Charge Readout in Liquid Xenon for the LUX Dark Matter Experiment

Mathew Winkelman
Advisors: Dan Akerib, Thomas Shutt
Department of Physics, Case Western Reserve University

Abstract
As part of its search for dark matter the Large Underground Xenon (LUX) detector must tag background events to better reveal potential dark matter candidates. There are sections of the xenon that are outside of the current detector region that if instrumented can detect and discriminate backgrounds. This project seeks to explore the electric fields present in this region and then to create a system for reading the charge signal from a scattering event. This system will be tested in a prototype xenon detector under conditions that replicate the conditions present in the LUX detector for xenon outside of the detector region.

Motivation
The Large Underground Xenon (LUX) Experiment is a multi-school collaboration seeking to search for Weakly Interacting Massive Particles (WIMPs). The detector region is nested inside of a pair of titanium cans. Inside the active detector region a scattering event will cause a charge and light signal in the liquid xenon. The first signal is known as S1, the charge is drifted up by an electric field where it will cause a second light signal, S2, both signals will be seen by both an upper and lower PMT array. There is a region of xenon outside of the detector that will interact to a scattering event just as the xenon in the detector, and give off both charge and light. This event will only produce S1 light and represents a background signal that can be discriminated. The goal of this project is to read the charge of this scattering event directly out of the liquid xenon.

Theory
The goal is to read the charge deposited by a scattering event as it passes by an electrode grid. To create a model of the conditions in the region outside of the detector we treat the fields in the detector as a high voltage plane and the detector wall with a grounded plane parallel to the high voltage plane. In between the two planes there are a set of wire electrodes.

Fields: The fields can be considered uniform at a distance from the fields given by the following equation which for the scales in the experiment is about 0.04".

\[ E_z = \frac{V_{electrode}}{\pi z} \]

The fields can then be defined by:

\[ E_z = \frac{V_{electrode}}{\pi z} \]

\[ V_{electrode} = V_2 - V_1 \]

\[ V_2 = \frac{g_2}{a_2} \ln \left( \frac{d_2}{g_2} \right) \]

\[ g_1 = \frac{a_1}{a_2} \]

Charge Transparency: in order to see all of the charge all electrons must pass through the grid and not intersect an electrode. The condition for this transparency is decided by the ratio of fields and the physical construction of the electrode grid.

\[ \frac{E_{grid}}{E_{grid to ground}} = 1 + \frac{4\pi r}{z} \]

Graph showing the conditions under which full transparency will occur. For all field ratios (blue line), above the condition of transparency (green), there will be full transparency.

Design of the detector rendered in Alibre Design. The green structure is the PMT, it is supported above the electrode grid, which along with the planes is contained within the Teflon block.

Experiment
The detector is made up of:

- Electrode Grids – 1/32” steel wire, spaced at 0.25”, soldered to copper coated Cirlex®
- Planes - 3.5”x3” and made of mirror polished aluminum for light collection
- Planes are spaced 1” apart with the grid located at 0.5” directly in the center
- High Voltage plane set at ~5kV, grid voltage can vary between 0 to ~5kV, and the other plane is grounded

Above the electrode grid is located a Photomultiplier Tube (PMT) for light collection, which allow for the testing of the grid by seeing all of the possible scattering events inside of the detector.

One half of the Teflon block removed to show electrode grid and a plane. The plane is made of mirror out aluminum for light collection.

Results
There are currently no experimental results, beyond the construction of the detector, however some conclusions can be made from the theory work.

- Full charge transparency should be possible for the constraints given for this experiment
- Non-uniform fields and lack of charge separation will make events surrounding an electrode grid difficult to observe

Future Work
The experimental set-up needs to be tested in the Xed 1 detector for different configurations of grid and plane voltages. Additionally the grid spacing and electrode radius can be altered to change the transparency and uniform field conditions. Using the PMT every scattering event should be visible and by directing a source the charge collection at various locations in the detector can be probed.

The next step in detector construction would be to model the gradient high voltage field in the LUX detector. This will allow for a better knowledge of whether the data from this project can be transferred to the next generation detector.

Acknowledgements
I want to thank my advisors Dan Akerib and Thomas Shutt for their help as well as the entire LUX Lab at Case Western Reserve University.

References