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

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Xe XENON Dark Matter Project

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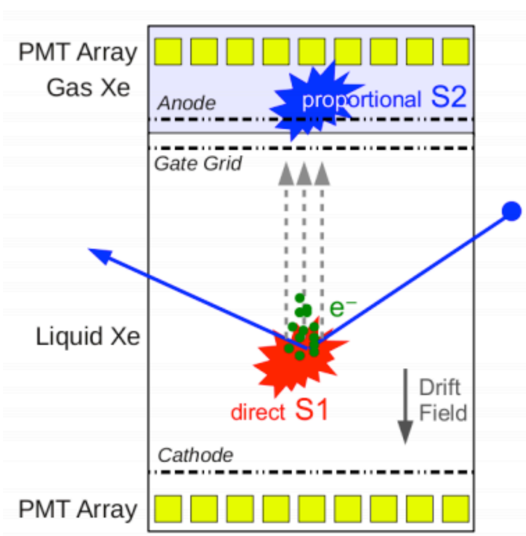
Motivation

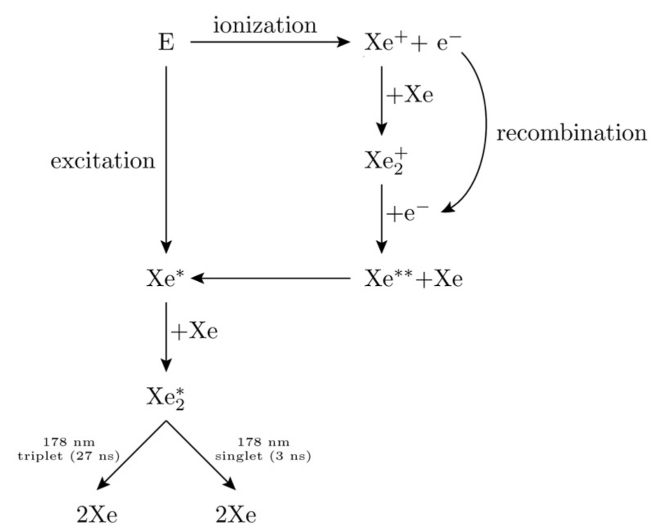
Currently, LXe experiments lead in the search for spin-independent dark matter scattering

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

These detectors are dual-phase, giving them the ability to simultaneously detect the light and charge from an interaction inside of the detector

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





Motivation

Persisting question for this type of detector: how do we best relate these signals to the energy of the interaction?

- Current approach is to use prompt scintillation signal (S1) only for energy reconstruction
- Ideal approach would be to use both prompt scintillation signal (S1) and proportional scintillation signal (S2) for energy reconstruction
- Energy reconstruction is limited by the light and charge yield
  - Yield = Photoelectrons / Energy

Large detectors, while ideal for dark matter detection, are ideal for the direct detection of light and charge yield

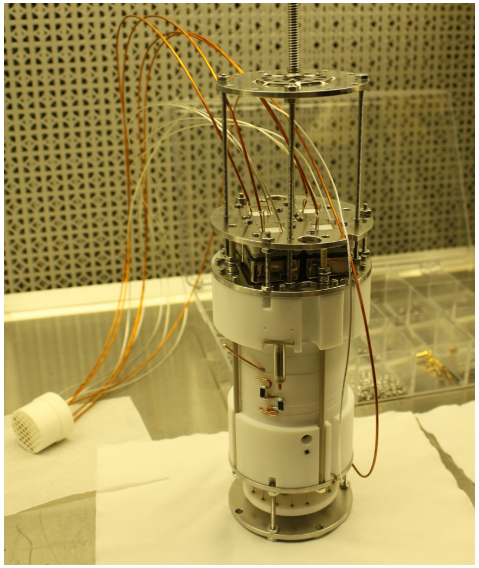
- Self-shielding property of LXe becomes detriment in these measurements

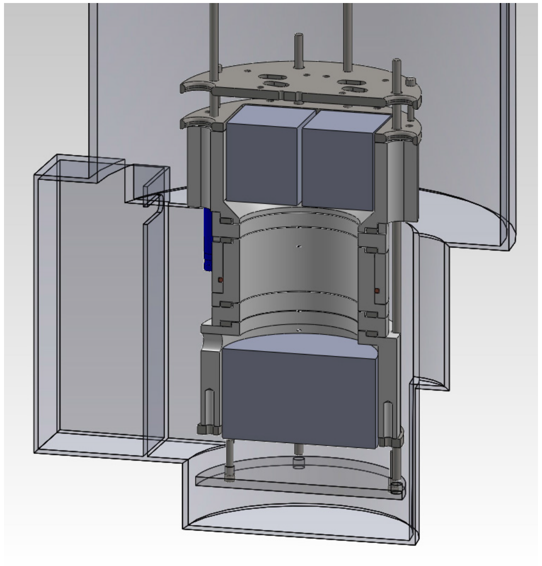
Must create specialized detector to measure these quantities precisely and down to low energies

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





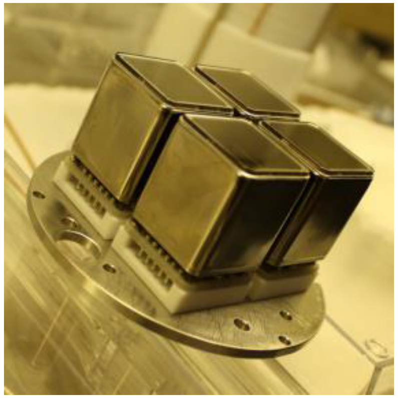
neriX Detector

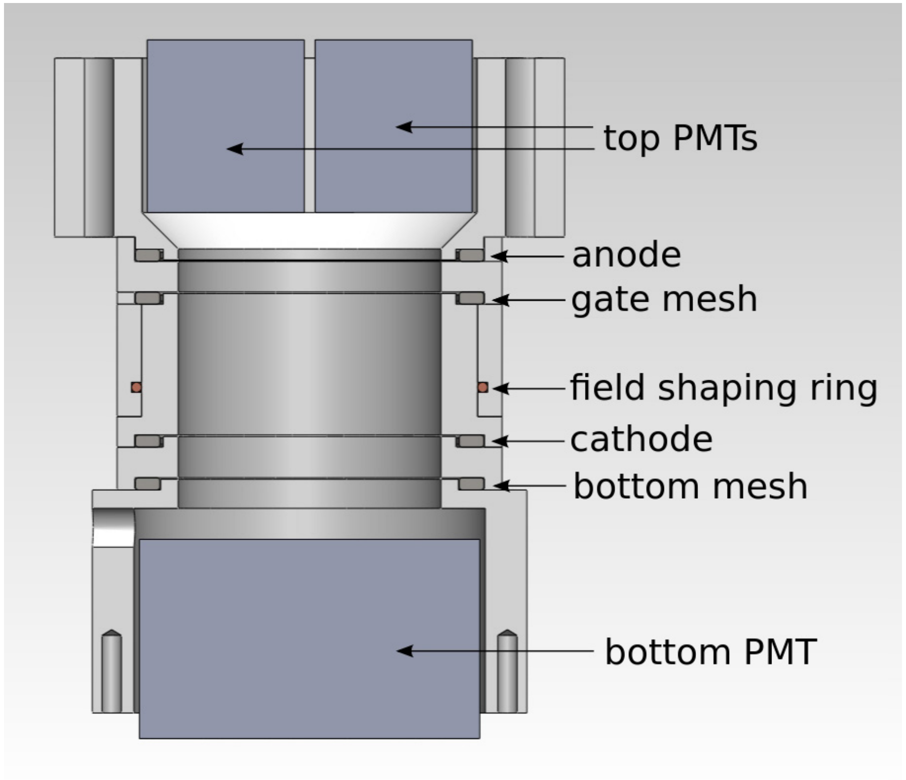
Very similar design to its much larger cousins

- 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



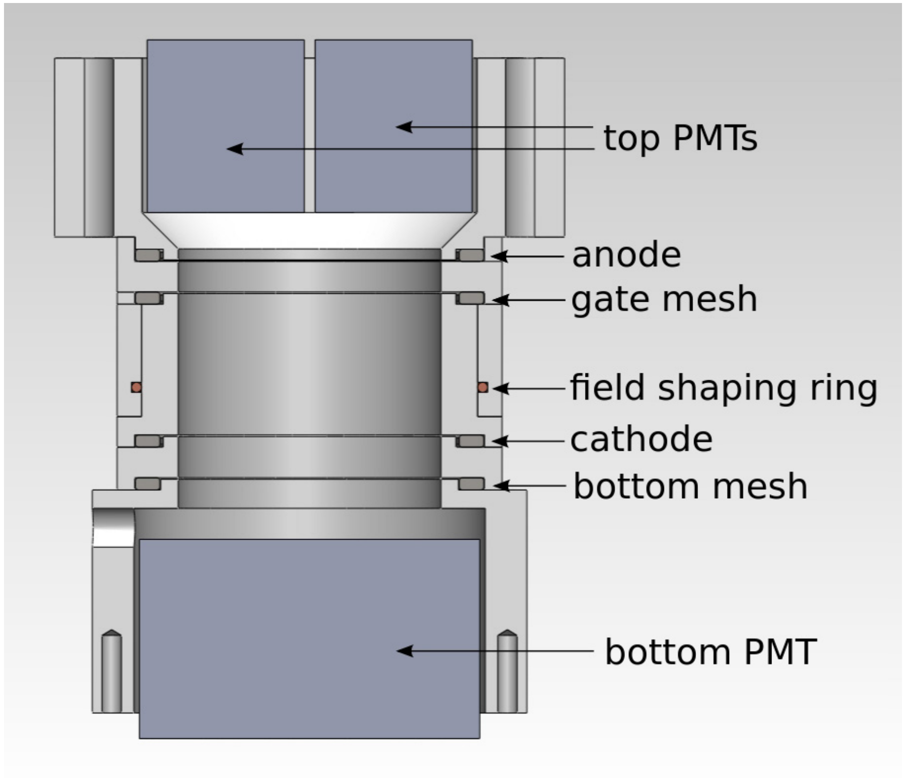


Component	Voltage [kV]
Anode Grid	4.5
Gate Grid	0
Shaping Rings	0
Cathode Grid	-0.345, -1.054, -2.356, -5.500
Bottom Mesh	0

Drift Fields

Measured the light and charge yield at four different drift fields

- Anode grid, gate grid, shaping rings, and bottom grid all kept constant between setups
- Cathode varied to voltages listed below
- Simulations of the field performed in Comsol

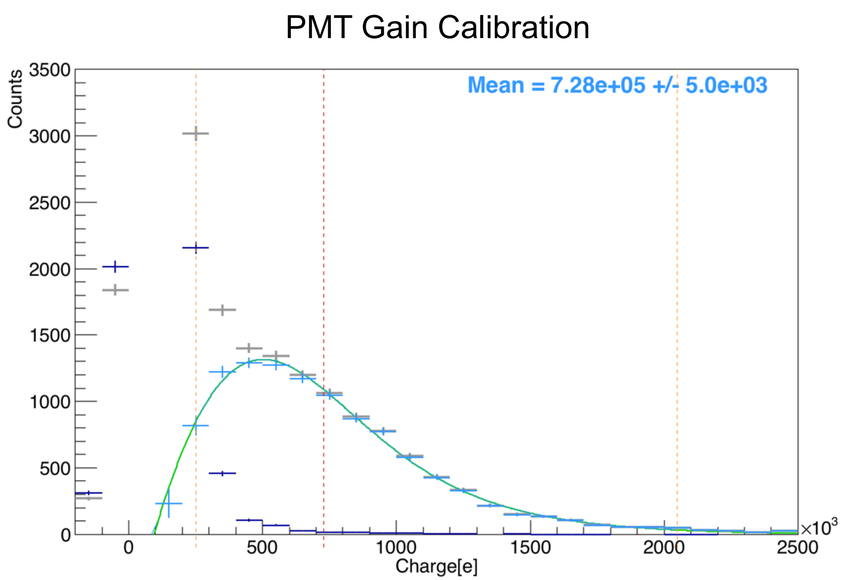


Cathode Voltage [kV]	Drift Field [V/cm]
0.345	200
1.054	480
2.356	1000
5.500	2250

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

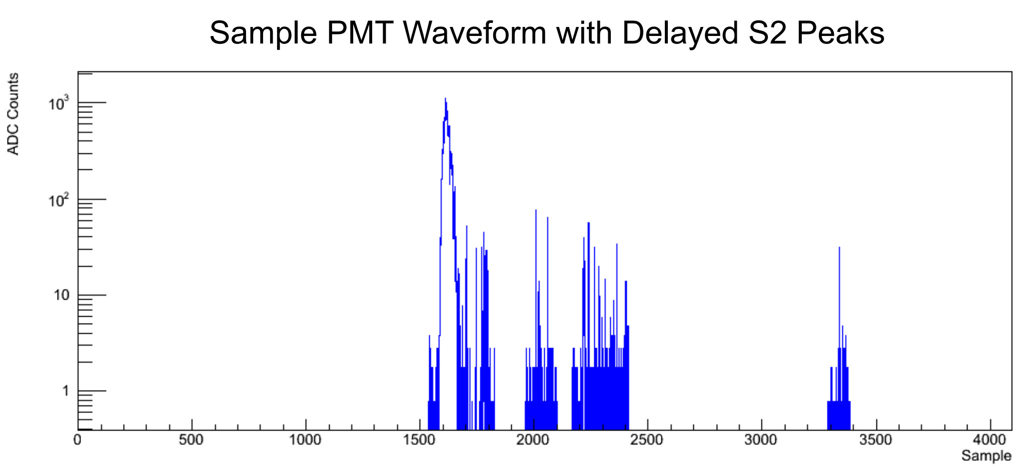
Single Photoelectron Detection

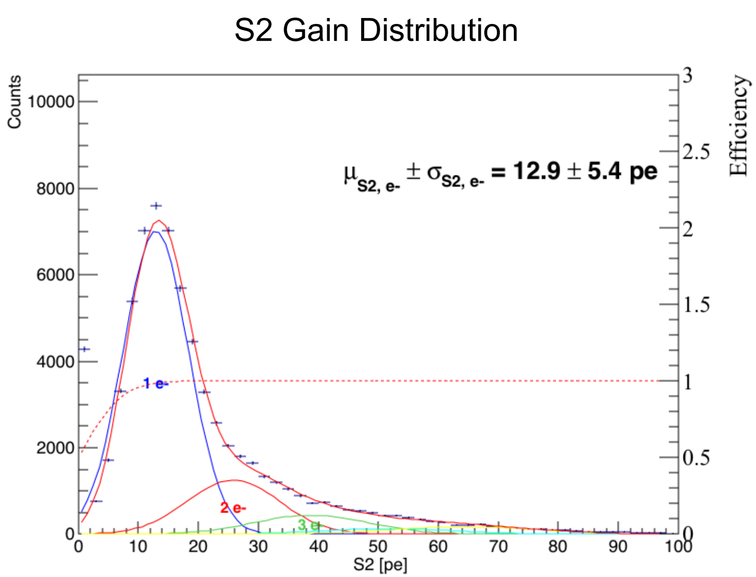
- Using LED at low light level, we are able to determine the response of each of the 17 PMT channels
- To avoid PMT saturation at higher energies, we use a relatively low gain (~4-7 x 10^5 e^-)
- Use background subtraction and coincidence cut to clean distribution
- Determine the gain by using a MC where individual fit parameters were varied according to their means and uncertainties



Single Electron Detection

- Some small number of electrons that are freed after an interaction in the LXe will become trapped at the liquid-gas boundary
- Some of these electrons will eventually make it through the boundary and produce an S2 signal several microseconds after the main S2 signal
- These single electrons that make it through can be used to determine the S2 gain (PE per extracted e^-)





Position Reconstruction

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

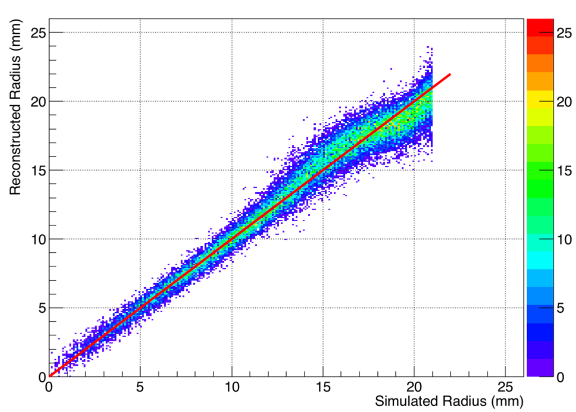
- More difficult given small size of the detector
- Used Geant4 construction of the detector to simulate S2 patterns at given positions
- Train neural network on the simulation using FANN open source library
- Perform small correction to account for different QE and CE of each PMT and PMT channel
- Average error of simulated data inside radius of 18 mm ≅ 0.5 mm

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

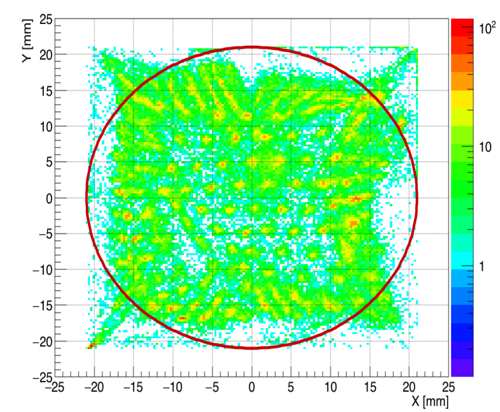
FANN

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

Simulated vs. Reconstructed Position



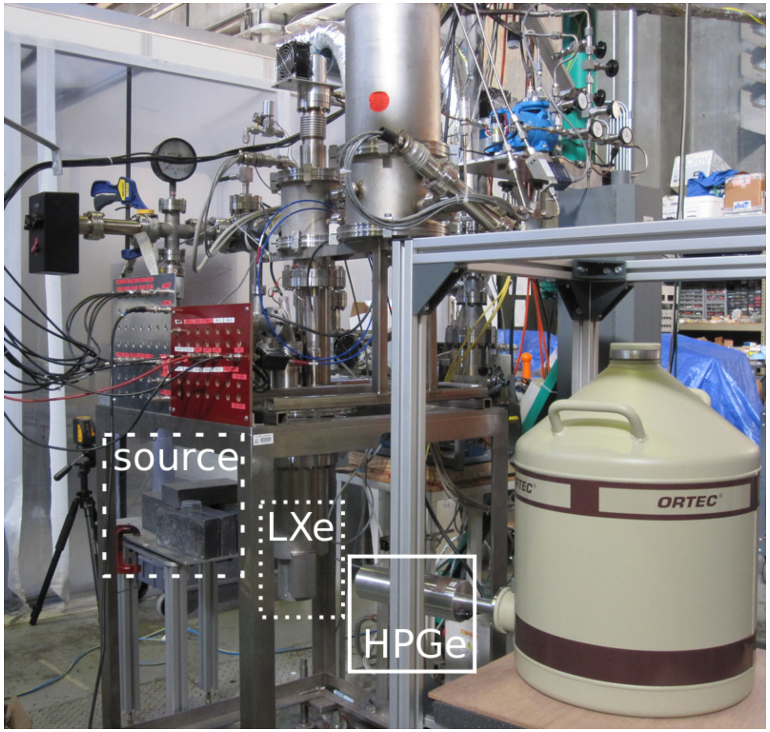
Co-57 Position Reconstruction

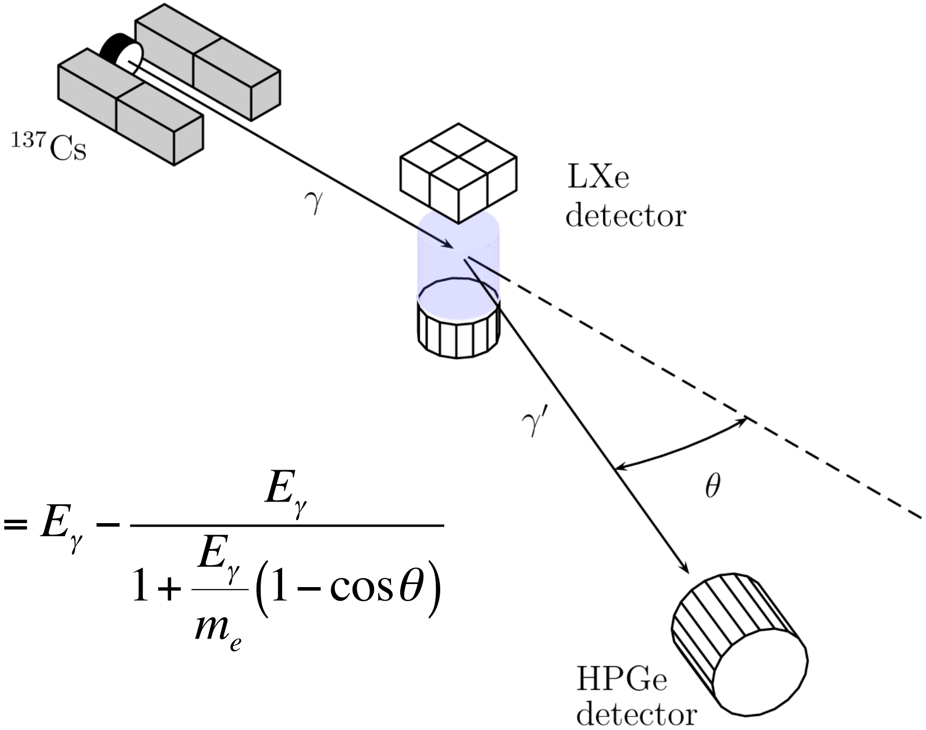


Compton Coincidence Technique

Energy deposited in LXe determined using Compton Coincidence Technique

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





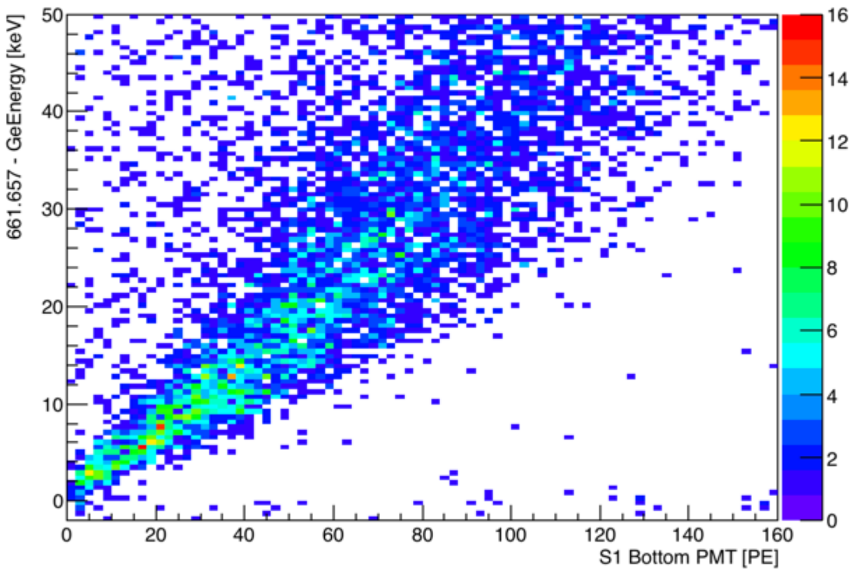
$$E_r = E_\gamma - \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e}(1 - \cos\theta)}$$

Coincidence Spectrum

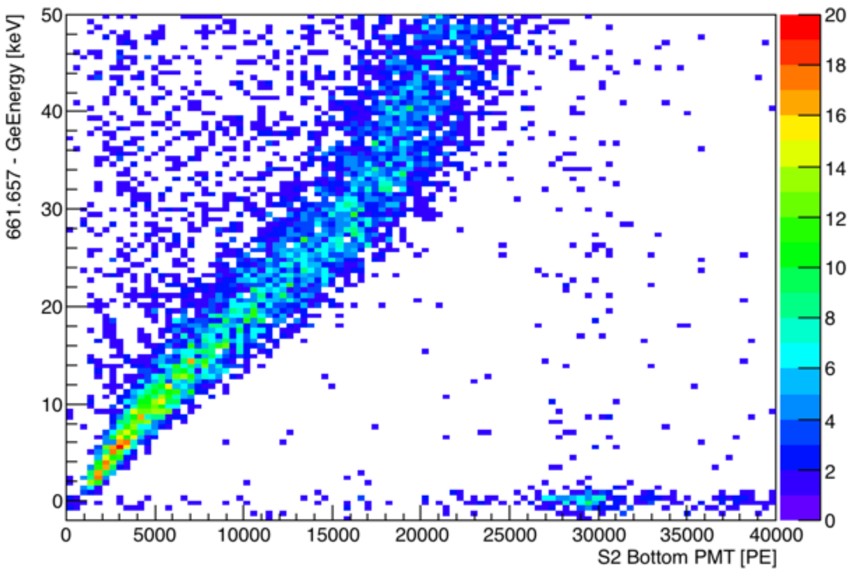
Below are two sample coincidence spectra that are used to determine the light and charge yield at a given energy

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

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

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