Abstract

The Large Underground Xenon (LUX) detector is an underground particle detector full of liquid xenon intended to detect dark matter. It utilizes photomultiplier tubes (PMTs) which output a voltage pulse in response to incident light from events within the xenon. The analysis of these pulses will ultimately tell what type of particle interacted with the xenon, and hopefully support the existence of dark matter, or at least provide new limits on the masses and probability of interaction of dark particles. The analysis software for the detector is being developed in two languages (Matlab and C++ with the ROOT library) to ensure accuracy, and thus far few major discrepancies have been found between the analyzed data created by the two codes.

LUX Detector: Data Analysis in C++/ROOT

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1 The LUX Detector

The Large Underground Xenon (LUX) detector is a large container filled with 350 kg of liquid xenon with 61 photomultiplier tubes (PMTs) at each end, placed underground with the intent of detecting dark matter. While dark matter is theorized to make up 25 percent of the universe, it has gone undetected by experiment and its exact composition is still unknown. One leading candidate for dark matter is a small, barely interacting particle known as the Weakly Interacting Massive Particle (WIMP). Liquid xenon was chosen as a detection medium for this mysterious matter for a few reasons: one, it scintillates and is transparent to its own scintillation light, two, it is dense as a liquid which increases the likelihood of an interaction, and three, it has a high elemental mass number. The fact that it has a high elemental mass number is important because WIMPs can either interact in a spin dependent (SD) way or a spin independent (SI) way. SI interactions are when, for example, a WIMP collides with a xenon nucleus causing nuclear recoil. They are dependent on the number of nucleons so xenon's large nucleus makes these interactions more likely. SD interactions are when, for example, a WIMP interacts with either one neutron or one proton in a nucleus which matches its spin. These interactions are only possible with an odd number of either protons or neutrons, and so xenon's odd isotopes make SD neutron interactions possible.

2 Xenon—Particle Interactions

When a particle interacts with xenon inside the detector, either nuclear or electron recoil occurs. This recoil then causes scintillation and ionization of the xenon in different percentages, depending on the type of particle that interacted with the xenon. Scintillation is the process of an excited electron falling back to its rest state, releasing a photon as it falls. This light that is produced is called S1 light, and travels through the liquid xenon to the PMTs which then interpret this light into a signal. The signal, which is pulse-shaped, is generally short (on the order of tens of nanoseconds), due to the short lifetime of the excited xenon. The ionization of the xenon releases electrons which drift to the top of the detector due to an electric field set up for the detector. Once they reach the top of the detector they encounter an extraction field which is a stronger electrical field than that in the liquid xenon, which pulls them into a layer of gaseous xenon. Within this gaseous xenon the electrons create more scintillation photons, which is referred to as S2 light. This light then reaches the PMTs which interpret the light into a signal. Since S2 light is not released directly from a xenon-particle interaction and is instead caused by slower moving electrons, the S2 light is detected by the PMTs at a later time than the S1 light.

The ratio between the S1 and S2 light (and their resulting signals) relies on what type of particle interacted with the xenon, causing either nuclear or electron recoil. WIMPs and neutrons will cause nuclear recoil, while gamma and beta rays will create electron recoil.

3 PMT Signal

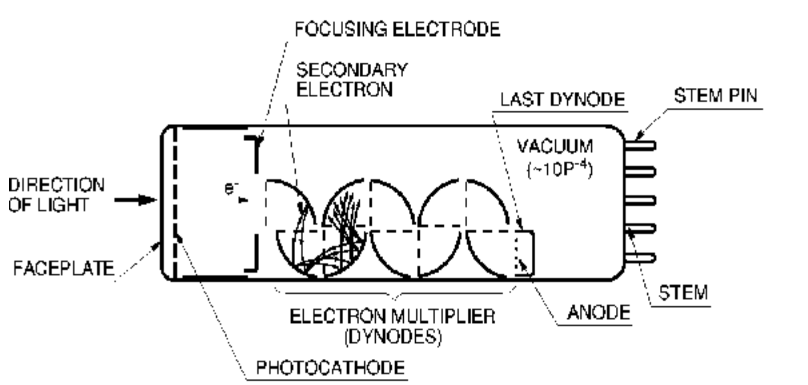

Figure 1: Schematic of a PMT (2)

When photons hit a PMT, they are converted to photoelectrons by the photocathode(see figure 1). The number of photoelectrons that are created from these photons relies on the quantum efficiency (QE) of the PMT. QE is a statistical relationship between the number of photons entering a PMT and the number of photoelectrons which are produced from these photons. The QE of the PMTs that LUX uses is approximately .3 which means, for example, that 17 photons become 5 photoelectrons (on average). These photoelectrons are then multiplied in the electron multiplier, which creates a secondary electron cascade. Finally, the anode at the end of the PMT collects these secondary electrons and interprets them into a signal.

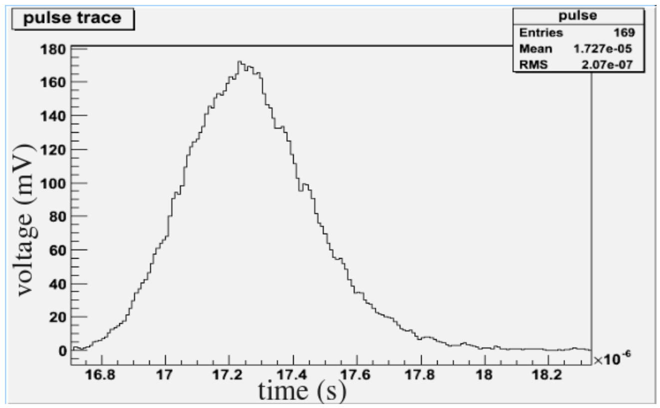

Figure 2: Example of a pulse signal from a PMT

The signal is initially in Analog-to-Digital (ADC) counts, which is a number that is proportional to the voltage produced by the secondary electron cascade. These ADC counts are put into histograms (one histogram per pulse), with each tick on the x axis representing 1 ns, and the y axis representing the number of ADC counts. These can be converted to real time and millivolts (mV) (as in figure 2) for later analysis using a predetermined conversion factor.

4 Data Analysis

The analysis of these pulses is crucial, for they contain enough information to tell analysts what particle it was that interacted with the xenon. In order to ensure the accuracy of the analysis of these S1 and S2 pulses, the LUX collaboration decided to write parallel code in two different languages; one using Matlab and one using C++ and the ROOT library. Each code takes in pulse data and outputs a list of reduced quantities (RQs), which are the important numbers that are extracted or calculated from the PMTs' raw data. The ultimate goal of these two parallel codes is to compare their results, ensuring total accuracy.

Since the full LUX experiment has not been built yet, the data that is being used at this time is from a small mock-up of the full LUX experiment, LUX 0.1, which had radioactive samples of material placed near to it to ensure many events.

The code that I wrote was in C++ and found the following RQs: the beginning and end of the pulse, the maximum height of the pulse, the bin number (x value) of this maximum height, where the pulse reaches 10 percent and 50 percent of the max height on its rising and falling edges, and the area underneath the pulse. When compared with the Matlab results the beginning, end, maximum, and percentages all matched up nearly exactly once the numbering conventions were matched. However, the area RQs differ from the Matlab results but match the visual output of the pulses. This points to another difference in numbering conventions which must be resolved to accurately compare the two results.

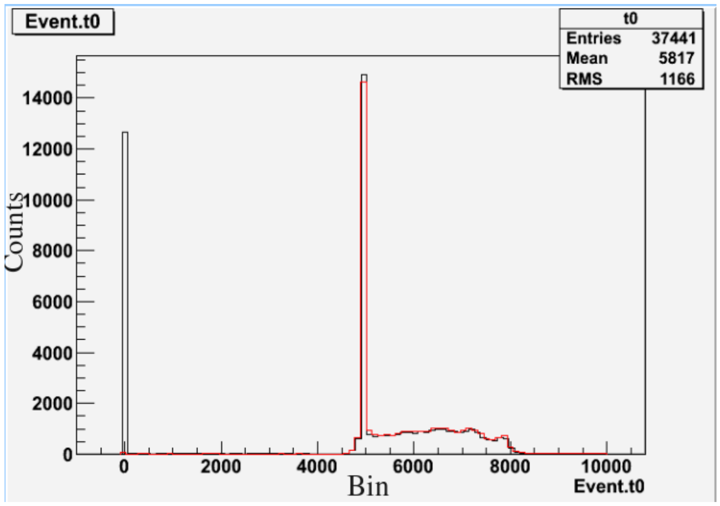

Figure 3: Example of Matlab/ROOT comparison. This particular comparison is of the t0, or beginning time, of around 37000 pulses. C++ results are in red, Matlab results are in black. Matlab's large bin at 0 remains unexplained.

5 Future Work

Work has yet to be done on the LUX detector and the analysis of its data. The analysis software written for LUX 0.1 may have to be rewritten to better match real data from the LUX detector once it is up and running.

Event reconstruction will be crucial in later analysis due to the fact that neutrons and WIMPs will both cause nuclear recoil in the xenon, causing their events to look similar. However, neutron events are more likely to occur towards the outside of the detector while WIMP events could happen anywhere within the xenon. This is because the LUX detector is self-shielding due to its size, and so most (if not all) neutrons will be stopped near the edge of the detector, while WIMPs and other dark matter are suspected to be very penetrating and so could interact anywhere within the xenon. Therefore, neutron-recoil type events in the center of the detector have a high likelihood of being potential dark matter-xenon interactions.

References

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