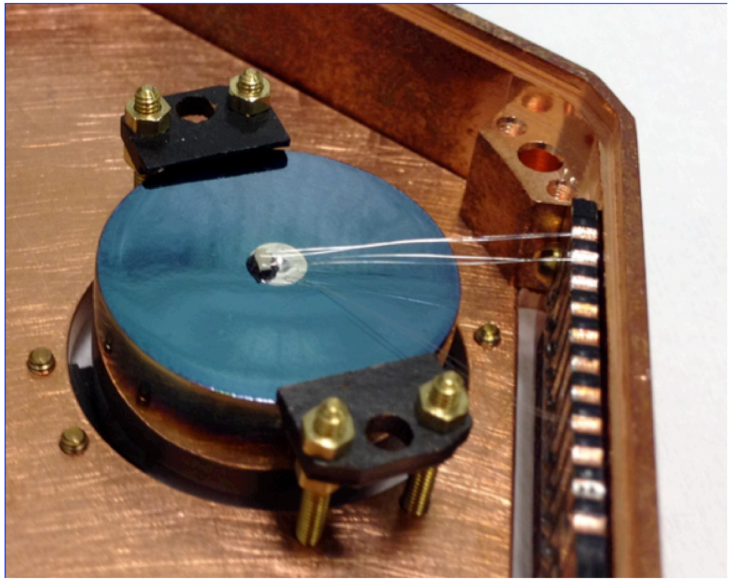


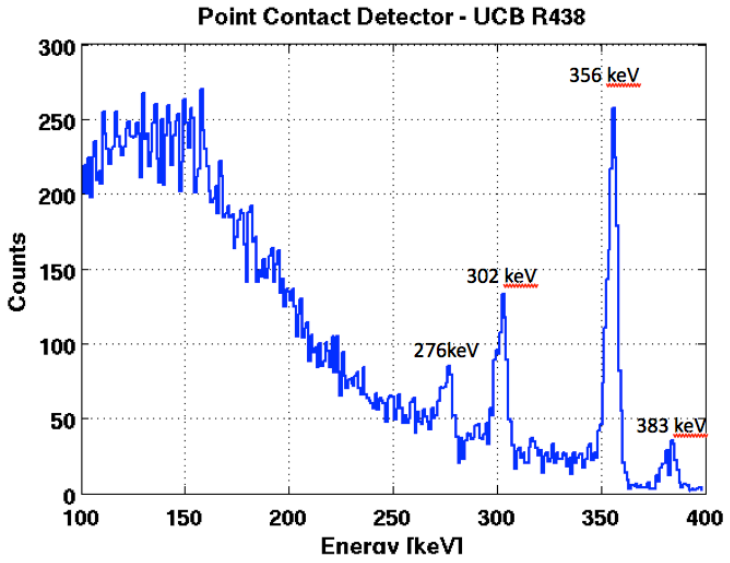
1) PPC with thermal phonon readout

- Φ=20 mm, h=10 mm p-type Ge: 10^{10} cm^{-3}

- The thermistor glued (Stycast 1066 epoxy) to substrate and only measures thermal phonons.

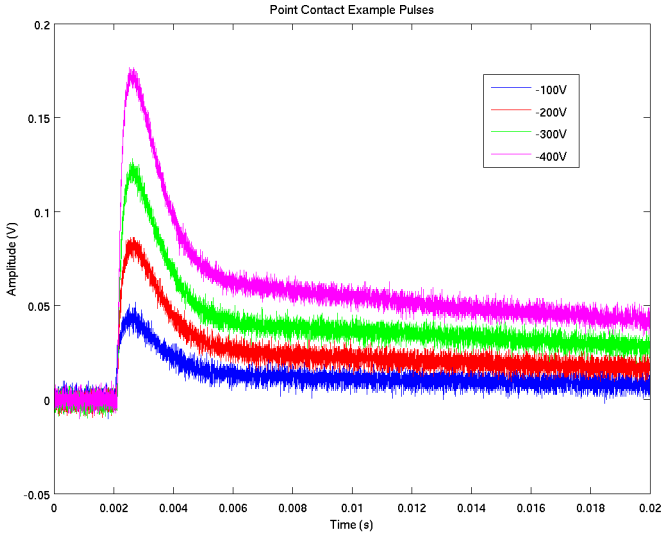


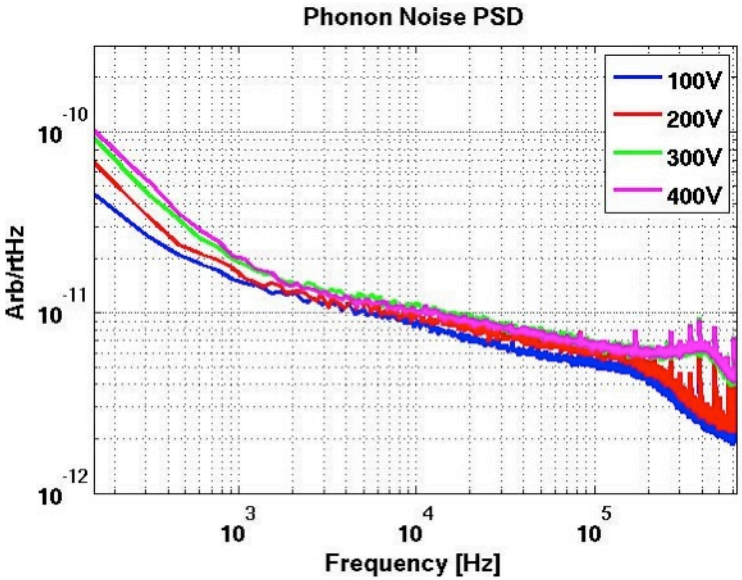


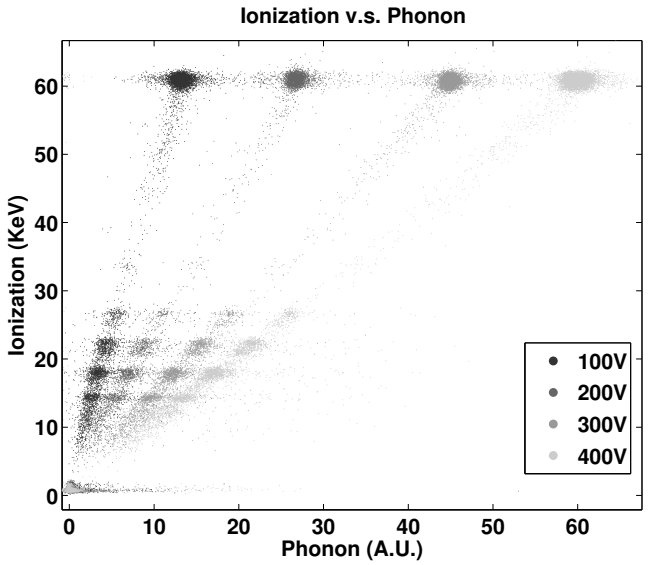


PPC thermal performance

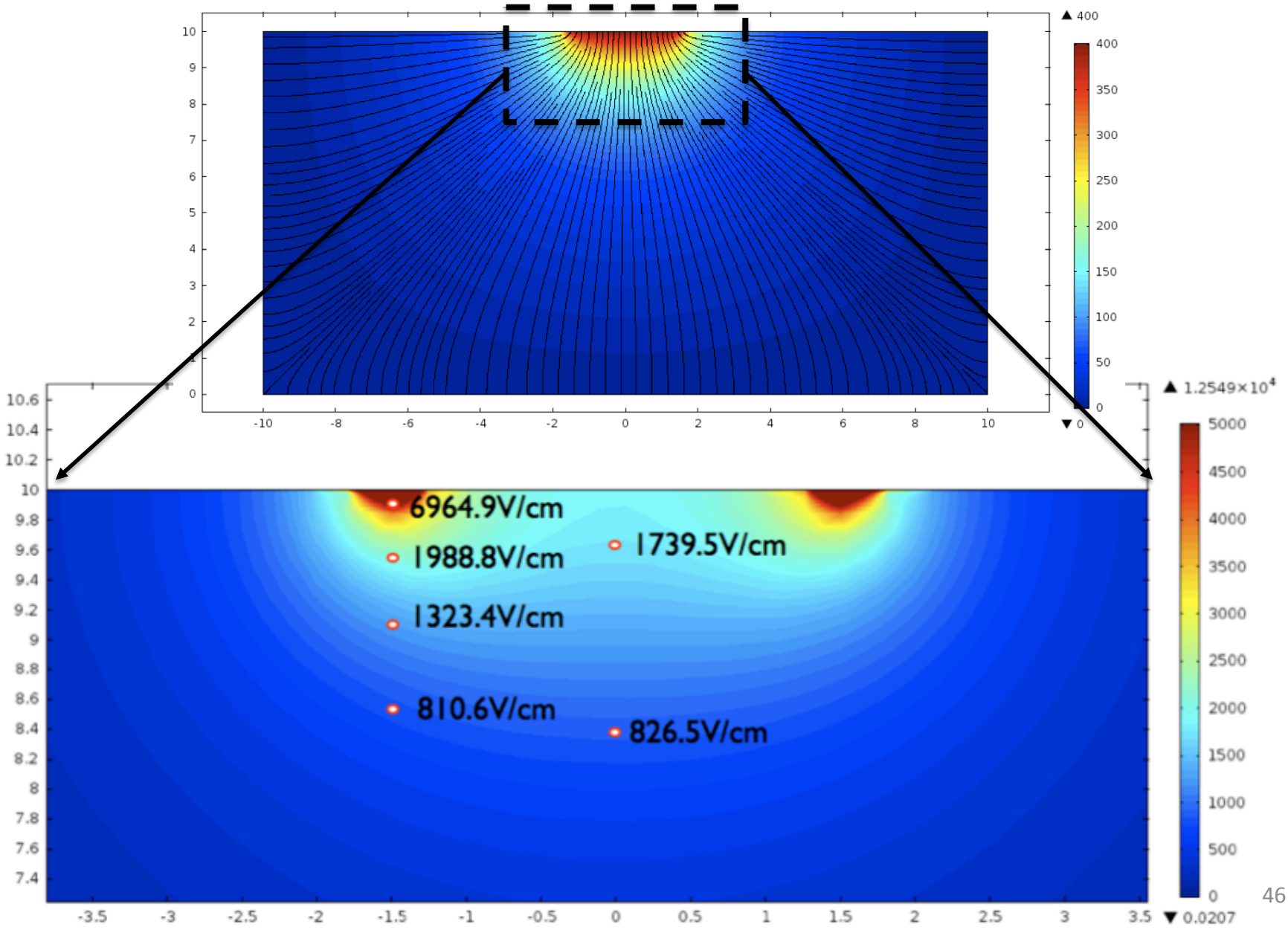
- Found no break down for Vbias up to +400 Volt
- Phonon signal increase linearly with the bias.
  - Linear Luke gain
  - No steady state Joule heating
- Ionization signal independent of V bias





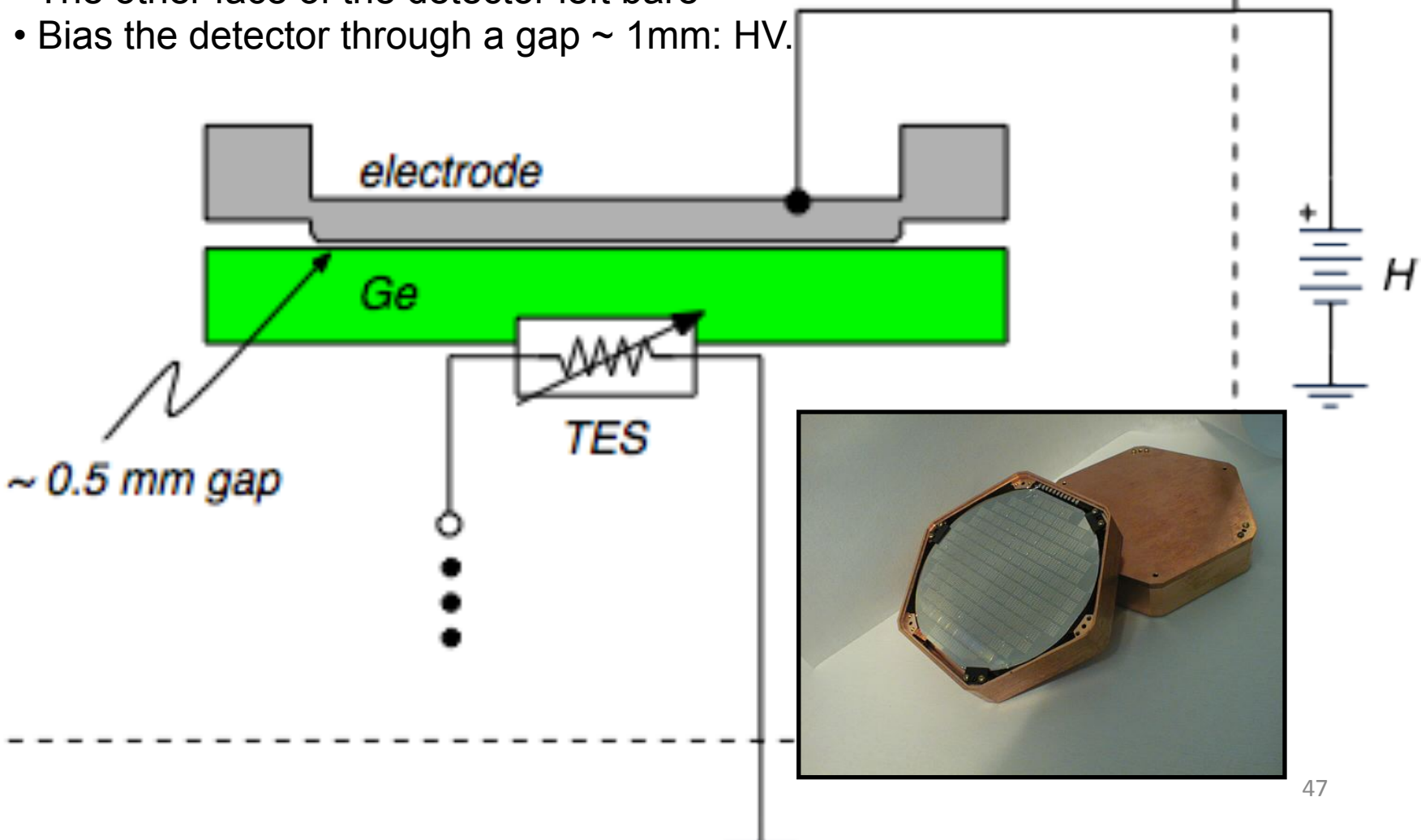


Field strength in PPC



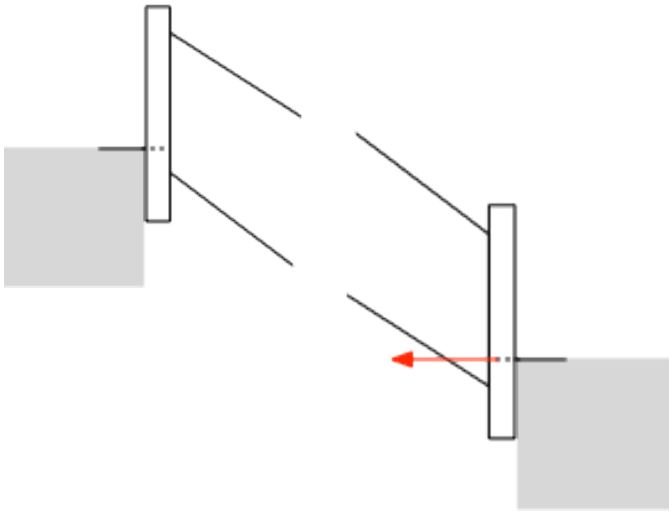
2) Asymmetric Contact Device

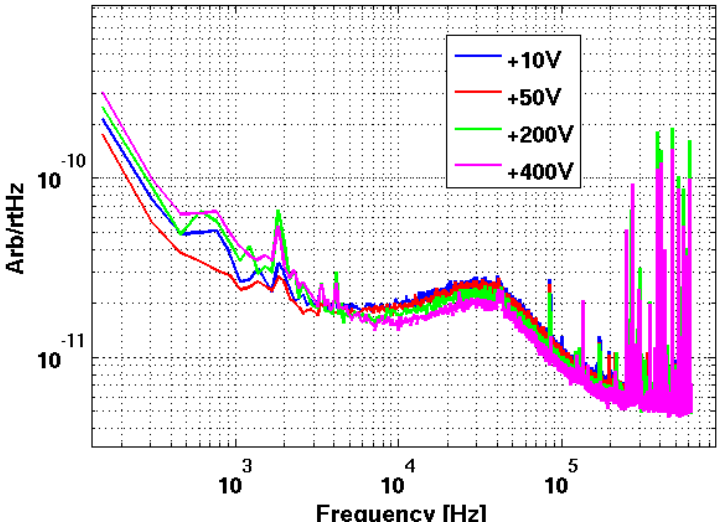
•One face of the detector processed similar to CDMS II detectors:
  • fully covered by Four W based athermal phonon readouts.
• The other face of the detector left bare
• Bias the detector through a gap ~ 1mm: HV.



Results: Asymmetric Contact

- No breakdown up to +400V
- No e- leakage at the Al/aSi/Ge Boundary

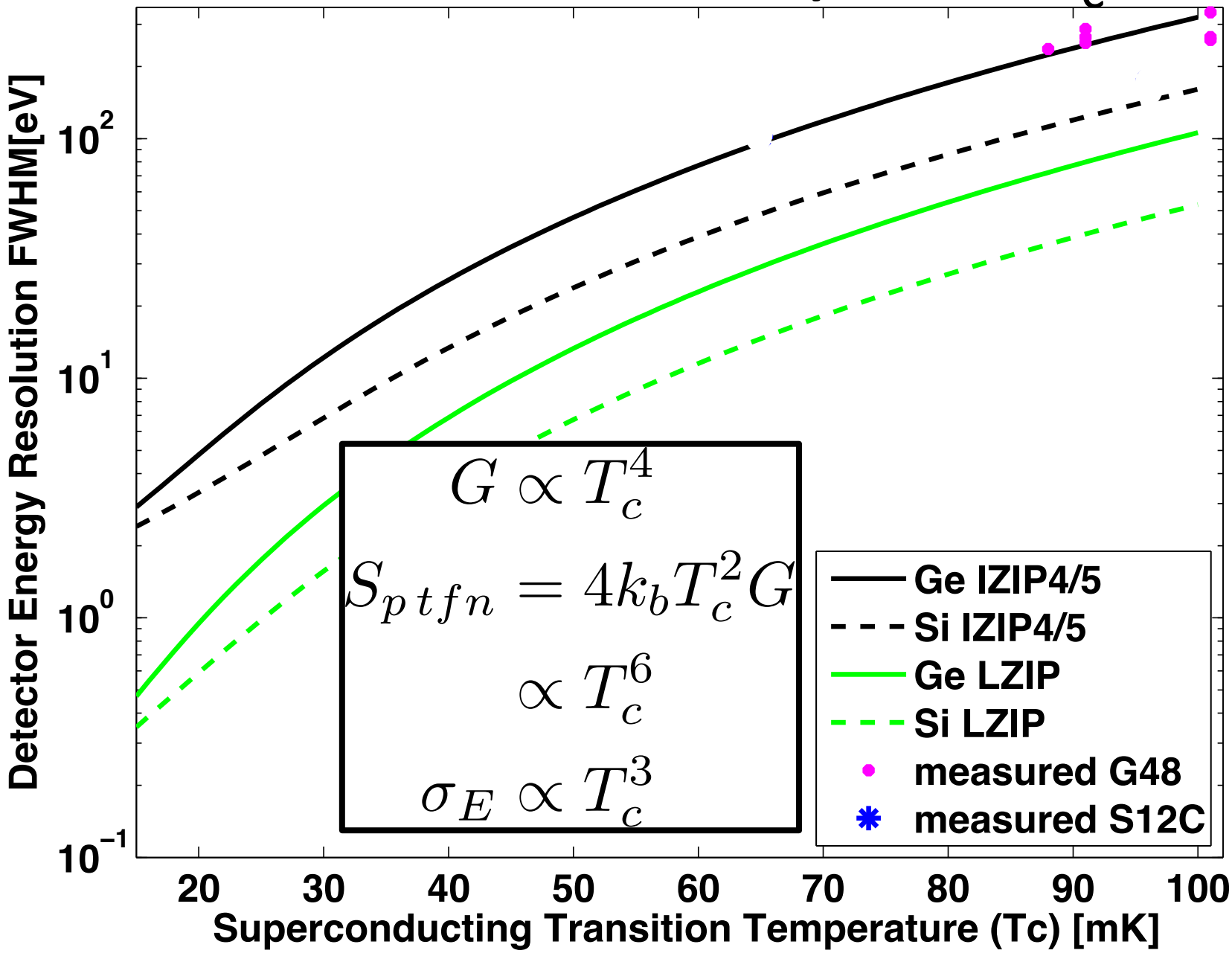




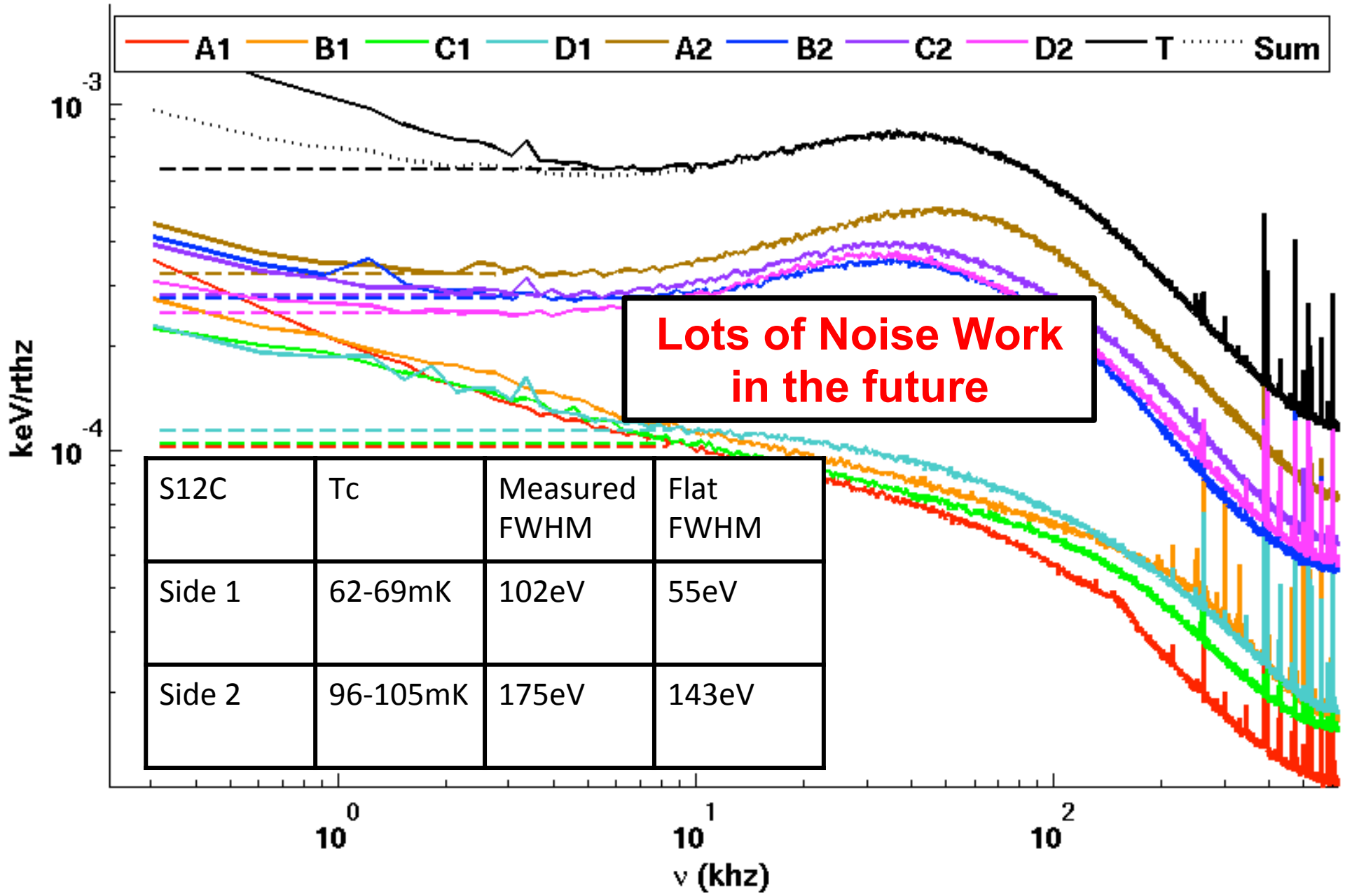
- Immediate breakdown for negative biases
- h+ leakage at Al/Ge Boundary
- aSi -> aGe?
- aSi -> SiO2

SNOLAB G2: Assume 100V with no breakdown

Phonon Sensitivity with T_c

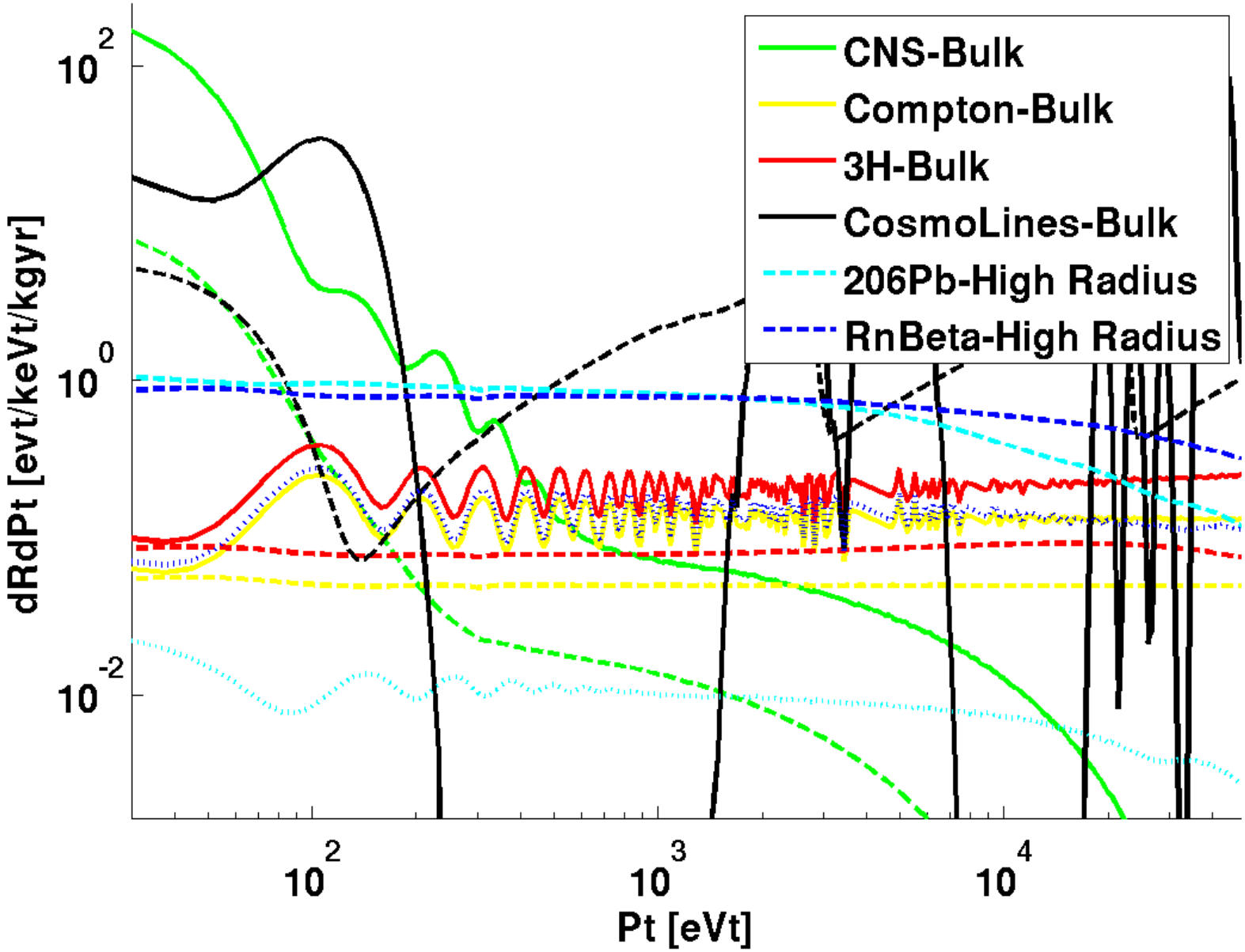


S12C: Our Best Resolution Ever

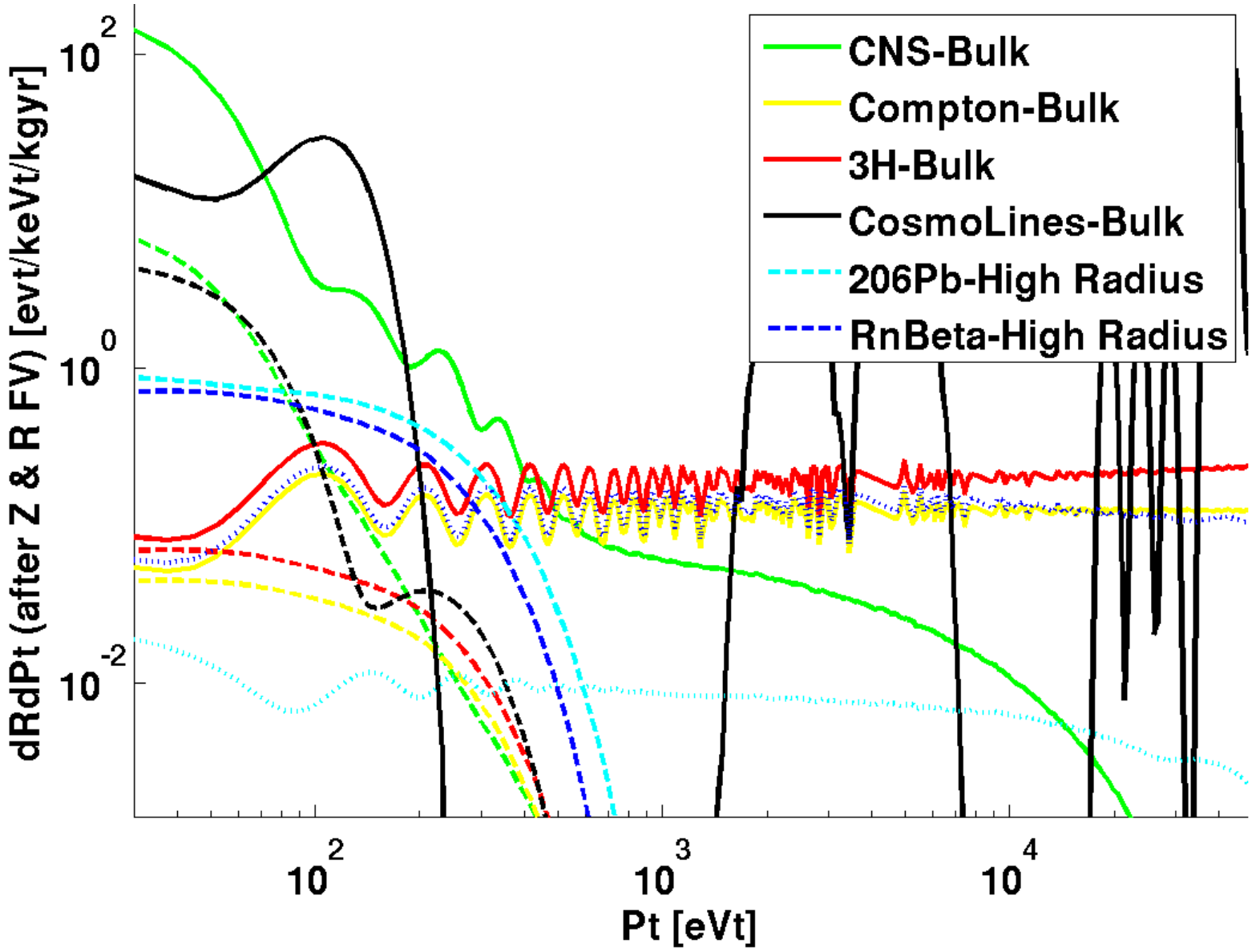
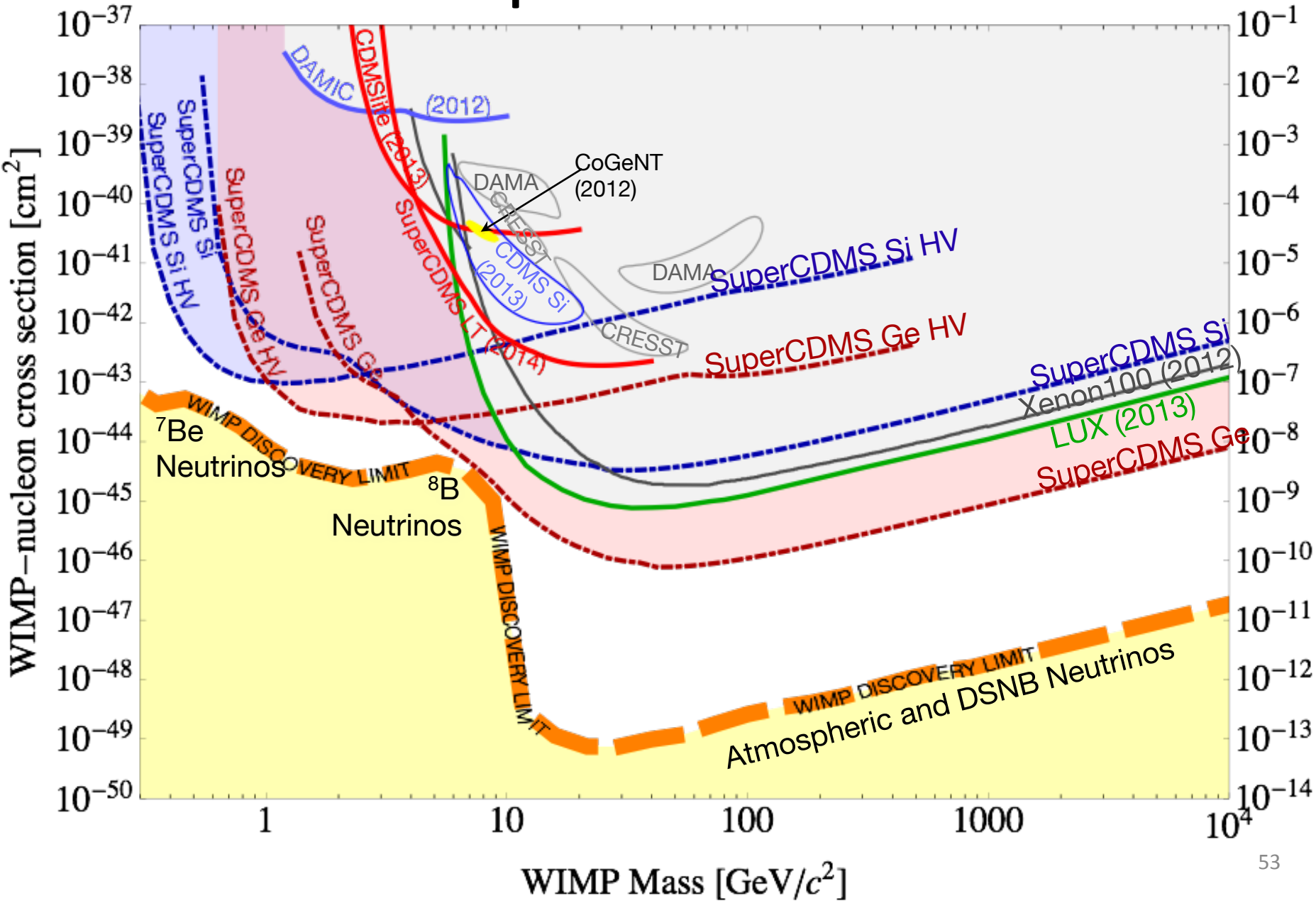


S12C	Tc	Measured FWHM	Flat FWHM
Side 1	62-69mK	102eV	55eV
Side 2	96-105mK	175eV	143eV

SuperCDMS G2:
Simulated Raw Background Rates



SuperCDMS G2: Simulated Post FV Rates



SuperCDMS G2