Delayed photon noise in liquid xenon time projection chambers

Ryan Gibbons, LBNL

Berkeley
UNIVERSITY OF CALIFORNIA

BERKELEY LAB

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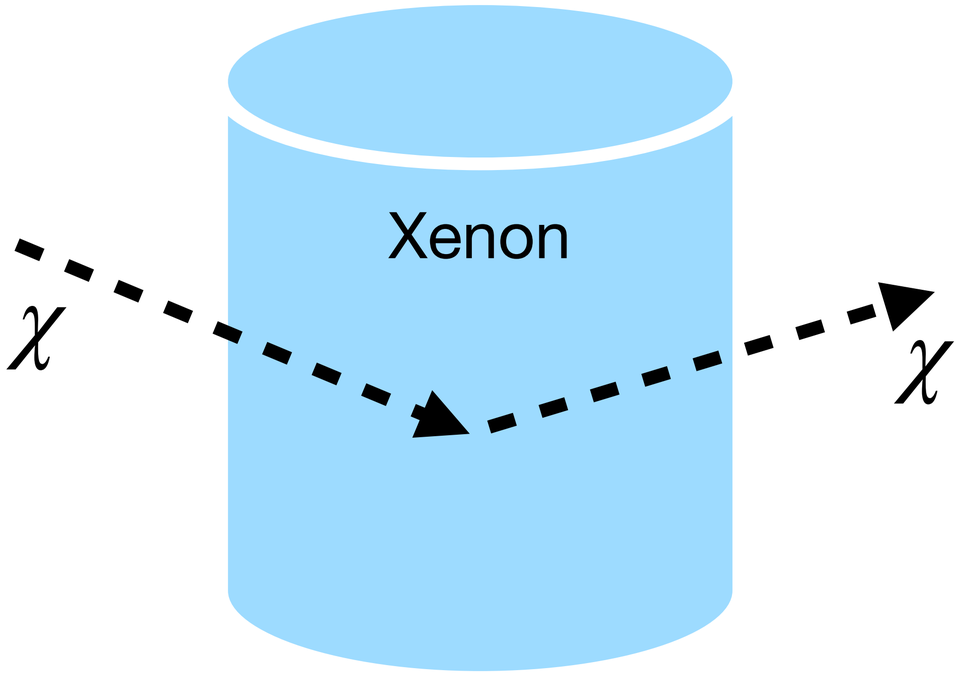
Xenon as a dark matter target

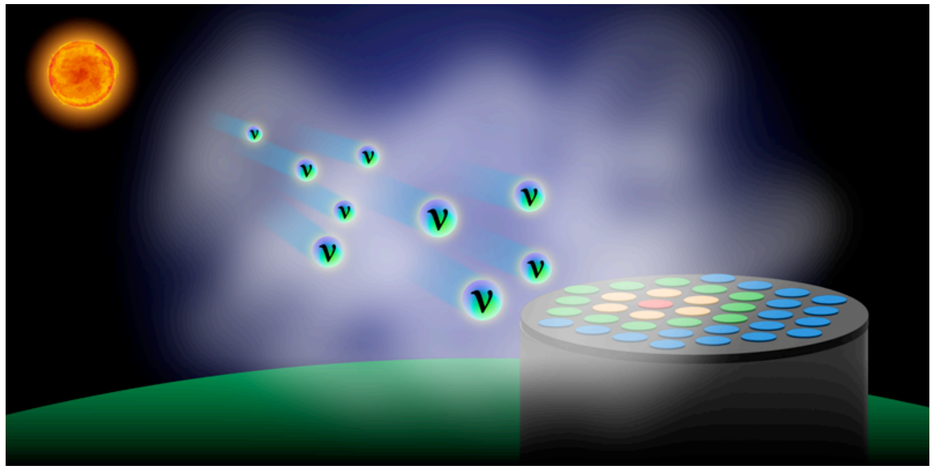
- Goal: detect WIMP-nucleus scattering
- Xenon is excellent WIMP target material
  - Kinematic matching of WIMP mass
  - Rate $\propto A^2$
- keV-scale energy depositions



Coherent “Billiard ball” scattering

Neutrinos can scatter the same way as WIMPs

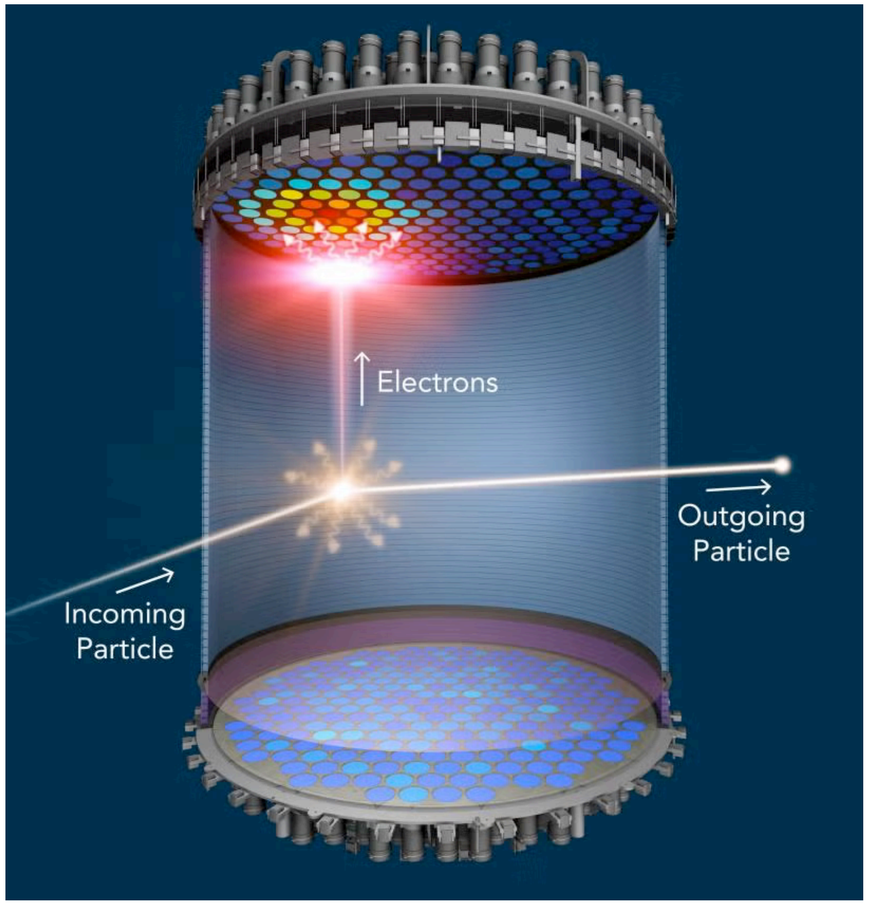
- “Neutrino fog” from solar and atmospheric neutrinos
- CEvNS: Coherent Elastic Neutrino-Nucleus Scattering
  - Rate $\sim N^2$
  - ~0.1 keV energy depositions (^{8}B)
- First hints from current xenon detectors



Credit: APS/Alan Stonebraker

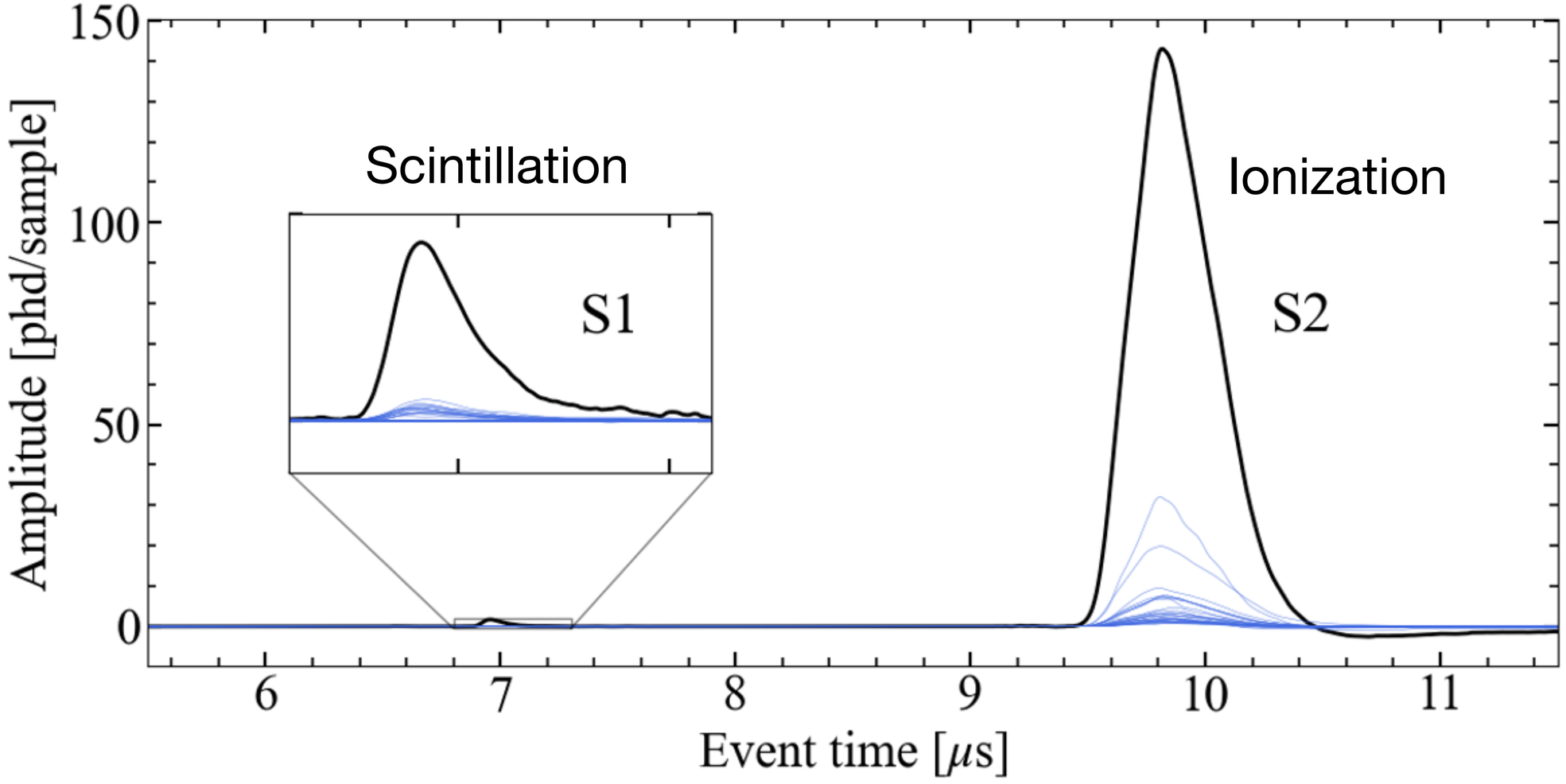
Dual-phase xenon time projection chamber

- Detect **scintillation (S1)** and **ionization (S2)**
  - Both detected as ~175 nm photons
- Use photodetectors as photon sensors
  - Photomultiplier tube (PMT)
  - Silicon photomultiplier (SiPM)
- Active region enclosed by PTFE reflector



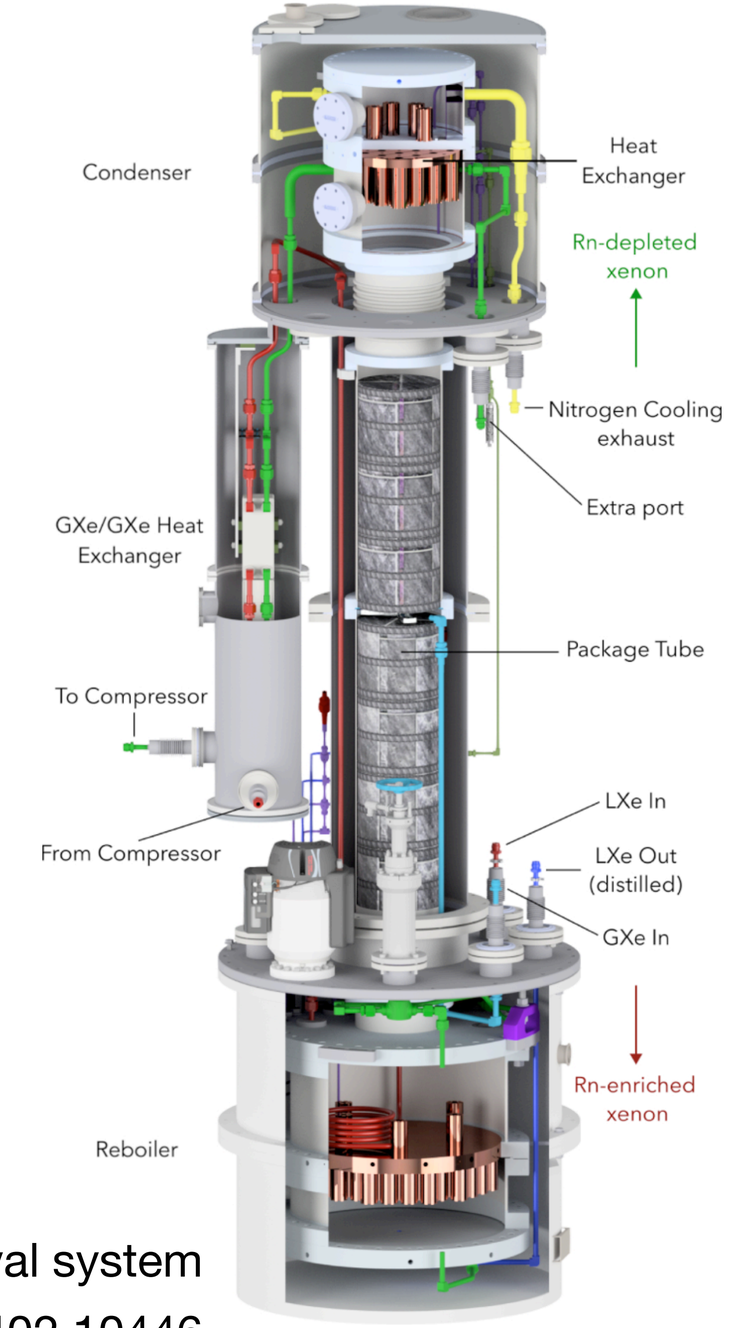
Credit: SLAC

Example waveform from LBL Xenon TPC



Radiological backgrounds

- Radon progeny, neutrons, …
- Large efforts to mitigate
  - Purifying xenon: chromatography and distillation
  - Selection of ultra-pure materials
- Bigger detector —> lower radiological backgrounds
  - Square-cube law (roughly)



XENONnT radon removal system

2402.10446

Instrument backgrounds

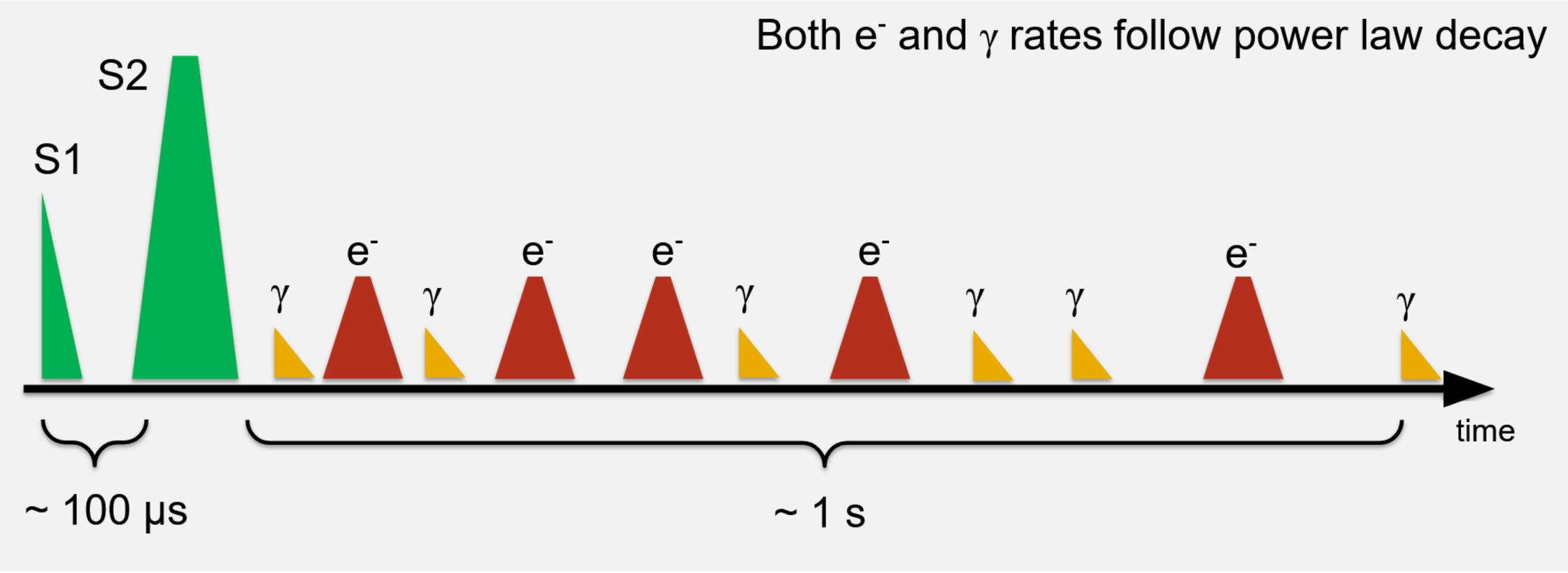
- Accidental coincidence events: “accidentals”
  - Lone S1, lone S2 coincidence in time
- Where do the lone S1 or S2 originate from?
  - Events in inactive detector regions
  - Electrode emission
  - Photodetector dark-count pileup
  - **Delayed photon/electron noise**

LZ electrode, treated to prevent emission

Credit: SLAC

Delayed photon/electron noise — “trains”

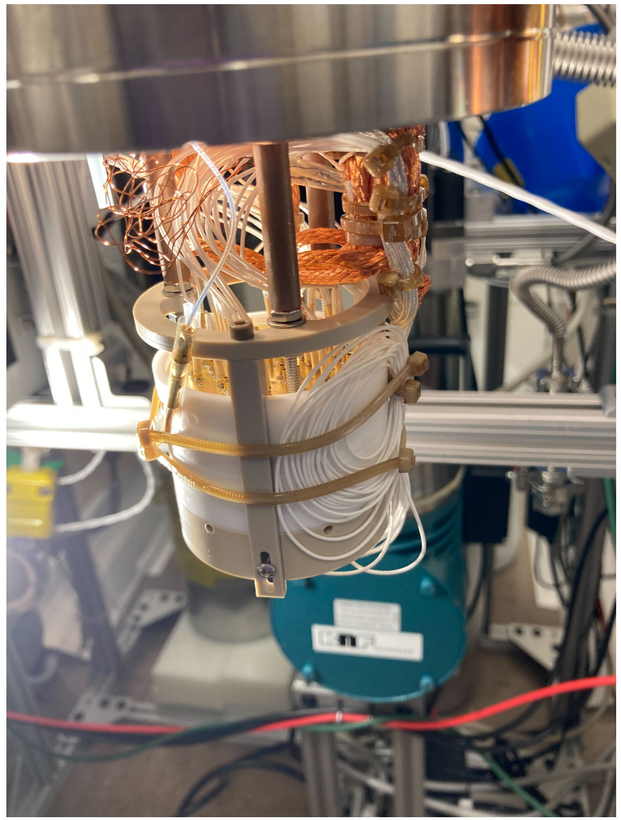
- Elevated rates of single photons/electrons following a regular event

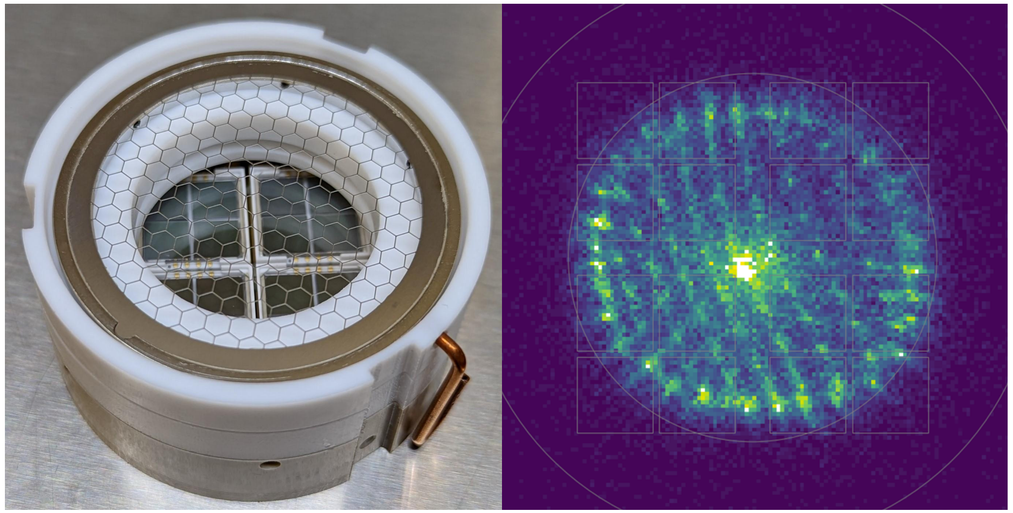


Investigations with a xenon TPC at LBNL

- ~500 g dual-phase xenon TPC with SiPMs
- Previous work:
  - Solid xenon TPC (crystaLiZe): 2312.15082, 2201.05740
  - H/He doping (HydroX): 2308.02430
  - SiPM R&D: 2309.07913

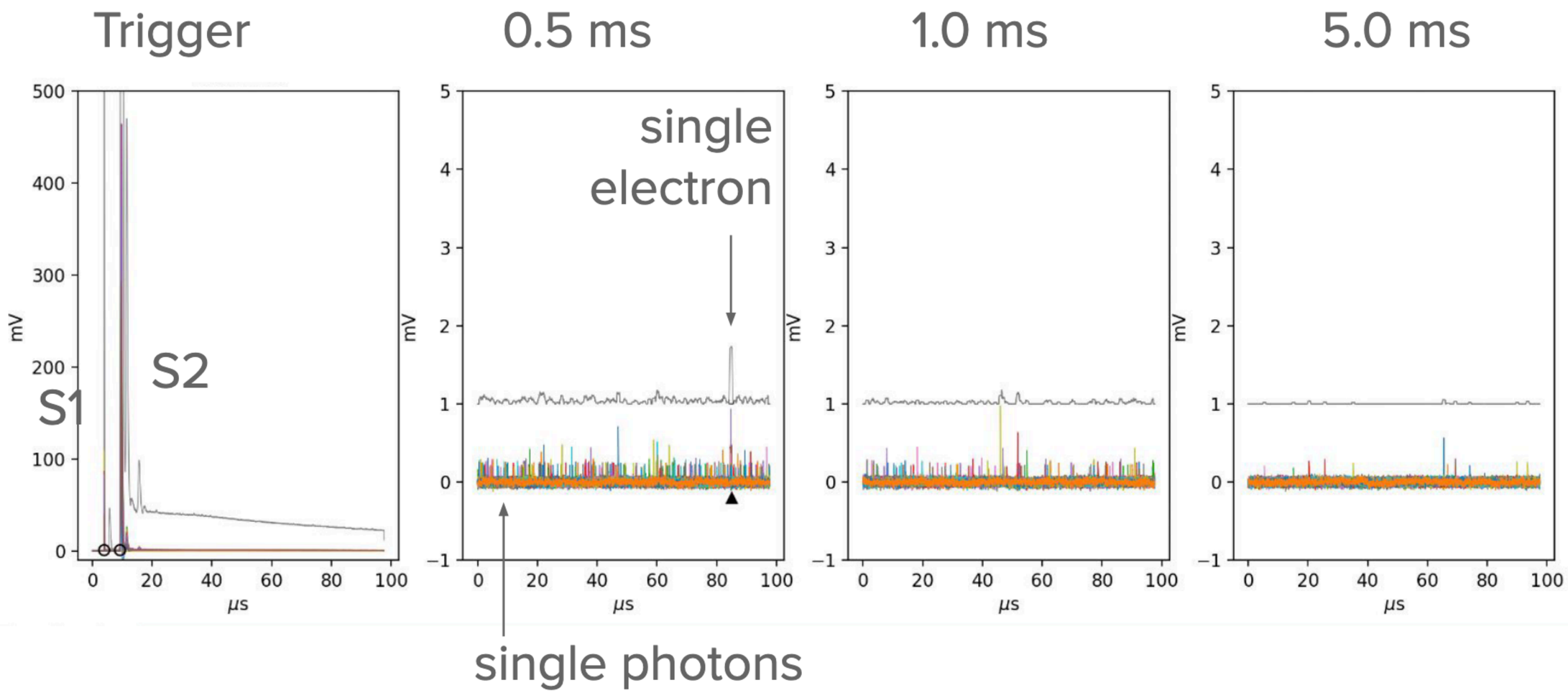
Assembled TPC





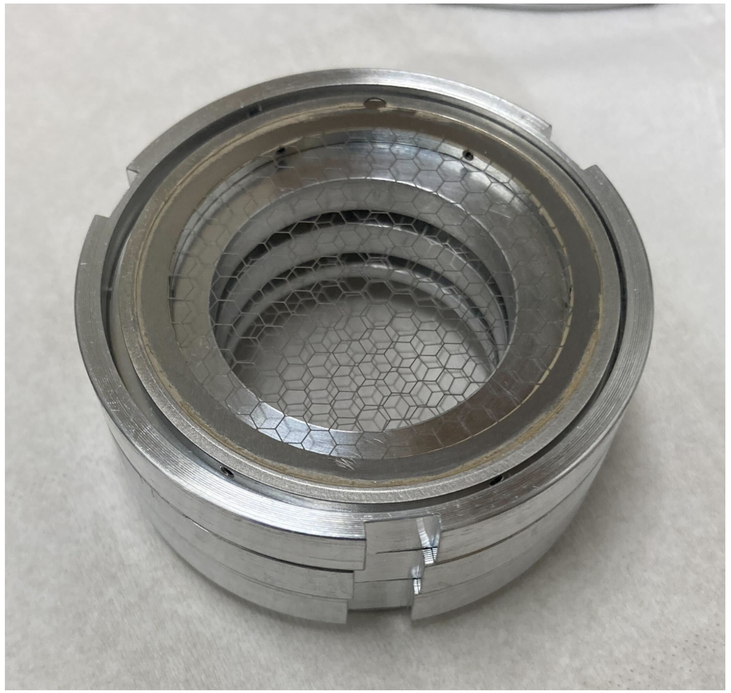
Cross section and (x,y) reconstruction

Sample delayed times using “cascade trigger”



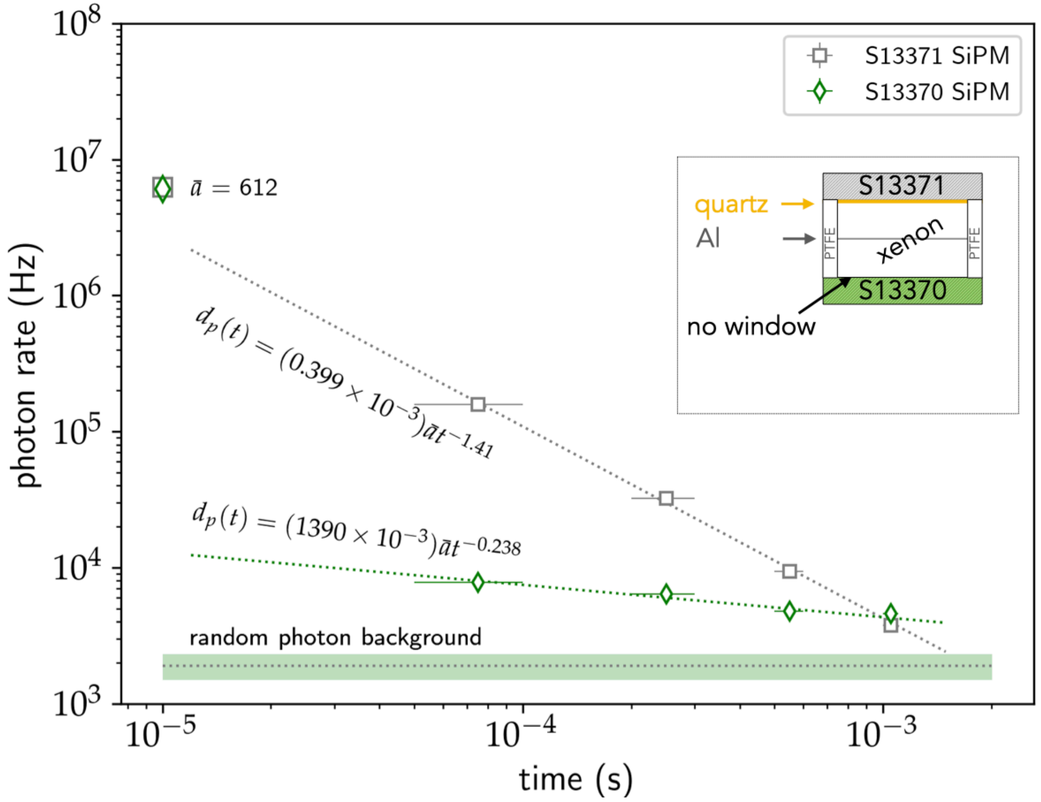
What's causing delay photon noise?

- Main hypothesis: PTFE fluorescence stimulated by xenon 175 nm light
- Investigated with xenon TPC at LBNL
- Swap PTFE —> Aluminum (no electric fields)
- Still see delayed photons!
  - PTFE fluorescence is not main component



Quartz window is fluorescing

- Main cause: quartz window of photodetector fluorescing
  - SiPMs: physically protective
  - PMTs: holds vacuum
- Compared windowed/windowless SiPMs
- Results published: 2505.08067



Summary

- Delayed photon/electron emission is background dual-phase xenon TPCs
- Identified quartz fluorescence as primary source of delayed photons
- Ongoing studies to characterize other sources of delayed photons

- Acknowledgements:
  - Peter Sorensen (grad advisor)
  - Aaron Manalaysay (HEPCAT mentor)

Current postdoc projects

- TESSERACT
  - Low-mass particle dark matter search
  - Transition Edge Sensors (TES) as sensors
  - Multiple targets: superfluid ^{4}He, GaAs, Al_2O_3, …
- SQUATs (Superconducting Quasiparticle-Amplifying Transmons)
  - Qubit-based detectors to measure ~meV energies
  - THz axion and reactor neutrino CEvNS detection