Implementation of "Salting" as Blinding Scheme for CDMSlite

Xiaohe Zhang

(For the SuperCDMS Collaboration)

Queen's University

2017 CAP Congress

Outline

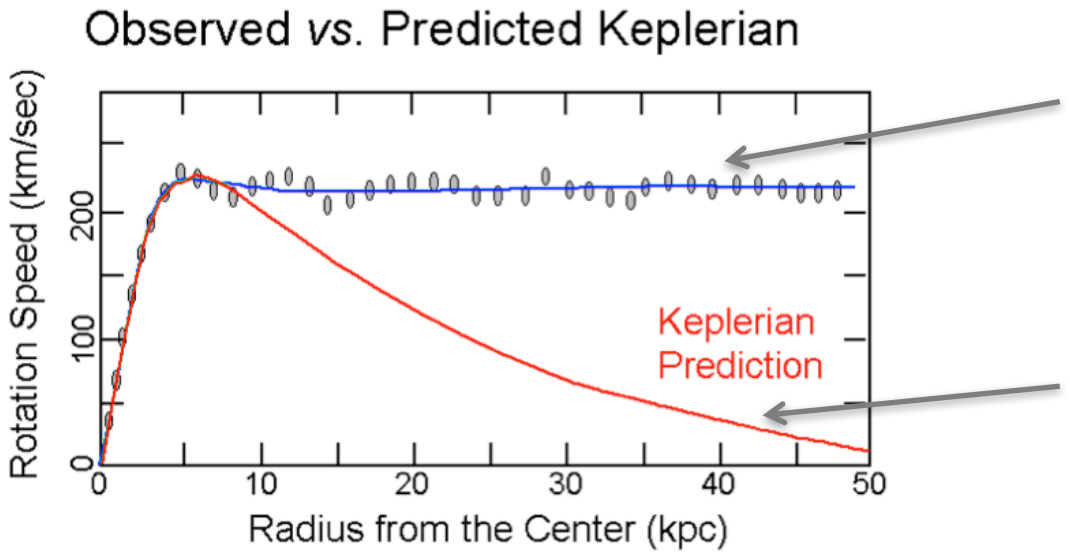
- Dark Matter & SuperCDMS
- Blinding Choices
- CDMSlite Salting Implementation
- Salting SuperCDMS SNOLAB

Dark Matter & SuperCDMS

Xiaohe Zhang - 2017 CAP Congress

Dark Matter

- Postulated by Fritz Zwicky in 1933
  - "Missing mass" in the rotation of galaxy



Approximately constant instead

Should $\sim 1/\sqrt{r}$

Observed galactic rotation curve with Keplerian prediction

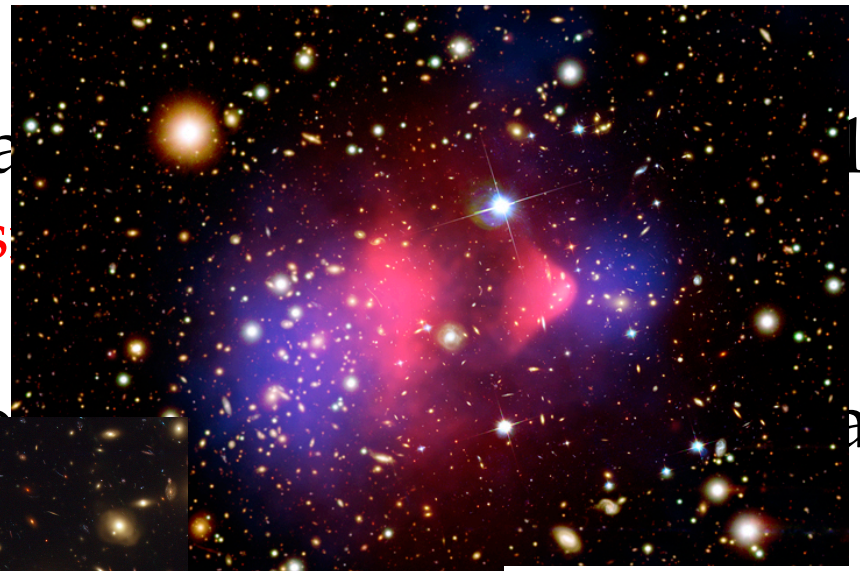
Dark Matter

- Postulated by Fritz Zwicky in 1933
  - "Missing mass" in the rotation of galaxy

- Cosmological and astrophysical evidence
  - Rotation curve of spiral galaxy
  - Merging galaxy clusters - "the bullet cluster"
  - Gravitational lensing
  - Cosmic Microwave Background
  - Big Bang Nucleosynthesis
  - …

Dark Matter

- Postula 1933
  - "Miss galaxy
- Cosmo al evidence



al lensing
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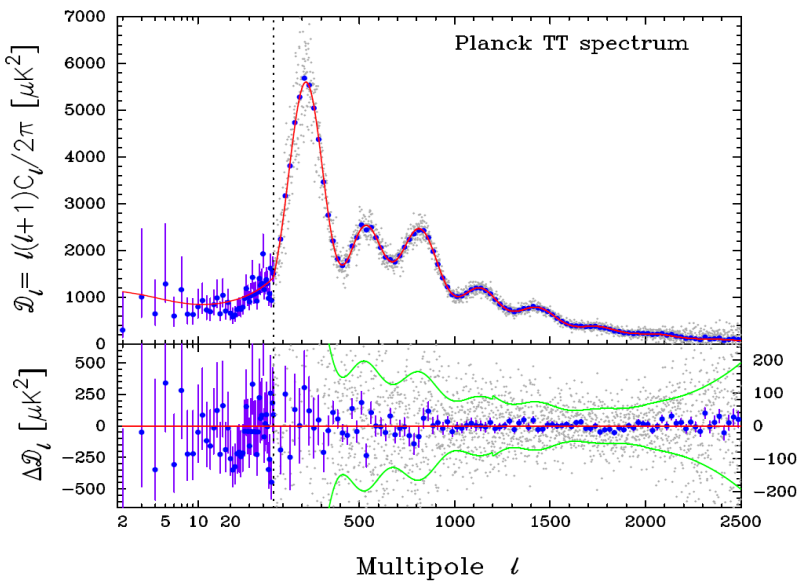
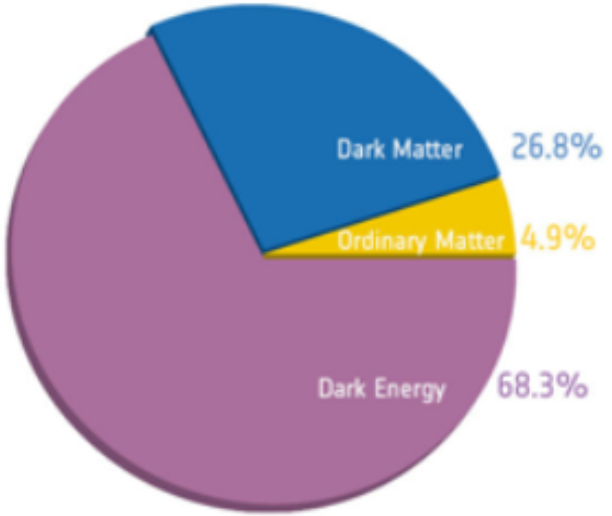
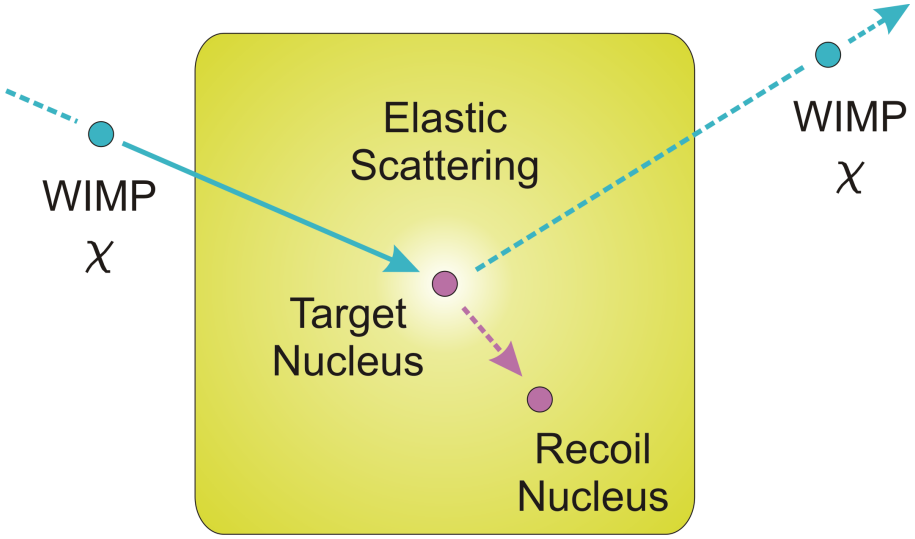


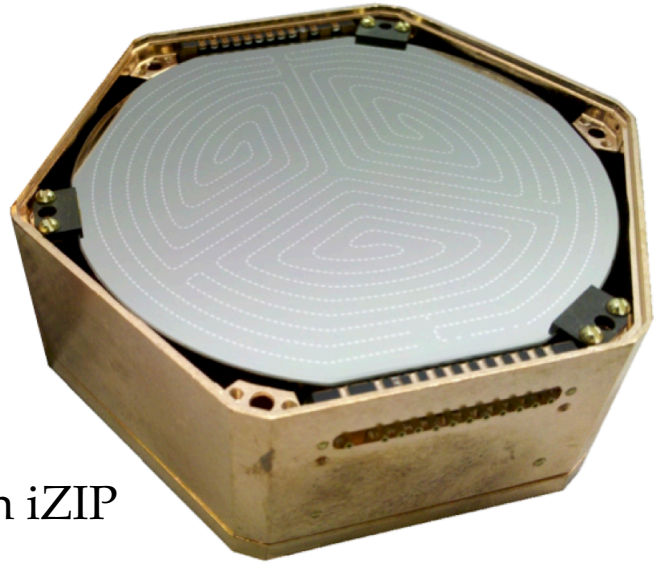


Queen's University

Super Cryogenic Dark Matter Search

Aim to directly detect dark matter interactions using cryogenic Ge and Si detectors.





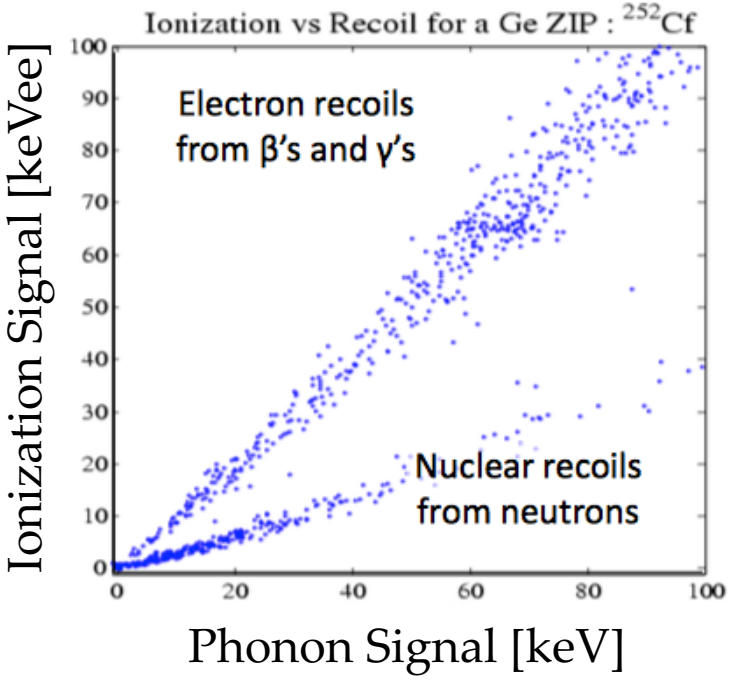
SuperCDMS-Soudan iZIP

SuperCDMS

- Simultaneously measure two channels of signal
  - **Phonon signal**: energy deposition
  - **Ionization signal**: NR produce smaller signal than ER of same energy
  - Provides background discrimination between

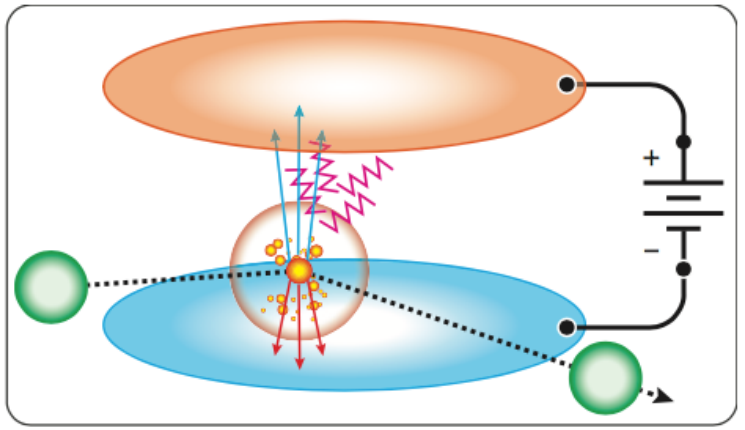
ER (β, γ) vs. NR (n, *WIMP*)

Main background



CDMSlite (SuperCDMS HV)

- CDMS Low Ionization Threshold Experiment
- Operating at "high voltage" (-70V for Run 2; -75V for Run 3)
- Neganove-Luke effect:
  - Charge carriers gain kinetic energy in the field
  - Deposited as phonons (Luke phonons)
  - $E_t = E_r + N_{eh} e V_b$



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- Neganove-Luke effect:
  - Charge carriers gain kinetic energy in the field
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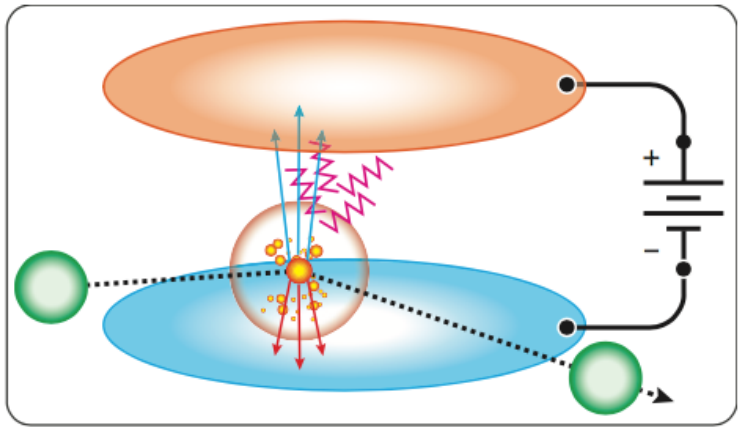
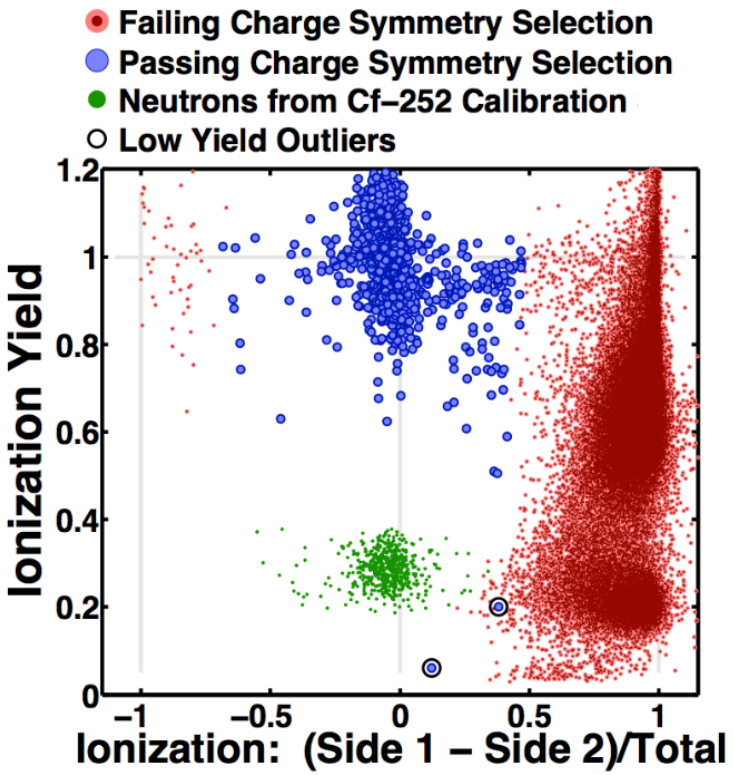
  - $E_t = E_r + N_{eh} e V_b$
- Results:
  - Much lower threshold with high bias voltage
  - Lose ER vs. NR discrimination



Blinding Choices

Traditional Blinding – Blind Box



i. Define signal region of interest (ROI) based on calibration data

ii. Define ”box” that covers a bit more than ROI

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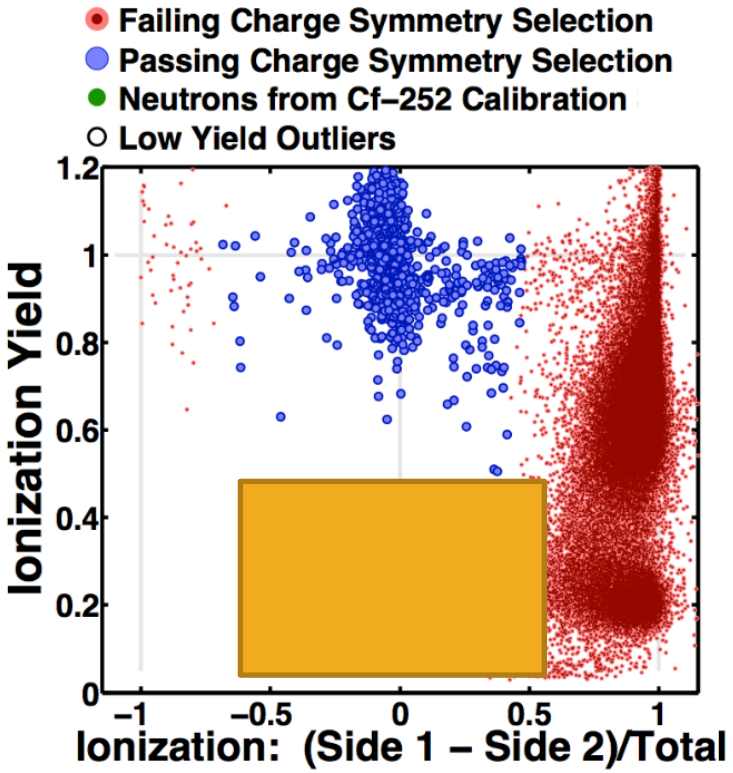


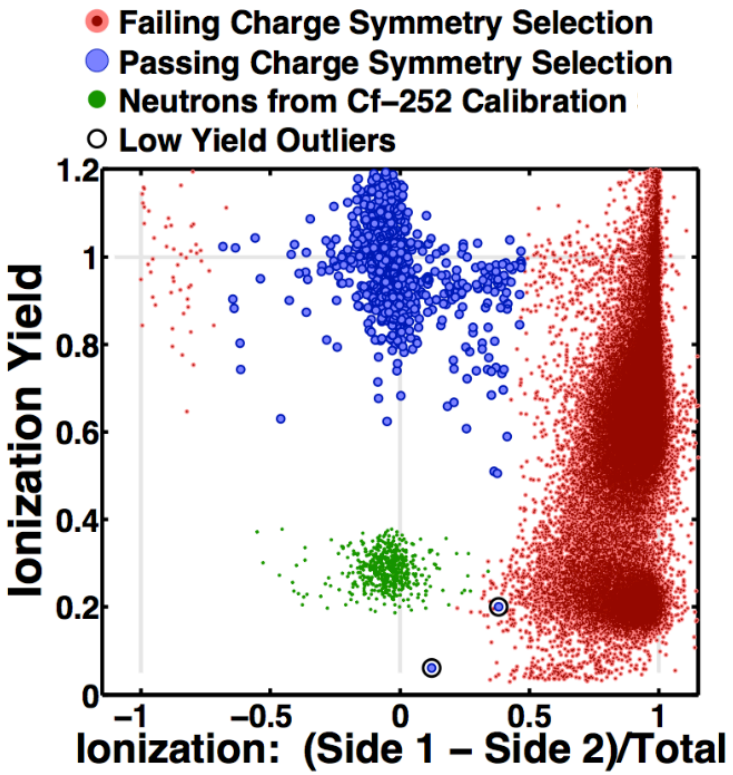
i. Define signal region of interest (ROI) based on calibration data

ii. Define ”box” that covers a bit more than ROI

iii. Restrict access to events within the blinding box

iv. Develop and tune cuts based on sidebands and calibration data

Traditional Blinding – Blind Box



i. Define signal region of interest (ROI) based on calibration data

ii. Define ”box” that covers a bit more than ROI

iii. Restrict access to events within the blinding box

iv. Develop and tune cuts based on sidebands and calibration data

v. Open the box

Traditional Blinding – Blind Box

- Relatively straightforward

- Well suited for rare signals as long as:
  - Signal region is known
  - Little / No background is expected in the box

    or

    Background in the box can be estimated well

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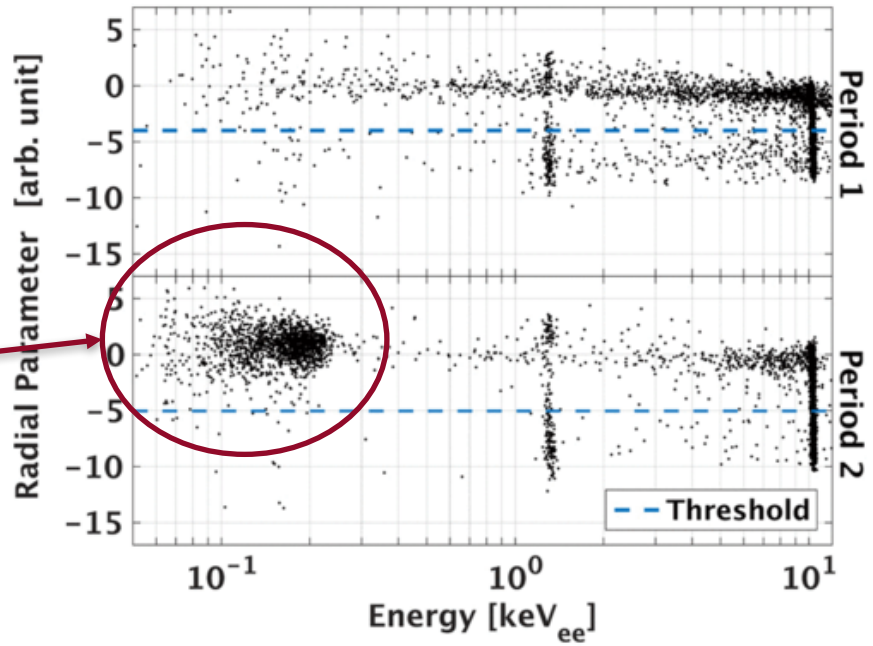
- Problem:
  - In the case of CDMSlite:
    - No discrimination between NR and ER
      - What is the "box"?
      - Restrict based on energy?

Traditional Blinding – Blind Box

- Problem:
  - In the case of CDMSlite:
    - No discrimination between NR and ER
      - What is the "box"?
      - Restrict based on energy?
    - Unexpected background would also be blinded, e.g.



Alternative Blinding - Salting

- Adding fake signal-like events ("salt") to data
  - Allows all events in the signal region to be examined while keeping the ambiguity regarding which events are real
  - Avoid bias, over-tuning while creating cuts, but can still tune them as a function of energy

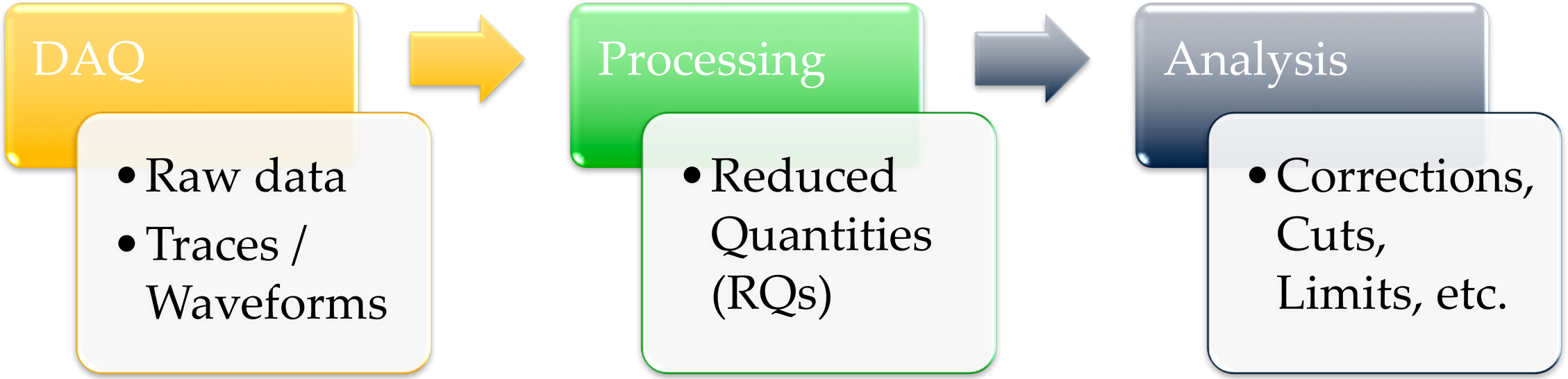
CDMSlite Salting Implementation

Implementation of Salting

- CDMSlite **Run 2** analysis was not blinded
  - Perfect playground for developing algorithm

- A different detector was used for **Run 3**, with slightly higher voltage, lower threshold, and similar exposure
  - Collaboration decided to try out salting
  - Principle:
    - Salt is not accidentally identifiable
    - Should not lead to unnecessary cuts

Salt Injection – Where & What



Salt Injection – Where & What

DAQ

- Raw data
- Traces / Waveforms

Processing

- Reduced Quantities (RQs)

Analysis

- Corrections, Cuts, Limits, etc.

Implementation of Salting

Pulses have sequential event numbers

→ Replacing instead of inserting

Implementation of Salting

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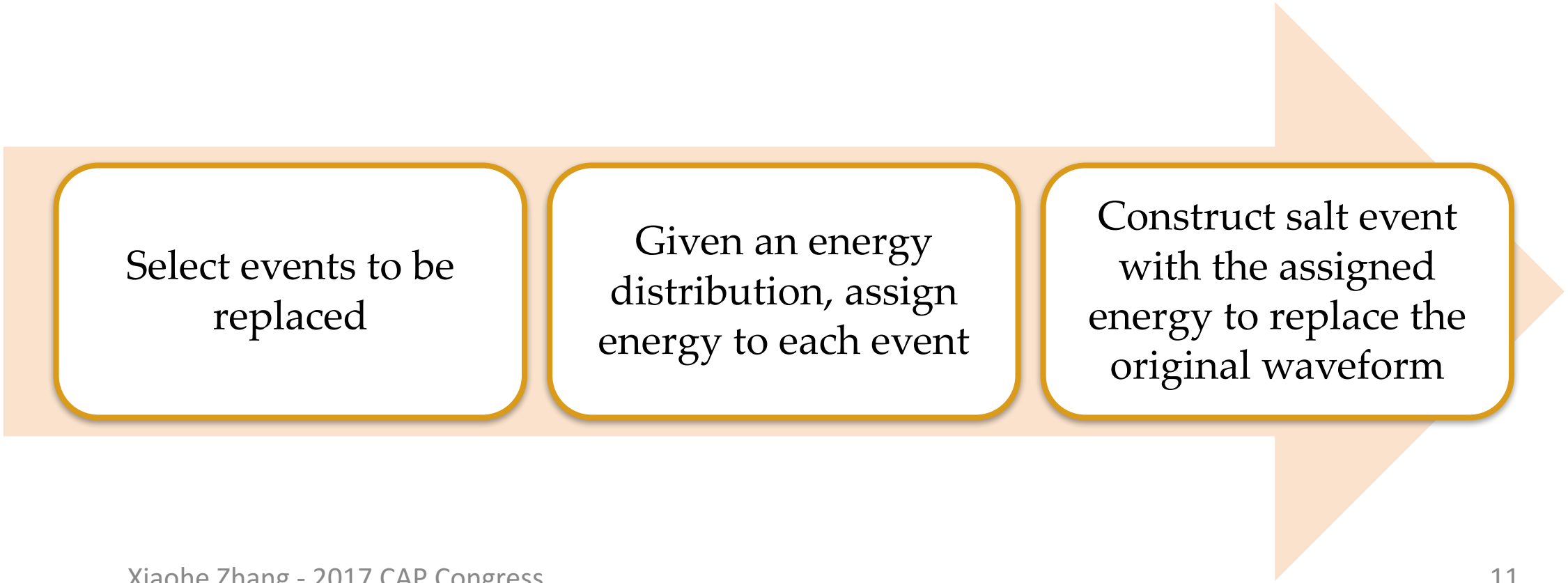
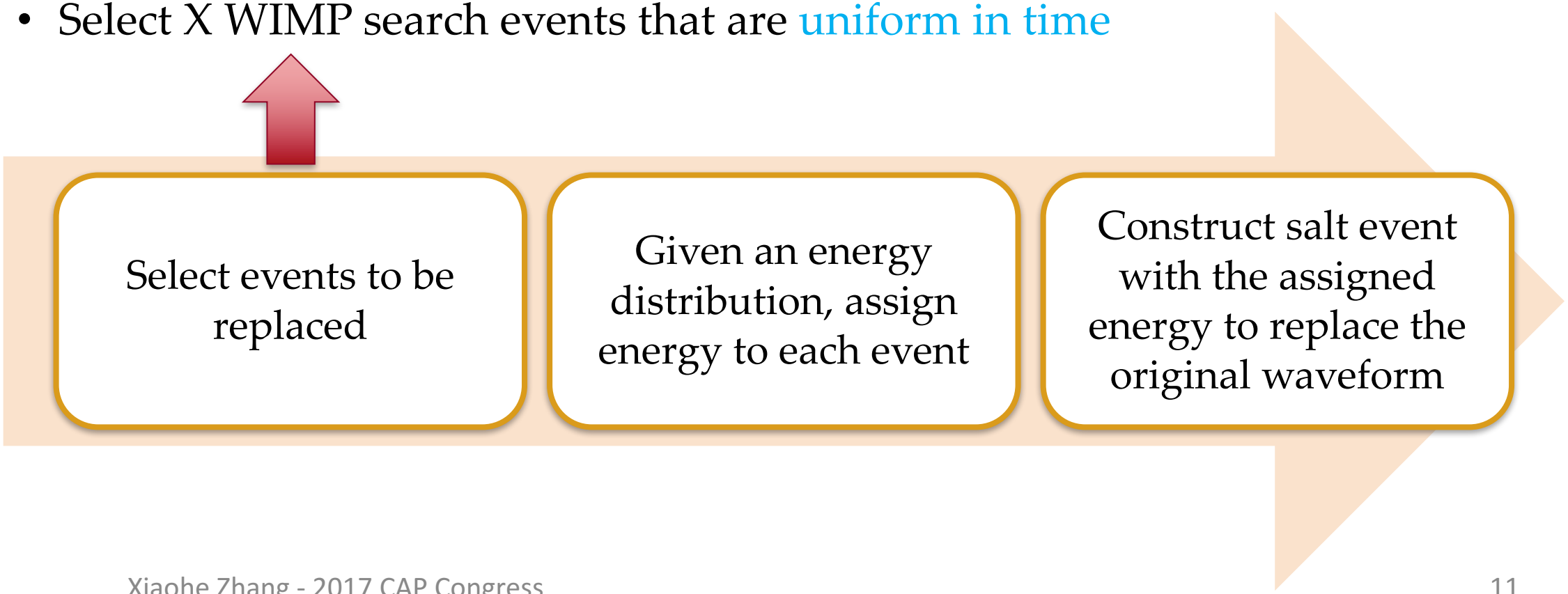


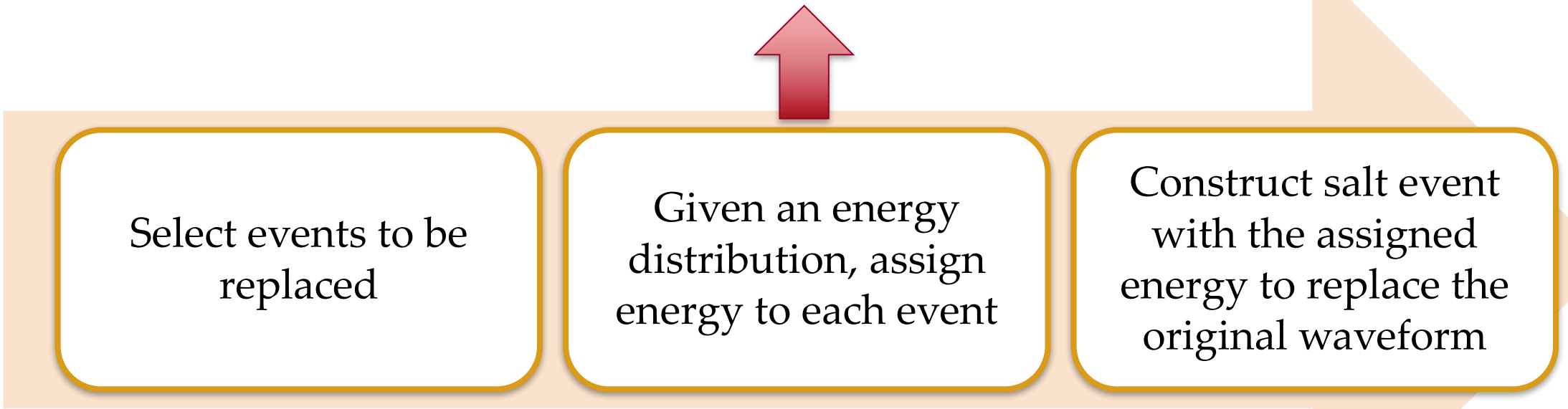
Implementation of Salting

- Calculate expected number of events in the final spectrum, N
- Generate a random number X between N and 3N to be the number of salt
- Select X WIMP search events that are uniform in time

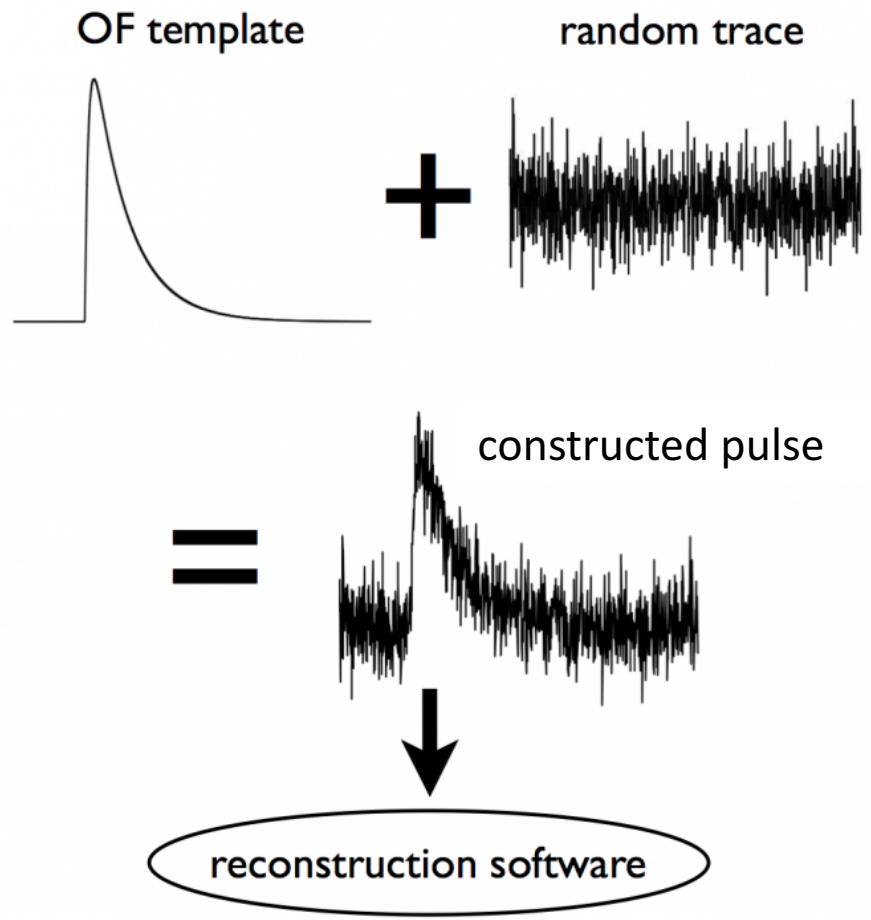


Implementation of Salting

- Energy is drawn from an exponential + constant spectrum
- Decay constant is randomly picked between 0.5 - 2 keV
- Ratio between exponential and constant components varies from 1/3 to 3



Salt Construction



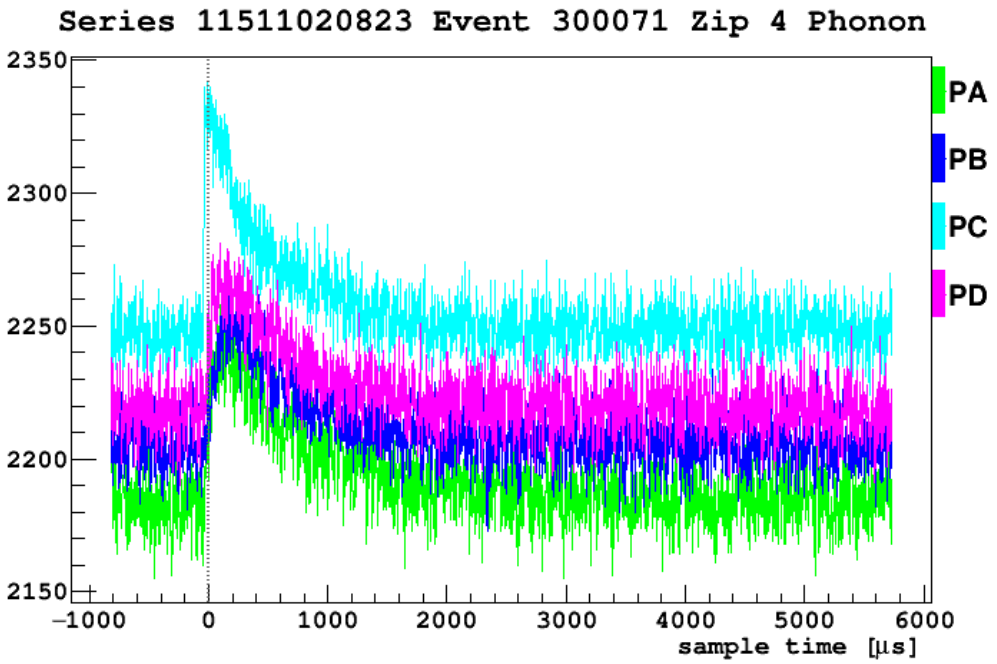
Construct salt pulses

1. Take templates of the four individual channels of a selected pulse
2. Scale them to desired energy
3. Add in selected noise traces from a randomly triggered baseline event

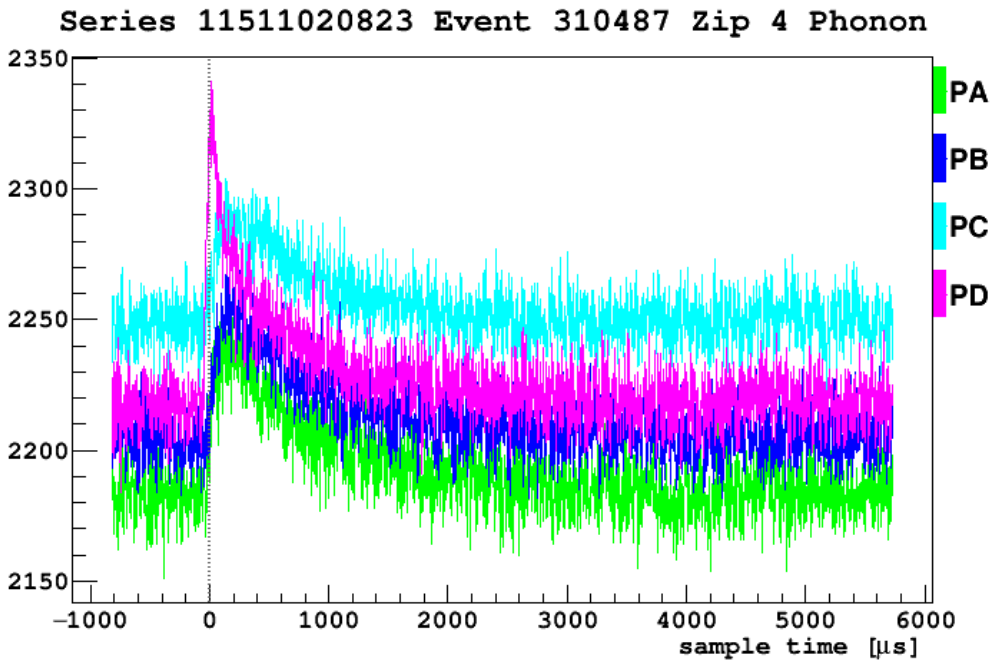
Salt Construction

Typical examples from a test data set

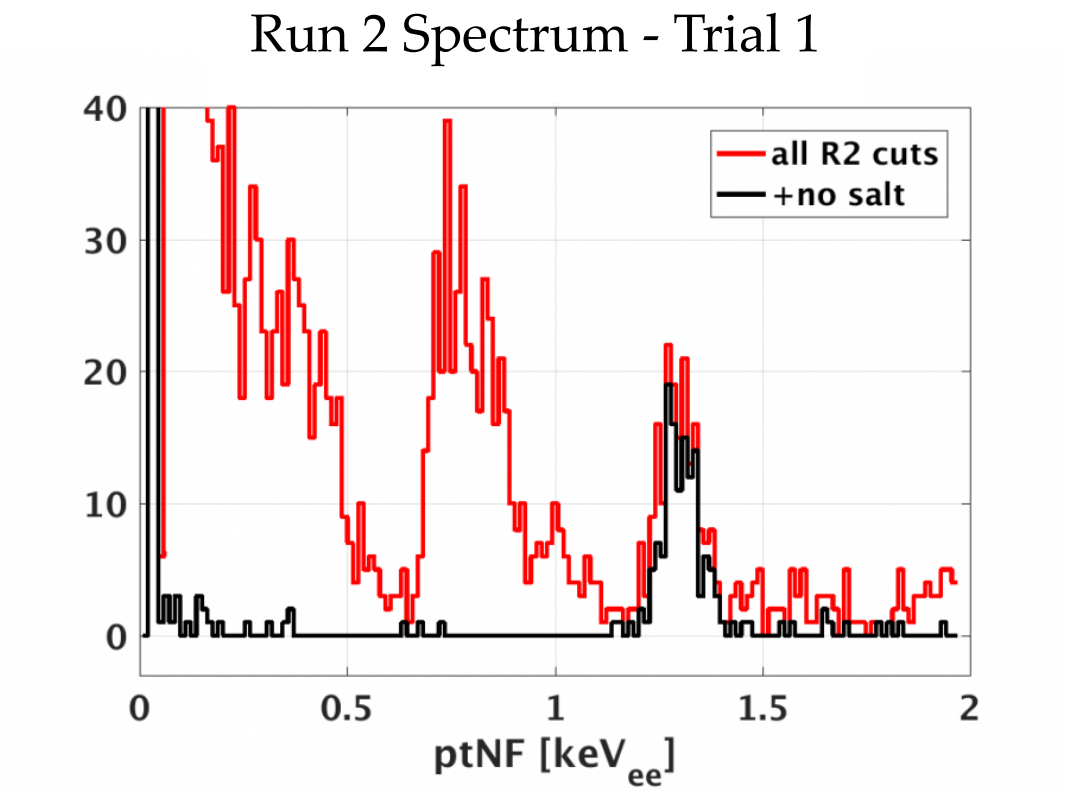
Real raw pulse



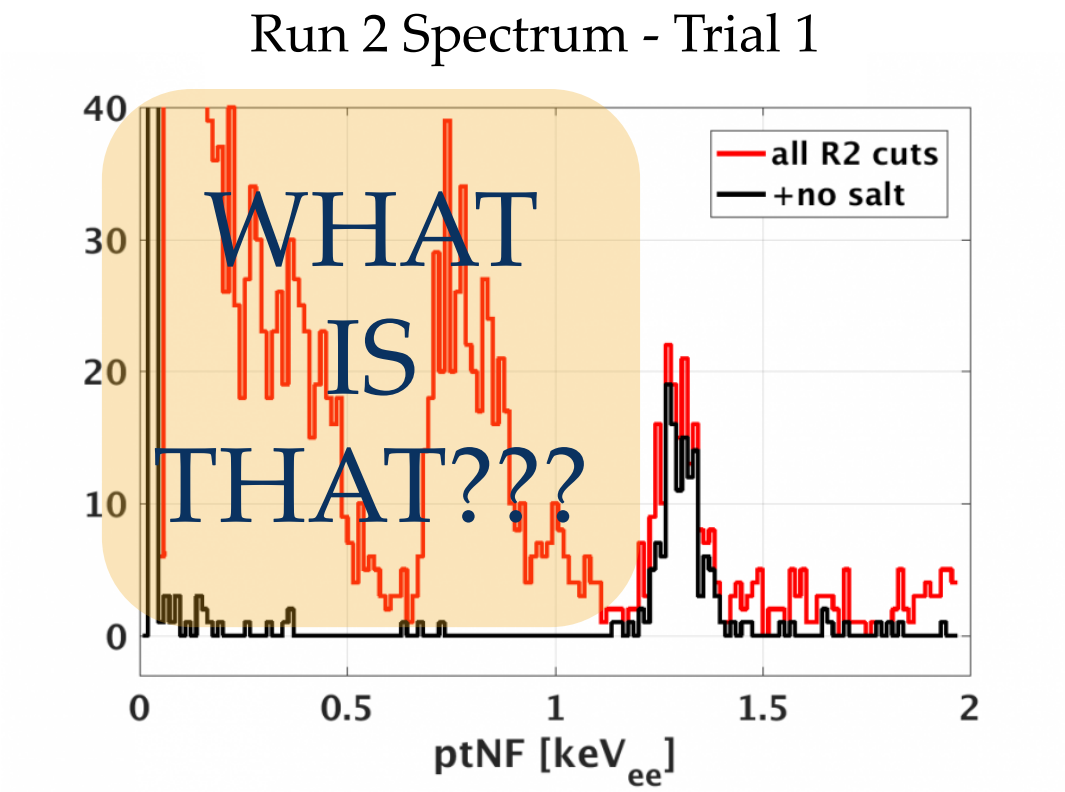
Constructed salt event



Take One …


Run 2 Spectrum - Trial 1
all R2 cuts
+no salt
40
30
20
10
0
0
0.5
1
1.5
2
ptNF [keV$_{ee}$]

Take One …


Run 2 Spectrum - Trial 1
WHAT
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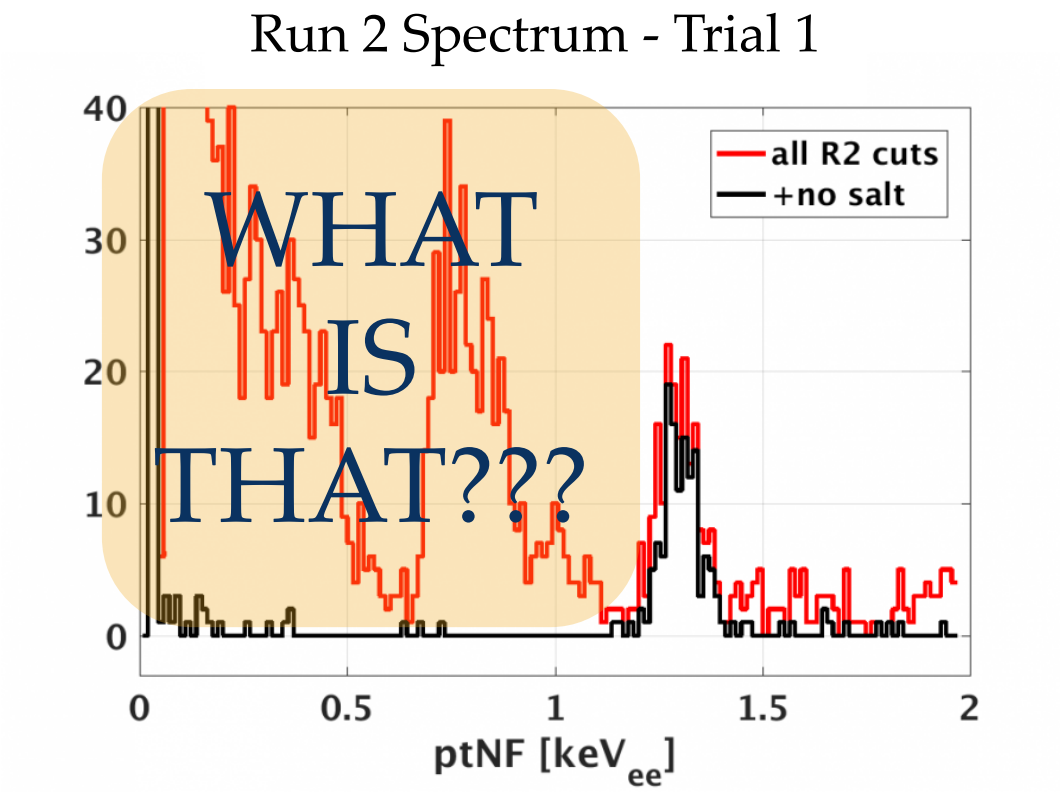
Take One …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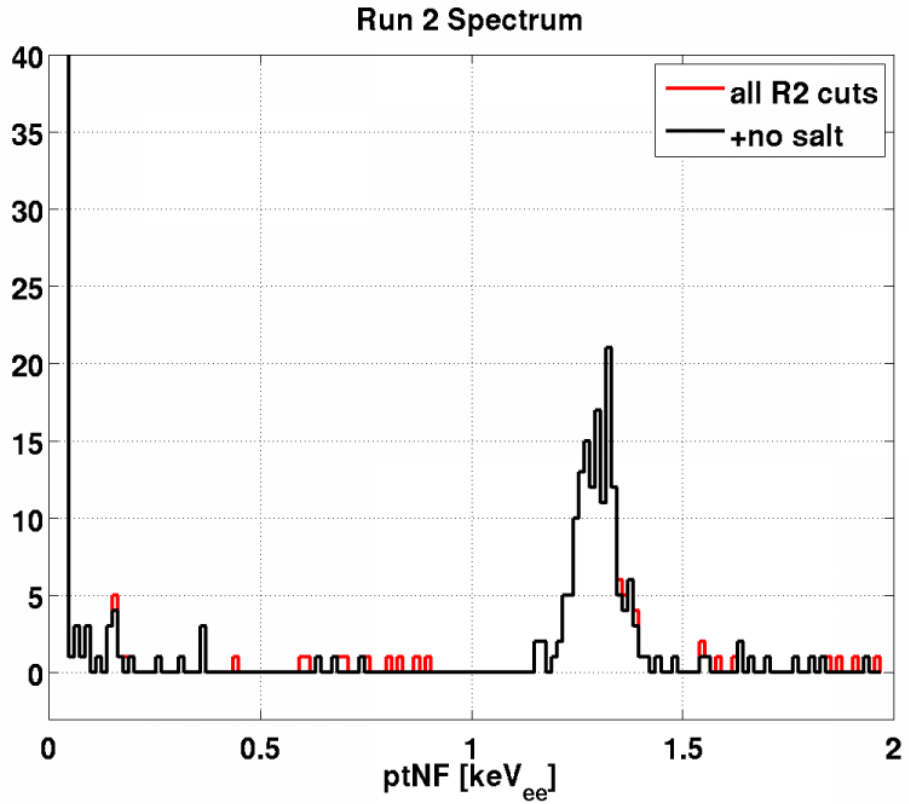
all R2 cuts
+no salt
40
30
20
10
0
0
0.5
1
1.5
2
ptNF [keV$_{ee}$]


SALT

Take One …

And Finally …


Run 2 Spectrum
all R2 cuts
+no salt
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
ptNF [keV$_{ee}$]

Current Status

- For Run 3
  - One analyzer* inspected the salted data set and made sure salt is not accidentally identifiable
    * Only this analyzer has seen with / without salt plots, thus will not participate in Run 3 analysis
  - One more issue was noticed during this process, and fixed in the following rounds
  - Generated and processed the final salted Run 3 data

  - Salted Run 3 data has been released to the collaboration
  - Analysis in progress…

Salting SuperCDMS SNOLAB

Future – SuperCDMS SNOLAB

- Next generation of SuperCDMS
- Main focus is low-mass WIMP direct detection

- More advanced detector: larger crystal, new sensor design
- Upgraded hardware: detector tower, front-end electronics, DAQ, etc.
- Reduced background: deeper underground, extensive material screening, etc.
- …

Future – SuperCDMS SNOLAB

- Plan to use salting as the blinding scheme
- The hope is to salt while taking data
  - Not delaying data analysis
  - (Almost) real time data analysis would be possible

- Many things to consider…
  - Schedule calibration runs accordingly
  - Need to understand detector characters / energy dependent distributions / energy scaling corrections – how to do these as soon as possible
  - How to do quality control
  - …

Future – SuperCDMS SNOLAB

- For more information about SuperCDMS:
  - Talks
    - 29 May 2017, 15:30 - Towards an Infrared Photon Based Calibration of Super Cryogenic Dark Matter Search (SuperCDMS) Detectors, M. Ghaith
    - 1 Jun 2017, 08:45 - Background strategy in SuperCDMS SNOLAB, S. Scorza
    - 1 Jun 2017, 11:30 - SuperCDMS and CUTE at SNOLAB, W. Rau
  - Posters
    - POS-33 - Vibration Analysis of a Dry Dilution Refrigerator at the Queen's SuperCDMS Test Facility, R. Germond
    - POS-39 - Radial Fiducialization in CDMSlite, R. Underwood
    - POS-46 - SuperCDMS SNOLAB Data Acquisition System, M. Wilson

SuperCDMS Collaboration

California Inst. of Tech.
CNRS-LPN*
Durham University
FNAL
NISER
NIST*
Northwestern
PNNL
Queen's University
Santa Clara University
SLAC
South Dakota SM&T
SMU
SNOLAB
Stanford University
Texas A&M University
TRIUMF
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Minnesota
U. South Dakota
U. Toronto

* Associate members

Thank you!

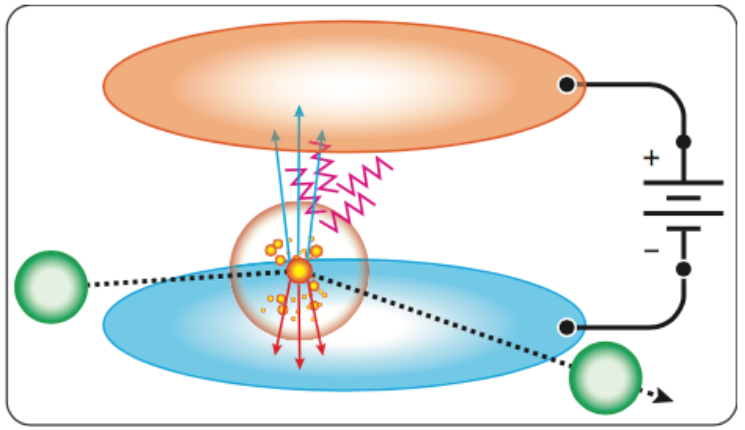
SuperCDMS Collaboration

Thank you!

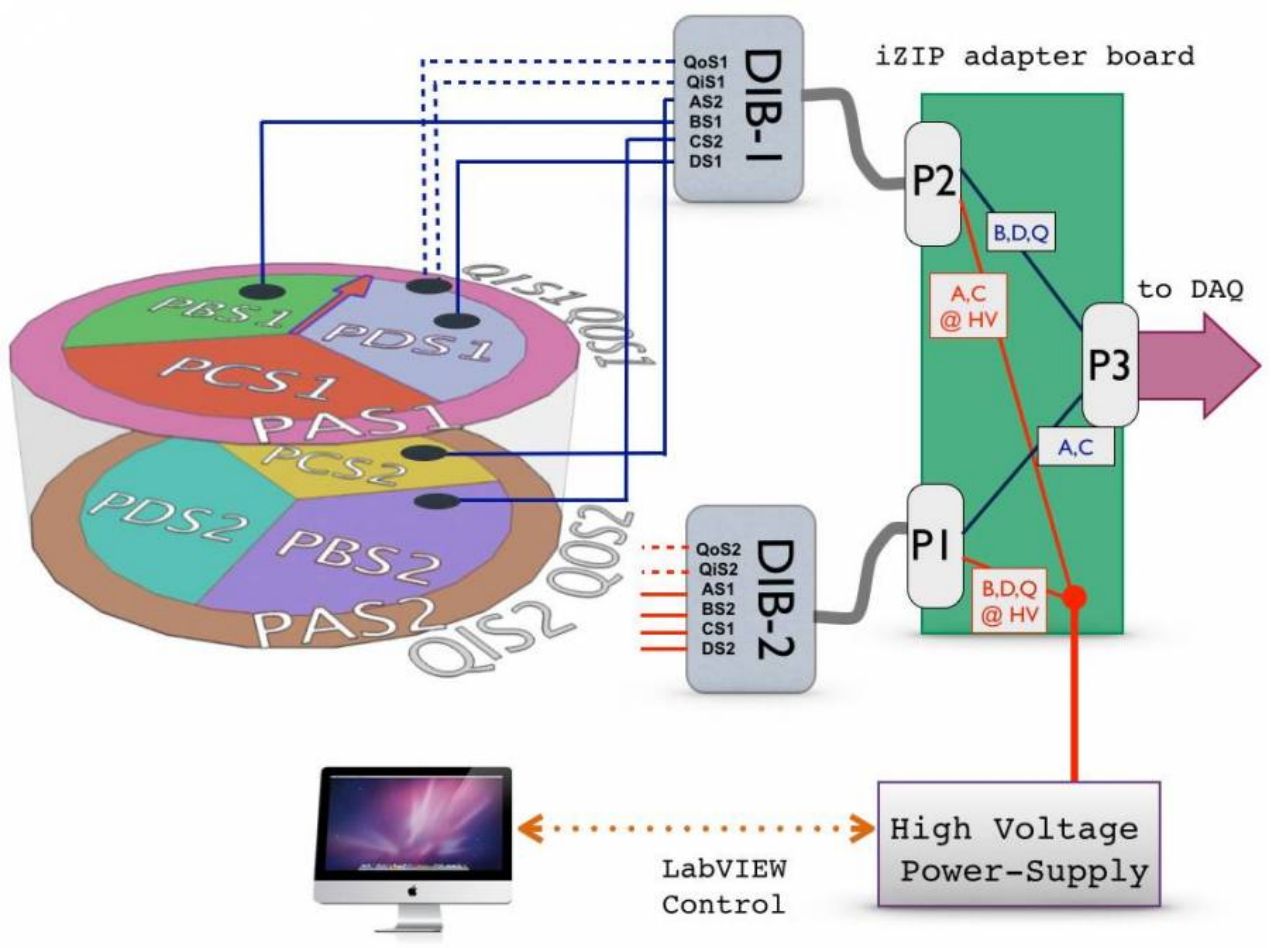
Back-up Slides

CDMSlite (SuperCDMS HV)

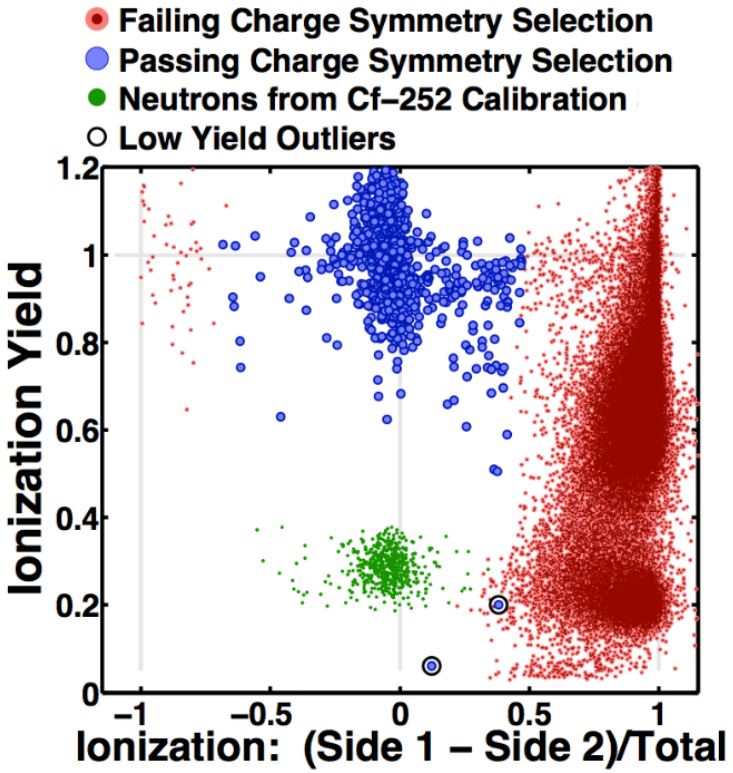
- CDMS Low Ionization Threshold Experiment
- Operating at “high voltage” (-70V for Run 2; -75V for Run 3)



CDMSlite Setup



Traditional Blinding – Blind Box



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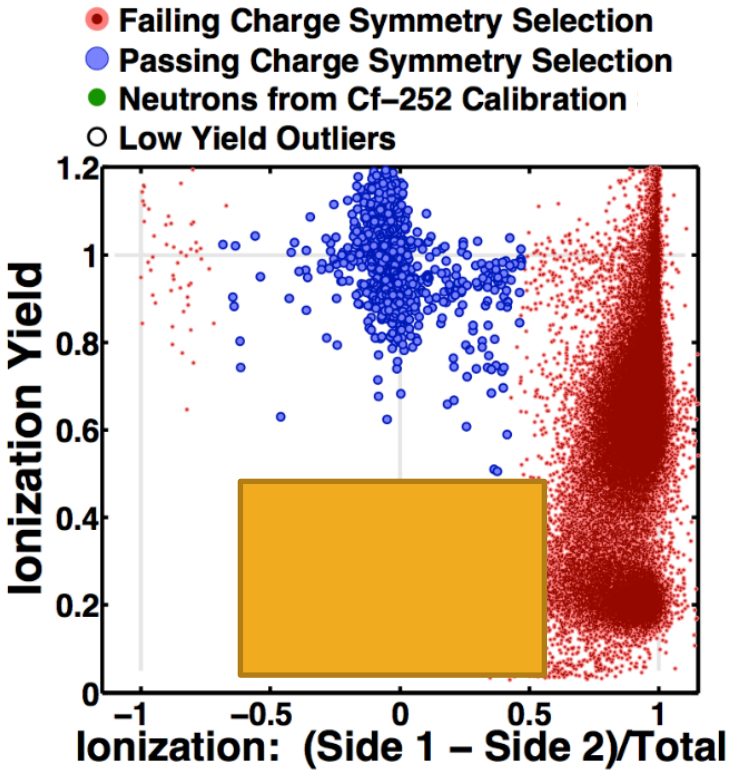


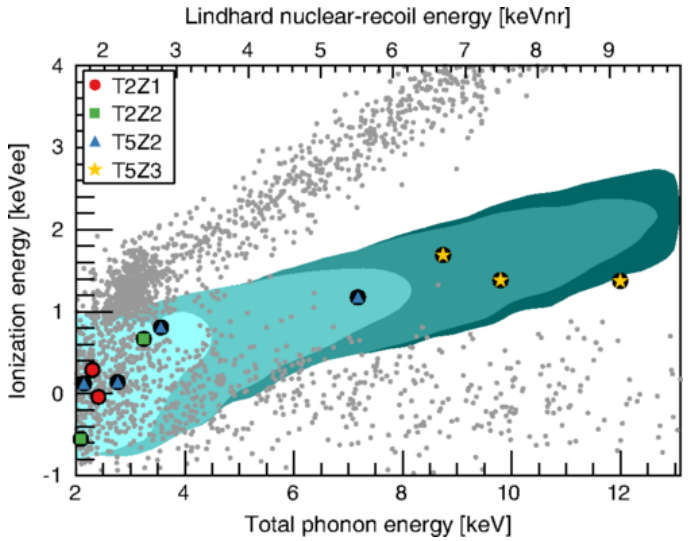
i. Define signal region of interest (ROI) based on calibration data

ii. Define ”box” that covers a bit more than ROI

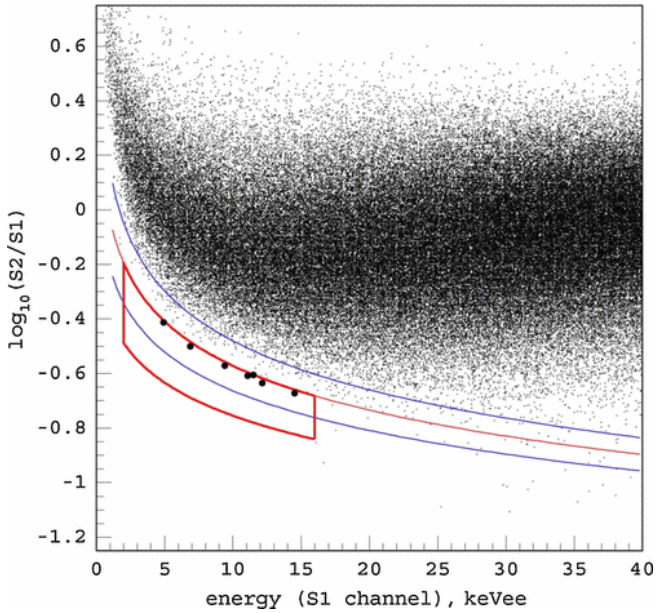
iii. Restrict access to events within the blinding box

Traditional Blinding – Blind Box

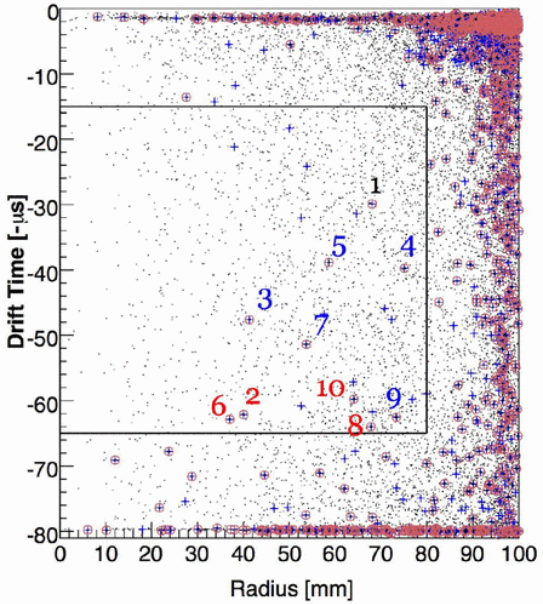
- Problem:
  - Unexpected, pathological background events
    - For example:



SuperCDMS, Phys. Rev. Lett. 112, 241302



ZEPLIN-III
Phys. Rev. D 80, 052010

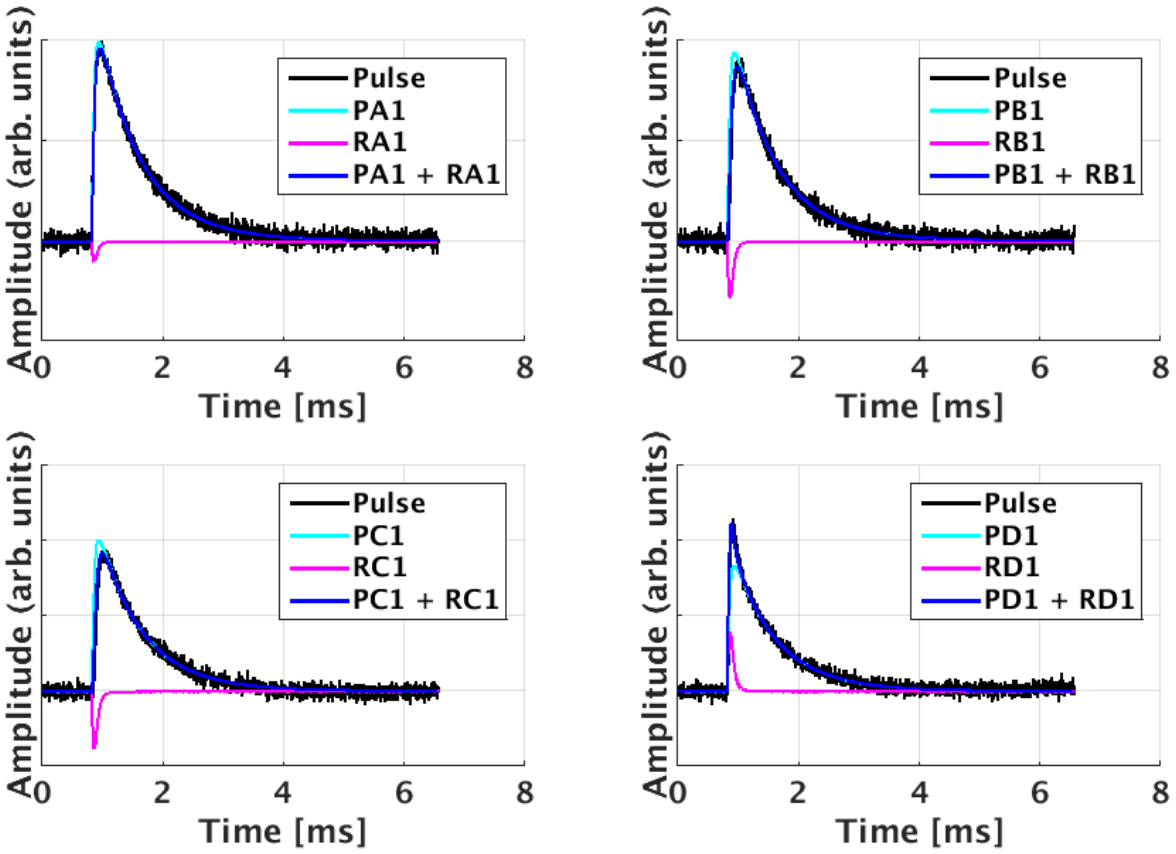


XENON10
Phys. Rev. Lett. 100, 021303

Alternative Blinding - Salting

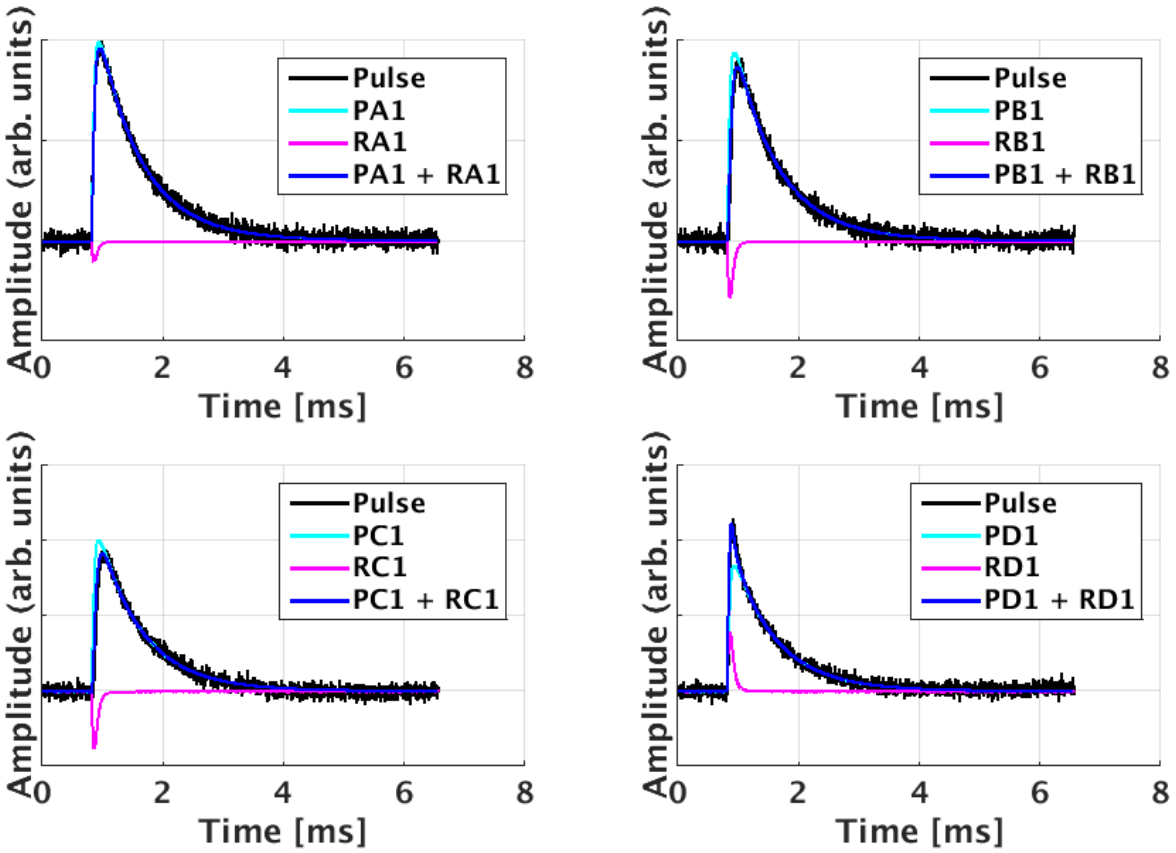
- Adding fake signal-like events (“salt”) to data
  - Check some cut efficiencies
  - Verify background model by estimating number of salt before un-blinding
  - Explore future SuperCDMS SNOLAB blinding technique

Salt Construction



- Phonon pulses are fitted with the sum of two templates
  - "slow" template
  - "fast / residual" template
- Figure on the left shows an example of the four phonon channels of one pulse

Salt Construction



- Raw calibration pulses
  - Noise / run conditions are different
  - Pile up, unstable baseline, etc.
- Still need real waveform
  - "Characters" of each detector
  - Fast component carries position information

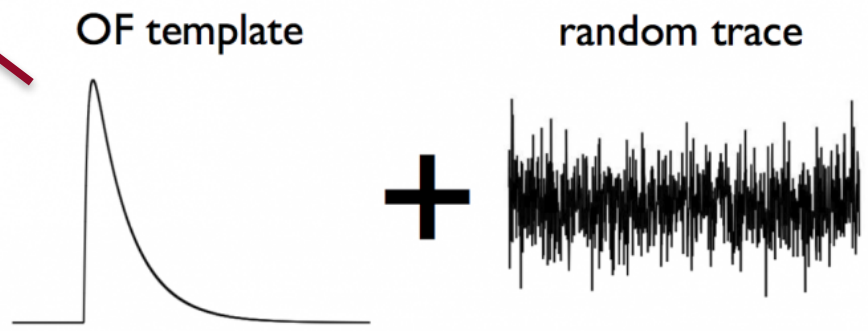
Salt Construction

Waveform Template

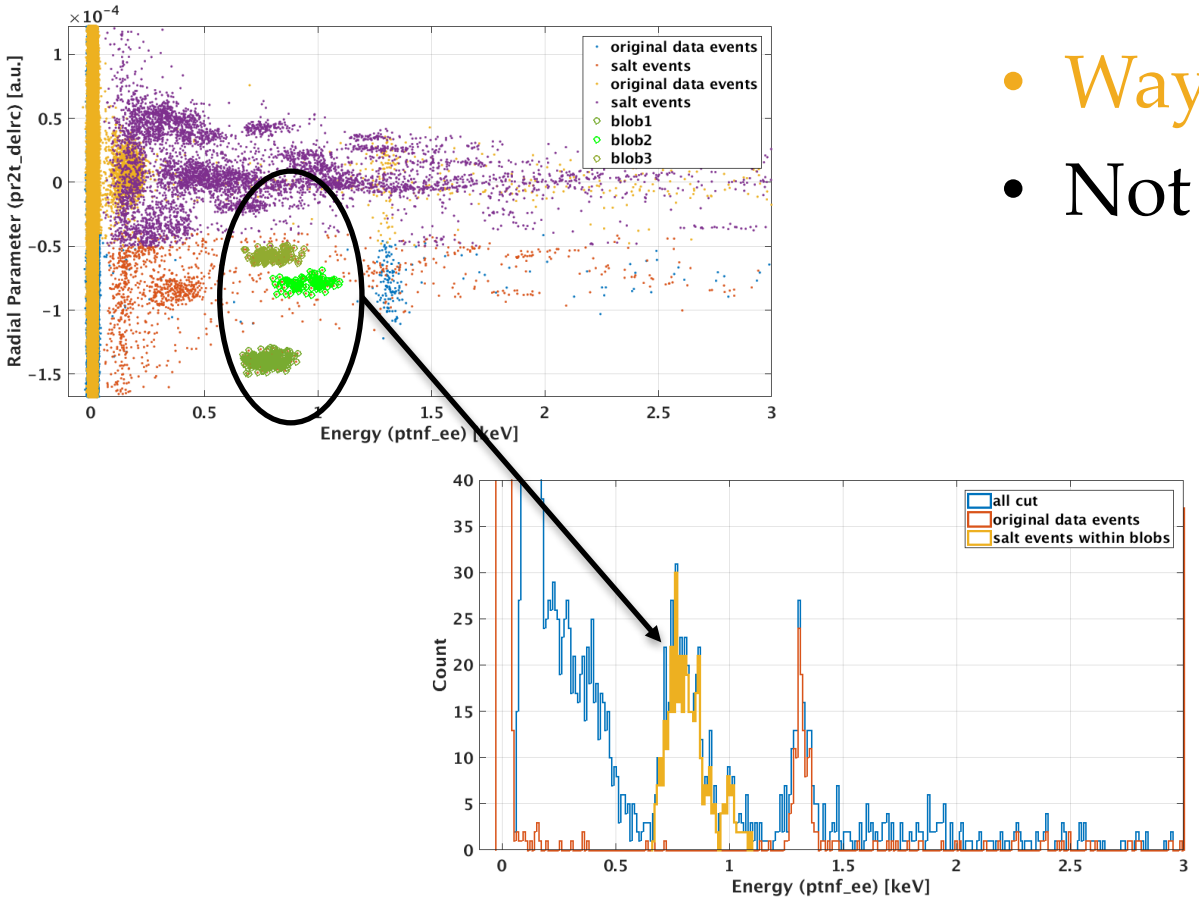
- Select from calibration data
- Strict pre-selection cuts to ensure signal-like salt events
- For each assigned energy, select event with similar but slightly larger energy
  - All the energy dependent distributions will be carried over with this tight energy selection
  - Only scaling down so only picking events above trigger threshold

Noise

- Select from close time period to ensure similar run conditions



Take One …



- Way too much salt
- Not enough calibration data

Multiple salt events (signal-like) generated from the same calibration event

Pass cuts &
End up in the spectrum