Energy Reconstruction with the Sweeper Magnet Focal Plane Detector

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Abstract

The Sweeper Magnet Focal Plane Detector project is a collaboration of the National High Magnetic Field Laboratory (NHMFL) at Florida State University and the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. The NHMFL will construct the Sweeper Magnet, a large C-type magnet necessary for the bending of rigid nuclear beams. The NSCL will build the Focal Plane Detectors consisting of two Cathode Readout Drift Detectors (CRDCs) for taking precise position measurements and an Ion Chamber with plastic scintillators for taking ΔE and E_{tot} measurements. During beam experiments, the Sweeper Magnet will bend the charged fragments for detection in the Focal Plane Detector. As fragments pass through, each CRDC will measure a position where fragments impinge. This will allow experimenters to calculate a fragment's trajectory and determine where it will strike the large stopping scintillator for the E_{tot} measurements. In order to obtain accurate energies of the fragments, the position sensitivity of the large scintillator must be mapped. By finding a functional relationship between the position of the impinging particles and the attenuation of the light emitted by the scintillator, one can use the known position information from the CRDCs to reconstruct the energy of fragments. The position sensitivity of the large plastic scintillator as measured with a collimated, pulsed blue diode will be presented.

Introduction

Physics in general is concerned with formulating models to describe and quantify the properties of families of mechanical systems. Classically, the best test of how versatility of a model is to apply it to the most extreme systems the model is intended to describe. For example, Newton's Laws provide the basis for a model of how forces, energy, space and time are related. When applied to conventional scenarios, these laws are sufficient to predict and describe observed phenomena. However, there are limits to the applicability of Newton's Laws. When dealing with very minute exchanges of energy, small special or small temporal dimensions (quantum mechanics), Newton's Laws are inadequate. At the opposite end of the spectrum, when dealing with extreme velocities or vast spacial or temporal dimensions (relativity), Newton's Laws also break down. Testing Newton's Laws at these extremes reveals that they are incomplete.

In the same spirit, nuclear physicists apply models to extreme examples of nuclear structure in order to test the versatility of their models of atomic nuclei. Neutron rich nuclei, particularly the class of nuclei known as "halo-nuclei", are providing excellent tests of nuclear structure models. Neutron rich nuclei are nuclei that have characteristically large neutron to proton ratios and therefore lie far from the valley of stability. In extreme cases, loosely bound valence neutrons can form "halos" that have neutron wavefunctions tailing far beyond the proton wavefunctions. These properties can give rise to complicated, multi-body nuclear systems possessing unique characteristics unlike that of any of the more familiar, stable nuclei.

The weakly bound, unstable character of extremely neutron rich nuclei makes production and measurement of their properties challenging. Since the half-lives of many neutron rich nuclei, especially those of the halo-nuclei, are very short, it is necessary to produce and deliver them to experiments as fast a possible. The coupled cyclotron facility at the National Superconducting Cyclotron Laboratory is ideally suited to deliver such nuclei for experiment. Production and delivery is achieved by forming a high-energy, high-intensity beam of the desired isotope. Since the achieved beam velocities can be as high as 0.5c, the isotope to be measured is produced and reaches experiments very quickly.

Production of the beam begins with the ionization of a sample of atoms consisting of stable nuclei. These nuclei will be used to create a primary beam. The atoms of the sample are ionized and accelerated through foils in order to strip off valence. The end result of this process is a beam of partially ionized atomic nuclei. This is then injected into the coupled cyclotrons to be accelerated. Using magnetic and electric fields, the first cyclotron accelerates the nuclei. Upon achieving the desired energy, the nuclei are completely ionized, leave the cyclotron and are injected into the second cyclotron to be further accelerated. Nuclei leaving the second cyclotron compose the primary beam. This beam is then impinged upon a target in order to fragment the nuclei of the beam. This produces many different kinds of nuclei, some of which are the isotope desired for a given experiment. These products are injected into the A1900, a series of large dipole magnets and magnetic multi-pole lenses that repeatedly bend and re-focus the beam. The amount by which a fragment's flight path is bent by the dipoles is proportional to its charge to mass ratio. As a result, the products can be separated and a beam composed of a particular isotope can be selected to continue on to experiments.

In order to study the internal structure of neutron rich nuclei, it is often necessary to impinge a beam of the isotope to be studied on a second target. Depending on the target selected, the beam nuclei can be Coulomb dissociated or directly broken up. This will result in the production of neutrons, charges particles and charged fragments. By measuring these particles in coincidence and studying correlations between their properties, such as momentum distributions, one can gain insight into the internal structure of the isotope.

There are several complications involved in measuring the products of dissociation and breakup reactions in coincidence, particularly neutrons. In fact, since neutrons carry no charge, they are somewhat weakly interacting and can only be indirectly measured. One method of detecting neutrons is by projecting the neutrons through scintillator materials, often liquids or plastics. As the neutron passes through the scintillator material, it may deposit some of its energy into its molecules. This energy takes the form of excitations in the scintillator molecules. When the scintillator molecules return to their ground states, photons are emitted which photomultiplier tubes can easily detect. This method of detection however, is undermined by the presence of charged particles, which also cause scintillator materials to emit light. This can give rise to unacceptably high backgrounds that can obscure the measurement of neutrons.

The Sweeper Magnet Focal Plane Detector is a solution to this complication. Neutrons can be measured in coincidence with charged particles and charged fragments by bending the charged particles and fragments out of the beam of neutrons to be measured in a separate detector. The neutrons continue at zero degrees to be detected while charged particles will be measured in a focal plane detector. Hardware and software solutions can then be implemented to expose correlations between corresponding spectra.

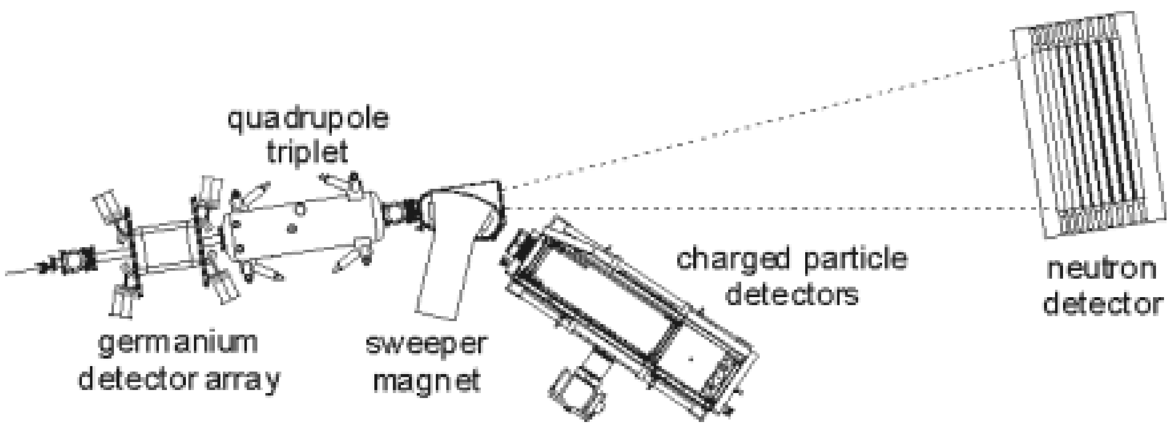

Figure 2: The SMFPD as arranged in NSCL N4 vault.

The Sweeper Magnet Focal Plane Detector (SMFPD) consists of two tracking detectors for determination of fragment trajectory, an ion chamber for measuring changes in energy, and a large scintillator for measuring total energy. For the purposes of this text, the reconstruction of fragment energies from the large scintillator block is examined in detail. In order to achieve reconstruction, it is first necessary to map the position sensitivity of the scintillator block, reading out the scintillator light by hotomultiplier tubes(PMTs). The ultimate goal of this work is to find the attenuation length of the large scintillator block and fit a function that, given the position of an impacting particle, will allow the energy of the particle to be reconstructed. In order to map the position sensitivity of the large scintillator block, we make use of a pulsed, light emitting diode to simulate the application of nuclear beam. Pulses of light from the diode impinge on the scintillator block and cause molecules of the scintillator plastic to emit secondary light.

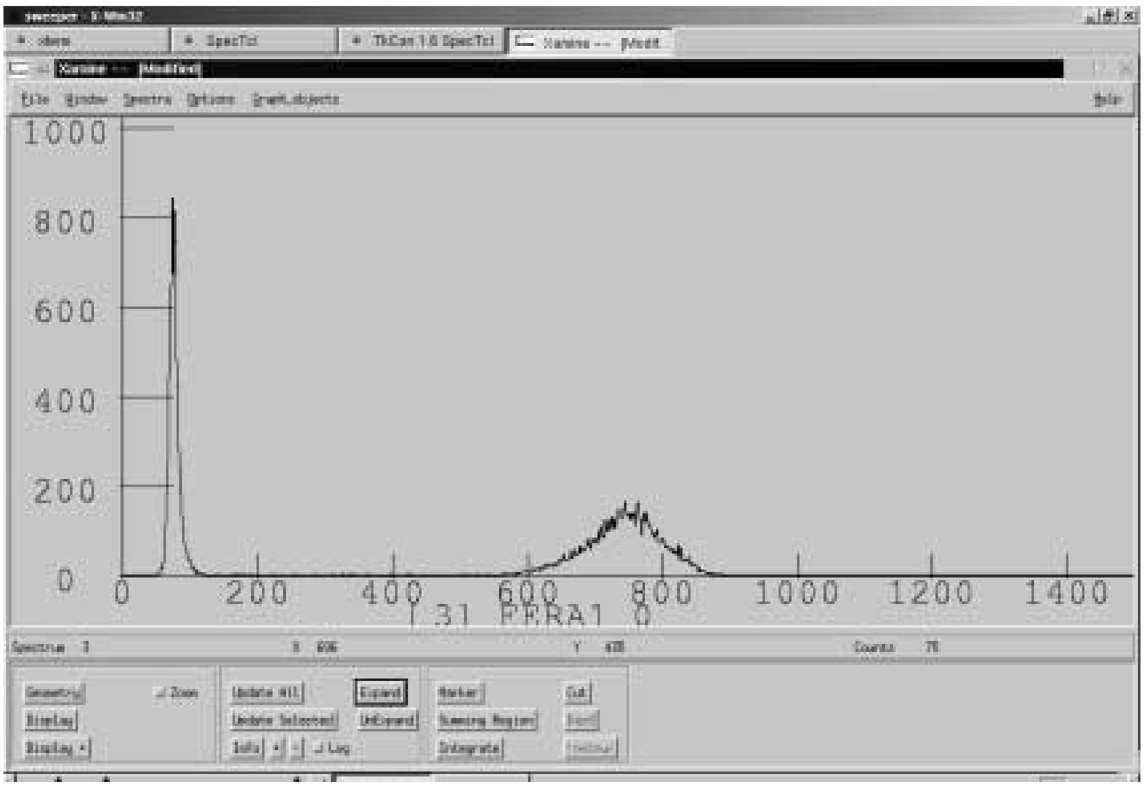

Figure 1: An example spectrum as displayed by SpecTcl

A photomultiplier tube (PMT) mounted to the block surface detects this light. Upon detecting the photons, the PMT generates a voltage pulse proportional to the number of photons. This signal is then modified by electronics that map the magnitude of the voltage pulses to digital channels. A readout program for display in an analysis program called SpecTcl then receives these channels, which are proportional to the event energy. Figure 1 is an example of a spectrum as displayed by SpecTcl.

Experimental Setup: Physical Assembly

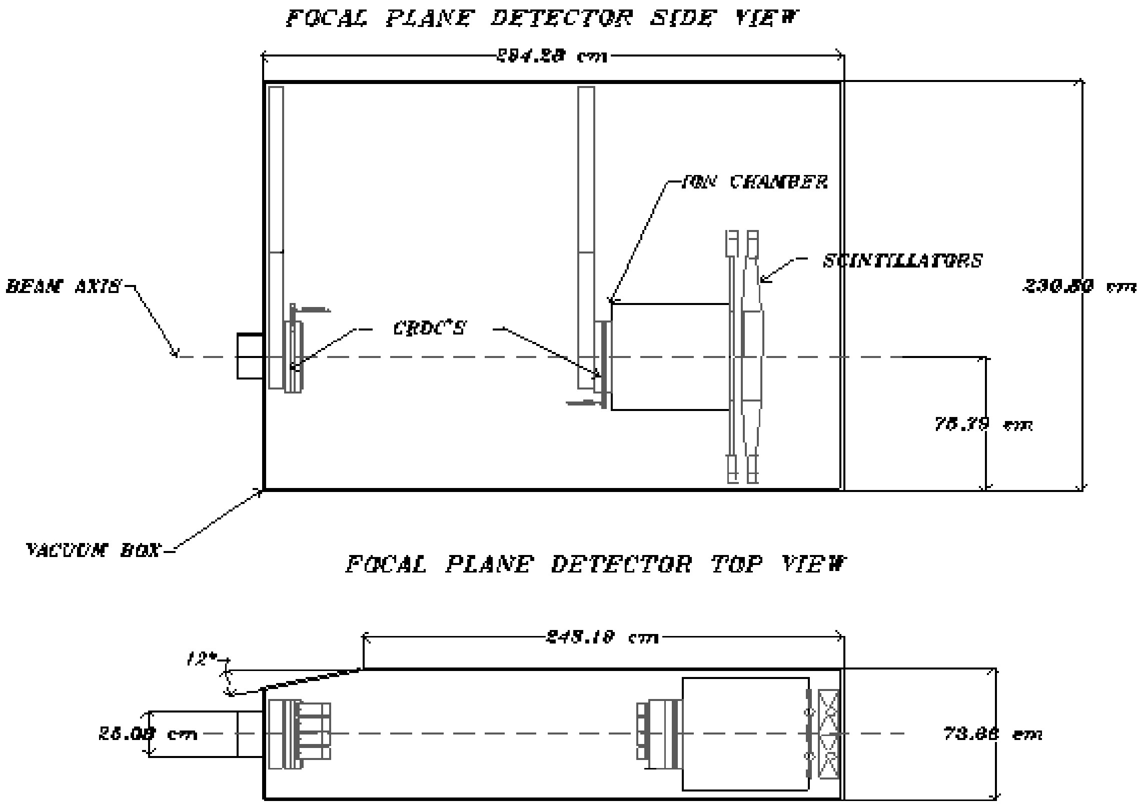

Figure 3: Schematic of the Focal Plane Detector

Since PMTs are very sensitive to light, they must be optically isolated from everything except the scitillator plastic they are to detect events from. This places several constraints on the design of an apparatus to measure the position sensitivity of the large scintillator block. First, the Focal Plane enclosure must be “light-tight”; it must be closed and sealed well enough to stop as much ambient light as possible, which can potentially overwhelm light emitted from real events. However, to test the position sensitivity of the scintillator block, one must be capable of moving the light source with ease. Furthermore, the PMT operates at significantly reduced efficiency due to thermal variation, if not left on constantly. To solve these complications, we made use of two Whedco precision electric motors mounted to guide beams. Power and control for the motors is then fed through a face plate at the base of the SMFPD enclosure. Additionally we make use of a pulsed, light emitting diode (LED) as a light source. This LED is

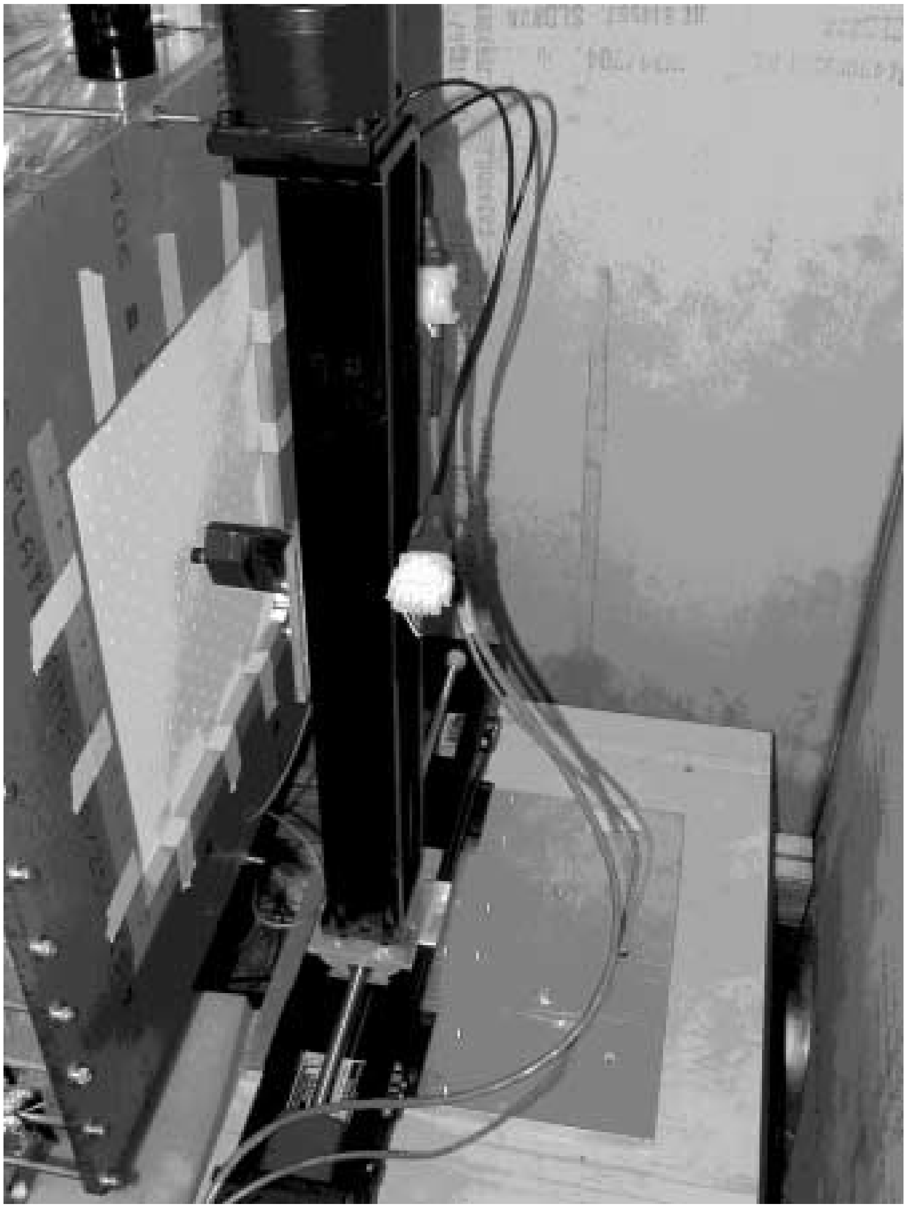

Figure 4: Picture of the Whedco Motor Control apparatus.

mounted to the vertical Whedco motor apparatus. This is then mounted to the horizontal Whedco motor apparatus. Both motors are powered by external Whedco power modules and controlled remotely by software command. In combination, this system allows for the movement of the LED over the surface of the large scintillator block with better than millimeter accuracy while maintaining a dark environment inside the SMFPD enclosure. To increase the resolution of data taken, a plane of collimating holes is placed over the face of the large scintillator. This confines the angular distribution of the light emitted by the diode.

Experimental Setup: Electronics

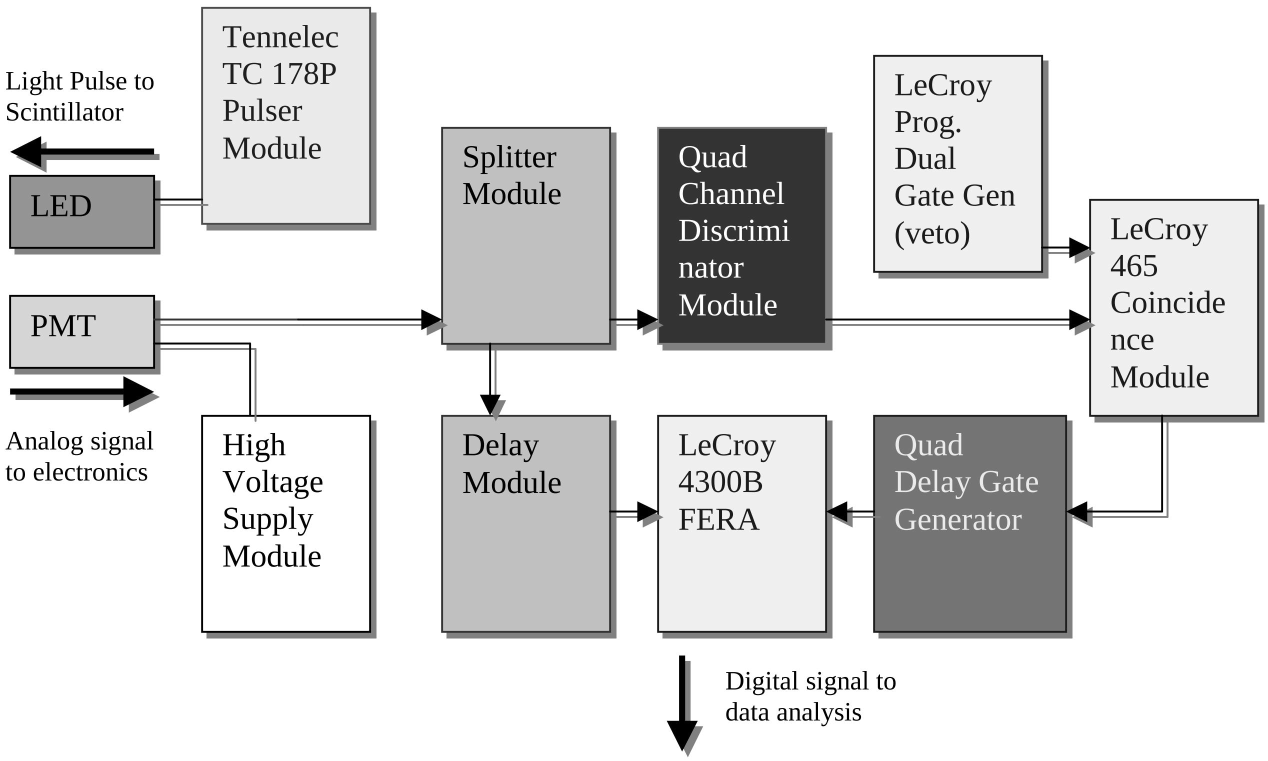

Figure 5: A conceptual layout of electronics modules used converting data from analog to digital signals.

Figure 4 provides a conceptual diagram of the electronics used in converting the PMT's analog signal to a digital signal for processing with computer software. The signal begins when an event in the scintillator triggers the emission of photons. When biased with a high voltage supply, the PMT will transmit a voltage pulse upon capturing these photons. This signal is a "raw" or analog signal and is not in a form that a computer can perform logic operations on and therefore must be converted into a digital signal. The signal first enters a splitter module from which duplicate signals are sent to a Quad Channel Discriminator module and a delay module. The Quad Channel Discriminator receives the signal and transmits a voltage pulse if the incoming pulse is equal to or greater than the discriminator's threshold setting. Since the magnitude of the incoming voltage pulse is proportional to the event energy, adjustment of the discriminator threshold allows low energy events to be isolated from higher energy events. For events with high enough energies, voltage pulses from the discriminator module are sent to a LeCroy 465 Coincidence module. This module acts as a simple “and-gate”, emitting an output voltage pulse if both input signals arrive in the module simultaneously. The second input for the coincidence module comes from a LeCroy Programmable Dual Gate Generator. This module is used to generate a “computer-ready” or veto signal that indicates whether or not the computer is ready to receive data or busy processing another event. When both the veto and the discriminator pulses arrive in the coincedence module, an output pulse is sent to a Quad Delay Gate Generator. This module generates a voltage pulse of an adjustable time-width. This pulse instructs the LeCroy 4300B FERA to record raw data arriving during the gate pulse. Raw data leaving the splitter module is sent to a delay module in order to synchronize the raw pulses from the PMT with the gate pulses of the gate generator. The FERA module then records the height of the analog pulse in a channel, of which the FERA has 2096. Since the magnitudes of the analog voltage pulses are being mapped to a channel number, the channel number is then proportional to the energy of the triggering event. A software program called a “readout” code initializes the FERA and allows the counts per channel data to be sourced by an analysis program called “SpecTcl”. From SpecTcl, counts per channel data for a given spectrum can be exported and manipulated by spreadsheet programs such as Excel.

Procedure

Before begin trials, ensure that the Focal Plane enclosure is “light-tight”, meaning little or no ambient light is leaking into the vacuum box. To check this, observe the PMT signal in an oscilloscope. Slowly increase the HV bias on the PMT until a weak signal is observed. Photomultiplier tubes will generally not emit an output signal until the bias applied to them is approximately –1500 volts. Any major light leaks must be isolated and covered before proceeding. Once the vacuum box is light tight, input the PMT signal into the electronics setup. Increase the voltage applied to the PMT to bias high enough to clearly see desired signals. Do not exceed –2400 volts for the PMT bias unless the tube is specifically rated to operate at higher voltages. Most PMTs reach the upper bound of their operational limit at this voltage. Adjust the discriminator threshold, using an oscilloscope to observe signal changes, and minimize the amount by which the discriminator pulses on low energy background counts and electrical noise. Also ensure the gate pulse that engages the FERA is of acceptable length and coincides with analog signal from the PMT. From a data acquisition computer, launch the readout code that initializes the FERA module. Next, launch SpecTcl, sourcing the appropriate setup file and attaching the desired data pipeline. Launch two instances of the Whedco motor control program, one for controlling the LED's motion about the X-axis and the other for controlling motion about the Y-axis. Connect each instance to the corresponding terminal server. Using the control programs, move the LED such that it emits pulses through the collimator at the desired position on the large scintillator block. Record counts for 120 seconds per position, covering 25 positions in a 5 by 5 point grid of 6cm resolution. Write spectra from SpecTcl to data files (.dat) for analysis with Excel or other spreadsheet program.

Data Analysis

Peak Channel versus Position						
X-Axis Pos.(cm)	Y-Axis Pos.(cm)	-12	-6	0	6	12
12		601	504	588	523	502
6		580	490	570	469	414
0		757	631	516	444	418
-6		884	684	479	473	353
-12		1137	786	580	476	447

Table 1: Peak channels for each of the 25 data points in the sampled grid.

As shown previously in Figure 1, each position sampled has a corresponding spectrum composed of a low channel, high intensity background peak, and a high channel, low intensity peak produced by the pulses of the LED. Table 1 displays the channel number in which the LED peak appeared for the spectrum taken at the corresponding position. Figure 5 below is a three dimensional plot of Table 1.

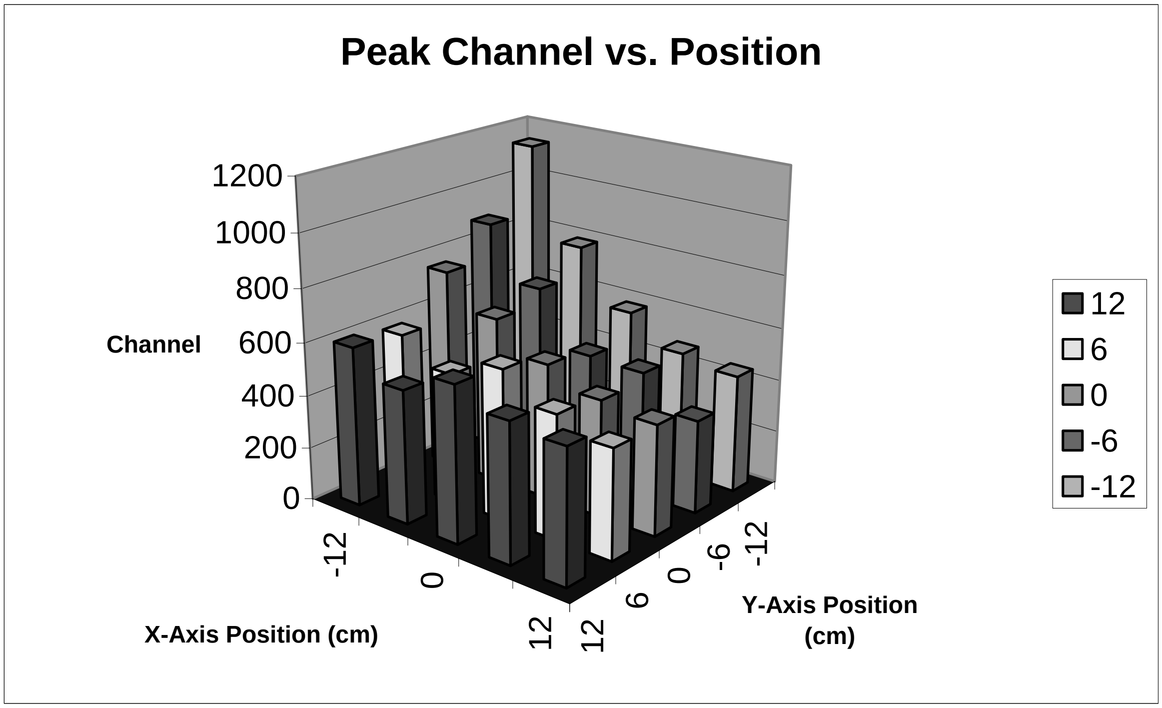

Figure 6: Peak Channel versus Position on the face of the large scintillator block.

From the above plot, attenuation is clearly observable as the LED is moved from the position closest to the PMT, corresponding to the (-12cm,-12cm) coordinate to more distant points on the block. By reflecting these data sets about the axes and summing these groups, we can emulate the presence of four PMTs mounted at the four corners of the block. This is shown on the next page in Figure 7. It is clear from the plot that the relationship needed to yield the attenuation length is not linear in either x or y variables however, further information cannot be obtained from this data. It is necessary to mount PMTs at the remaining corners and measure events in coincidence. From this data correlations between spectra can be studied and a function for reconstructing the energy

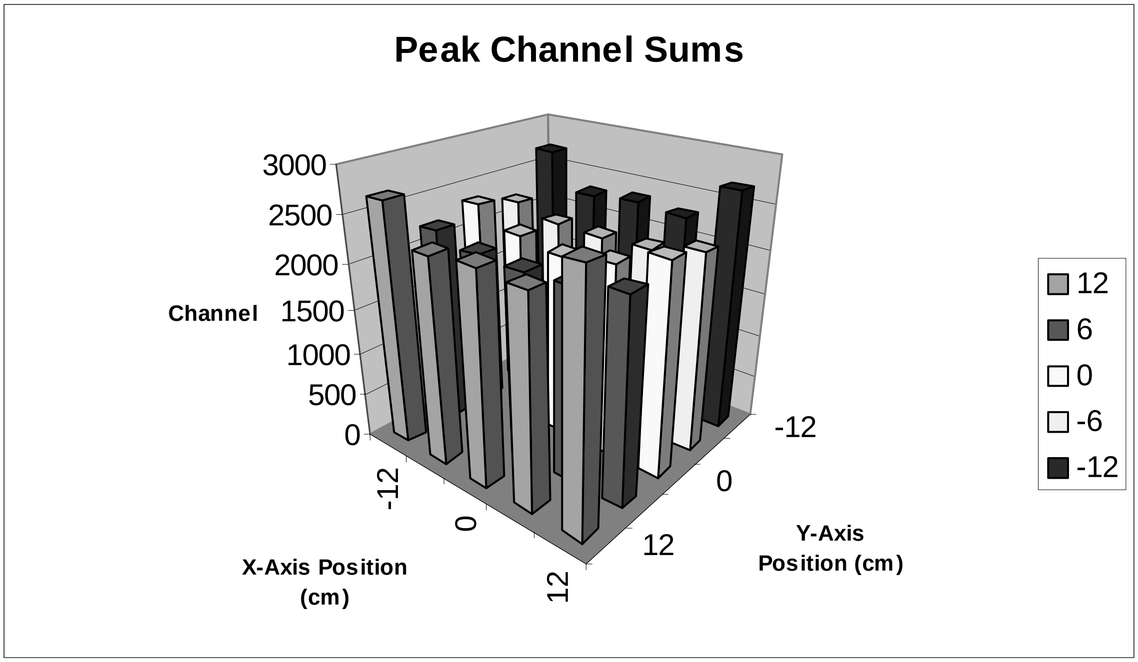

Figure 7: Peak Channel sums emulating the measurement of events from symmetrically mounted PMTs

as a function of event position can be determined. This is recommended as an avenue of further experimentation.

Conclusion

While this experiment proved unable to achieve its full objective, to formulate a relationship that allows the reconstruction of event energies as a function of position, it has nonetheless produced valuable results. Unlike the more ideal spectrum presented as an example in Figure 1, which is a spectrum taken with the source very close to the PMT, many of the spectra taken when the LED was distant from the PMT exhibited unusually peak characteristics. The expected effect of moving the LED further from the PMT location in successive spectra is the reduction of peak intensity, spreading of the peak and reduction of the peak's channel, and thus its mean energy. These effects are clear studying spectra that vary along lines of constant X value, especially the series of spectra taken from the column of points directly above the PMT location.

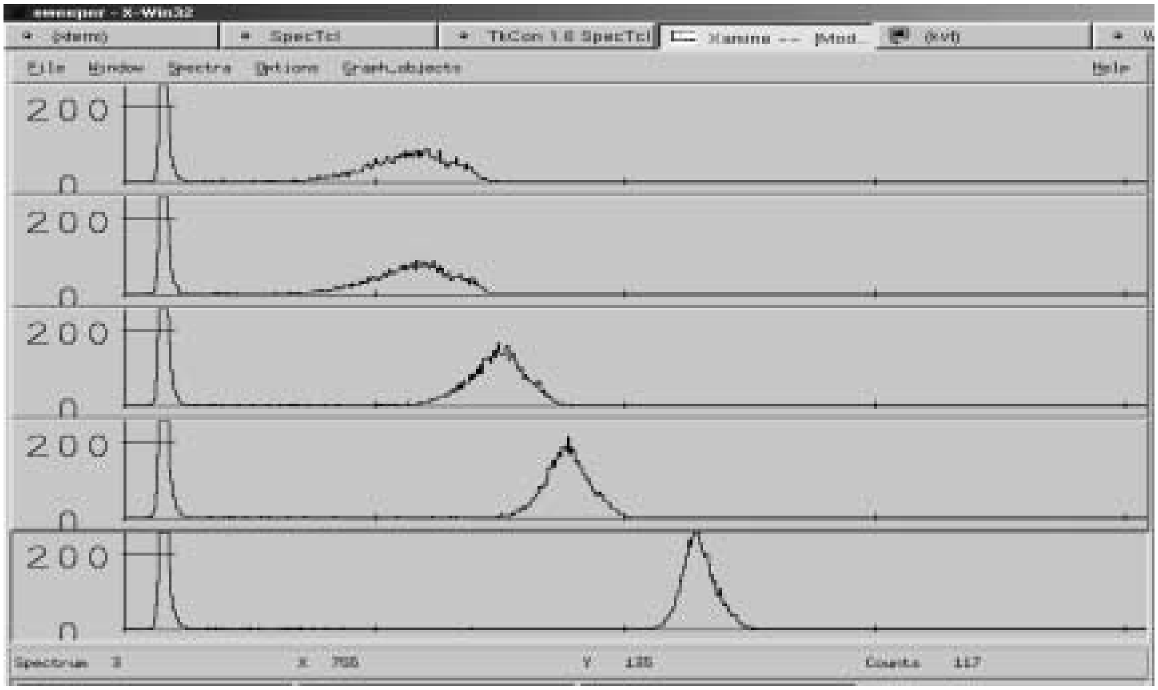

Figure 8: Spectra for LED positions directly above the PMT location; x = -12 cm with y values of 12, 6, 0, -6, and -12 cm from top to bottom respectively.

However, upon studying spectral trends along lines of Y value, we see a similar reduction in intensity, reduction in channel number, and a broadening of the peak, but we also see a splitting of the peak into second and even third order peaks. This result is most prominent along the horizontal series of spectra closest to the PMT as shown in Figure 9 below.

Figure 9: Spectra for LED positions along the bottom most grid line; y = -12cm with x values of 12,6,0,-6, and –12cm from left to right respectively.

It is very possible that effects besides those of attenuation are at work as is demonstrated in Figure 9. The exact cause of this phenomenon is unclear, but it is possible internal reflections of light in the scintillator block are responsible. It is necessary to mount additional PMTs at symmetric positions about the scintiallator. Once electronics and software are expanded to readout the additional tubes, the correlation of spectra from the different tubes for indivdual positions must be studied. From this data it would be possible to achieve the formulation of a relationship for reconstructing the energy as a function of event position. It may also be possible to explain the physics at work behind the splitting of peaks in the Figure 9 series of spectra.

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