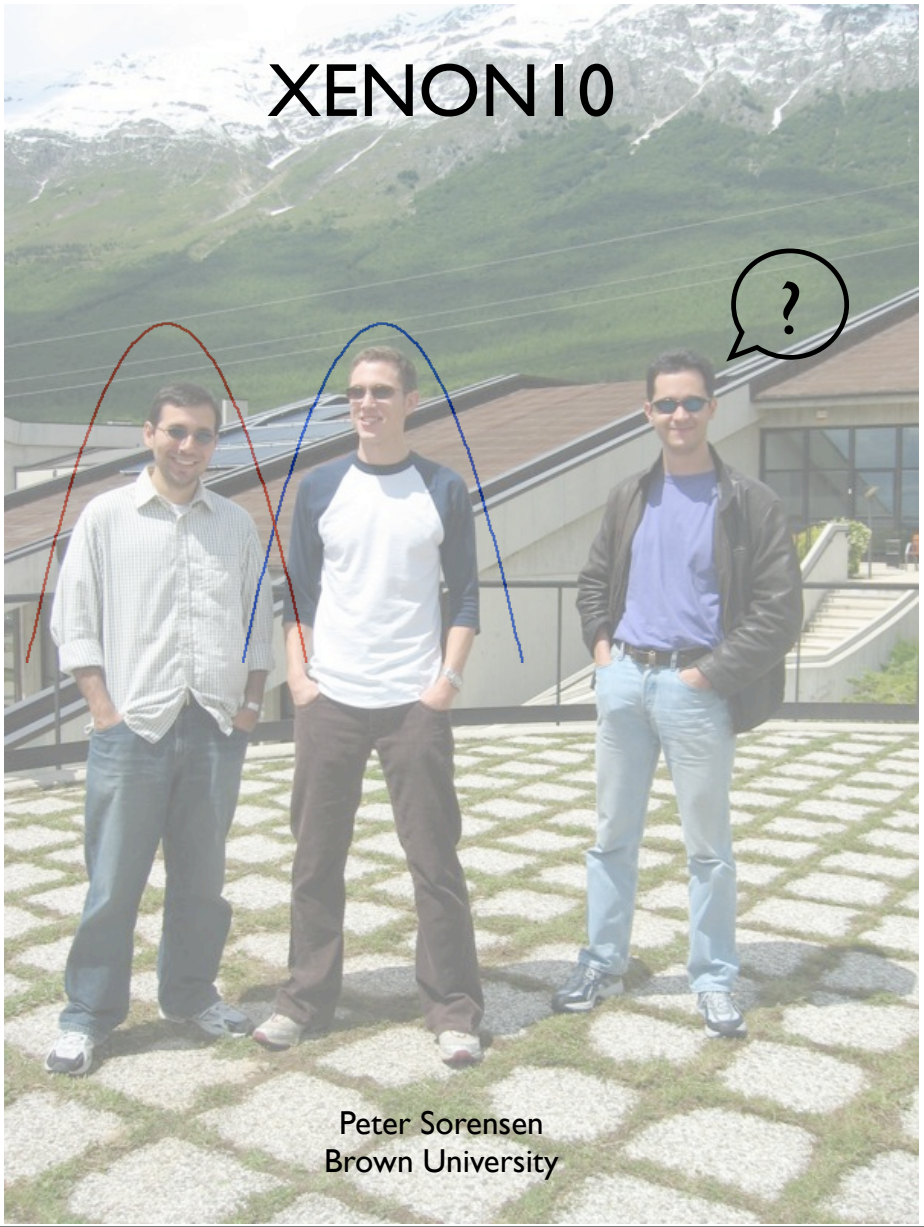
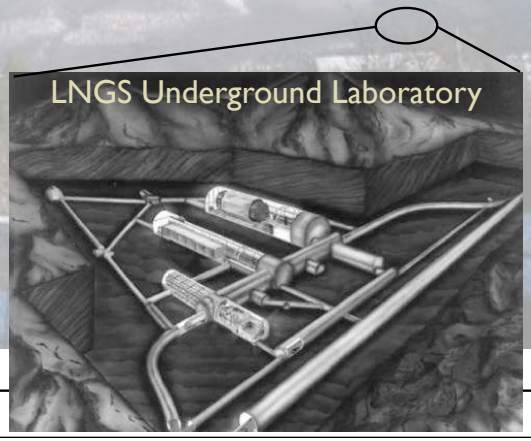
Optimization of Non-Gaussian Background Rejection in XENON10



Peter Sorensen
Brown University

Talk Summary

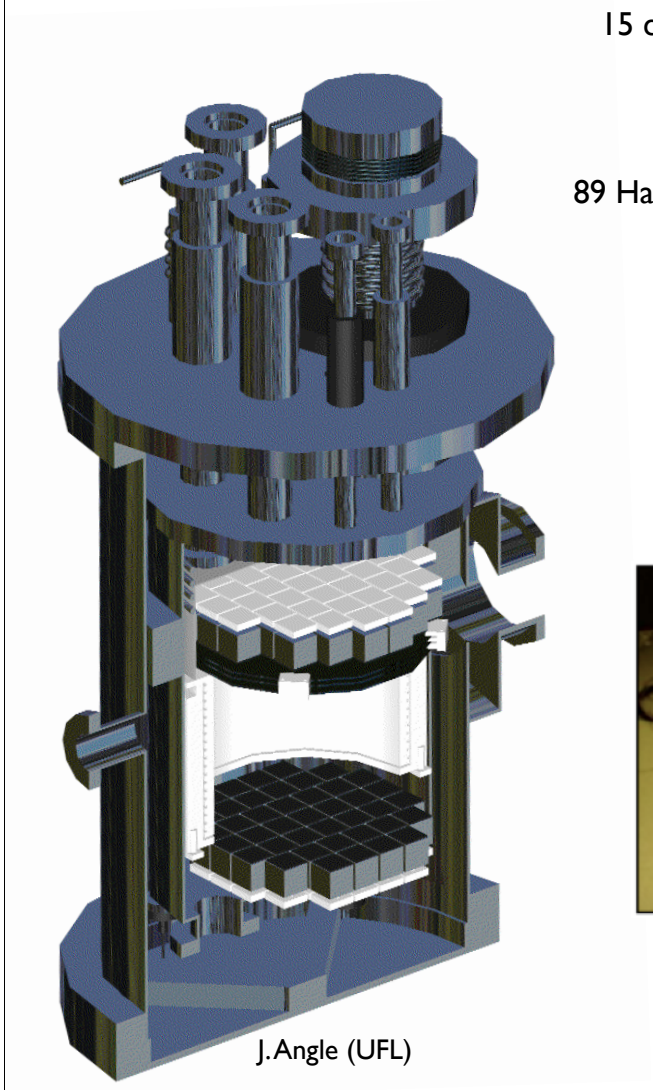
1. Brief overview of XENON10 installation/detector
2. Trigger Threshold / Analysis Threshold
3. Discrimination of ER v NR: Gaussian & non-Gaussian populations
4. Optimization of discrimination
   - Gaussian: corrections for detector non-uniformity (optimize sigma)
   - Non-Gaussian: identification of anomalous pathologies
5. Discussion of candidate events in XENON10 58.6 Live-Day Result



XENON10 Installation at LNGS

3100 m.w.e. / 20 cm HDPE / 20 cm Pb

XENON10 Detector



J. Angle (UFL)

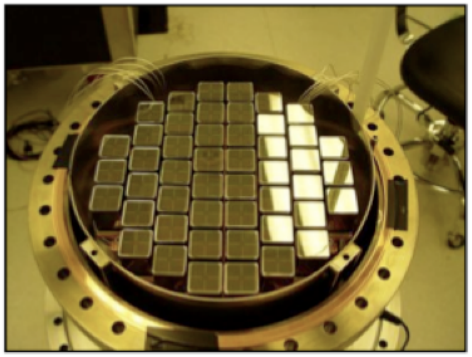
15 cm drift (z) defined by SS mesh grids
20 cm ∅ defined by Teflon Can

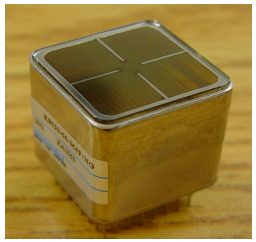
(max 13.5 kg LXe)

89 Hamamatsu R8520-AL PMTs (1" square)
48 Top Array
41 Bottom Array

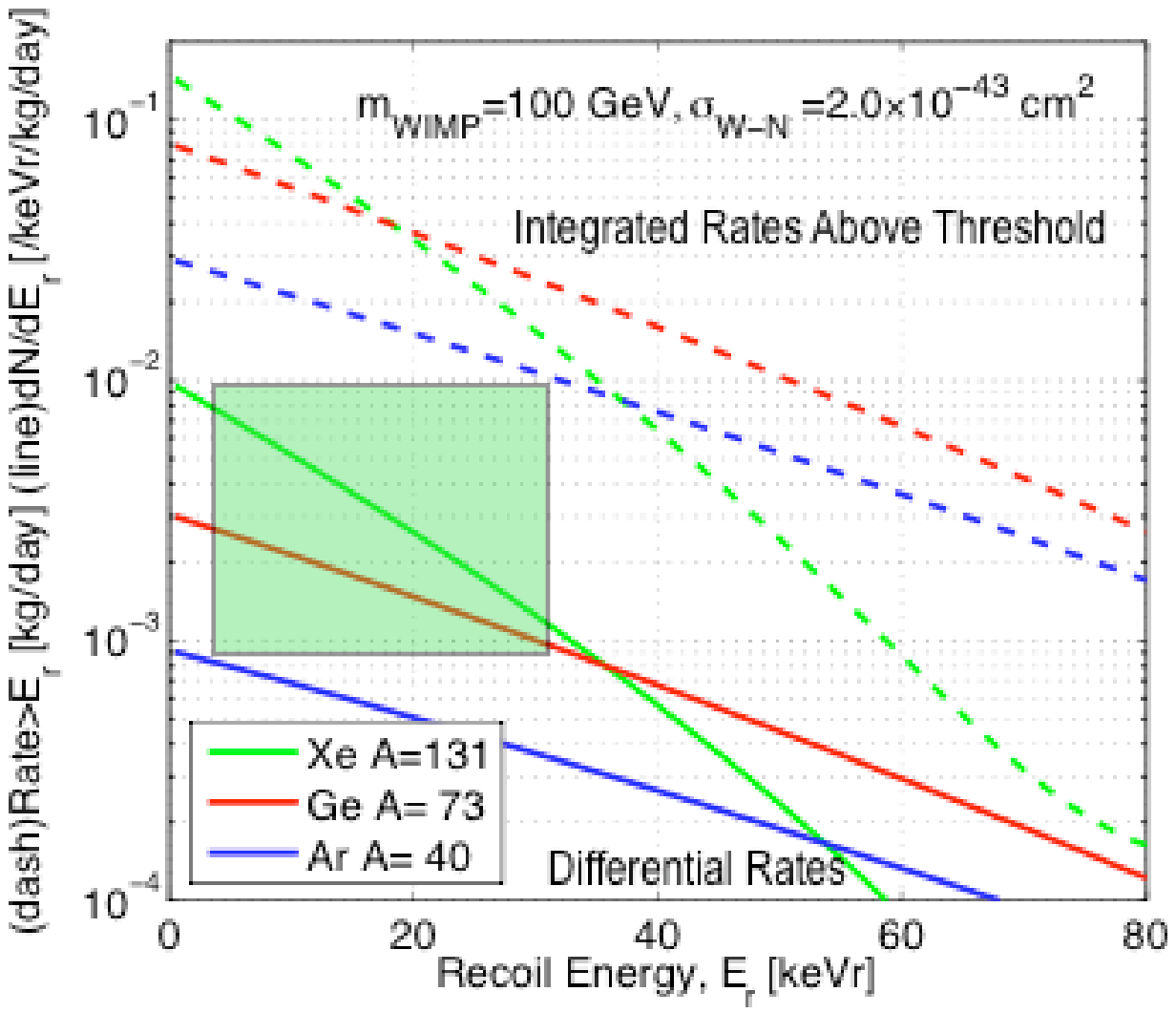
Liquid Xe maintained at
T=180 K and p=2.2 atm.

12 kV cathode
E_d = 0.73 kV/cm (drift)
E_{gas} = ~ 9 kV/cm (S2)

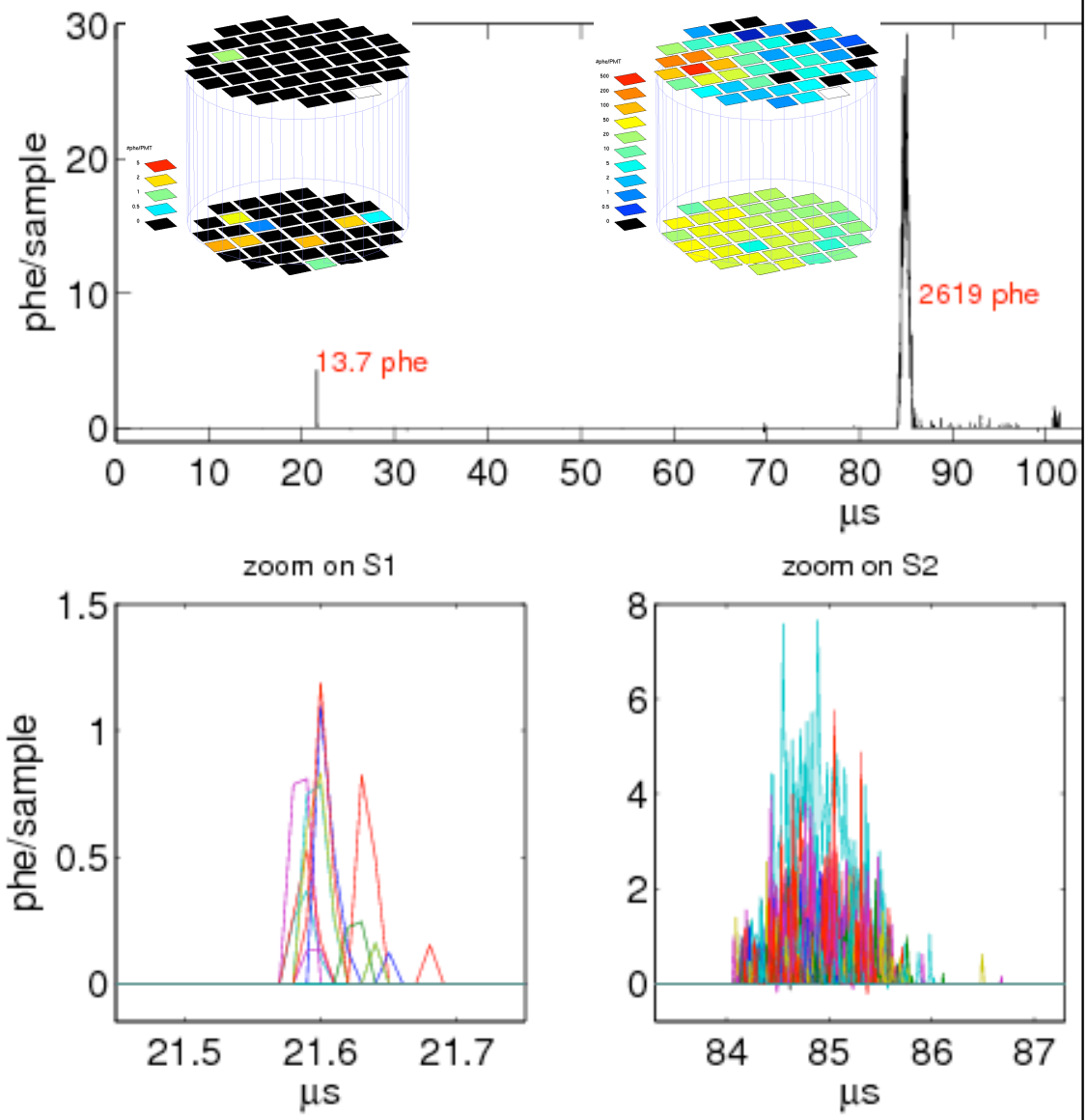




Direct Detection Event Rate



Typical Background Event at 4.5 keVee *



S1: primary scintillation

S2: ionization drifted, extracted, amplified in gas region (secondary scintillation)

Background Discrimination:
$(S2/S1)_{ER} > (S2/S1)_{NR}$

x,y coords. : from S2 Hit-Pattern

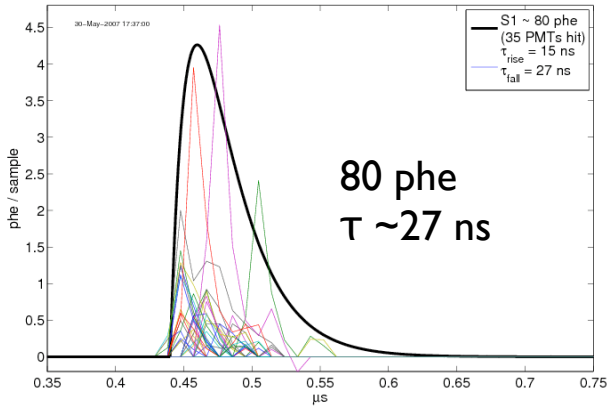
z coord. : from drift time Δt between S2 and S1

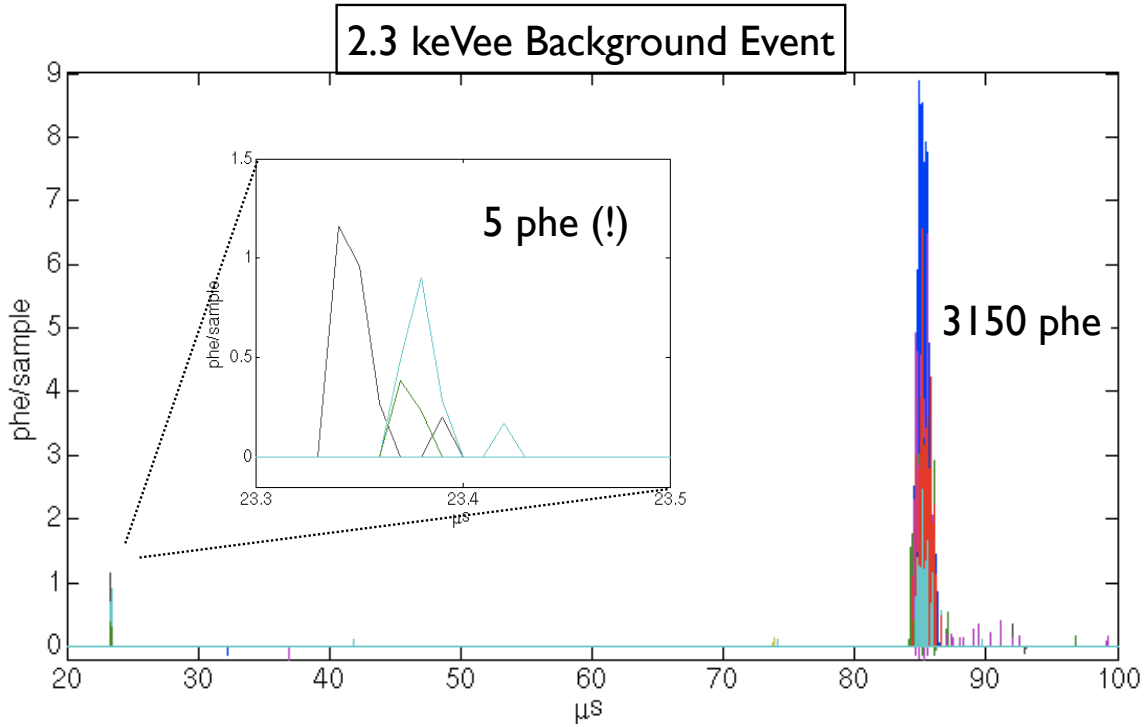
*(scaled using 3.0 phe/keVee from 122 keV gamma cal.)

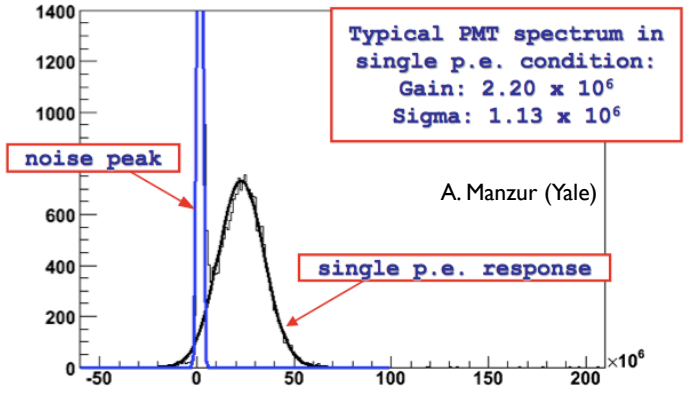
Trigger Schemes

1. S1 Trigger:
   (1) n-fold coincidence in 80ns window
   (2) 80% single photo-electron acceptance
   (3) 80% light on bottom (trigger) PMTs

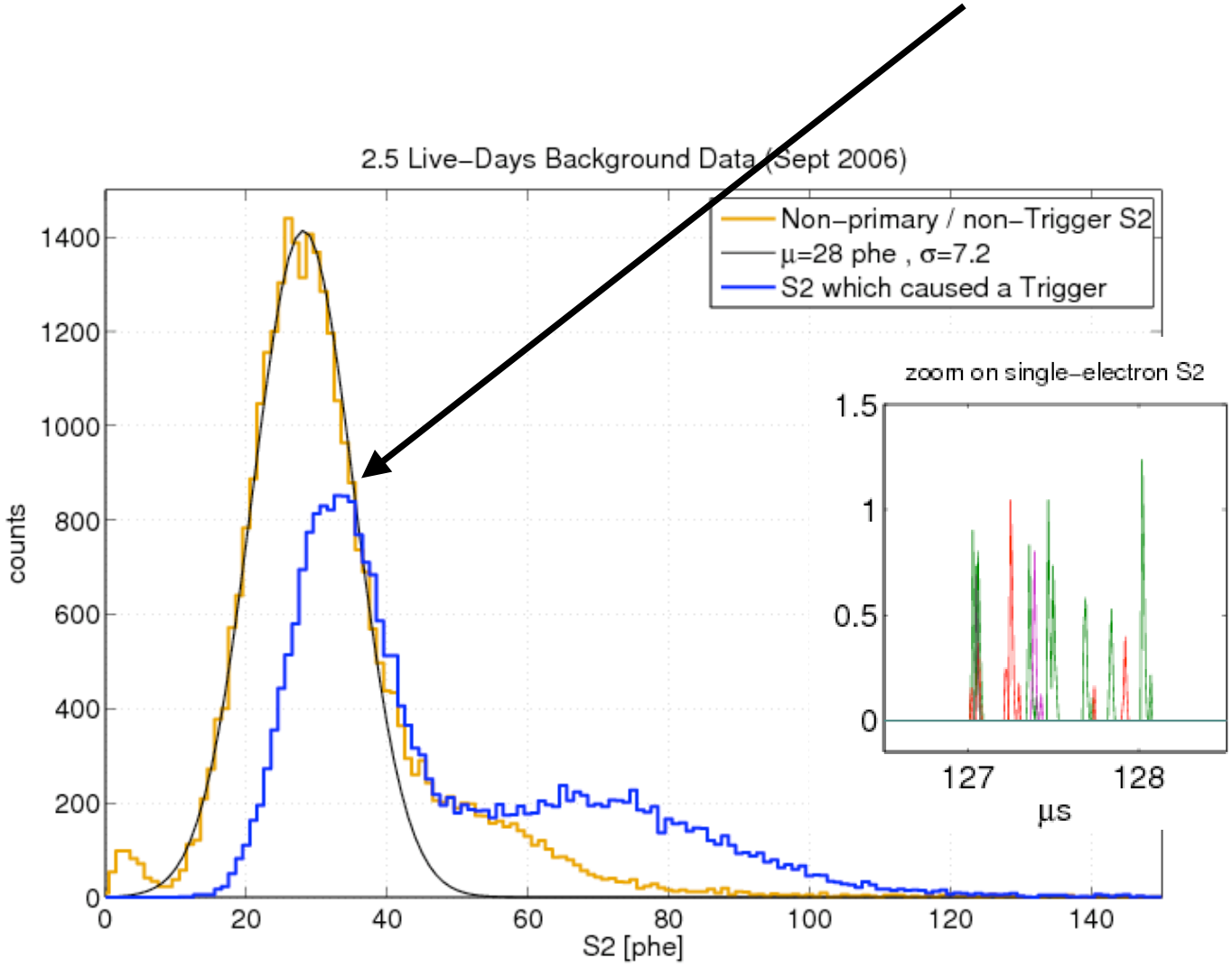
2. S2 Trigger:
   (1) Σ(34 top-center PMTs)
   (2) integrate with τ = 1 μs
   (3) threshold discriminator
   → (Final Trigger Solution)







S2 Trigger Threshold: single electron (!)



Typical S2 at threshold:

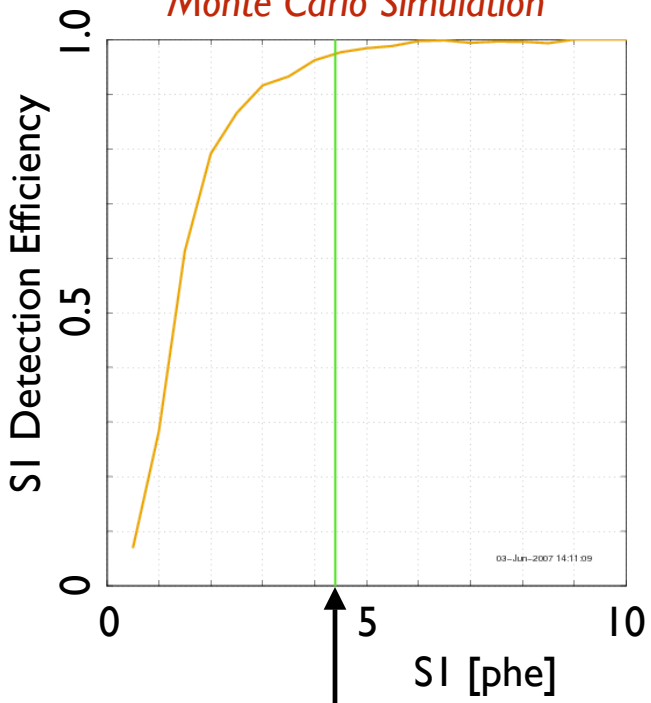
ER (2 keVee):
2800 phe **(~100 e-)**
NR(4.5 keVr):
1100 phe **(~40 e-)**

Smallest NR S2 at 4.5 keVr threshold:
300 phe **(~12 e-)**

Non-primary S2 => found in event waveform, not necessarily correlated with event energy deposition
Rate ~ 0.17 Hz

Analysis Threshold >> Trigger Threshold

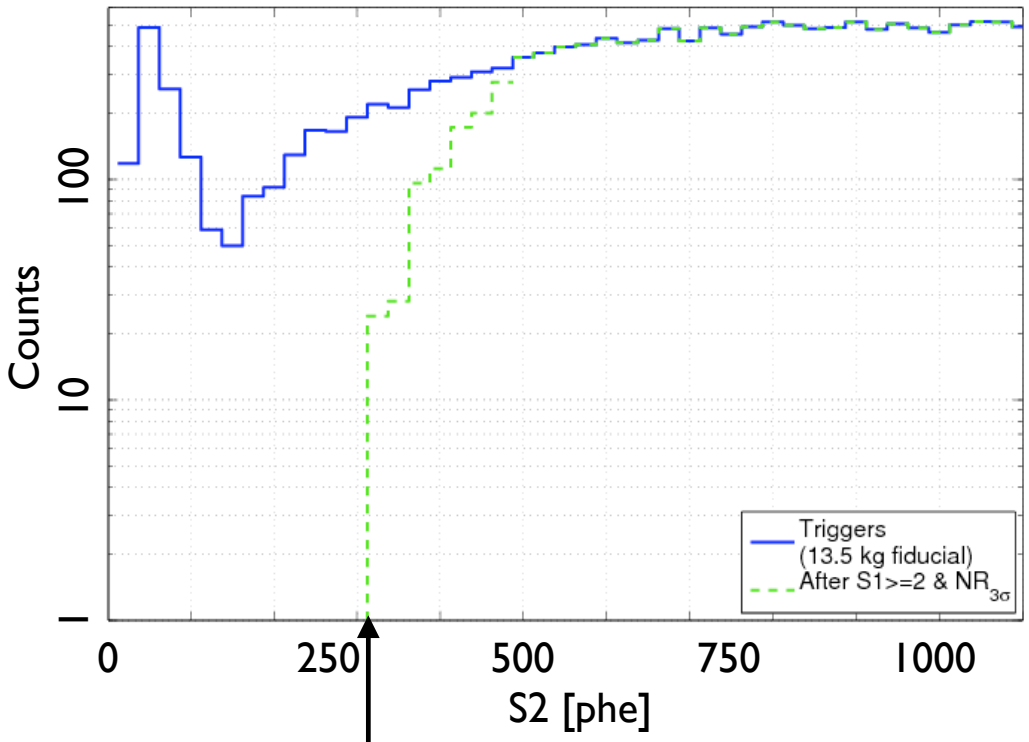
Monte Carlo Simulation



S1-lookback efficiency (n ≥ 2) from MC :

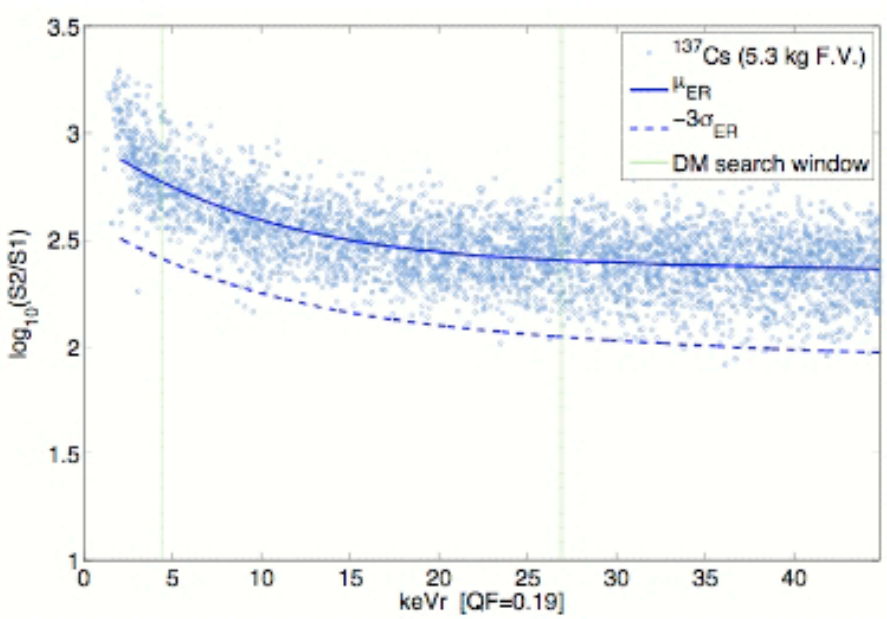
~ 99% at 4.5 keVr

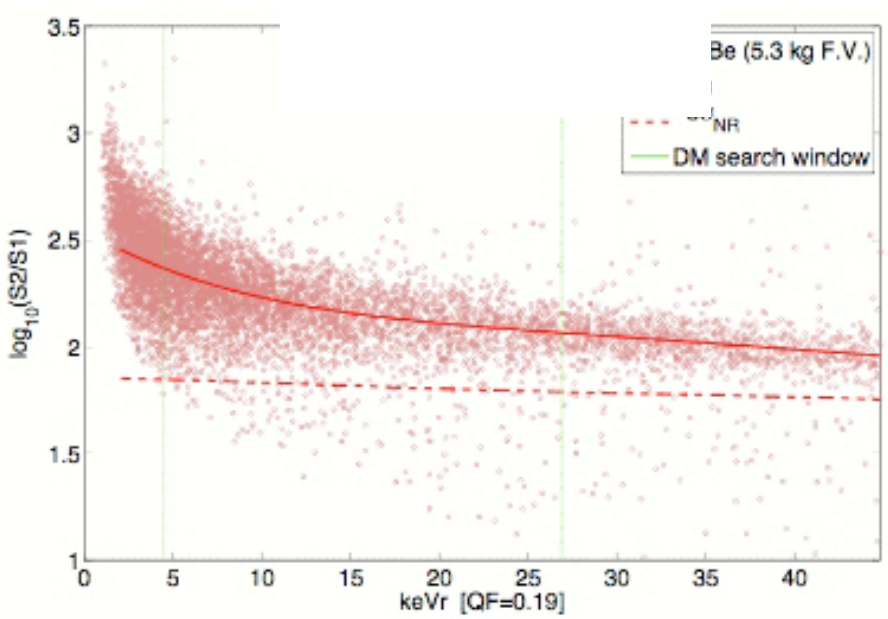
AmBe Calibration Data



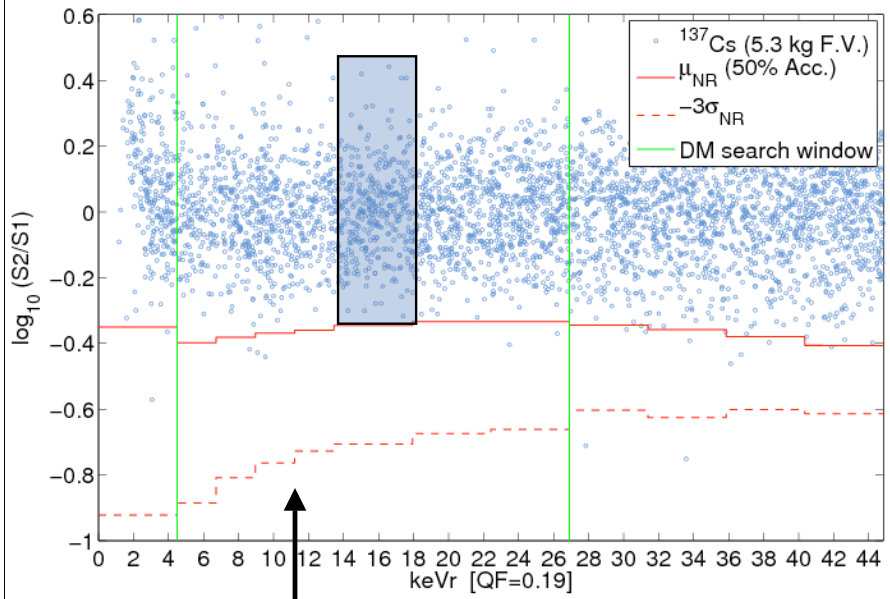
Effective S2 ***analysis*** threshold ~300 phe (12 e-) set by S1 coincidence req. (n ≥ 2) and NR -3σ contour

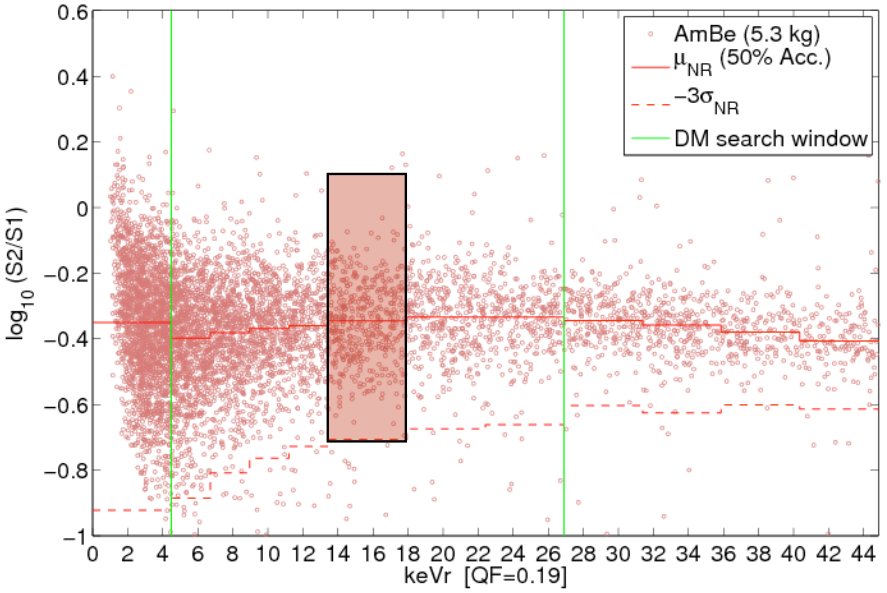
Calibration Data Band Centroid / -3σ





For DM-Search Analysis



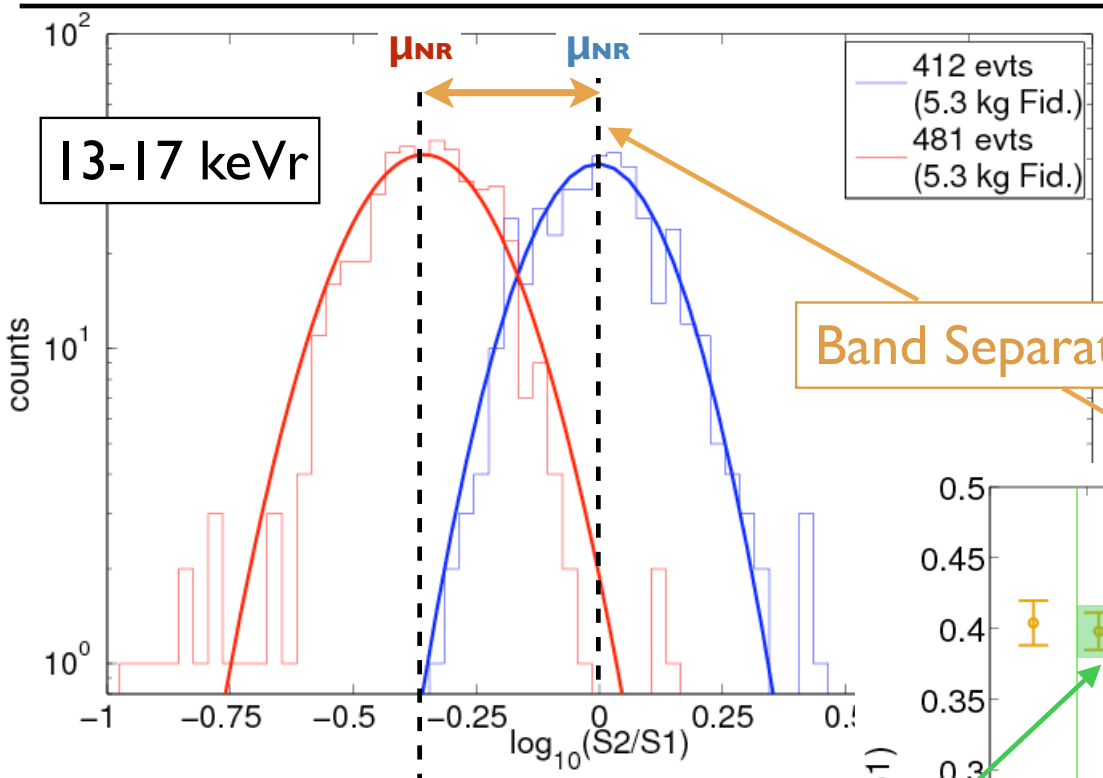


because Ionization yield rises at lower energy

Make a simple coordinate transform (based on μ_{ER})
to remove energy-dependence

DM-Search acceptance box in discrete bins

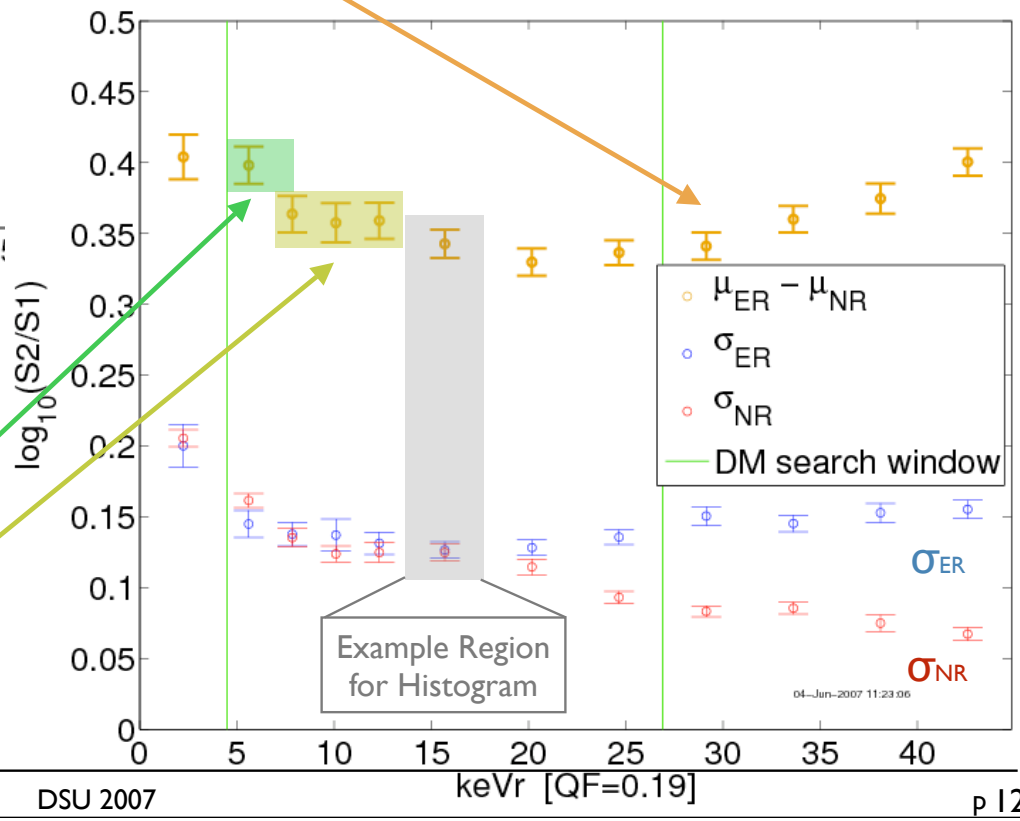
Discrimination Parameter appears Gaussian



Band Separation

NR v ER Band Separation
Improves at low E...

but still need to
minimize sigma
to
maximize
discrimination



50% acceptance for Nuclear Recoils

99.9% discrimination

> 99.5% discrimination

(discrimination calculated from Gaussian fit params.)

Corrections to data improve sigma

±20% variation in S2 across x-y

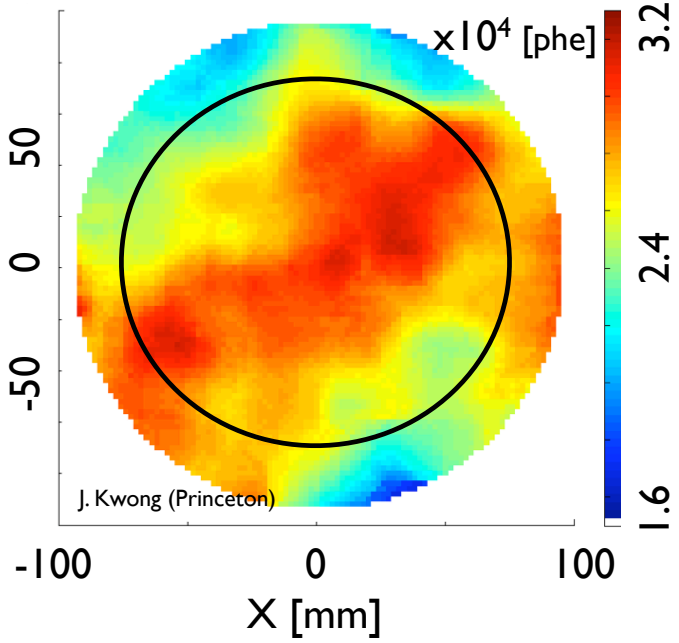
(± 25% in Full Volume)

± 10-15% variation in Relative Sensitivity

± 22% variation in S1 across z

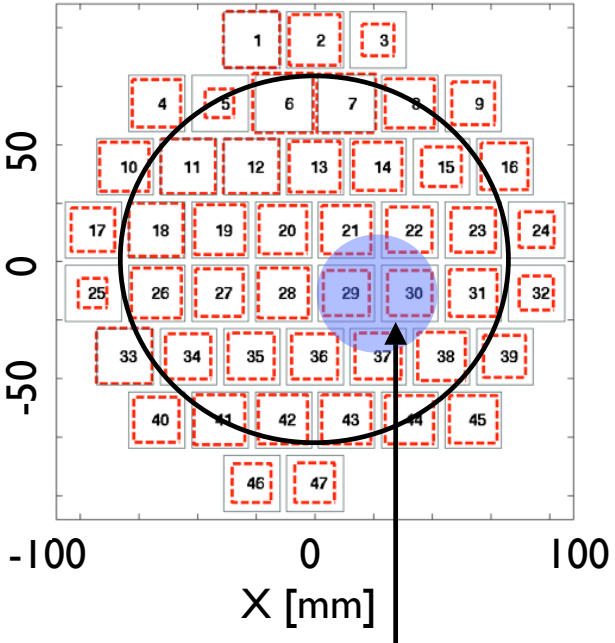
(± 28% in Full Volume)

S2 Variation: 40 keV line

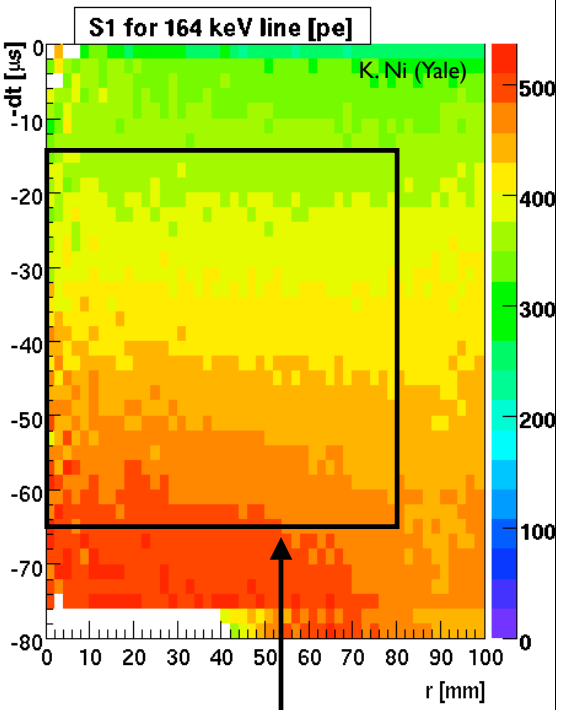


< 2% variation in S2 with z (electron lifetime > 2ms)

Top PMT Array Relative Sensitivity

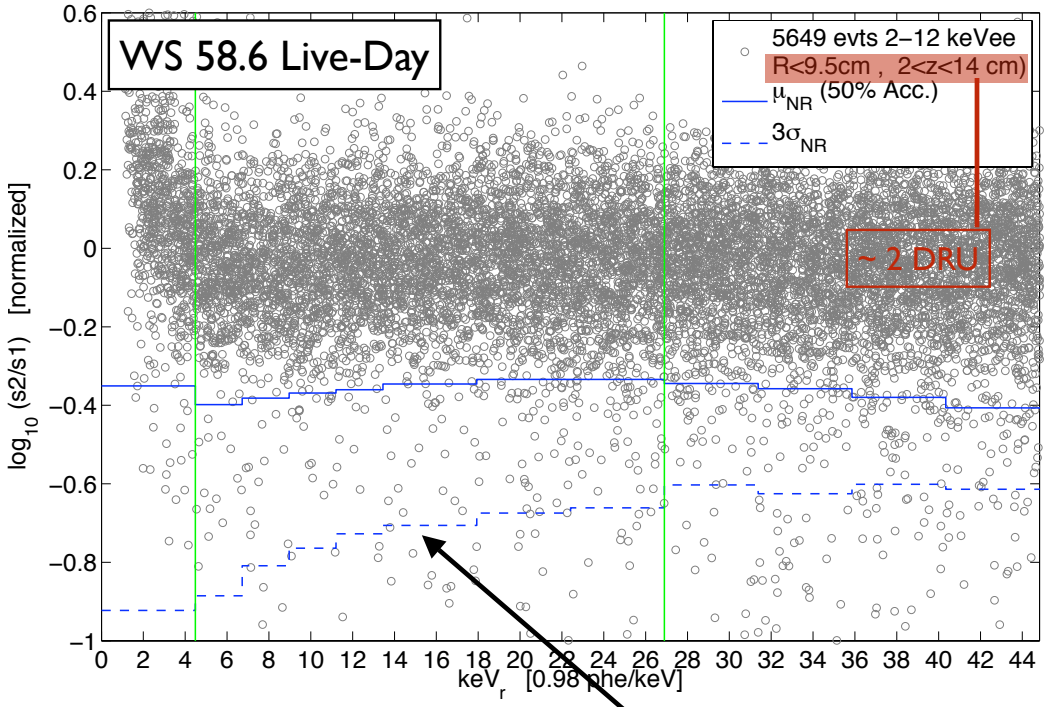


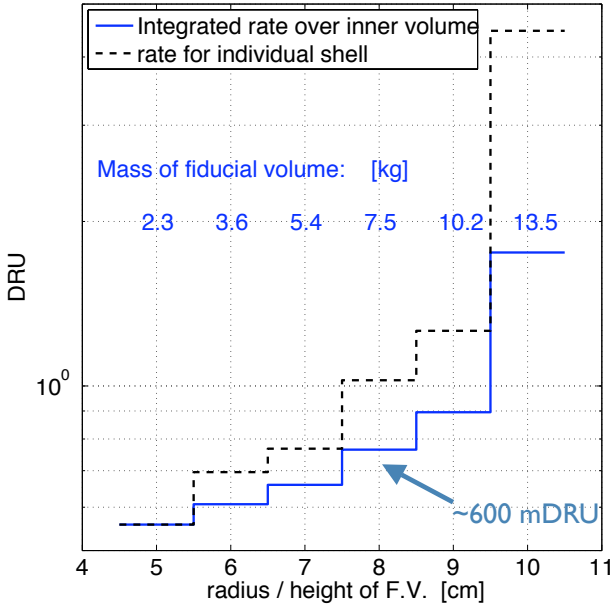
R.S. map obtained by comparing S1 signal in each nearest-neighbor pair, then diagonalizing the matrix



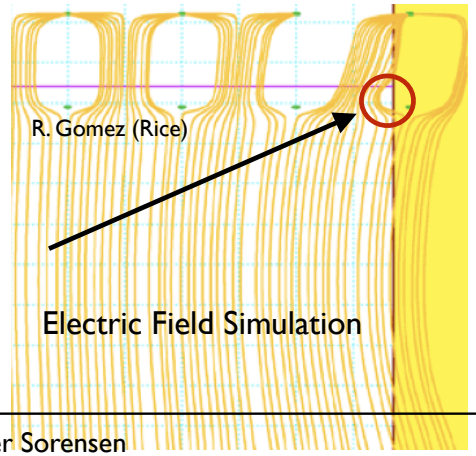
Fiducial Volume

Before Fiducial Volume Cuts

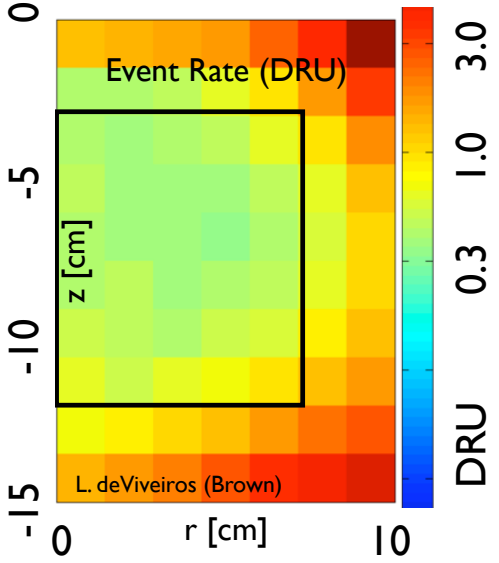




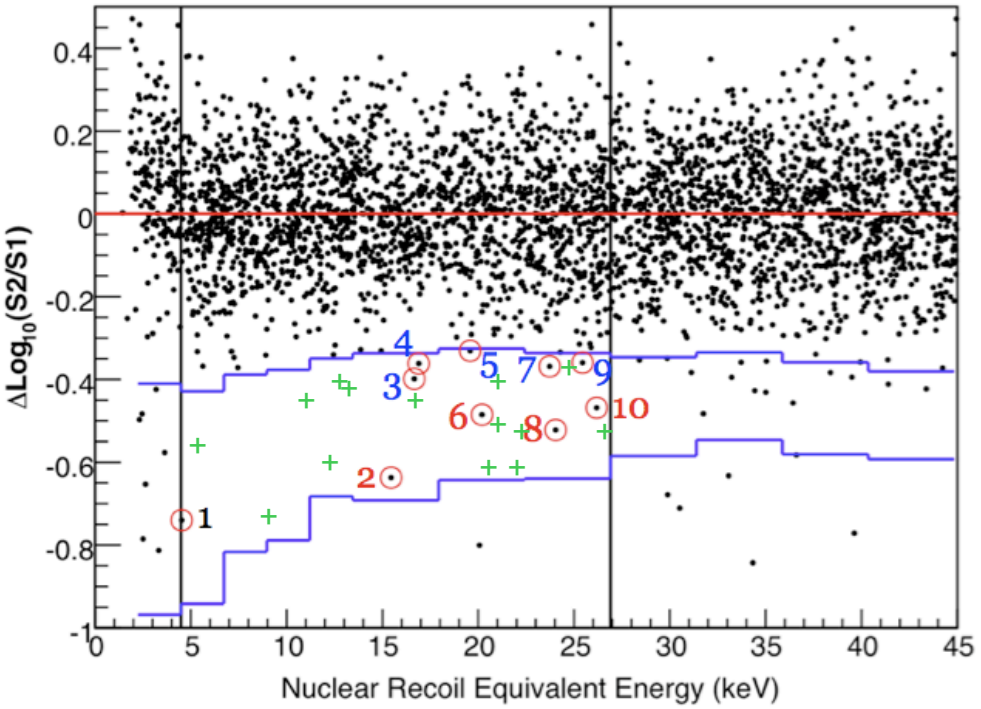
DRU = 1 cts/keVee/kg/day



Most (spurious) events in box are removed by Fiducial Volume Cuts



After Fiducial Volume Cuts



+ Removed by primary analysis Gamma X cuts

O Remaining after all primary cuts

still have 23 events (a significant fraction appear non-Gaussian).

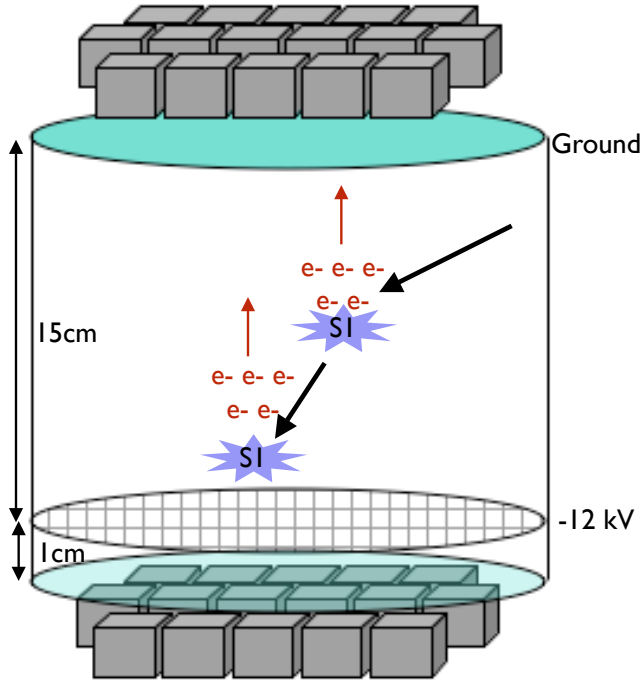
13 events (+) removed by (primary analysis) cut targeted at anomalous S1 hit-pattern

origin of non-Gaussian tails in ER distribution:
Gamma X events

Gamma X: what is it?

a multiple scatter in which the S2 from one of the scatters is absent

normal multiple scatter



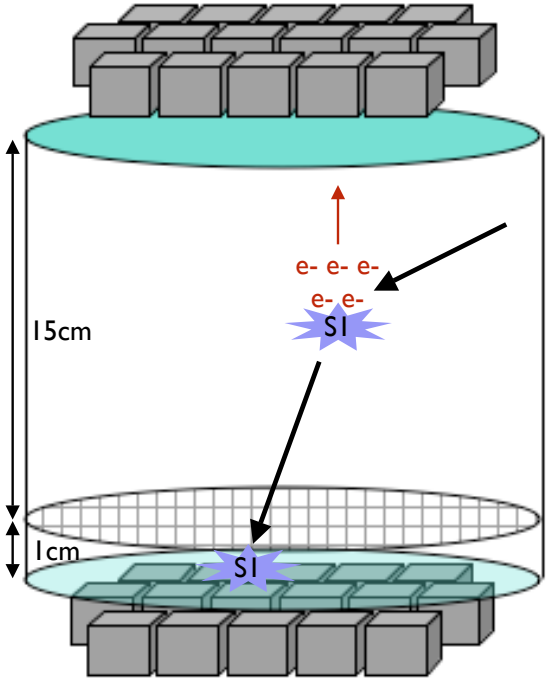
Example:

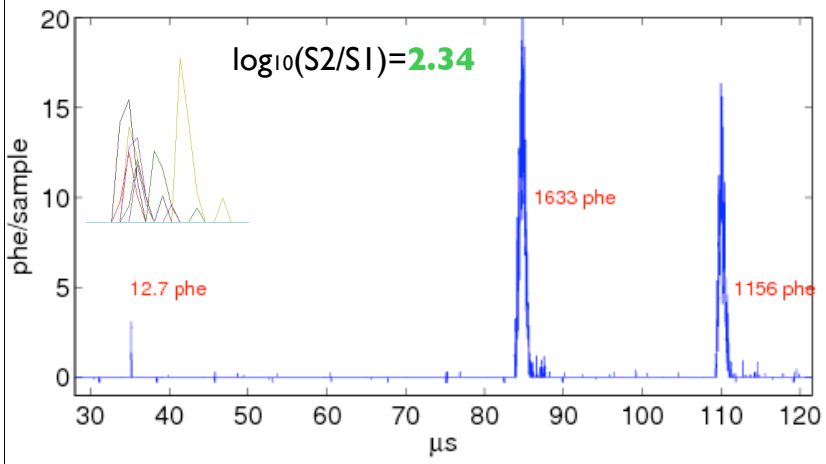
if the 2nd scatter happened **below** the cathode grid, its S2 would be **absent.**

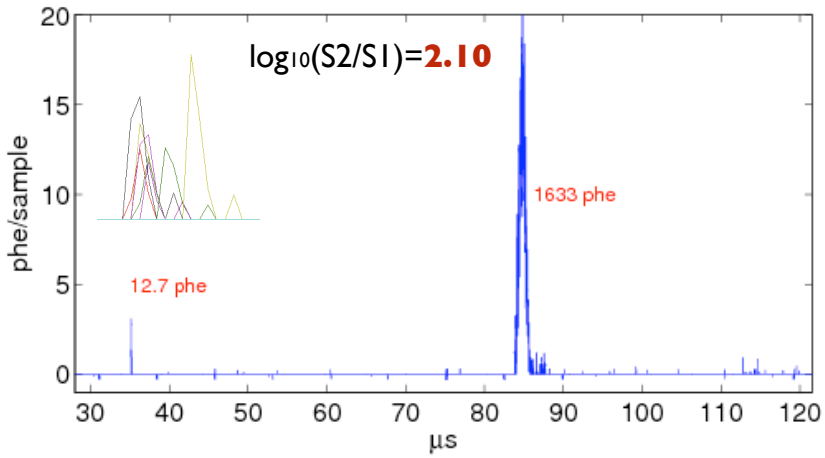
Result:

S2/S1 **decreases**, which can make an electron recoil look like a nuclear recoil

Gamma X multiple scatter

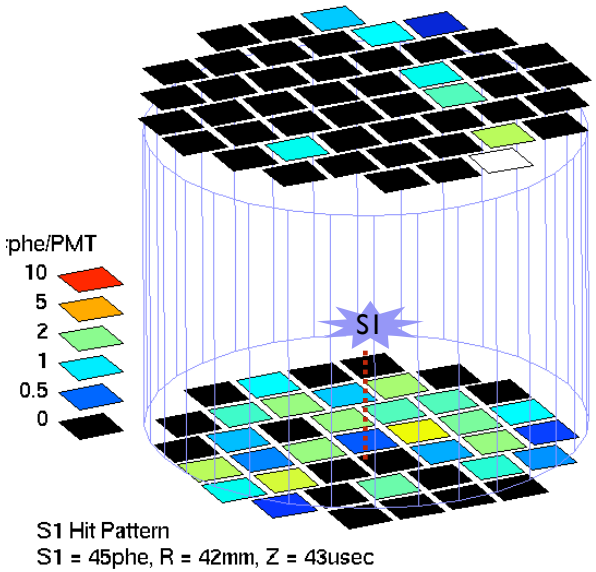




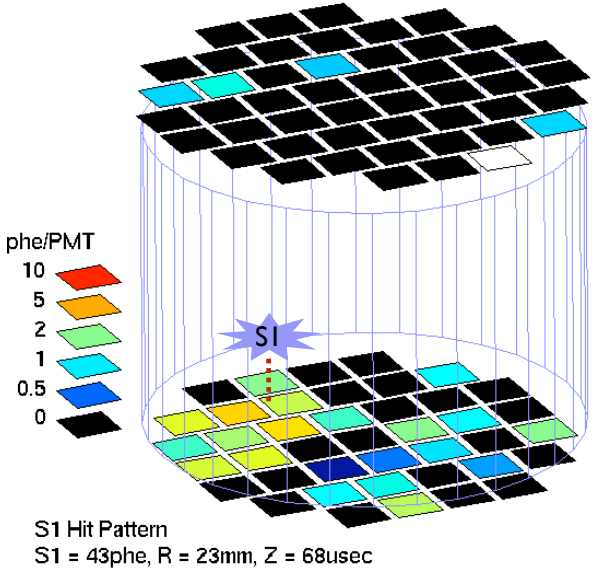


How to spot a Gamma X Event: S1 Hit-Pattern

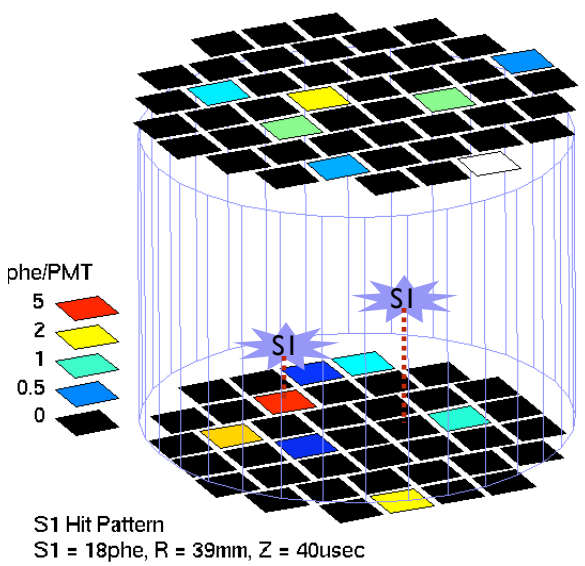
Scatter in center of FV



Scatter close to bottom of FV



Gamma X scatter



Events in Fiducial Volume => diffuse Hit Pattern

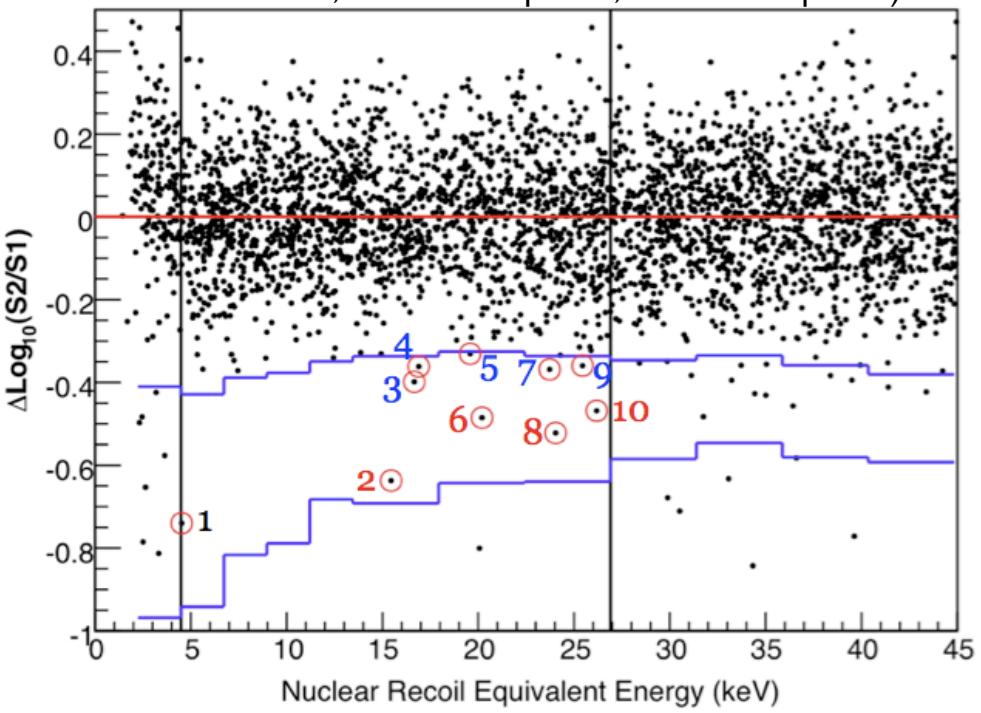
Events near bottom => more localized Hit Pattern

Events below cathode => highly localized Hit in ~ 1,2 PMTs

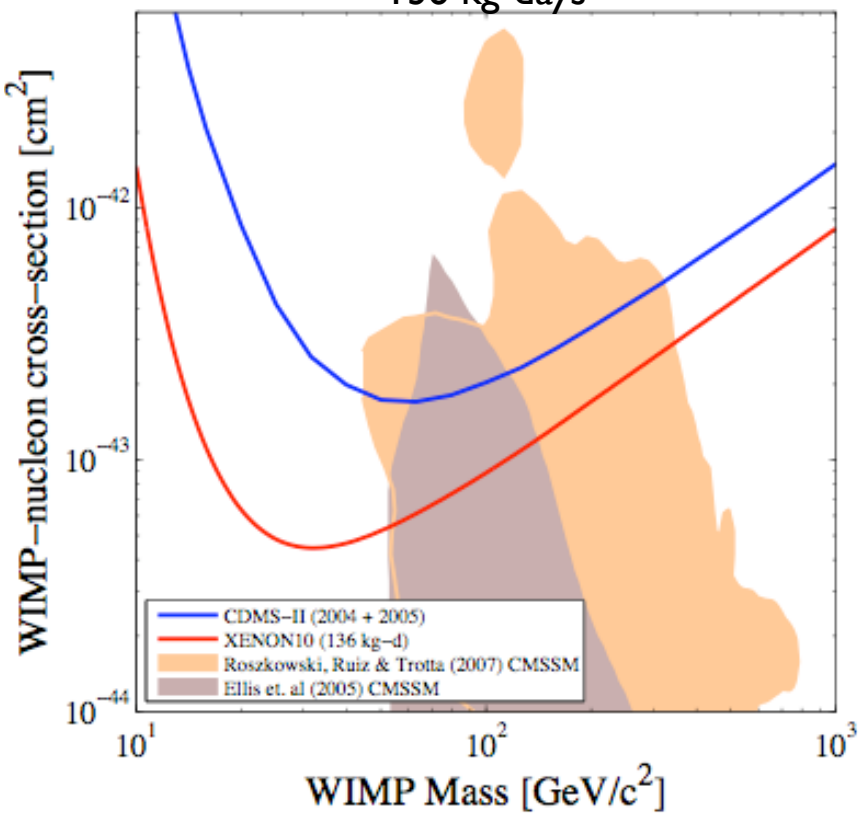
Primary Analysis Gamma X cut: $S1_{RMS} = \sqrt{\frac{1}{n}\sum(S1_i - \overline{S1})^2}$

XENON10 58.6 Live-Day Result

10 Events in box (Yellin Maximal Gap, no BG subtraction, 50% NR acceptance, 86% cut acceptance)



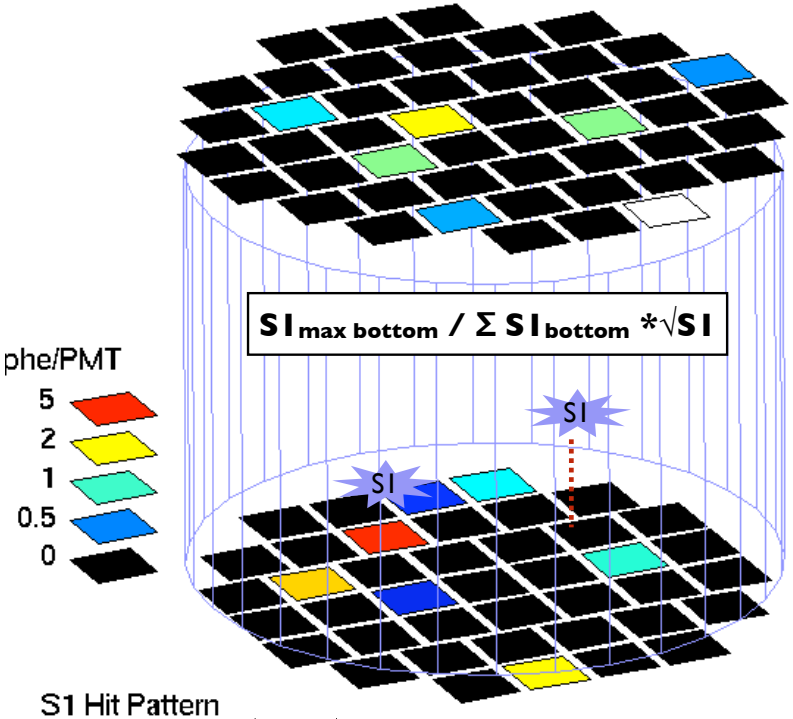
SI Cross-Section Exclusion Limit
136 kg-days



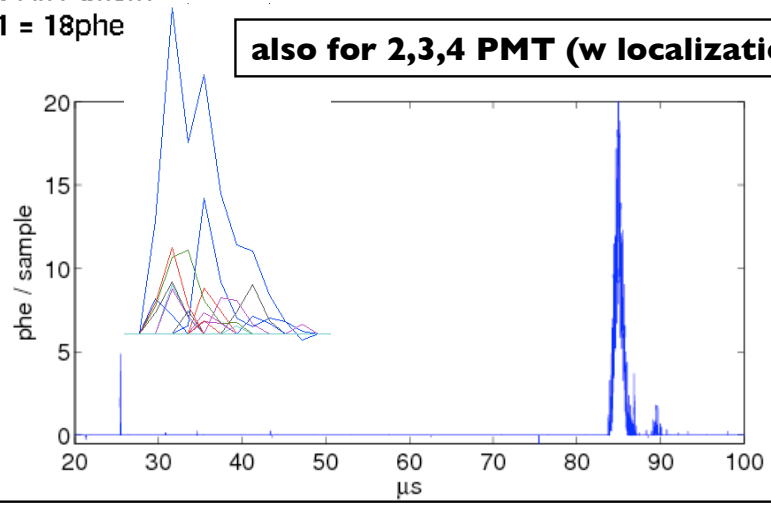
Events remaining in box are NOT dark matter... they are **Gamma X** events

A More Sophisticated Gamma X Cut

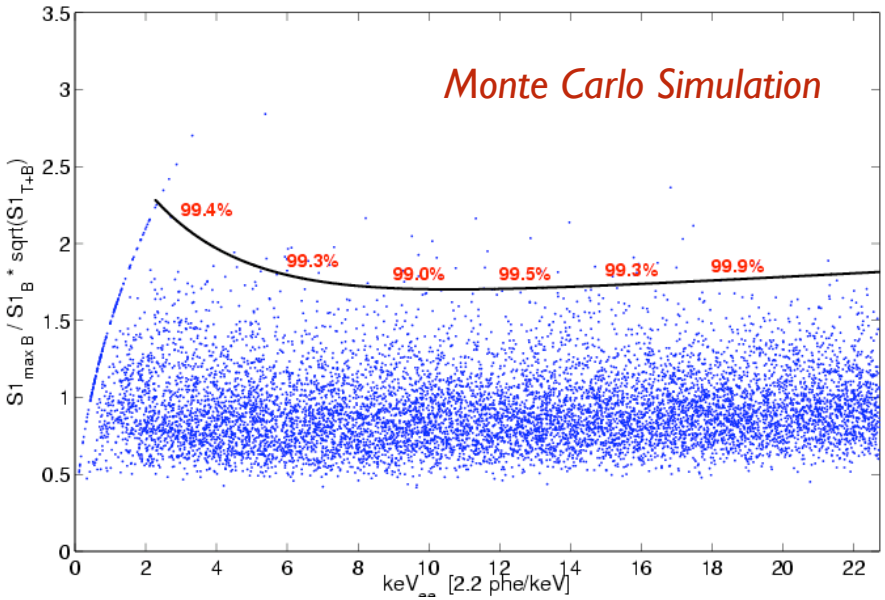
cuts developed as part of an independent (secondary) blind analysis

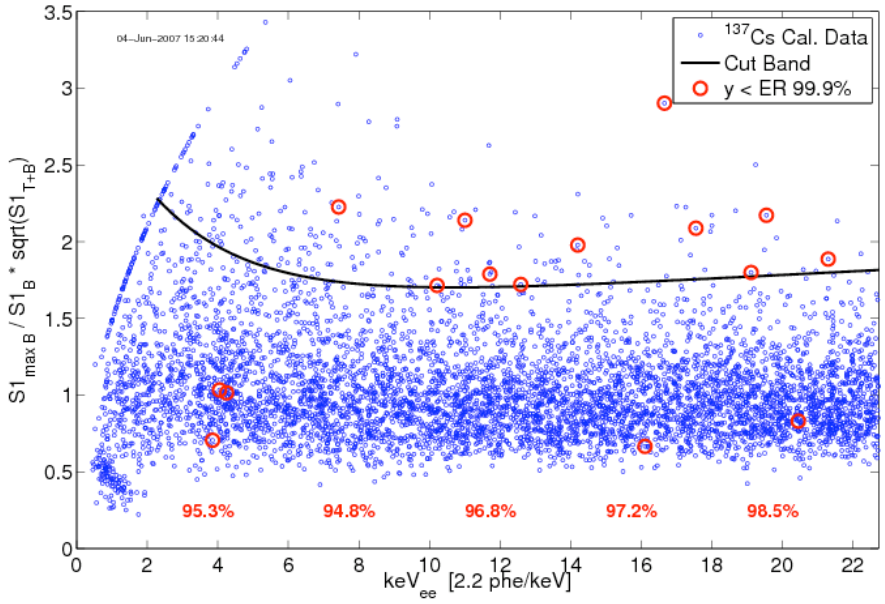


S1 Hit Pattern
S1 = 18phe



also for 2,3,4 PMT (w localization req.)

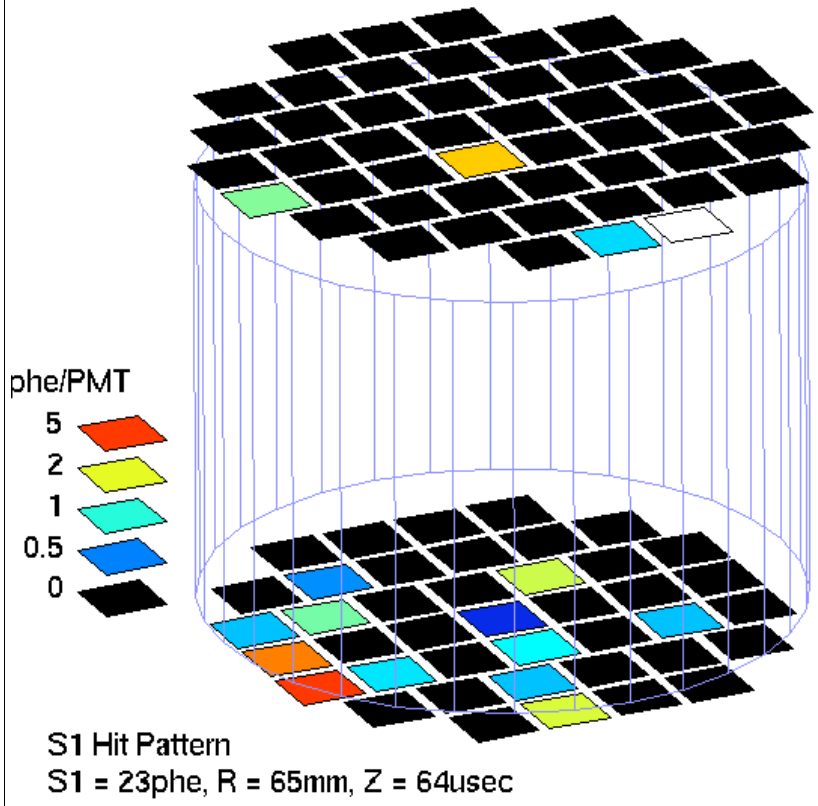


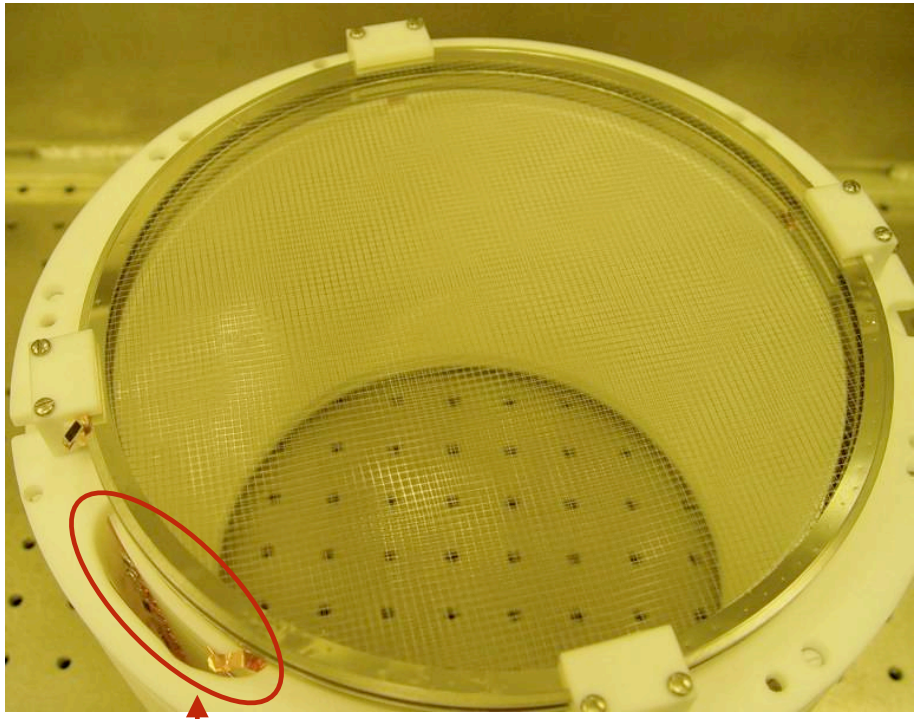


Identifying Anomalous Topologies

Subset of Gamma X events with signal concentrated in 2 PMTs: Resistor-Chain Events

Rare Effect: ~ 10 events in comined WS background data + Cs calibration data (175 Live-Days Equivalent)

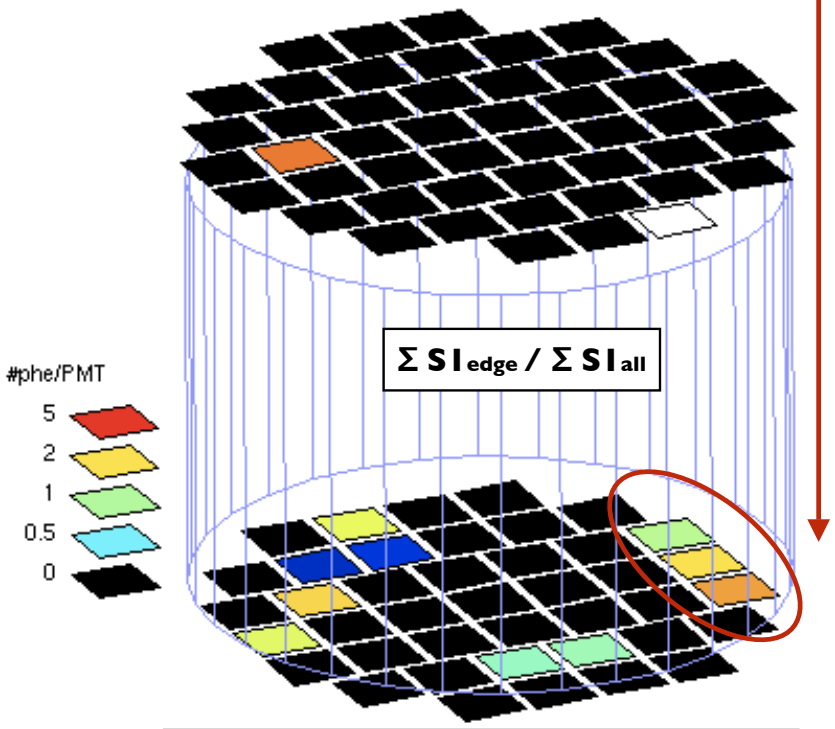




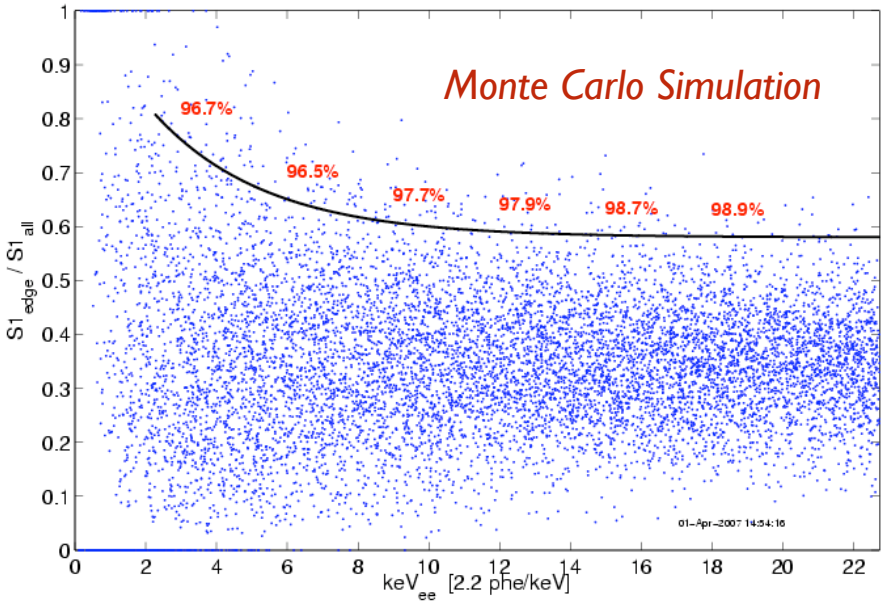
Resistor-Chain (for drift E-Field)
Pocket is filled with LXe

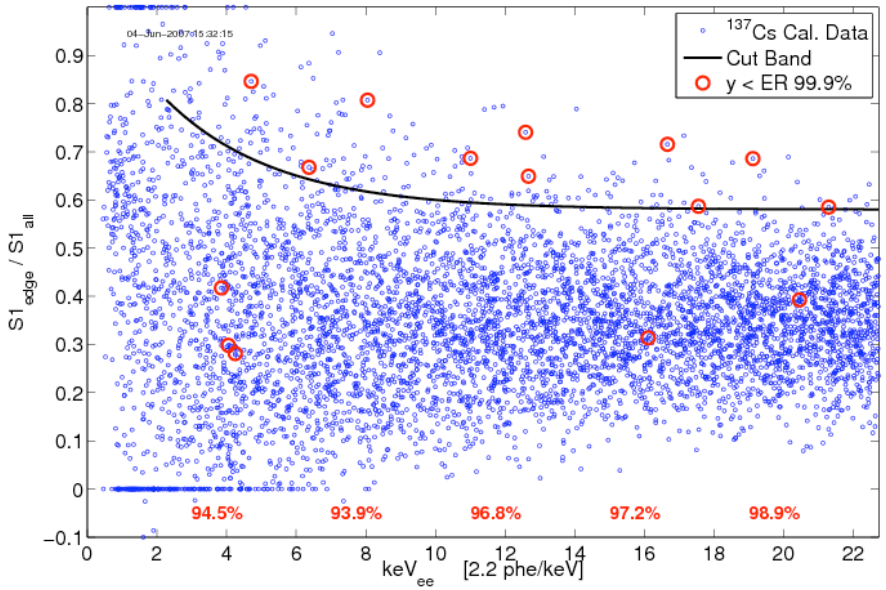
Edge Gamma X Events

Subset of Gamma X events with signal concentrated in **Edge** PMTs



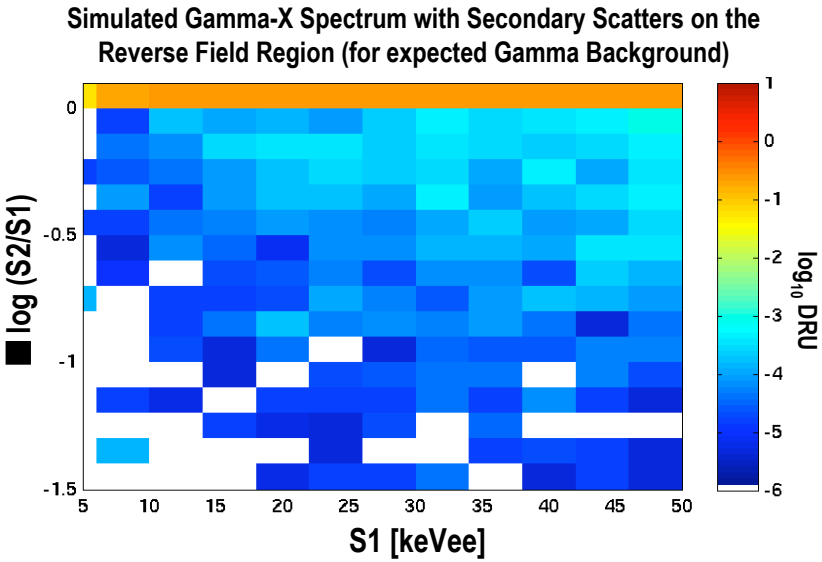
could indicate a 2nd scatter near edge of the detector, where there are regions of reduced/zero drift field

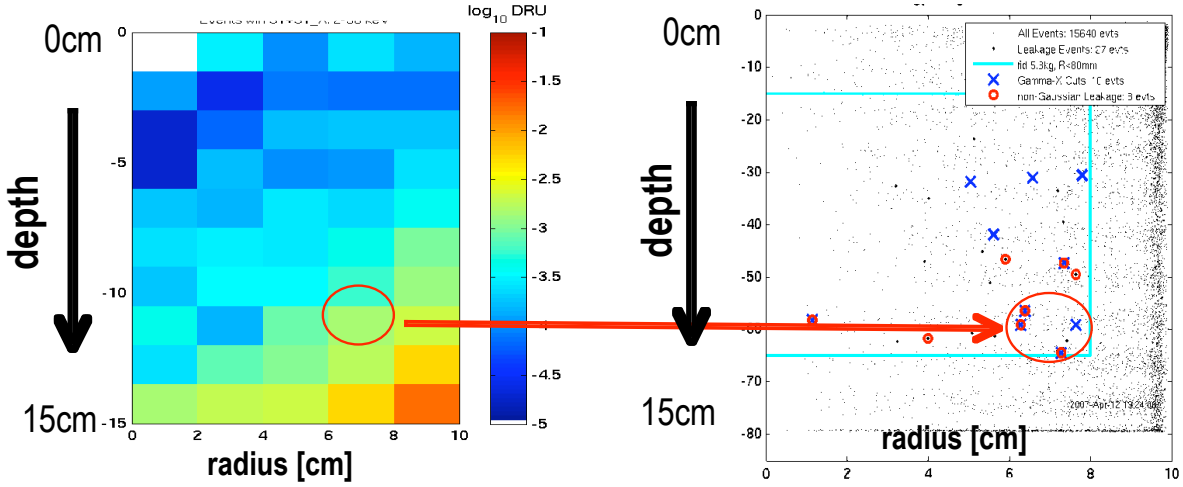




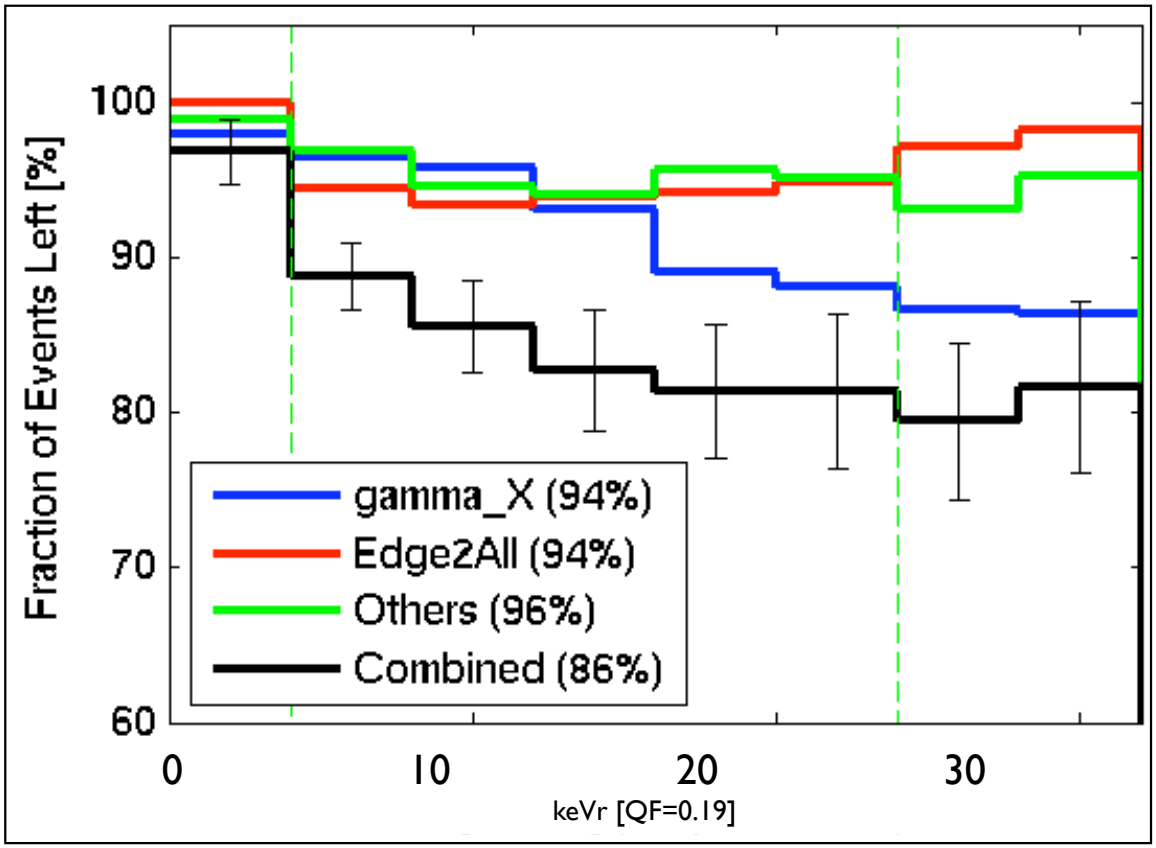
Gamma-X Monte Carlo

- We have simulated the expected Gamma-X background due to gammas generated in the detector (i.e. PMT radioactivity)
- We have found the rate for Reverse Field Region Gamma-X events to be sub-dominant for our ER vs NR discrimination – their rate at low energies (<25keV) is 1mdru or less.
- Comparing the spatial distribution of events
  - 10^{-3} DRU x 10keVee x 5.3kg x 59livedays = ~3 events



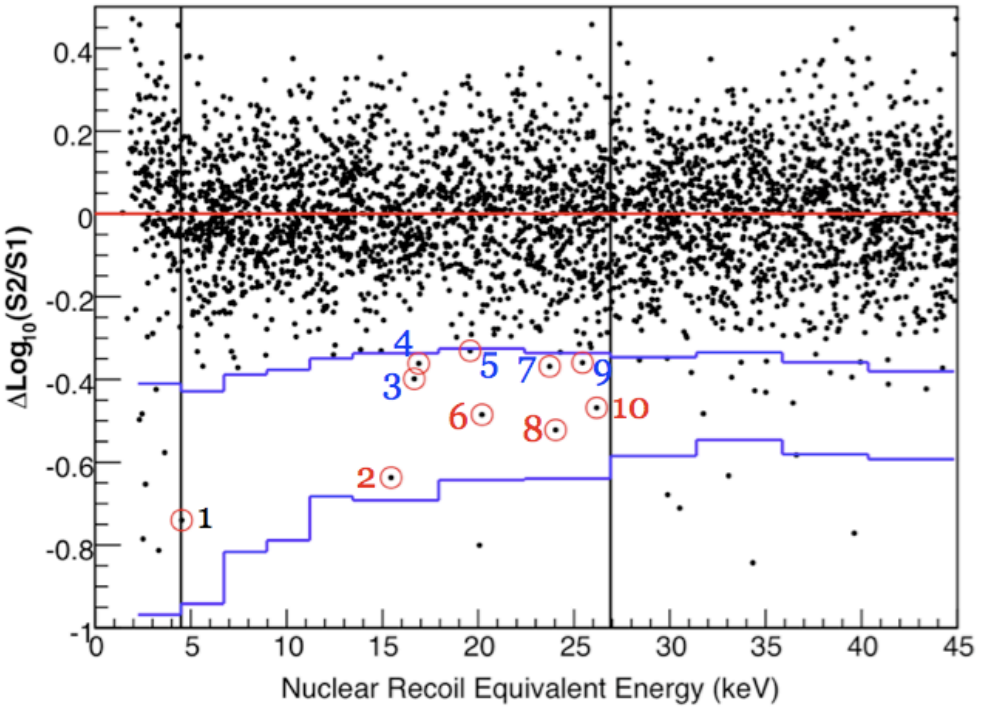


Cut Efficiencies for AmBe NR Calibration Data



Efficiency shown for secondary analysis (primary analysis is within 1%)

Summary



☞ 10 Events in box:

5 are consistent w Gaussian ER background
5 are NOT.

☞ events 1,6, 8,10 **removed** by Secondary (blind) Cuts:

#6: Gamma X (Resistor-Chain Hit-Pattern)
#8: Gamma X (Resistor-Chain Hit-Pattern)
#10: Gamma X (Anomalous Edge Hit-Pattern)
#1: Coincidence n=1 (Requirement: n=2)

☞ event 2 **almost** removed by Secondary (blind) Cuts:

Gamma X (signal concentrated in 3 PMTs)
a posteriori **1%** decrease in acceptance => would have been cut

<u>Discrimination challenges we can certainly overcome:</u>

☞ Maximize discrimination against Gaussian leakage by correcting for instrumental (detector) variation (x,y,z position / PMT)

☞ Non-Gaussian Pathologies seem to arise predominantly from "dead" regions of LXe

XENON10 Collaboration

Brown University Richard Gaitskell, Simon Fiorucci, Peter Sorensen and Luiz DeViveiros
Case Western Reserve University Tom Shutt, Paul Brusov, Eric Dahl, John Kwong and Alexander Bolozdynya
Coimbra University Jose Matias Lopes, Luis Coelho, Luis Fernandes and Joaquin Santos
Columbia University Elena Aprile, Karl-Ludwig Giboni, Maria Elena Monzani, Guillaume Plante, Roberto Santorelli and Masaki Yamashita
Lawrence Livermore National Laboratory Adam Bernstein, Chris Hagmann, Norm Madden and Celeste Winant
LNGS Francesco Arneodo and Alfredo Ferella
Rice University Uwe Oberlack, Roman Gomez, Christopher Olsen and Peter Shagin
RWTH Aachen University Laura Baudis, Jesse Angle, Joerg Orboeck, Aaron Manalaysay and Stephan Schulte
Yale University Daniel McKinsey, Louis Kastens, Angel Manzur and Kaixuan Ni