Xenon nuclear recoil calibration down to single ionization electron signals *(PRL 123, 231106)*

Jingke Xu, LLNL

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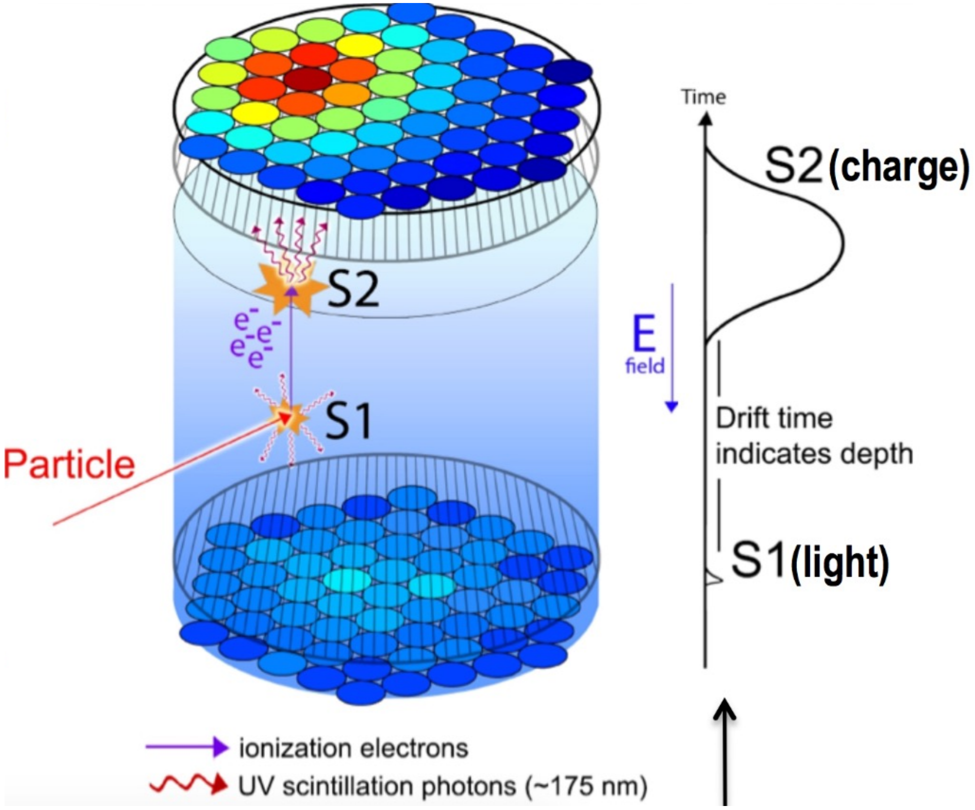
Xenon TPC basics

Dual-phase, dual signal readout

- Scintillation photons
  - Promptly detected
  - ~10% collection efficiency
- Ionization electrons
  - Delayed by electron drift time (depth below liquid surface)
  - ~100% collection efficiency

This calibration measurement focuses on the ionization yield of xenon recoils around 1keV (scintillation undetectable)

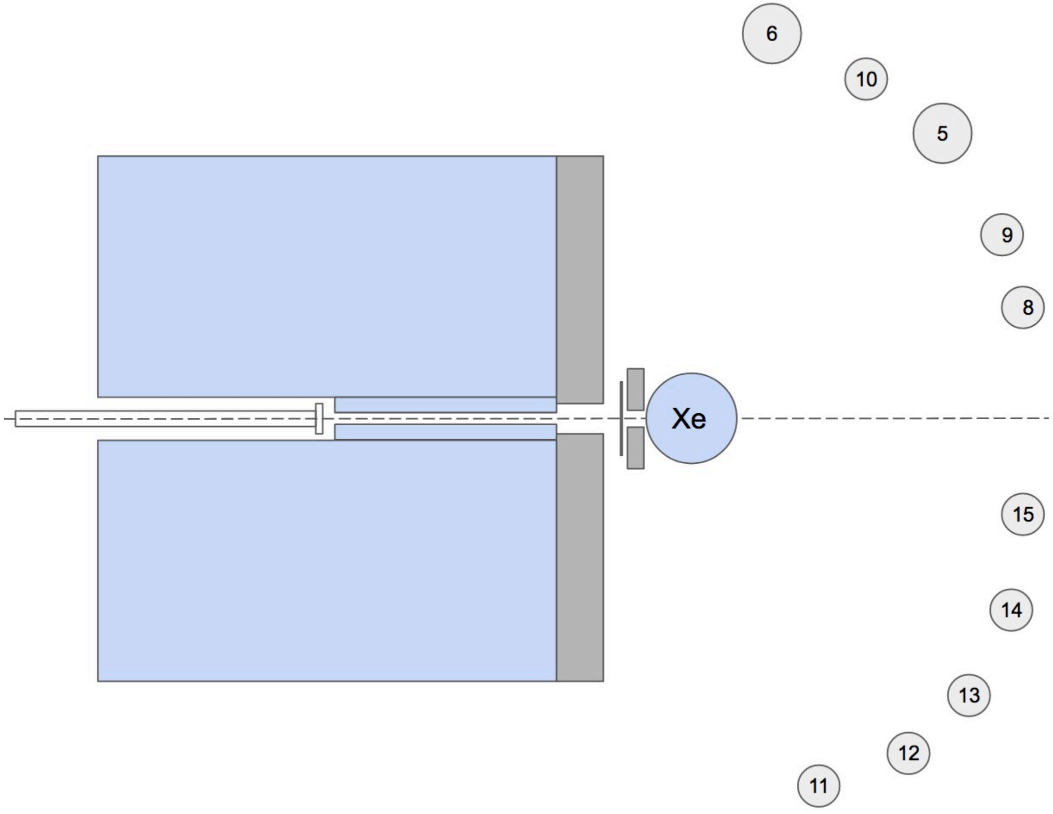


An illustration of signal generation in a dual-phase xenon TPC. For low-energy events, only charge signals can be detected.

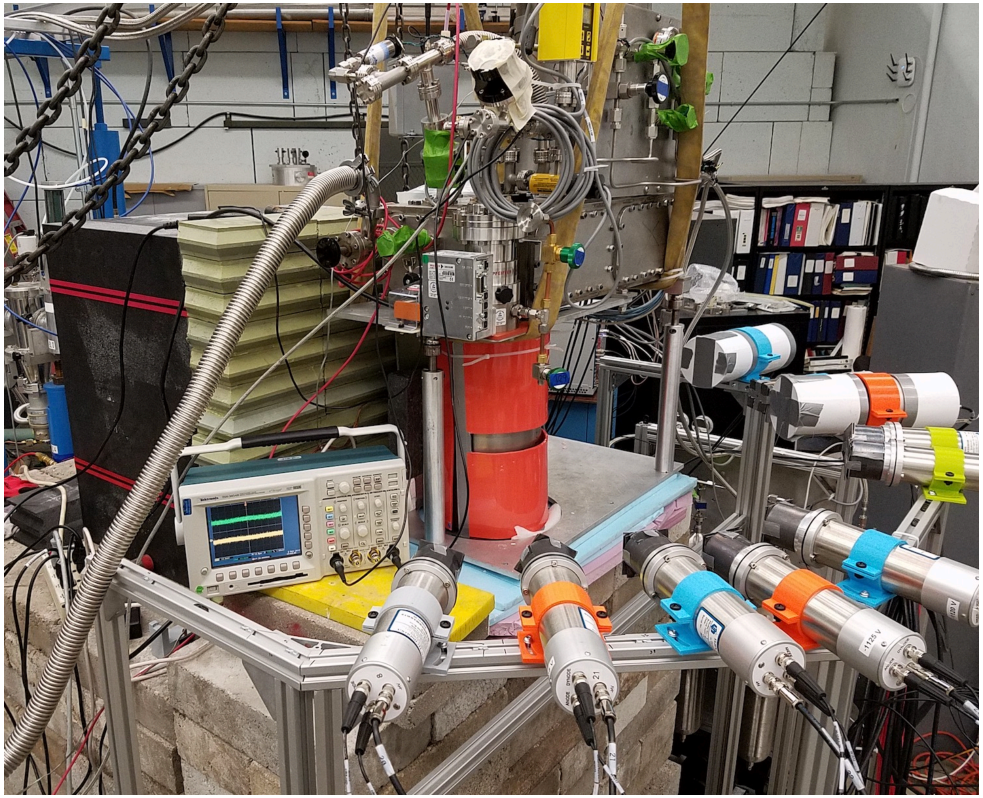
Experimental Setup at TUNL

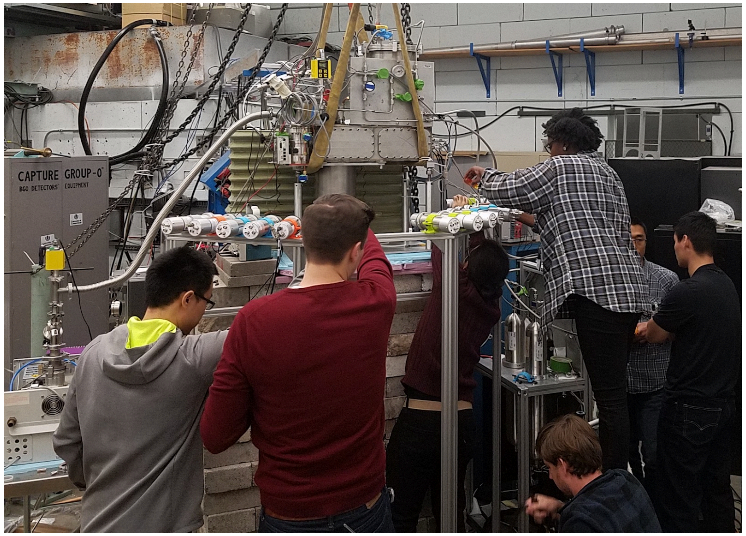
Measurement at TUNL (2018)

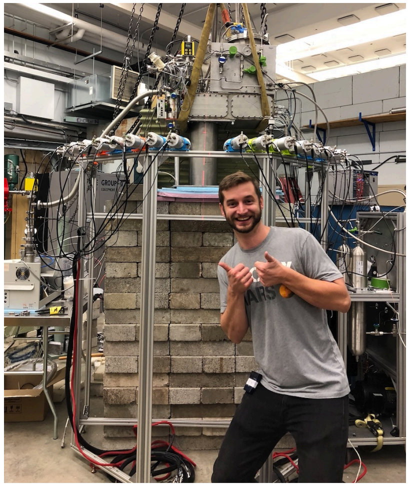
- 579 keV neutron
- 3.2us pulsing period (~10ns pulse cluster width)
- 10 backing neutron detectors (LS) with PSD
- 15-70 degree scattering angle
- 0.3-6 keV Xe recoil energy
- 0.2-6kV/cm electric field at interaction sites
- 95% electron extraction efficiency



XeNu in the TUNL target room



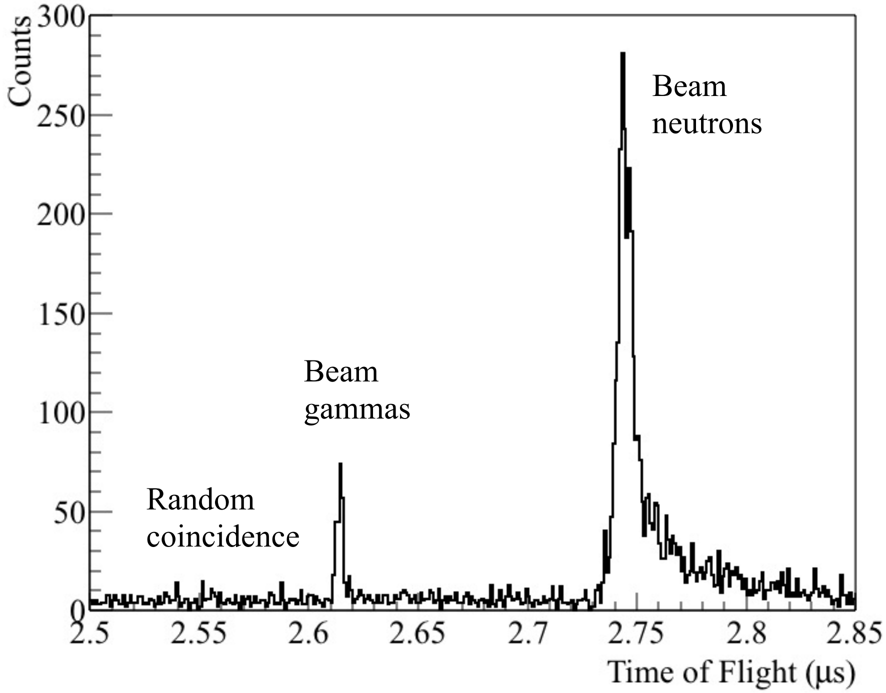




Neutron Time of Flight (TOF)

TOF provides substantial rejection of beam-induced gamma background and random coincidence backgrounds

- Neutron traveling speed: ~1cm/ns @579keV
- Gamma traveling speed: ~30cm/ns
- Backing detector distance: ~1m
- Neutron TOF: ~120-130ns
- Gamma TOF: ~4ns

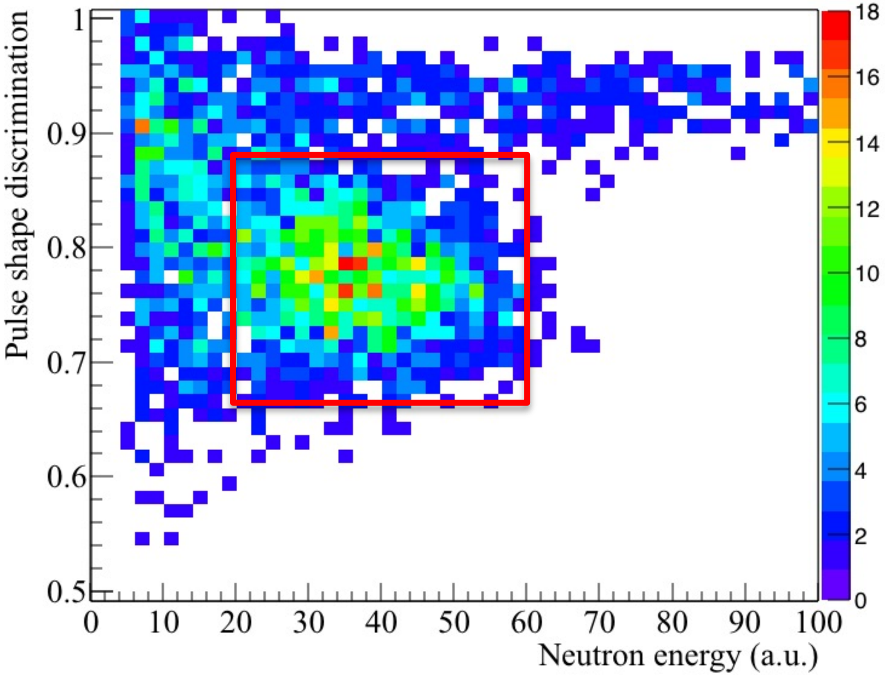


Time difference between neutron production on LiF target and detection in LS backing detectors

Neutron Pulse Shape Discrimination (PSD)

Liquid scintillator neutron detectors have PSD capability to reject Xe TPC events in coincidence with gamma backgrounds

- Fast scintillation for gammas
- Slow scintillation tail for neutron events
- Low kinetic energy of neutrons can be fully captured by LS detectors



Pulse shape discrimination (PSD) of recorded signals in LS backing detectors after TOF cut. The PSD parameter used is the fraction of pulse area within the first 50ns. The cluster around (35,0.76) are the neutrons.

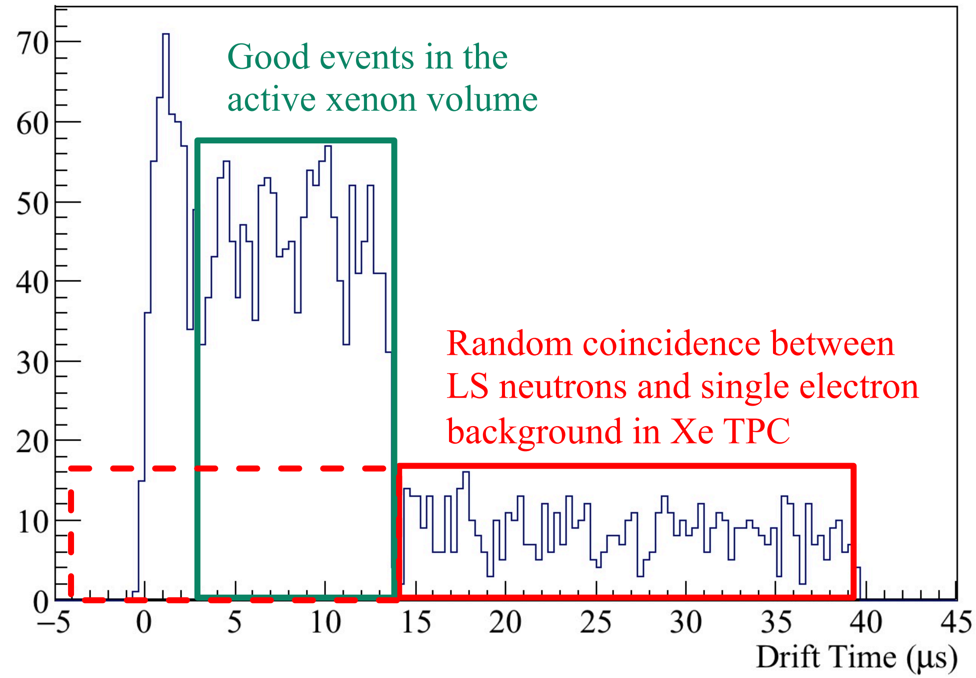
Random coincidence electron background

Xe TPCs are flooded with single electron backgrounds *(PRD 102, 092004)*

- Photoionization
- Impurity-capture and release
- Delayed emission of trapped electrons

Time separation between neutron detection and electron signal provides:

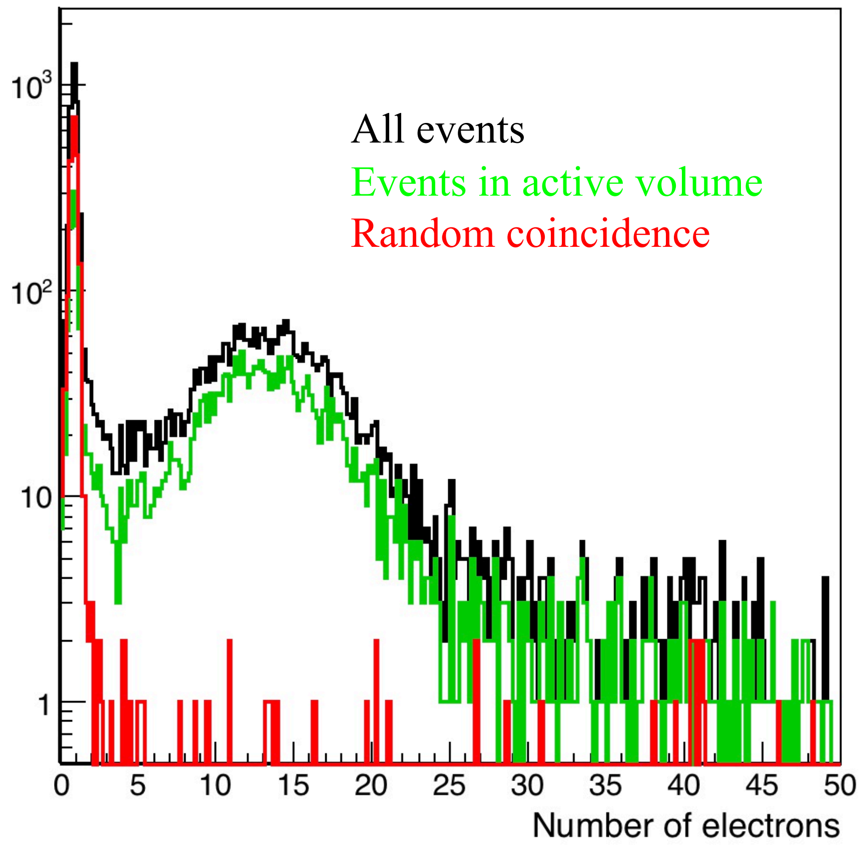
- Depth of the interaction (fiducialization)
- Estimation of random coincidence rate between neutron detection and background electron pulses



Drift time distribution of candidate events for 2.95keV xenon recoils

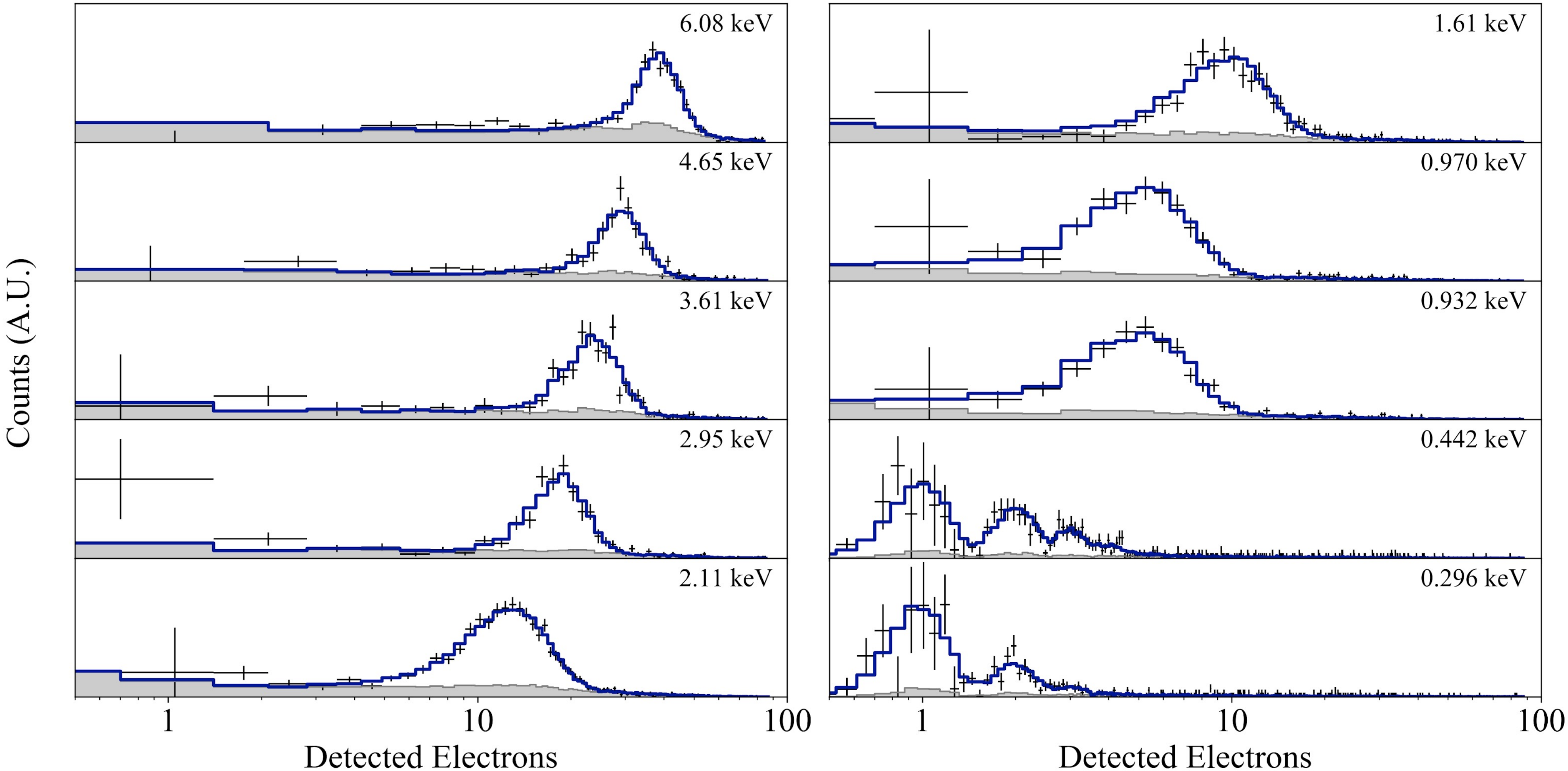
Background electron events subtraction

- Random coincidence are mostly single electrons
- Coincidence background in the active volume needs be estimated
- Background subtraction enabled ionization measurement down to 1e-
- Trigger efficiency for 1e- signals verified to be ~100%



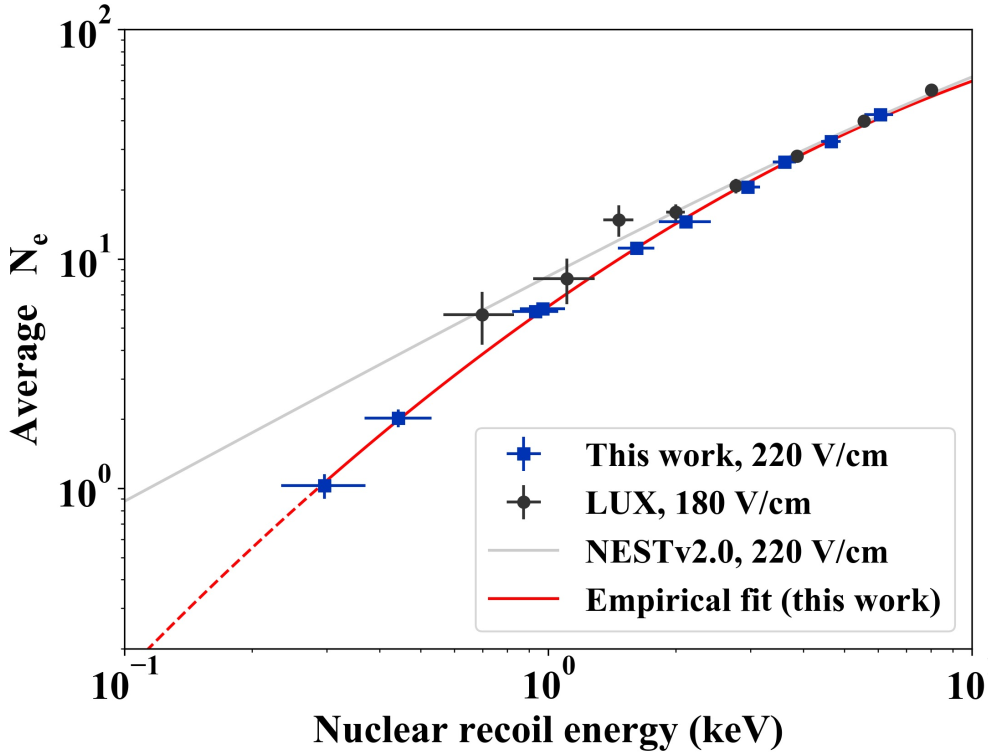
Energy spectra of candidate events for 2.1keV xenon recoils in different drift time regions

Background-subtracted recoil spectra



Xenon recoil calibration result

- Xenon recoil ionization yield calibrated down to 300eV
- ~1e- is produced on average at 300eV (near quantum limit)
- Greatly improved accuracy from previous results
- TOF and PSD are essential in achieving low backgrounds
- Excessive background at threshold needs special care



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