



# Delayed Signals in Liquid Xenon Particle Detectors

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# Two-Phase Xenon Time Projection Chamber (TPC)

Two signals from particle interaction:

S1 – Prompt Scintillation

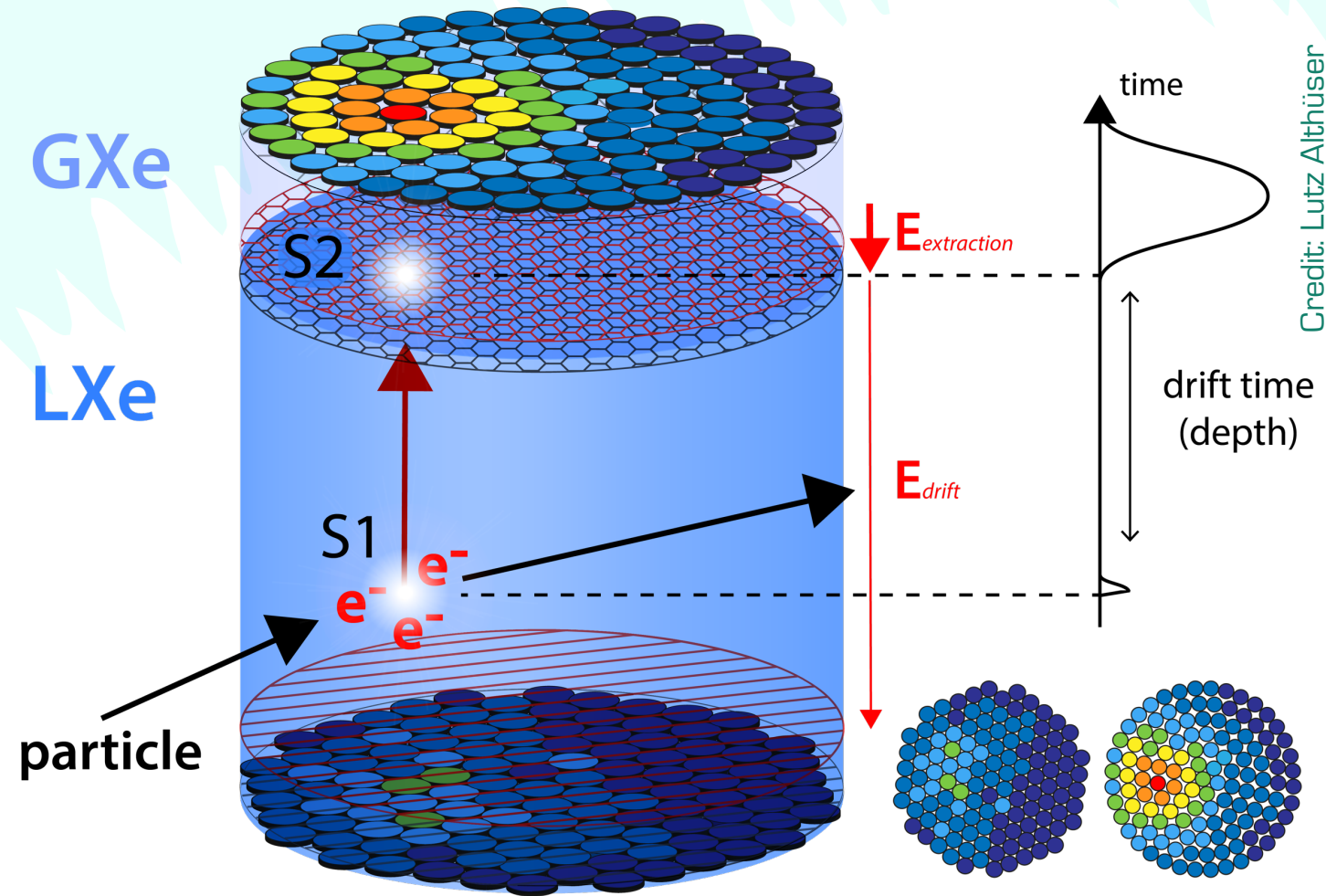
S2 – Delayed Ionization Electroluminescence

Photon detection efficiency for S1  $\sim 10\%$

Theoretically perfect electron detection efficiency for S2, except for:

Extraction Efficiency

Electronegative Impurities (Electron Lifetime)

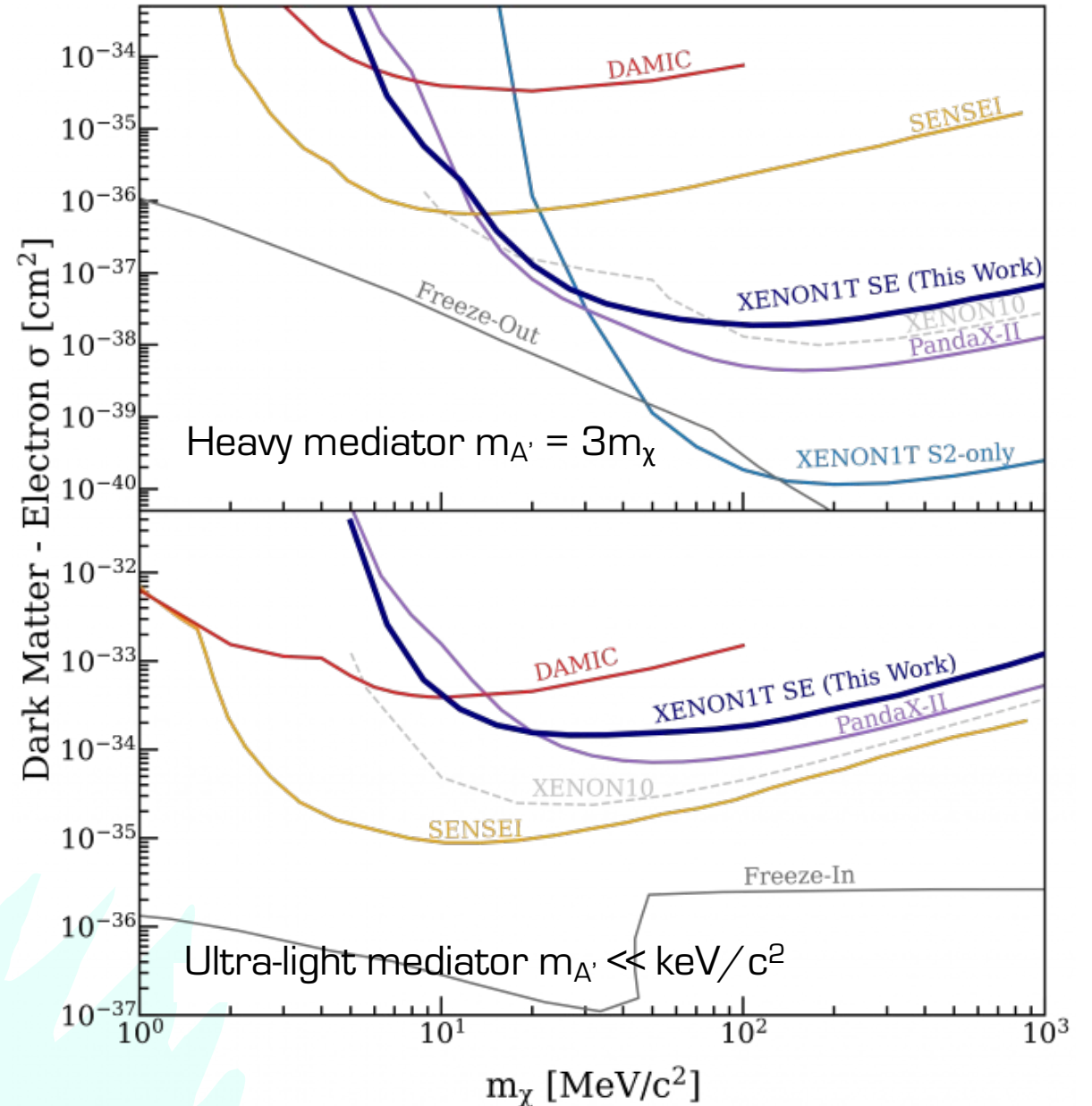


Credit: Lutz Althüser

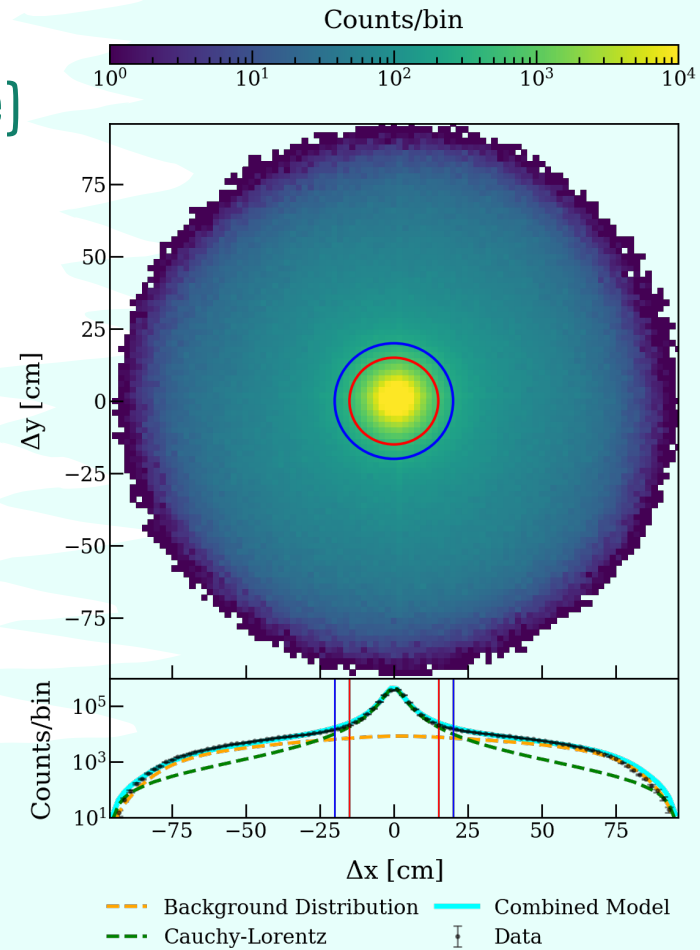
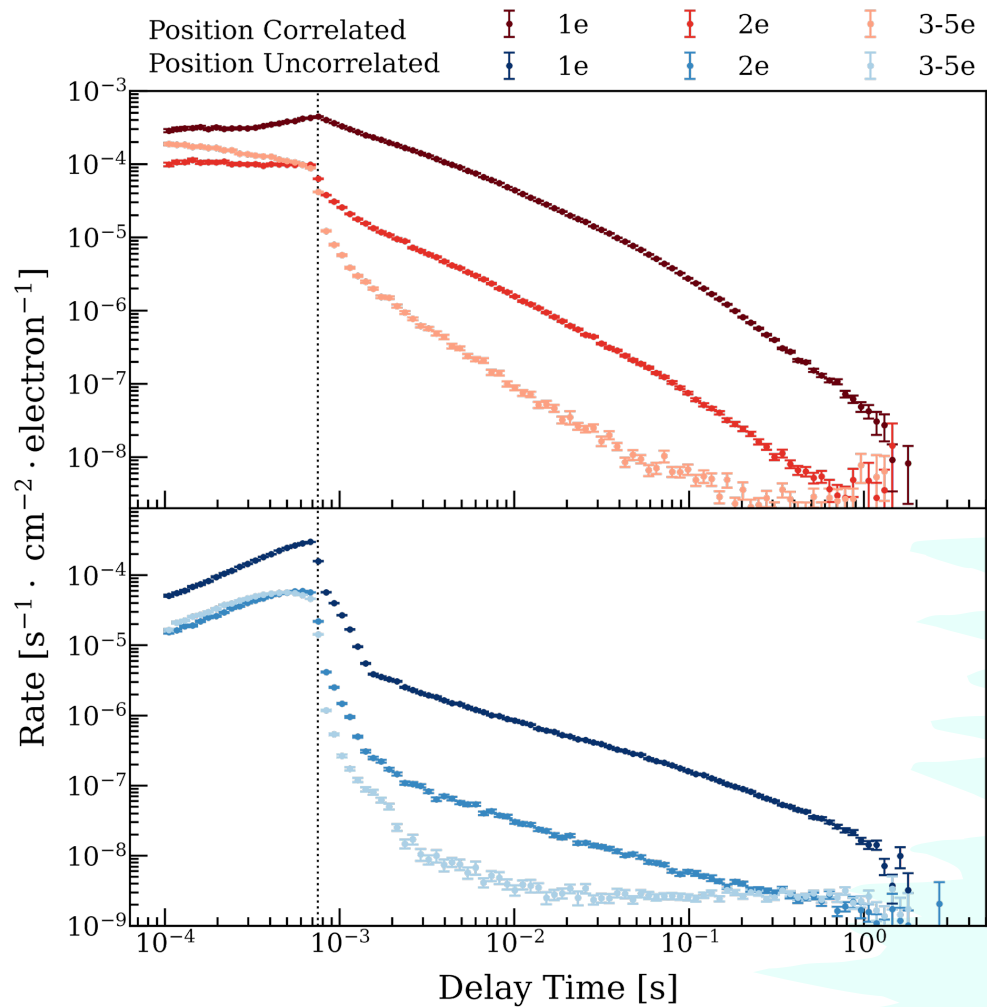
## Single-Electron Detection Threshold

Important to expand the physics reach of dedicated experiments

Complementary to dedicated searches.



# Delayed Electrons (XENON1T for Example)



Elevated rates of Single- and Few-electron signals are correlated in time and location with previous energetic particle interactions.

## Hypotheses:

- Delayed Extraction at Liquid Surface
- Emitted from impurities in the xenon

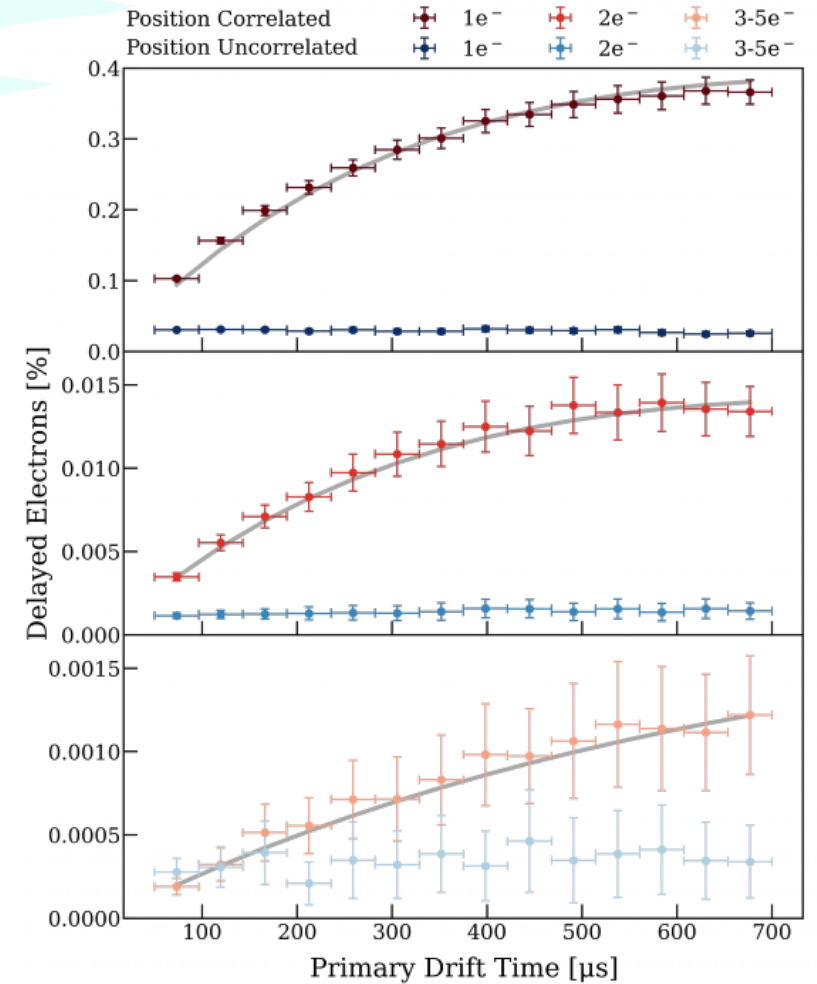
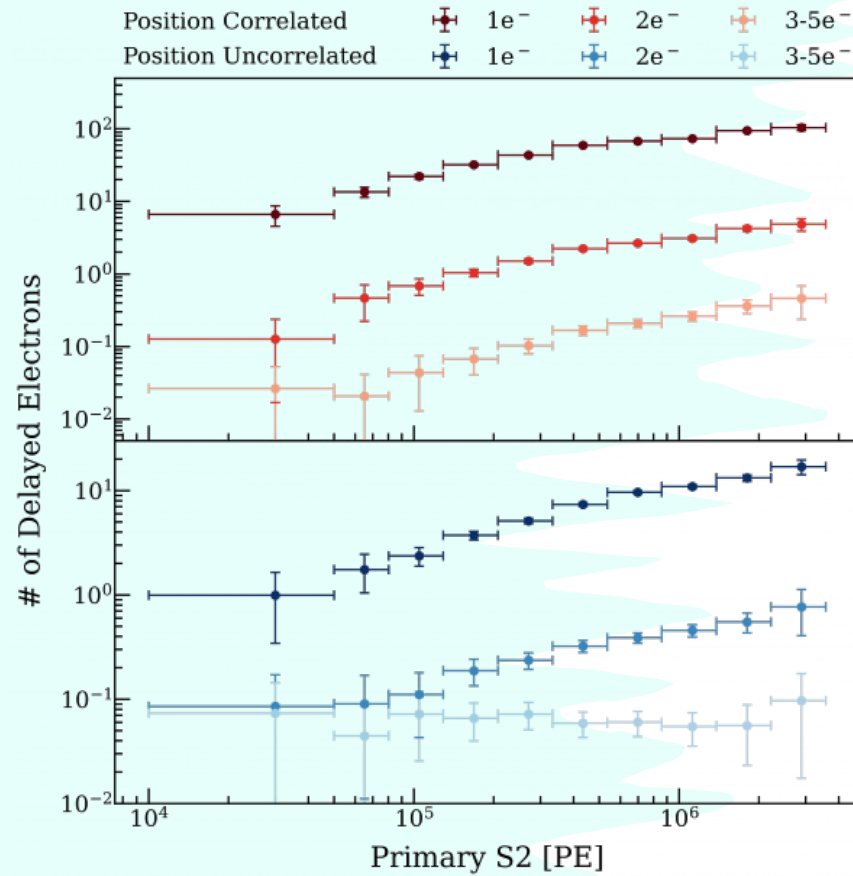
# Delayed Electrons Phenomenology

Some Dependence on:

- Previous Interaction Energy
- Previous Interaction Depth
- Extraction Field

Unclear/No Dependence on:

- Extraction Field
- Xenon Purity (Electron Lifetime)
- Drift Field
- Extraction Field



Hypotheses:

- Delayed Extraction at Liquid Surface
- Emitted from impurities in the xenon

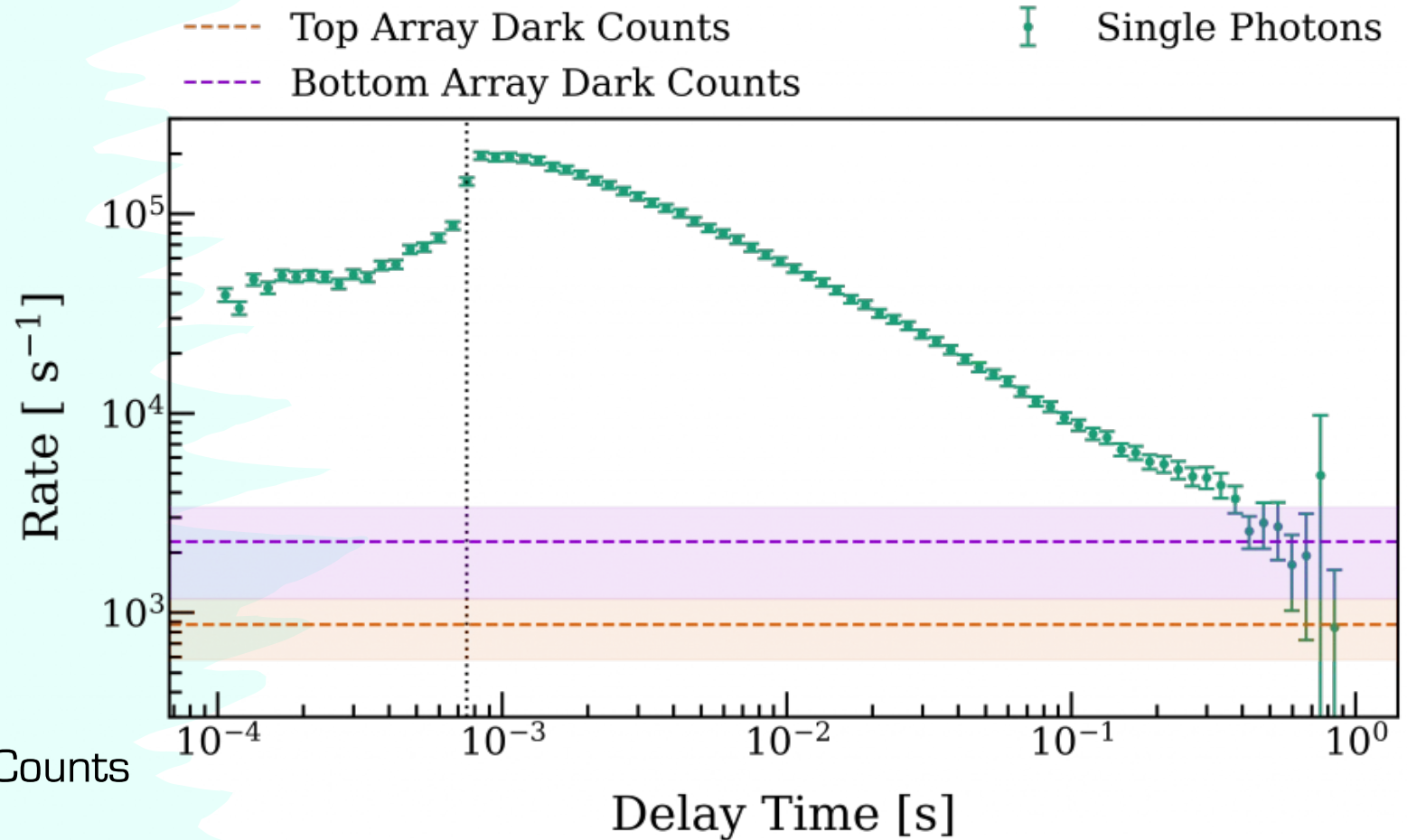
## Delayed Photons (XENON1T for Example)

Elevated rates of Single-Photon pulses are correlated in time with previous energetic particle interactions.

Not xenon scintillation light!

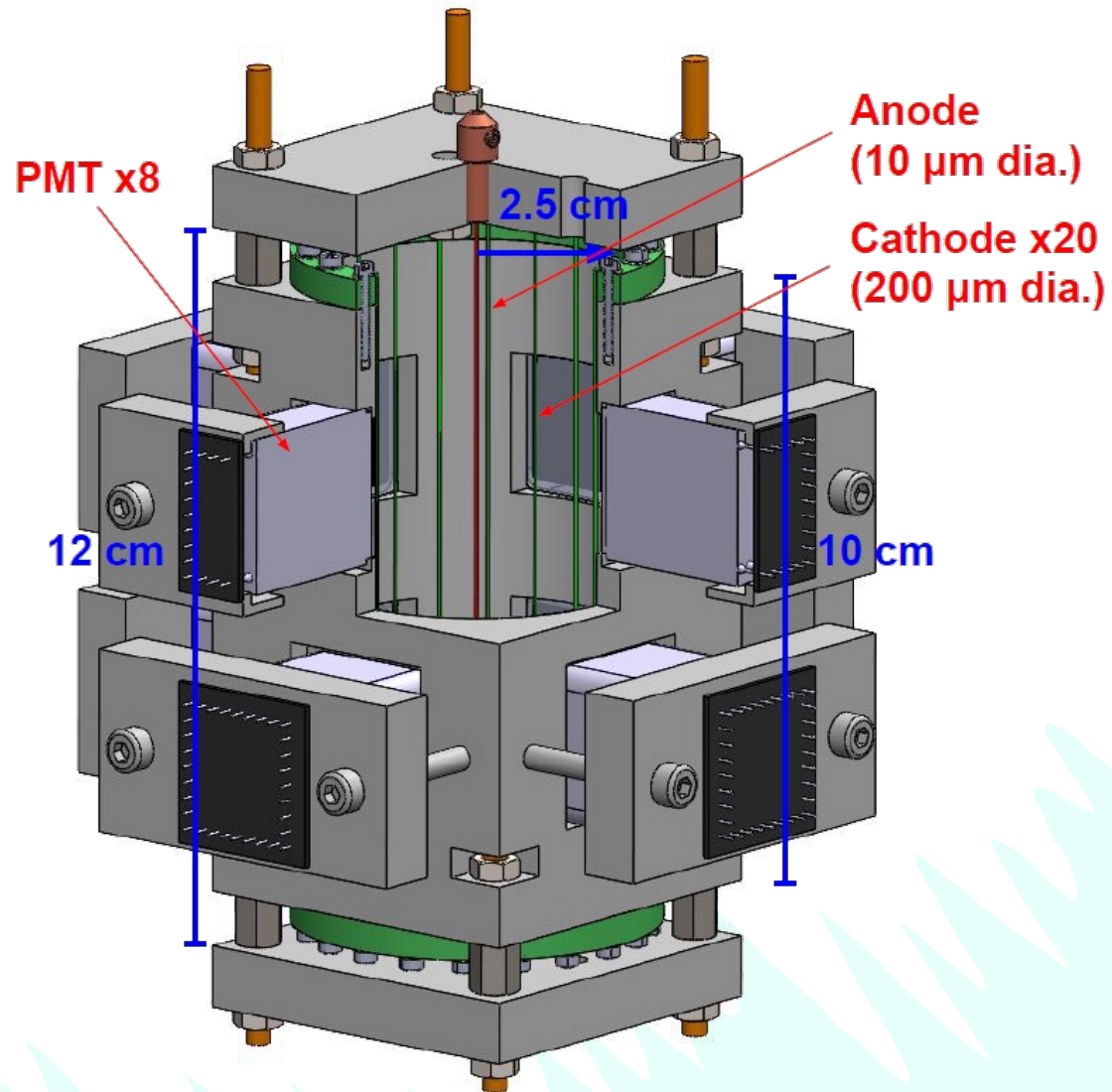
Hypotheses:

- Teflon Fluorescence
- Stressed PMTs with transient Dark Counts





# Proportional Scintillation Counter (PSC)



Same Detection Principles as TPC

Electroluminescence in Liquid

Radial Chamber

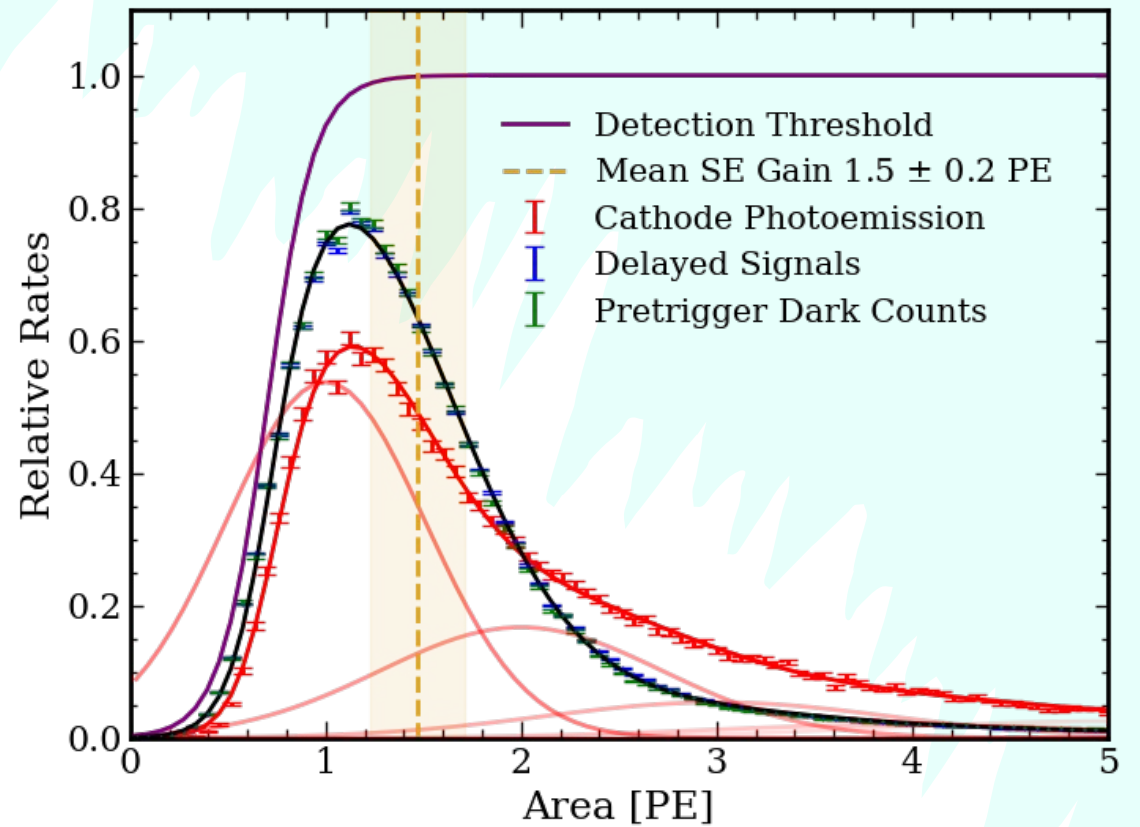
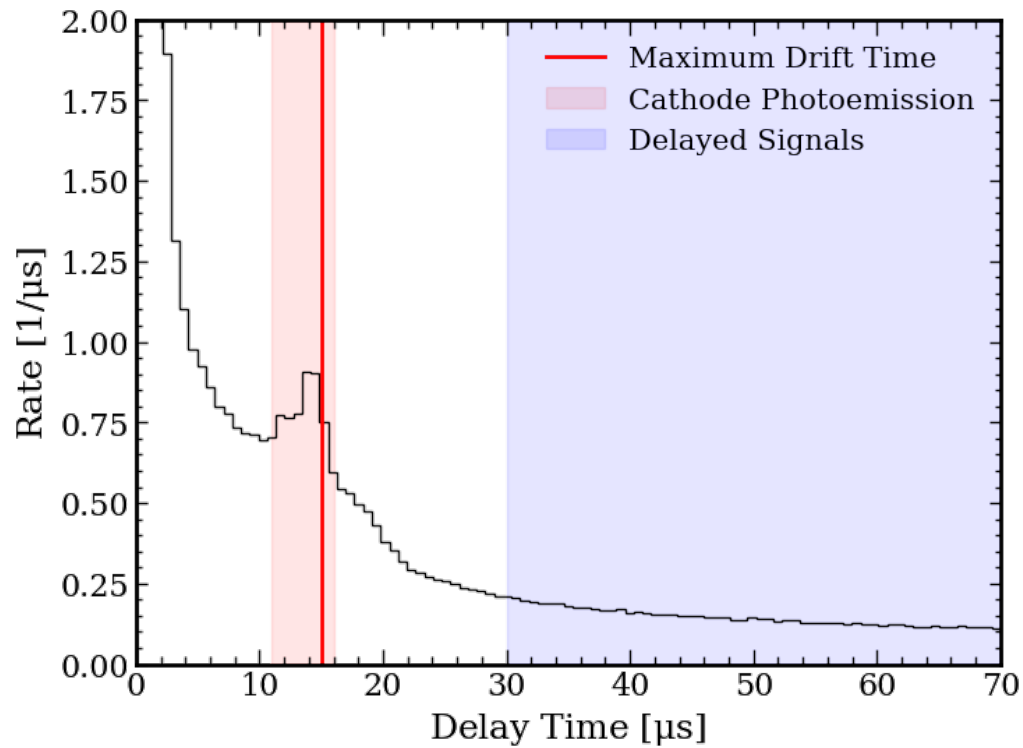
No liquid surface

→ No incomplete extraction

Theoretically perfect electron  
detection efficiency for S2

Using Photoionization to calibrate the SE spectrum, delayed signals are not dominated by electrons.

## Delayed Signals





## Summary

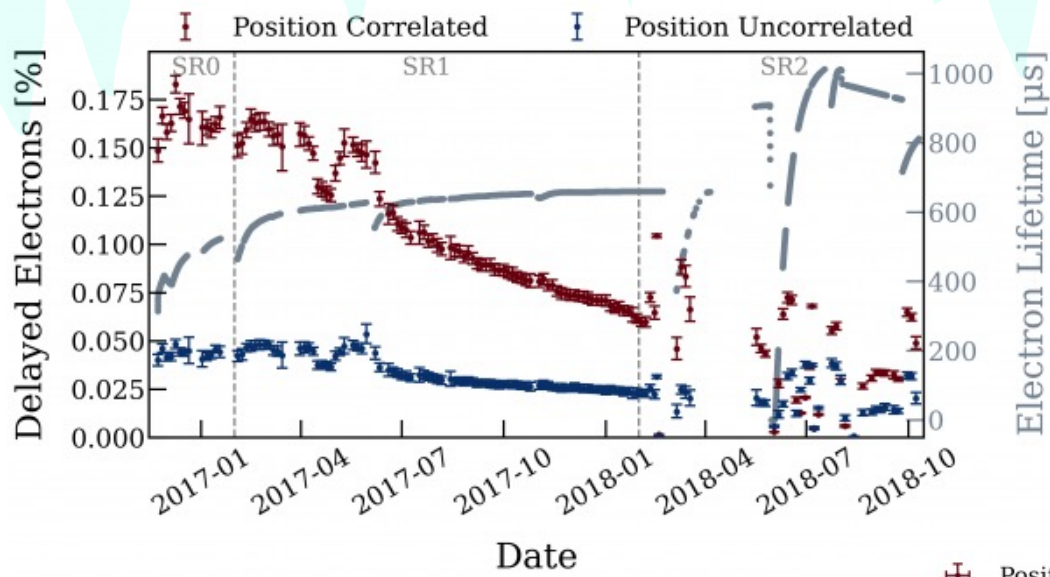
Dark matter searches using signals down to single electrons maximize the science reach of liquid xenon detectors.

The most recent two-phase TPCs have significant electron and photon backgrounds after energetic interactions.

A liquid-phase PSC does have delayed signals, but they are not dominated by electron signals.

A higher SE gain ( $>5\text{PE}$ ) is required to determine if delayed electrons are present in a single-phase PSC and thus rule out the delayed extraction hypothesis.

Larger detectors such as LZ and XENONnT may be able to determine the cause of the delayed photons.



## Back-up Slide: Phenomenology

