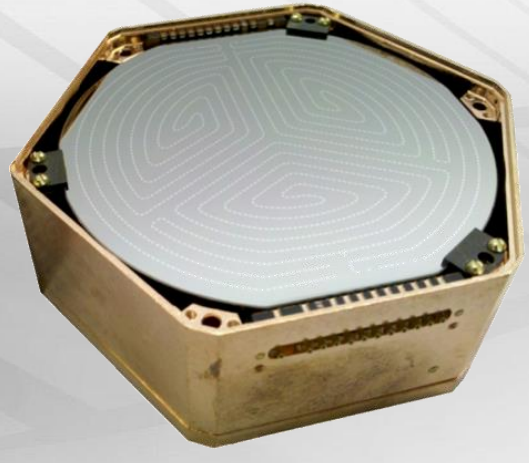

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Blinding and Salting in SuperCDMS

BEN LOER

Pacific Northwest National Laboratory

Blind Analysis in High-Stakes Survey Science: When, Why, and How?

On behalf of the SuperCDMS Collaboration

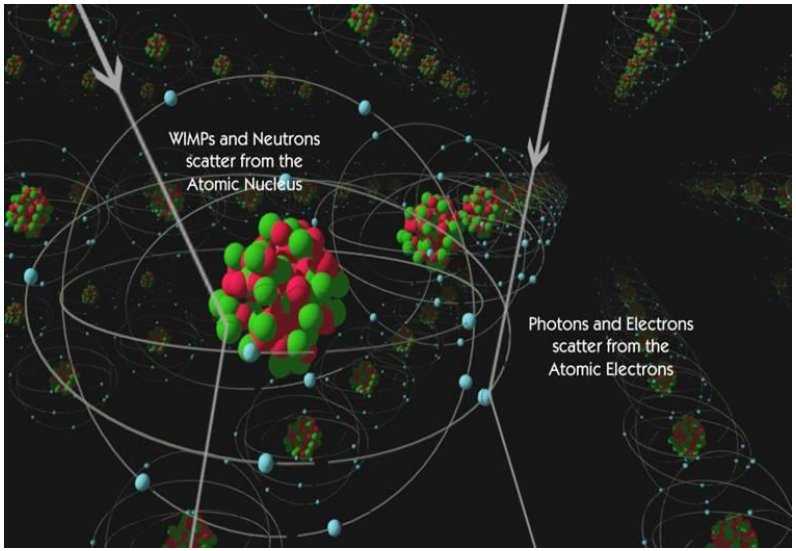
U.S. DEPARTMENT OF ENERGY

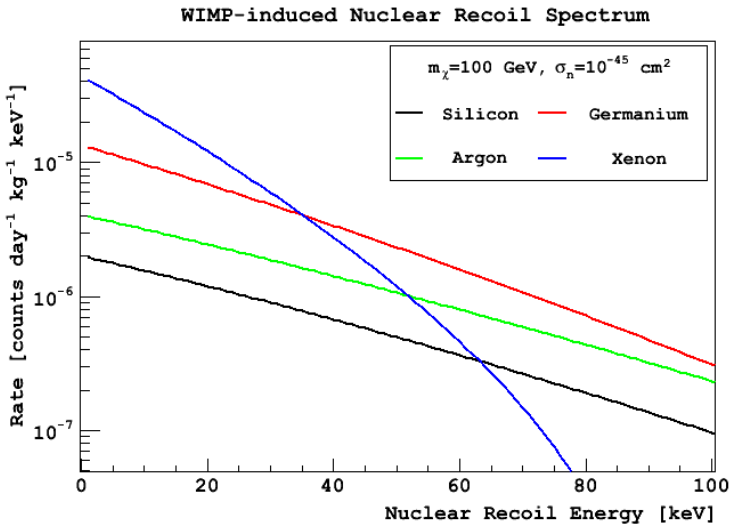
Outline

- Dark matter direct detection signals
- SuperCDMS detectors
- Traditional box blinding
- Salting in current analysis
- Looking ahead

Direct detection of dark matter

- Dark matter is non-rotating, non-interacting gas with thermal distribution
- Interaction velocity ~250 km/s
- Billiard ball physics
- Exponential spectrum of low energy nuclear recoils (NRs)
- Current limits: few counts per ton*year for ~100 GeV mass
- Lower mass requires lower threshold





SuperCDMS iZIPs: *i*nterleaved *Z*-sensitive *I*onization and *P*honon sensors

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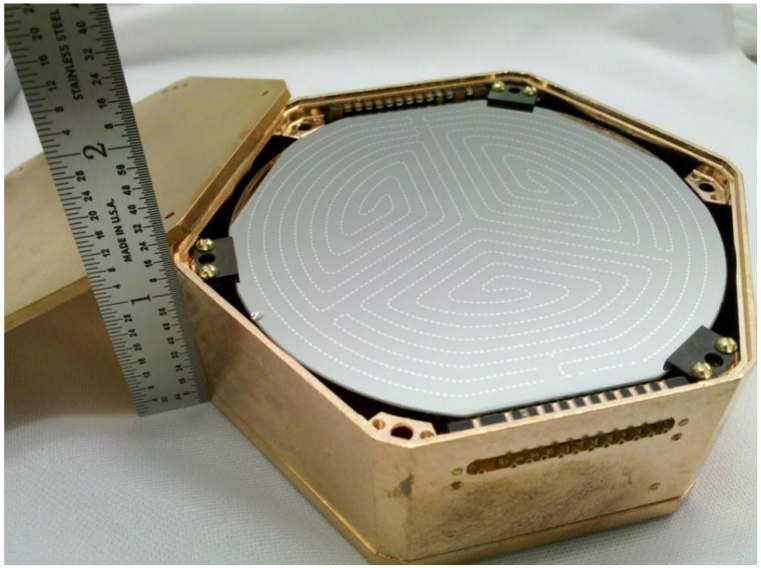
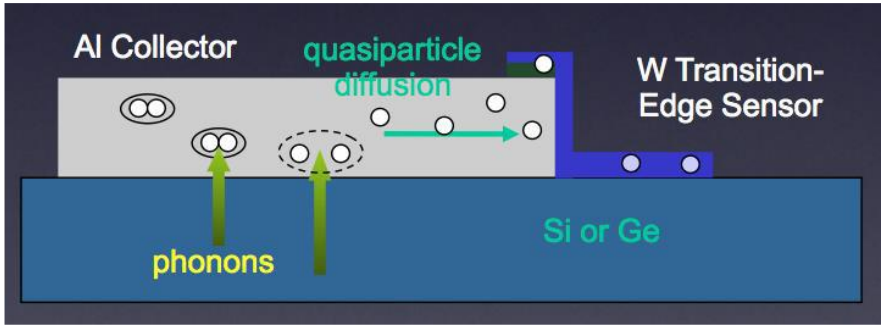
- Ultra pure Ge and Si crystals operated at ~50 mK
- Simultaneously measure ionization and phonon signals





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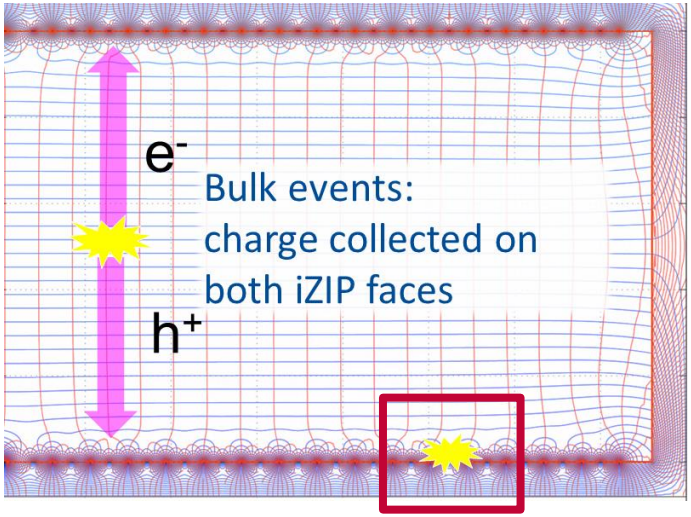
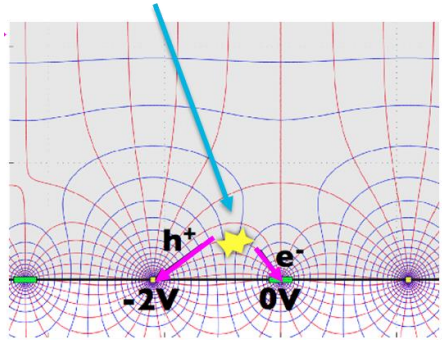


Surface events: only detect charge on one face



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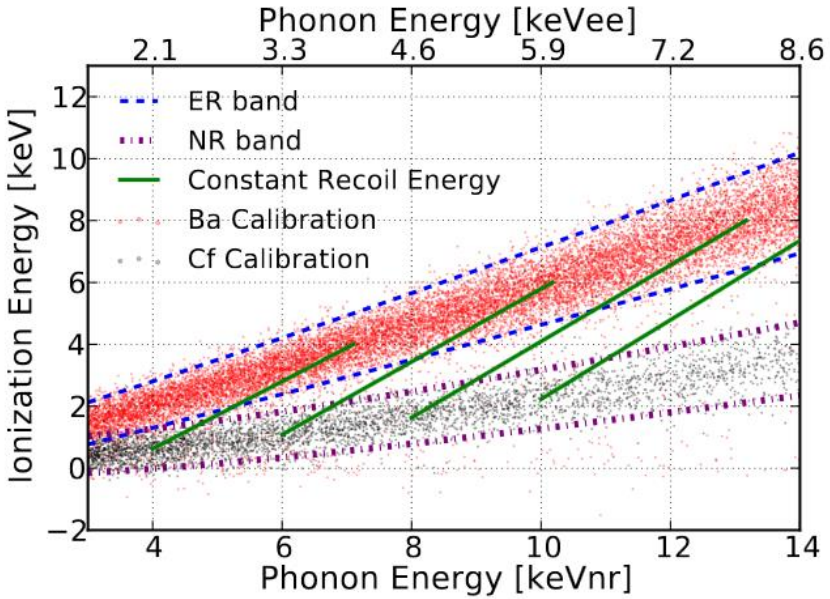
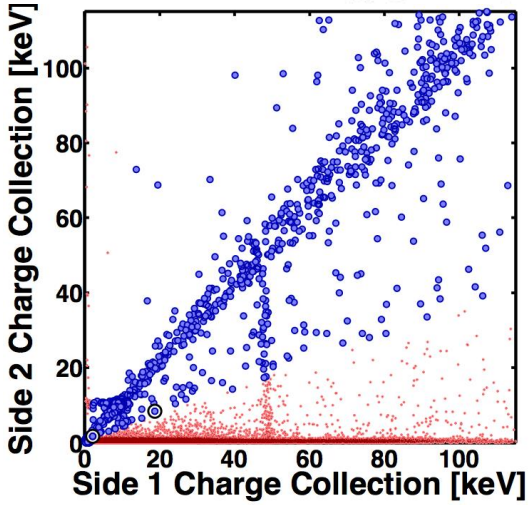
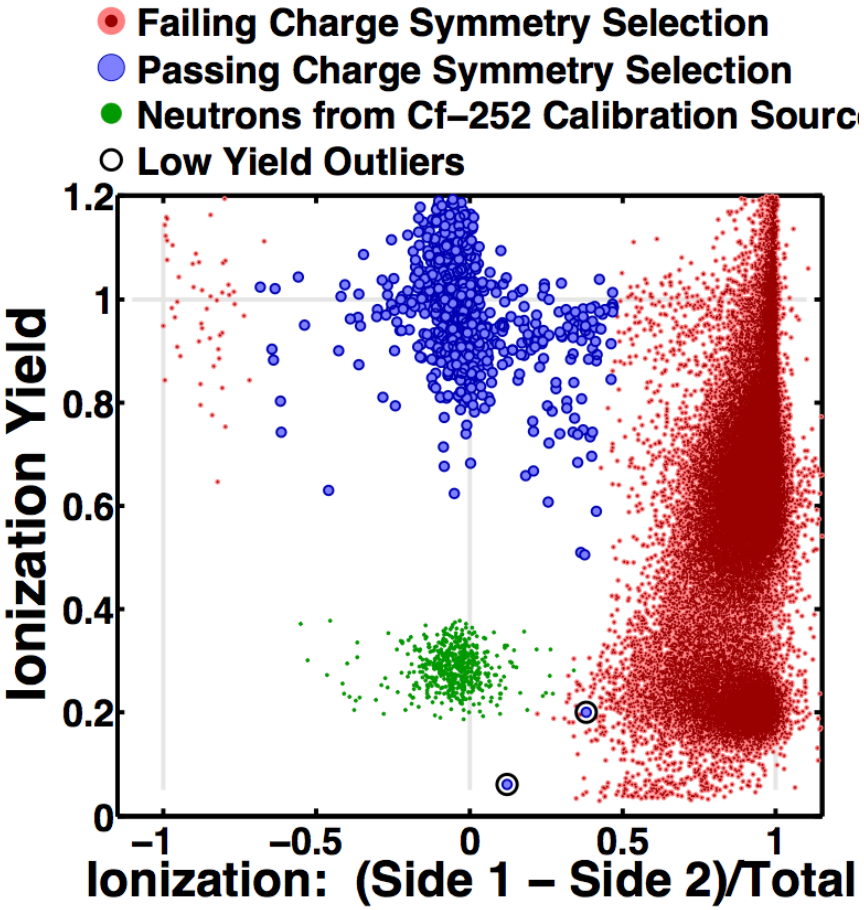
- Ultra pure Ge and Si crystals operated at ~50 mK
- Simultaneously measure ionization and phonon signals
- Outer guard ring and interleaved charge sensors reject surface events
- Ionization/phonon signal less for nuclear recoil (signal-like) events than electron-recoil (Compton backgrounds)





SuperCDMS Traditional box blinding

- Take signal and background calibration data
- Identify signal region of interest (ROI)
- Remove events in a slightly larger region
- Tune cuts
- Open the box
- No attempt to subtract backgrounds remaining in the box



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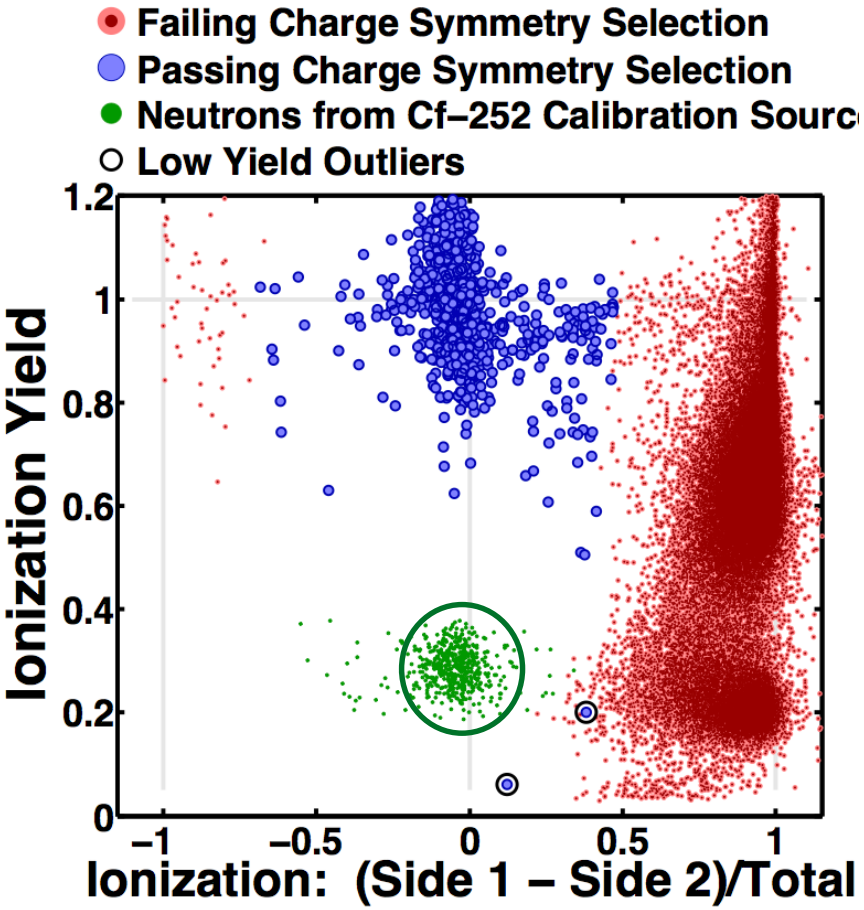

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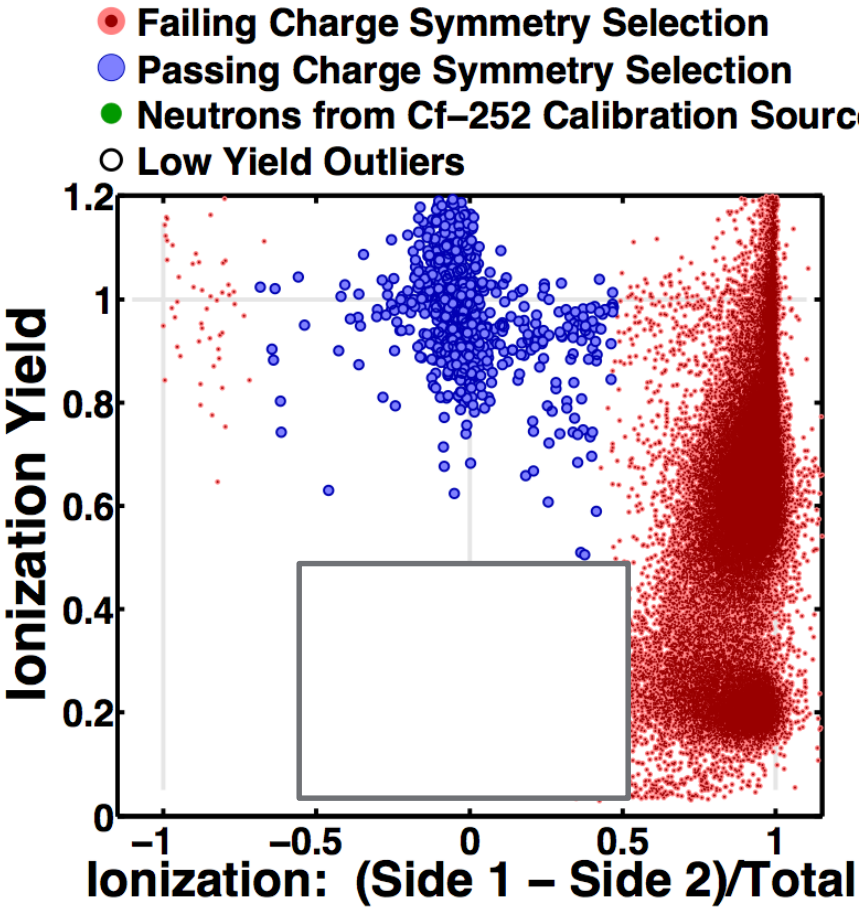
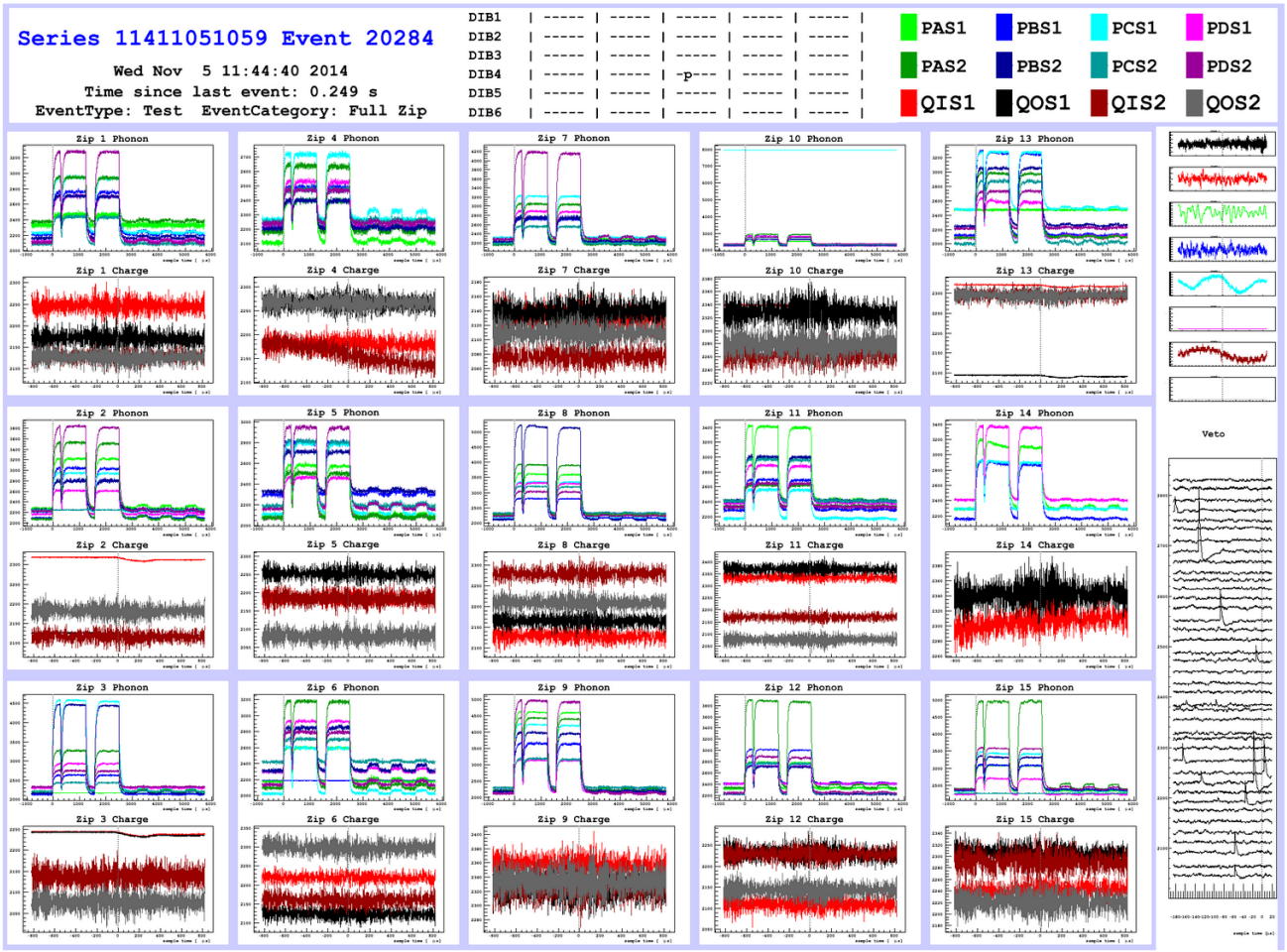


Problems with box blinding

- Delayed access to data: first must acquire and analyze calibration data to determine the box, then apply blinding cut
- Unanticipated backgrounds
- Anomalous events

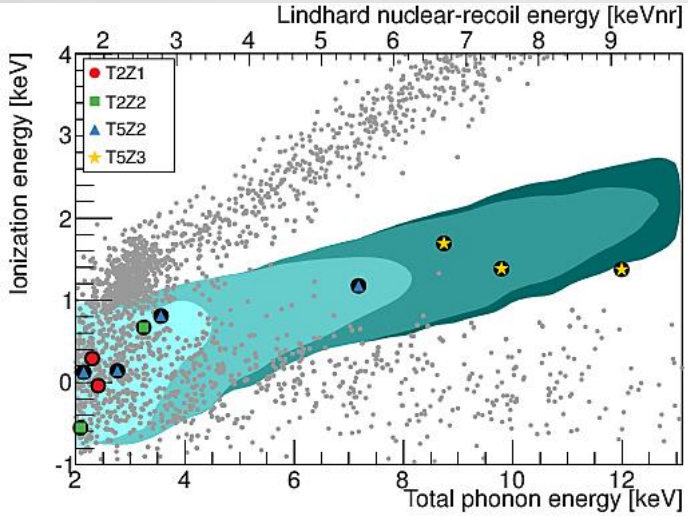
That's what dark matter looks like, right?

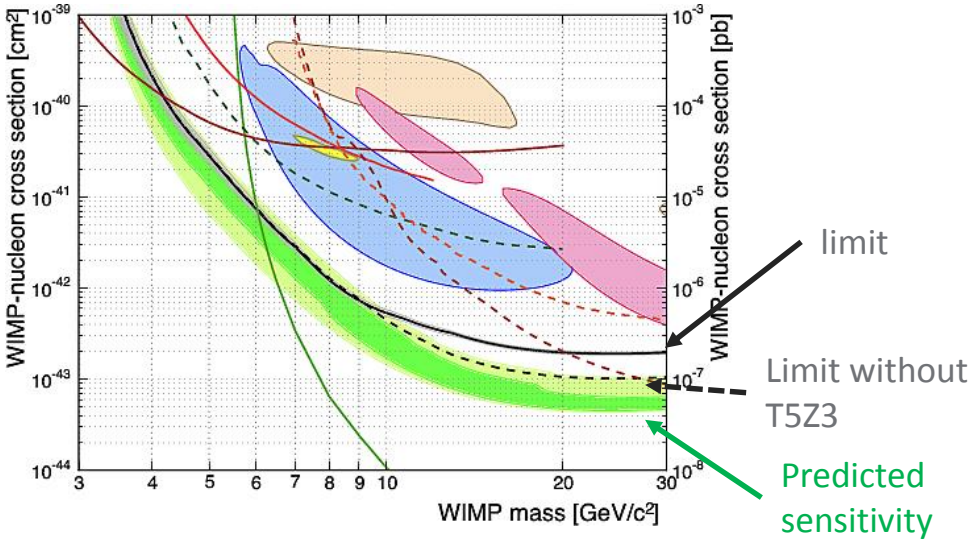


No cell phones near the detectors!

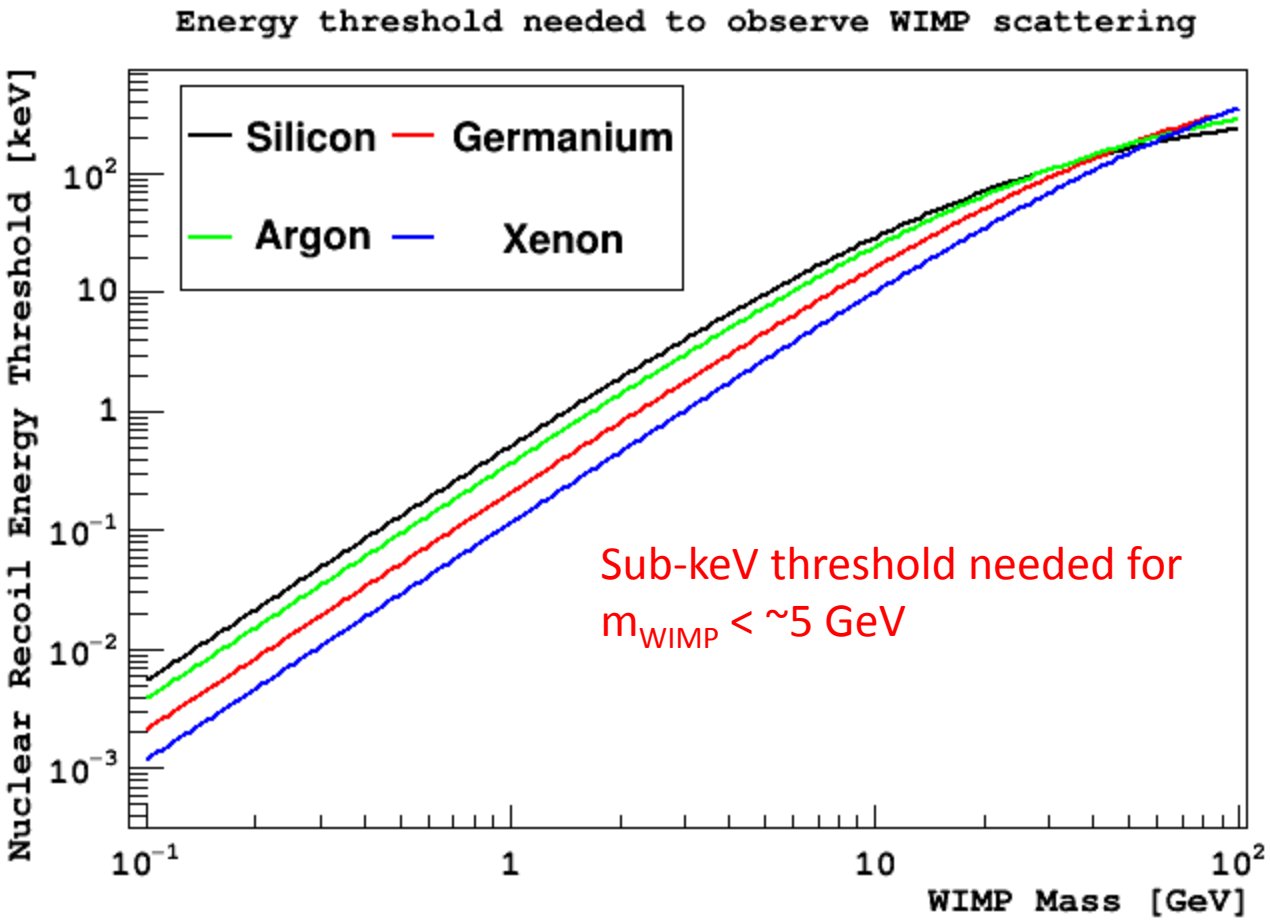
Case Study: SuperCDMS Low Threshold iZIP analysis

- Boosted Decision Tree (BDT) machine learning used to optimize signal/background identification
- Predicted 6 events in signal region, found 11 at unblinding
- Most significant leakage at high energy from single detector with shorted ionization channel
- Would earlier inspection have led to better modeling?
- Even on post-inspection, high energy events appear good quality, so not clear that non-blind analysis would have changed result





Pushing to lower mass



CDMSlite (low ionization threshold experiment) => SuperCDMS HV

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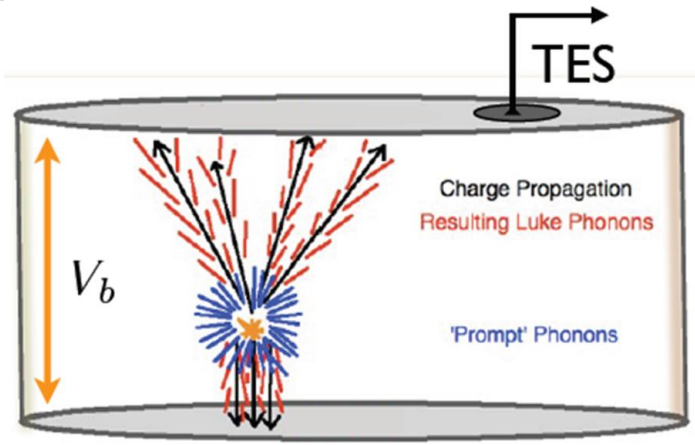
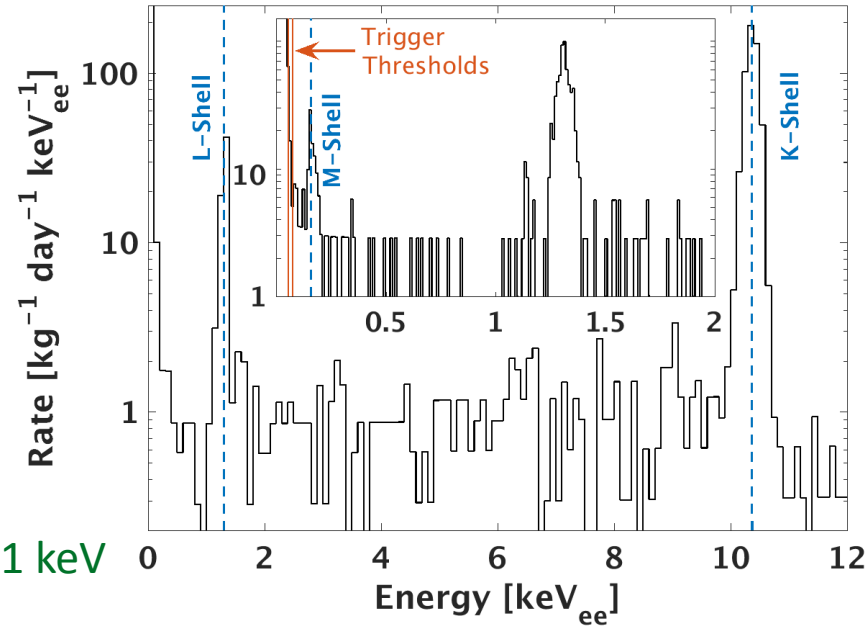
- Electrons/holes gain energy from voltage bias, release as phonons
- High bias => high gain charge signal
- BUT lose “true” phonon signal and yield discrimination variable
- If “box” blinding, what is second parameter?
- If just blind entire energy range, no sidebands left!

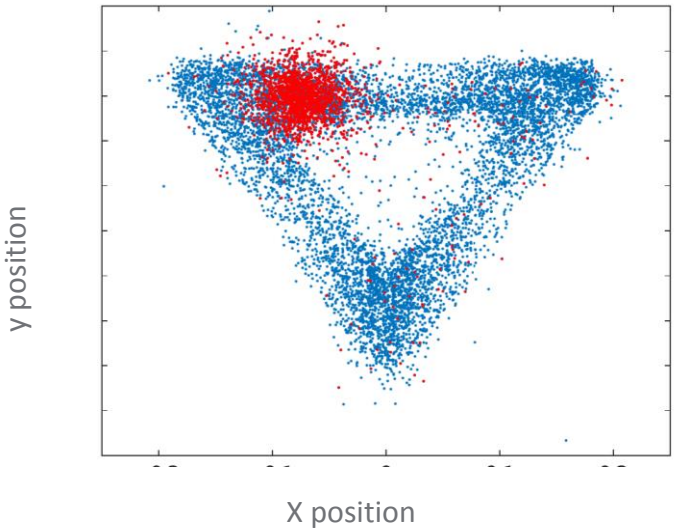


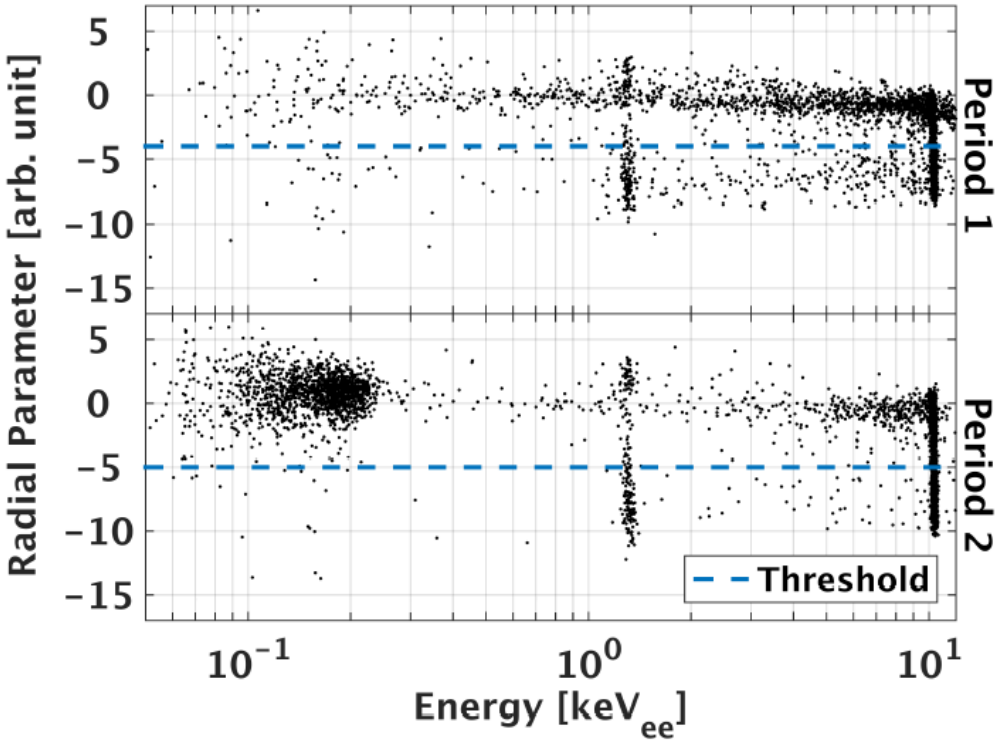


2% resolution at 1 keV

Case Study: CDMSlite Run 2

- Source of clustered events in signal region spontaneously appeared
- Would not have been visible in box blinding analysis





CDMSlite Run 2 vs Run 3

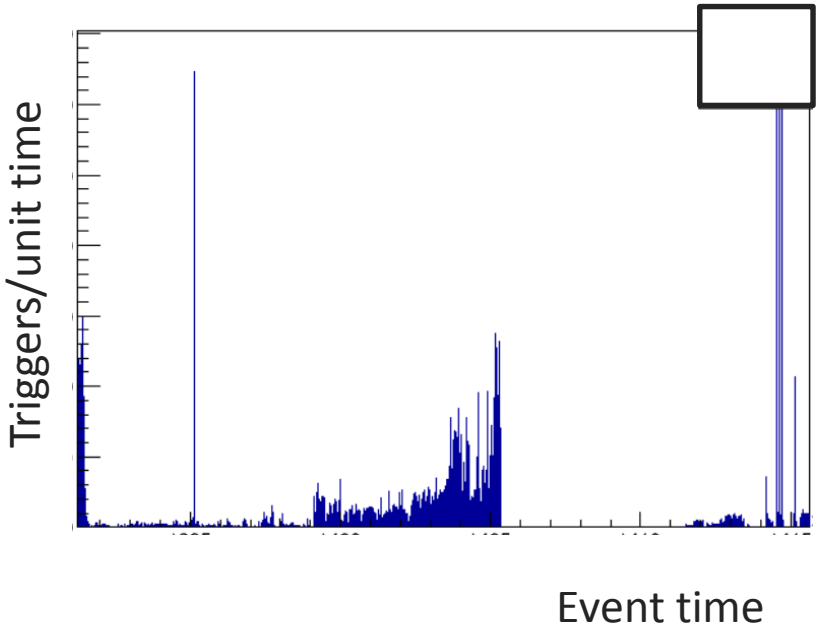
- CDMSlite at Soudan primarily R&D; thus far was non-blind analysis
- Run 3 data has been acquired
- Different detector with lower threshold, slightly less exposure
- Opportunity to test new analysis techniques for next generation SuperCDMS SNOLAB
- E.g., partial background modeling/subtraction
- With perils of box blinding recently shown, collaboration decided to try salting our data with fake signal events as blind analysis technique

Attempting data salting for SuperCDMS

- Principle: salt not **accidentally** identifiable
  - A sufficiently motivated malicious actor can always find a way
- The more signal-like the better, but does not need to follow signal distributions exactly
  - E.g. can not use salt to measure signal acceptance. Don't expect to recover "right" answer if a WIMP signal input
  - Salt tails are OK so long as small fraction of total salt
  - But presence of salt should not lead to unnecessary cuts
- Can't insert events at will with sequential event IDs
- Therefore method is to select events with correct metadata (e.g. trigger on correct detector) and replace waveform portion of data only

Salting method

- Pick a WIMP mass, estimate our 90% CL predicted sensitivity, calculate how many events would be in the final spectrum, call that N
- Randomly select between N and 3N events in raw data to replace with salt
- Weight selection to be uniform in time



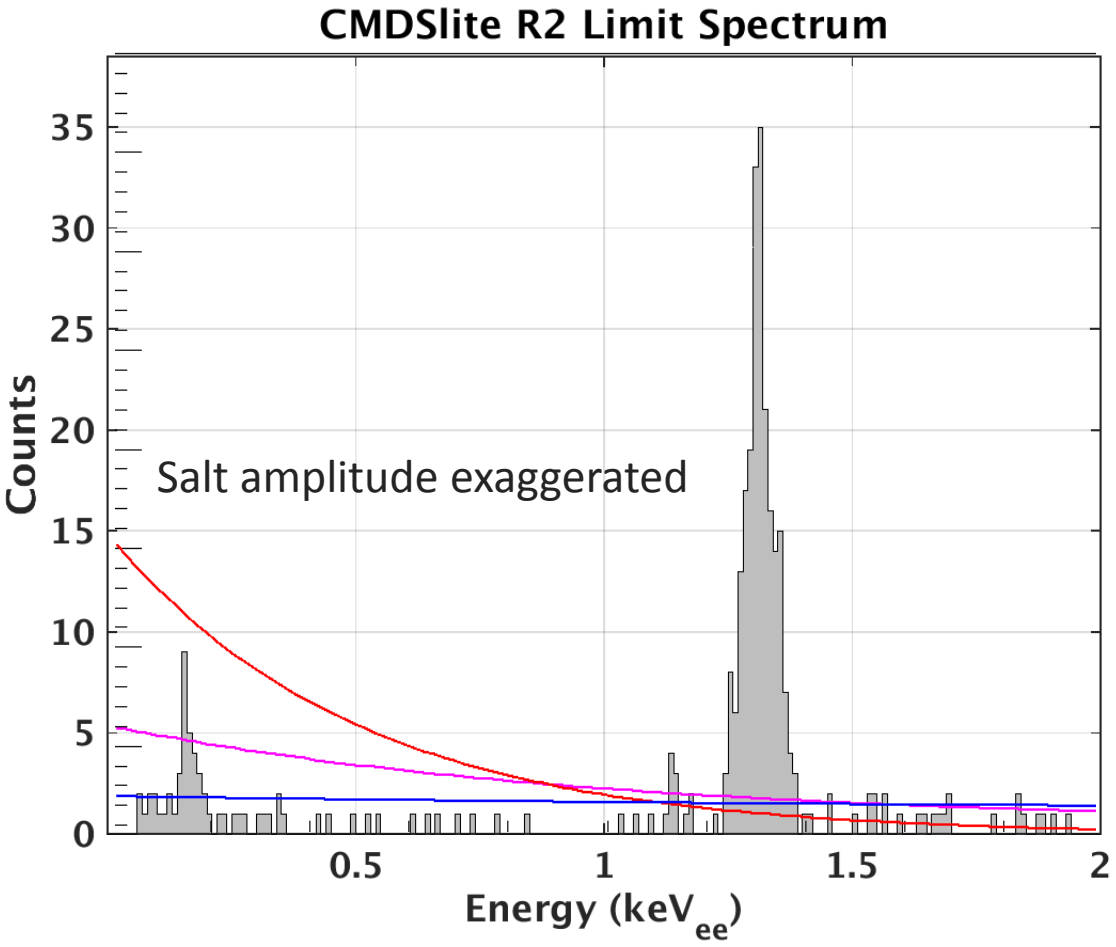
Salt Spectrum

- Assign energy from exponential+constant spectrum
- Slope varies from 0.5-2 keV, expo/constant varies from 1/3 to 3

3*exp(-x/0.5)+const

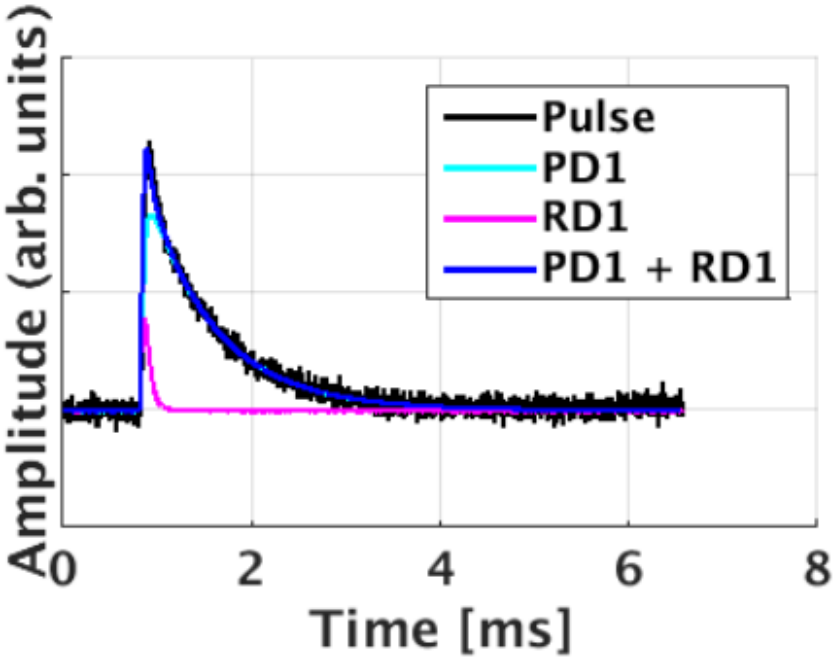
exp(-x)+const

1/3*exp(-x/2)+const



Creating fake pulses

- Select calibration events with similar energy
  - Want to avoid modeling distributions as much as possible
  - Lots of energy dependence, so tight energy selection
  - Hard to use real calibration events due to pileup, falling baselines (i.e. near pileup), etc
- Fit each channel of calibration events to 2 templates (average + residual)
- Scale template amplitudes to new target energy (keeping same trigger delay values)
- Add to empty trigger to sample noise



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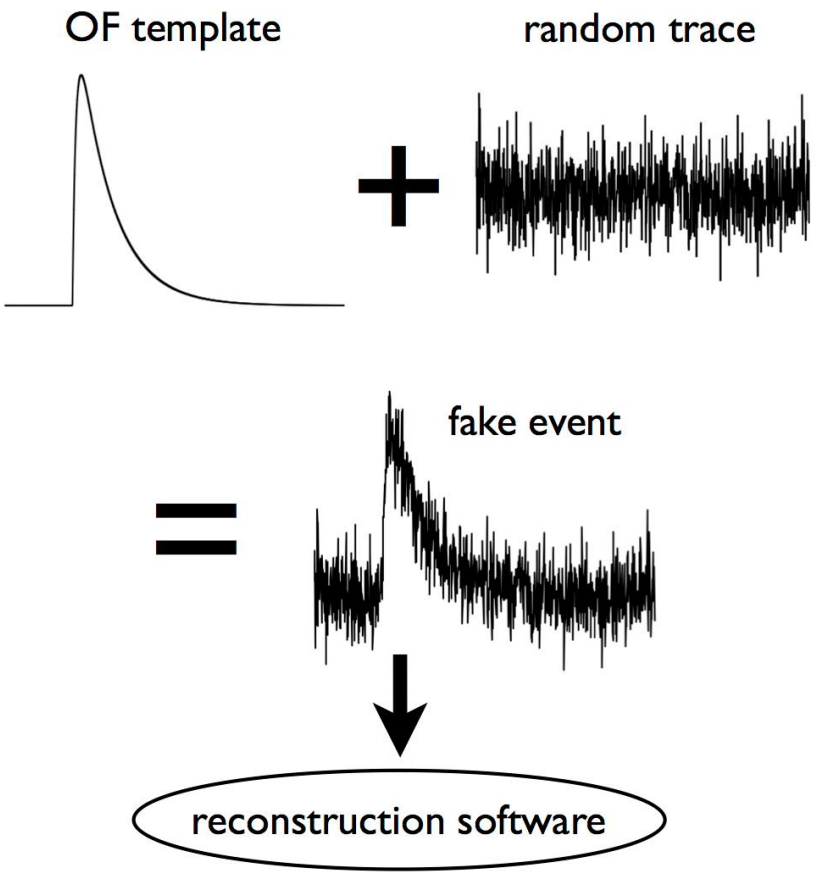
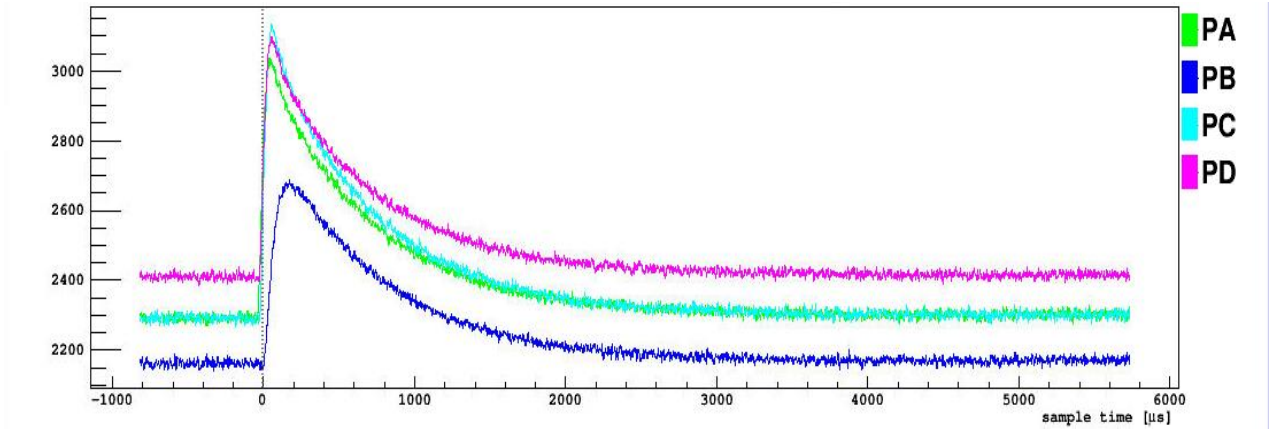
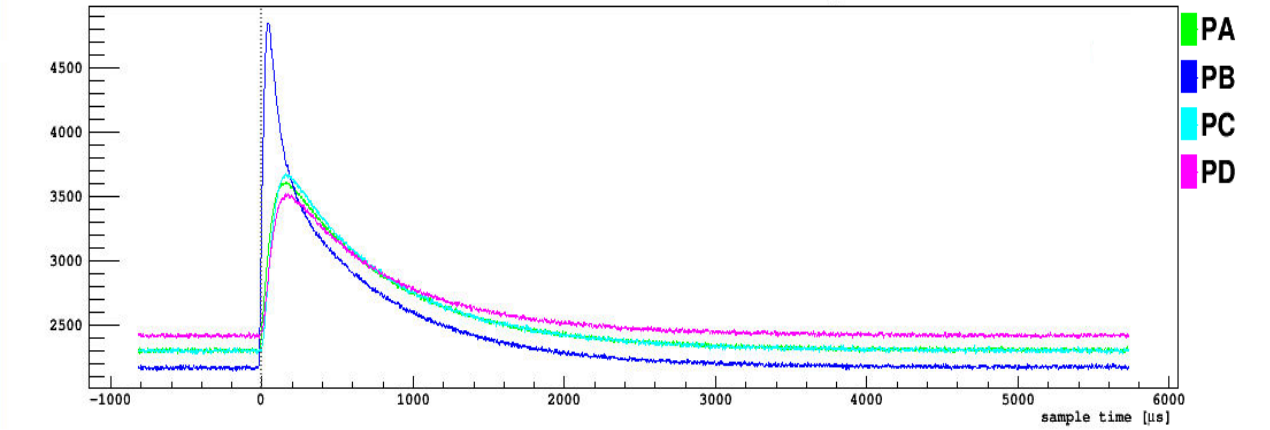


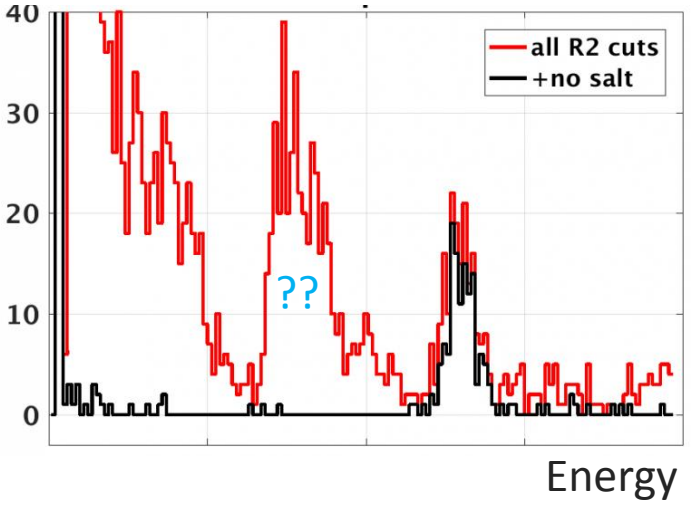
Can you spot the difference?

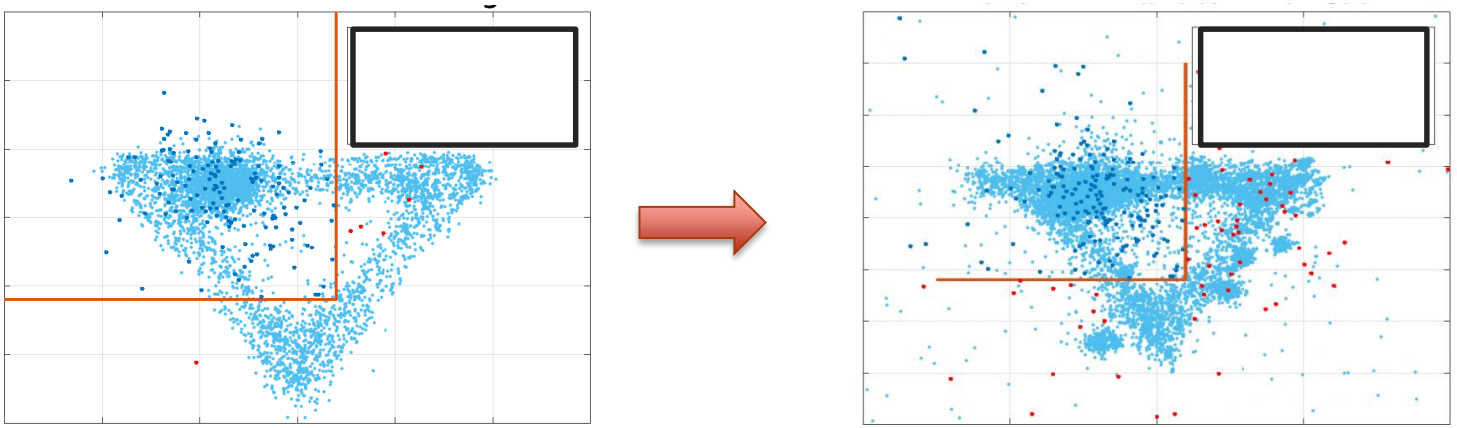




First attempt at salting

- Was supposed to be 2-5% of final dataset
- Supposed to be exponential + constant
- Clustering from using same calibration events multiple times





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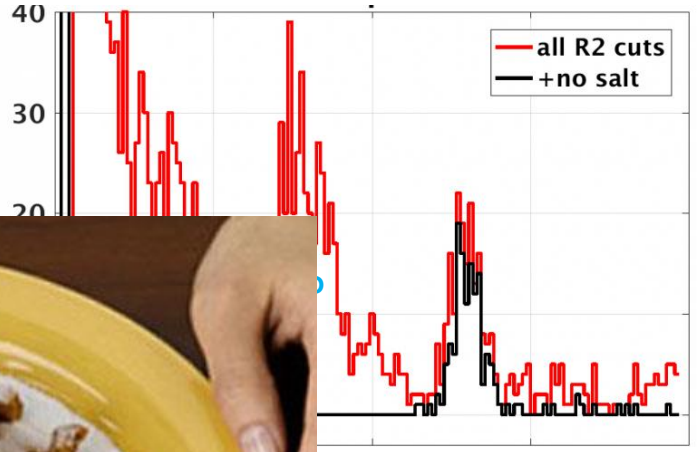
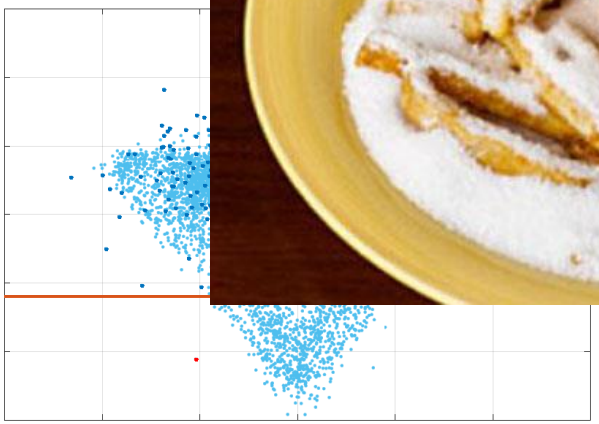
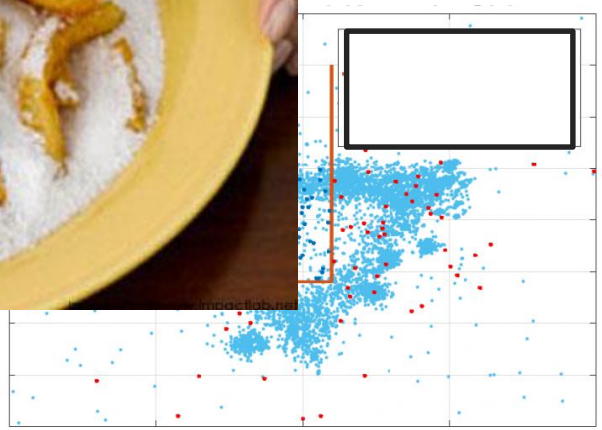
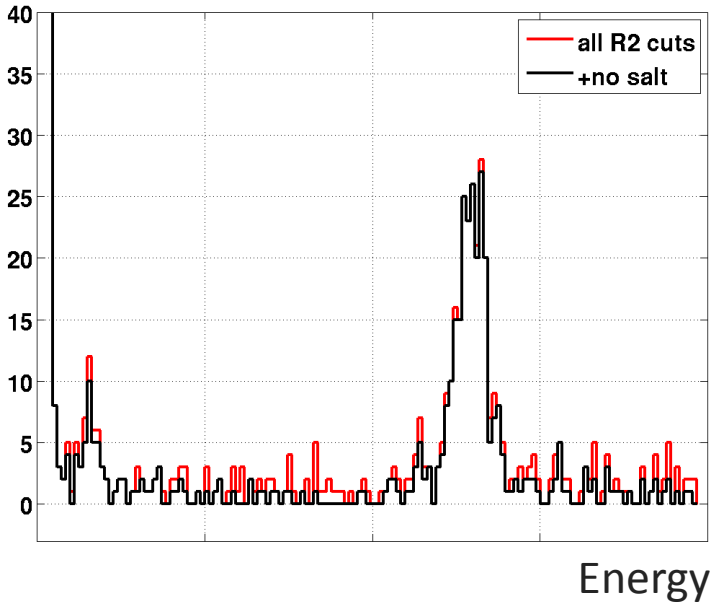






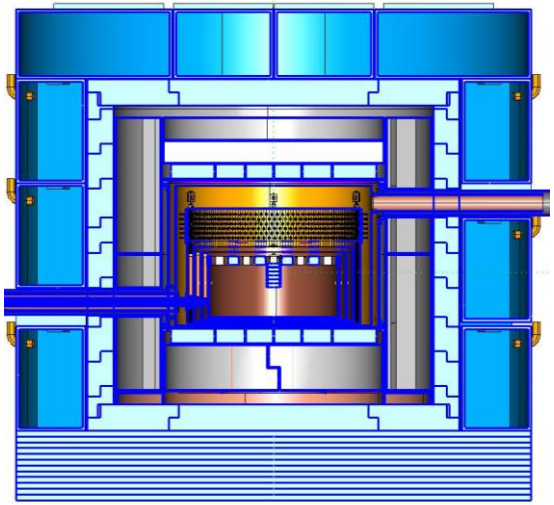
Current status

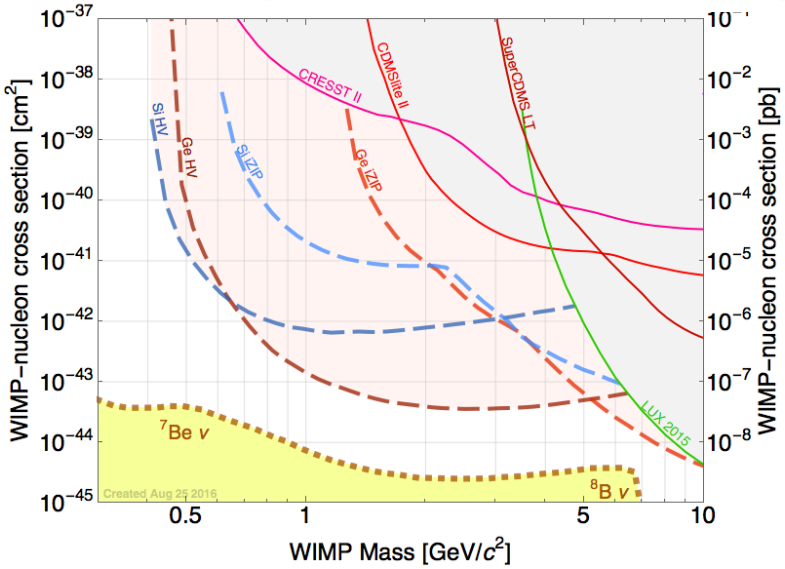
- We now have better understanding of effect of cuts on salt events
- Unclear what factors should drive min/max amount of salt to insert
  - Is it all in our heads?
  - 90%CL * rand(1,3) arbitrary
- Plan to generate salted data for CDMSlite Run 3 analysis next week!
- Before release, one analyzer will perform quality control inspection and be removed from further analysis



The future: SuperCDMS

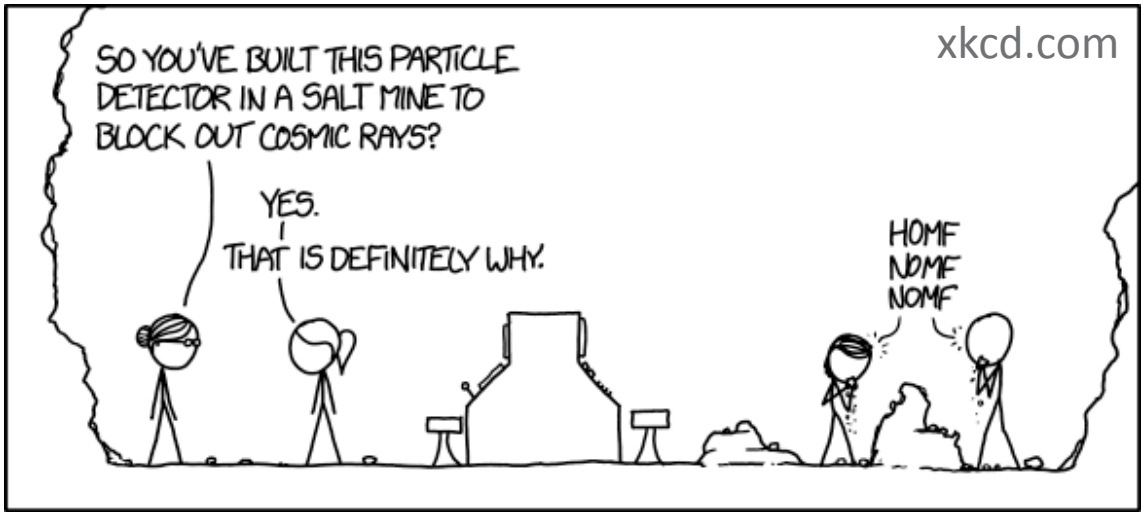
- 2 km under Sudbury, Ontario
- Entire lab is class 2000 clean room
- Bigger, cleaner shield
- Bigger, more advanced detectors
- Plan for salting as main blinding strategy





Salting in SuperCDMS SNOLAB

- Just beginning to think about this now
- Faking signal events with brand new detector types will not be easy
- Bandwidth, disk are cheap => DAQ stores **piles** of metadata
- Salting and DAQ efforts will be loosely integrated
- Once calibration preselection is in place, hope to have data available to analyzers within days instead of months



Thank you!

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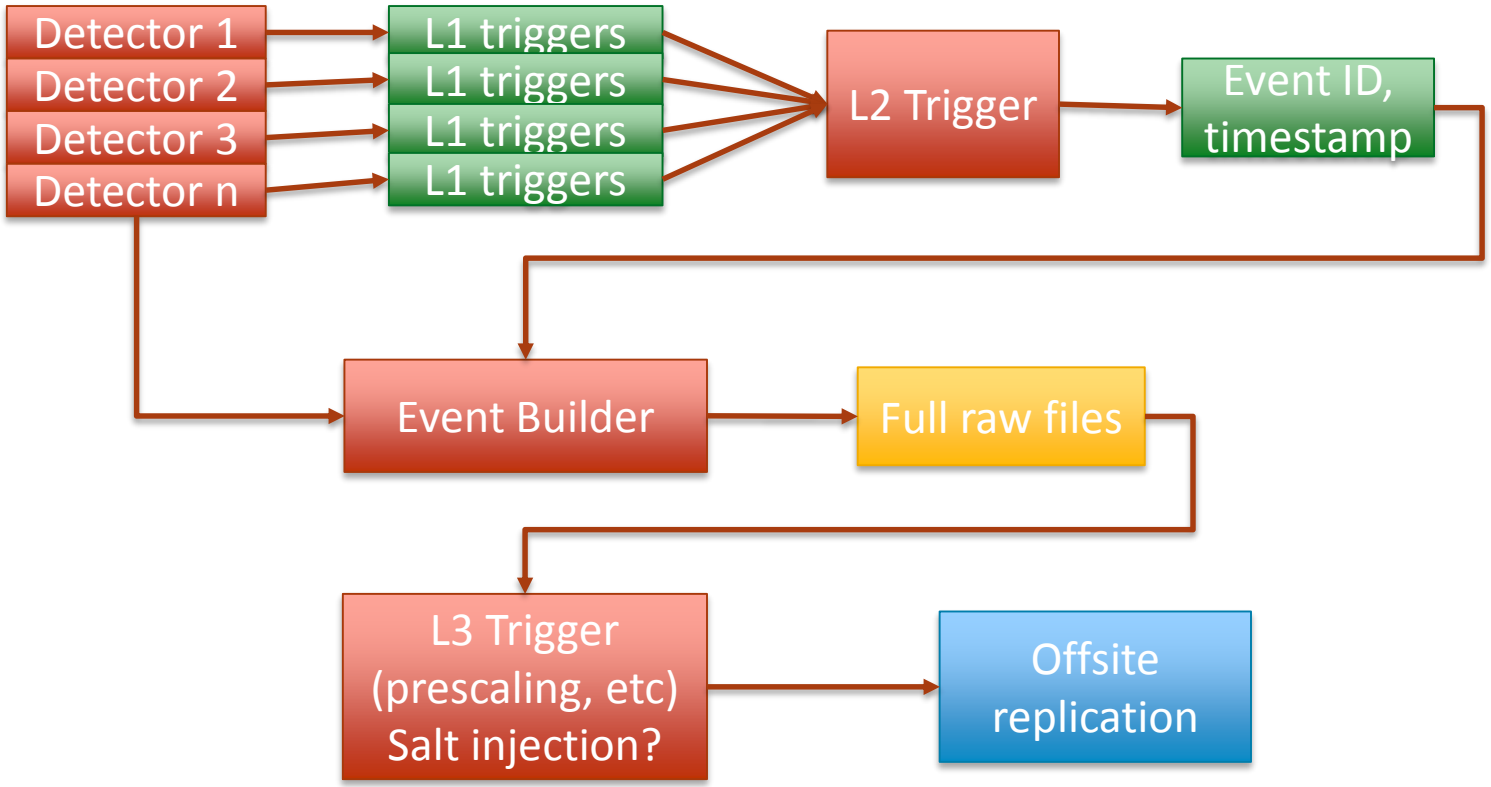
U. Toronto

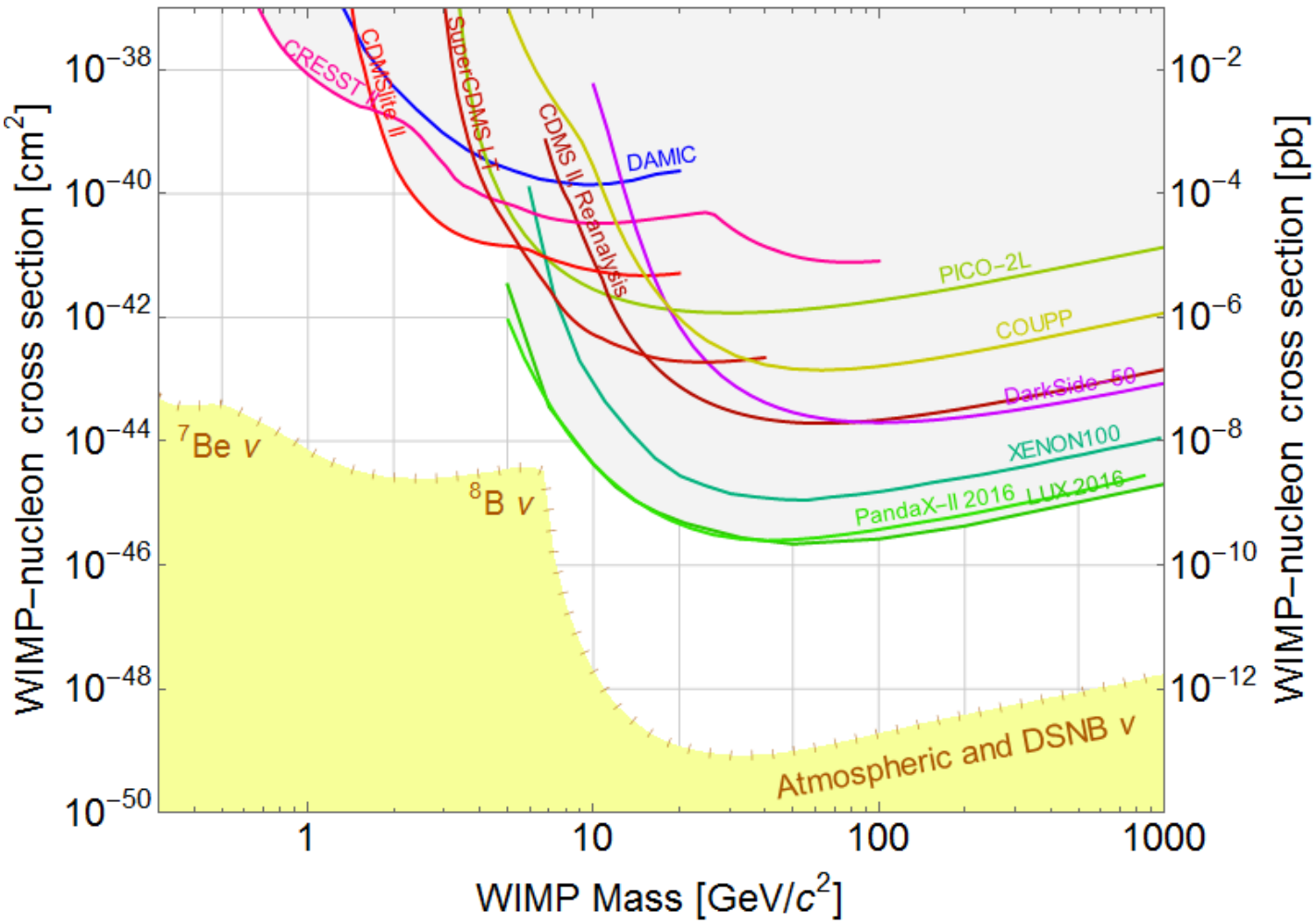
* Associate members

Backup slides

SuperCDMS SNOLAB trigger



Bridging the technological divide



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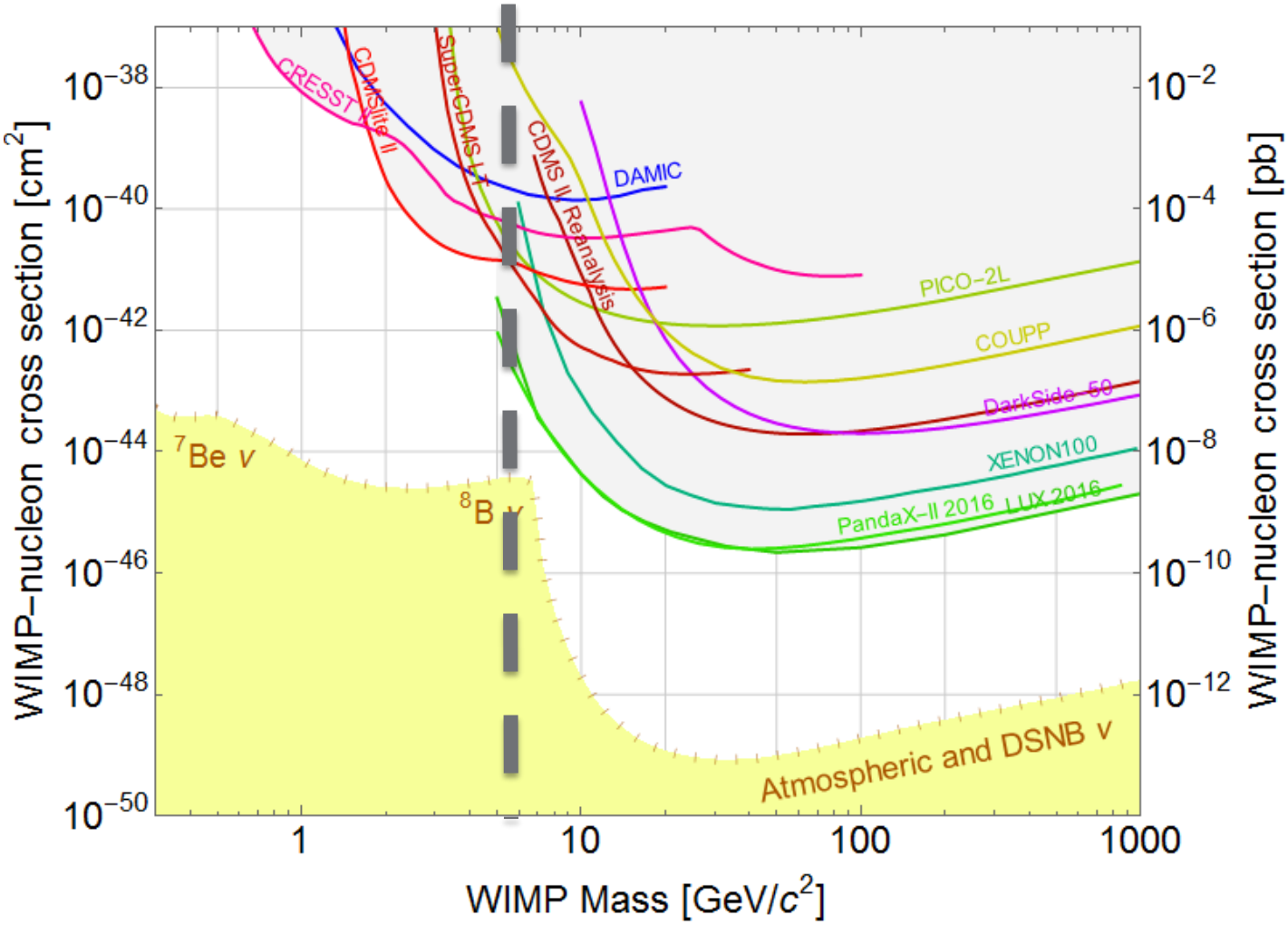

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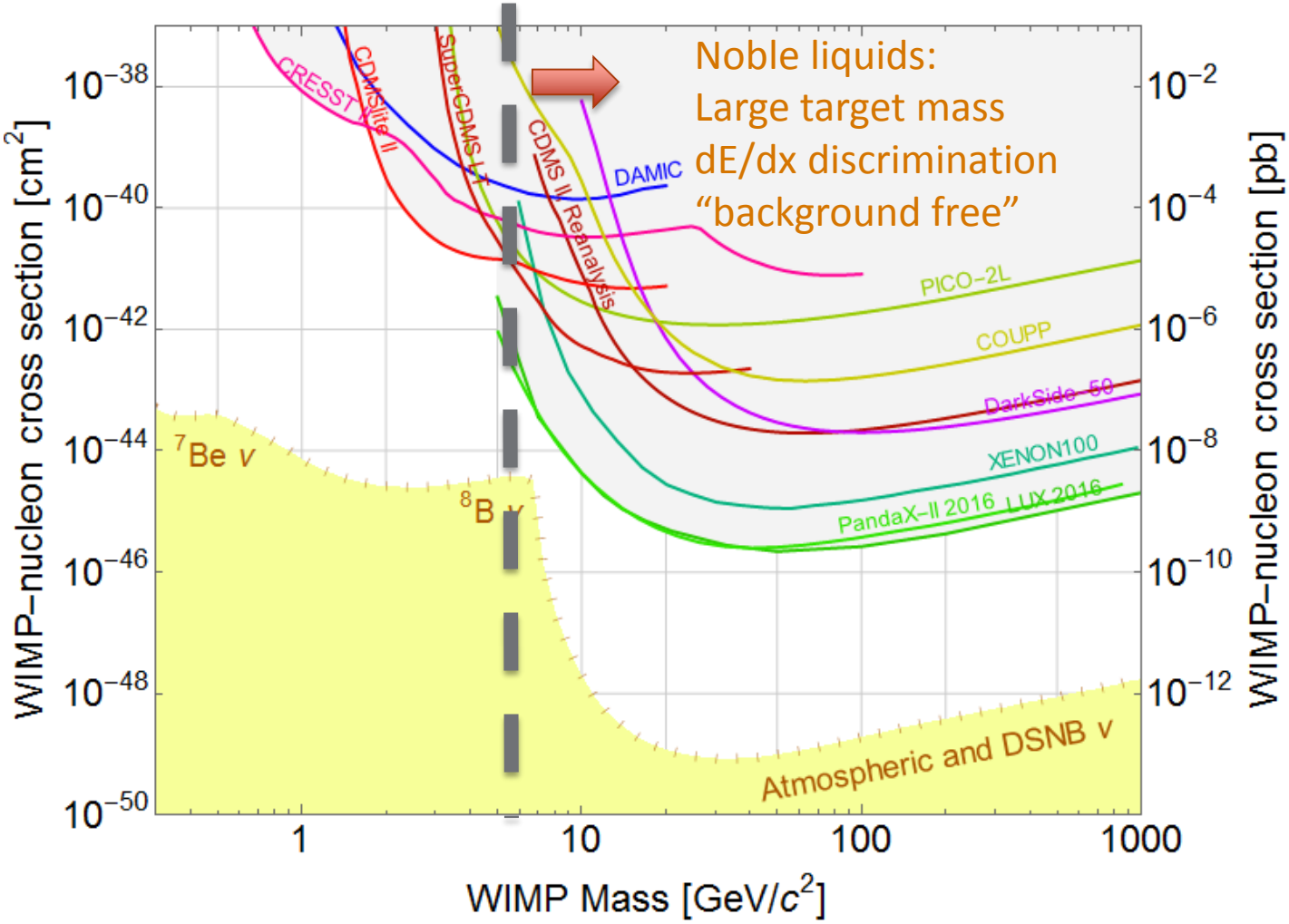

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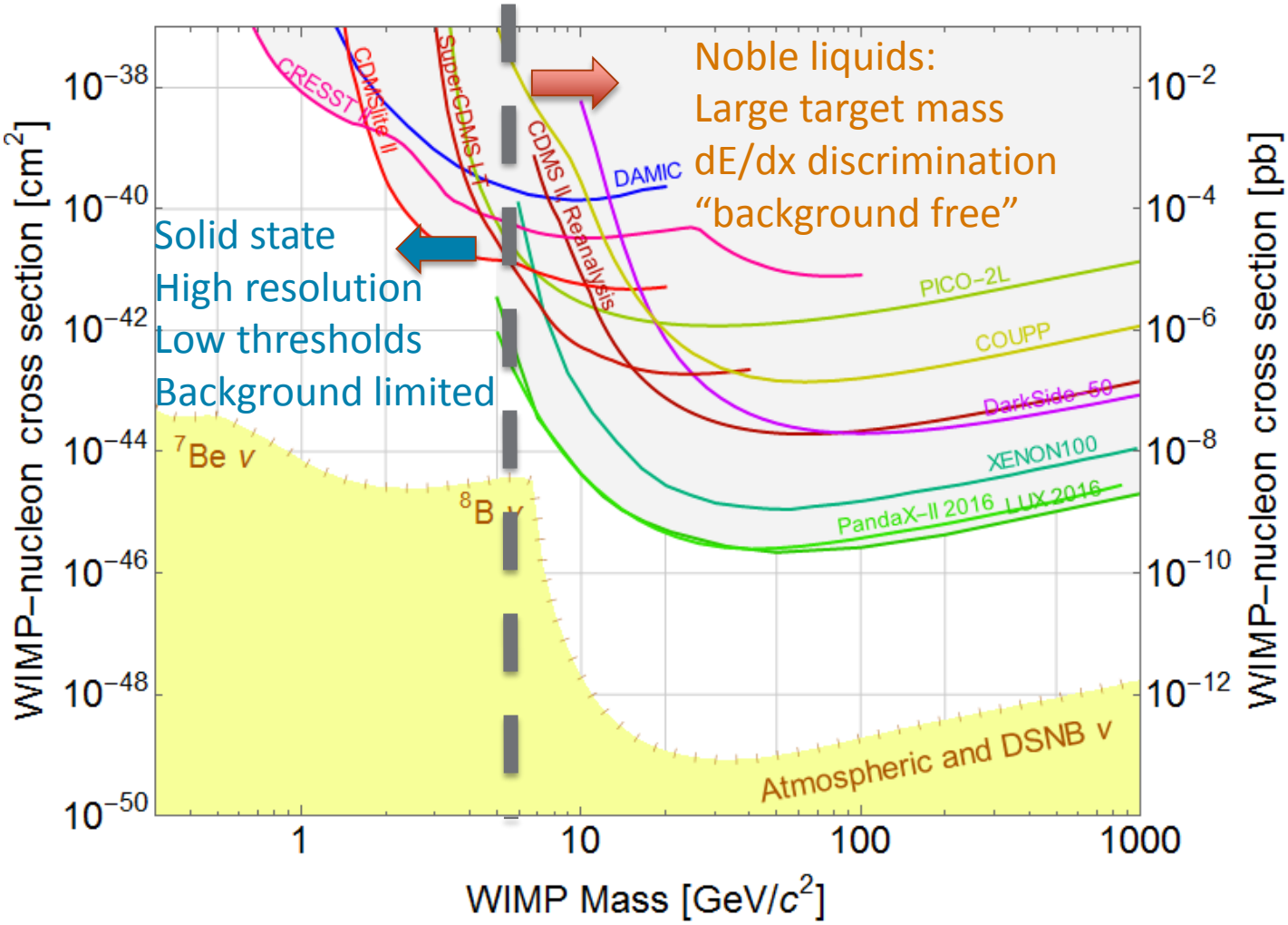
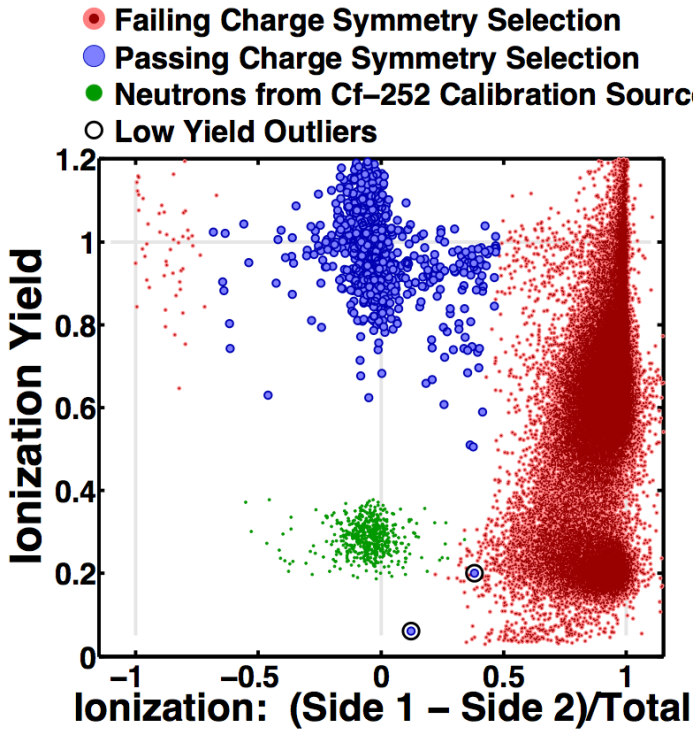
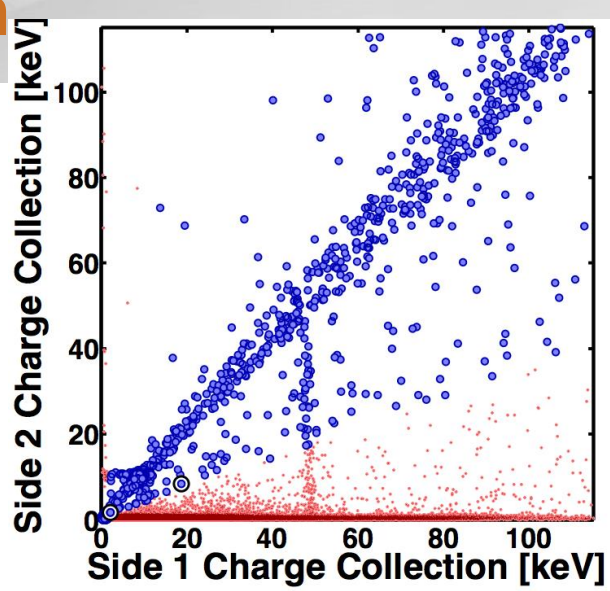
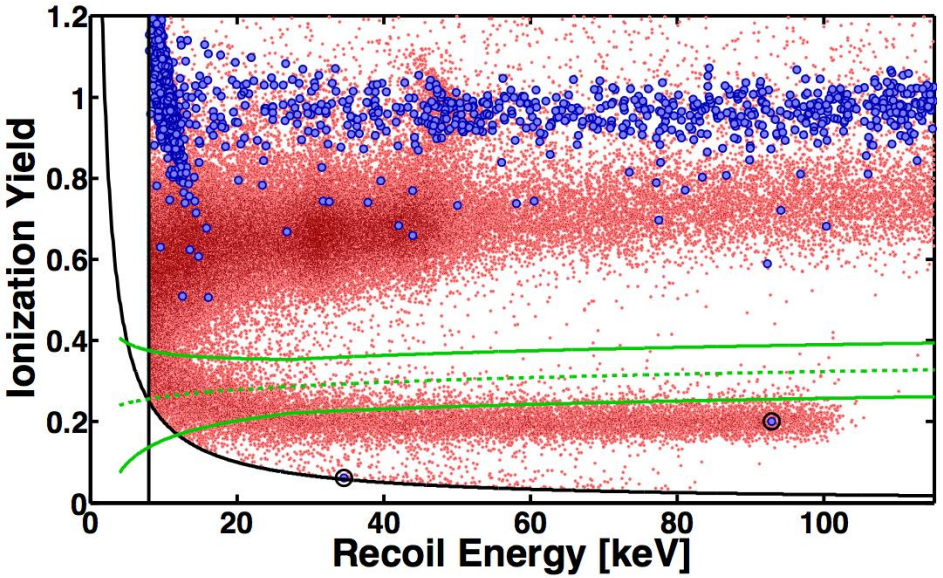


Yield and charge fiducial volume background discrimination



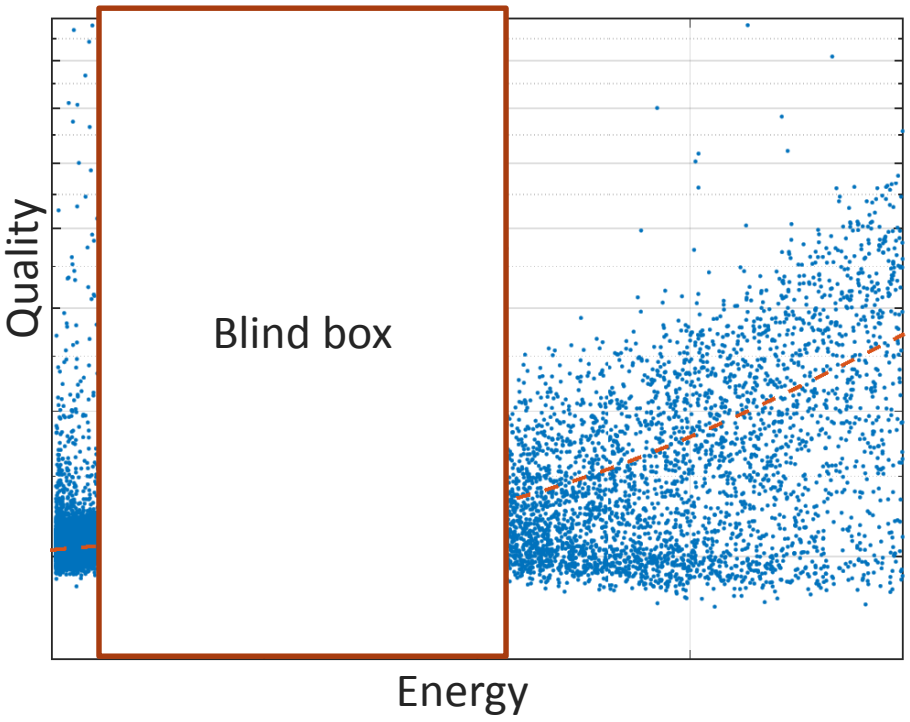




- Surface leakage < 1.26E-5 (90% CL)
  - for ~50% signal acceptance
- Not using phonon position info

Problems with box blinding

- Delayed access to data: first must acquire and analyze calibration data to determine the box, then apply blinding cut
- Hidden trends →
- Unanticipated backgrounds
- Anomalous events



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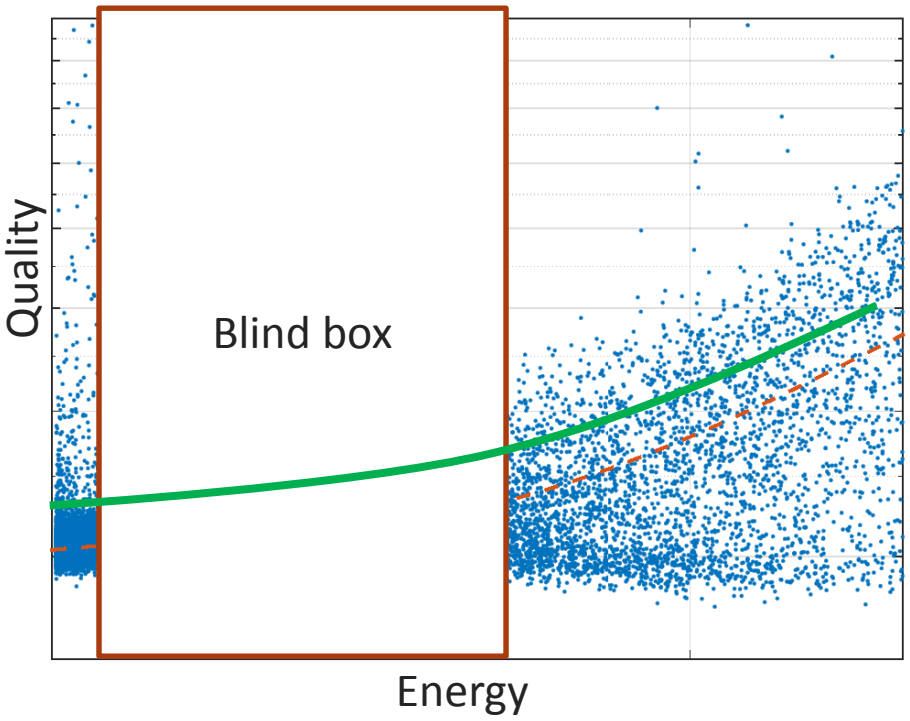

Problems with box blinding

- Delayed access to data: first must acquire and analyze calibration data to determine the box, then apply blinding cut
- Hidden trends →
- Unanticipated backgrounds
- Anomalous events