MicroBooNE: LArSoft simulation runs and PMT stress tests

Jessica Esquivel

St. Mary's University, San Antonio Tx.

Nevis Laboratories, Columbia University

August 7, 2009

Abstract

MicroBooNE is a Liquid Argon Time Projection Chamber detector(LArTPC) that detects and analyzes neutrino interactions using the FermiLab booster neutrino beam as well as the Neutrinos from the Main Injector beam(NuMi). This experiment was proposed to look into the excess of low energy neutrino events observed by the MiniBooNE experiment. Unlike MiniBooNE, MicroBooNE has the capability to distinguish between electrons and photons. Since a significant fraction of the background in MiniBooNe is due to know sources of photons, this greatly increases the signal to background ratio as well as giving this experiment the capability to answer the question of whether or not the excess of low energy neutrino events are electrons or photons. MicroBooNE is also the beginning for future large liquid argon detectors used for analysing CP violation in neutrino interactions, proton decay, and the main topic of this paper, Super Novae detection.

1 Introduction

LArTPC technology has been researched for many years.[4] These time projection chambers are very promising for large scale neutrino detectors, but because of the lack of experimental data rather than simulated data, the realization of making these detectors has been delayed. MicroBooNE is supposed to help prove that these LArTPC's do in fact work, as well as answer the question of the low energy excess events seen in MiniBooNE. MicroBooNE is a 175 ton LArTPC.[5] MicroBooNE will also be a learning experience when it comes to using cold electronics, which hepls reduce electronic noise because of shorter connecting wires and cold temperature, achieving the highest level of LAr purity, which is needed to drift electrons over 2.5 meters, and being able to reconstruct events in a surface detector rather than an underground one.

1.1 Introduction: Supernova Neutrinos

When a massive star collapses into a neutron star almost all of its binding energy gets released in the form of neutrinos, which have energy that range from 10 to 30 MeV. These neutrinos come in all different flavors. The neutrino signal is the first to emerge from the core of the star, whereas the photon signal takes hours or days. Therefore the neutrino signal can give information about the very early collapse of a star. These neutrinos can be detected in various ways. A dozen neutrino events were detected in neutrino detectors, like the Super-K, operating at the time of SN1987A. For water Cerenkov detectors, the most important is the inverse beta decay.[1]

$$\bar{\nu}_e + p \rightarrow n + \bar{e} \tag{1}$$

The positron is detected from its Cerenkov light, but there is also the neutrino-electron elastic scattering events that are two orders of magnitude smaller than the inverse beta decay, but are just as important because the scattered electron retains information about the direction of the incoming neutrino.

$$\bar{\nu}_e + e \rightarrow \bar{\nu}_e + e \tag{2}$$

$$\nu_e + e \rightarrow \nu_e + e \tag{3}$$

The reason why supernova neutrinos are important to the MicroBooNE experiment is that all future large neutrino detectors should have the ability to detect supernova neutrinos. MicroBooNE will be the first in a series of large LAr detectors, and the ability to detect supernova neutrinos needs to be implemented in its design.

2 Hardware Project

A photomultiplier tube(PMT) is a vacuum tube that is a very sensitive detector of light. These detectors multiply the current produced by incident light by as much as 100 million times, in multiple dynode stages, enabling individual photons to be detected when the incident flux of light is very low. PMT's take into account two discoveries, the photoelectric effect and secondary emission.

Although much is known about PMT's, how they would react in a LArTPC was unknown as well as if the angle of incidence as well as an electric field would have any affect on the output of the PMT. PMT's in the MiniBooNE experiment went through extensive tests to see the dependence of the PMT response on the angle of light, but none of the tests measured a specific point on the surface of the photomultiplier tube, rather the light diode was held two meters away from the phototube, illuminating the whole face of it, and changed the 'yaw' and 'pitch' of the PMT.[6] The PMT used for the response tests was a ten stage dynode chain, where as the MicroBooNE experiment will be using a fourteen stage dynode chain.

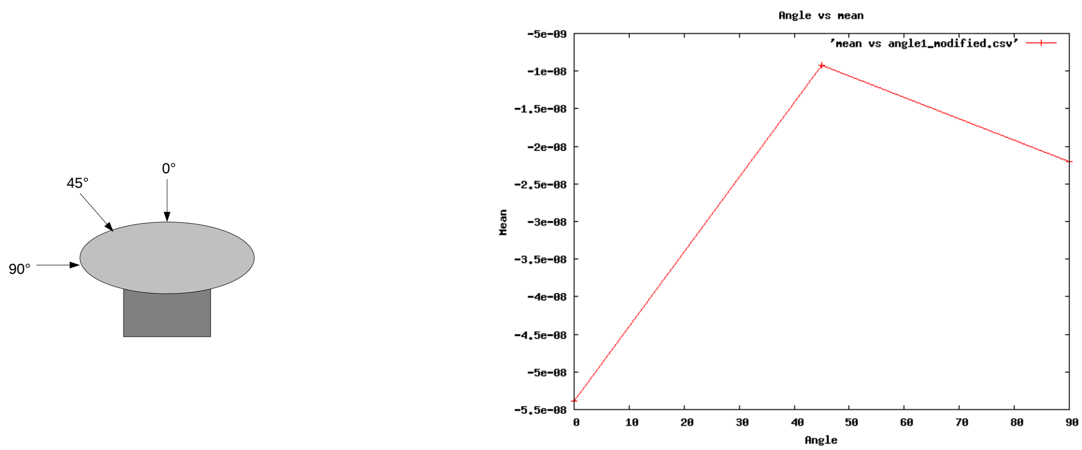


Figure 1: Original Setup

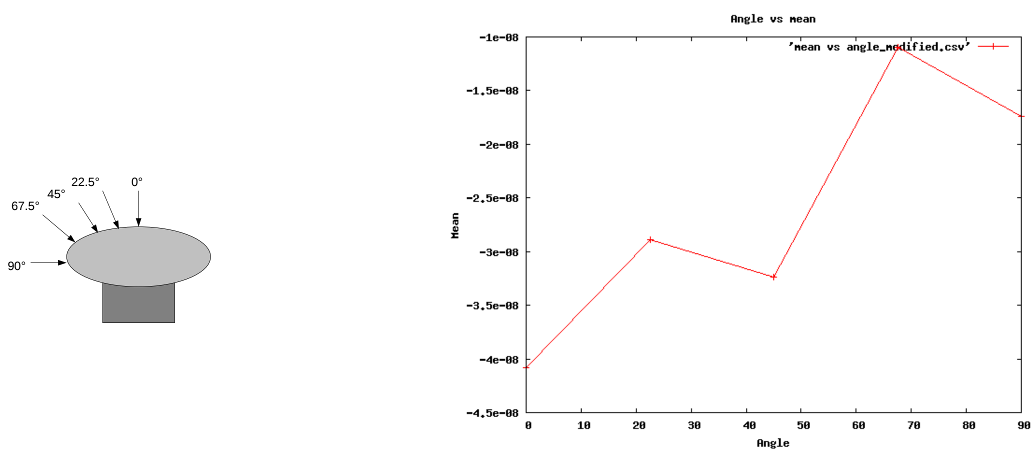


Figure 2: Original Setup with more points on the PMT

2.1 Hardware Project: Photodetector Respose as a function of Angle of Incidence

The setup for the experiment was quite simple. The PMT and a light diode were placed in a black box. The PMT was connected to high voltage set at 1200 Volts and the light diode was connected to a pulse generator. Both the pulse generator output and the output of the PMT were then connected to an oscilloscope. The first round of data collected were deemed not usable due to the fact that the pulse generator that was being used was not stable. The data collected is shown in fig 1 and 2.

After switching the pulse generator for a more stable one, the reproducibility of the data at each point was accomplished. The reproducibility ranged from .5E-9 to 2.5E-9 on all three points. The testing began with moving the light diode to different points on the PMT keeping the angle of incidence constant and testing position dependence that way.

After seeing results and comparing it with previous results taken by the photomultiplier tubes in the MiniBooNE experiment [6], it was decided that changing the angle of incidence of the light relative to the normal of the PMT surface would be more beneficial to understanding how the PMT would react.

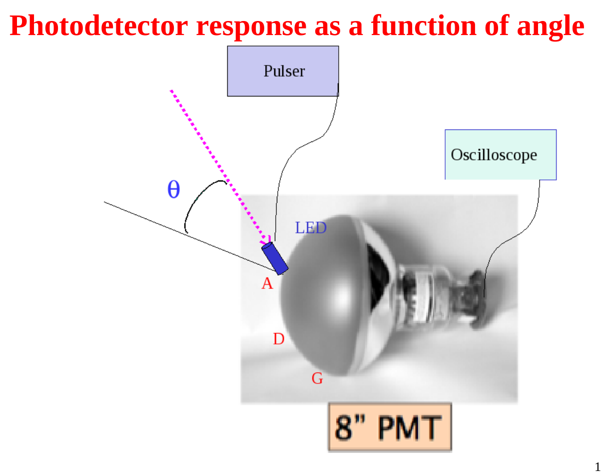


Figure 3: Incidence Angle Setup

Data was collected at three points on the PMT shown in fig 3 and the light diode was moved from 0 degrees to 60 degrees relative to the PMT. A protractor was used to measure the relative theta between each run.

A C++ code was implemented to calculate Fresnel's equations shown in fig 4 to make sure the experimental data that was collected was close to the calculated data. There may be discrepancy with the calculated data because the index of refraction of the PMT was not verified by the PMT distributors, but an index of refraction of 1.5 was used instead.

To compare all plots, the intensity at each angle was divided by the intensity at 0 shown in fig 5. When comparing all plots, it was surprising to see that point A, the

$$R_s = \left[\frac{\sin(\theta_t - \theta_i)}{\sin(\theta_t + \theta_i)}\right]^2 = \left(\frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t}\right)^2 = \left[\frac{n_1 \cos\theta_i - n_2 \sqrt{1 - \left(\frac{n_1}{n_2}\sin\theta_i\right)^2}}{n_1 \cos\theta_i + n_2 \sqrt{1 - \left(\frac{n_1}{n_2}\sin\theta_i\right)^2}}\right]^2$$

$$R_p = \left[\frac{\tan(\theta_t - \theta_i)}{\tan(\theta_t + \theta_i)}\right]^2 = \left(\frac{n_1 \cos\theta_t - n_2 \cos\theta_i}{n_1 \cos\theta_t + n_2 \cos\theta_i}\right)^2 = \left[\frac{n_1 \sqrt{1 - \left(\frac{n_1}{n_2}\sin\theta_i\right)^2} - n_2 \cos\theta_i}{n_1 \sqrt{1 - \left(\frac{n_1}{n_2}\sin\theta_i\right)^2} + n_2 \cos\theta_i}\right]^2$$

Figure 4: Fresnel's Equations

center of the PMT has the largest drop off relative to the incidence angle. A reason for point G being greater than point A is that maybe the photons from the light diode have two chances of hitting the PMT cathode. Photons can either directly hit the cathode directly, or bounce off the other end of the PMT and then hit the cathode, but this hypothesis has yet to be proven. A more sophisticated setup is needed to minimize the amount of human error, and enhance the angle dependency results.

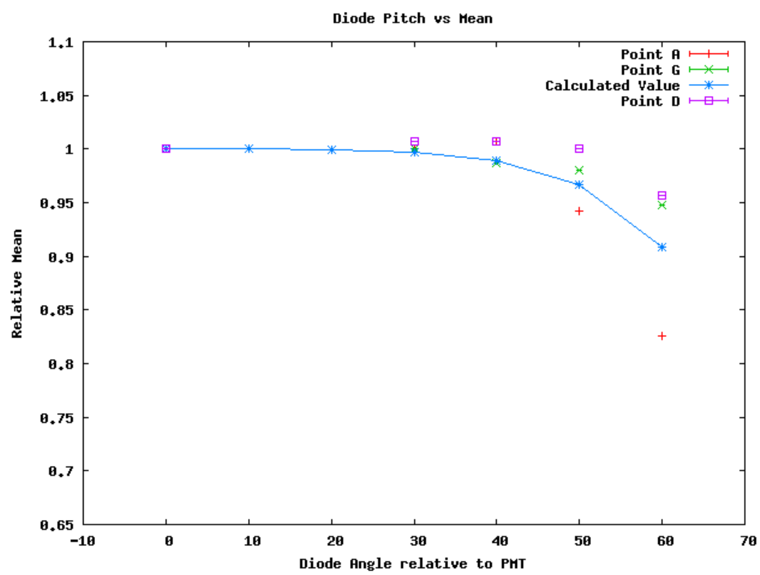


Figure 5: Incident Angle vs. Mean

2.2 Hardware Project: Photodetector Response in an Electrostatic Field

The next PMT test was to see if an electric field would affect the photodetector response. A black box that contained two parallel aluminum plates that are 50 cm. apart was built, shown in fig 6. A high voltage wire was then connected to one of the plates, while a ground was connected to the other. A voltage of 500 Volts was then connected. Using a voltmeter, the voltage between the plates was measured to make sure it was the same voltage that was being passed through. The PMT and light diode were then

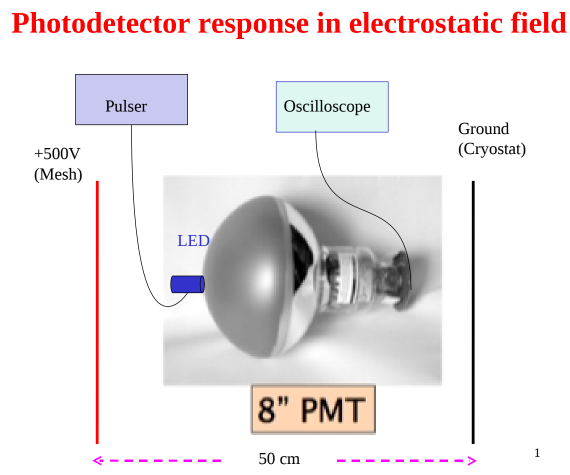


Figure 6: Electric Field Setup

placed into the black box. The PMT pulse height before the electric field was turned on and after the electric field was turned on was recorded. There was no change in the pulse height. The reason for this is because the cathode is at ground and the outside field lines terminate when it reaches the cathode. There is an electrostatic shield on the outside of the PMT that acts like a Faraday cage meaning no outside electric field will affect the output of the PMT.

3 Software Project: LArSoft Monte Carlo Code

LArSoft software is used for liquid argon experiments at FermiLab.[2] The geometry of the LArSoft events generated are specific to MicroBooNE. This simulation software creates events in GENIE, an event generator, sends the events to LArG4 which models the detector response to a first elastic event using the Geant4 toolkit, then drifts the ionization electrons and then does the readout simulation. The interactions that were generated with GENIE were all mono-energetic electron flavored neutrino-electron(NUE-e) interactions. Due to the fact that this software is still in its development stages, there were many bugs that we ran into during the course of this internship. Communicating with William Seligman and Brian Rebel about the bugs encountered and asking a plethera of questions on how to run the LArSoft simulation helped greatly.

3.1 Software Project: Extracting Data from LArSoft

Learning how to run LArSoft was a task, mainly because there were daily updates to the software. Because the main interest in this project was simulating supernova neutrino events, it was necessary to generate NUE-e interactions, as well as generate events at low energies. Due to the fact that NUE-e interactions were not the default setting, understanding and interpreting what was written in the LArSoft code was

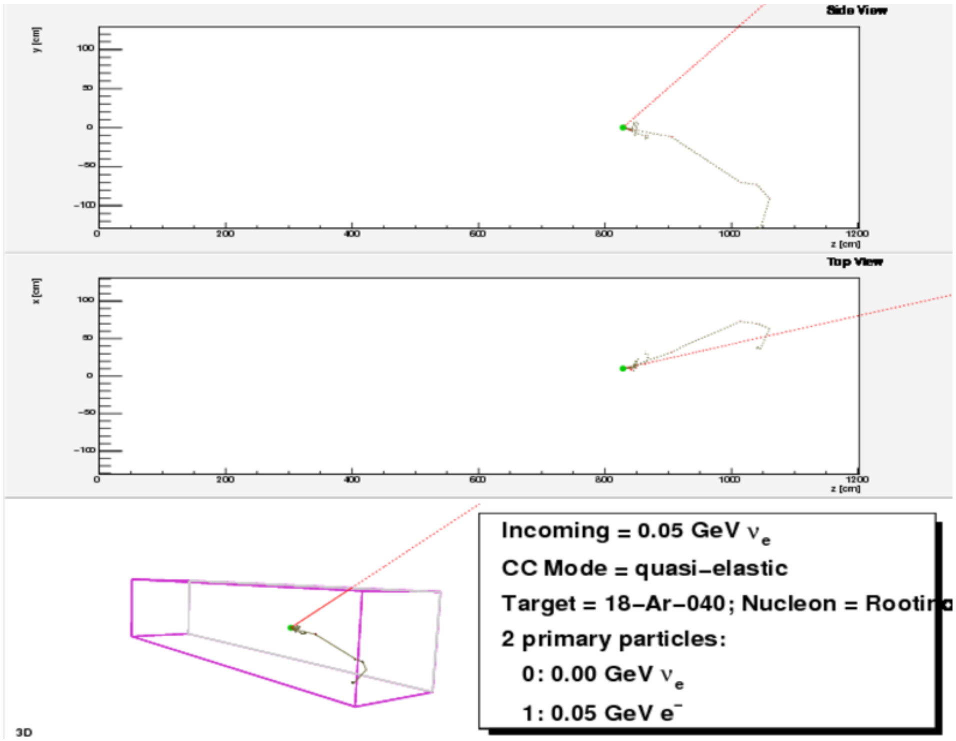


Figure 7: Event Display Window

necessary to change these settings. There were many emails and questions asked to both William Seligman and Brian Rebel while trying to understand these classes. After reading many .h files and skimming the surface of this software, it was plausible to run LArSoft for the specific configurations that were wanted. The figure below shows an event in the event display window, fig 7. At the start of the internship, this was the only way to look at events. A C++ program was then written to extract and analyze information. The energy of the incident neutrino and energy of the scattered electron as well as the direction of the scattered electron relative to the incident neutrino were a couple of things that were important to analyze.

3.2 Software Project: Simulation Results and Analysis

There were some difficulties with the coordinate system in LArSoft, so in the event display window, the actual vertex of the particle was not shown in the right place, but because the truth information was correct, it was possible to do data analysis. LArSoft was first ran for 100 events with three different energies, 50MeV, 100MeV and 150Mev. The events generated were then exposed to the extracting C++ code to make sure that the code was reading the events and information stored for each event correctly. After this, LarSoft was run for 1000 events with the same three energies. The results shown below are for these 1000 events.

Figure 8(a) and fig 8(b) are two plots that show that the incoming energy is equal to the sum of the outgoing electrons and neutrino energy. The .0005 differences is the rest mass of the Argon electron that the neutrino hits. Fig 8(c), is a plot of the energy of the outgoing electron for both $\bar{\nu}_e - e$ and $\nu_e - e$ interactions. The next plot, fig 8(d), shows the outgoing ν_e's. The next plot though has a peak at a certain energy, fig 8(e), the reason for this is due to the conservation of angular momentum. Because $\bar{\nu}_e$'s are right handed, to conserve angular momentum, there is only one direction that the $\bar{\nu}_e$ can go, where as the ν_e is left handed and there are many directions that it can go while still conserving angular momentum. The next three plots are of great interest. All plots show a correlation between the energy of outgoing electron and the number of voxels. This result is to be expected because if the outgoing electron has more energy, it will drift longer, causing many more voxels to be hit.

4 Conclusion

Although there is much more left to do for this project, the work done over this summer was deemed beneficial for the MicroBooNE collaboration as a whole. The next step in this project is to be able to histogram the energy of each voxel relative to the energy of the outgoing electron and be able to find a resolution. Also, being able to distinguish what electrons were from an ν_e or an $\bar{\nu}_e$ interaction and plotting these electrons seperately would be important. Also for all of our PMT response tests, a ten dynode chain was used. In the MicroBooNE experiment, a fourteen stage dynode chain will be used so seeing if there is any different results using this PMT would be interesting to see as well.

5 Acknoledgments

Many thanks go out to Lesli Camilleri, Willian Seligman, and Gary Cheng for all the help that was provided along the way. A special thanks to Mike Shaevitz and John Parsons for allowing the opportunity of working as a Summer REU at Nevis. Much was learned and everything learned is appreciated. Thank all of you for the patience in explaining physics concepts. It is one of the most rewarding experiences to date.

References

[1] Neutrinos from supernovae, http://hep.bu.edu/ superk/gc.html.

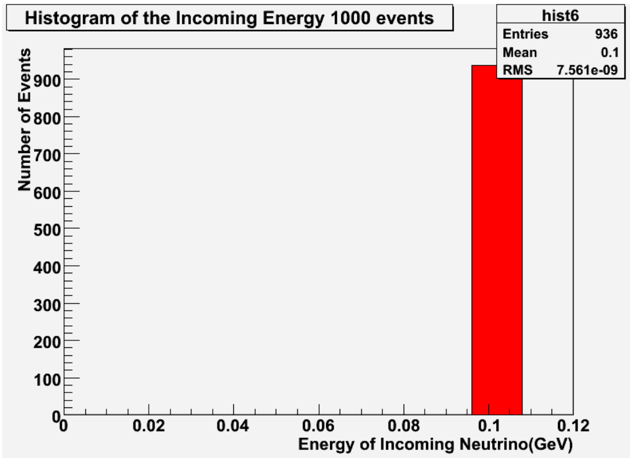
[2] Larsoft, http://www.nevis.columbia.edu/twiki/bin/view/LArSoft/WebHome.

[3] Large photocathode area photomultiplier tubes, www.hamamatsu.com.

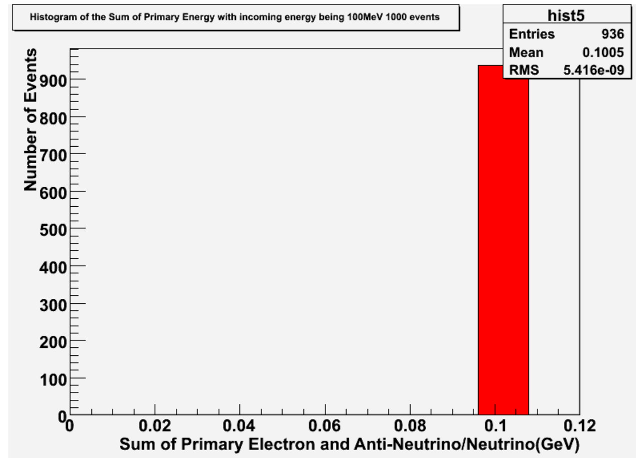
[4] F. Arneodo. The icarus experiment, a second-generation proton decay experiment and neutrino observatory at the gran sasso laboratory, 2001.

[5] H. Chen et al. Proposal for a New Experiment Using the Booster and NuMI Neutrino Beamlines: MicroBooNE. FERMILAB-PROPOSAL-0974.

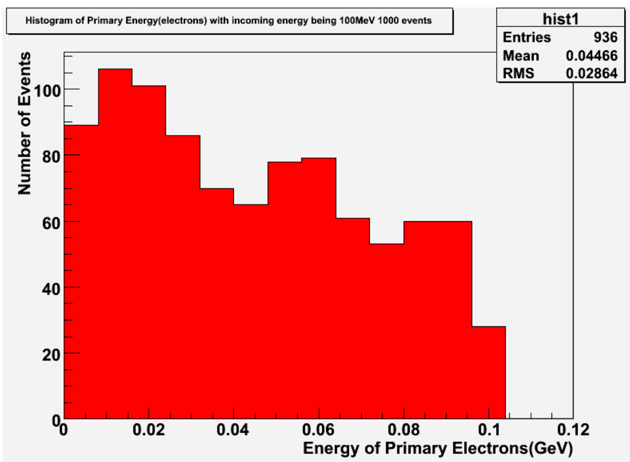
[6] M. S.J. Brice et al. MiniBooNE Collaboration. Photomultiplier tubes in the miniboone experiment, 2006.



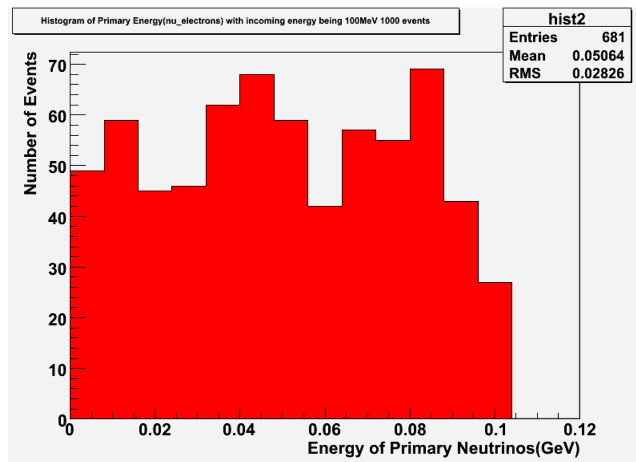
(a) Incoming Energy



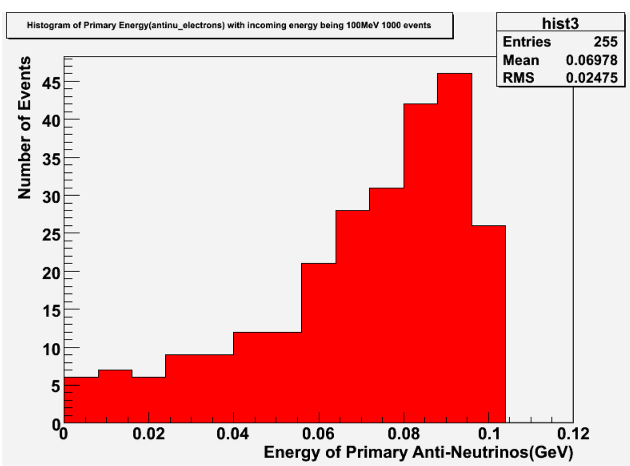
(b) Outgoing Energy



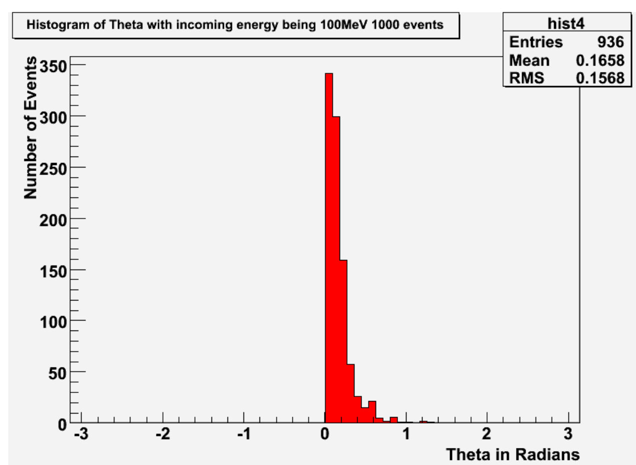
(c) Energy of Outgoing Electrons



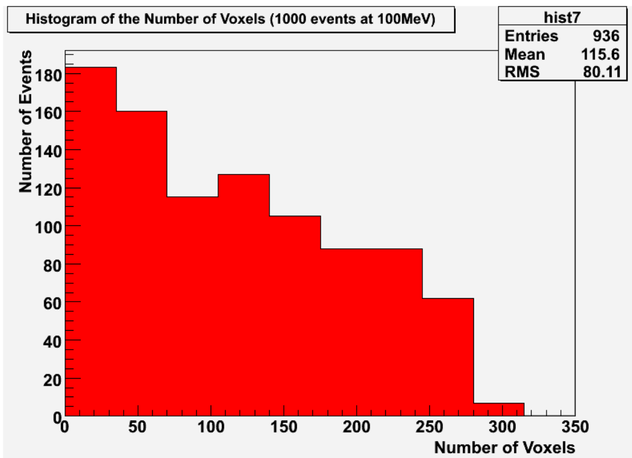
(d) Energy of Outgoing Neutrinos



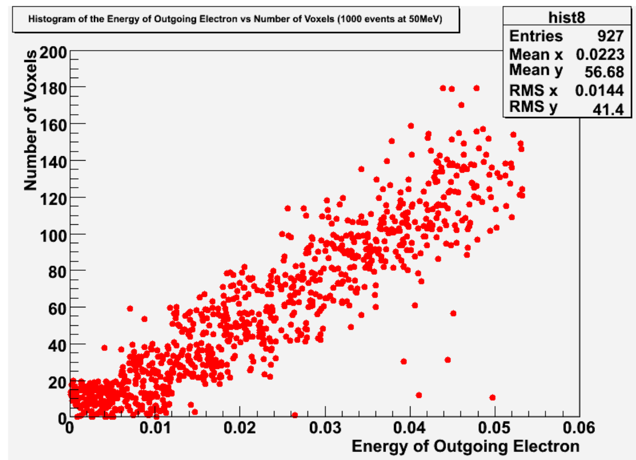
(e) Energy of Outgoing Anti-Neutrinos



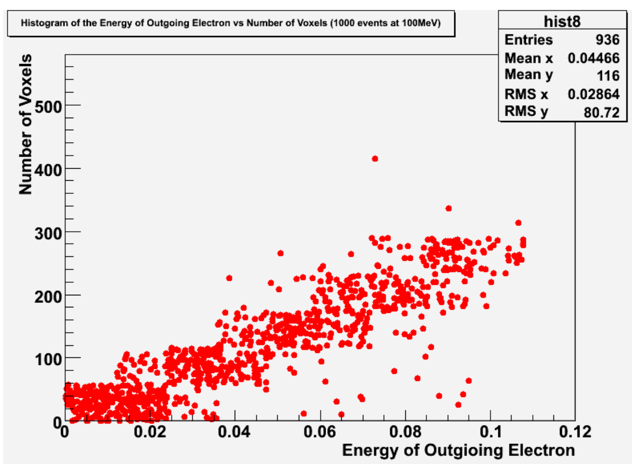
(f) Theta between Neutrino and Lepton



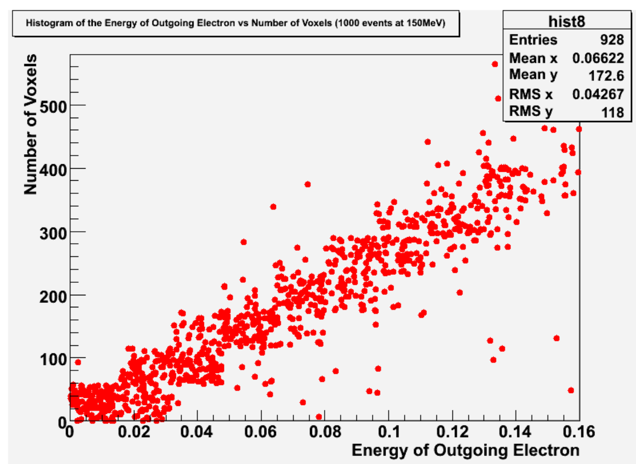
(g) Voxels



(h) Scatter Plot of the Energy of Outgoing Electron Relative to the Number of Voxels @ 50MeV



(i) Scatter Plot of the Energy of Outgoing Electron Relative to the Number of Voxels @ 100MeV



(j) Scatter Plot of the Energy of Outgoing Electron Relative to the Number of Voxels @ 150MeV