Studies of Photoelectricity and Multi-Photon Ionization in Gaseous and Liquid Xenon

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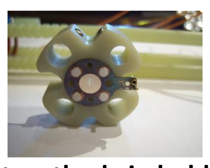
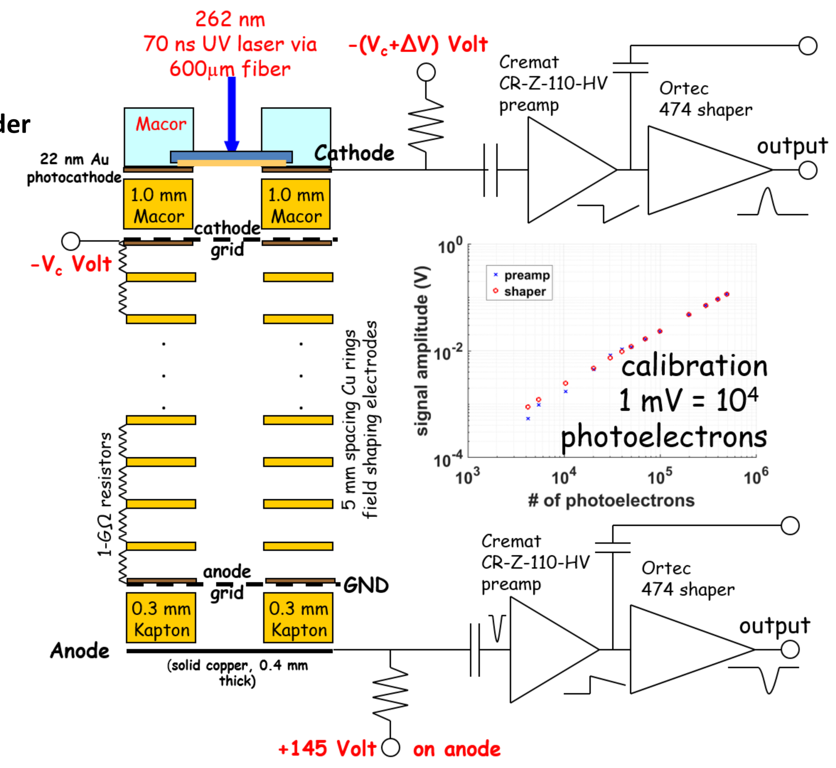
Motivation and apparatus

Goal:
- R&D to develop novel calibration tools for nEXO
- Towards continuous monitoring of liquid xenon properties via laser-driven charge injection


Photocathode in holder

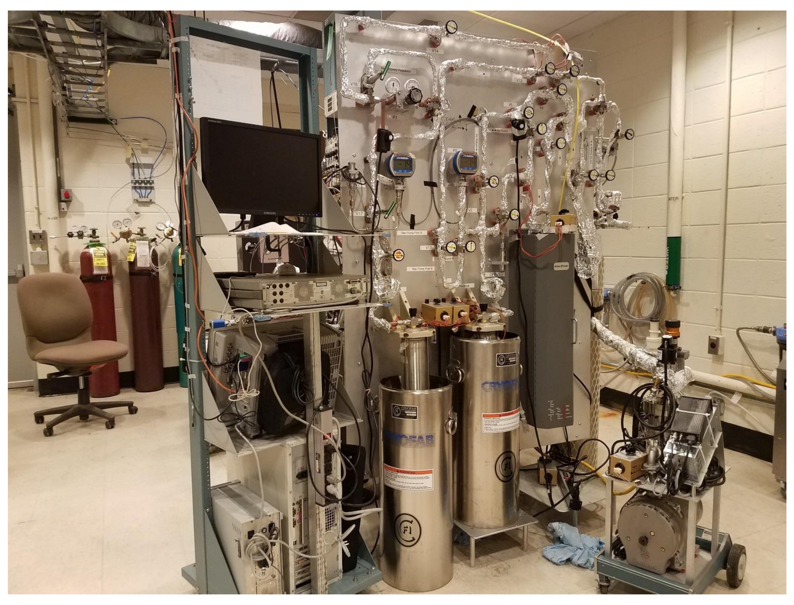

Kapton layer between drift stack and cell

BNL/SBU setup



UV light back-illuminates a gold photocathode using a 600 μm fiber.

Photoelectrons drift in a uniform field between the cathode and anode grids; charge collection takes place on the Anode.



The photocathode quantum efficiency can be extracted from the cathode grid signal

The drift stack is encased in a 0.5L liquid xenon cell. Cell cooling takes place via a cold ethanol bath.

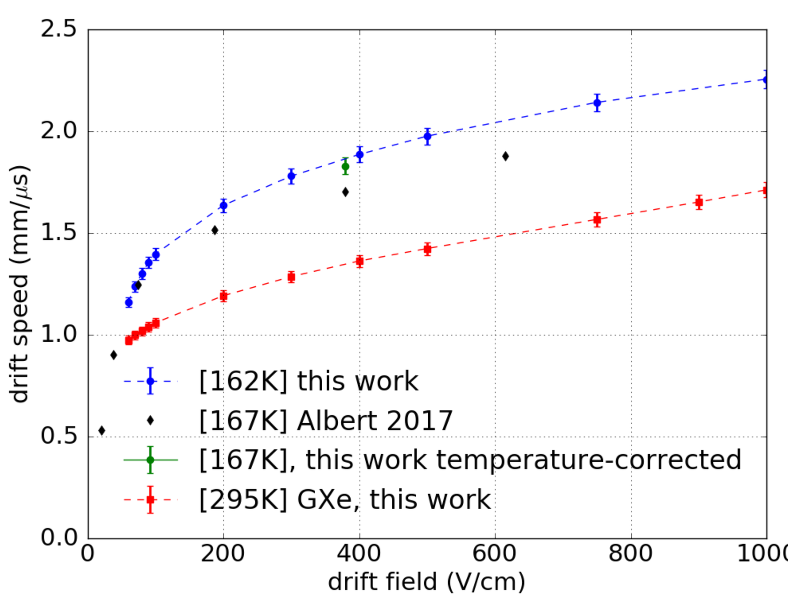
Injected xenon passes through a cold trap and an Oxisorb purifier to maintain Xe purity.

Stable operation of the cell is achieved at 163K and -2.0psig, with the ethanol bath maintained at 155K.

Several thermocouples in the cell are used to monitor the temperature distribution.

Transport properties of electrons in LXe

Speed vs drift field

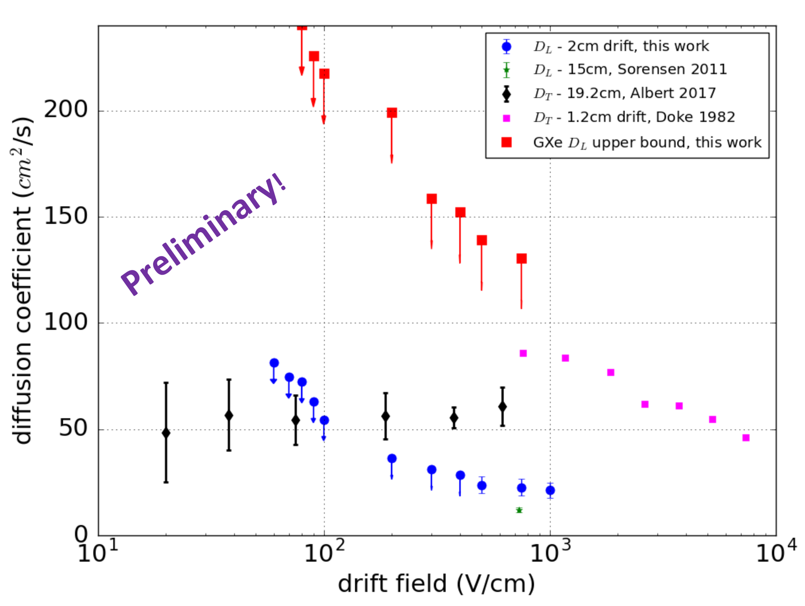


The drift speed increases with drift field.

Electrons travel faster in liquid than in gaseous xenon.

We observe slightly higher drift speed than that in EXO-200.

Diffusion vs drift field

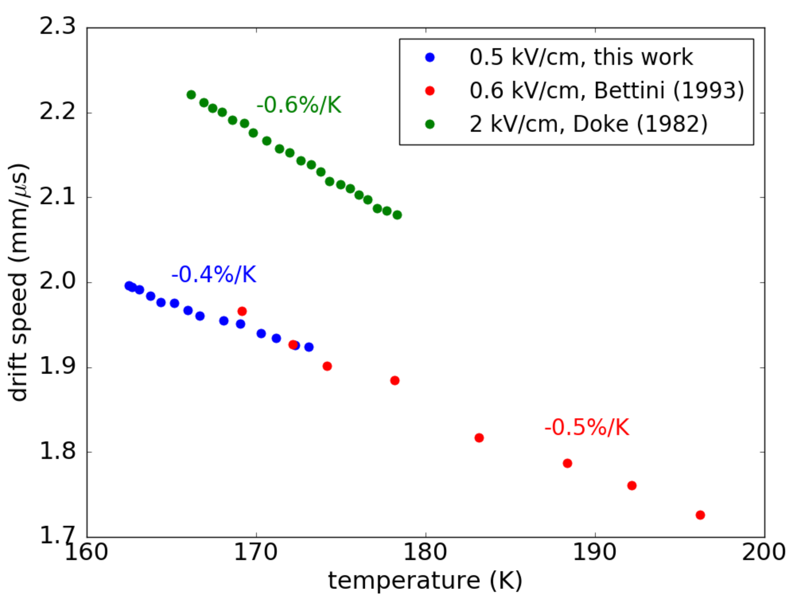


The diffusion coefficient is given by

$$D_L = \frac{d^2\sigma^2}{2t^3}$$

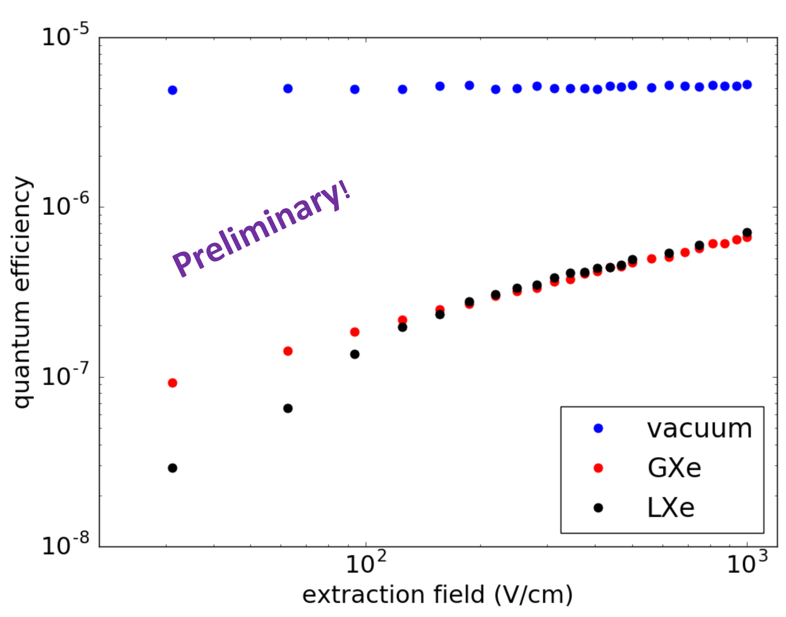
The upper bounds to the longitudinal diffusion coefficient are comparable to the corresponding (previously measured) transverse diffusion coefficient at lower electric field.

Temperature dependence



The drift speed decreases with temperature.

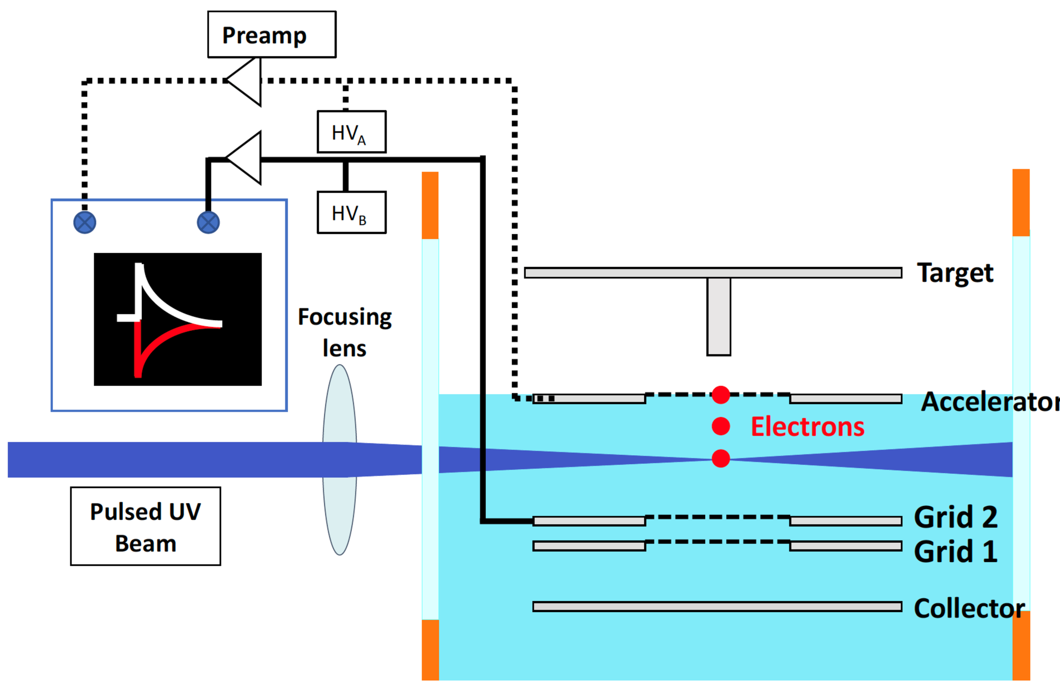
Quantum efficiency



The extraction field is the field between cathode and cathode grid.

Multiphoton ionization (MPI) in LXe

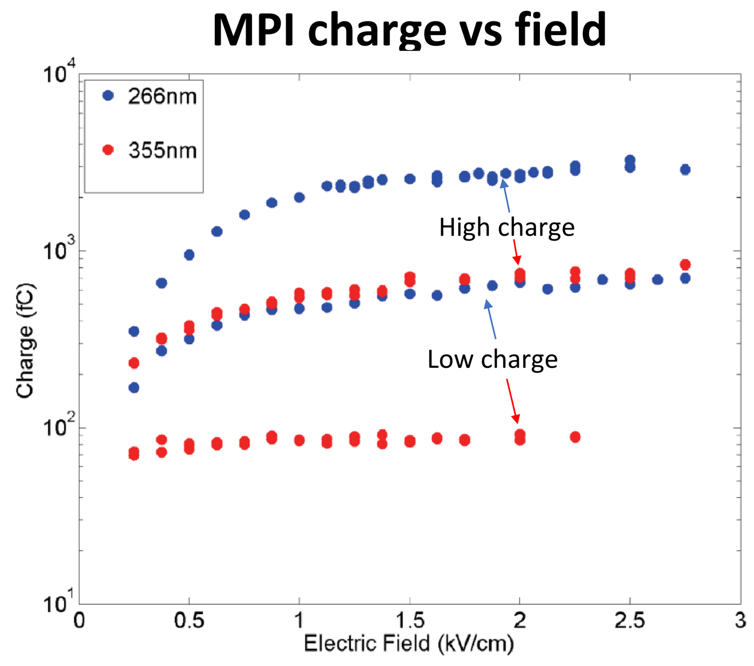
MPI order and cross section measurements in the CSU setup



Laser focused between Accelerator and Grid 2.

Equivalent but opposite induction signals from charges created by MPI are recorded on both plates by charge preamplifiers to give MPI charge yield.

MPI charge vs field



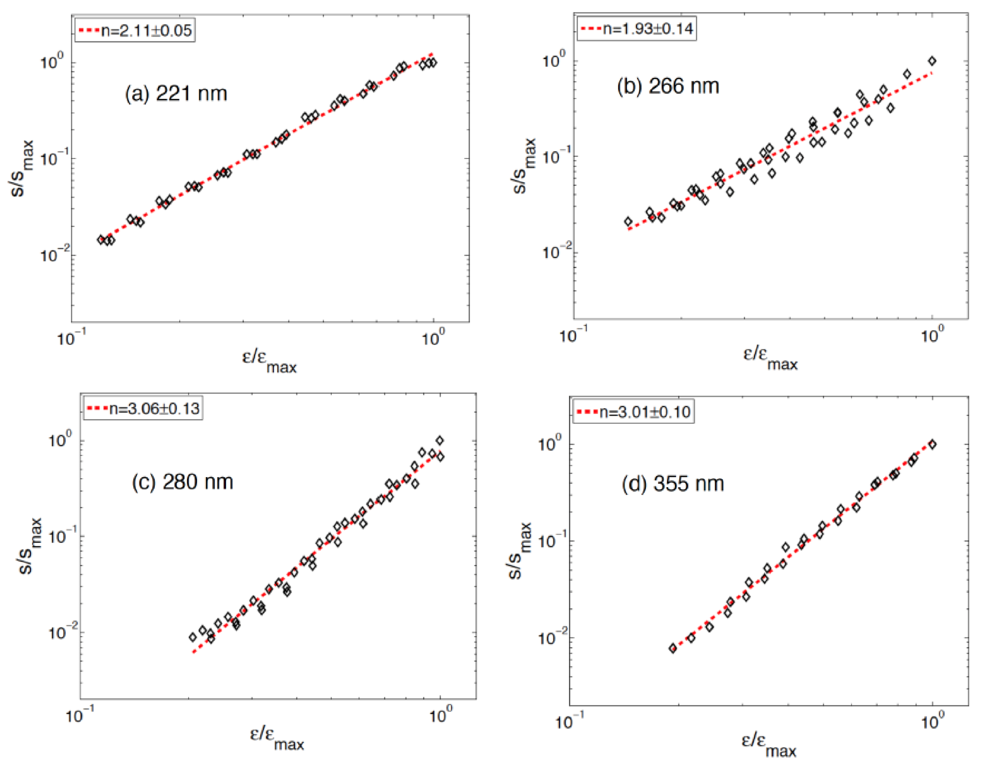
The collected charge is constant for electric fields higher than 1kV/cm, independent of the ionizing photon wavelength.

To ensure recombination is minimal, all charge vs pulse energy measurements are carried out at the highest drift field.

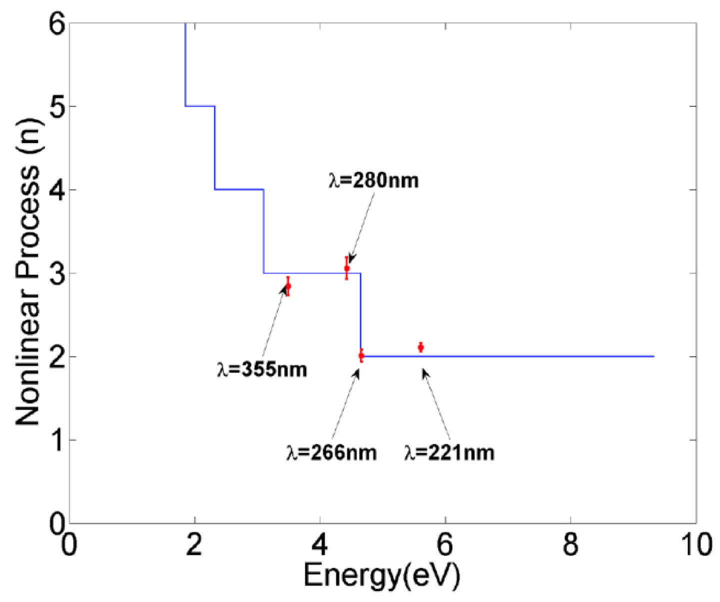
Multiphoton ionization (MPI) of LXe observed at four different wavelengths.

MPI probability increases nonlinearly with power n of laser intensity.
MPI nonlinearity orders of n=2 for 221nm and 266nm and n=3 for 280nm and 355nm were observed.

MPI charge vs laser pulse energy



Order of MPI vs. wavelength

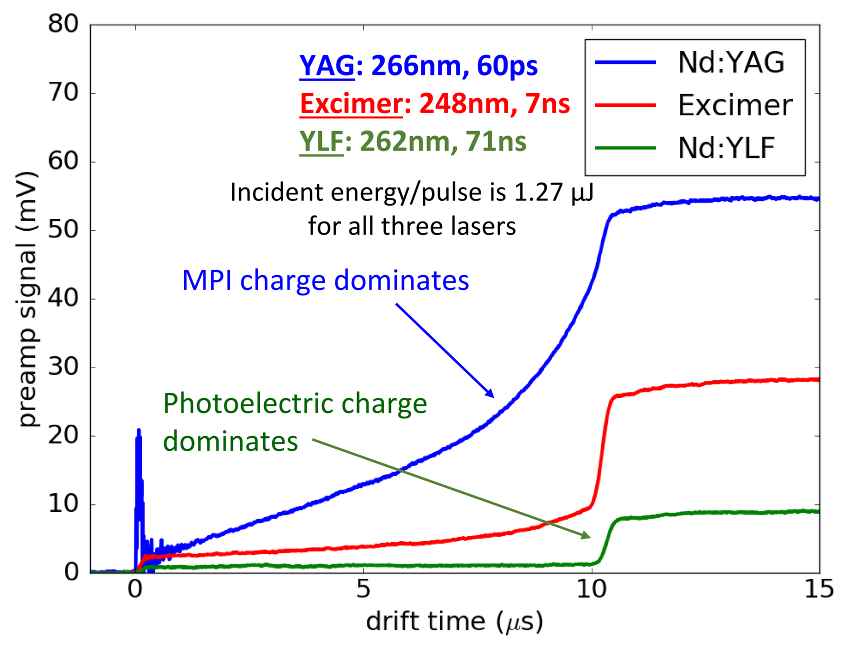


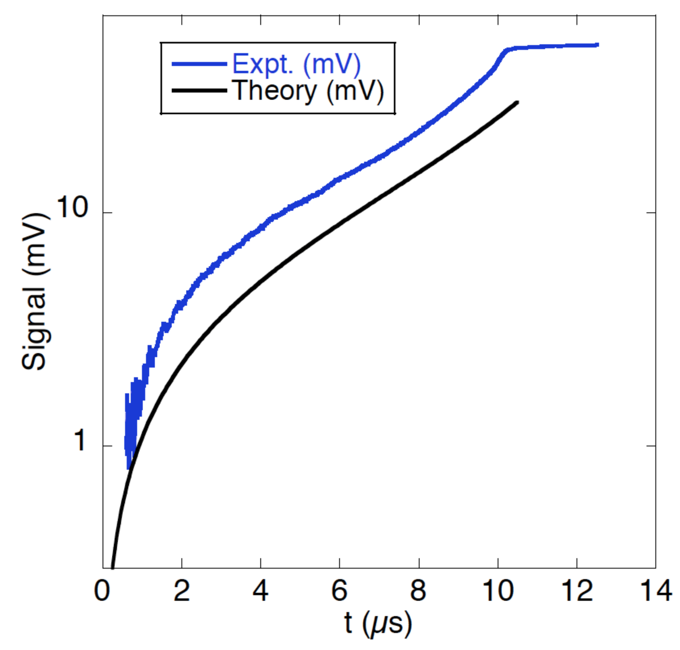
Step from n=3 to n=2 occurs when two photons span LXe bandgap 9.3eV.

Measured cross section for 2-photon ionization of LXe at 266 nm:
σ_2 = 1.26 x 10^{-52} cm^{4}s. Uncertainty is a factor of 2.

Multiphoton Ionization in the BNL/SBU setup

Multiphoton Ionization the LXe occurs because 50% of the laser light is transmitted by the semitransparent photocathode. For short pulse laser (blue curve), MPI charge generated all along the path dominates charge generated at the cathode by photoelectricity. For long pulse laser, photoelectric charge dominates (green curve).





Calculated MPI signal using the CSU cross section reproduces the shape of the BNL/SBU data (blue curve) well and the absolute signal to within σ_2 uncertainty.
Agreement with laser pulse widths differing by two orders of magnitude.

Outlook

- With this demonstration of both photoelectricity and multiphoton ionization in liquid xenon, we are ready to design a dedicated test to evaluate the stability of charge clusters generated by laser pulses. Few % pulse-to-pulse stability of normalized injected charge and sub-1% knowledge of the absolute scale will allow monitoring of ~10 ms electron lifetimes.
- A demonstrated, in-situ, stable monitor of electron attenuation deep in the detector would circumvent one of the source calibration limitations of nEXO, namely self-shielding.
- As anticipated, the longitudinal diffusion coefficient is smaller than the transverse diffusion coefficient at the projected operating electric field strength range of future experiments.