WIMP SEARCHES WITH THE SUPERCDMS EXPERIMENT

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University of Florida Physics Department
June 8, 2015

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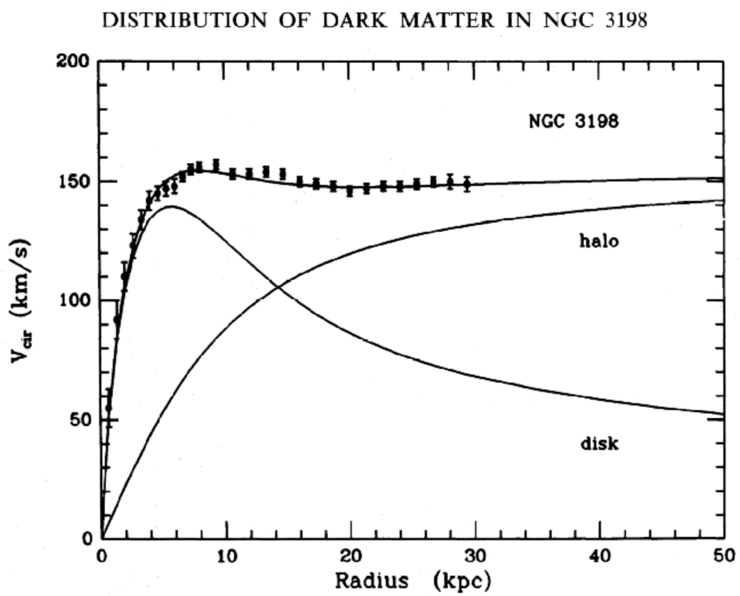
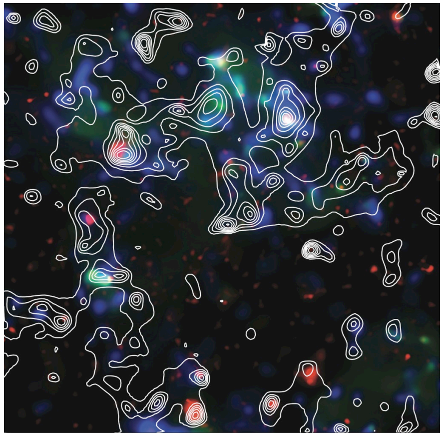
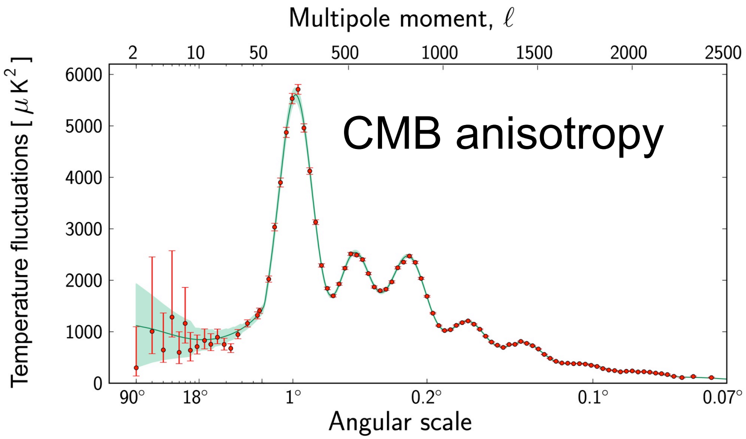
Dark Matter

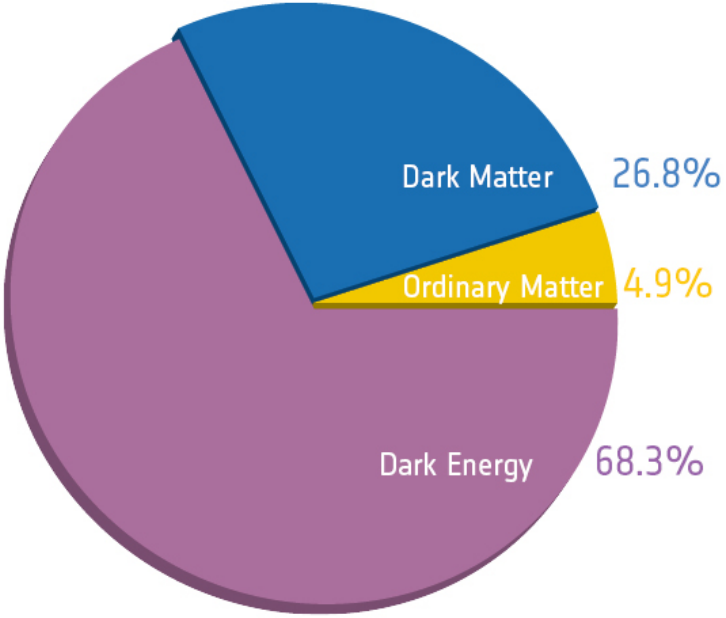


Galactic rotation curves

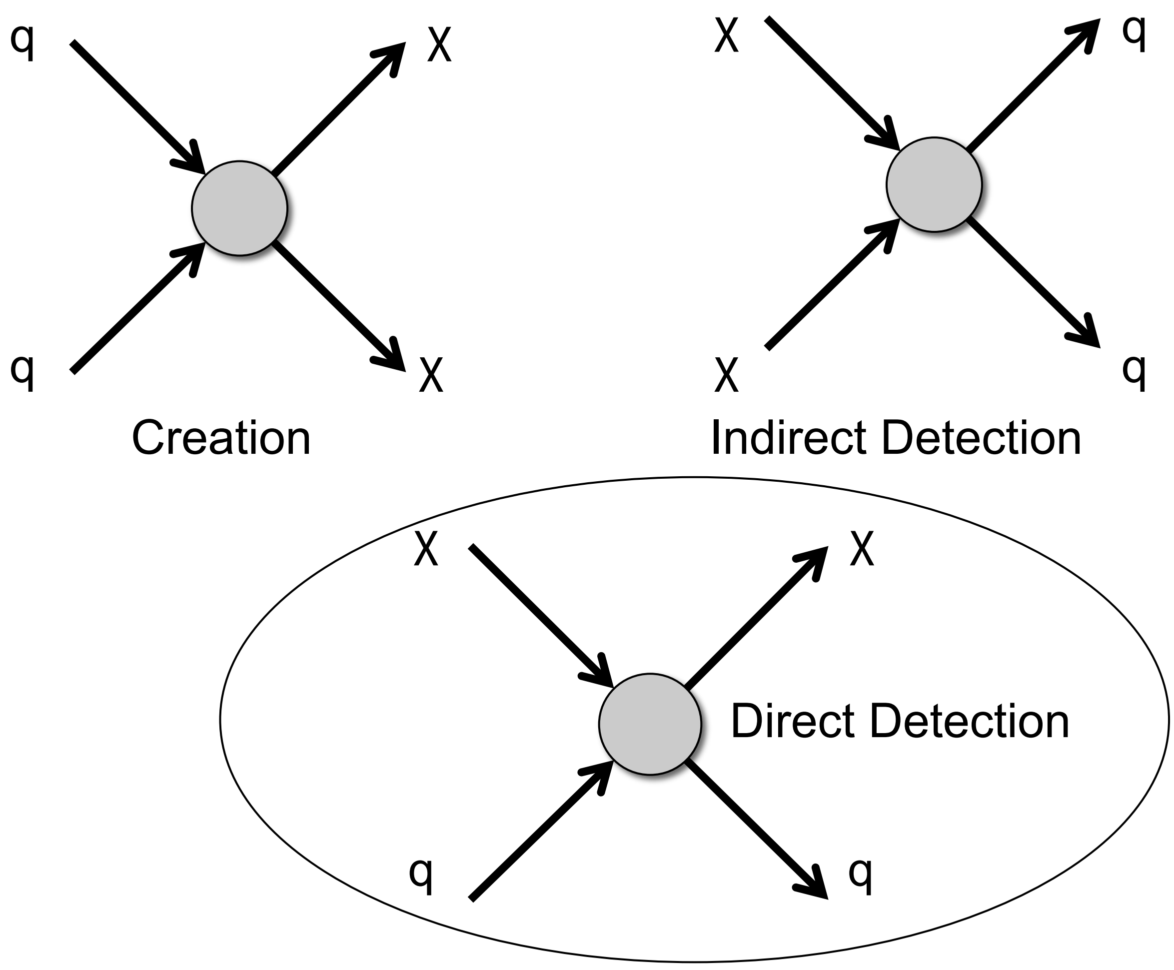


Weak lensing





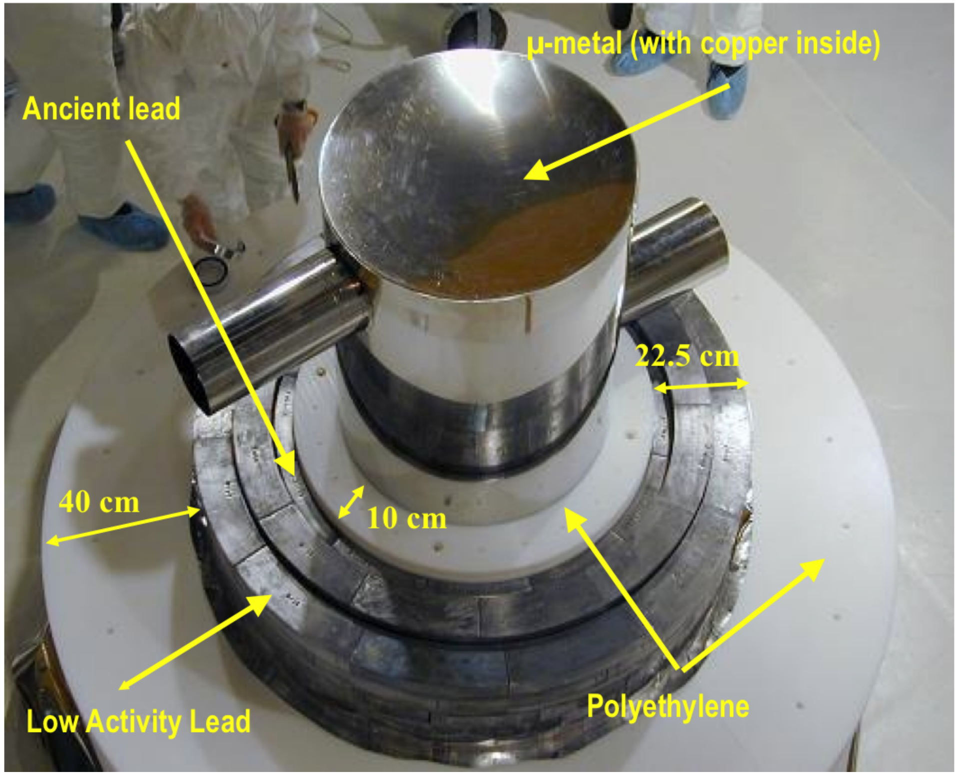
Dark Matter

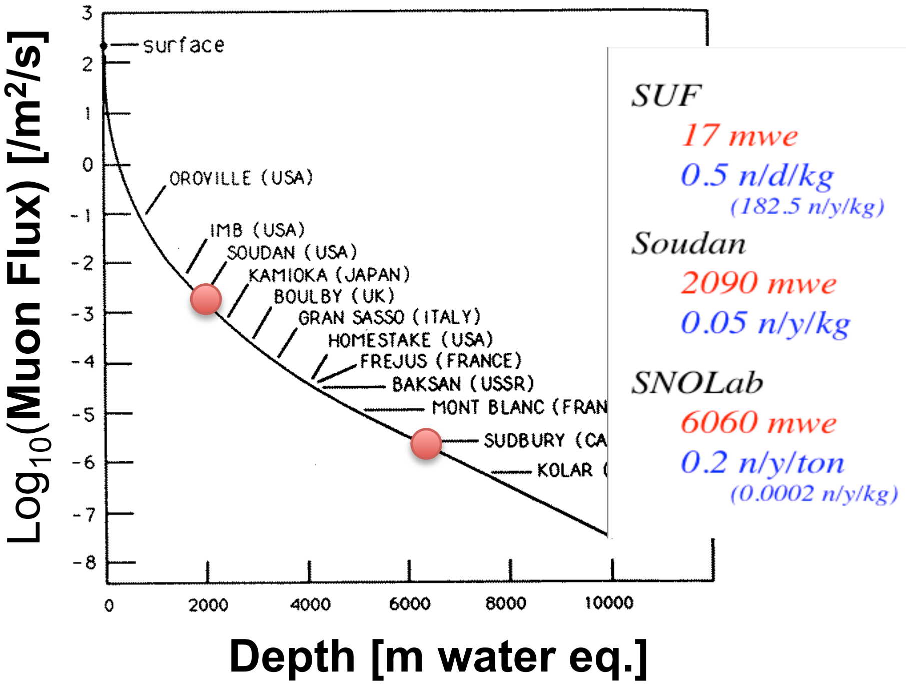


Small cross-sections = sensitive detectors!

Background Reduction

- Need to go far underground to escape cosmogenic sources of radiation (μ,γ)
  - Soudan Underground Lab at Soudan Minnesota
- Several layers of shielding to keep out local sources (everything)
- Contamination from Rn daughters

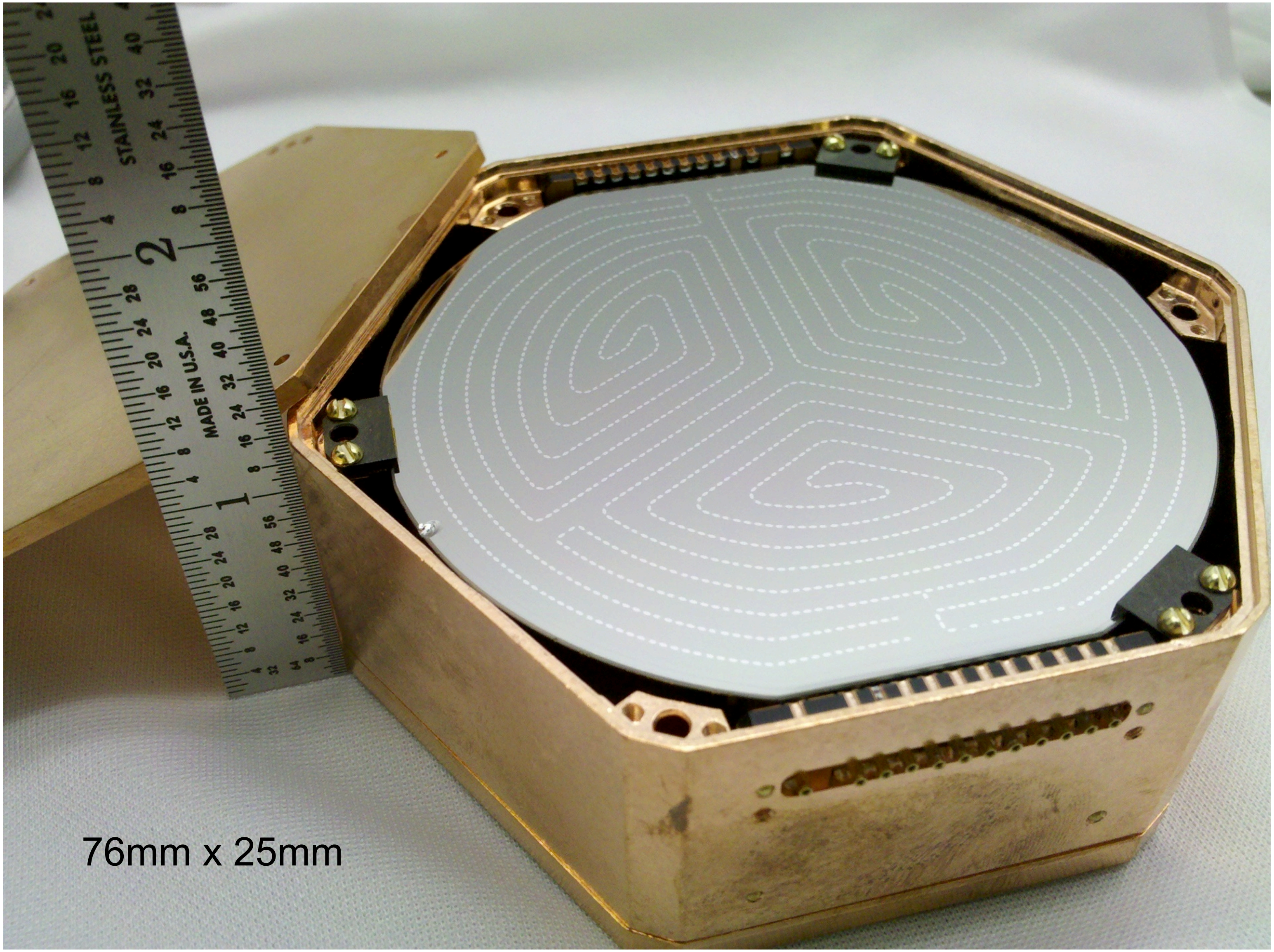




- Active muon veto
- Polyethylene (n and α's)
- Lead to moderate γ's
- Ancient lead to shield from low-activity lead
- Housings made of low-activity copper (γ's)

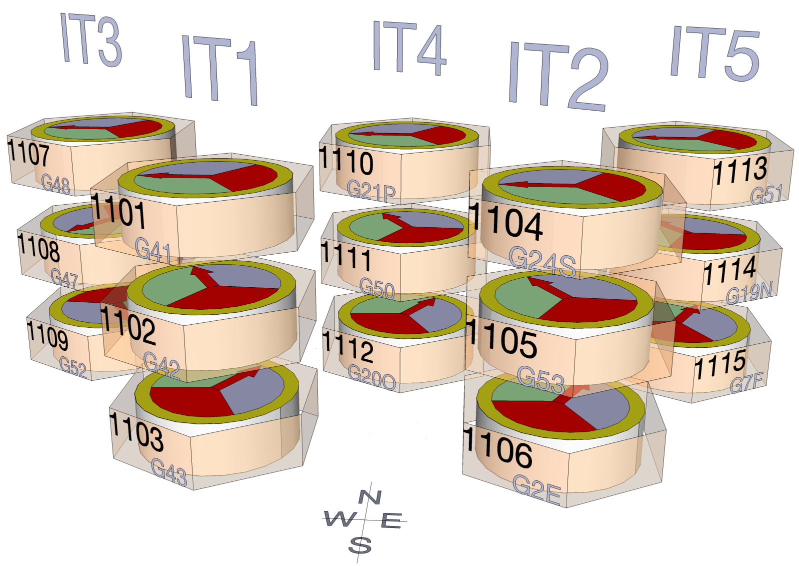
Detectors

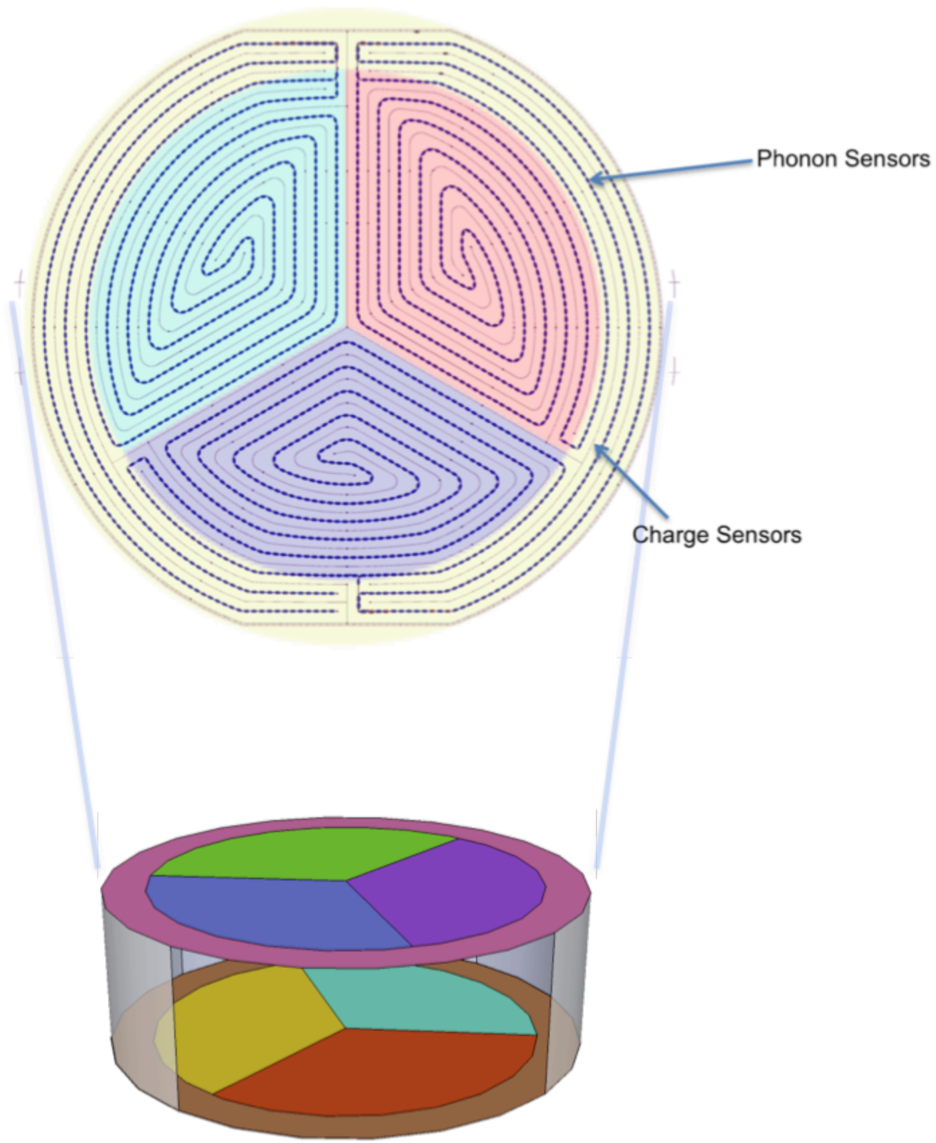
iZIP detectors: Interleaved Z-sensitive Ionization and Phonon detectors



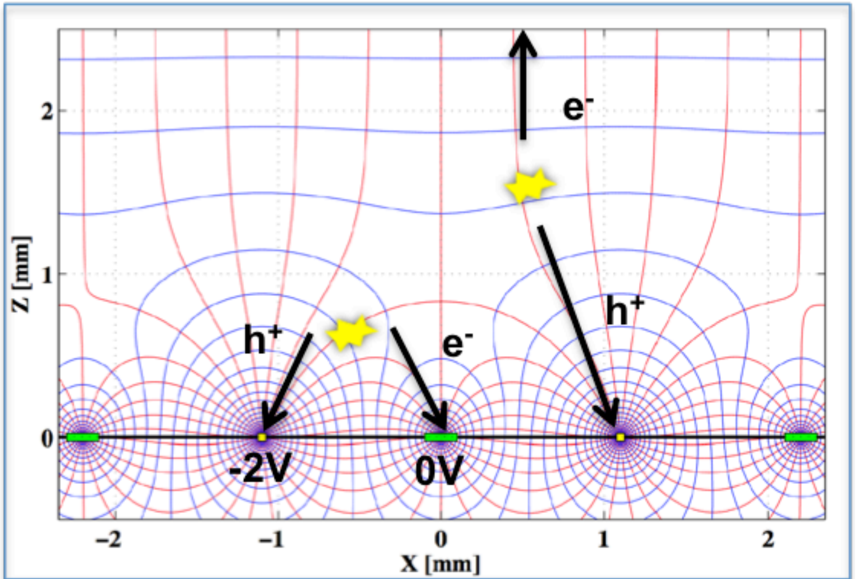
The SuperCDMS Array

- 15 iZIPs each a 0.6-kg Ge crystal
- Cooled to ~50mK
- 2 Ionization sensors on each face biased at ± 2V
- Transition Edge Sensors for phonon measurement (grounded)
  - 4 on each face

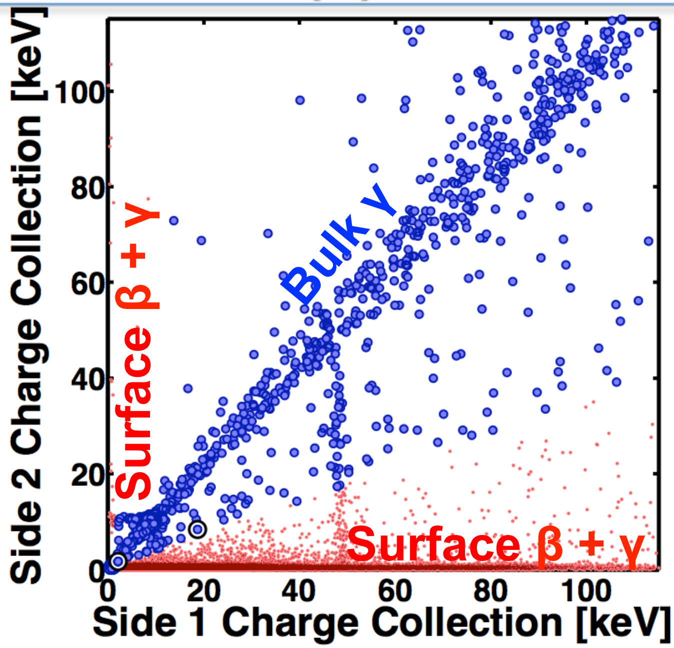


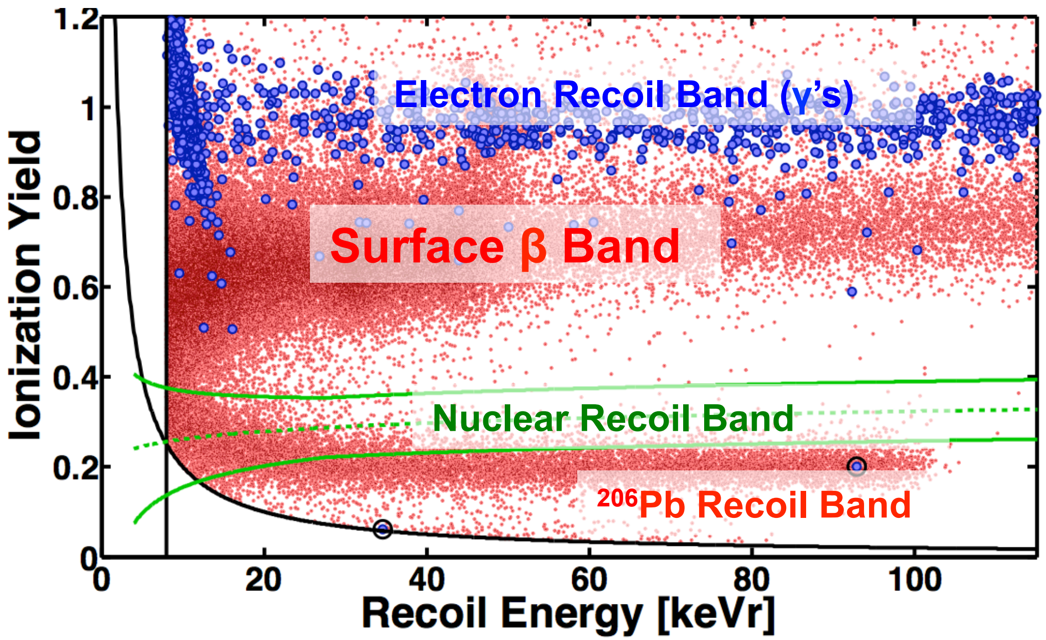


The Power of iZIPS

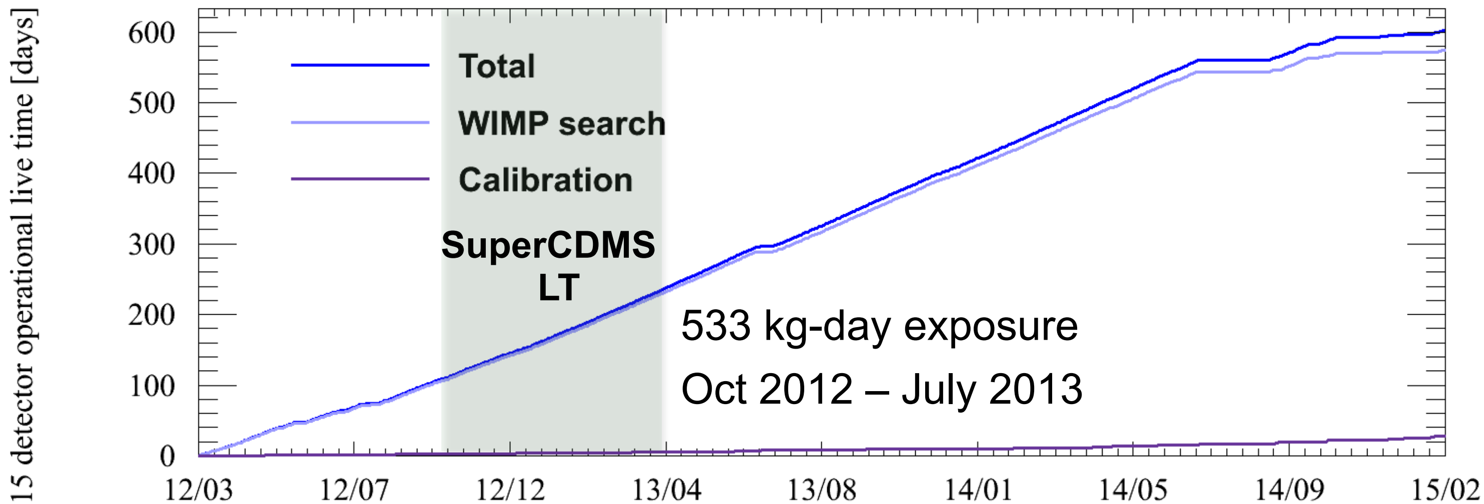


- Ionization Yield (discriminator)
  - $Y \sim E_{ionization} / E_{phonon}$
    - Splits electron recoils and nuclear recoils
  - Surface events suffer poor charge collection resulting in reduced yield
    - CDMS-II primary background
- Interleaved sensors → complex E field
  - Surface events collect on one face
  - Bulk events collect on both
- Combine these two for powerful discrimination

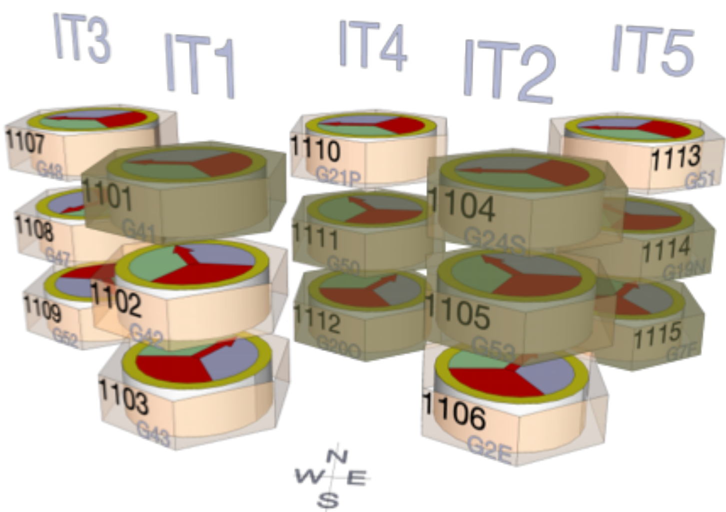




iZIP Array Based Dark Matter Searches



- SuperCDMS LT – Low Threshold Analysis
- Searched for low-mass WIMPs (< 20 GeV)
  - Sacrifice some background rejection
  - Phonon-based discrimination
- Low mass WIMP → less recoil energy
  - Lowered energy threshold in 7 best performing detectors
- Blinded Analysis
  - BDT to optimize discrimination cuts
- Background Modeled via pulse simulation



LT Results

- After unblinding:
  - Observed 11 events
  - BDT expected $6.2^{+1.1}_{-0.8}$
- Excess high energy events on 1 detector
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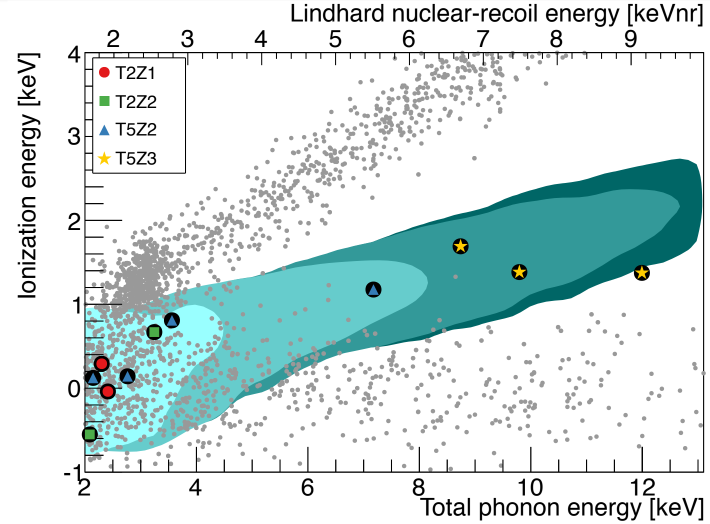
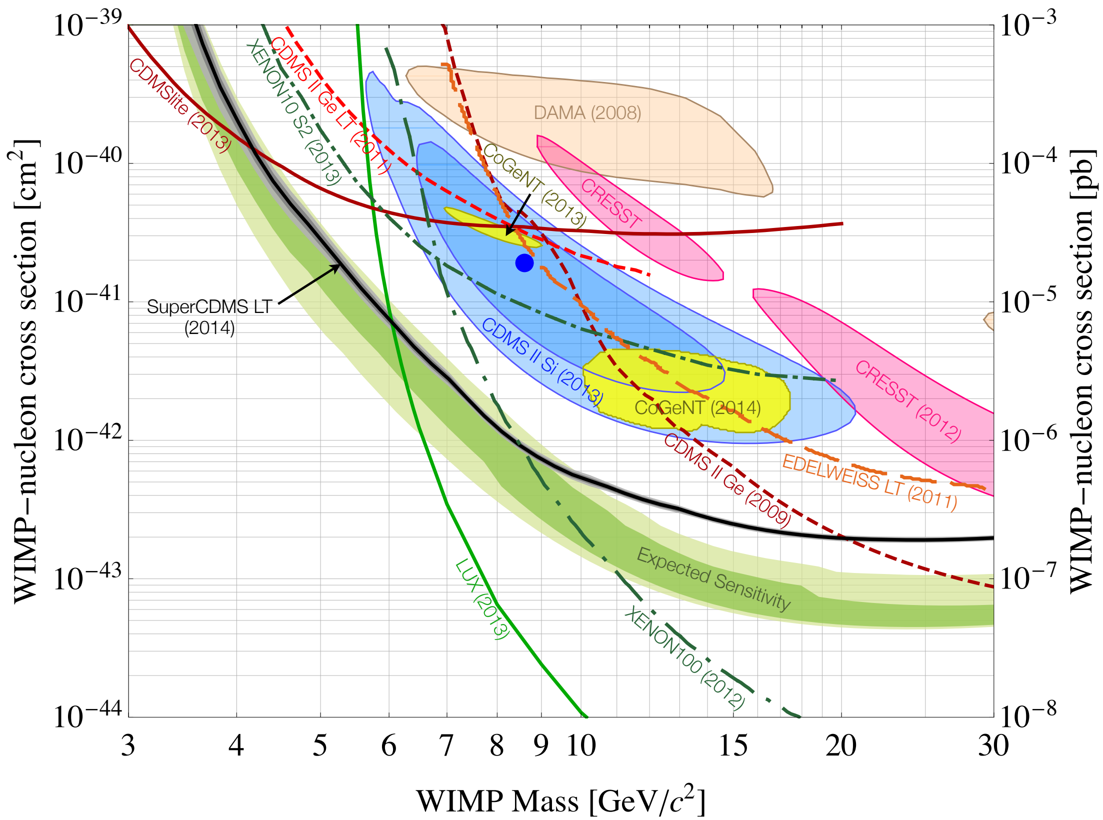
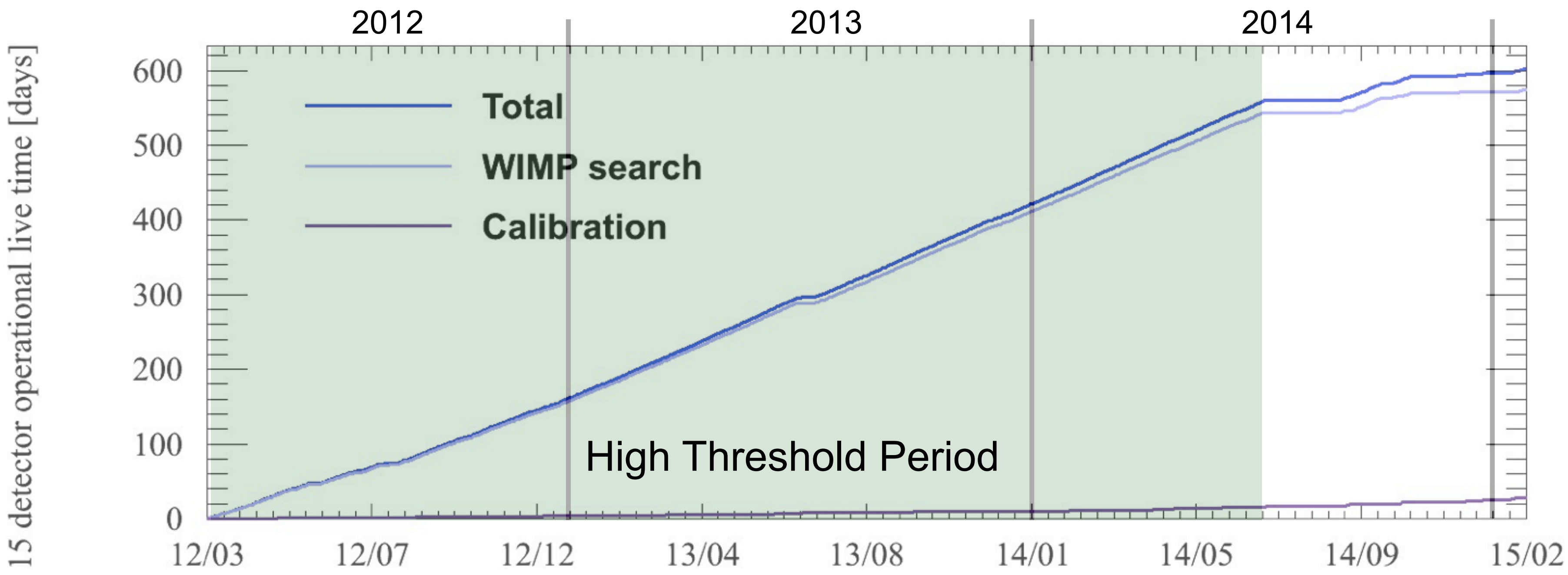
- PRL publication
  - Phys. Rev. Lett. 112, 241302 (2014)





- CDMSlite
  - High voltage mode on single detector
  - Luke phonon amplification
  - 6 kg-days
  - Phys. Rev. Lett. 112, 041302 (2014)

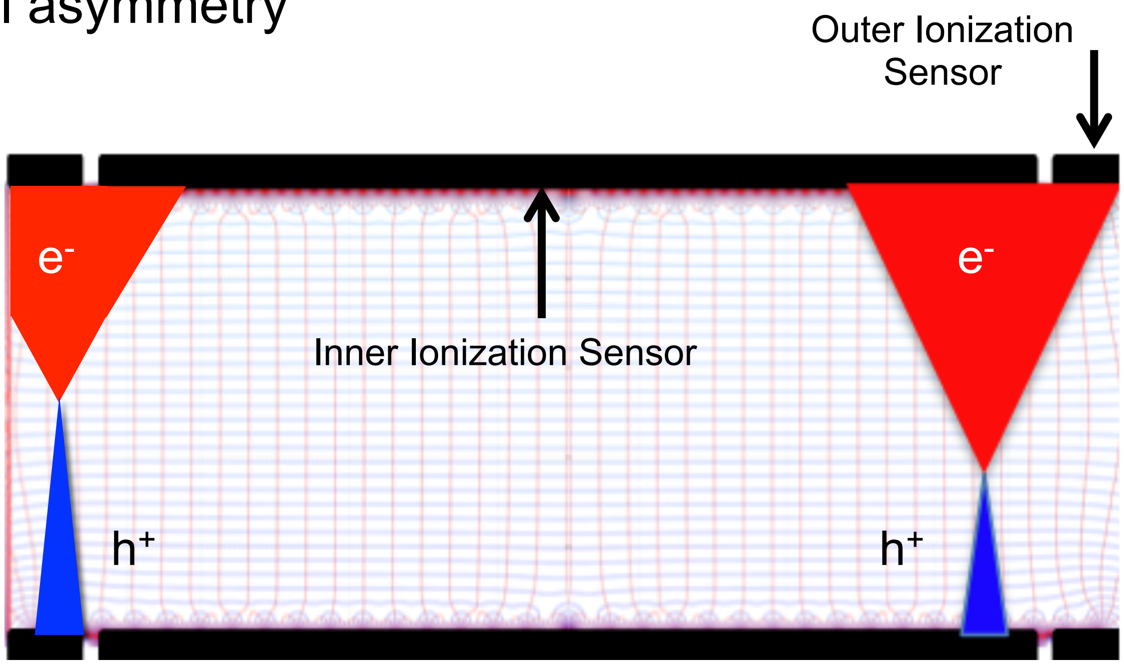
High Mass Search



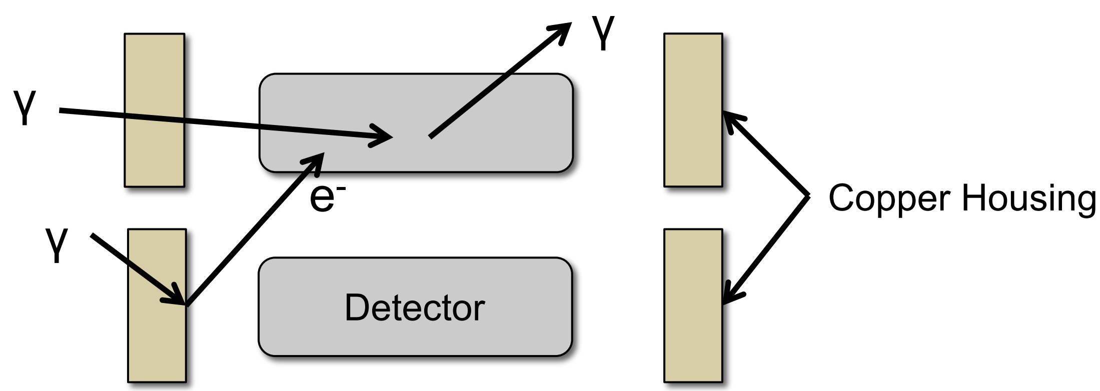
- Full dataset used (~3000 kg-days)
- Exposure limited
- Want <1 background event in signal region
  - Optimizing fiducial volume to do this is non-trivial
  - Investigating cuts-based and machine learning methods
- Calibration datasets to model backgrounds and signal
  - ^{133}Ba → γ source for electron recoils
  - ^{232}Cf → n source for nuclear recoils
  - Implanted ^{210}Pb source to study decay chain daughters (2 detectors)

Background Locations

- Surfaces are evil ☹
  - Backgrounds enter due to charge trapping in surface dead-layer
- Sidewalls pose issues too
  - Charge trapping
  - Oblique propagation of charges
  - Outer ionization and phonon sensors help tag these
- Powerful discriminators exist
  - Yield, ionization z and radial asymmetry
  - Possibly phonons too



Background Discrimination

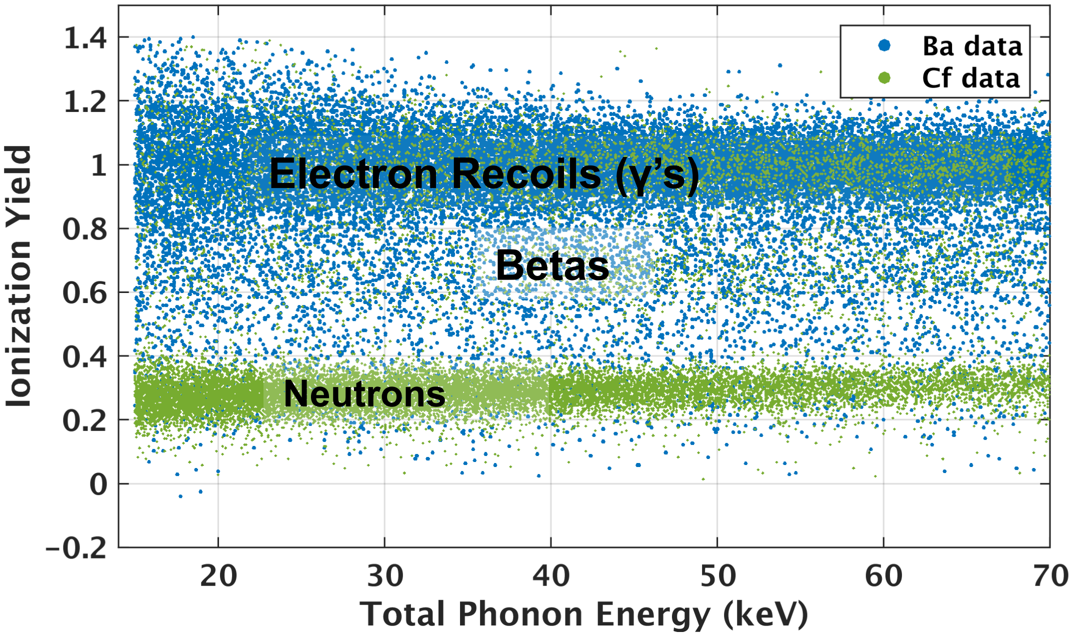


External Gammas

Ionization
+
Phonon

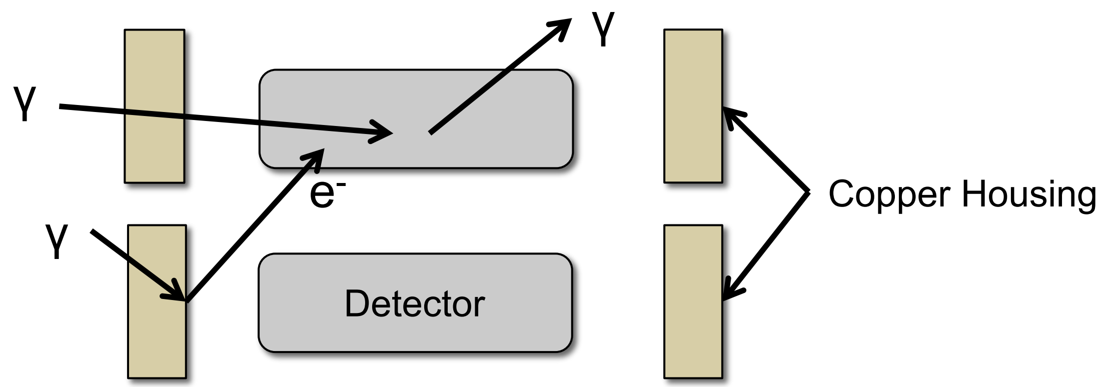
Yield

Bulk γ's



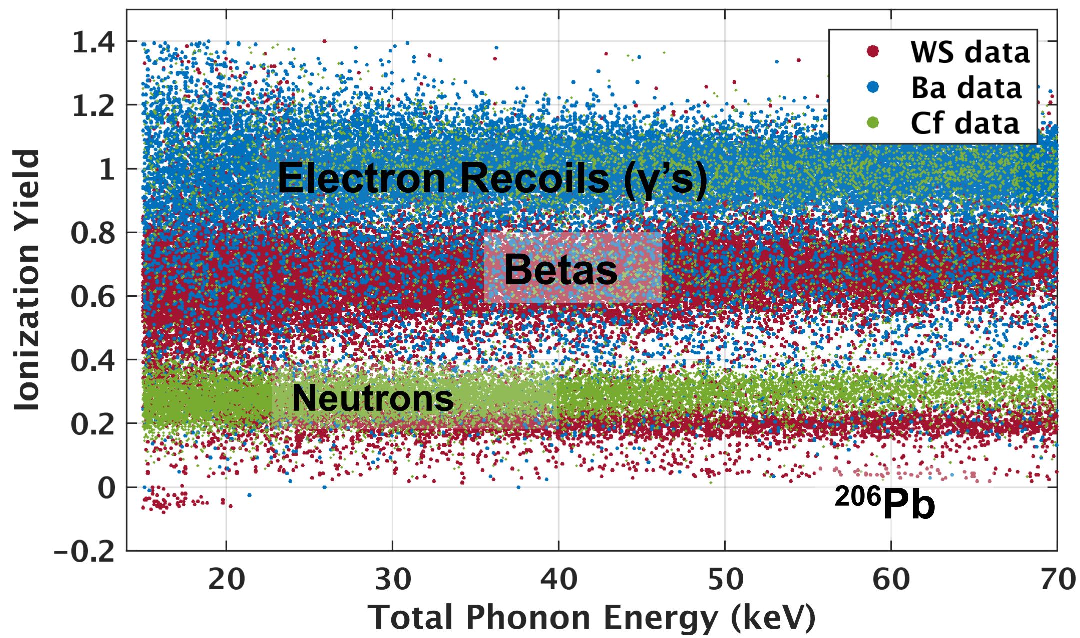
Low Yield β's a problem

Background Discrimination



External Gammas

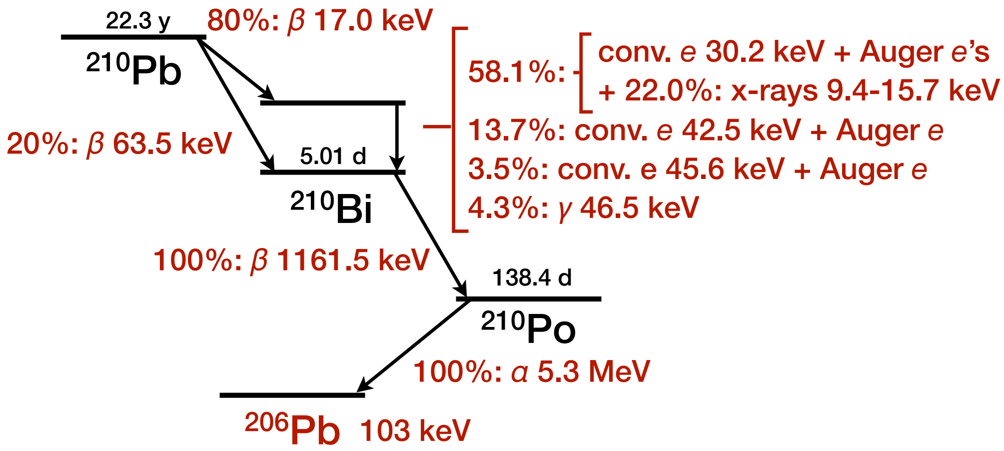
Ionization + Phonon → Yield: Bulk γ's

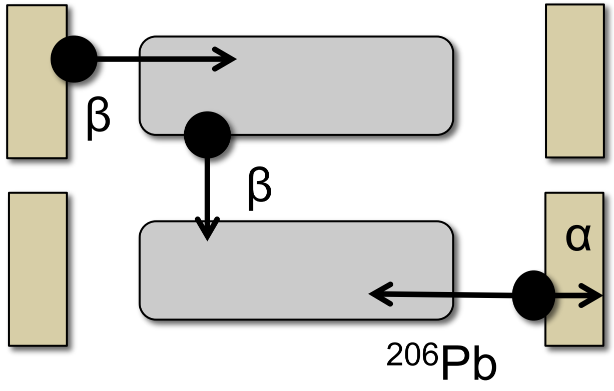


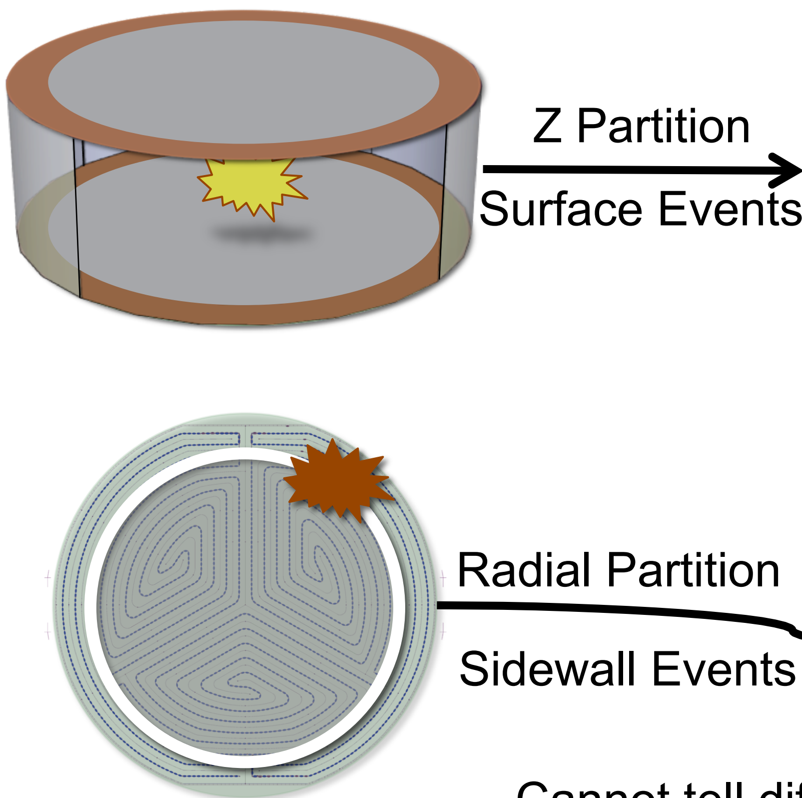
Low Yield β's a problem

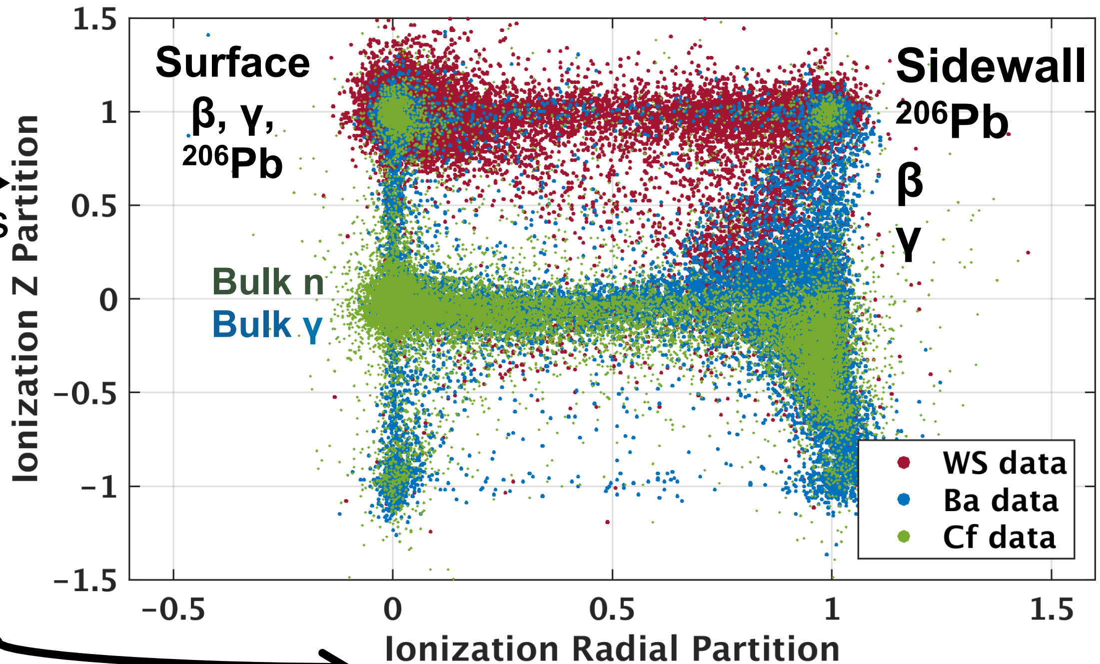
^{210}Pb sheds some light

Background Discrimination





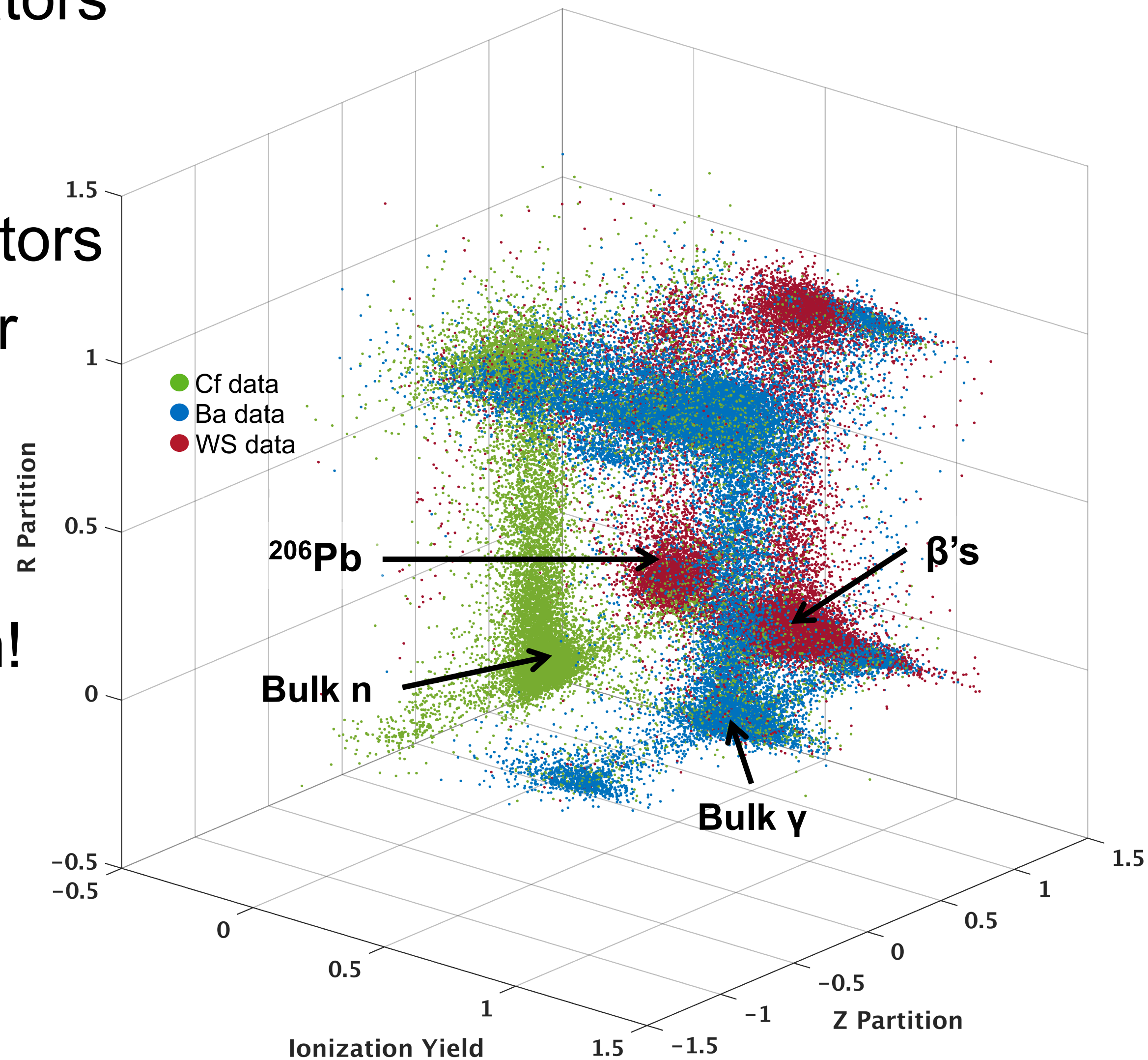




Cannot tell difference between electron-recoil and nuclear recoil

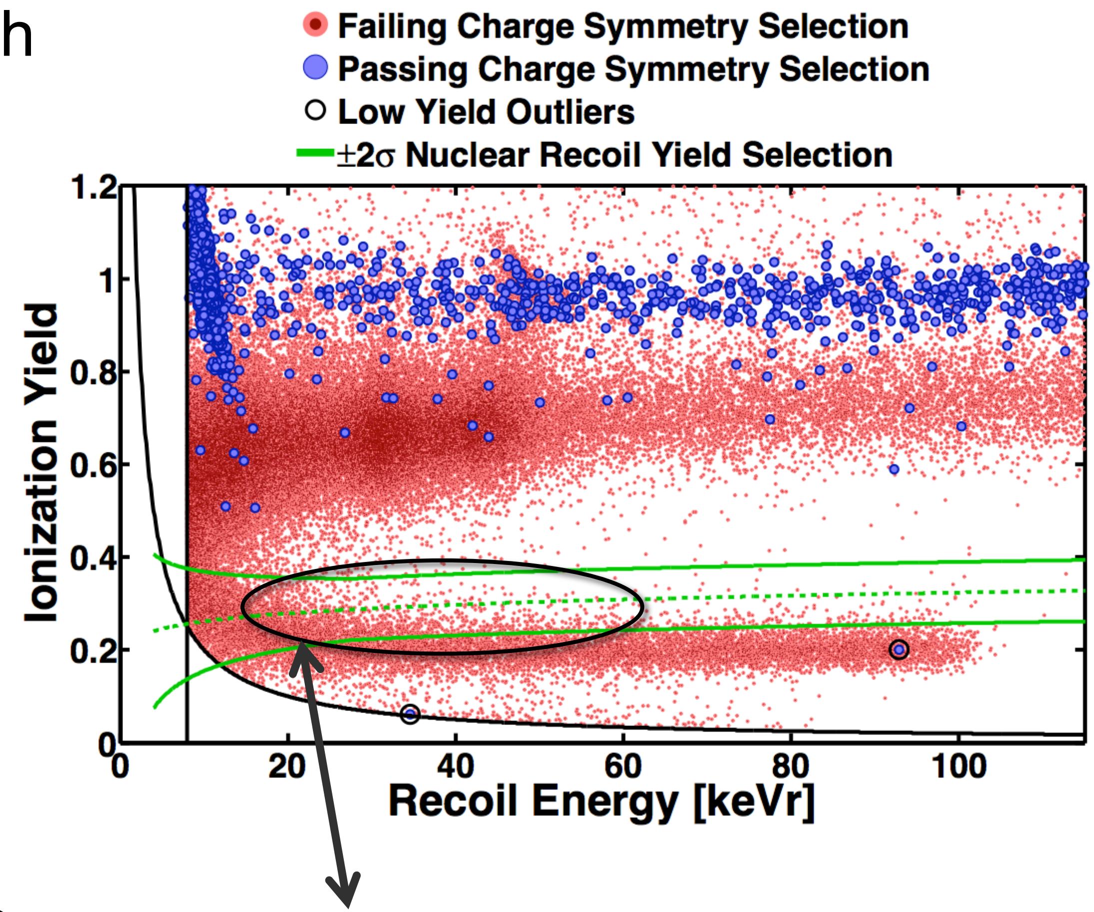
Ionization Discrimination Space

- Combine all 3 discriminators for best separation
- Signal region has low values in all 3 discriminators
- Backgrounds have larger values in at least one quantity
- Tails of background distributions are problem!



Background Leakage Estimates

- Multi-dimensional Approach
  - Model the background
  - Locate regions in n-D parameter space for each background
  - nD KDEs
  - k-means classifiers
  - LDA (dimension reduction)
- Simpler Approach
  - Mimic CDMS-II style and estimate leakage without modeling background
  - Example: Surface event leakage from Yield and Z-partition
  - Construct independent model as a function of energy, and side
  - Vary potential cut locations and count what is inside



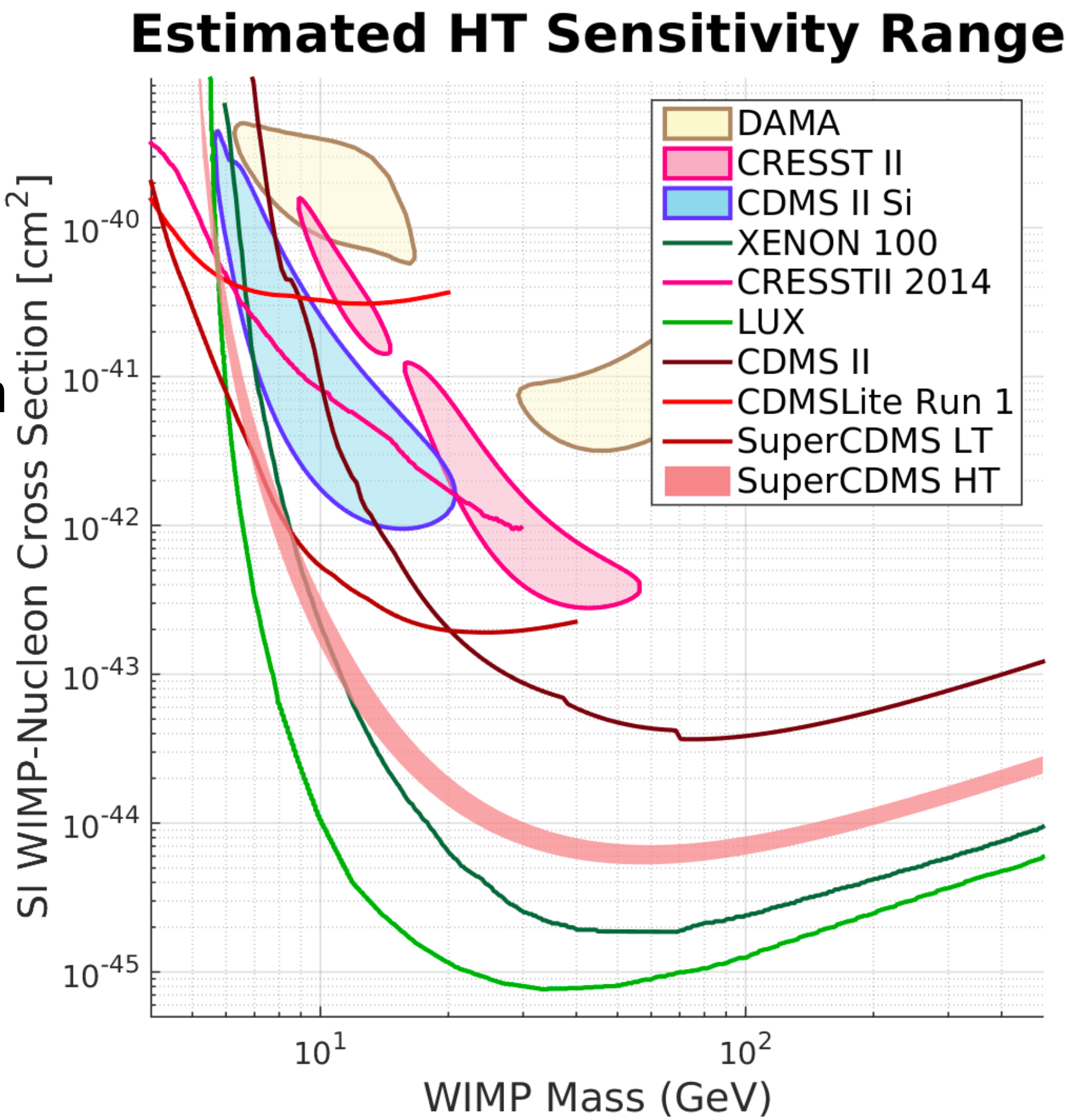
Leakage Estimate

$n_i = N_i \sum b^i_{e,f} s^i_{e,f}$

b = passage fraction of neutrons from calibration data
N = expected number of single scatter surface events
s = fraction of type of event (e.g., β or ^{206}Pb) in WIMP-search data
i = detector
e = energy bin
f = face

Summary

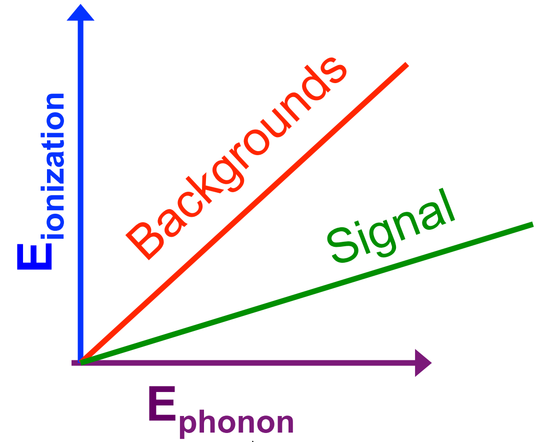
- iZIPs are versatile!
- Low mass WIMP search completed
- Higher mass WIMP analysis underway
- Powerful background rejection allows larger exposure
- Both phonons & ionization possible
- Stay tuned!
  - Expect analysis wrap up this year

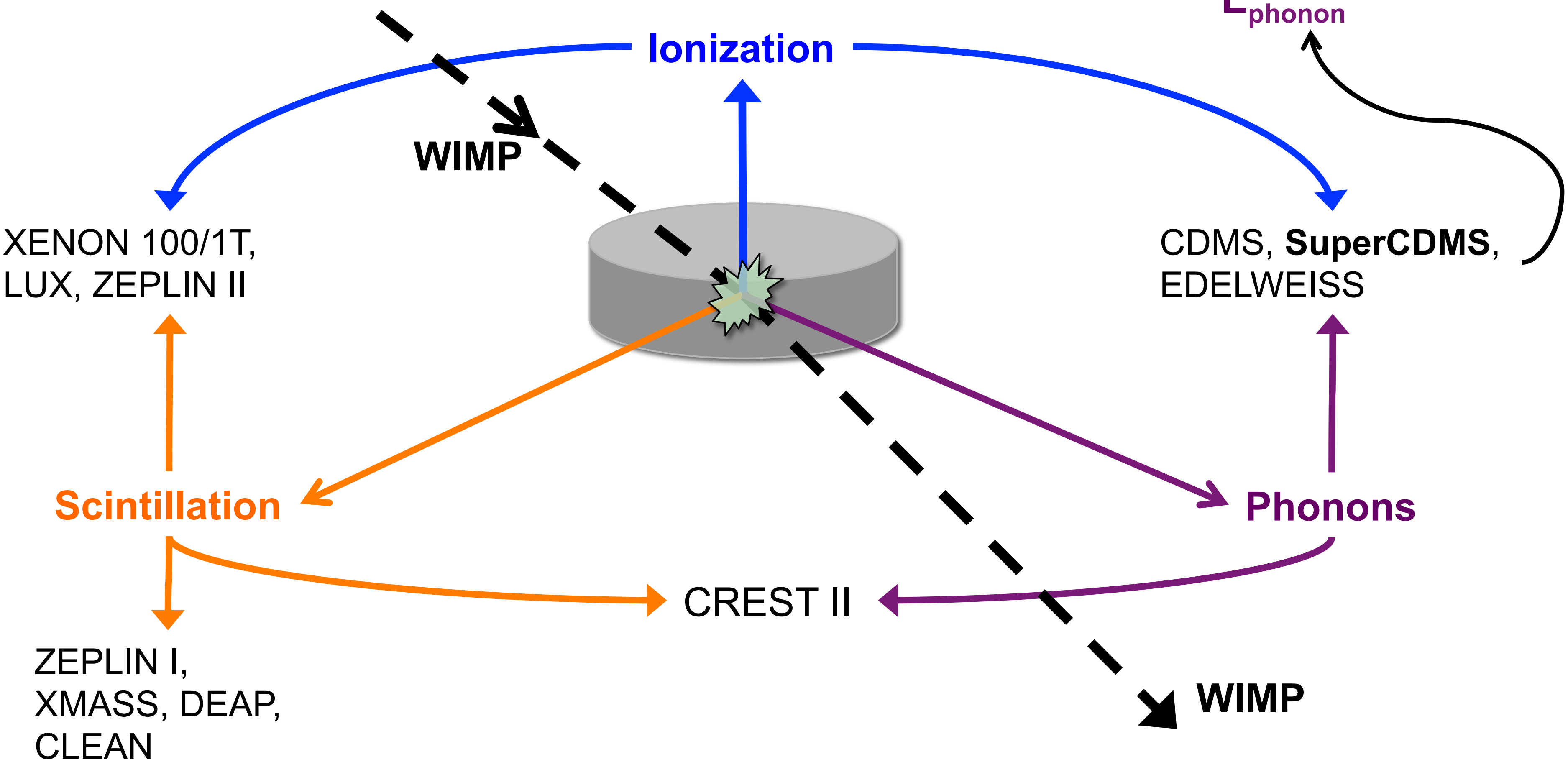


Backups

Direct Detection Methods

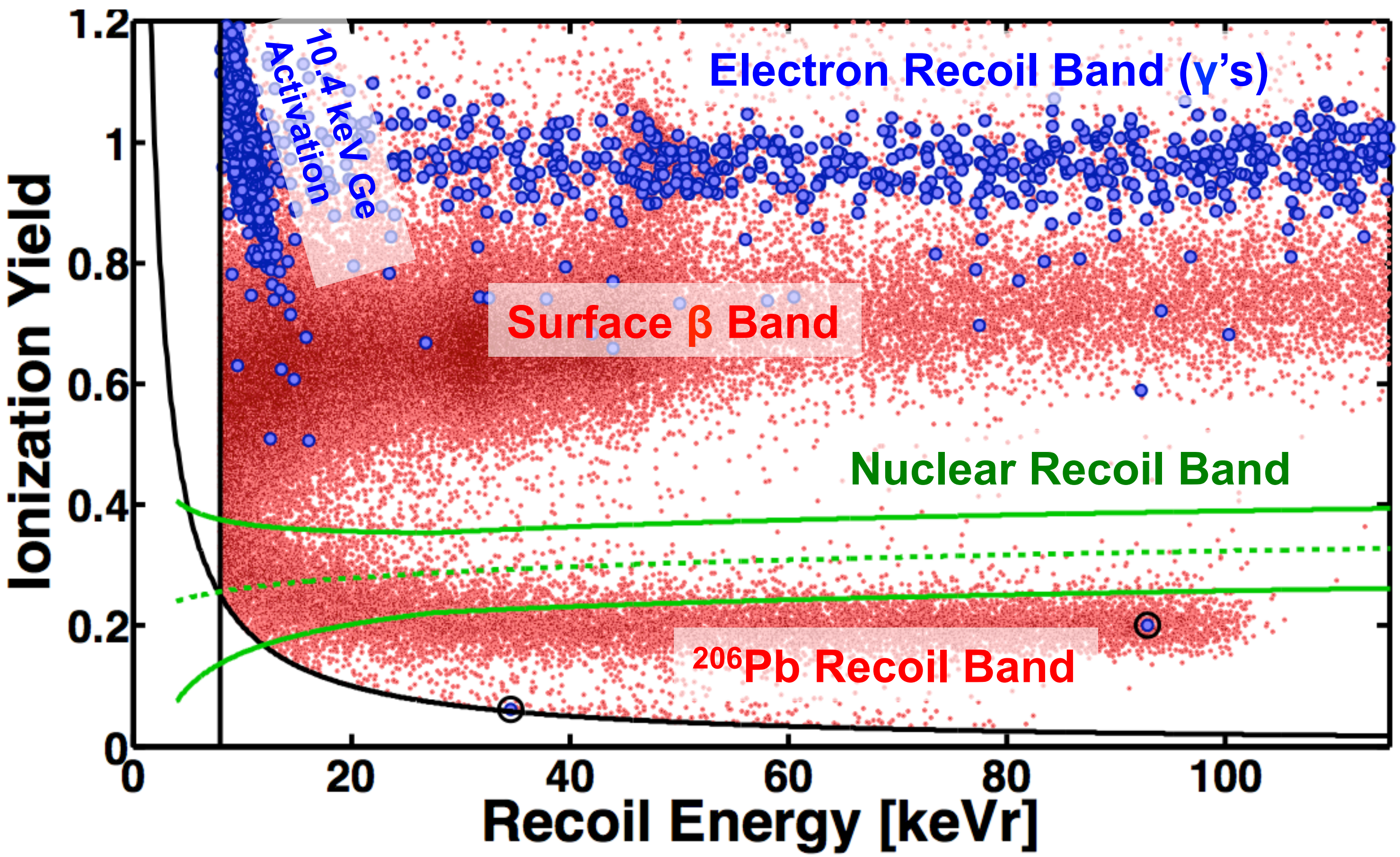
- Three primary methods a WIMP can deposit energy in target
- SuperCDMS uses joint ionization and phonon measurement
- Provides discrimination between backgrounds and signal (inelastic nuclear recoil)



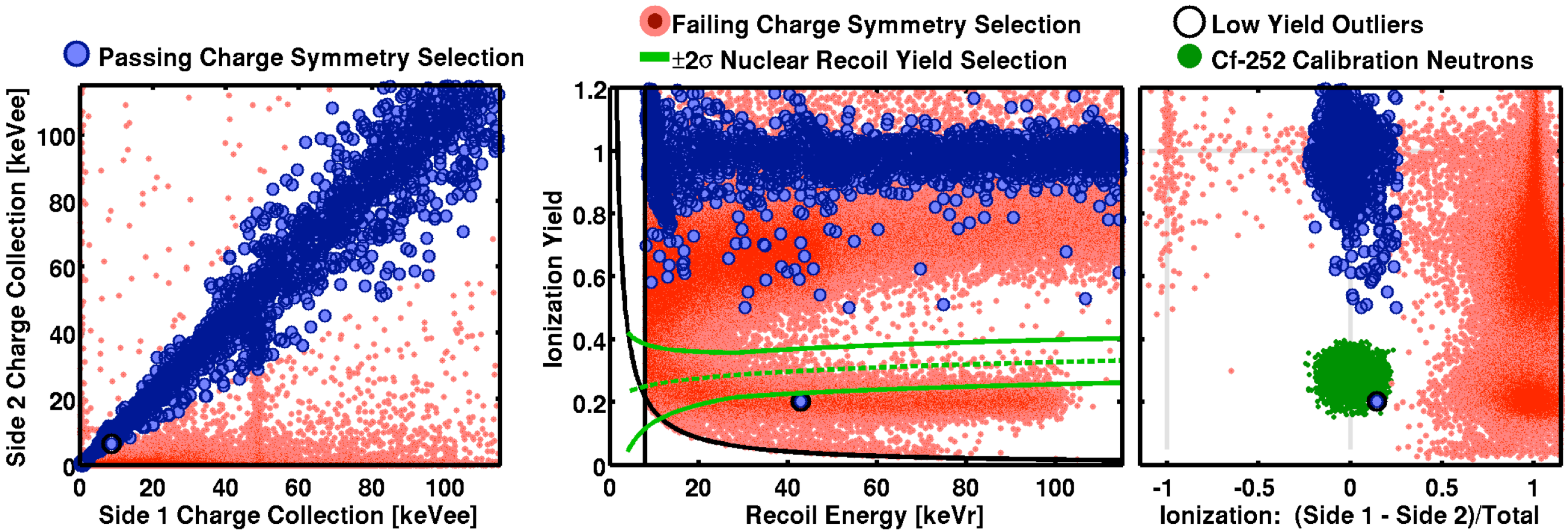


The SuperCDMS Array

- Ratio of ionization to phonon signals called "yield"
- A useful discriminant for electron recoils and nuclear recoils
- Other backgrounds exist in the NR band!



What Can We Expect? (Ionization)



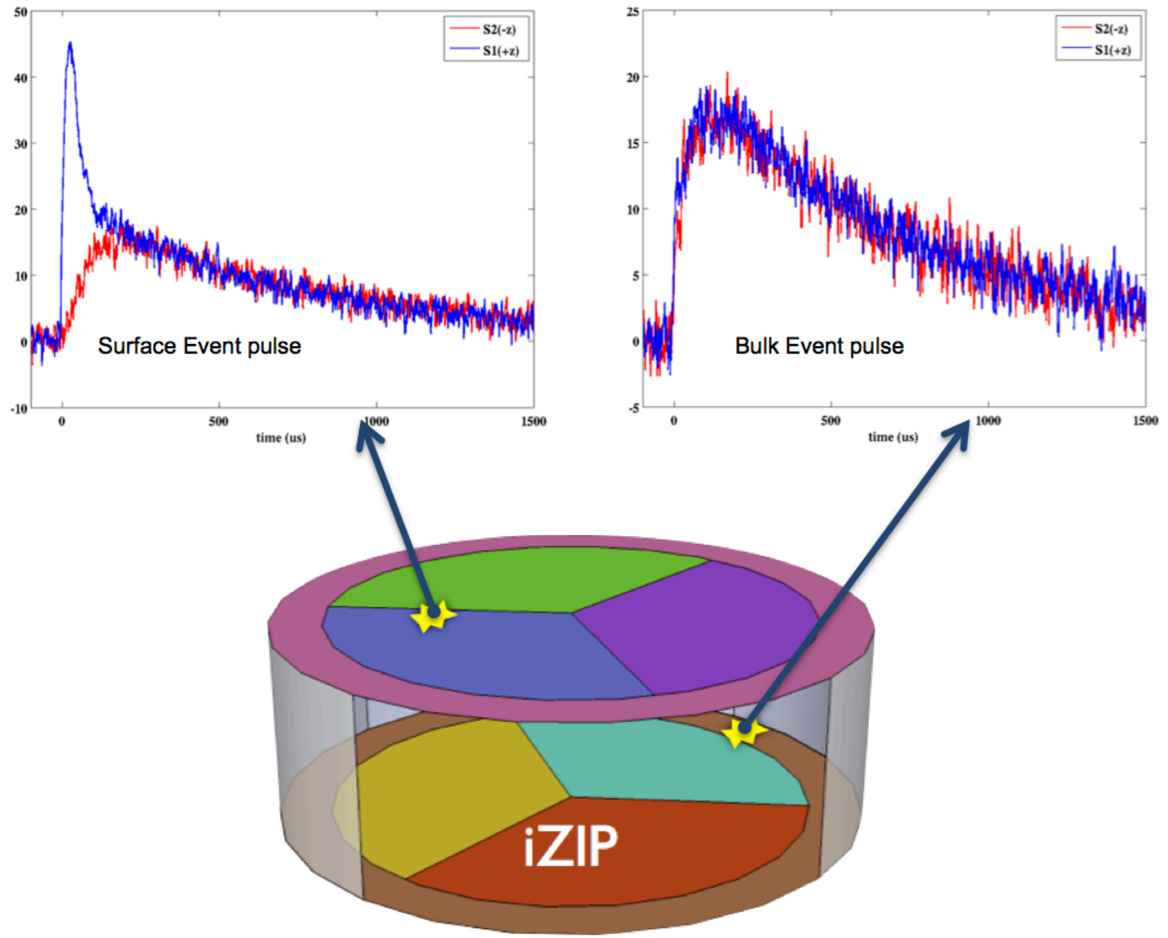
- Two detectors have ^{210}Pb sources for study of background rejection capabilities
- Over 2500 live-hours of data examined
- Rejection of bulk electron recoils: < 4.7 x 10^{-6} (90%C.L.)
- Rejection of surface events: < 1.26 x 10^{-5} (90% C.L.)

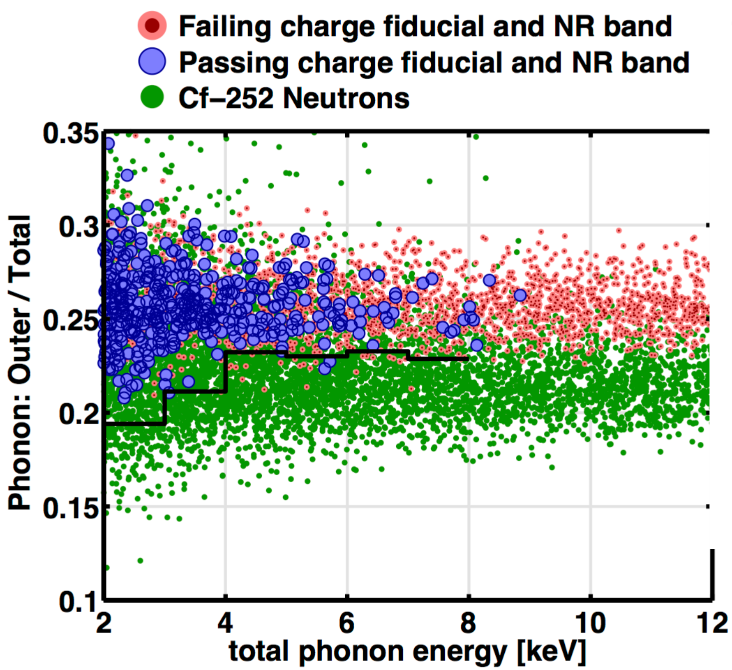
Phonon Discrimination

- Phonon signals can be used along with ionization
- At low E_{recoil} can provide better discrimination than ionization
- Use face-to-face phonon signal symmetry for z discrimination
- Use inner-outer for radial

25 keV Surface Event

25 keV Bulk Event





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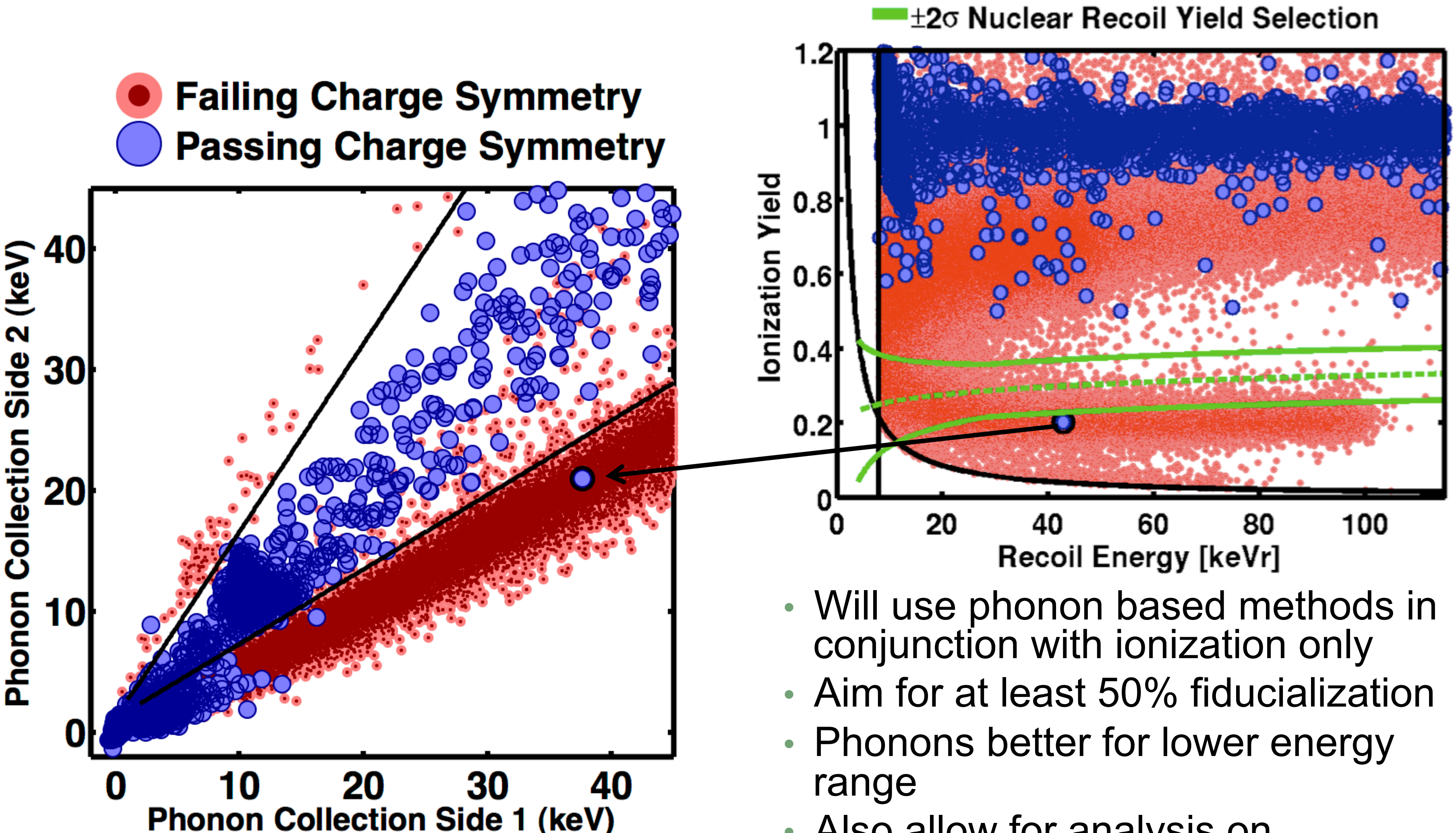
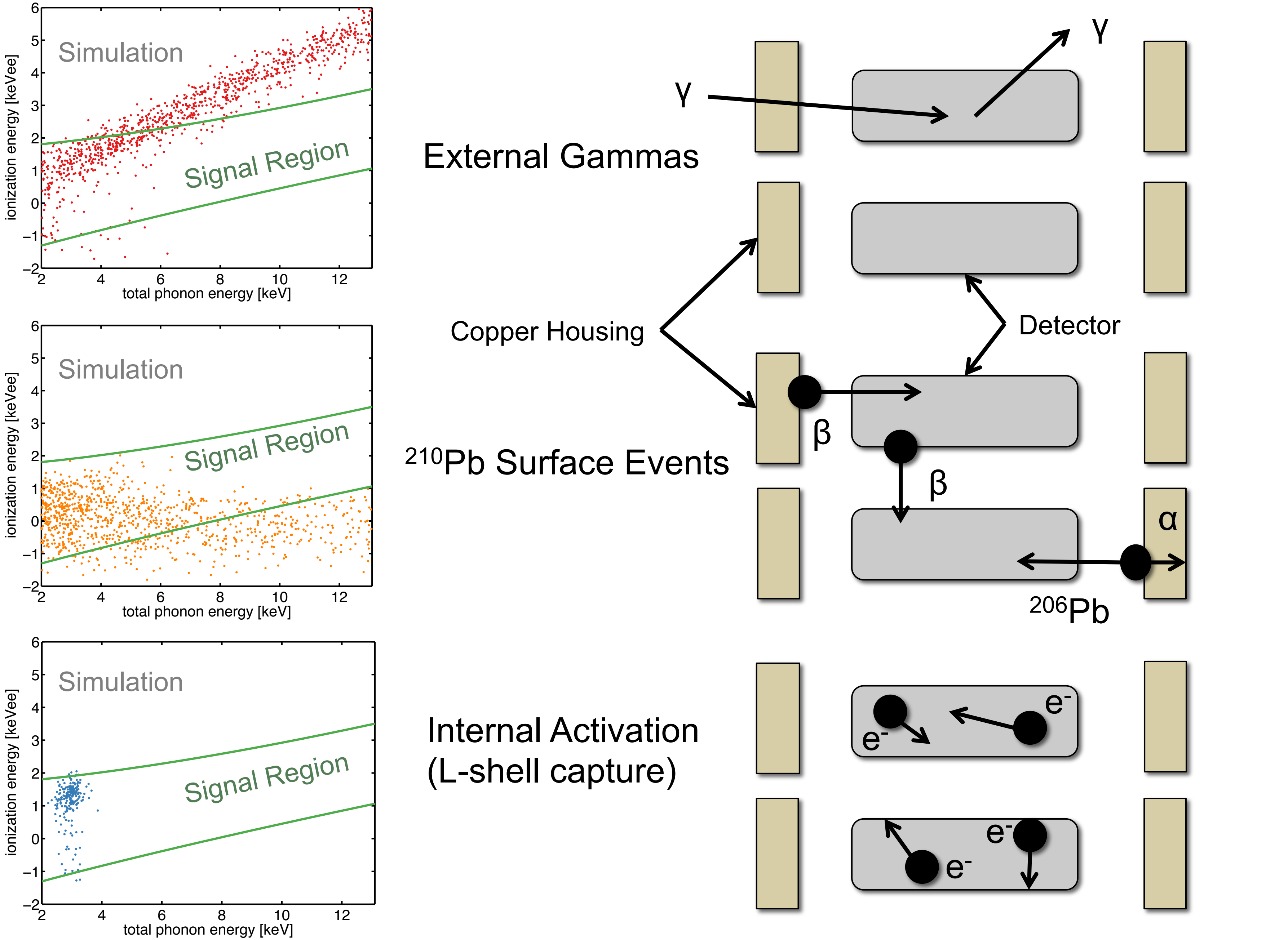


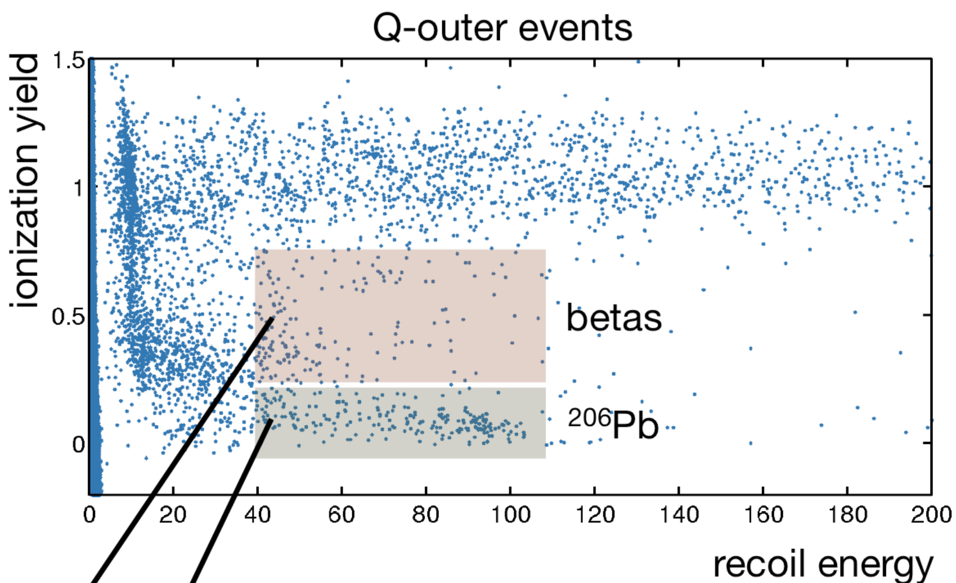
- Will use phonon based methods in conjunction with ionization only
- Aim for at least 50% fiducialization
- Phonons better for lower energy range
- Also allow for analysis on detectors with broken ionization sensors

Backgrounds



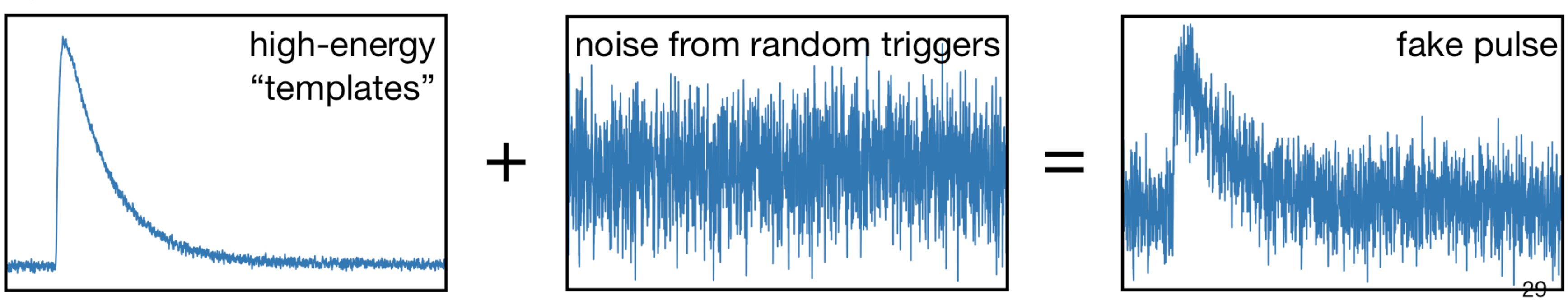
Model Background

- Method devised by Adam Anderson
- Sample higher energy locations
- Rescale pulse size and inject with noise
- Run through standard processing tools



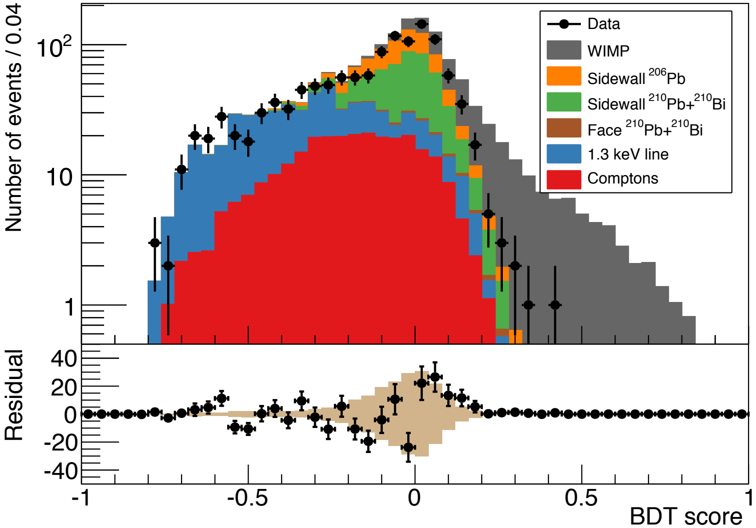
background type	*template source*
^{210}Pb daughters	WIMP-search data (~40-100 keV)
External gammas	^{133}Ba calibration data (~100 keV)
L-shell lines (~1 keVee)	K-shell decays (~10 keVee)

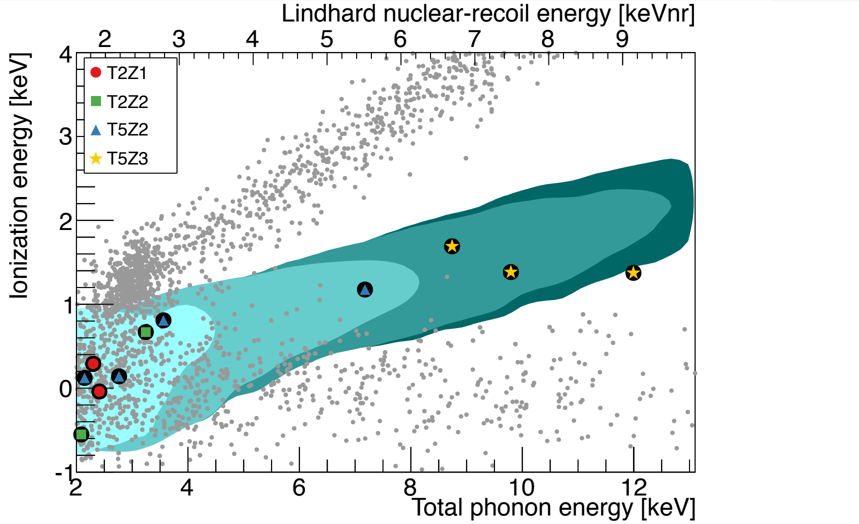
High-E events as templates for low-E events: **preserves pulse shape info**



Slide Courtesy of Adam A.

LT Results





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  - Had shorted outer ionization channel
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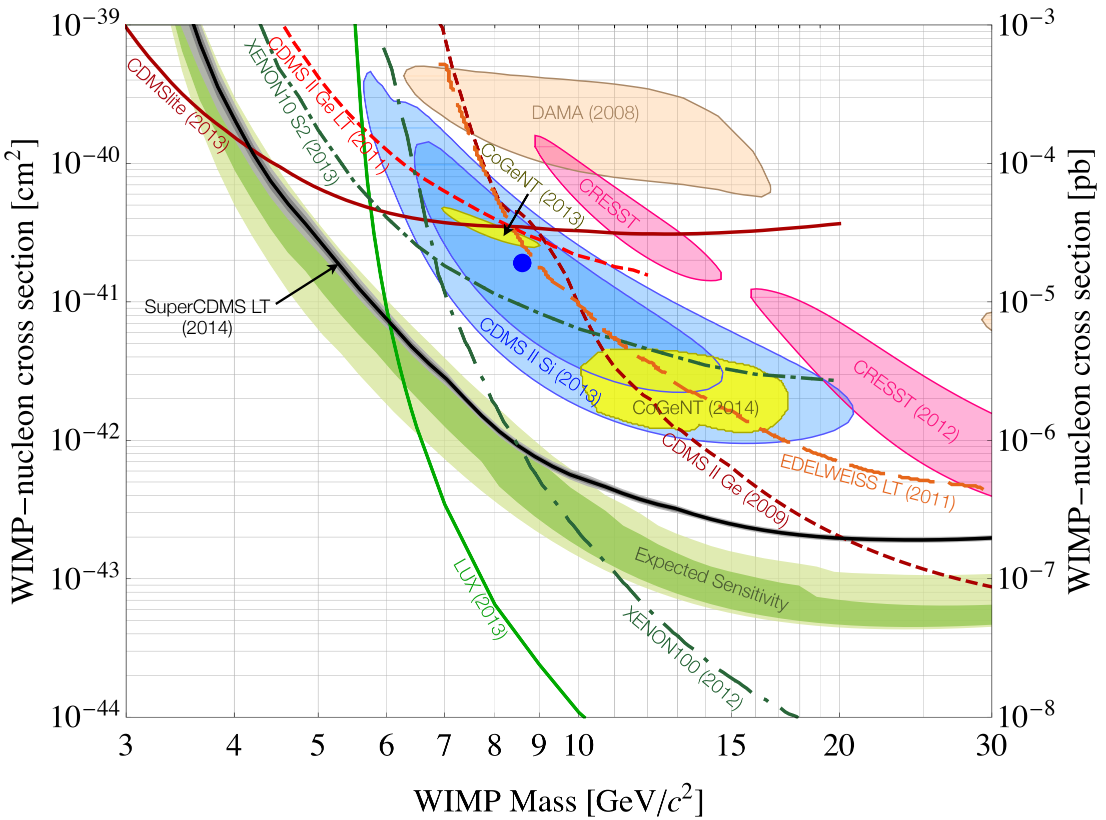
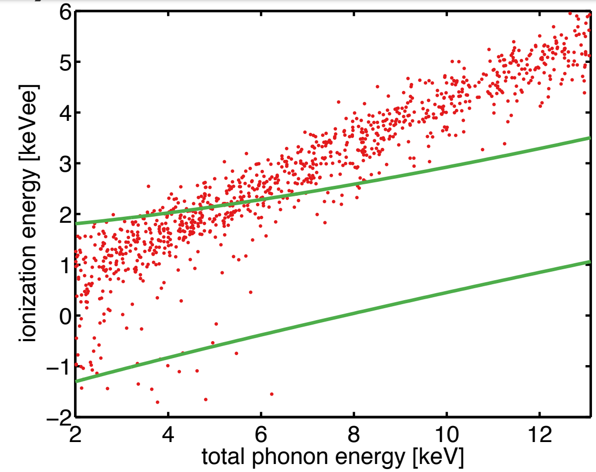
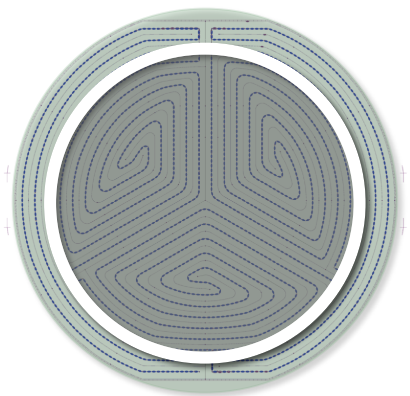


Discrimination Quantities (Phonons)

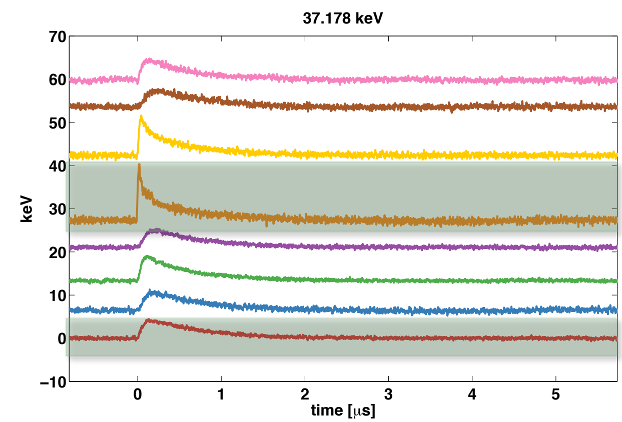
Ionization
+
Phonon

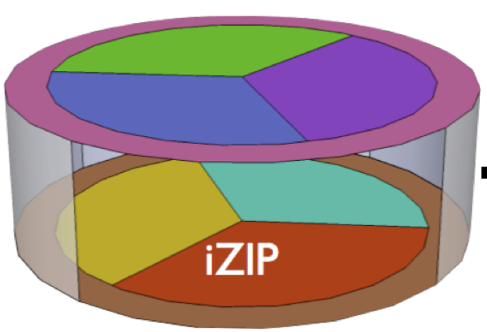
Bulk γ's



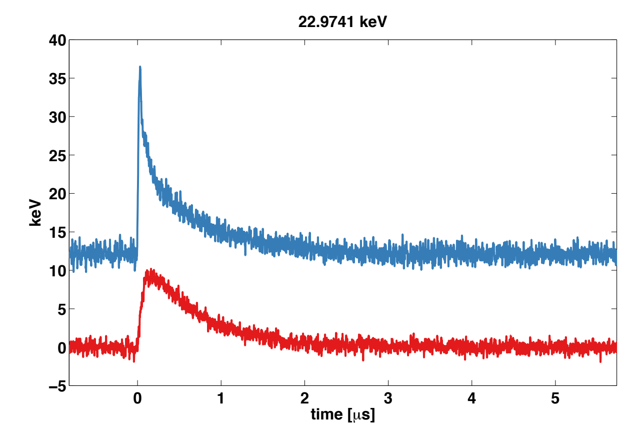


Sidewall Events



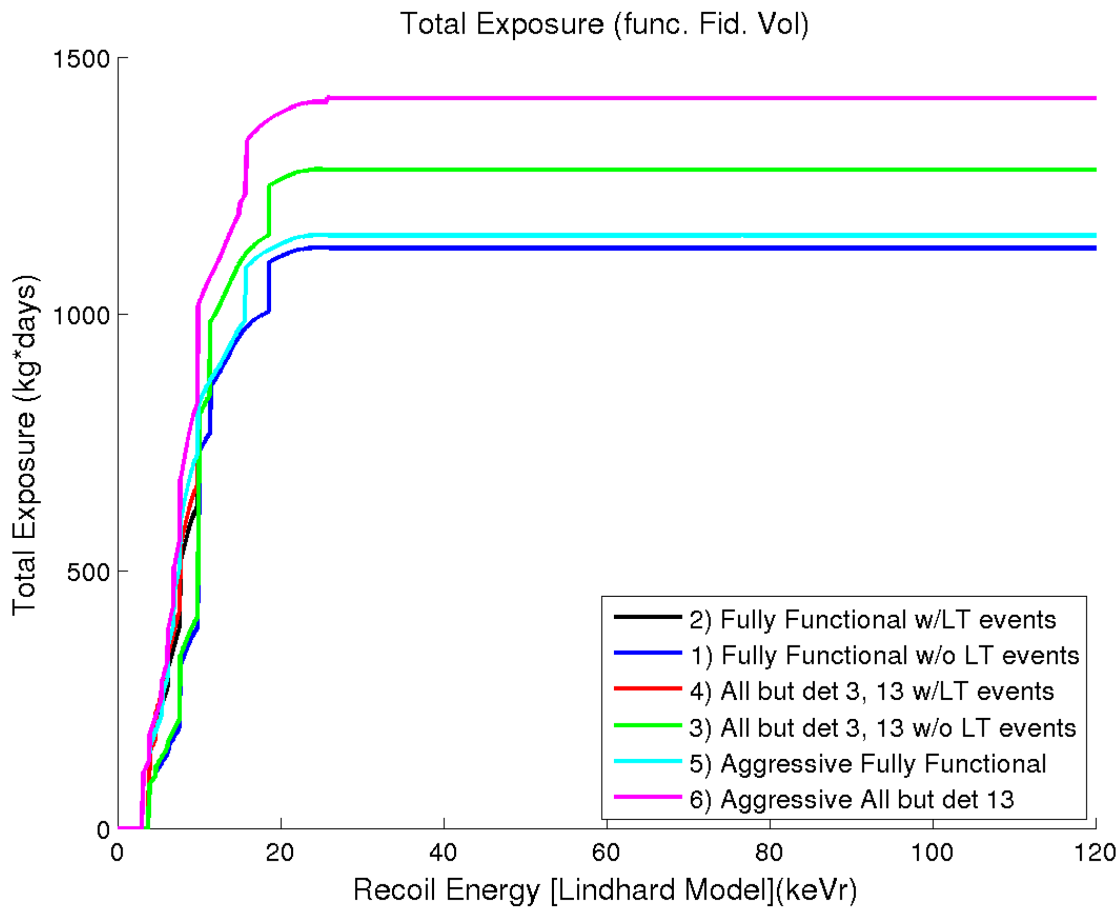


Surface Events



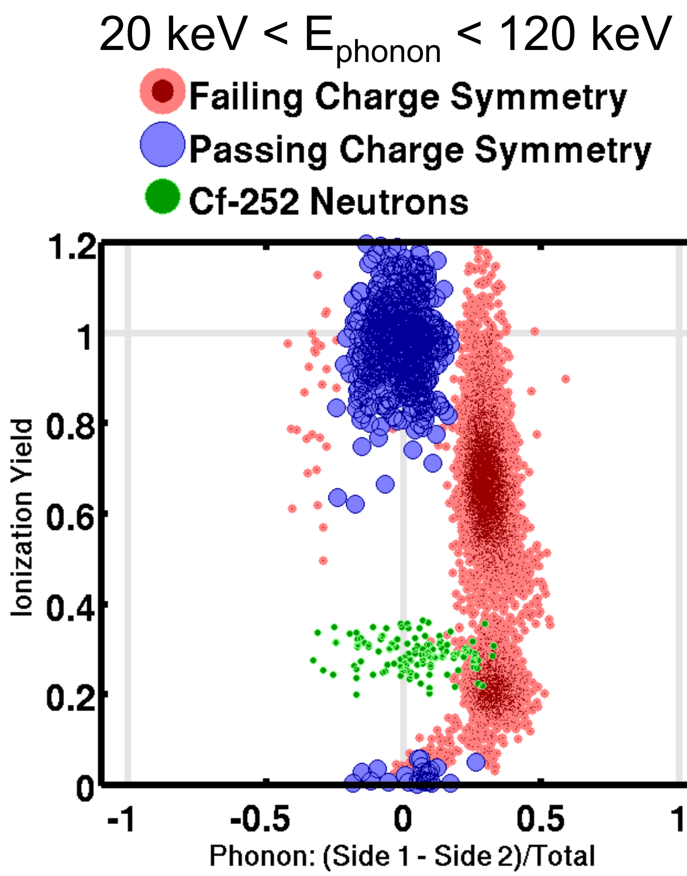
Exposure Estimates

- Uses conservative energy-dependent fiducial volume
- Range of exposures depending on detector cases
- Ultimately only a factor of a few difference in limit



Phonon Discrimination

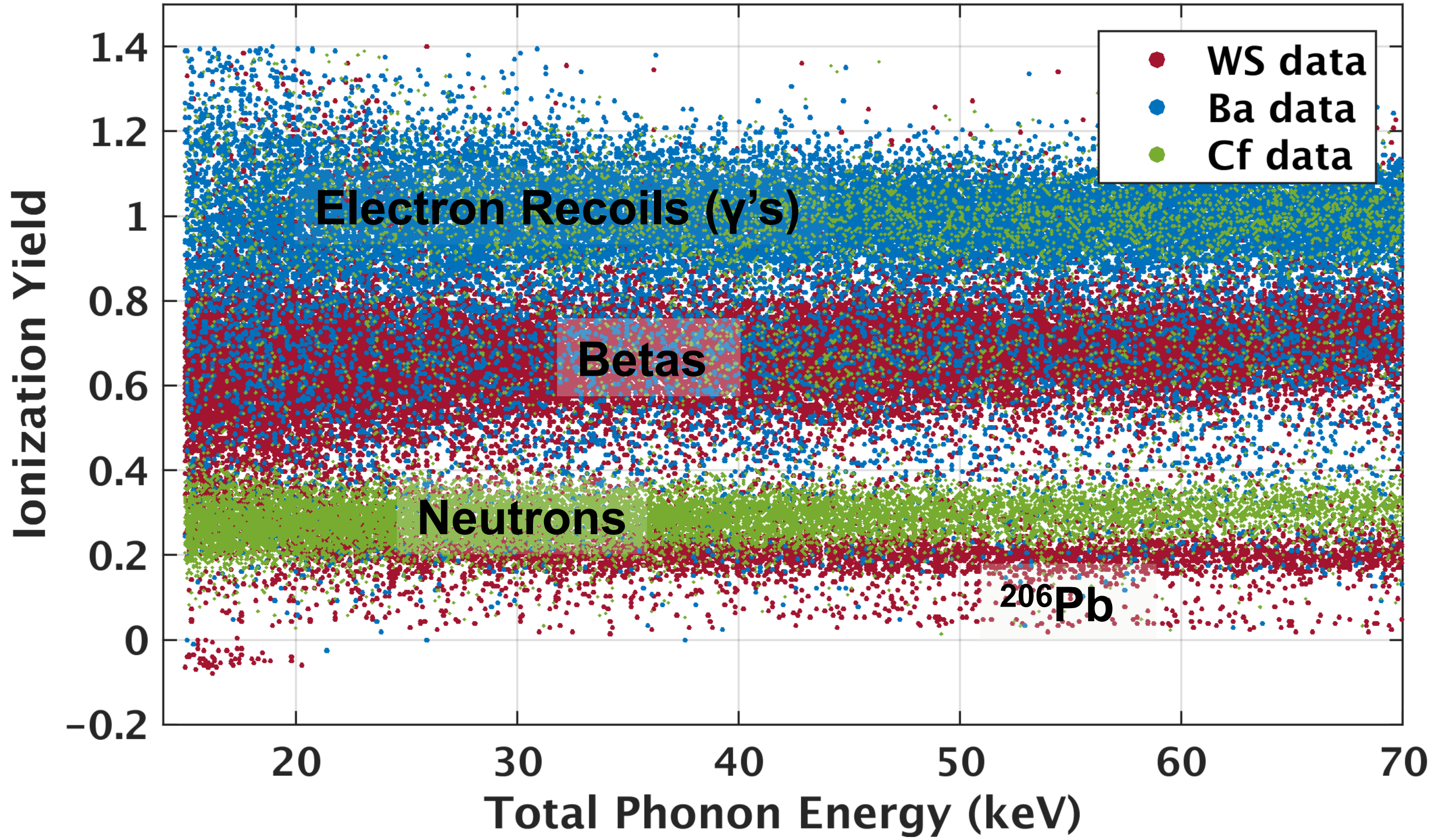
- Clear separation of bulk electron recoils in phonon plane as well
- Separation of surface events
  - Ionization is more powerful
  - Planned enhancements to pulse reconstruction algorithms in future



Discrimination Planes: Yield vs Energy

- Ionization quantities powerful for most of our energy range
- Ionization Partitions mostly flat as a function of energy
- Yield vs Energy gives us event bands
- Separate ER from NR
- Surface and sidewall β's, ^{206}Pb leak into neutron band

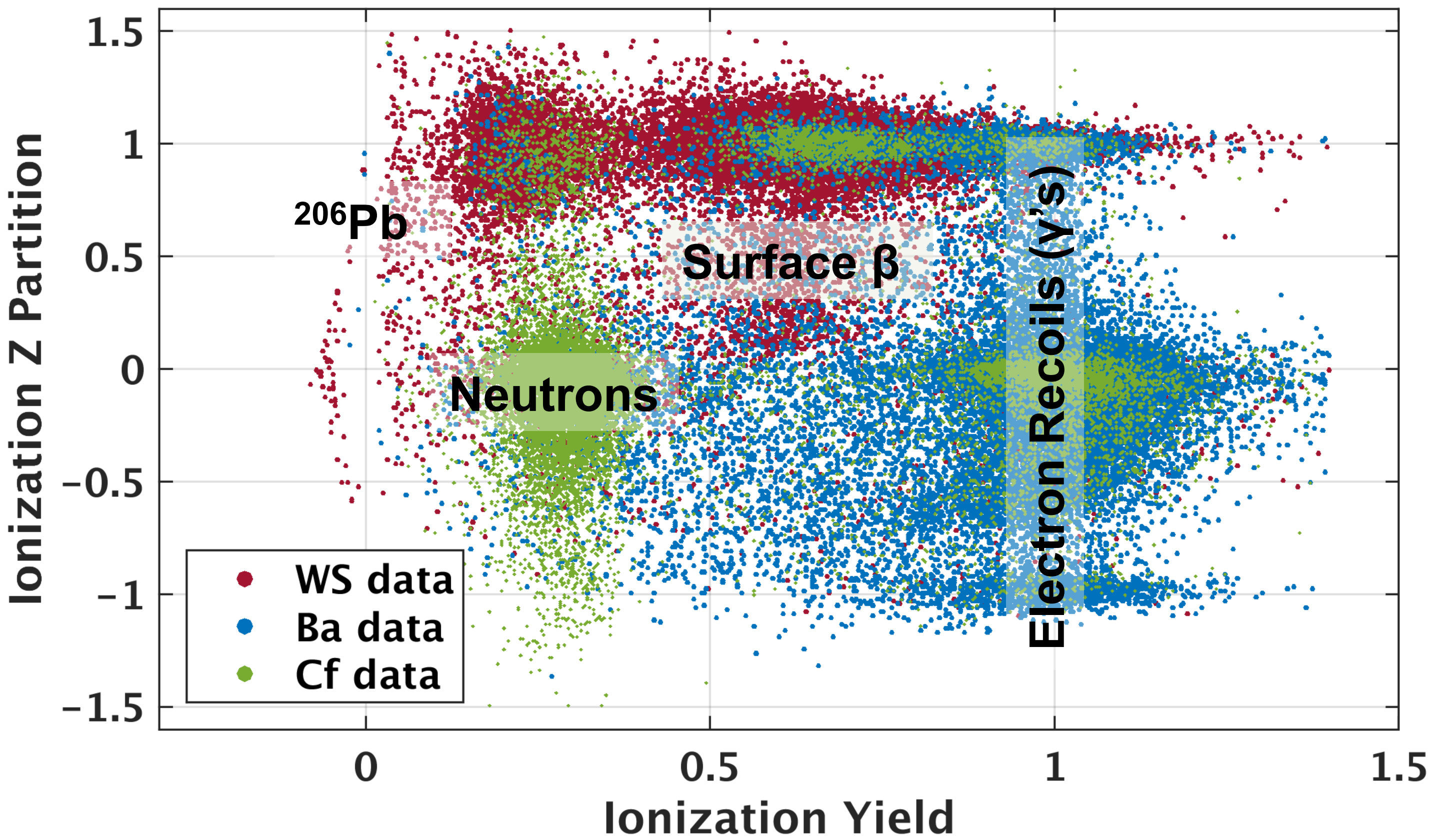
Data from detector with ^{210}Pb source embedded on top surface



Discrimination Planes: Z Partition vs Yield

- Ionization quantities powerful for most of our energy range
- Ionization Partitions mostly flat as a function of energy
- Z partition separates bulk from surface
- Can remove surface events and ERs
- Cannot discriminate against sidewall events

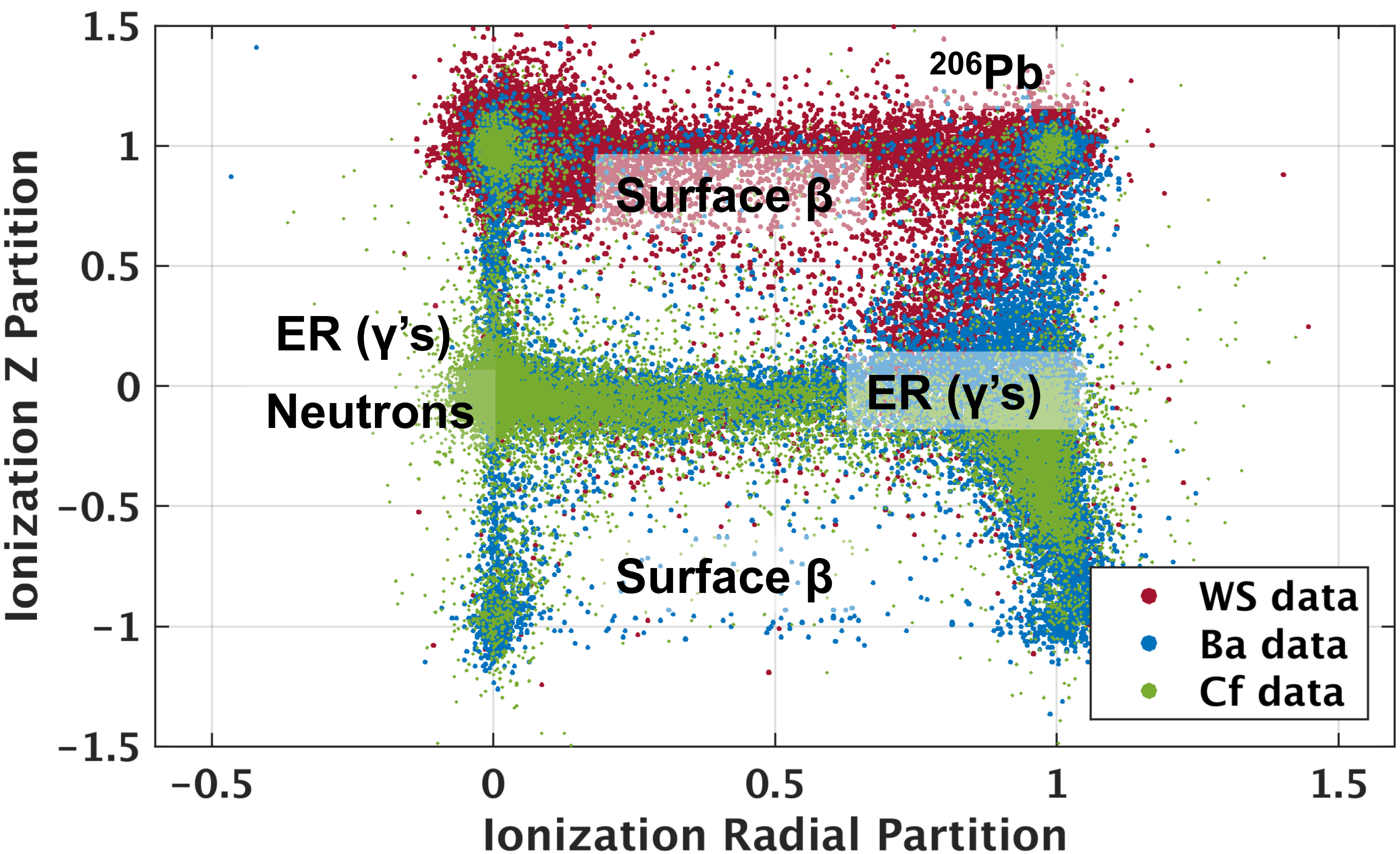
Data from detector with ^{210}Pb source embedded on top surface



Discrimination Planes: Z vs R Partition

- Ionization quantities powerful for most of our energy range
- Ionization Partitions mostly flat as a function of energy
- Z partition separates bulk from surface
- R partition separates inner from sidewall
- Cannot discriminate NR from ER here

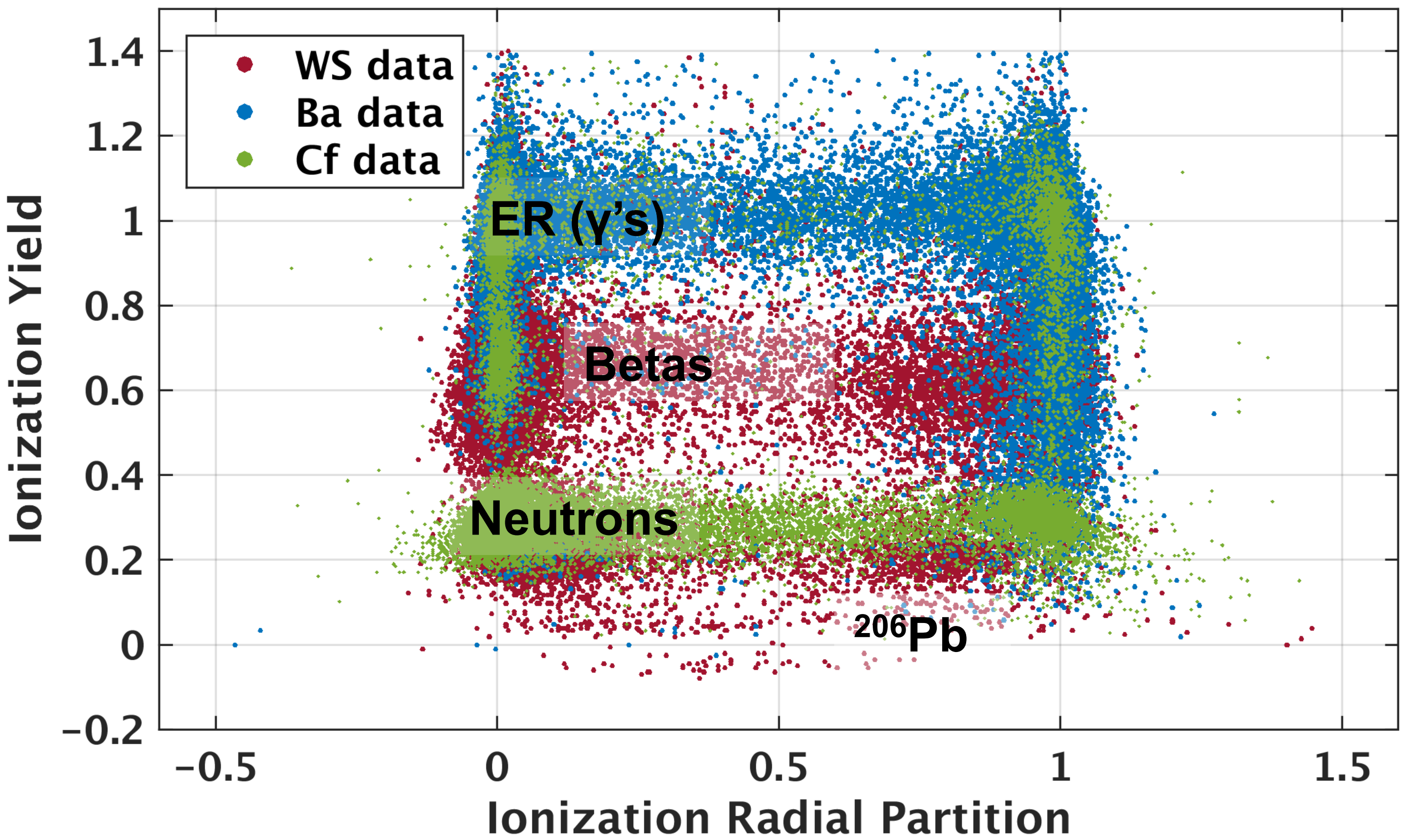
Data from detector with ^{210}Pb source embedded on top surface



Discrimination Planes: Yield vs R Partition

- Ionization quantities powerful for most of our energy range
- Ionization Partitions mostly flat as a function of energy
- R partition separates inner from outer
- Can discriminate against sidewall events and ERs
- Cannot discriminate surface from bulk

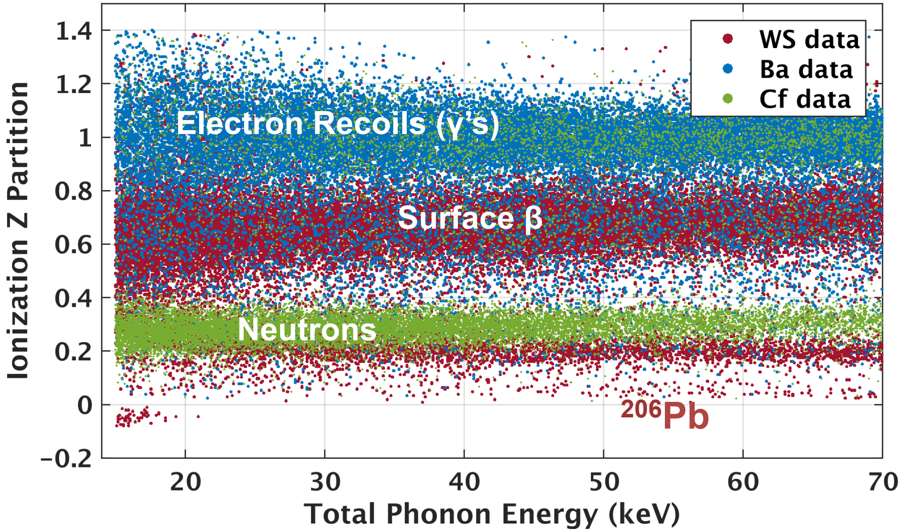
Data from detector with ^{210}Pb source embedded on top surface

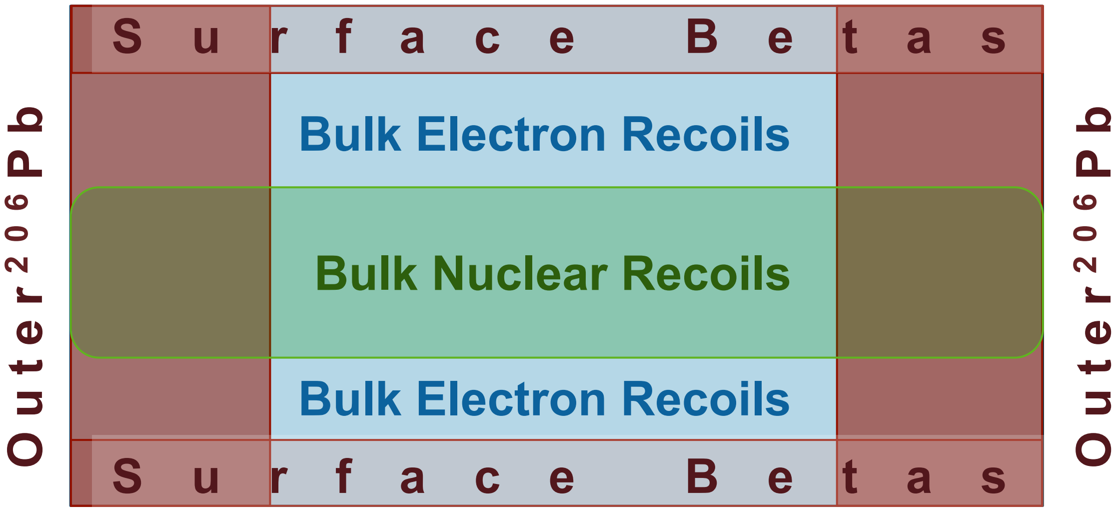


Discrimination Planes

- Ionization powerful for most of our energy range
- Ionization Partitions mostly flat as a function of energy
- Data from detector with ^{210}Pb source embedded on top surface

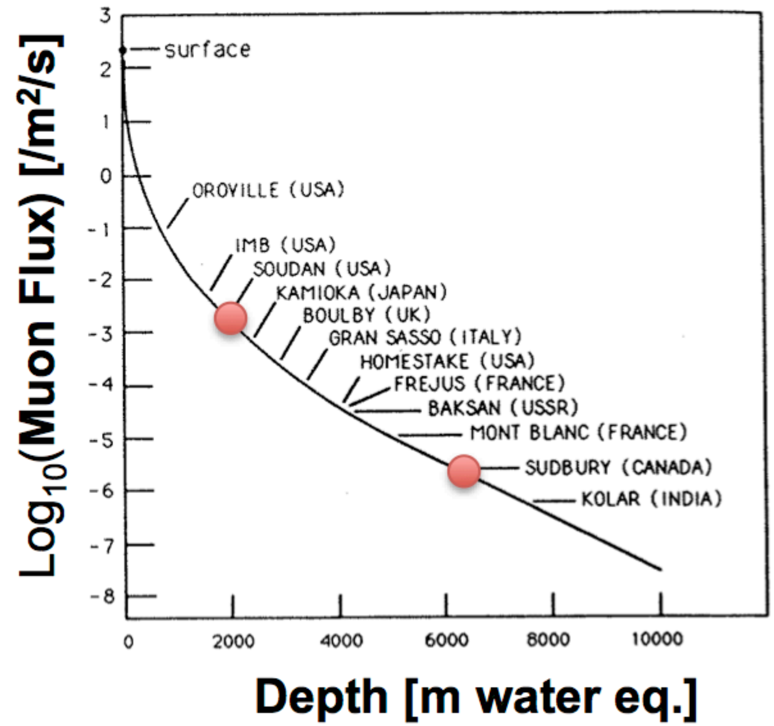
- Yield vs Energy gives us event bands
- β, ^{206}Pb, and Outer events leak into n band

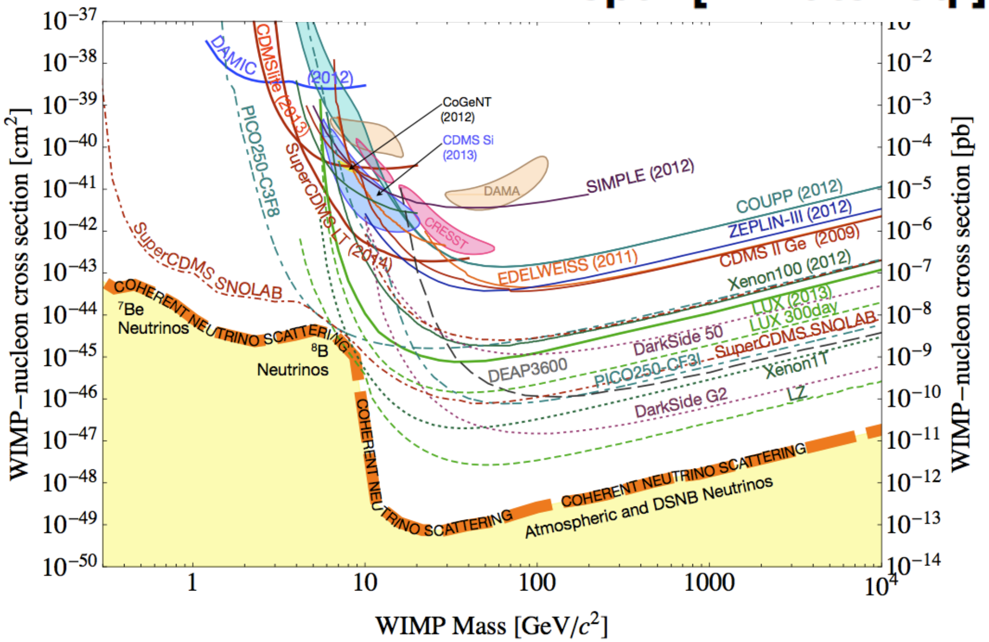




The Future

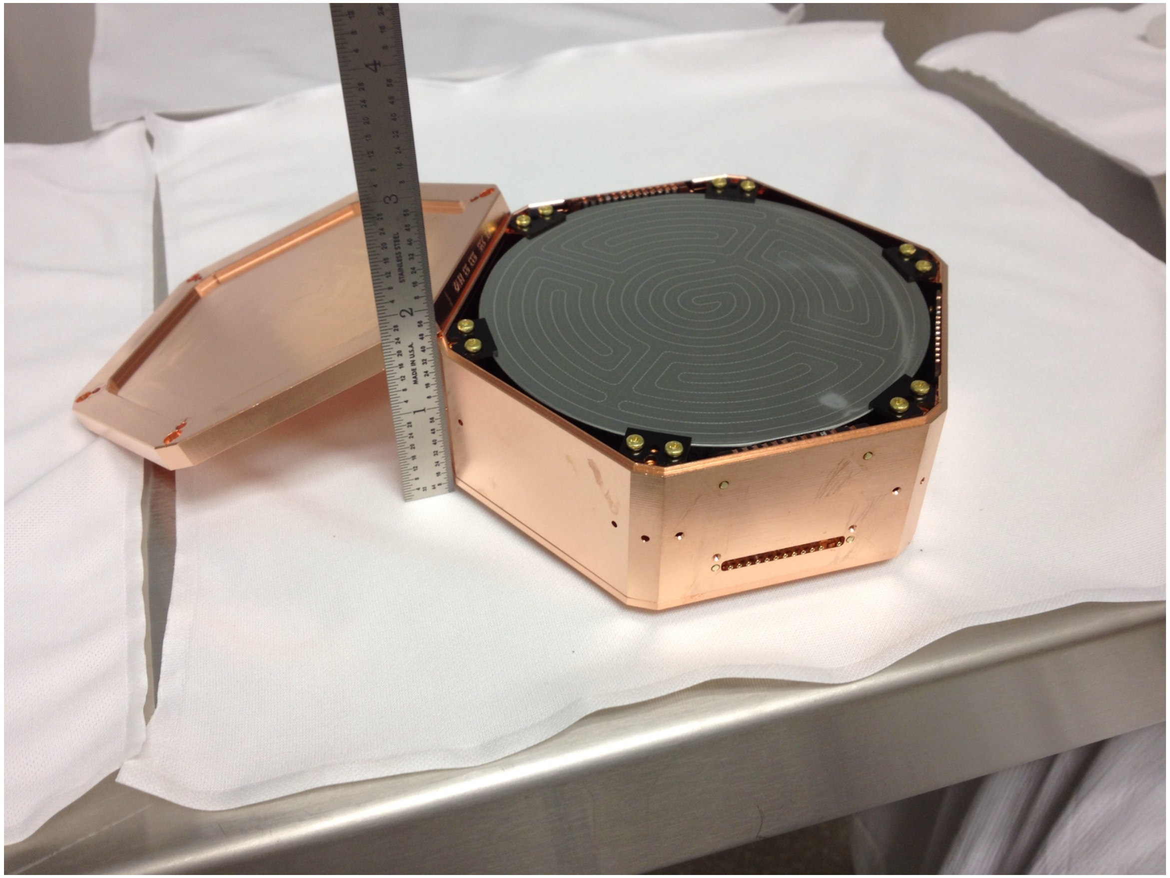
- SuperCDMS at SNOLAB
- Larger payload O(100) iZIPs
- Lower background rates
- Low and high mass WIMP searches!

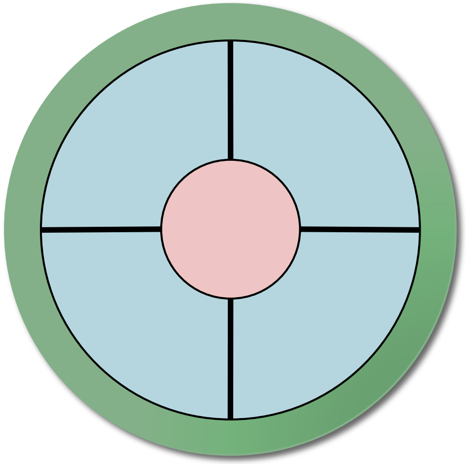




Larger iZIPs

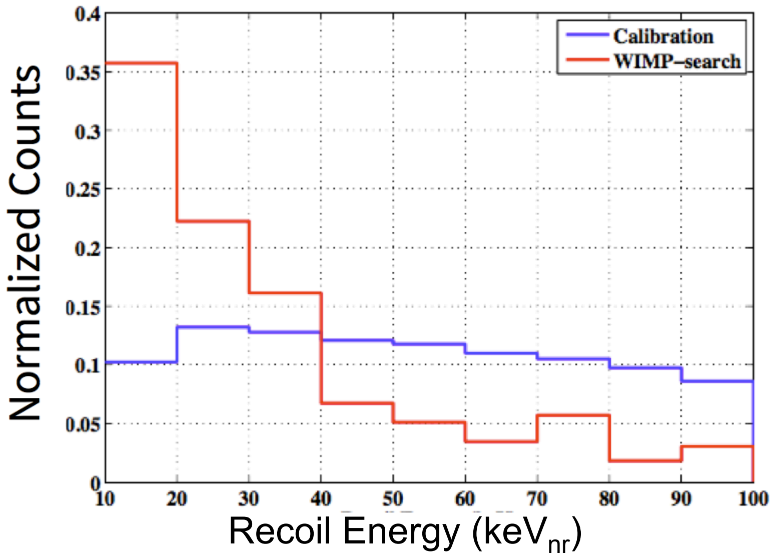
- 1.4 kg Ge
- 100mm diameter
- New Pattern
- 6 phonon channels per side
- Fabrication demonstrated





In Search of A Background Model

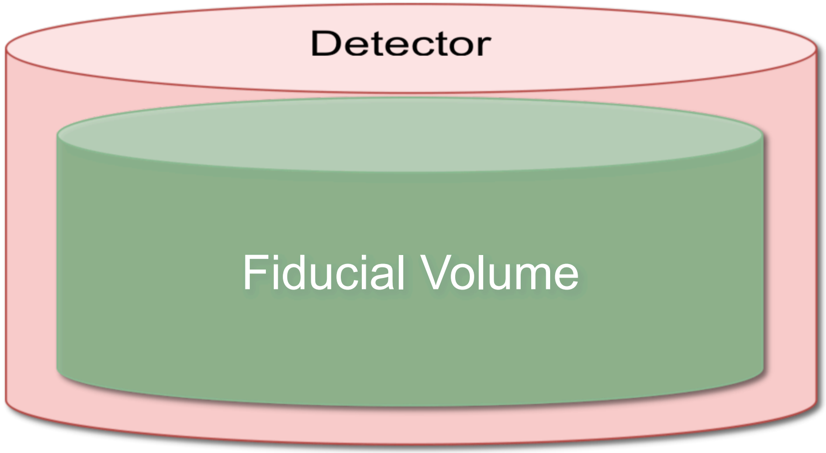
- Cannot use same technique as LT analysis here
- iZIP discrimination is excellent
  - Bulk of background distributions are well separated from signal region
  - Tails are the problem!
- Can take cue from previous CDMS-II high mass search
  - Use Barium data as proxy for backgrounds
  - Energy systematics
    - More low energy γ's in WS
    - Ba naturally has more higher energy γ's
  - Estimate leakage rates



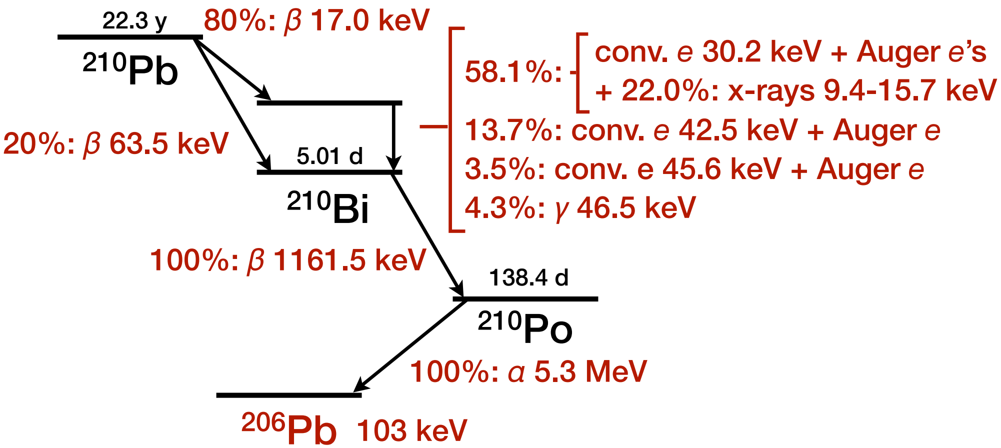
SuperCDMS HT Strategy

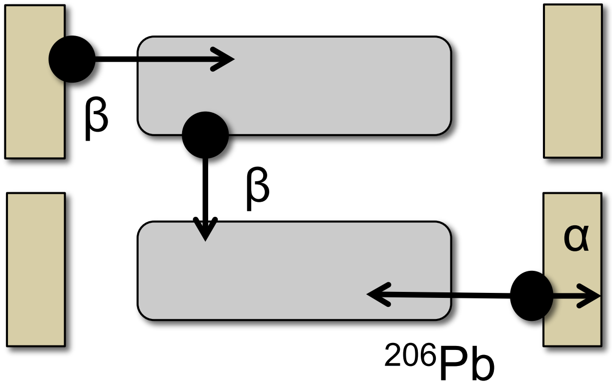
- Identify appropriate discrimination quantities
  - Ionization Yield (ratio of ionization to phonon recoil energy)
  - Ionization-derived radial and Z locations (‘partitions’)
  - Phonon-derived partitions possible
- Use calibration datasets to model backgrounds and signal
- Optimize fiducial volume
  - Machine learning algorithms
    - BDT, Neural Net(?)
    - SuperCDMS LT used BDT
  - Linear discriminants
    - Slightly problematic if there are non-linear correlations between quantities
  - Traditional Rectilinear Cuts based
    - Not as powerful as other methods
    - Provides simple cross-check of more sophisticated methods

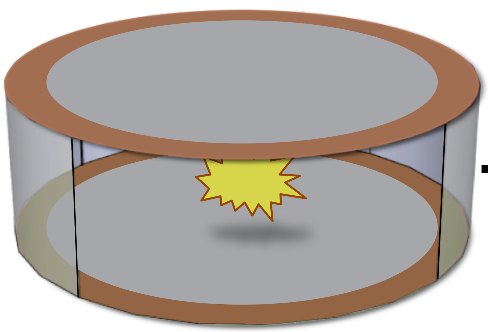
Cartoon Fiducial Volume



Background Discrimination

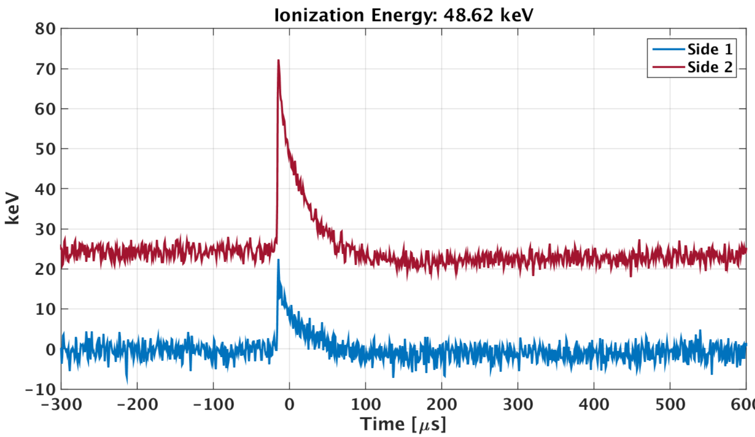


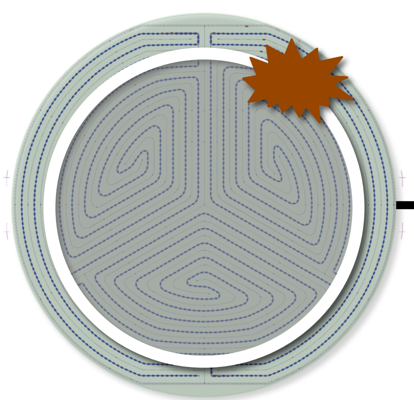




Z Partition

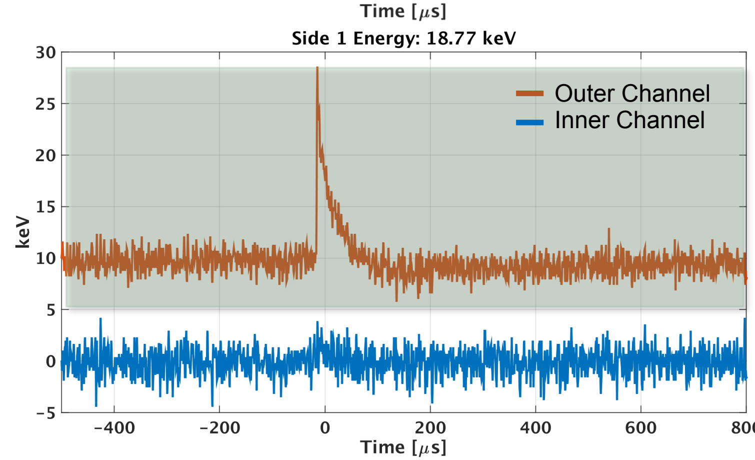
Surface Events





Radial Partition

Sidewall Events

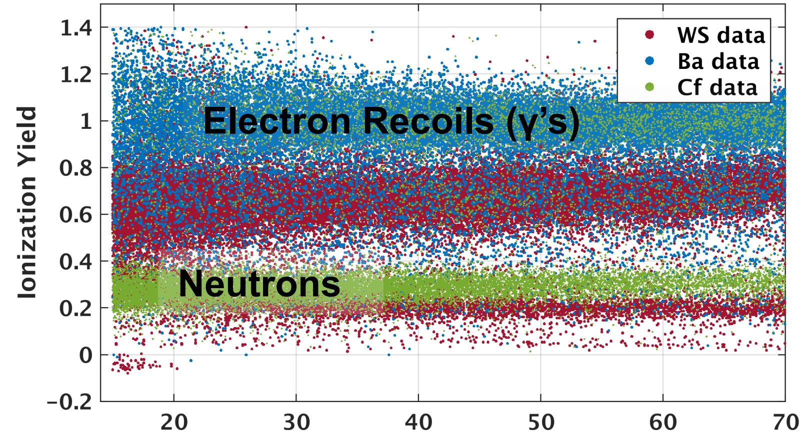


Ionization Based Discrimination

Ionization
+
Phonon

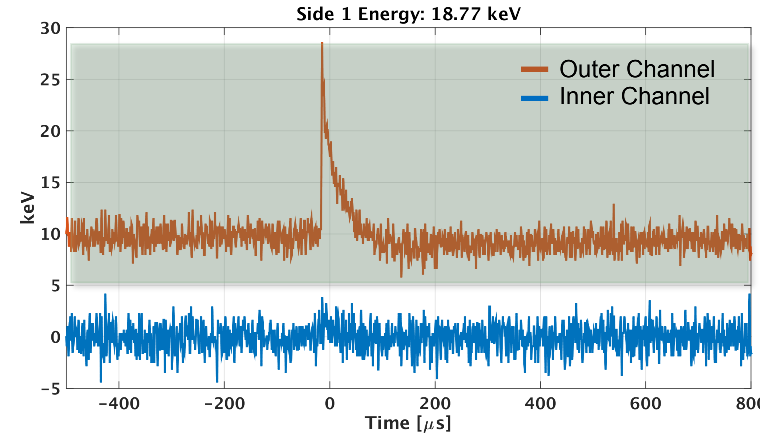
Yield

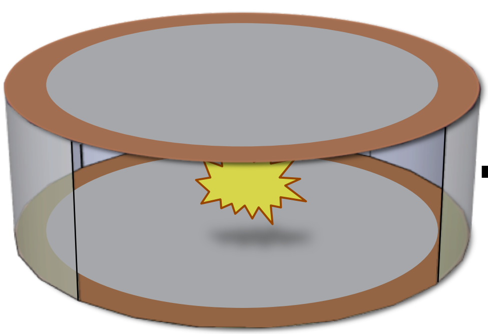
Bulk γ's



Radial Partition

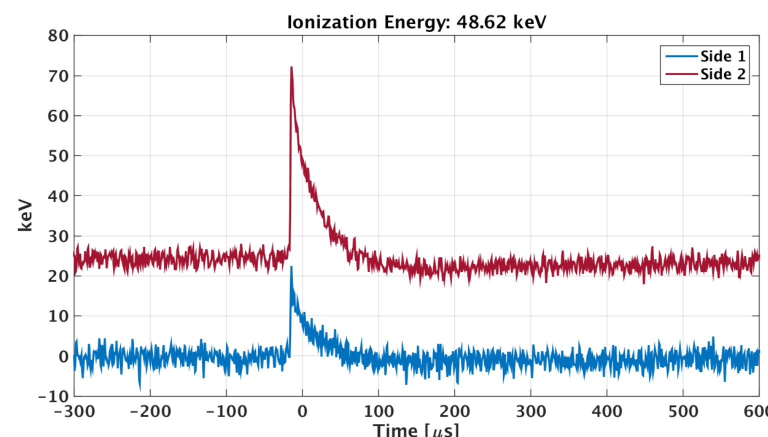
Sidewall Events





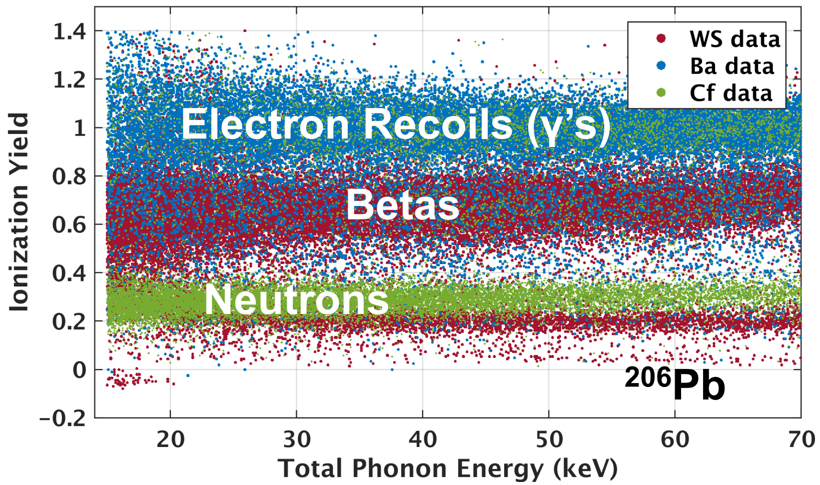
Z Partition

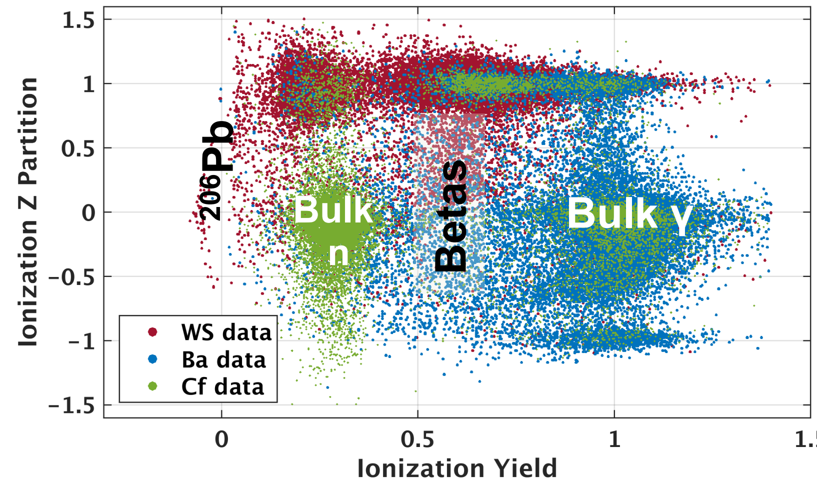
Surface Events



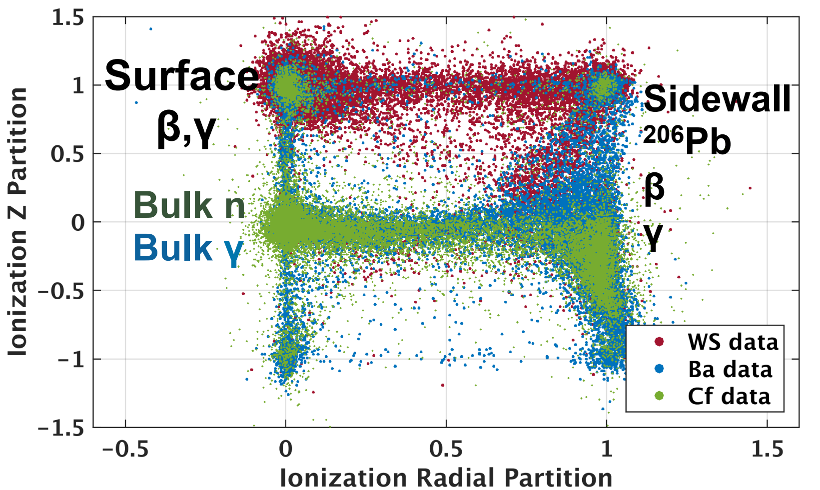
Ionization Discrimination Planes

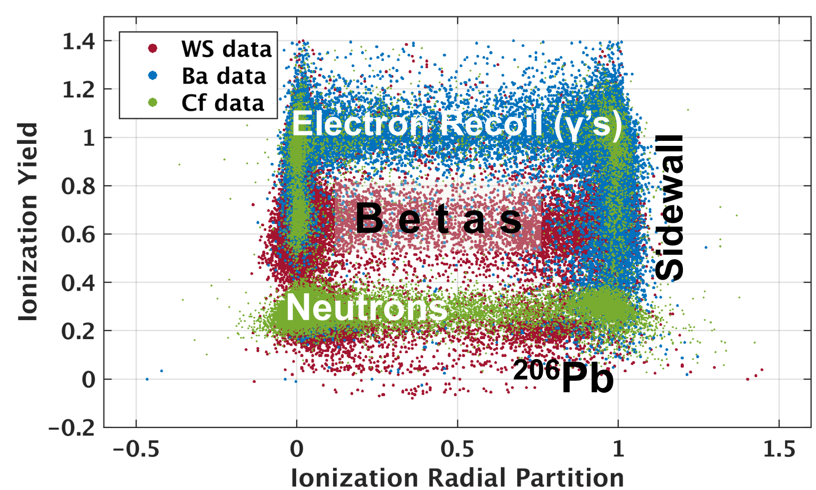
- Data taken from detector with ^{210}Pb source implanted on top surface





- Yield vs Energy:
  - Separate ER from NR
- Z part vs Yield:
  - Separate ER/NR & bulk/surface





- Z part vs R part:
  - Separate bulk/surface & inner/sidewall
- R part vs Z part:
  - Separate ER/NR & inner/sidewall