# SuperCDMS Soudan:

## High Threshold Analysis

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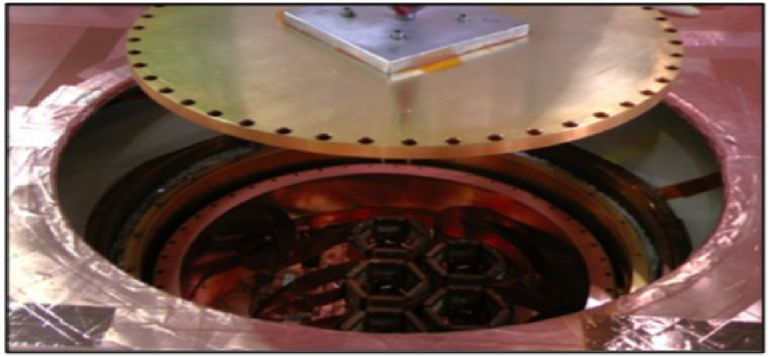
Caltech

# SuperCDMS Soudan

- **15 Ge iZIP detectors (9 kg) installed in CDMS II apparatus in Soudan Underground Lab**
- **Data taken March 2012 – July 2014:**
  - 510 total live-days
  - 496 low bg live-days
  - Additional high stats Ba
- **Multiple Analyses**
  - Low Threshold
  - CDMSlite
  - CDMSlite run 2
  - **High Threshold**



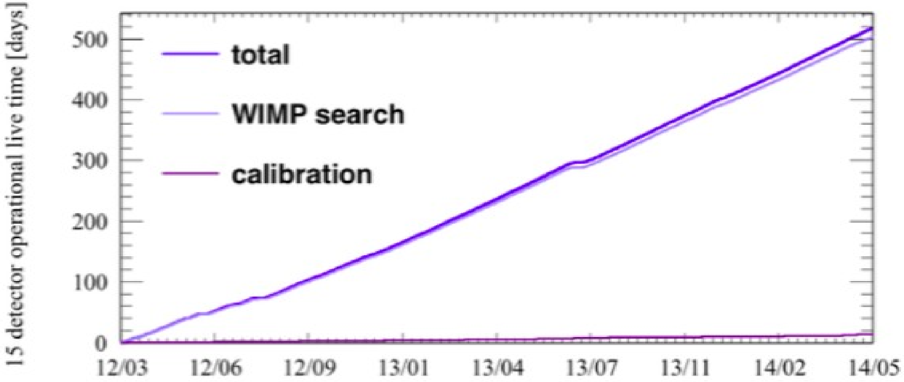


Image from R. Calkins

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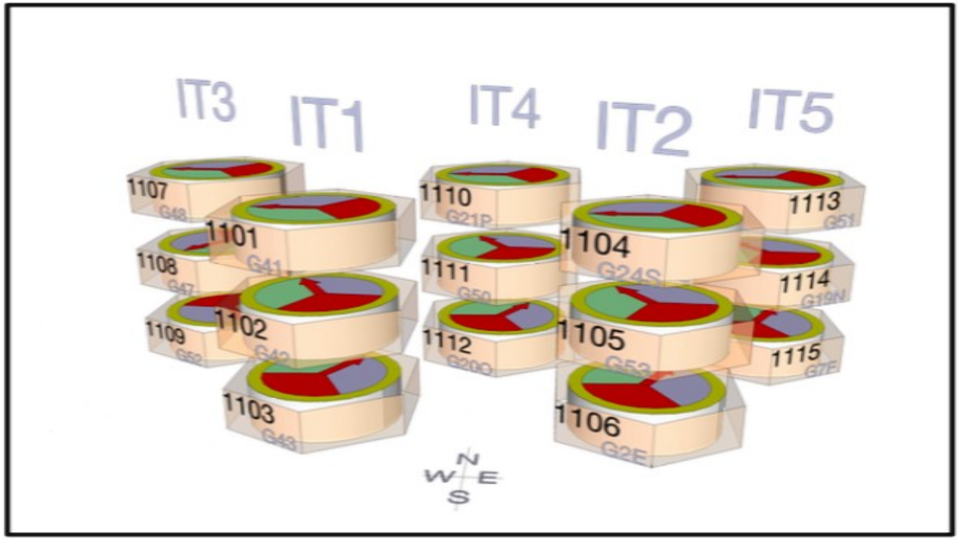
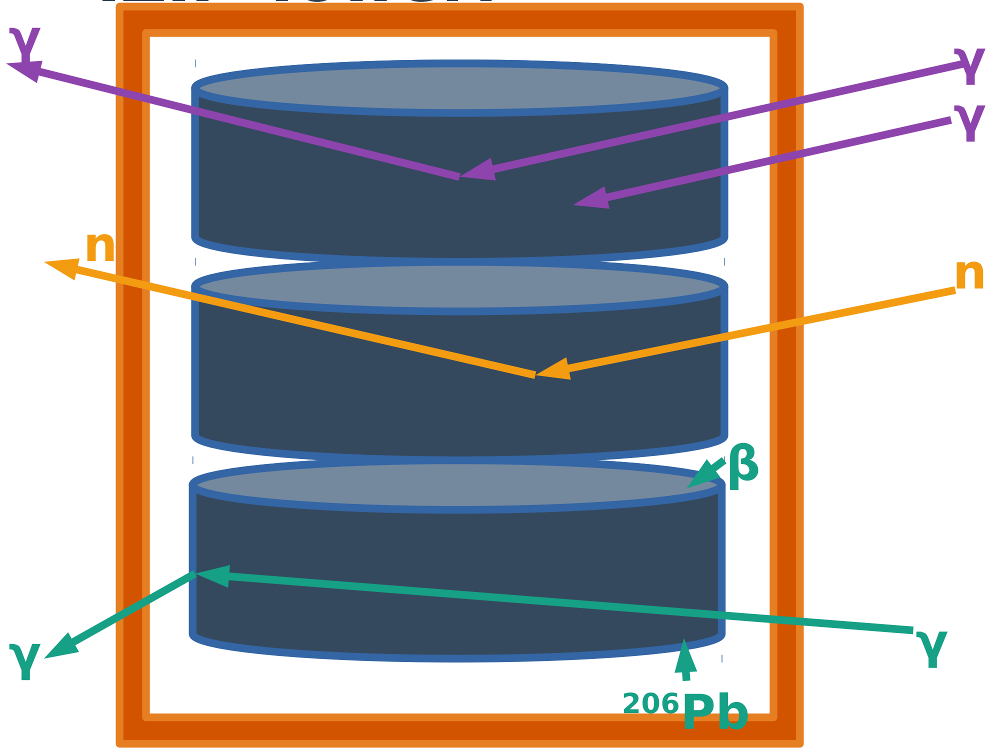
# High-threshold analysis

- **Exposure limited:**
  - Mass x Time
  - Ideally uses entire array
  - 1690 kg day after quality cuts
- **Employ volume fiducialization and background rejection**
  - Optimize analysis for < 1 misidentified BG event in WIMP acceptance region
  - **~900 kg day final exposure**



# Backgrounds

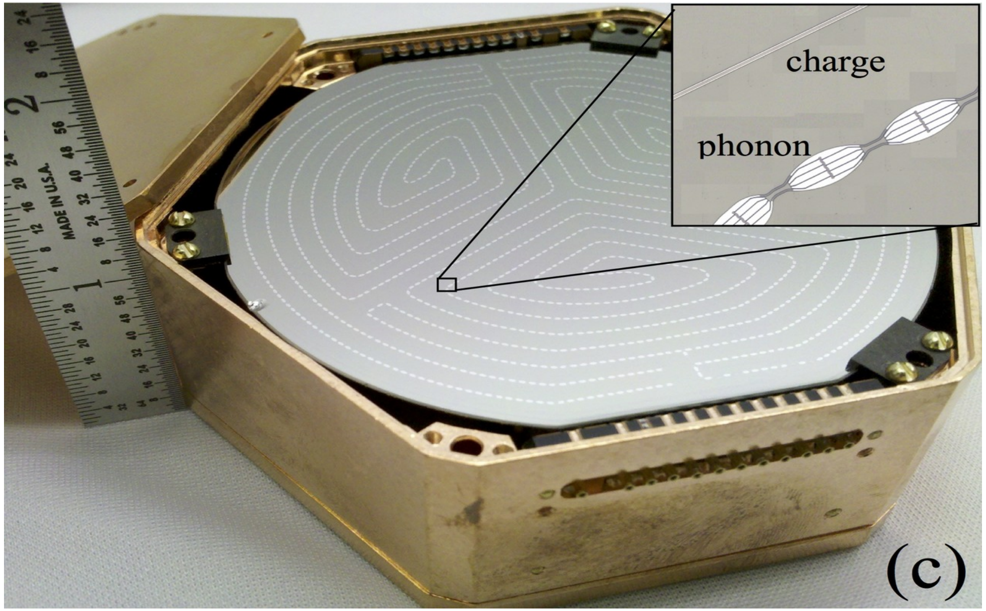
- **IZIP Tower:**



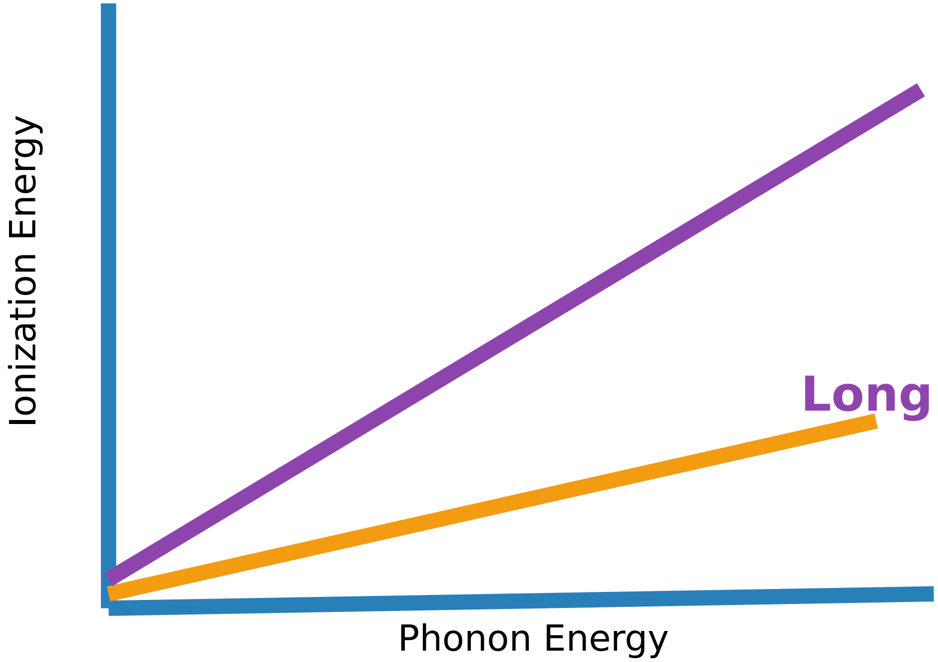

- **Photons (bulk)**
  - primarily Compton scattering (broad spectrum up to 2.5MeV)
  - small amount of photoelectric effect from low energy gammas (e.g. secondary scatters)
- **Neutrons**
  - radiogenic: arising from spontaneous fission and (α,n) reactions in surrounding materials (cryostat, shield, cavern)
  - cosmogenic: created by spallation of nuclei in surround materials by high-energy cosmic ray muons.
- **Surface events**
  - radiogenic: decay products of surface contaminates such as recoiling $^{206}$Pb nuclei or low-energy betas
  - photon-induced: interactions of photons or photo-ejected electrons in dead layer

# Ionization Yield

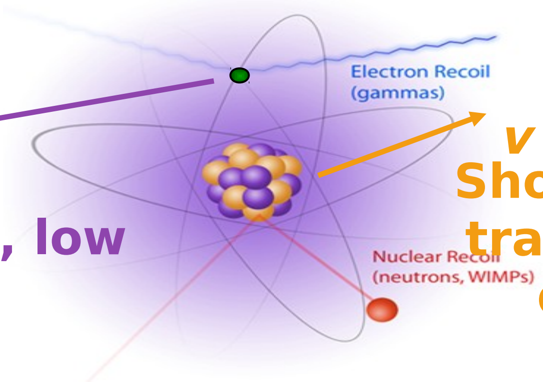
- **iZIP Ionization readout:**
  - Both holes and electrons collected
  - Outer charge channel tags high radius events
- **iZIP Phonon readout**
  - Provides extra position information for which collection is poor and charge measurement unreliable
  - Phonons and Ionization combined to estimate recoil energy
- **Ionization Yield formed from ratio of Ionization energy to phonon energy collected**
  - Together they provide event-by-event discrimination of nuclear recoils (WIMPs, neutrons, alphas, recoiling nuclei) from electron recoils (gammas, betas)



# Discrimination

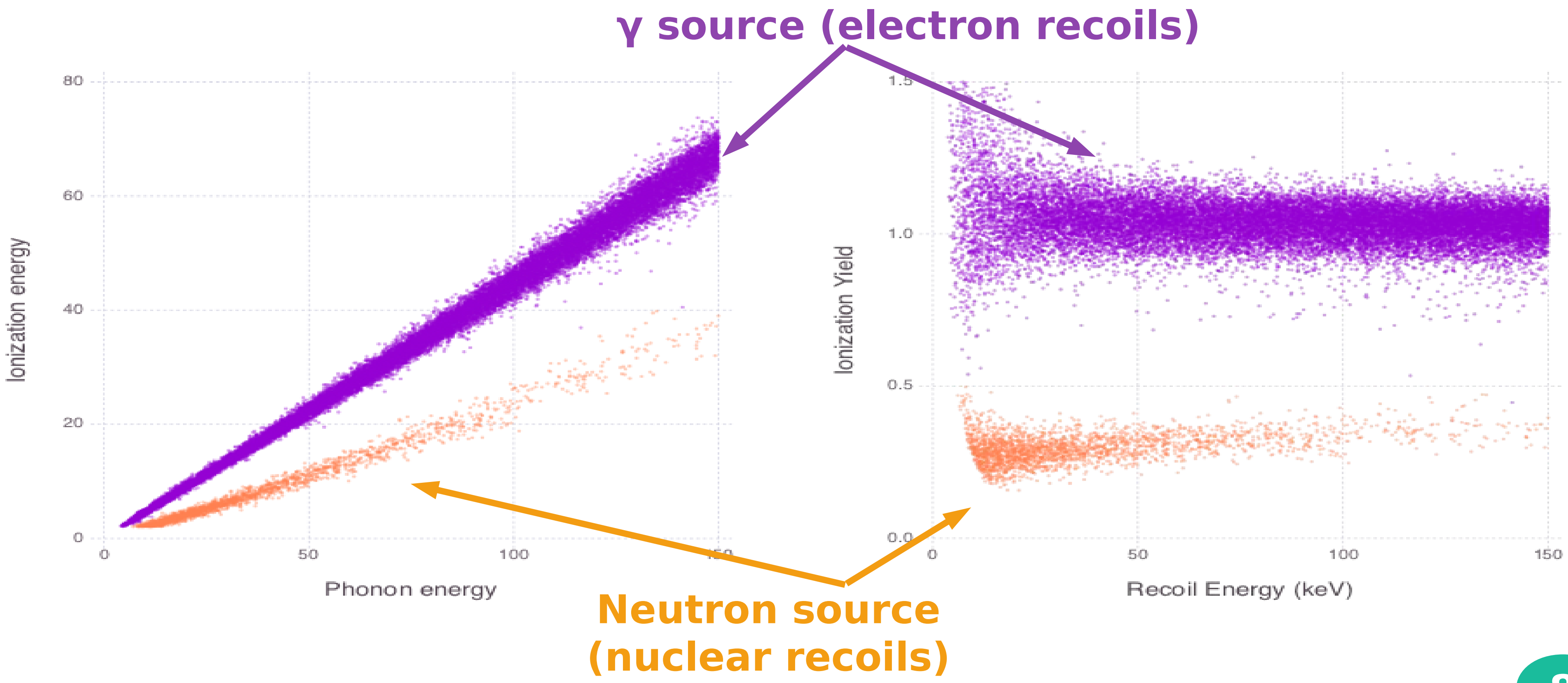



**$v \sim 0.3c$**
**Long recoil track, low dE/dx**




**$v \sim 10^{-3}c$**
**Short recoil track, high dE/dx**

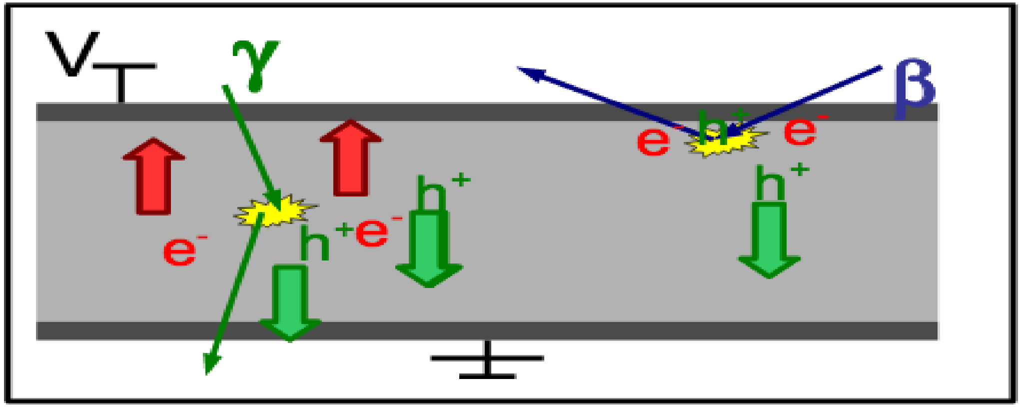
# Discrimination

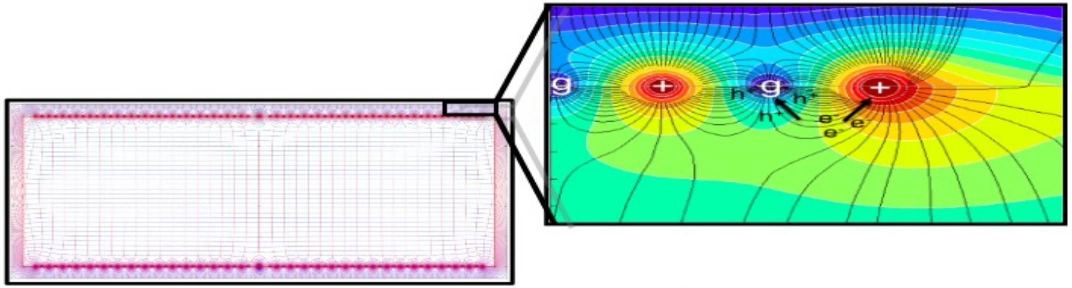


# Z fiducialization

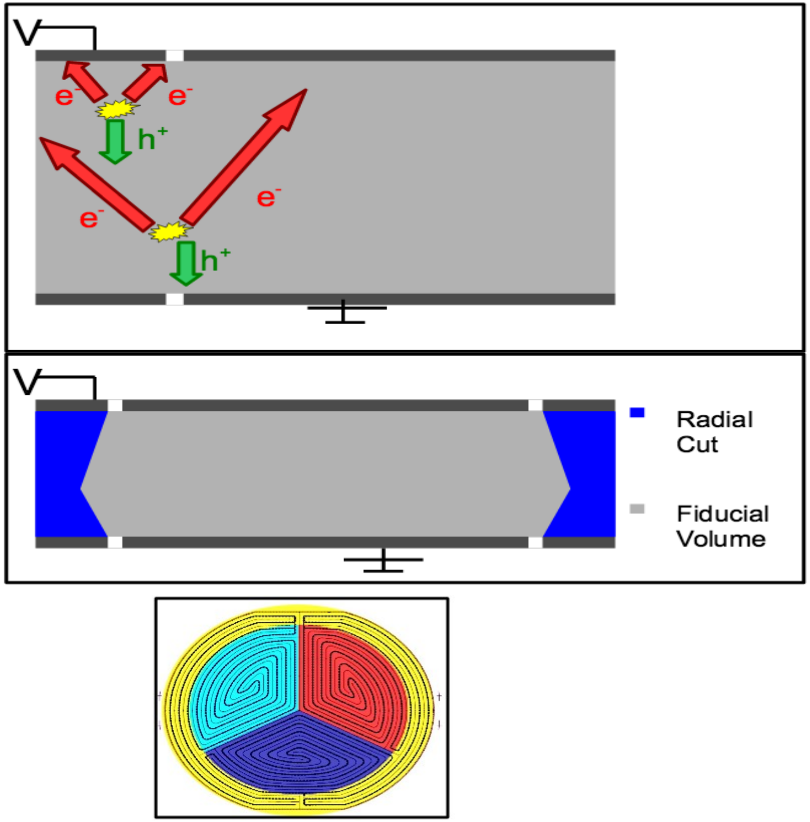
- **Purpose of iZIP design**
  - Surface events near top/bottom faces can suffer reduced ionization collection reducing yield and making discrimination difficult
  - Interdigitated electrodes allow discrimination of surface events
  - Allows for the construction of a z ionization parameter to be a proxy of z position

$$z\ parameter = \frac{Q_{electron} - Q_{hole}}{Q_{electron} + Q_{hole}}$$



# Radial fiducialization




- **Charges trapped on sidewall are not collected, effectively suppressing yield**
  - Oblique propagation exacerbates problem: electrons more susceptible to dispersion
  - Can construct a radial ionization partition measure for both electron and hole collection:

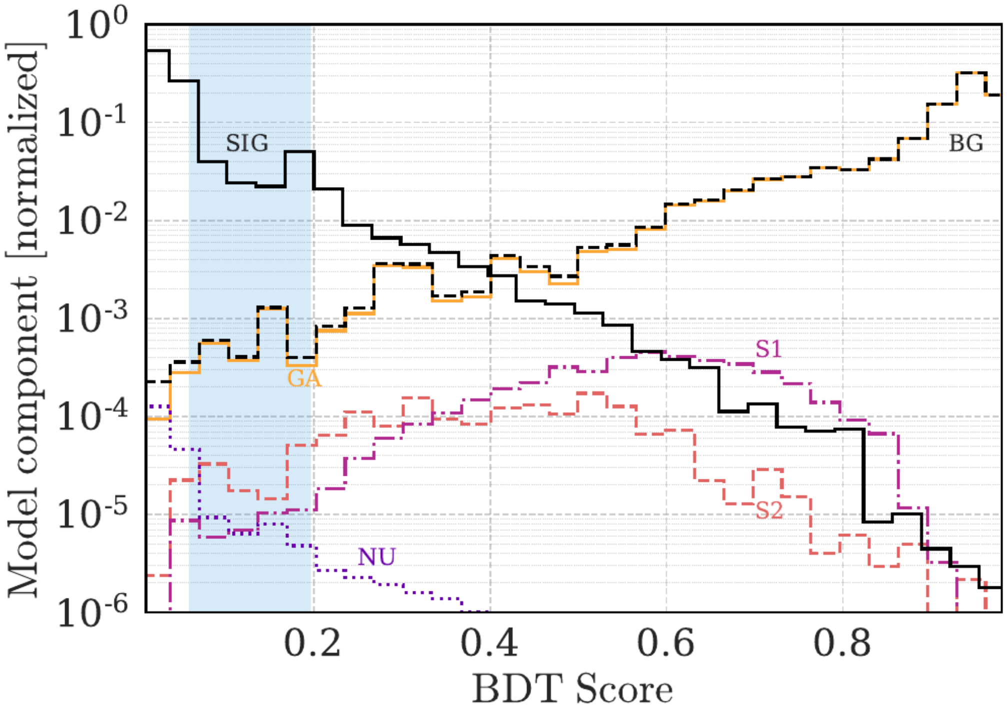
$$r\ partition_{hole} = \frac{Q_{hole}^{inner}}{Q_{hole}^{total}}$$

# Background Modeling

- **Signal region blinded: modeled via calibration data.**
- **Signal:**
  - Spectrum Average Exposure (SAE) modeled via $^{252}$Cf and a theoretical WIMP spectrum
- **Background:**
  - Gamma modeled via $^{133}$Ba data corrected to WIMP sidebands
  - Neutrons modeled with $^{252}$Cf corrected Geant4 simulated spectra
  - Surface events modeled with $^{210}$Pb source detectors corrected to all detectors

# Multivariate classification

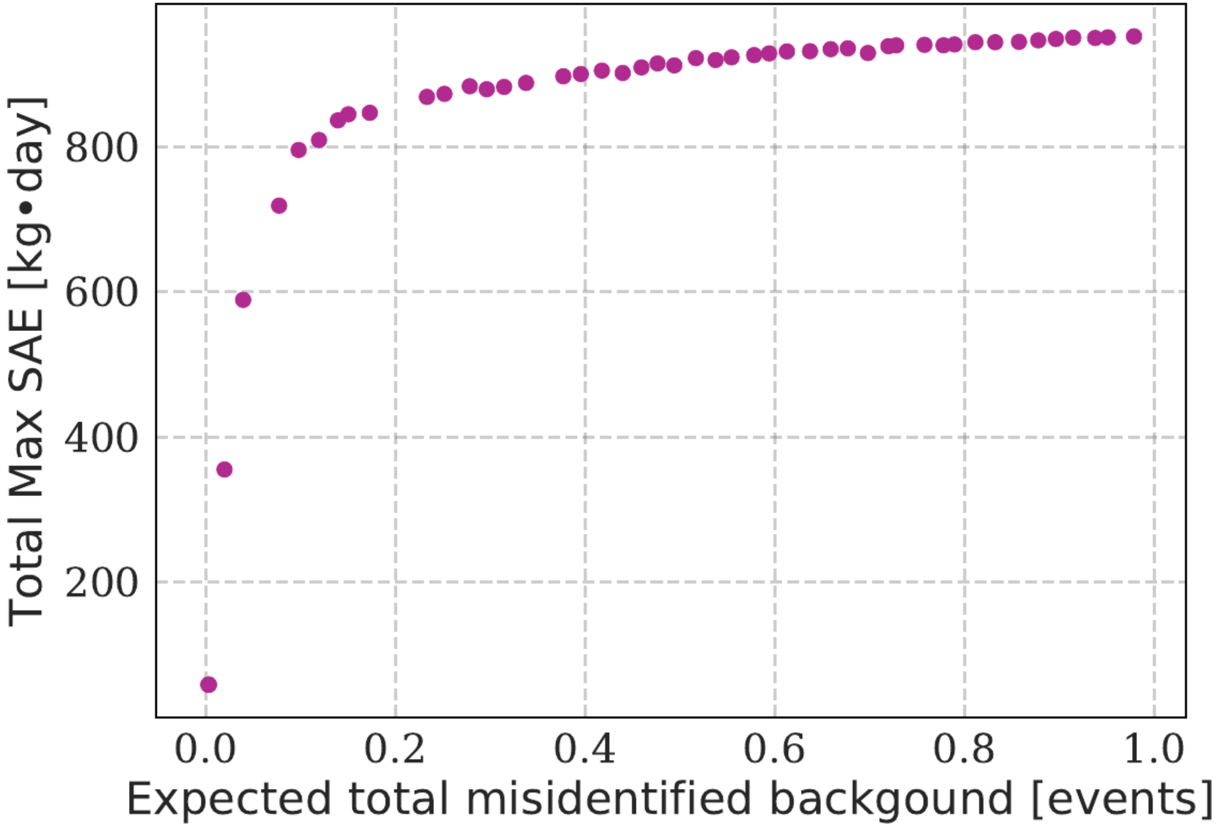
- **Can combine various measured quantities to form a single discriminating parameter**
  - Charge and phonon Z parameter, and R partition
  - Ionization and recoil energy
  - Ionization yield
- **Currently use a gradient-boosted decision tree**



# Maximize Exposure

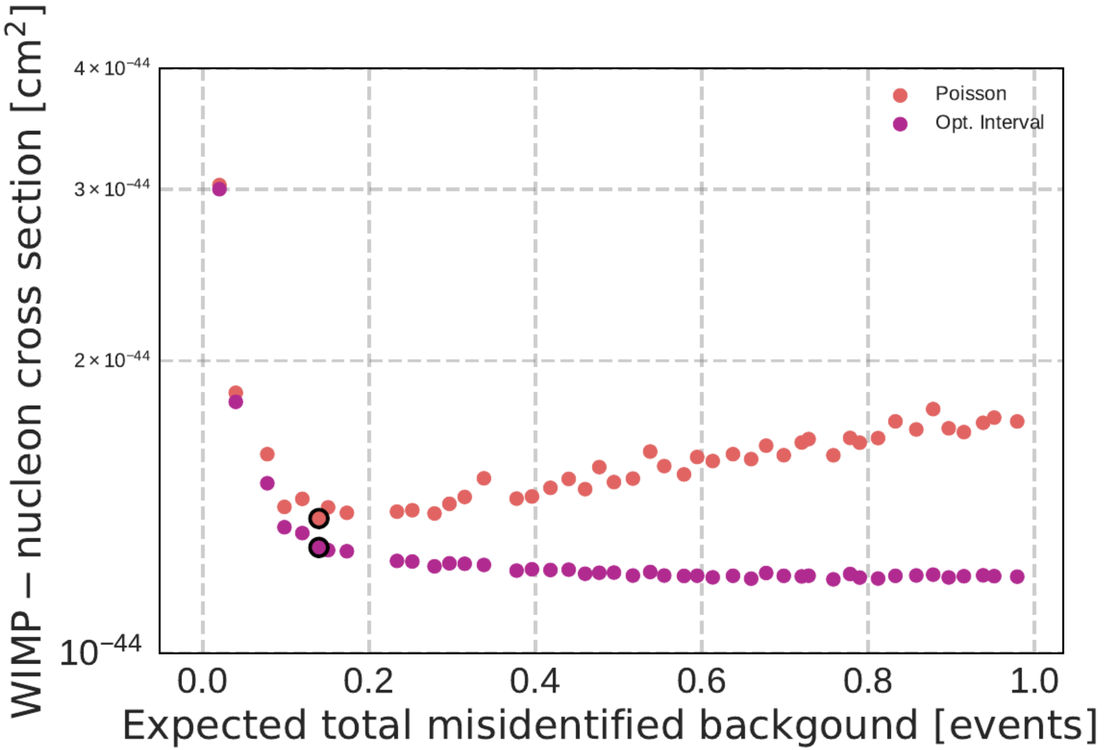
- **Maximize exposure (SAE) while forcing misidentified bg to be a constrained value**
- **Assume less than one bg event optimal**
  - Start at 0.02 events and end at 1 events with a step of 0.02
- **Start with gradient maximizer (fast), improve with MCMC maximizer**

# Maximize SAE



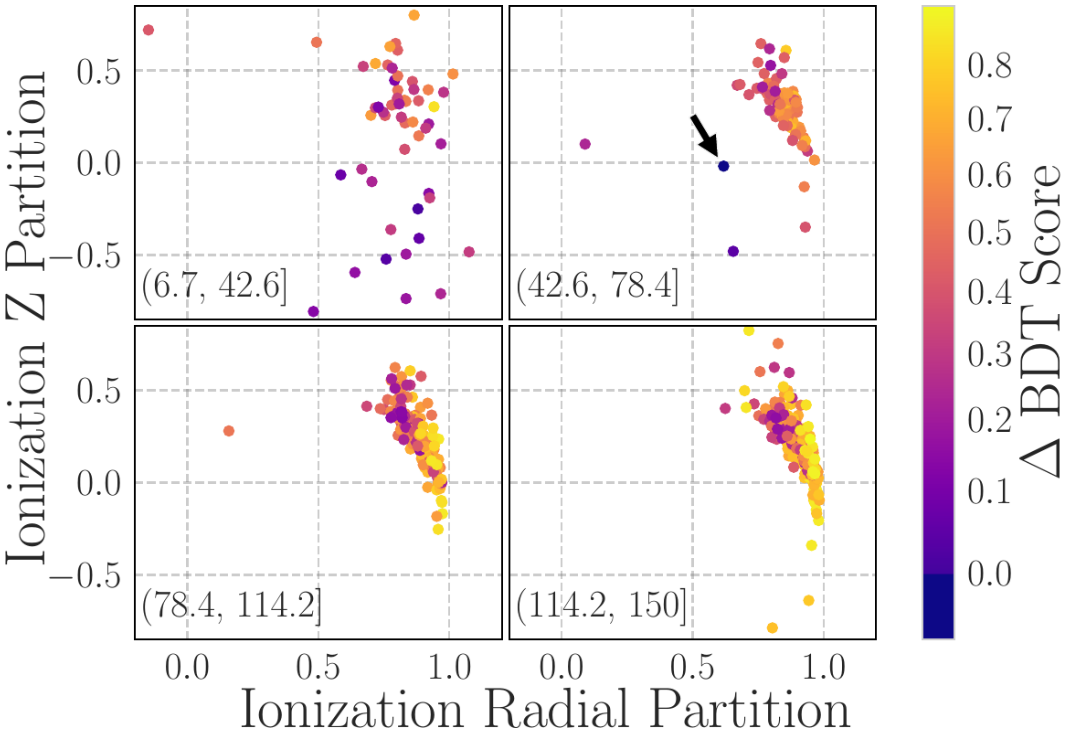
# Set 90% C.L. upper limit

- **Run MC experiments using the optimized cut positions for each value of allowed misidentified bg**
- **Set Poisson and Optimum interval limit**
- **Set tightest cut that does not overly sacrifice exposure (SAE)**
  - Poisson Minimum is a good rule of thumb



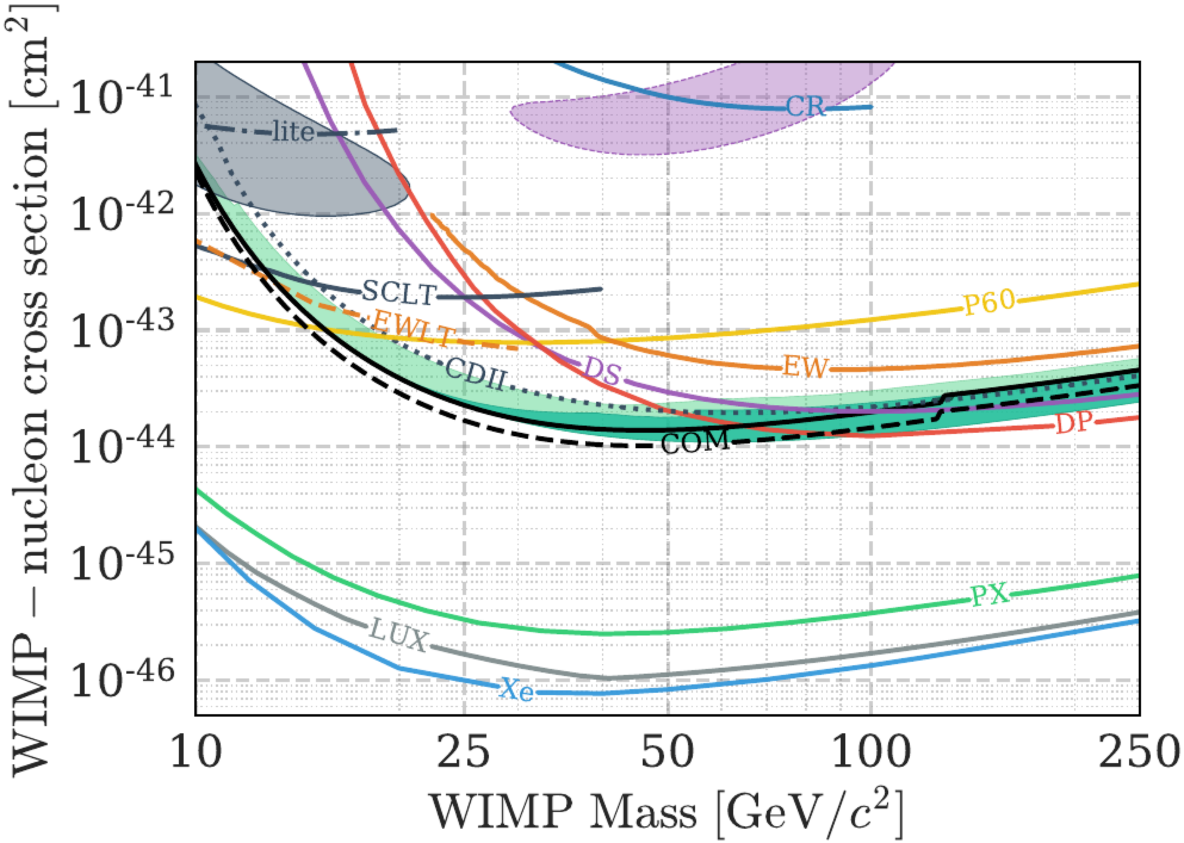
# Unblinding

- **Single event**
  - 42.8 keV recoil
  - IT2Z2
- **Consistent with BG model**
  - Predicts 1 (≥1) event in 24% (28%) of MC experiments



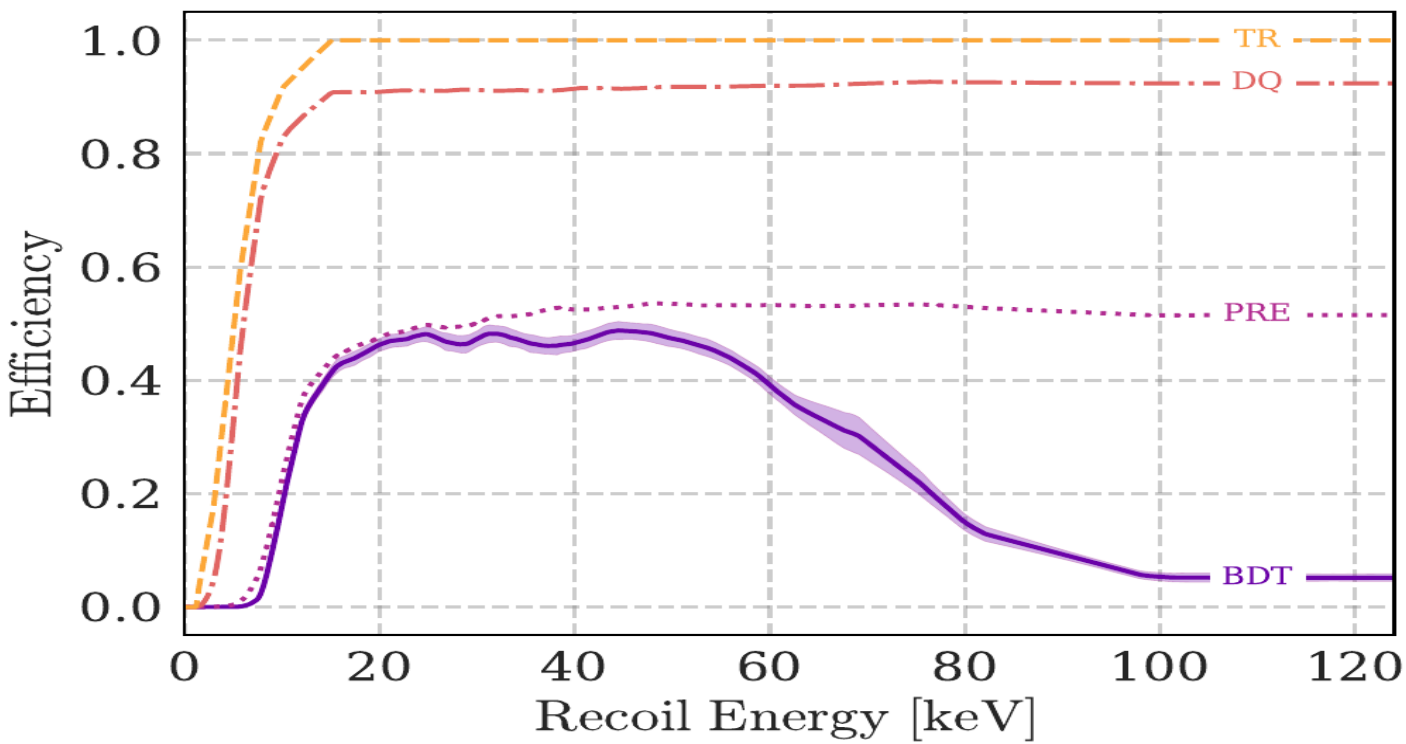
# Limit

- Consistent with expected sensitivity
- Most constraining Ge limit ~15-90 GeV/c²
- When combined with previous CDMS II data, provides most constraining Ge limit at all masses above ~15 GeV/c²



# Backup slides

# Analysis Efficiency



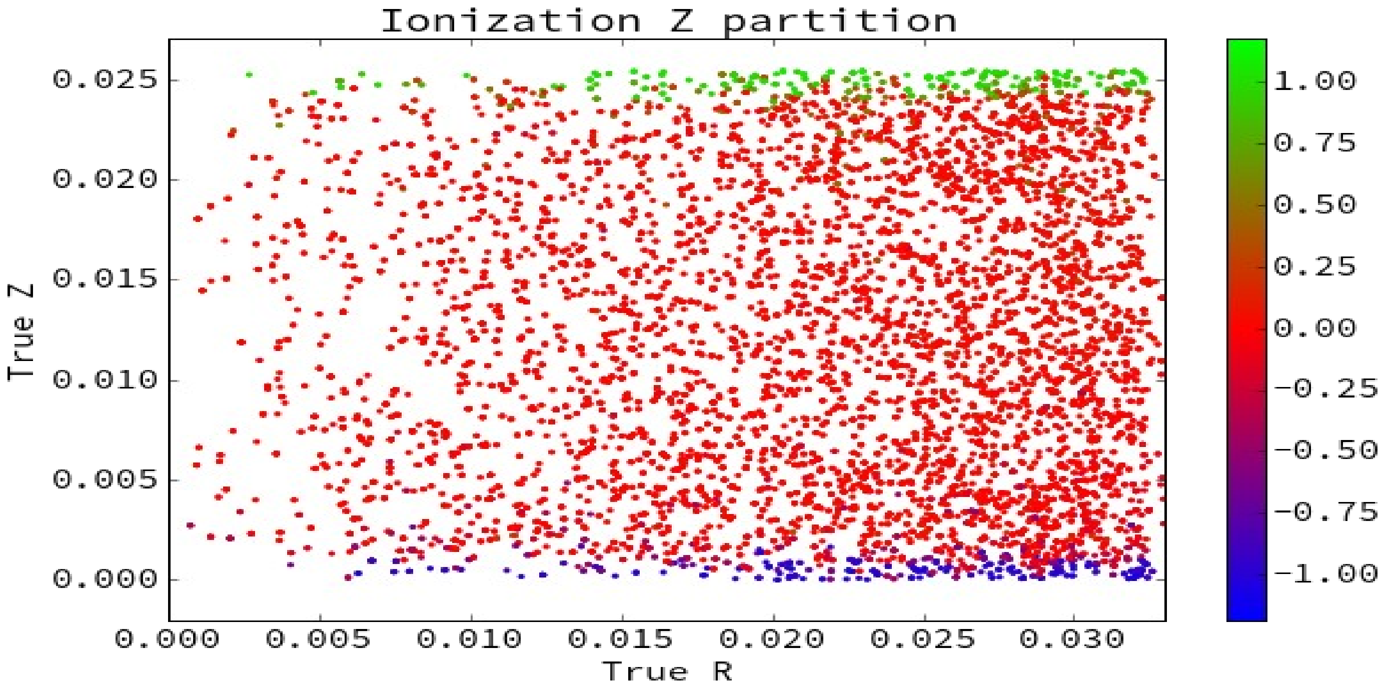
# Current status: Staged Unblinding

- **Stage One Unblinding:** everything that is outside the signal region (as defined by our new fiducial cut), will be unblinded**.**
- **Model Validation:** the newly unblinded data can now be compared to the portion of the background model that falls outside the fiducial volume.
- **Background re-estimation:** Backgrounds inside the still-blinded signal region may be re-estimated using the newly unblinded fiducial-volume-sideband and compared to the previous yield-sideband estimates (mostly effects the gamma model)
- **Stage Two Unblinding:** data that is inside the signal region is unblinded.

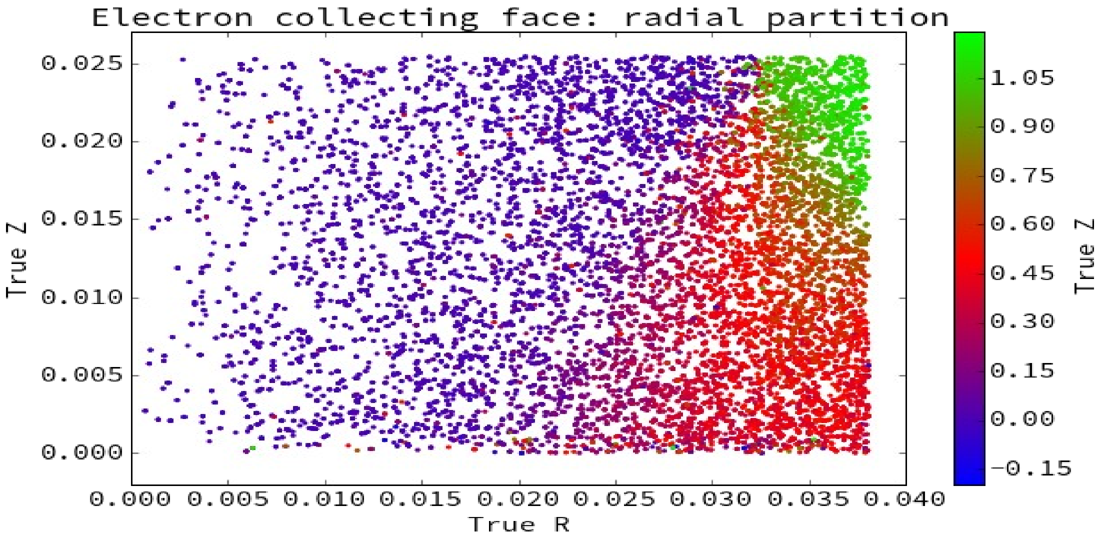
# Background Model

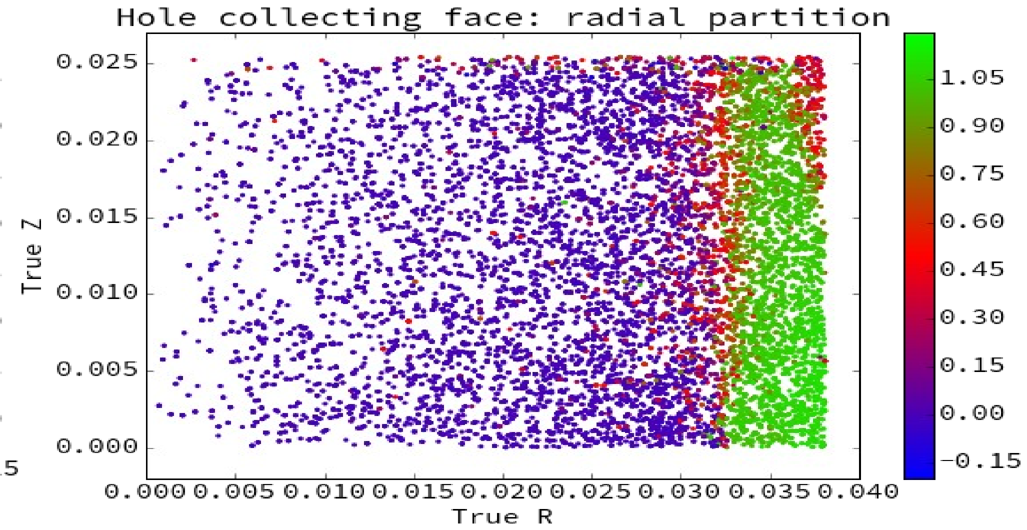
| Production step | WIMP Model | Gamma Model | $^{210}$Pb Model | Neutron Model |
| --- | --- | --- | --- | --- |
| Preselection | $^{252}$Cf calibration data (c34) | $^{133}$Ba calibration data. (c35)<br>WIMP search data "sidebands". (c34) | Unblind WIMP search data from $^{210}$Pb source detectors. (March - June 2012) | $^{252}$Cf calibration data (c34) |
| Systematic density correction | From cf to theoretical wimp spectrum.<br>RRQs: precoiltNF | From Ba to bg_restricted sidebands.<br>RRQs: precoiltNF, qrpart#OF, qzpartOF, ytNF | From source detectors to all others.<br>RRQs: p*#OF, q*#OF others reconstructed. | From cf to Geant4 simulation data.<br>RRQs: precoiltNF |
| Absolute normalization | Normalize to total Spectrum Average Exposure (SAE in kg day) | Normalize to in-NR-band, single-scatter background events using | Normalize to in-NR-band, single-scatter background events via the | From Geant4 simulated rate to WIMP search via livetime |

# Z fiducialization

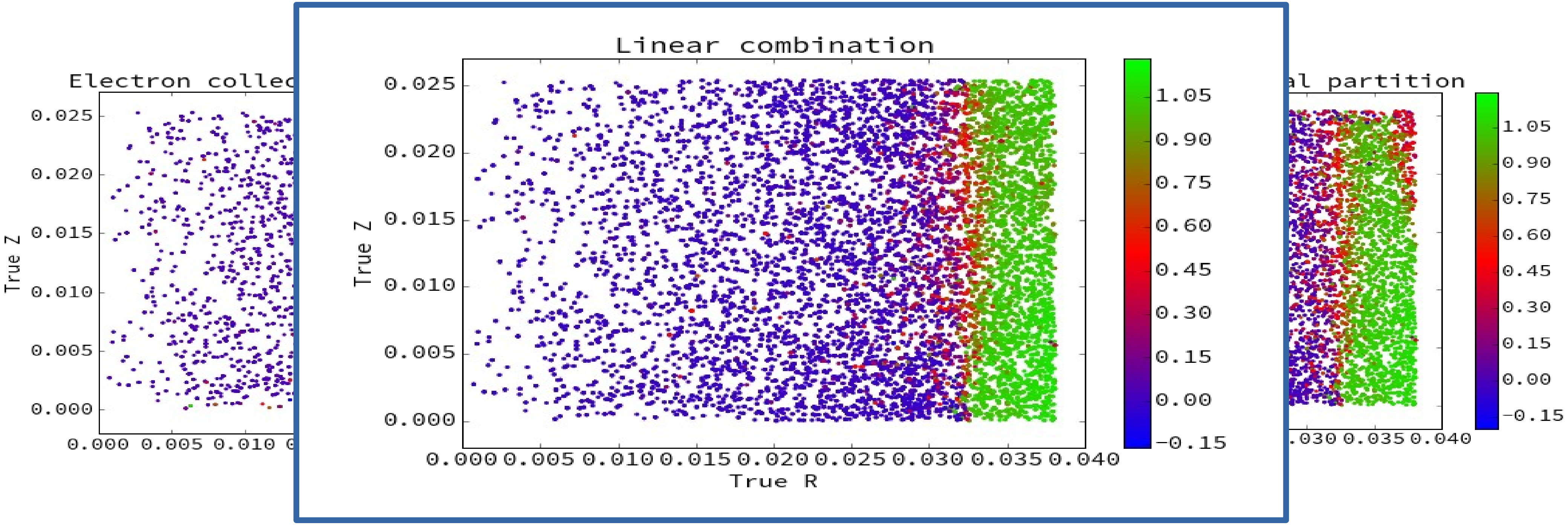


# Radial fiducialization



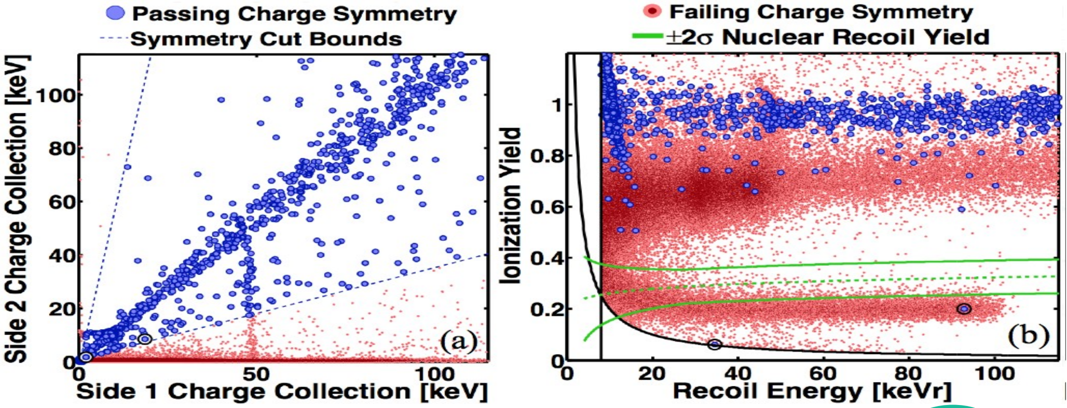
# Radial fiducialization



# Backgrounds

- **Neutrons**
  - Single scatter events mimic WIMPs → use simulation for expected rate
  - Cosmogenic
    - Rate estimated from simulation
    - Can be double checked: scale simulated unvetoed to vetoed ratio by measured muon veto single scatter
  - Radiogenic
    - Measured materials contamination used as Geant4 simulation input
  - << 1 event
- **Bulk photons**
  - With complete charge collection expect 1 in $1.7\times10^{6}$ misidentification: << 1 event expected

- **Surface events**
  - Incomplete charge collection reduces ionization yield
  - Need a model to:
    1) Define fiducial volume that maximizes sensitivity
    2) Estimate number of background events misidentified as signal



# Cuts on Mass

- **10 → 5.4 kg:**
  - Broken Channels
  - ½ of each source detector cut
  - 10 of 15 detectors usable
- **5.4 → ~3.5 kg:**
  - Bg rejection
  - Interior “fiducial” volume: 65% is an estimate

Good

Phonon Problems

Charge Problems

Change Shorts

Phonon and Charge Shorts

| | | | | |
|---|---|---|---|---|
| SQID Instability esp on PAS2 | | | QIS1 feedback short | QIS1 & QOS1 feedback short. PAS1 short |
| QIS1 & QOS1 Shorted Bias PAS2 & PCS1 Short | | | | QOS1 glitchy periods |
| QIS1 bias & | PBS1 & PDS1 | PCS1 large bias | | QOS1 |