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

Matthew D. Anthony

June 25, 2015

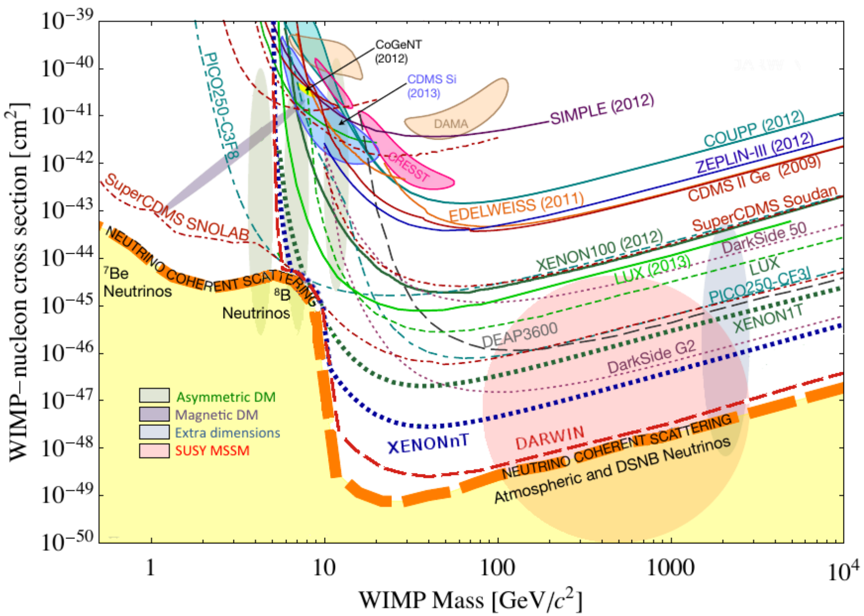
XENON Dark Matter Project

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

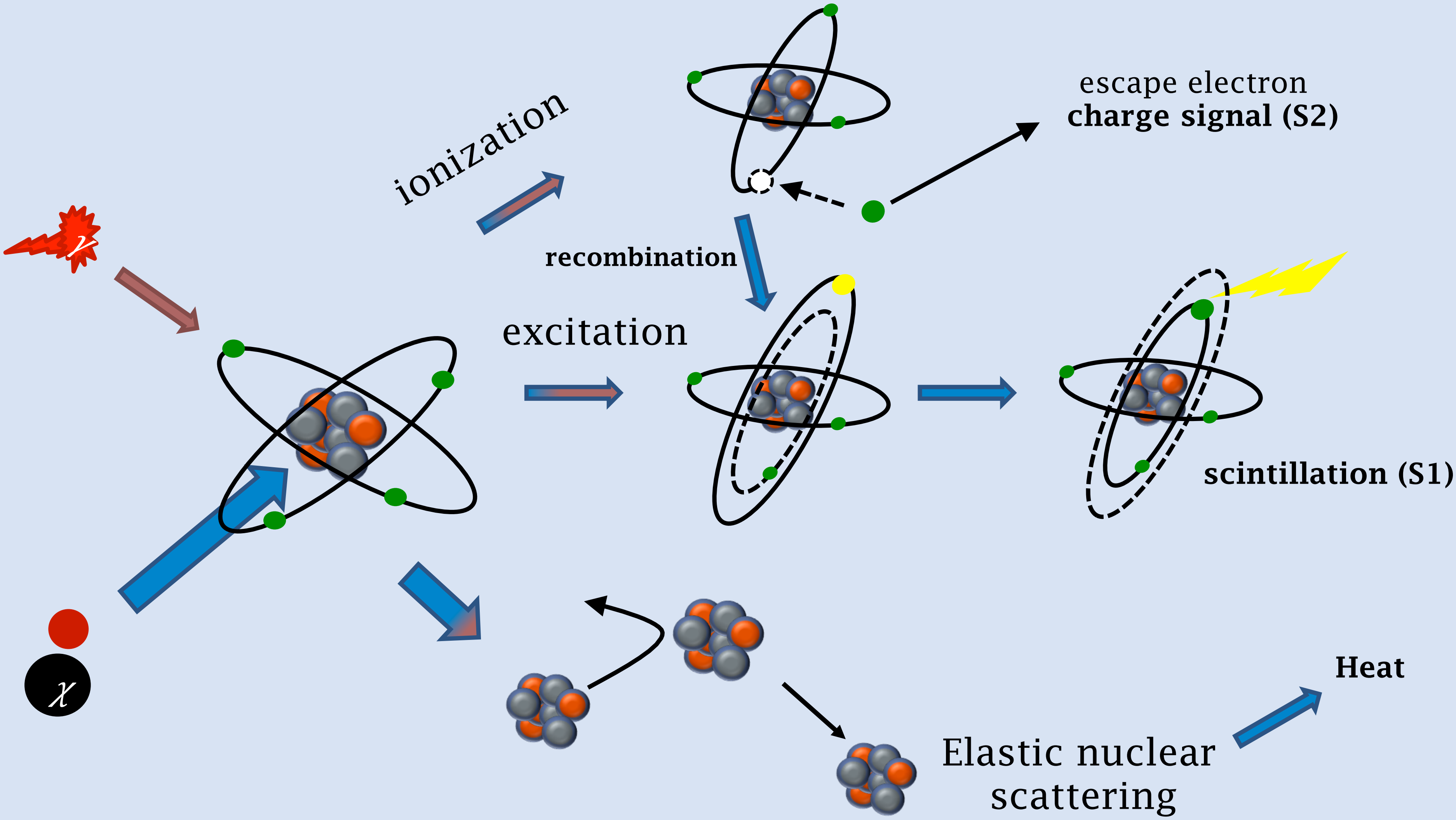
Motivation

LXe experiments lead direct search for dark matter

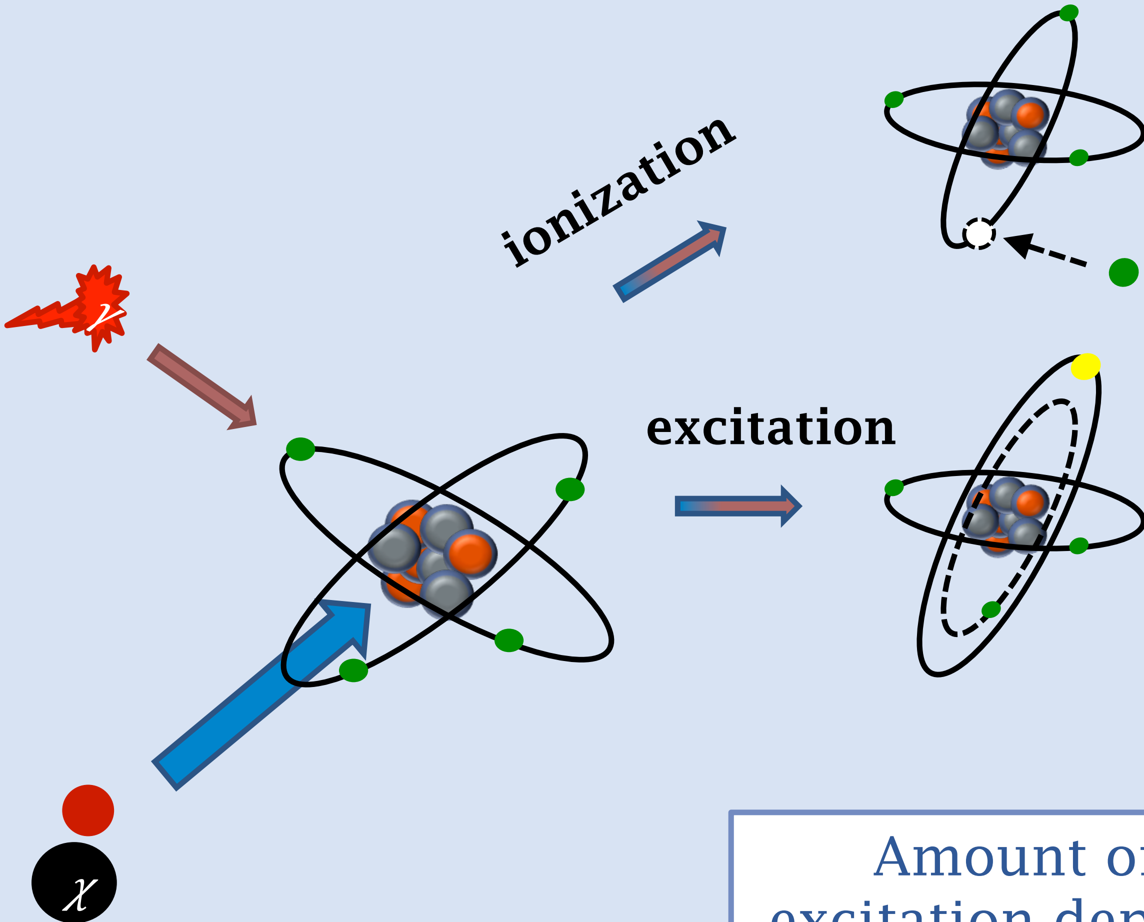
- Xenon100, LUX, Xenon1T



Motivation

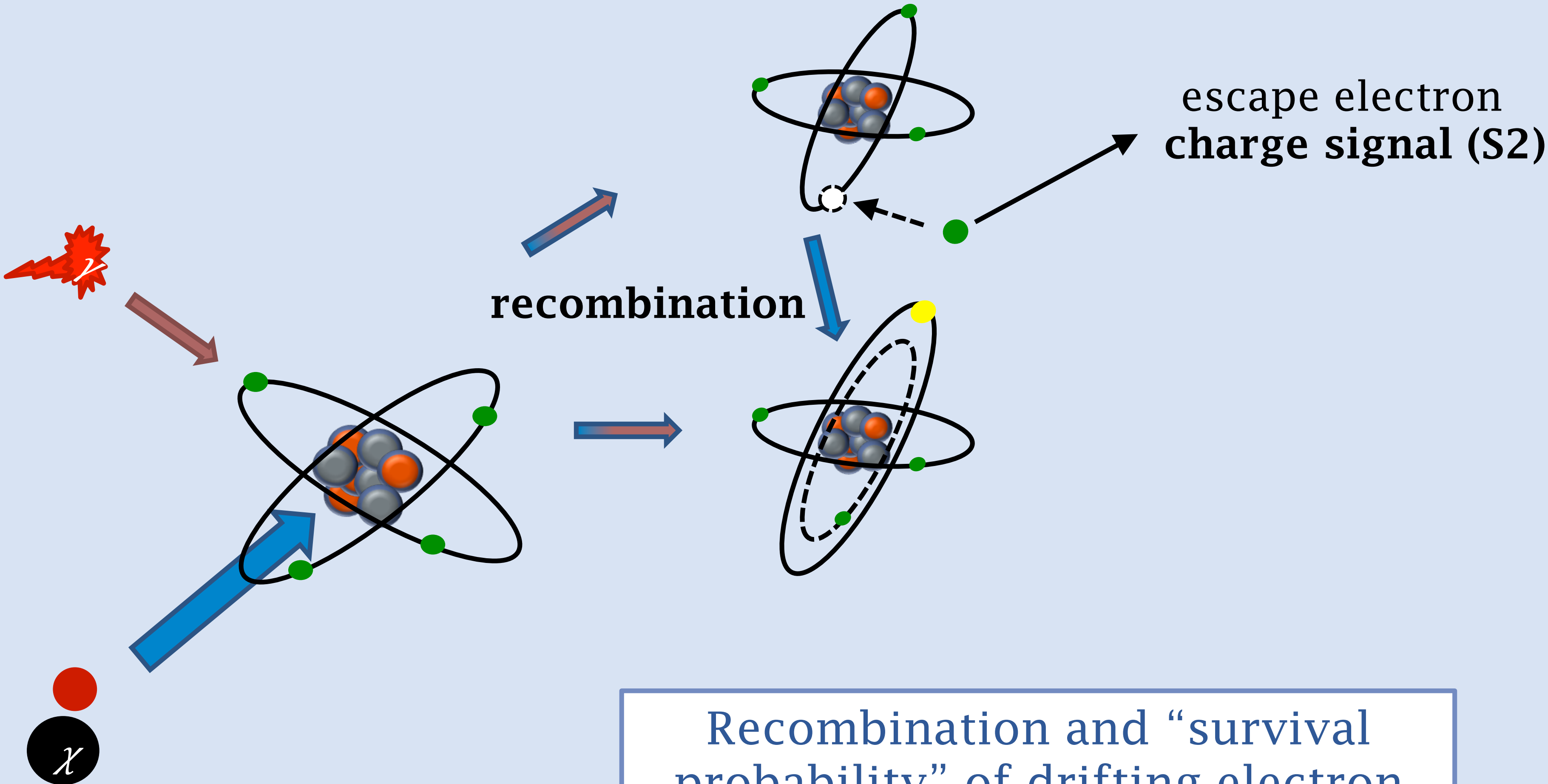

ionization
escape electron
charge signal (S2)
recombination
excitation
scintillation (S1)
χ
Heat
Elastic nuclear scattering

Motivation



Amount of ionization and excitation dependent upon **recoil energy** and **particle type**

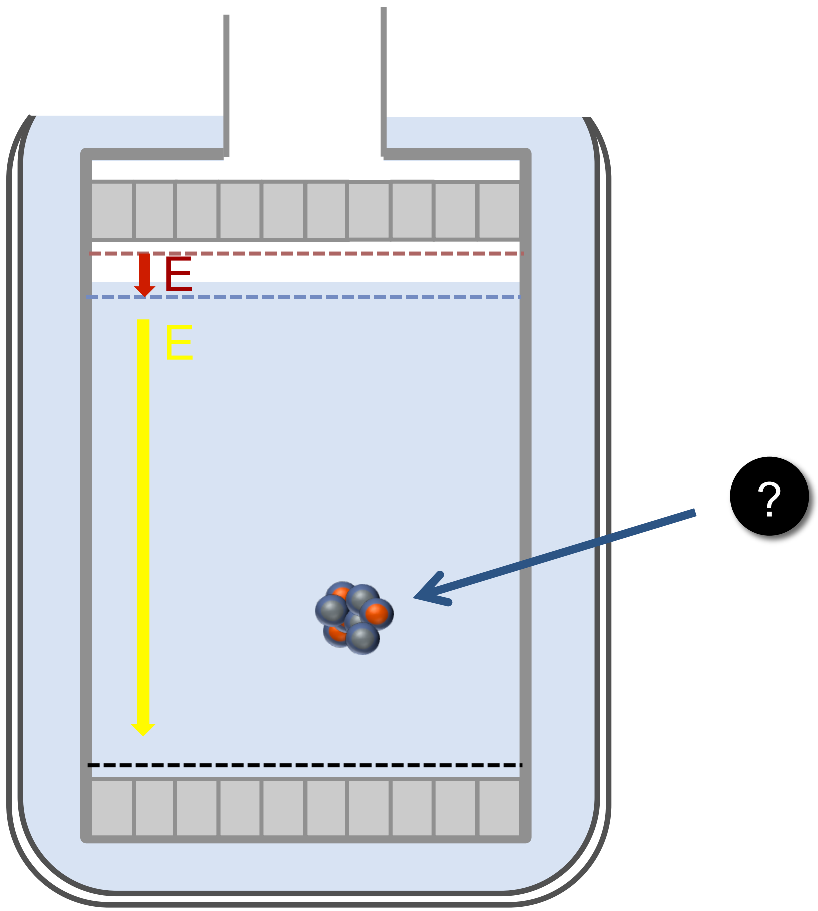
Motivation



Recombination and "survival probability" of drifting electron depend on **electric field**

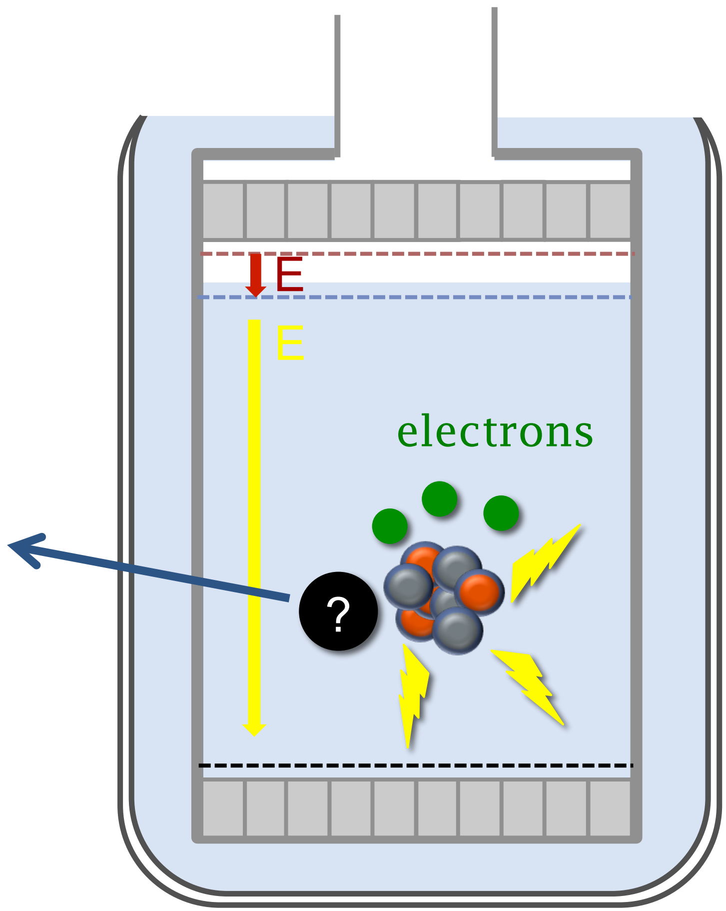
Motivation

A given particle enters the detector and interacts in the LXe



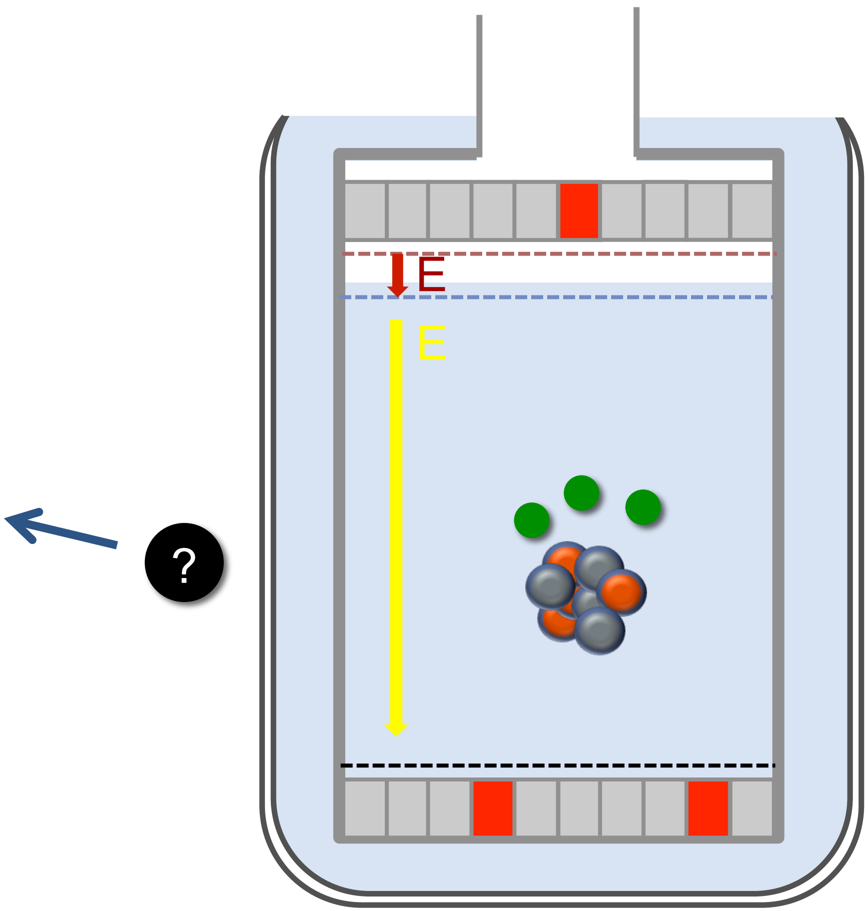
Motivation

Xenon atoms are simultaneously excited and ionized creating photons and free electrons

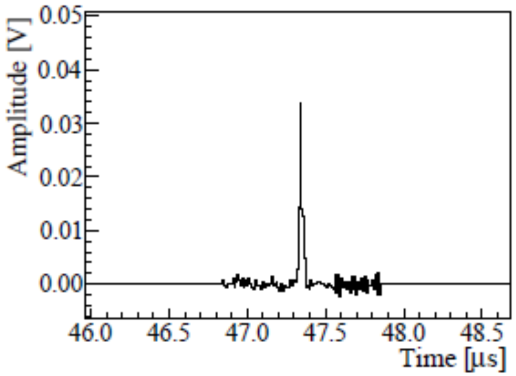


Motivation

Scintillation light from xenon excitation seen by PMTs almost immediately

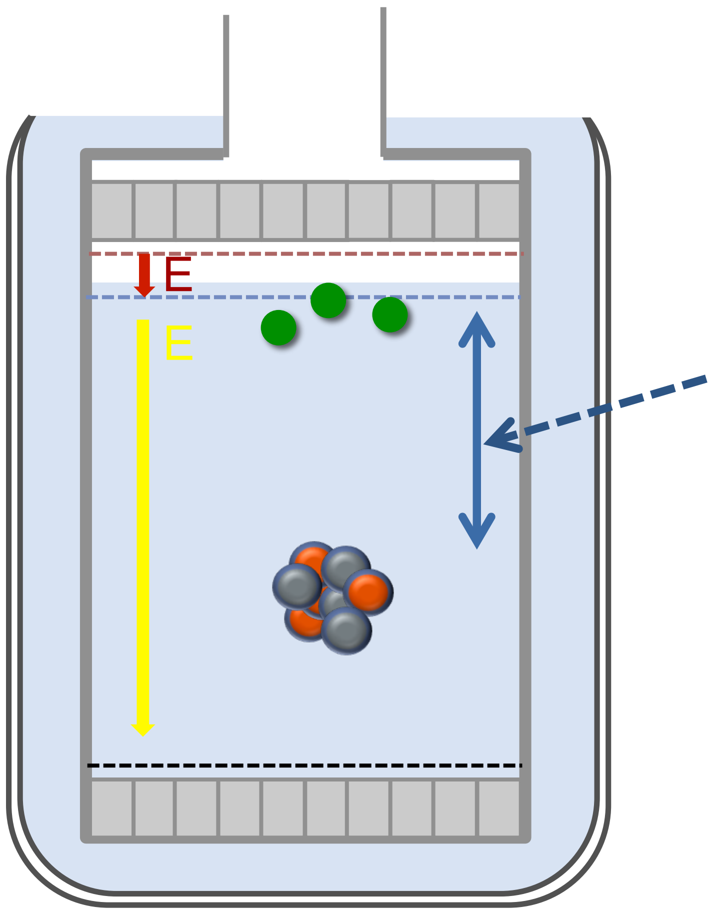


S1



Motivation

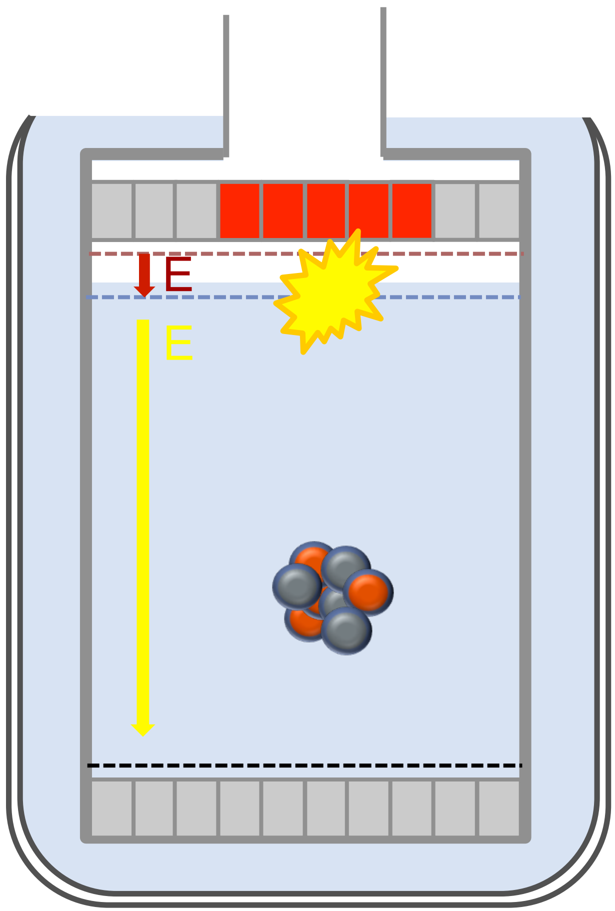
After a time on the order of microseconds, electrons that remain free reach liquid gas interface



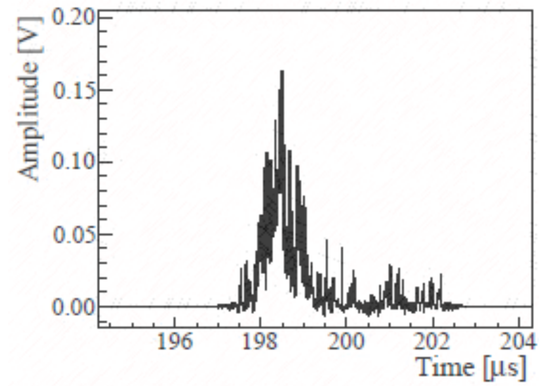
dt ~ μs

Motivation

Free electrons are extracted into the GXe and accelerated through creating light proportional to the number of electrons



S2



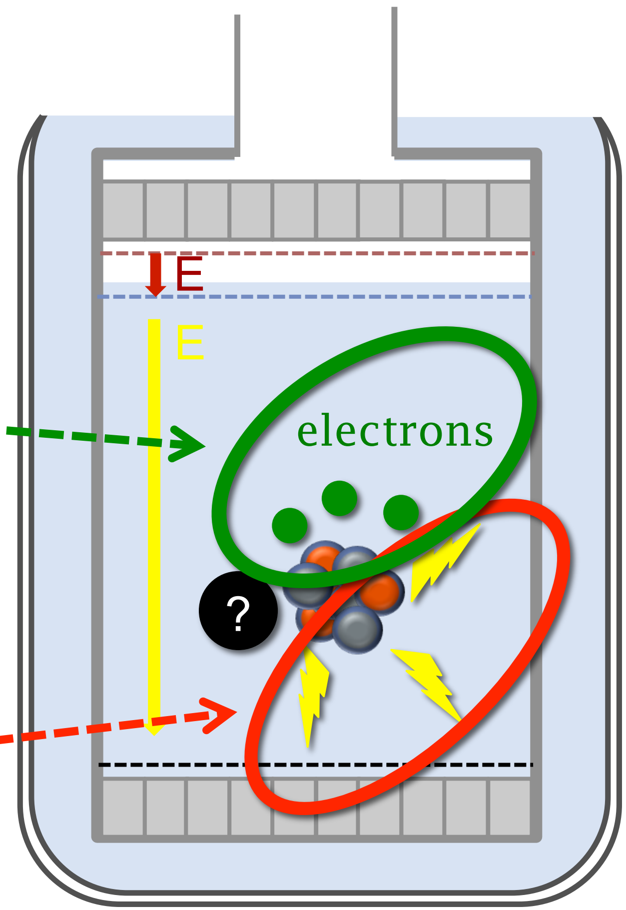
Motivation

Goal: improve understanding of low energy interactions in LXe

Charge Yield = **Electrons** / Energy

Energy | Drift Field | Particle

Light Yield = **Photons** / Energy



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?**

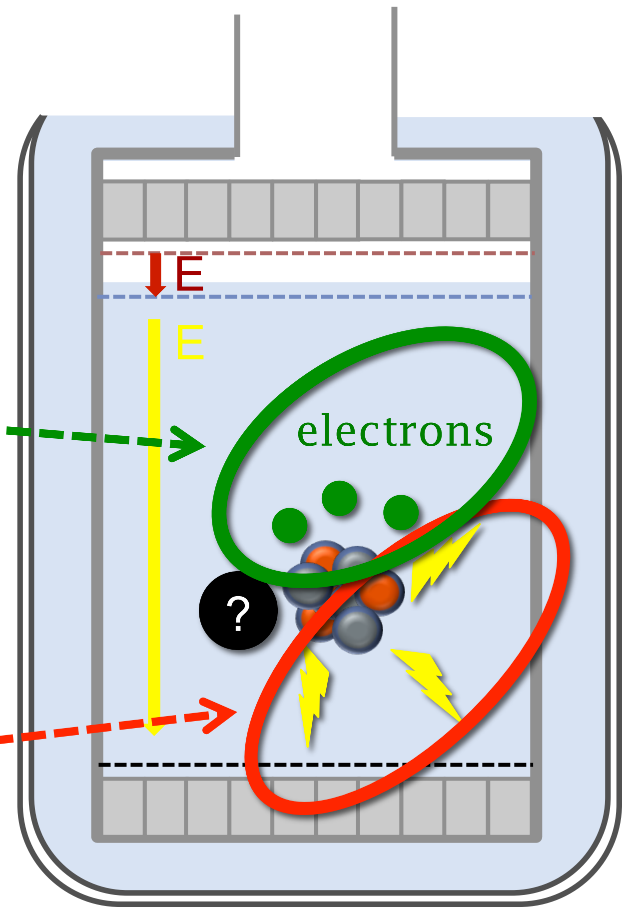
Charge Yield = Electrons / Energy

Energy

Drift Field

Particle

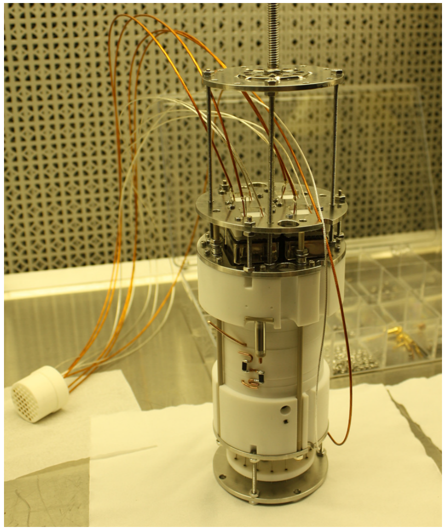
Light Yield = Photons / Energy

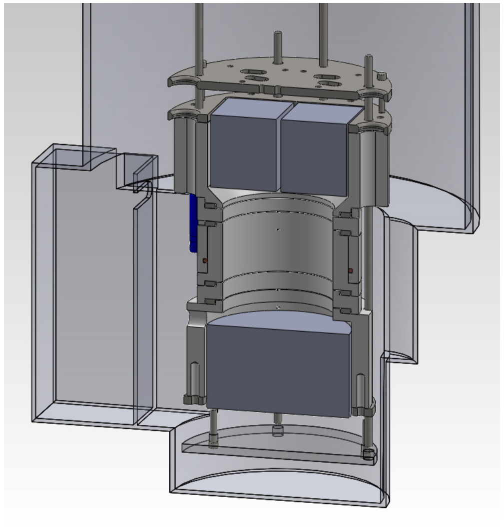


neriX Detector

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 and charge yield as a function of drift field applied
- Pursue light and charge yields as low as 1 keV





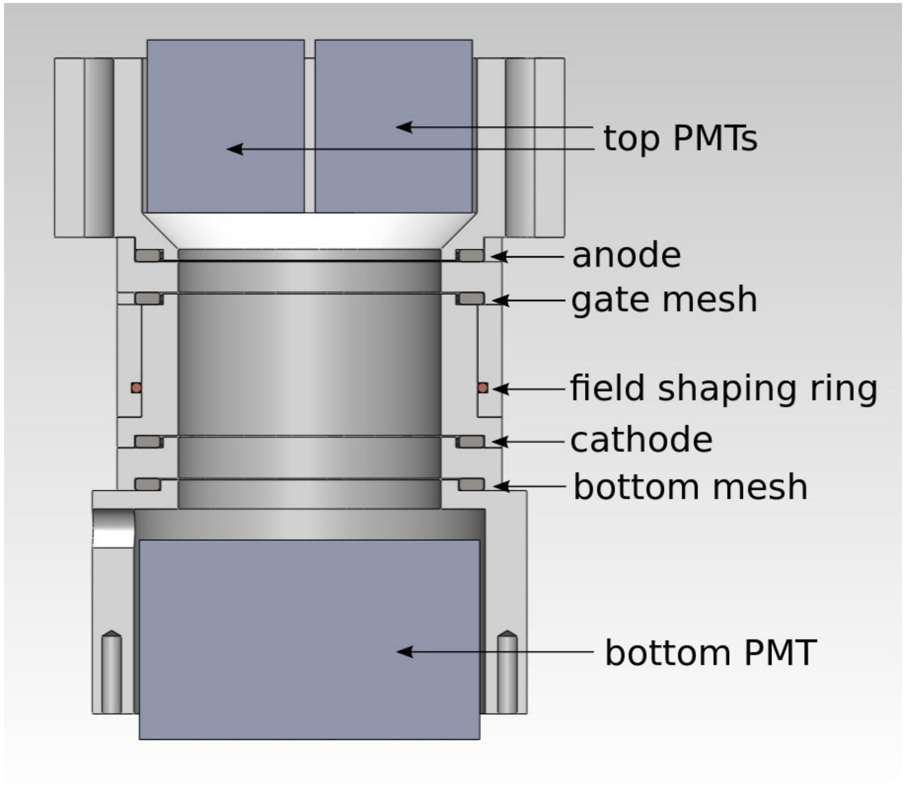
neriX Detector

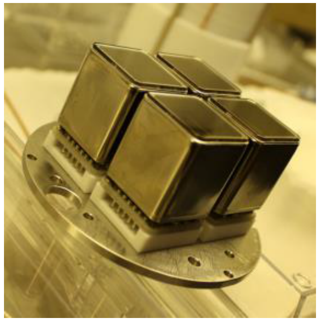
Very similar design to its much larger cousins

- Dual-phase (S1 and S2)
- 3D Position Reconstruction
- Stable cryogenics system
- Single photon and electron resolution

PMTs

- 4 1'' square 4 channel PMTs on top
- 1 2'' diameter HQE PMT on bottom



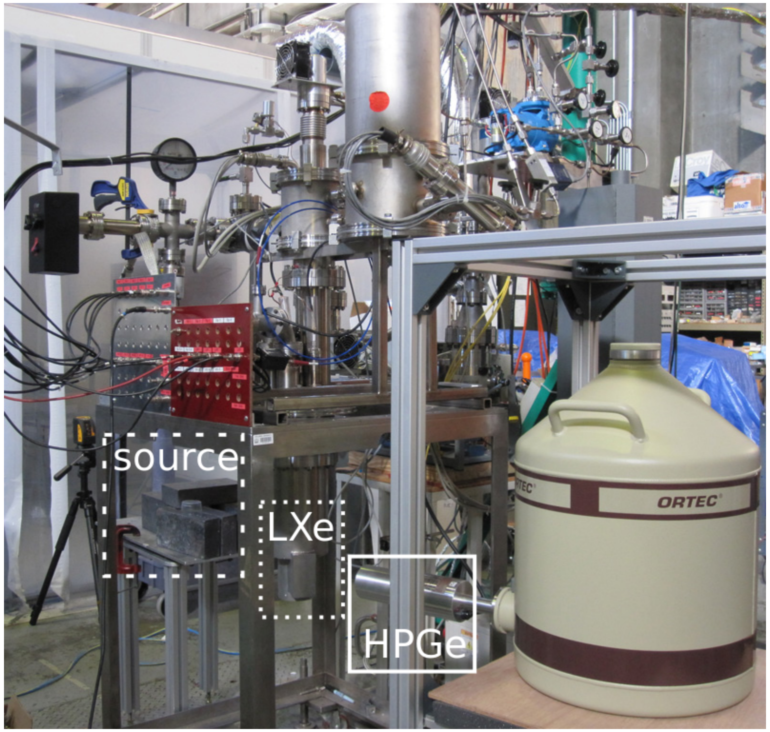


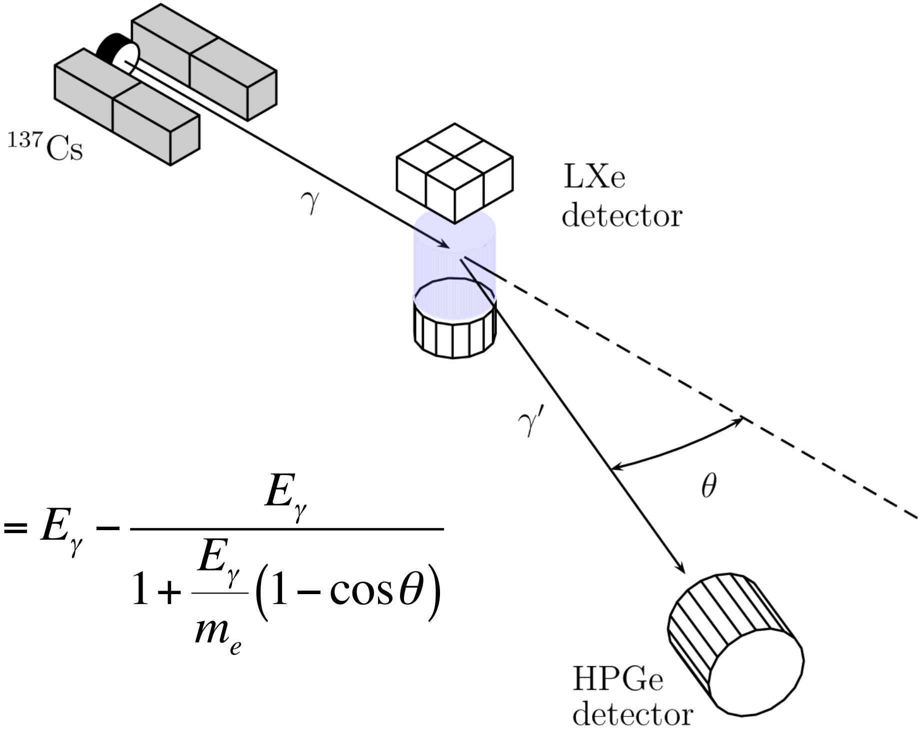
Drift Field [V/cm]
210
490
1000
2250

Compton Coincidence Technique

Energy deposited in LXe determined using Compton Coincidence Technique

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





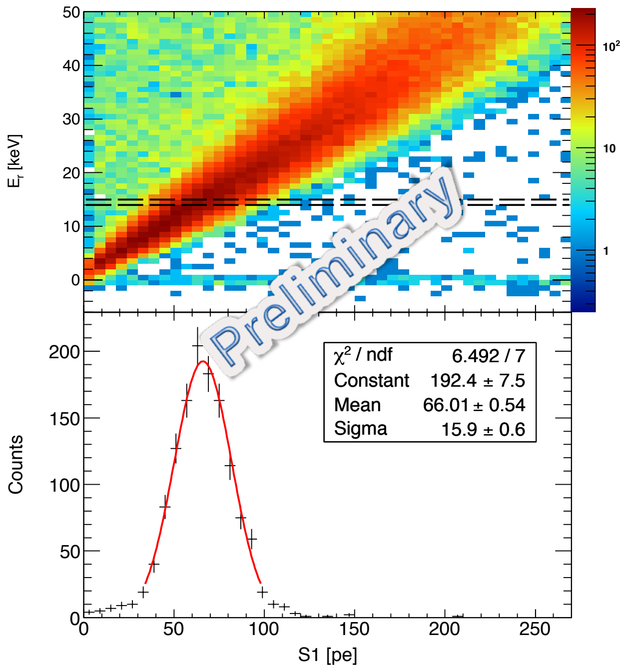
$$E_r = E_\gamma - \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e}(1 - \cos\theta)}$$

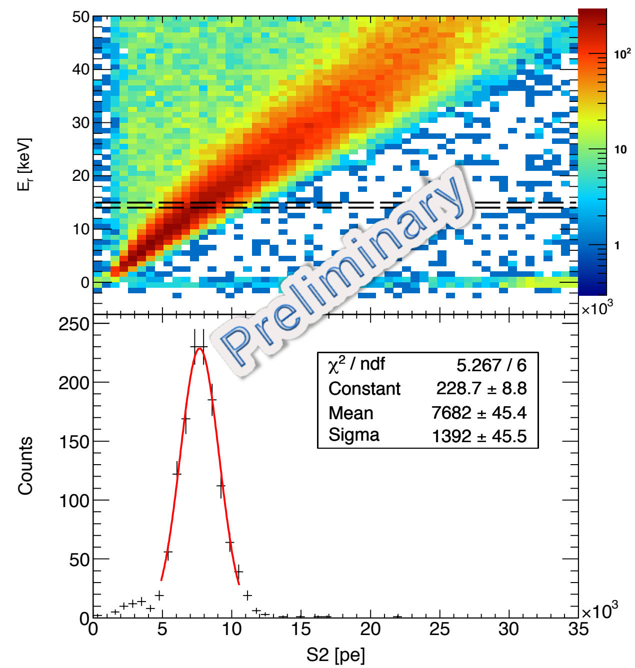
Coincidence Spectra

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

All data are **preliminary**

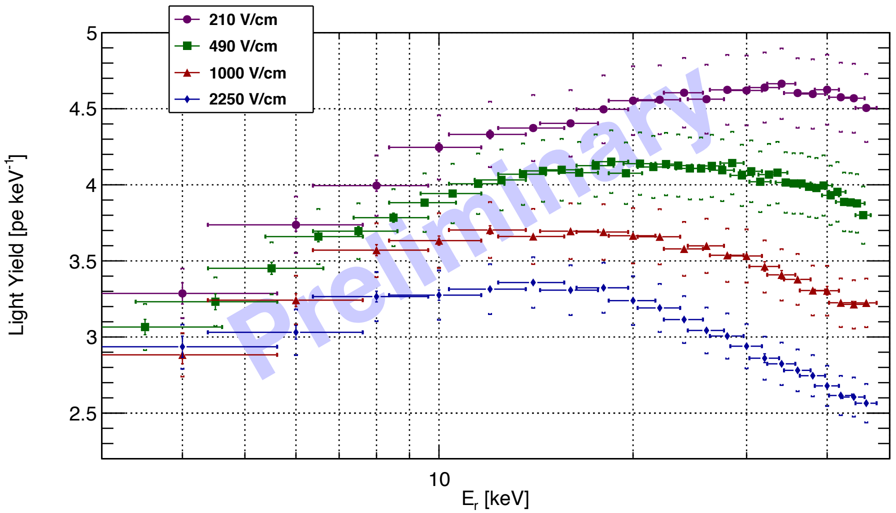
Prompt Scintillation Light (S1) vs. Energy Deposited in LXe	Proportional Scintillation Light (S2) vs. Energy Deposited in LXe



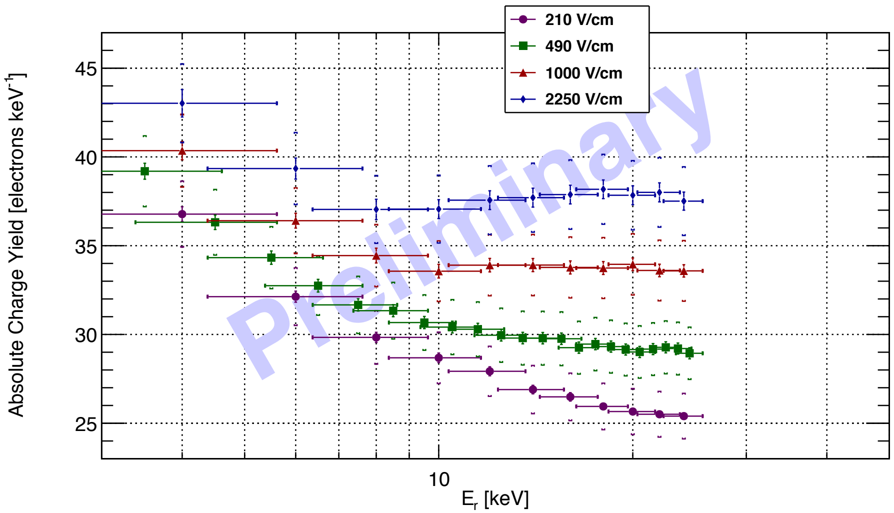


Electronic Recoils: Light and Charge Yields

Light Yield vs. Recoil Energy

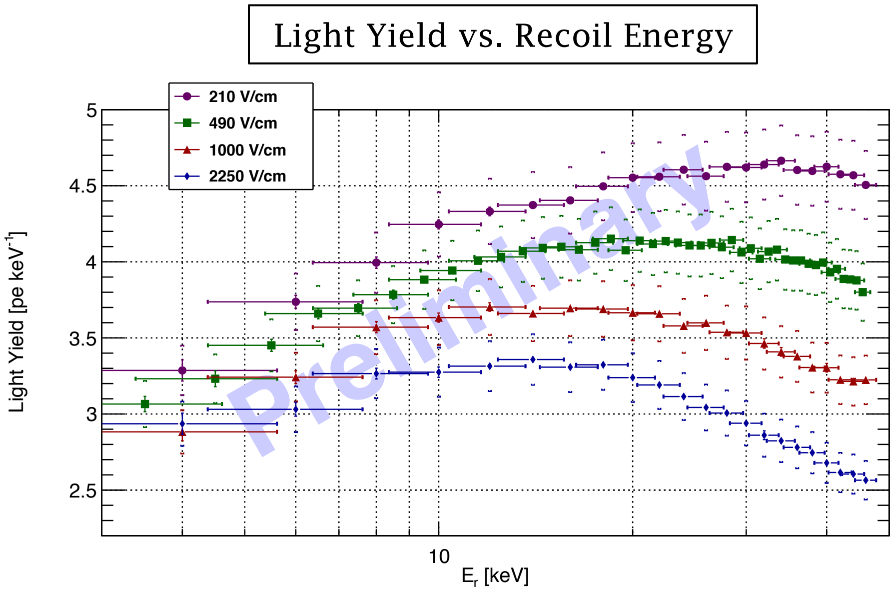


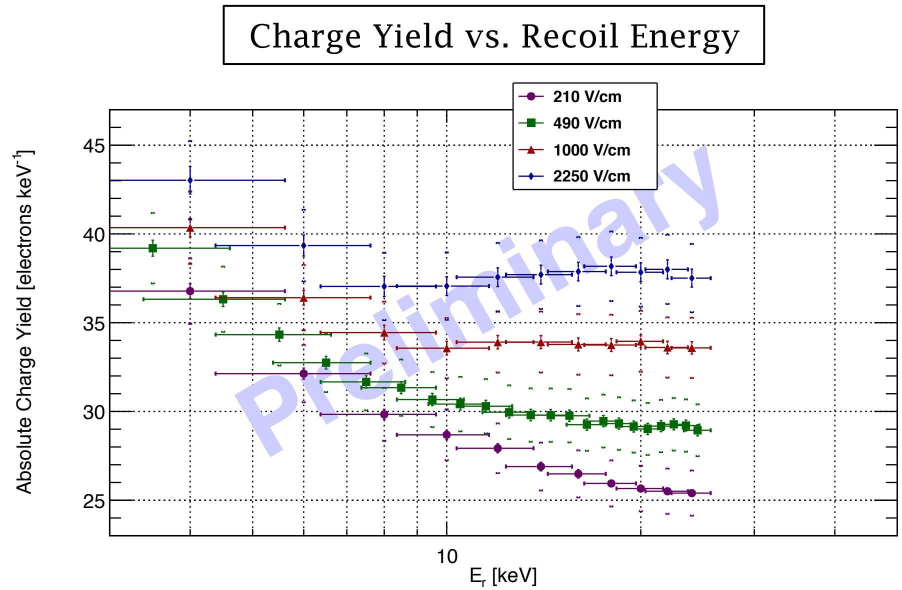
Charge Yield vs. Recoil Energy



- 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 as a function of recoil energy

Electronic Recoils: Light and Charge Yields



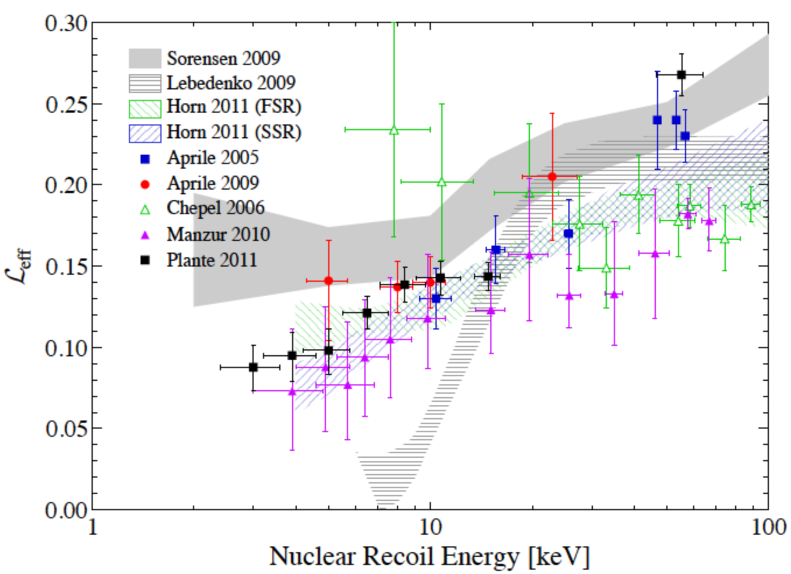


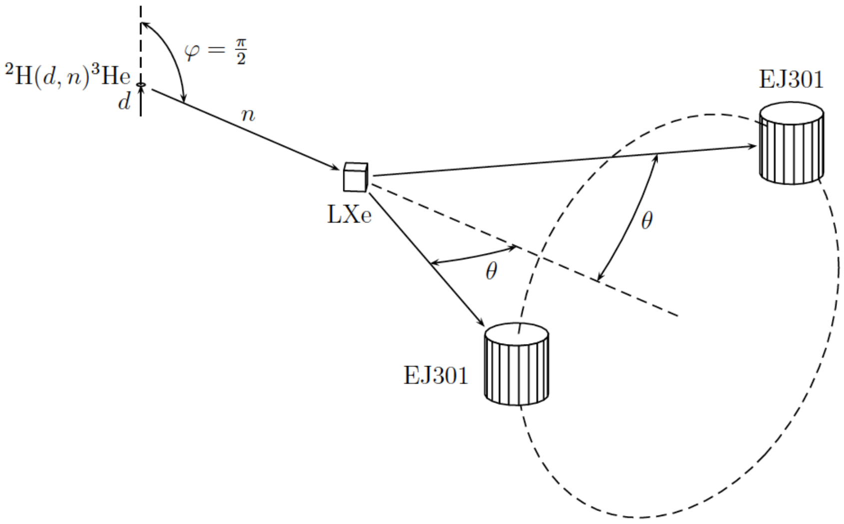
- S1 and S2 **anti-correlated** with respect to field
- Below 10 keV, light yield **increases** with increasing energy and charge yield **decreases** with increasing energy for all fields

- 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



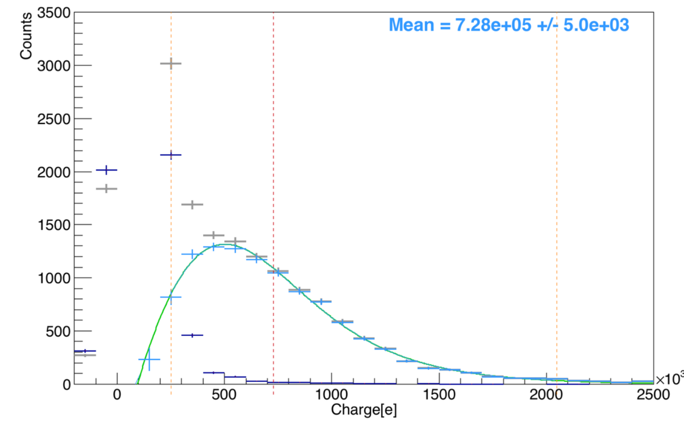


Backup

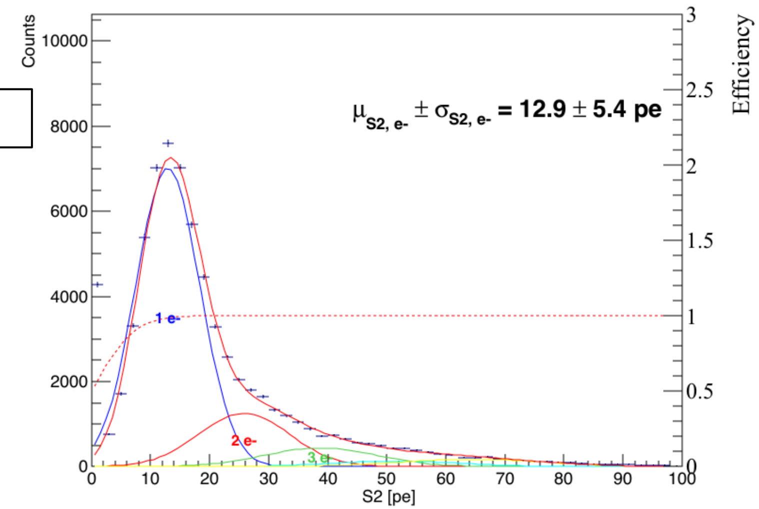
Single Photoelectron and Electron Detection

- 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

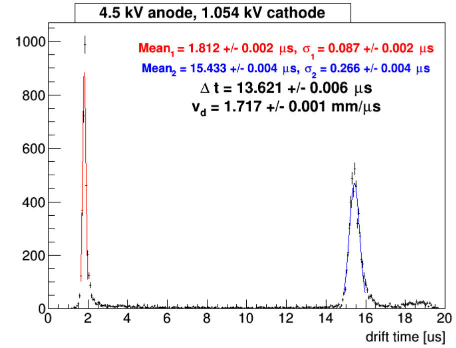
SPE Gain Calibration



Single Electron Gain



Photoionization of Gate and Cathode



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

Position Reconstruction

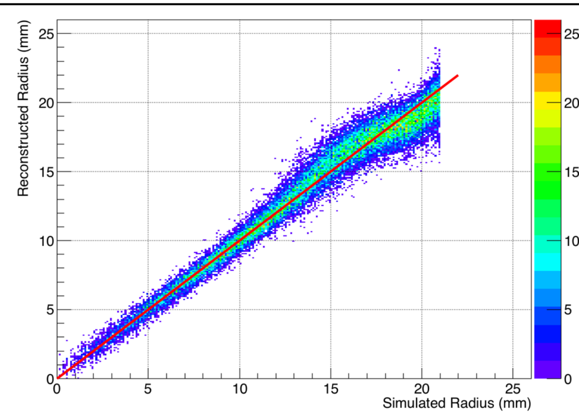
Similar to larger LXe detectors, neriX is able to reconstruct the 3D position of an event

- 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

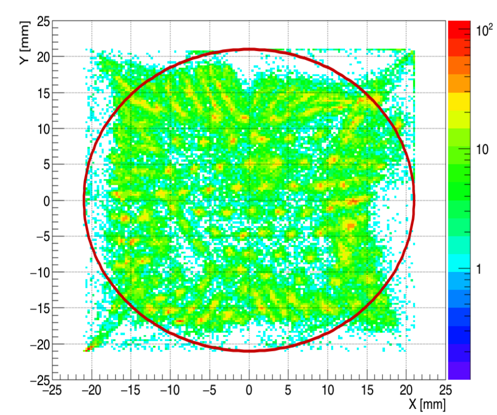
$$\{S2_1,\ \ldots,\ S2_{16}\} \Rightarrow$$

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

Simulated vs. Reconstructed Position

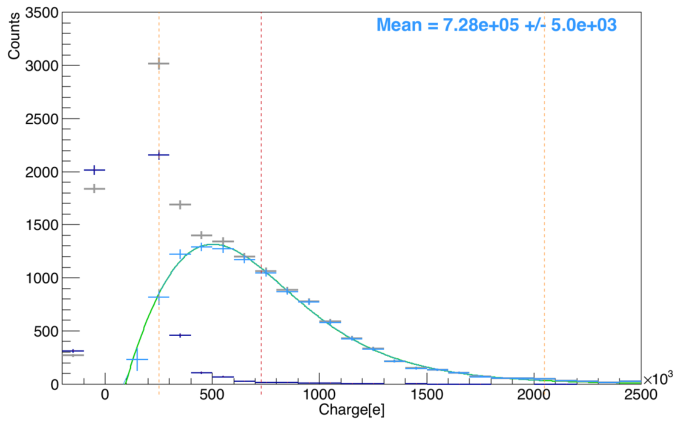


Co-57 Position Reconstruction

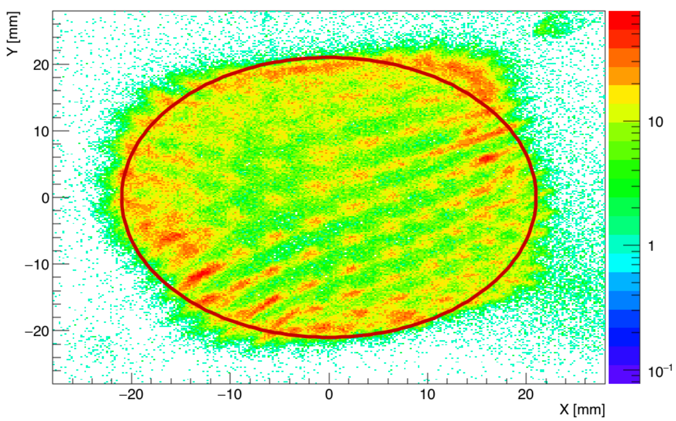


neriX Operation

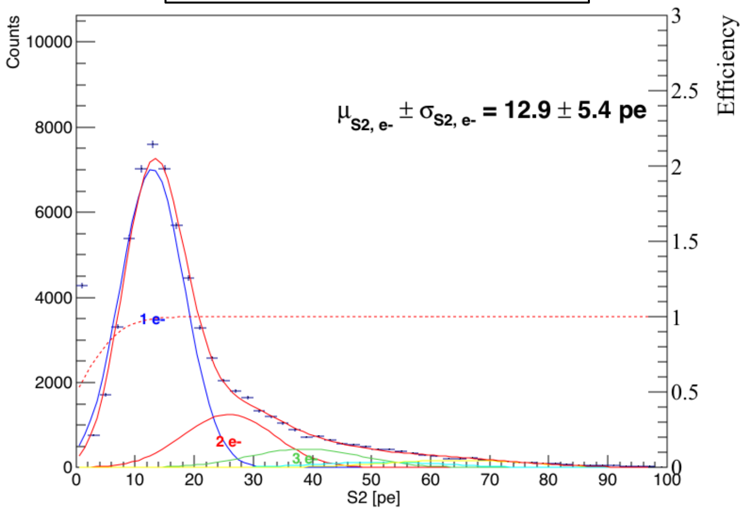
SPE Gain Calibration



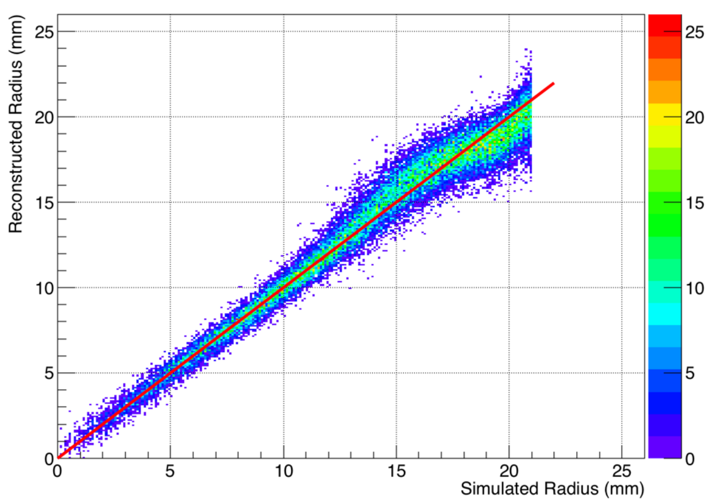
Position Reconstruction



Single Electron Gain



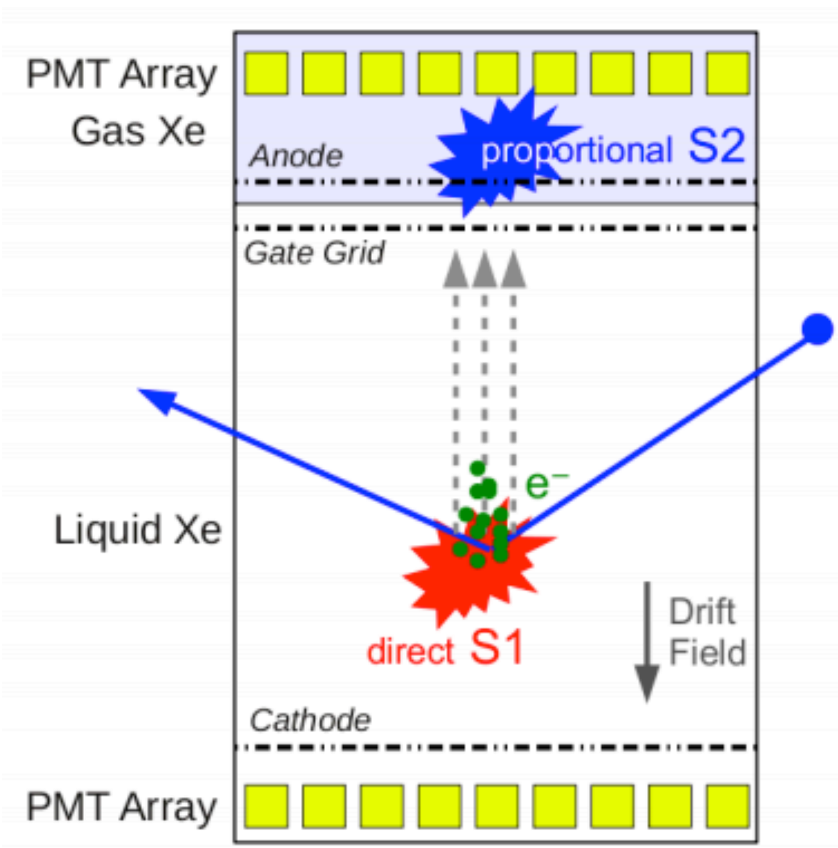
Simulated vs. Reconstructed Position



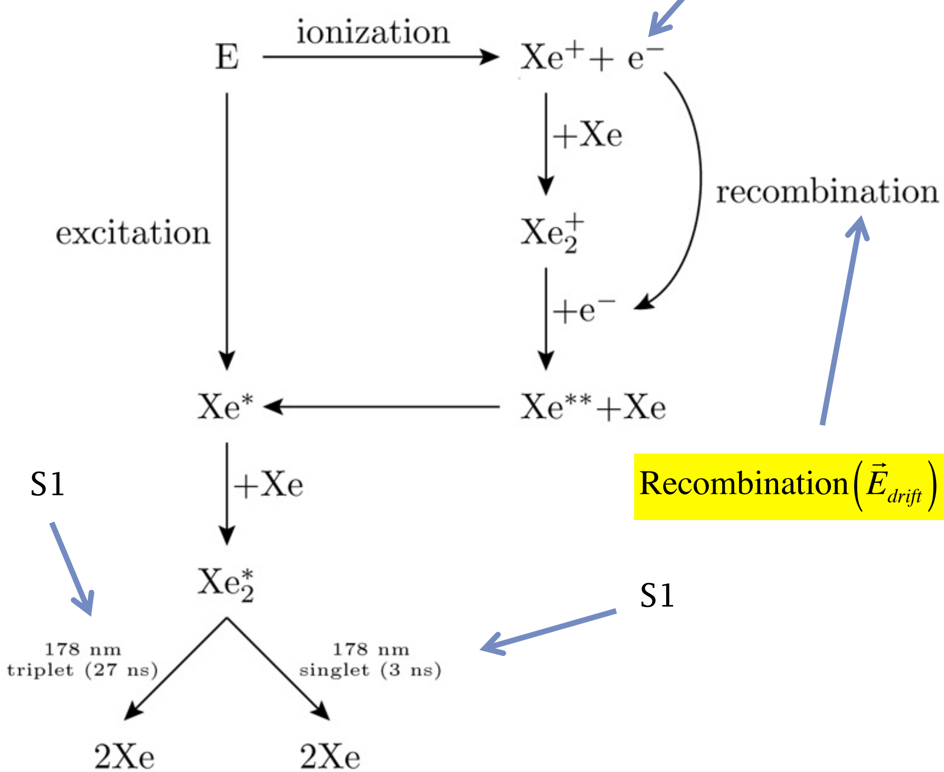
Motivation

LXe experiments lead direct dark matter scattering search

- Xenon100, LUX, Xenon1T



Leads to S2 **if remains free**



Recombination$\left(\vec{E}_{drift}\right)$

Motivation

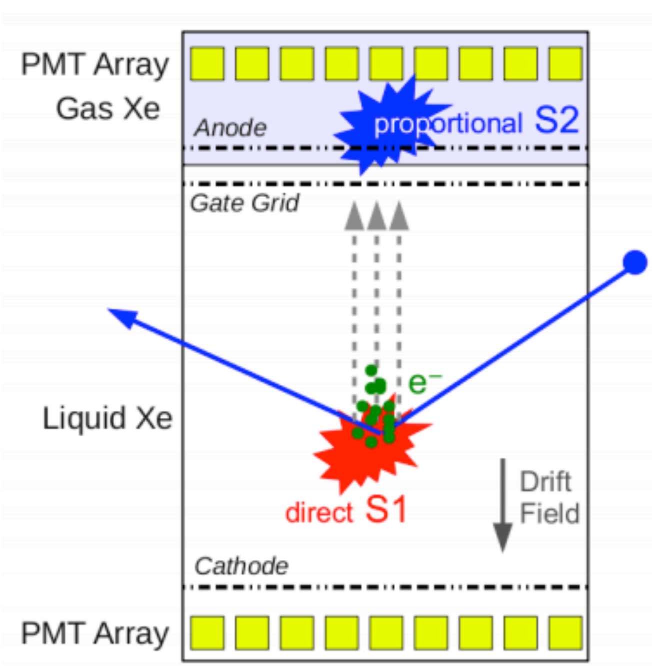
LXe experiments lead direct dark matter scattering search

- Xenon100, LUX, Xenon1T

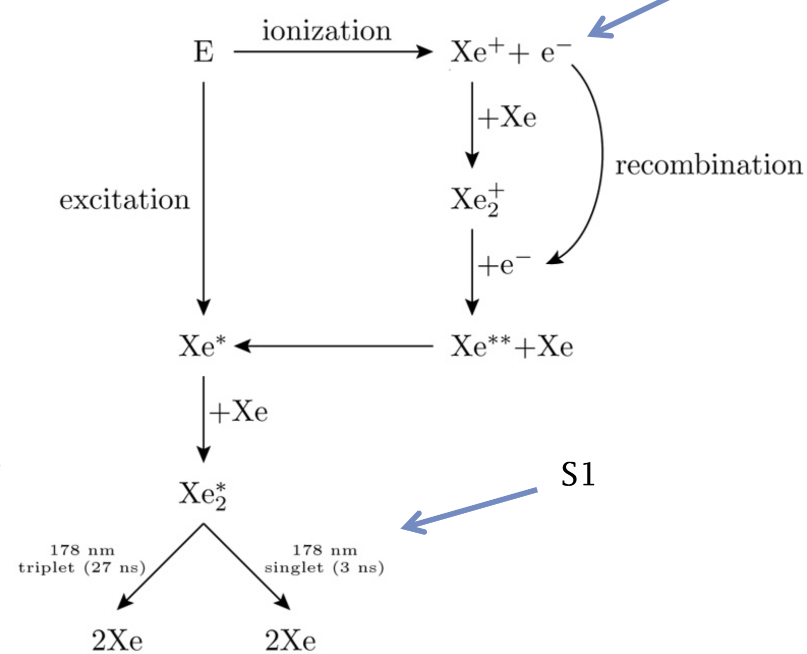
Dual-phase detectors ➔ simultaneously detect light and charge

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

Leads to S2 **if remains free**



S1



S1

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 and drift field
  - Light Yield = Photoelectrons / Energy
  - Charge Yield = Free Electrons / Energy