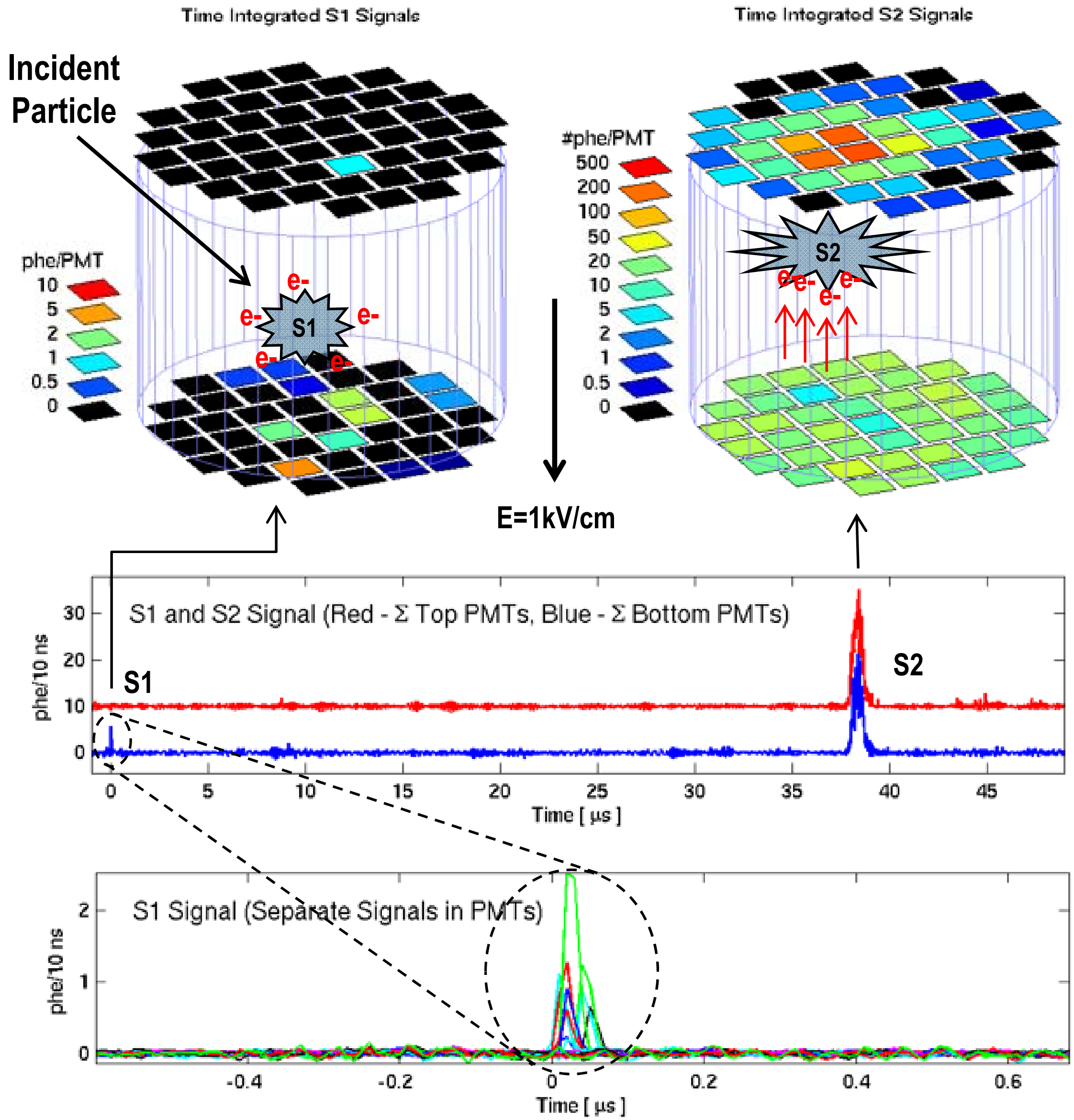
XENON10 Dark Matter Experiment

Optimization of Background Rejection in XENON10

Luiz de Viveiros
Brown University – Physics Department
(Supported by US DOE HEP)

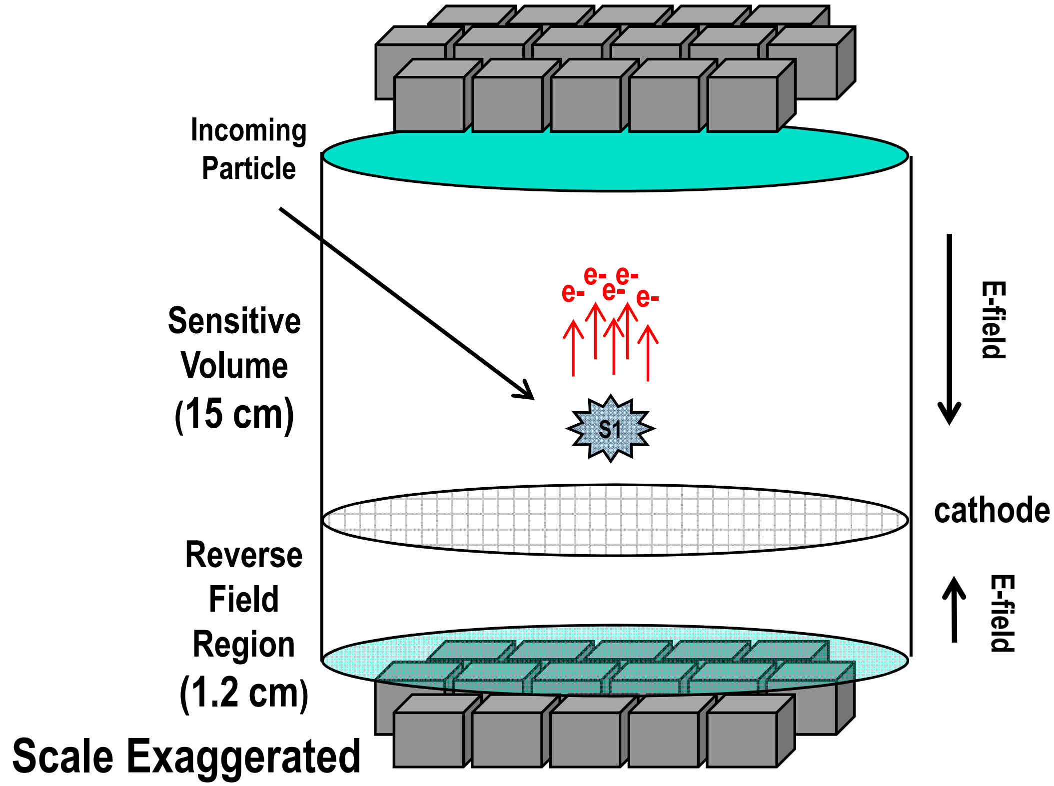
The XENON10 Signal

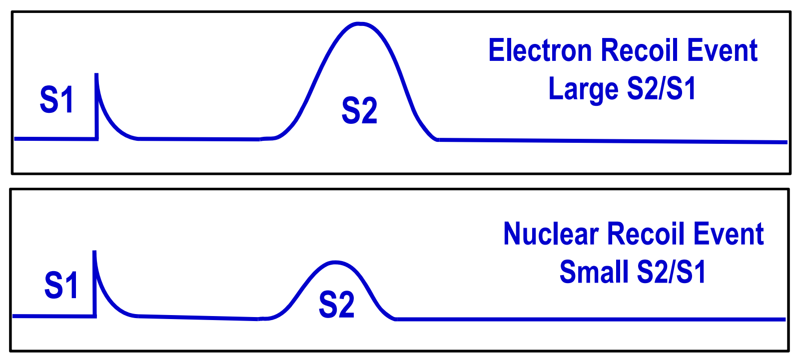
- **Typical Signal**
  - Primary Scintillation (S1) created by interaction in Lxe
    - Std Pattern - spread evenly
    - 20/80 top/bottom
  - Secondary Scintillation (S2) following Ionization: e- are extracted and accelerated in Xe gas
    - S2 signal Localized in XY - event position reconstructed from S2 Hit Pattern
    - Z-position proportional to drift time S2_time – S1_time
    - Maximum Drift Length = 15cm/80usec



Electron Recoils vs. Nuclear Recoils

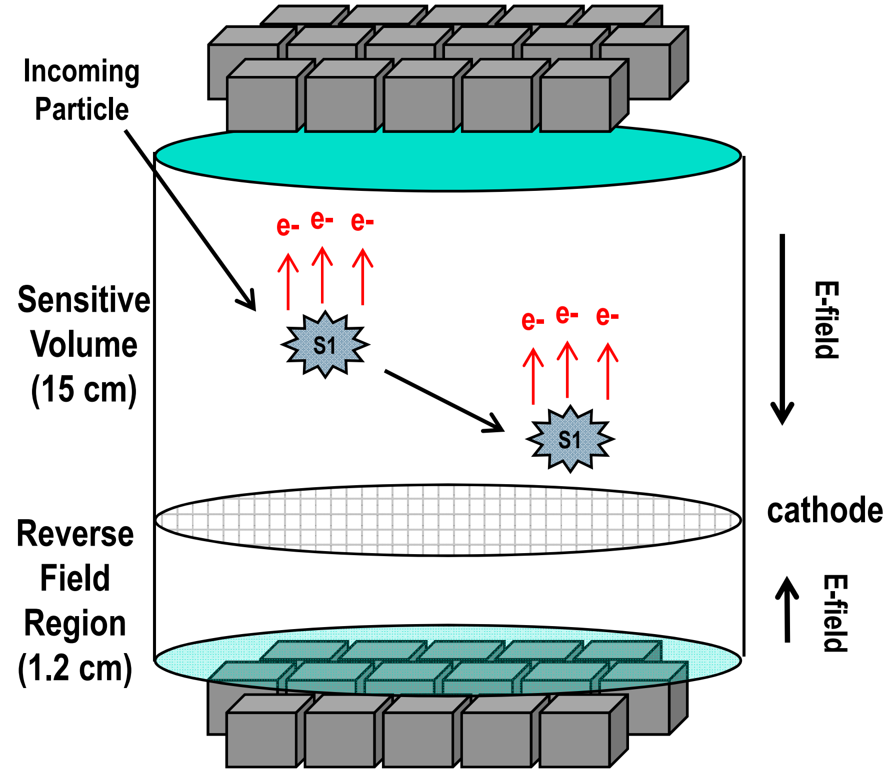
- **Discrimination**
  - Electron Recombination for Nuclear Recoils is larger
    - Light signal (S1) is preserved
    - Ionization signal (S2) is smaller
  - $(S2/S1)_{NR} < (S2/S1)_{ER}$
- **Reduction of Backgrounds => Reduction of low S2/S1 events ("leakage")**

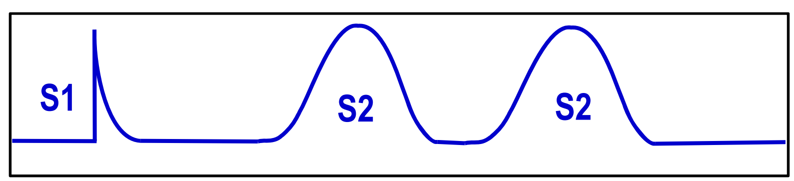




What Happens for Multiple Scatters?

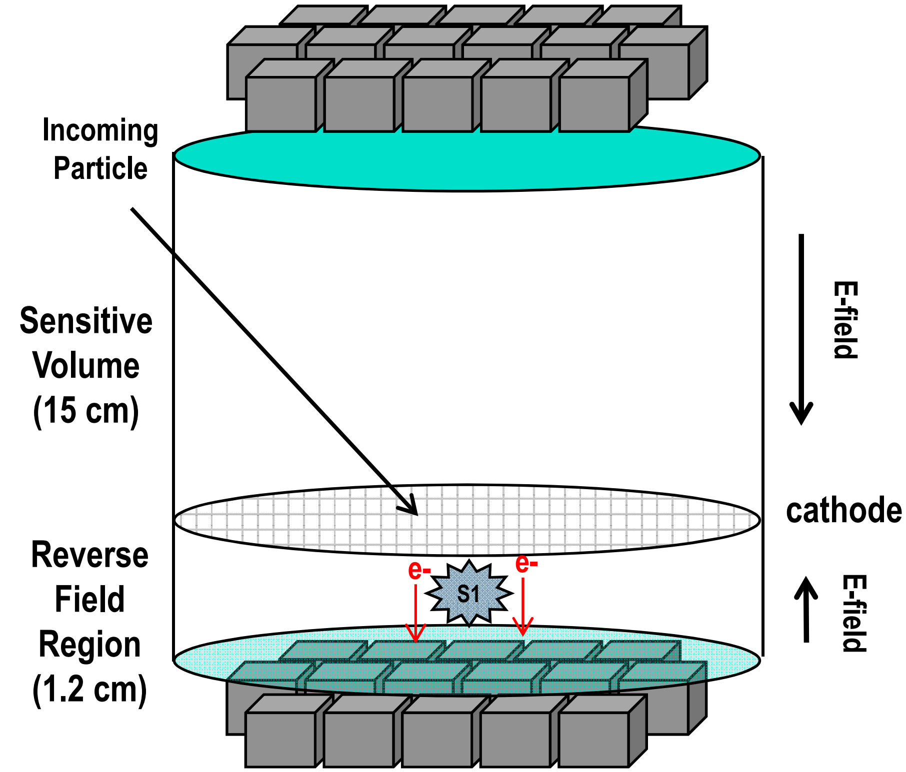
- WIMPs scatter are single scatter events
- Because of the resolution of the digitized signal (10nsec), S1 signals from multiple scatters are indistinguishable – S1 is the sum of the light from all scatters
- Multiple S2 pulses are evident in the trace
  - Z-separation ~ Drift Time separation





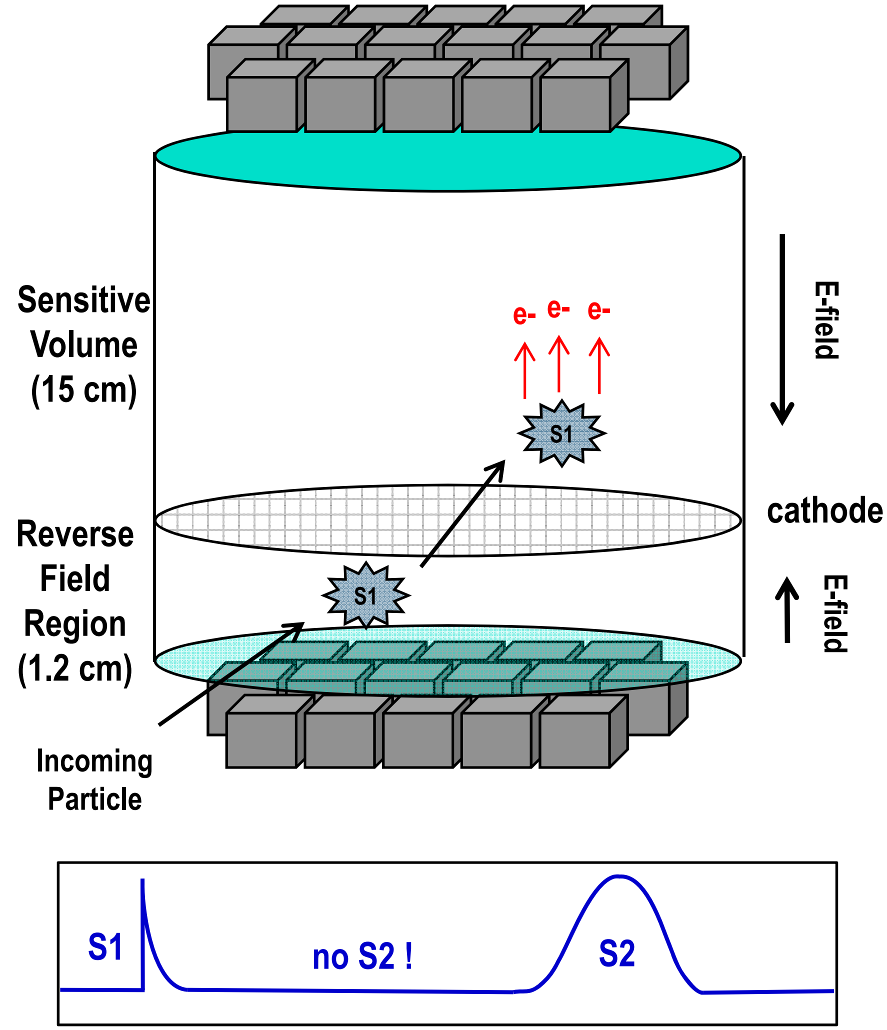
What Happens For Events Below Cathode?

- Cathode divides detector into **Sensitive Volume**, where we extract charge, and **Reverse Field Region**
- Scatters that happen below the cathode in the Reverse Field Region **produce S1 light but very little S2 signal**, due to poor charge collection of Electric Field configuration - *electrons is drifted downwards*



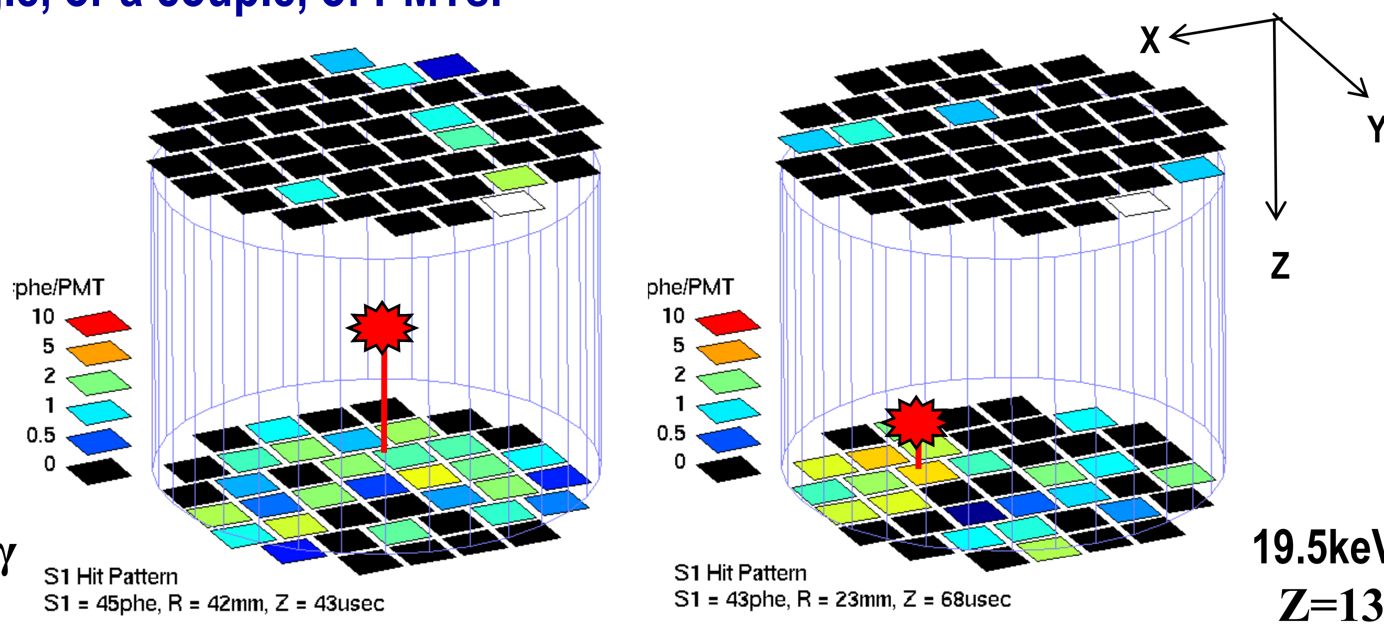
“Fake WIMPs” – Gamma-X Events

- Fake WIMPs can occur for Multiple Scatter events with 1 scatter in the Sensitive Volume, 1 scatter in the Reverse Field Region
  - Large S1 signal (Sensitive Volume S1 + RFR S1)
  - Small S2 signal (Sensitive Volume S2 only)
  - => low S2/S1
  - S2 position data only for scatters in the sensitive volume – no information about scatters in the Reverse Fiducial Region
- We call such events “Gamma-X”, because of the unknown component for scatters in Reverse Fiducial Region
- Electron vs. Nuclear Recoil Discrimination is very difficult for these events because of incomplete S2 information – these events might be a source of “leakage” (ER events might be identified as NR events).



S1 Hit Pattern - Variation with Z

- Internal Reflection: Asymmetry of the S1 light – 20% Top / 80% Bottom
- Localization of S1 signal for large Z (bottom of detector)
  - The hit pattern for events at the bottom of the detector tend to be more localized than events in the bulk, which have a more “spread out” hit pattern
  - Scatters very close to bottom PMT array (<1cm) tend to deposit most of their light in a single, or a couple, of PMTs.

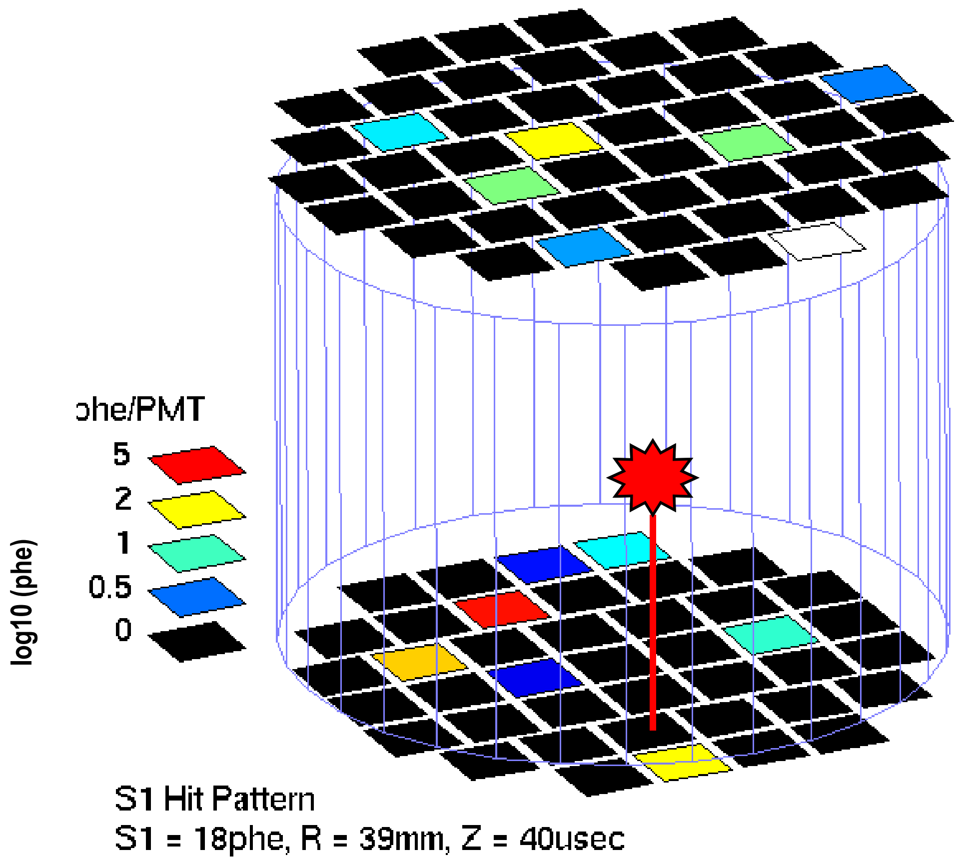


20.5keVee γ
Z = 8cm

19.5keVee γ
Z=13cm

Identifying Anomalous Topologies

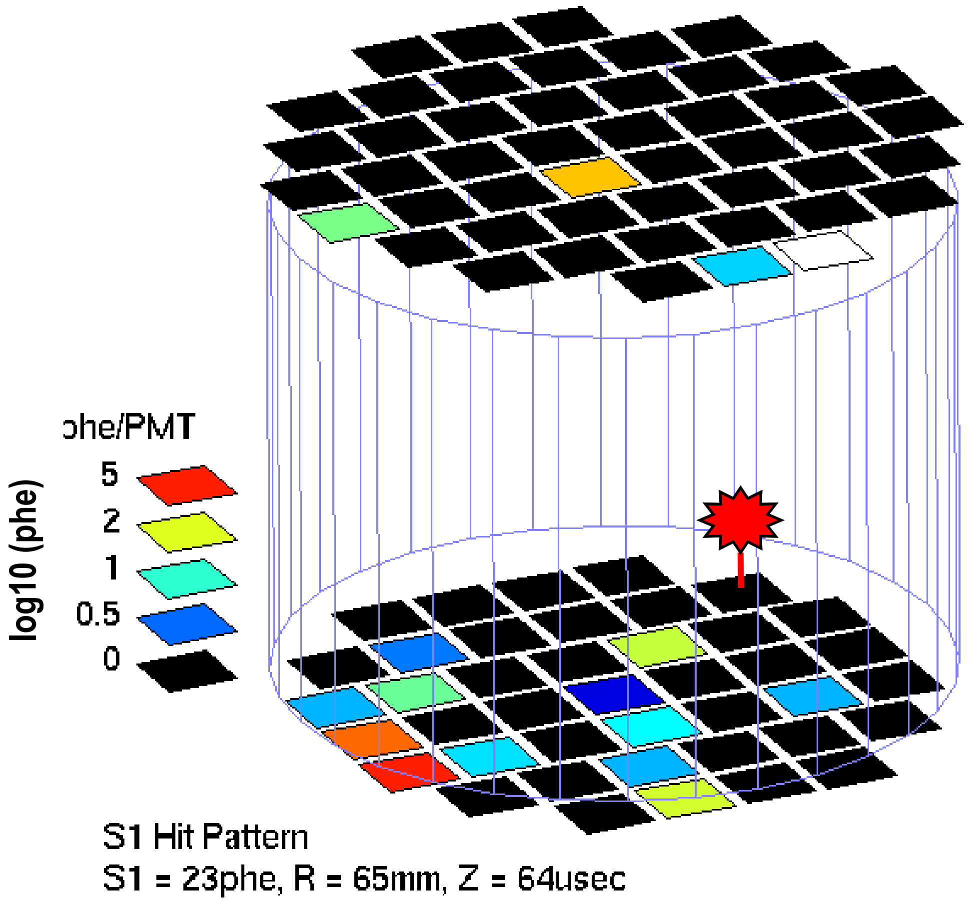
- Localization of Secondary Scatters (with no S2) point to specific anomalies
  - Reverse Field Region – Secondary Scatters Below Cathode have no Z information, but exhibit large degree of localization in single PMT and random XY distribution



Gamma-X Events
S1 Hit Pattern Bottom PMTs

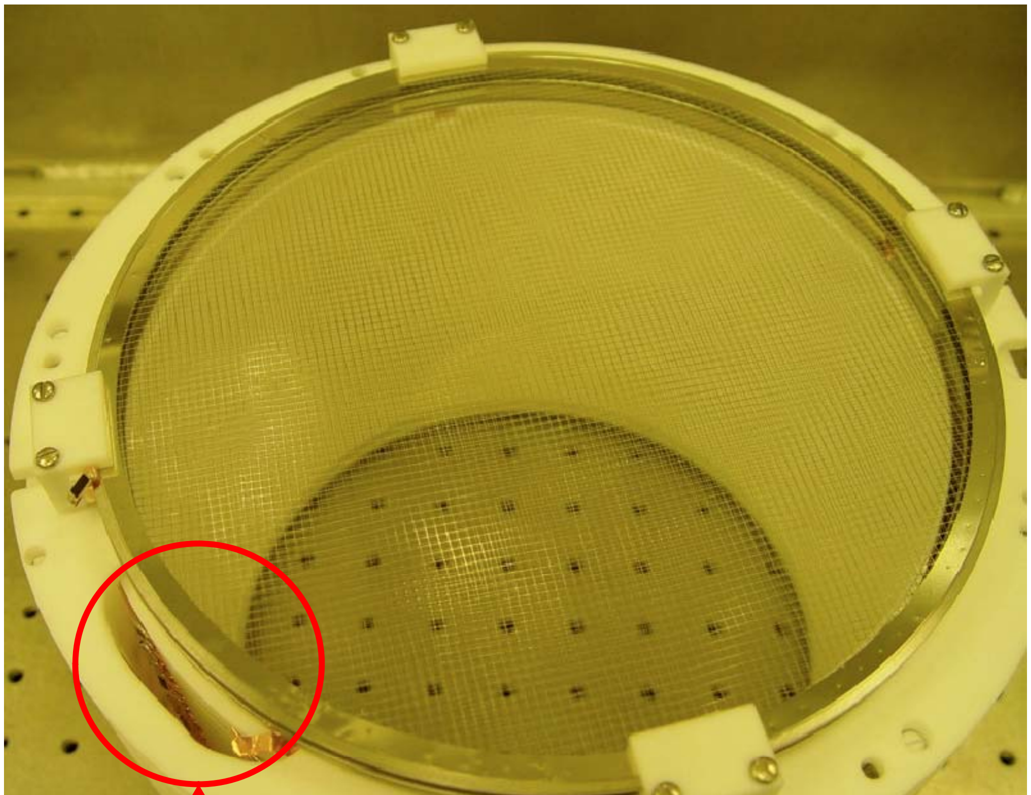
Identifying Anomalous Topologies

- We have identified a large number of events with secondary scatters over 2-3 PMTs near Liquid Xenon pocket in the Teflon Can - small hole made for resistor chain might be filled with liquid Xenon



Identifying Anomalous Topologies

- We have identified a large number of events with secondary scatters over 2-3 PMTs near Liquid Xenon pocket in the Teflon Can - small hole made for resistor chain might be filled with liquid Xenon



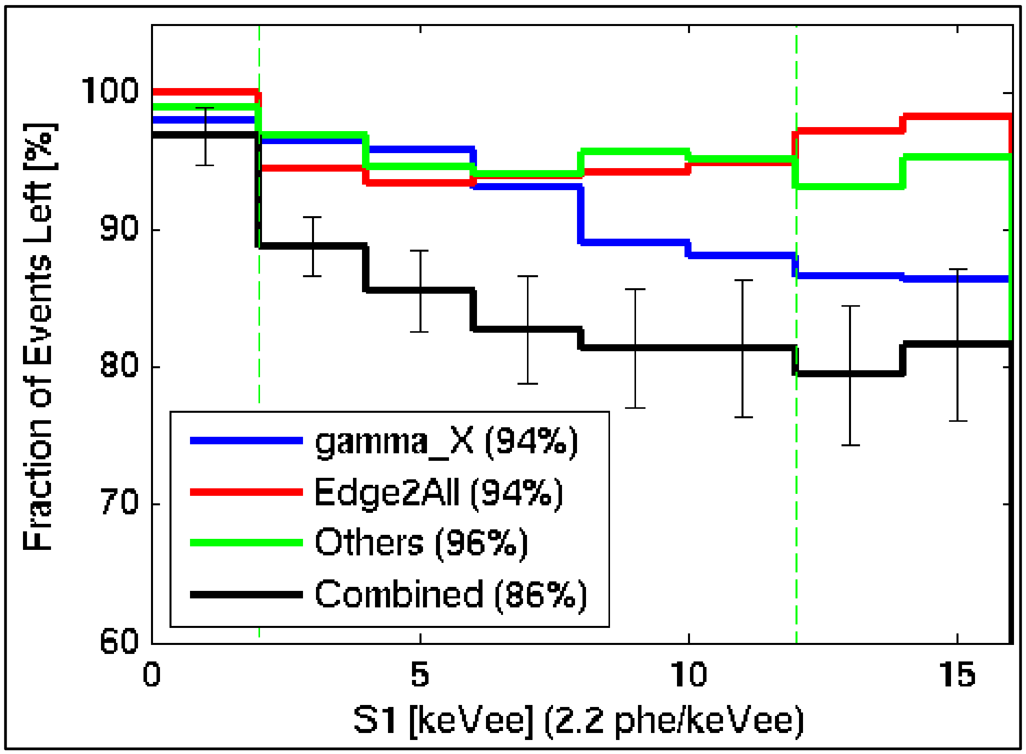
Resistor Chain Pocket – filled with LXe

The Gamma-X Cuts Package

- **Gamma-X Cuts checks for localization near the bottom PMT**
  - **Gamma-X Index N = Σ S1 (N most hit PMTs) / S1 Total Bottom; (for N=1-4 PMTs)**
  - **Localization = std(N most hit PMT-X) and std(N most hit PMT-Y).**
- **Other Cuts**
  - **Edge2All - Σ S1 (Edge PMTs) / S1 Total Bottom**
  - **Partial Gamma-X – Single Electron at Max Drift Time**
  - **S1 Top / Bottom Fraction**

Gamma-X Cuts Performance

- Cuts efficiency in Nuclear Recoil Band: 86%
  - (AmBe Neutron source)
  - Energy = 2-12eVee (2.2phe/eVee scale)
  - Fiducial = 5.3kg (R<80mm, Drift Time 15-65usec)

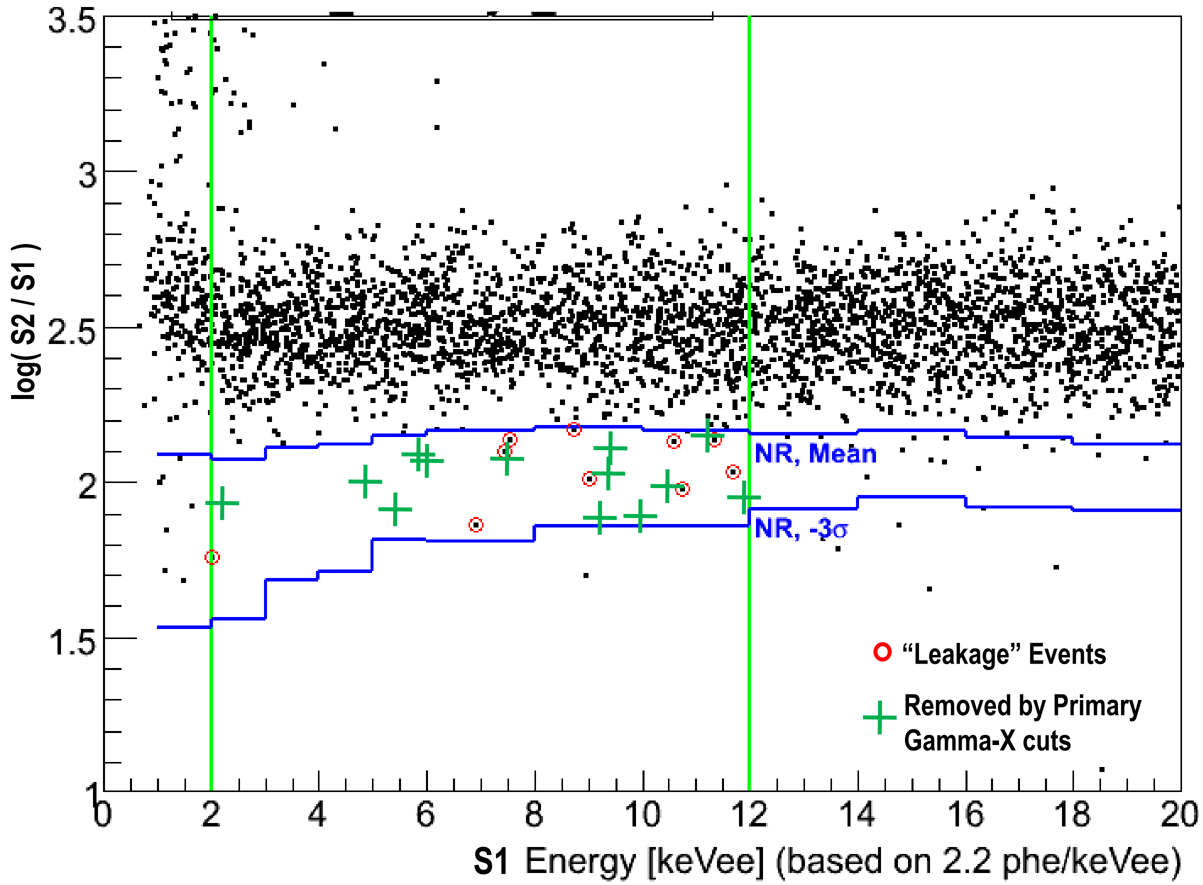


Applying the Gamma-X Cuts to XENON10 Data

- XENON10 Blind Analysis – 58.6 days
  - WIMP "Box" defined at
    - ~50% acceptance of Nuclear Recoils (blue lines): [Centroid -3σ]
    - 2-12keVee (2.2phe/keVee scale)
  - 23 Events in the Nuclear Recoil Acceptance Window
  - 13 events are removed from box by Primary Gamma-X Cuts (+)
  - 10 events in the "box" after all primary cuts (o)
  - 5 of these are *not consistent* with Gaussian distribution of ER Background

log (S2 / S1) vs S1

"Straightened Y Scale" – ER Band Centroid => 2.5

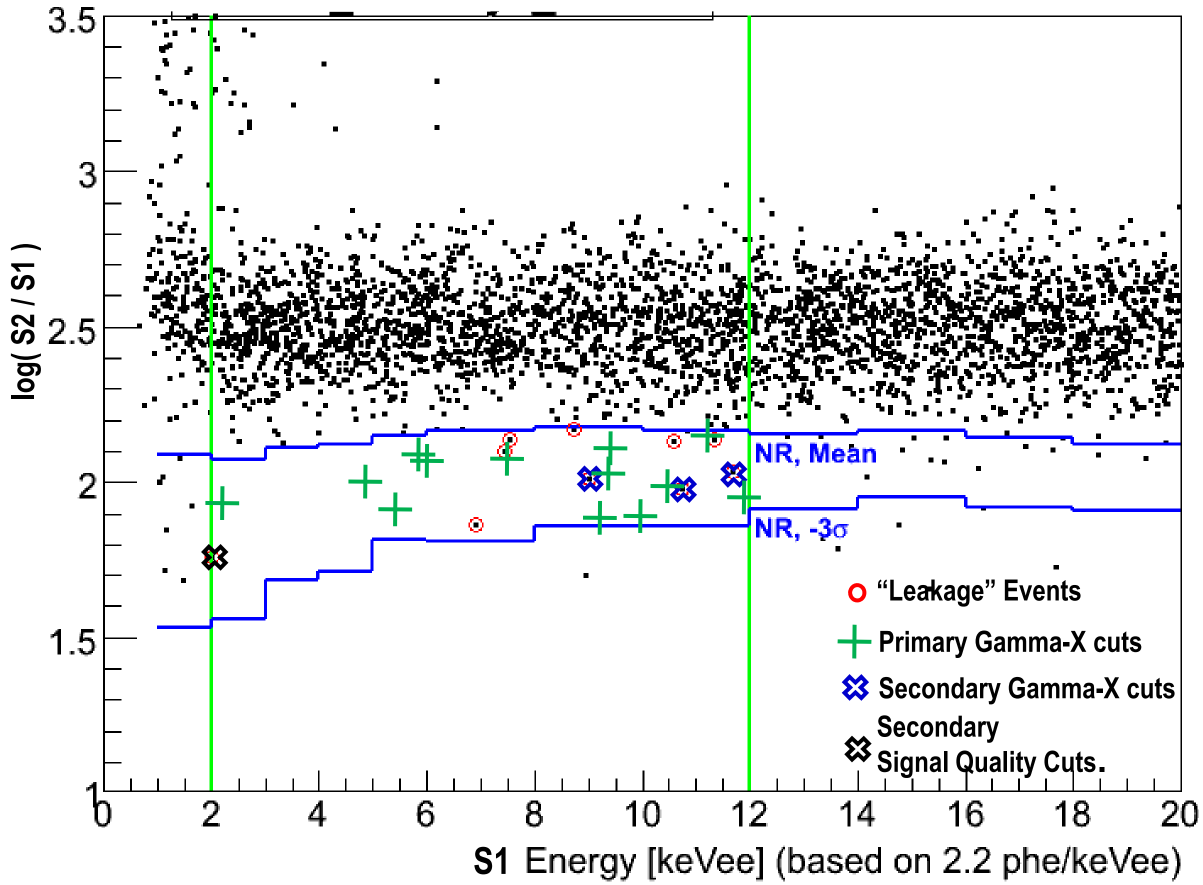


Applying the Gamma-X Cuts to XENON10 Data

- **XENON10 Blind Analysis – 58.6 days**
  - **WIMP "Box" defined at**
    - **~50% acceptance of Nuclear Recoils (blue lines): [Centroid -3σ]**
    - **2-12keVee (2.2phe/keVee scale)**
  - **13 events are removed from box by Primary Gamma-X Cuts (+)**
  - **10 events in the "box" after all primary cuts (o)**
  - **5 of these are *not consistent* with Gaussian distribution of ER Background**
  - **3 of the 5 non-Gaussian Events are removed by Gamma-X Cuts developed by the Secondary Analysis (x)**
  - **1 of the 5 non-Gaussian Events removed by Signal Quality Cuts from the Secondary Analysis (x)**
  - **Only 1 Event not consistent with Gaussian ER Background survives both Primary and Secondary Cuts (>15keVr, S2/S1 = 2.7σ away from centroid)**

log (S2 / S1) vs S1

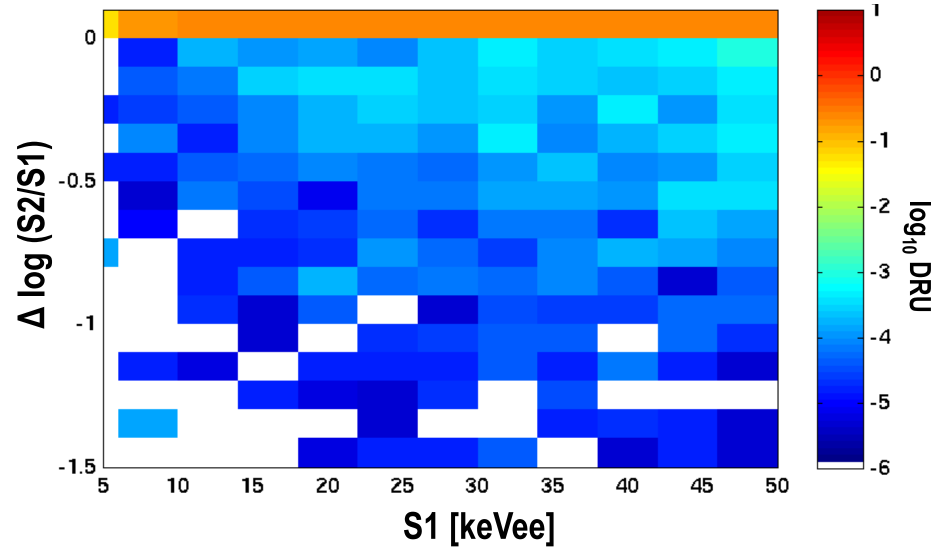
"Straightened Y Scale" – ER Band Centroid => 2.5

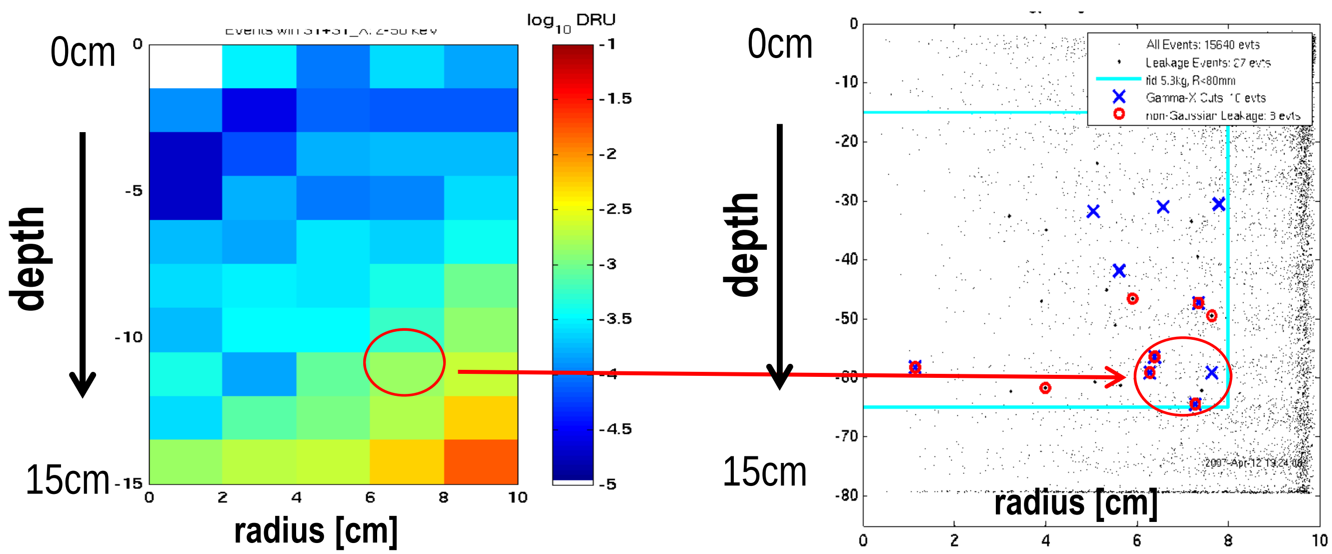


Gamma-X Monte Carlo

- 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

Simulated Gamma-X Spectrum with Secondary Scatters on the Reverse Field Region (for expected Gamma Background)





Conclusion

- The events in the Nuclear Recoil Acceptance Window have 2 components
  - Tail of the ER Background Gaussian distribution (0.01% of ER background)
  - Events with missing S2 (i.e. Gamma-X events)
    - Reverse Field Region – Charge Insensitive region of the detector, below cathode
    - Lxe trapped in pocket for resistor chain – Light can leak through Xe, charge is lost to recombination
    - LXe around Xe can – light can "leak in" for scatters in the thin layer of Xe (~1mm) around can. Very small amount of Lxe => Very few events
    - Field "distortions" on edge of detector ("Roman Region") – charge is drifted towards detector walls
- Analysis of Events with missing S2 suggests ways to improve detector (reduction of Reverse Field Region, removal of empty spaces in the Teflon Can, etc…)
- XENON10 BG:
  - 1800 events in fiducial (5.3kg), 2-12eVee
  - 5 events not consistent with Gaussian distribution of ER background after all cut in Primary Analysis
  - 1 non-Gaussian event after Gamma-X cuts developed by Secondary Analysis

The End

Thank you!