MEASUREMENT OF THE CHARGE AND LIGHT YIELD OF LOW ENERGY ELECTRONIC RECOILS IN LIQUID XENON AT DIFFERENT ELECTRIC FIELDS

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XENON Dark Matter Project

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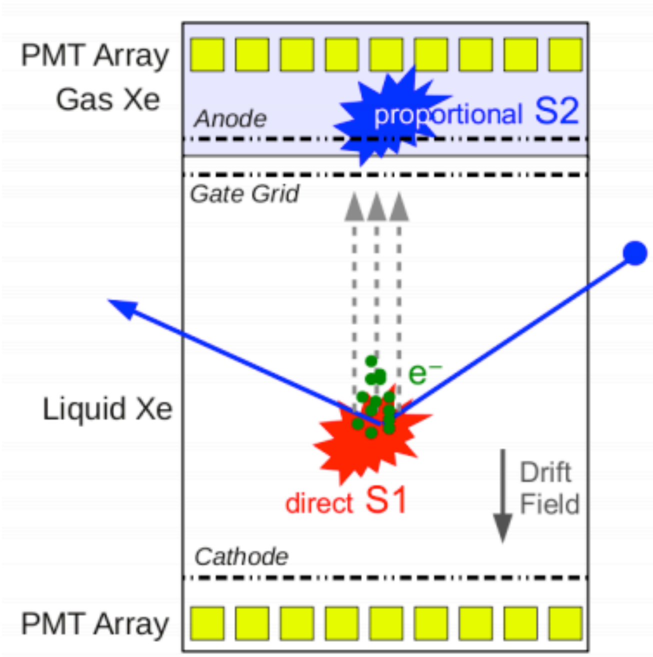
Motivation

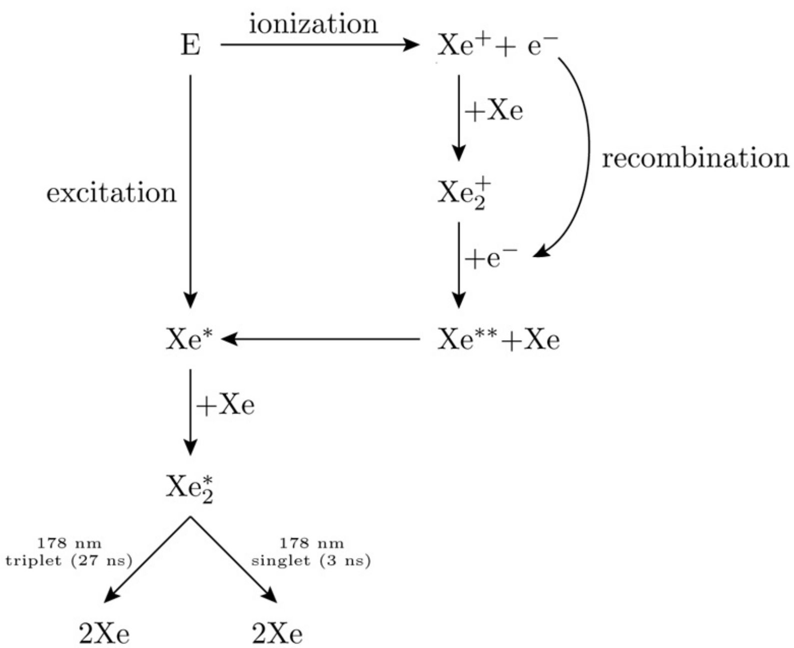
LXe experiments lead spin-independent dark matter scattering search

- Xenon100 (2012), LUX (2013), Xenon1T (2016?)

Dual-phase detectors ➔ simultaneously detect light and charge

- Prompt light emission from interaction in LXe (**S1**)
- Complementary signal from acceleration of electrons through GXe (**S2**)

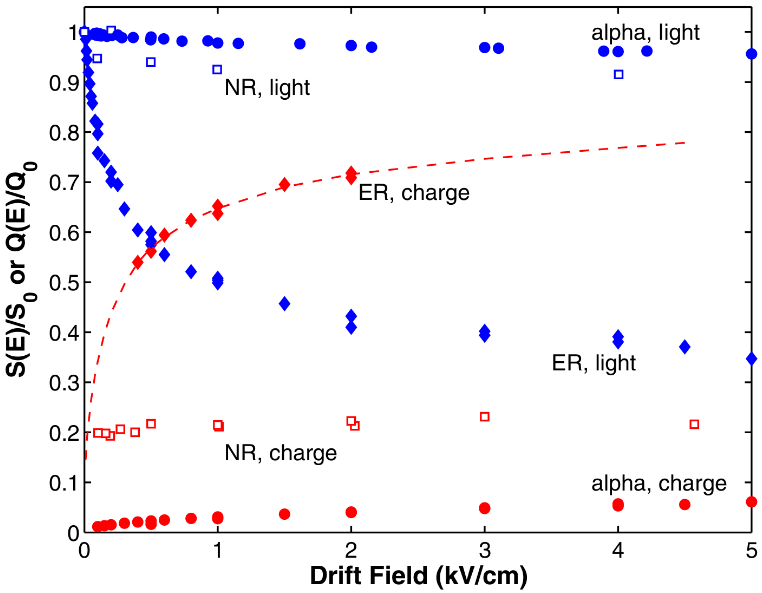


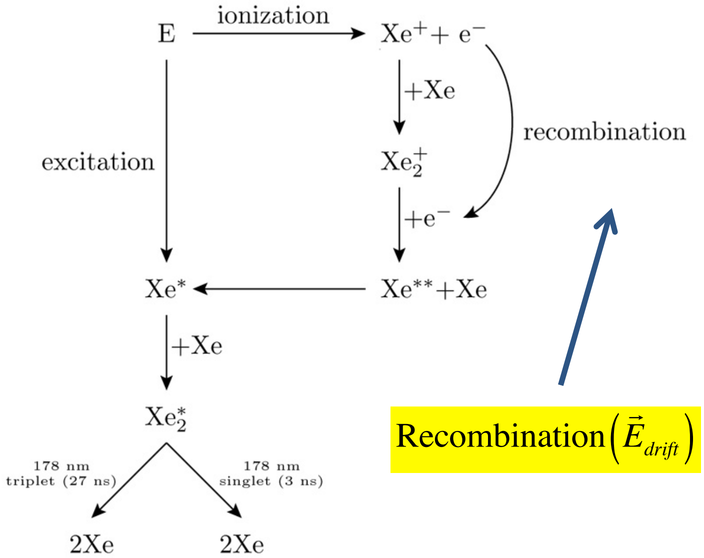


Motivation

Goal: improve understanding of low energy interactions in LXe

- **Given an electronic or nuclear recoil at a certain energy in a drift field, how much light and charge do you expect to be produced?**
- Light and charge yield **non-linear** in energy or drift field
  - Yield = Photoelectrons / Energy

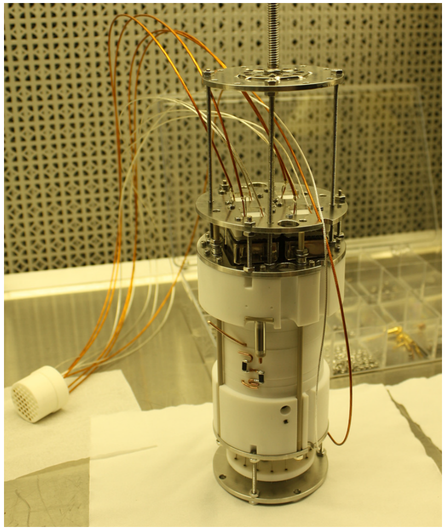


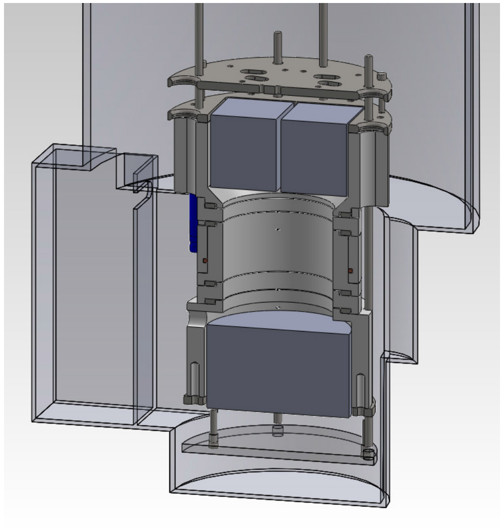


neriX Detector

Dual-phase LXe Time Projection Chamber for measuring **n**uclear and **e**lectronic **r**ecoils **i**n **X**enon

- Small size and minimal materials surrounding fiducial volume make this detector well-suited for measurements of the light and charge yield
- Unlike most previous measurements, can measure the light yield as a function of drift field applied
- Pursue light and charge yields as low as 1 keV





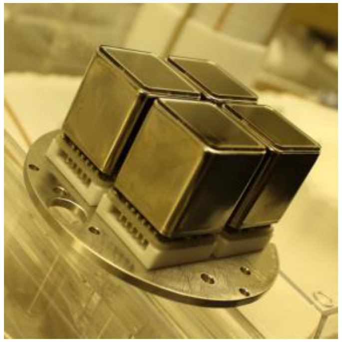
neriX Detector

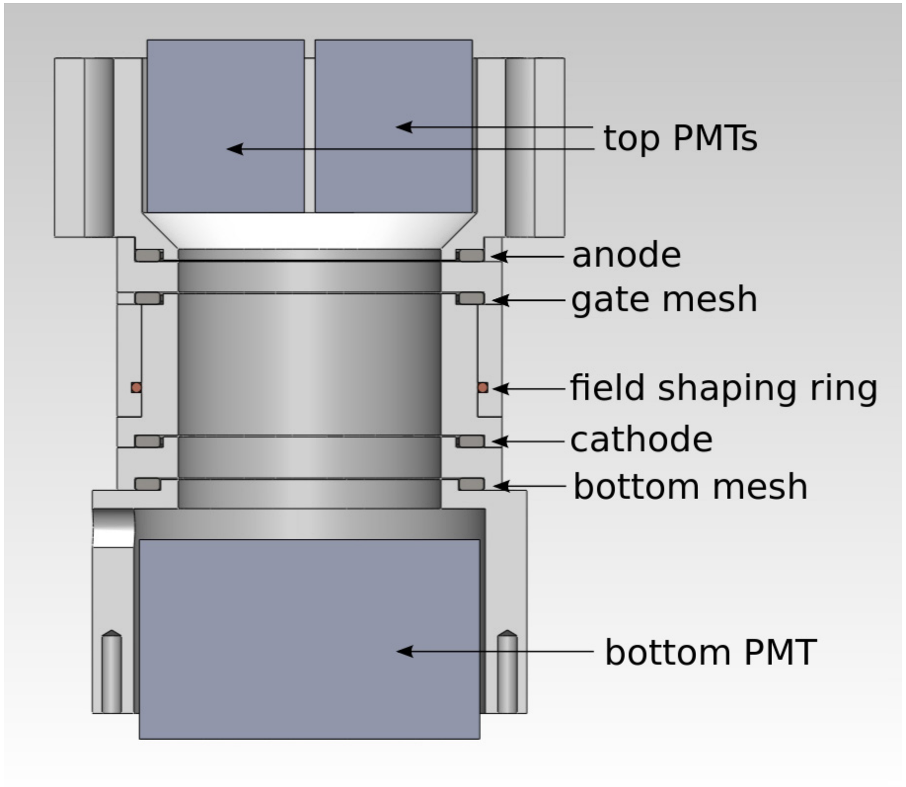
Very similar design to its much larger cousins

- Dual-phase (S1 and S2)
- 3D Position Reconstruction
- Stable cryogenics system

PMTs

- 4 1’’ square 4 channel PMTs on top (total of 16 channels)
- 1 2’’ diameter HQE PMT on bottom



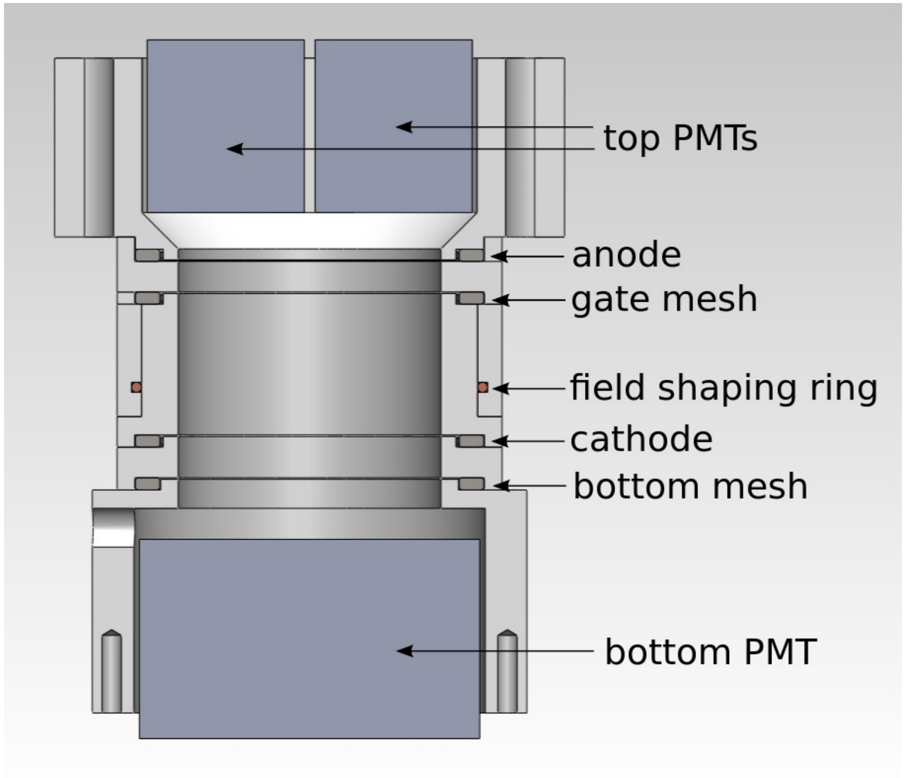


Component	Voltage [kV]
Anode Grid	4.5
Gate Grid	0
Shaping Rings	0
Cathode Grid	-0.345, -1.054, -2.356, -5.500
Bottom Mesh	0

Drift Fields

Measured the light and charge yield at four different drift fields

- All components but cathode kept constant between setups
- Simulations of the field performed in Comsol



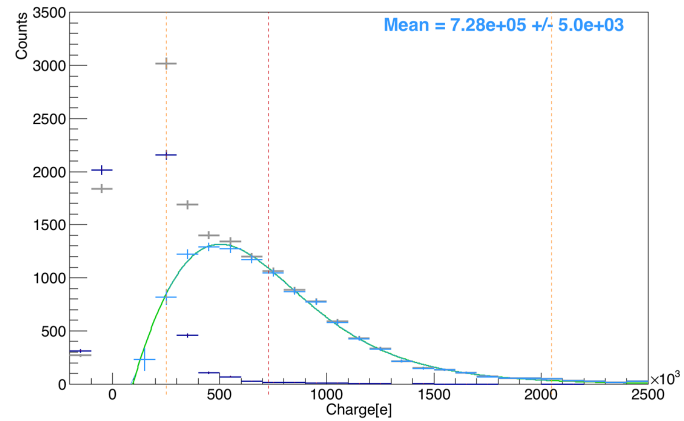
Cathode Voltage [kV]	Drift Field [V/cm]
-0.345	210
-1.054	490
-2.356	1000
-5.500	2250

Component	Voltage [kV]
Anode Grid	4.5
Gate Grid	0
Shaping Rings	0
Cathode Grid	-0.345, -1.054, -2.356, -5.500
Bottom Grid	0

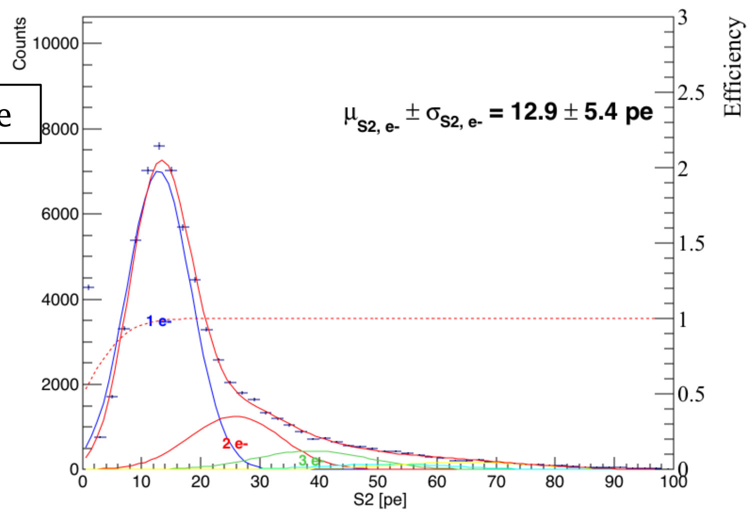
Single Photoelectron and Electron Detection

- Single Photoelectron Gain
  - Use LED at low light level to measure SPE gain
  - Relatively low gain (~4-7 x 10^5 e^-) to avoid saturation
  - Use background subtraction and coincidence cut to clean distribution
- Single Electron Gain
  - Use photoionization of cathode by S2 to find small numbers of electrons

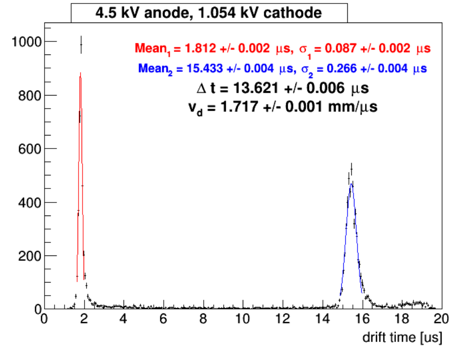
SPE Gain Calibration



Single Electron Gain



Photoionization of Anode and Cathode



More details on single electron gain: J. Phys. G: Nucl. Part. Phys. 41 (2014) 035201

Position Reconstruction

Similar to larger LXe detectors, neriX is able to reconstruct the 3D position of an event

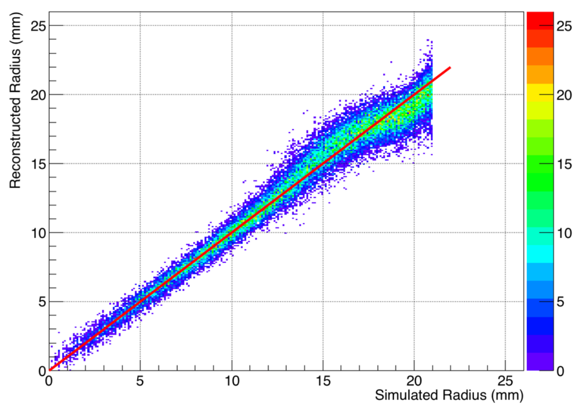
- More difficult given small size of the detector
- Used Geant4 construction of the detector to simulate S2 patterns at given positions
- Train neural network on the simulation using FANN open source library
- Average error of simulated data inside radius of 18 mm ≅ 0.5 mm

$$\{S2_1, \ldots, S2_{16}\} \Rightarrow$$

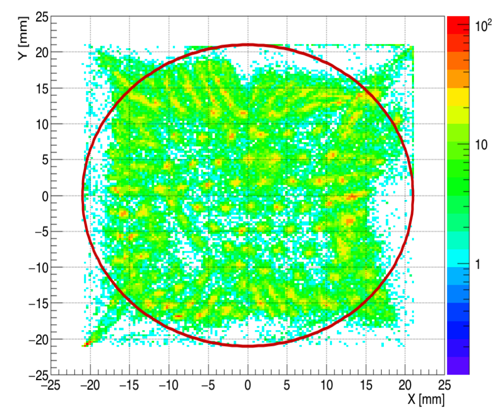
FANN

$$\Rightarrow \{X, Y\}$$

Simulated vs. Reconstructed Position



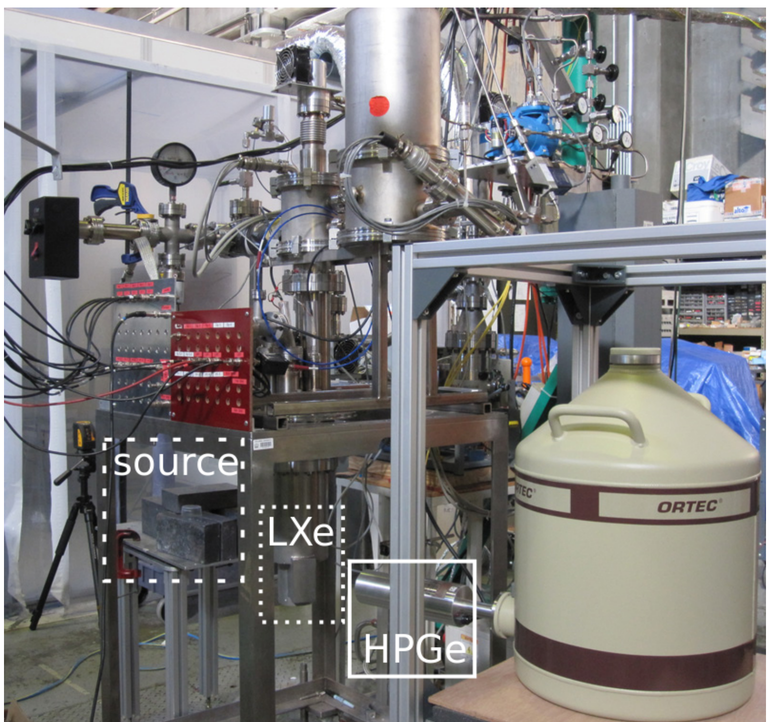
Co-57 Position Reconstruction

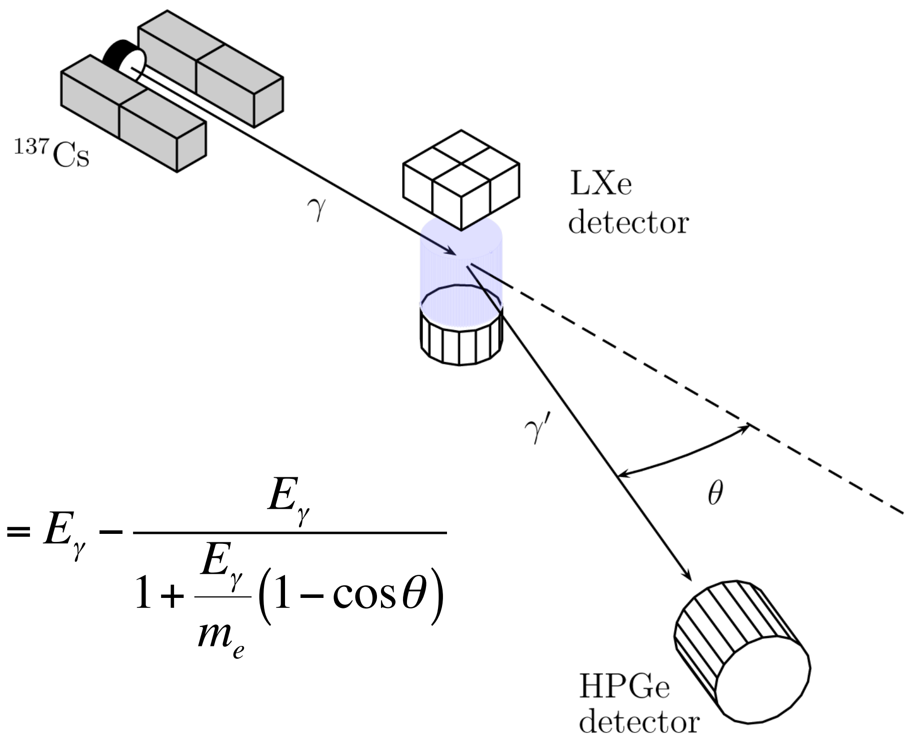


Compton Coincidence Technique

Energy deposited in LXe determined using Compton Coincidence Technique

- Photons Compton scatter in LXe then deposit remaining energy in HPGe detector





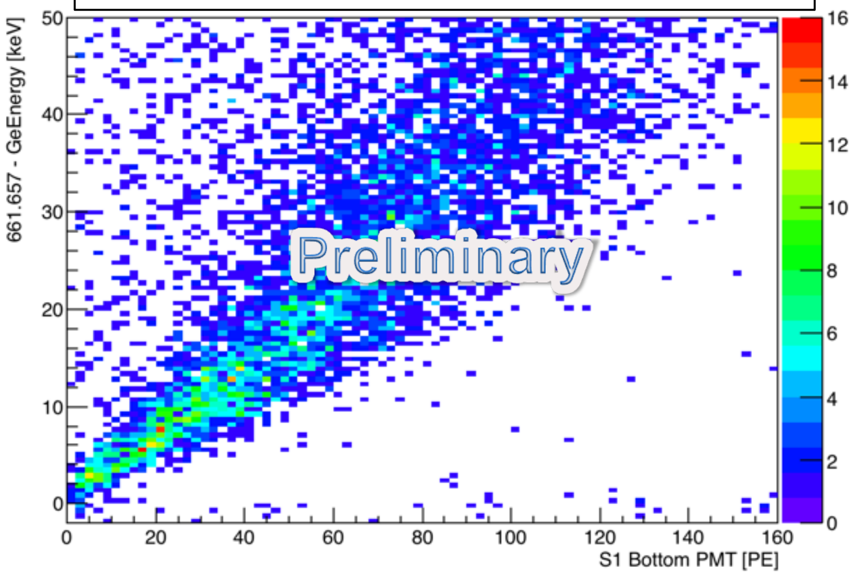
$$E_r = E_\gamma - \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e}\left(1 - \cos\theta\right)}$$

Coincidence Spectrum

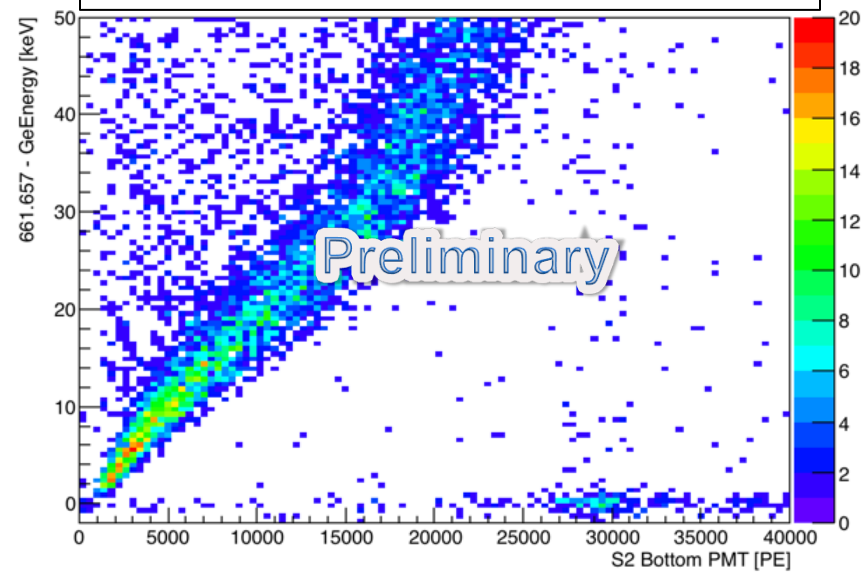
Below are two sample coincidence spectra that are used to determine the light and charge yield at a given energy

All data are **preliminary**

Prompt Scintillation Light (S1) vs. Energy Deposited in LXe

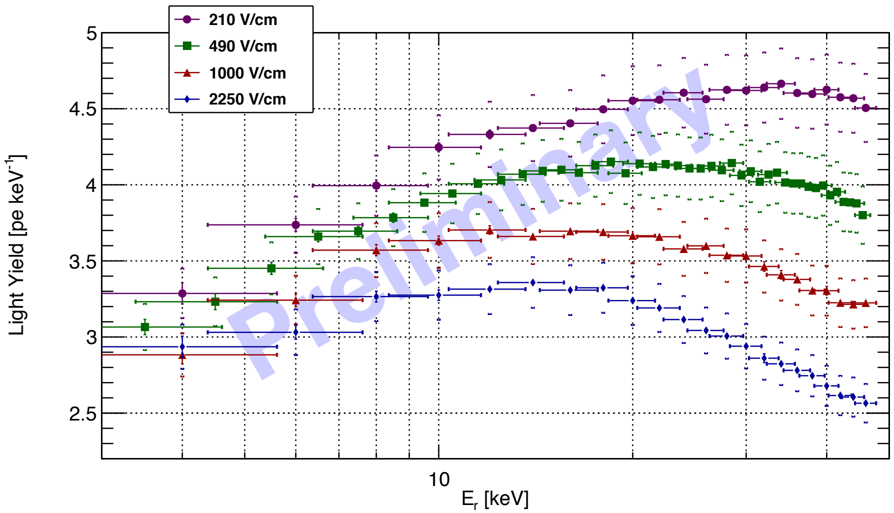


Proportional Scintillation Light (S2) vs. Energy Deposited in LXe

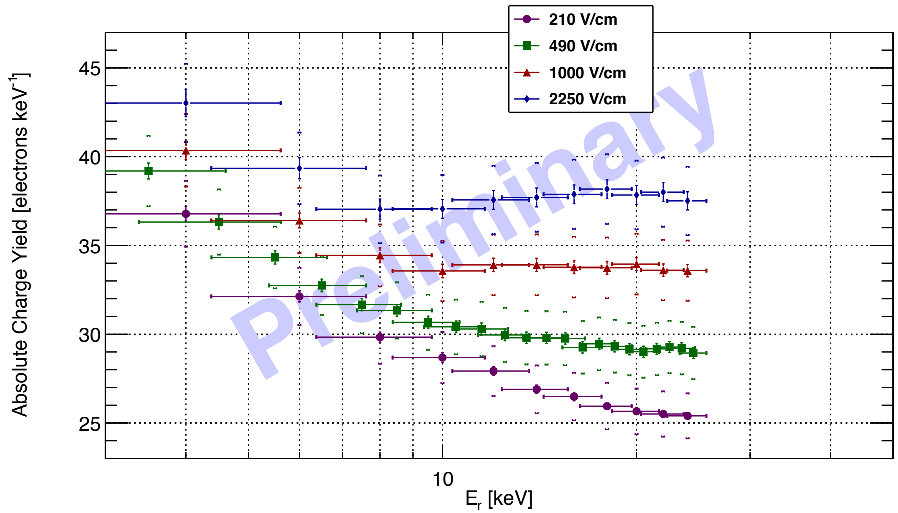


Electronic Recoils: Light and Charge Yields

Light Yield vs. Recoil Energy

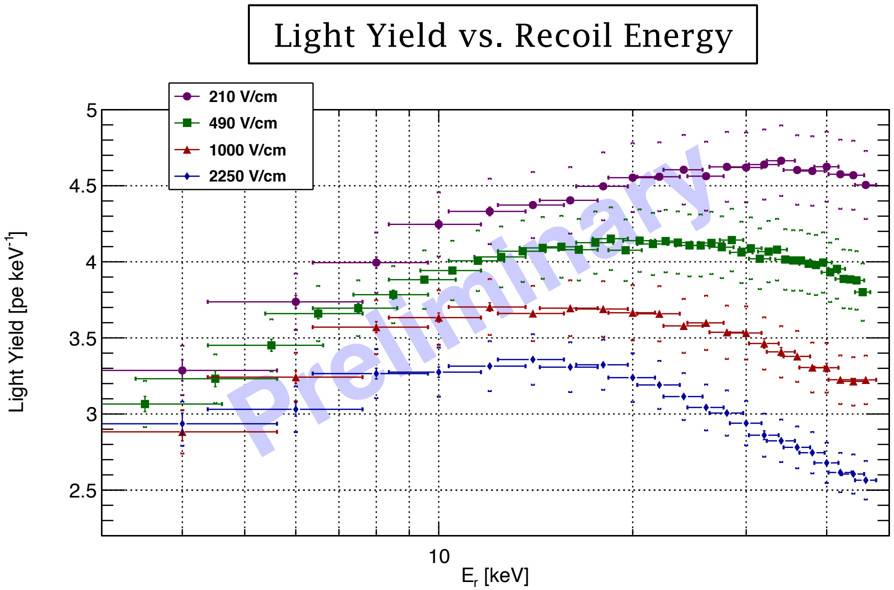


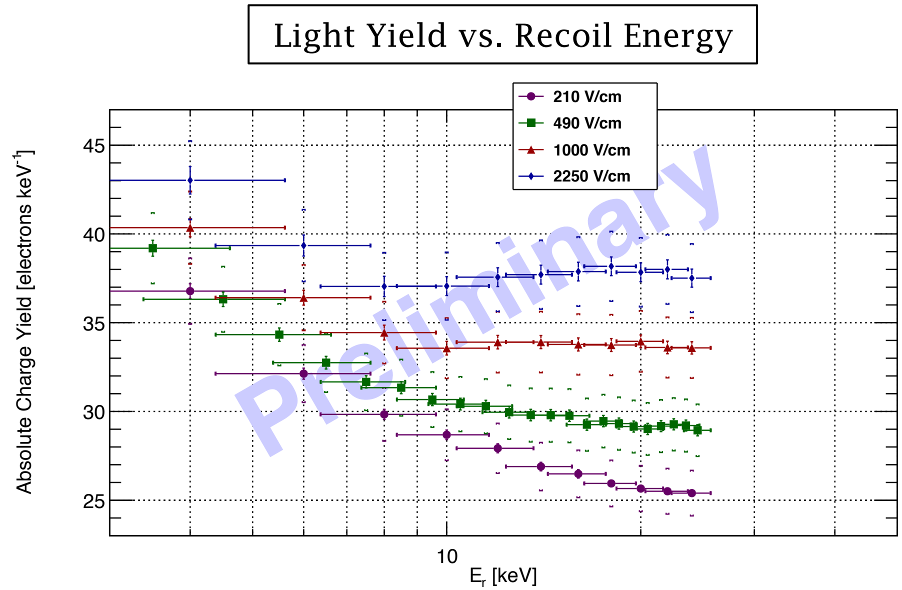
Light Yield vs. Recoil Energy



- By projecting energy slices in the previous plots into S1 and S2, we can fit the remaining spectrum for the yield
- Above are preliminary results for the light and charge yield at different drift fields

Electronic Recoils: Light and Charge Yields





- S1 and S2 **anti-correlated** with respect to field
- Below 10 keV, light yield **increases** with energy and charge yield **decreases** with energy for all fields

- Light and charge yield measured down to 1 keV – stay tuned!

Nuclear Recoils: Light and Charge Yields

- In coming months, will perform very similar measurement with neutron source
- Similar concept but with additional complications
  - No energy resolution in liquid scintillators – completely dependent on scattering angle for determination of energy deposited in LXe
  - Must account for neutron time of flight in coincidence trigger