Final Report

Abstract

This paper details the motivation for and the setup of the Proportional Counter and Silicon detector, as well as its use in the Helium-6 experiment. The Helium-6 experiment will use cyclotron radiation and beta spectroscopy to search for physics beyond the Standard Model. The experiment measures the energy spectra of emitted beta particles to look for anomalies that might be explained by new physics. The purpose of the detector is to be a stable measure of the number of Helium atoms entering the experiment. This paper shows preliminary results on the stability of this detector.

Introduction

The Helium-6 experiment searches for Beyond Standard Model physics. The experiment will use the technique of cyclotron radiation and the energy spectra of Beta particles to explore chirality-flipping interactions in the context of the Weak nuclear force. The Weak interaction is one of the four fundamental forces, along with the Strong nuclear force, electricity and magnetism, and gravity. It is mediated by the W+, W-, and Z, bosons, which are much (~90 times) more massive than the proton; accounting for the force's very short range. The Weak interaction is responsible for Beta decay since it has the ability to change the flavor of quarks within nucleons (protons and neutrons). The subsequent energy spectrum of the emitted Beta particles is continuous. This is due to the energy of the neutrino (or anti-neutrino) which is also emitted.

The interaction Hamiltonian of the Weak force is shown below:

$$H_{\rm int} = \sum_{i=V,A} (\bar{\psi}_p O^i \psi_n) \big((C_i + C_i') \, \bar{\psi}_e^L O_i \psi_\nu^L + (C_i - C_i') \, \bar{\psi}_e^R O_i \psi_\nu^R \big)$$

$$+ \sum_{i=S,T} (\bar{\psi}_p O^i \psi_n) \big((C_i + C_i') \, \bar{\psi}_e^R O_i \psi_\nu^L + (C_i - C_i') \, \bar{\psi}_e^L O_i \psi_\nu^R \big)$$

eq. 1

It is split into the vector and axial vector currents and scalar and vector currents. It should also be noted that the Standard Model only includes left-handed vector and axial vector components. The new physics would also include right-handed and scalar and tensor currents which would flip chiralities. To understand chirality, one must first become familiar with helicity.

Helicity is the projection of the spin of a particle onto the direction of its momentum. If they are both in the same direction, the particle is said to have right-handed helicity, and vice versa. However, helicity cannot be used in Hamiltonians because it is not Lorentz invariant; an observer moving faster than the particle would see that the particle's helicity was flipped. Therefore, a Lorentz invariant variable must be determined; chirality. Chirality is defined as the spin projection onto the "internal velocity" direction of a particle. To find the instantaneous velocity of a particle, the time interval must approach zero. Using the Time-Energy Uncertainty Principle, the energy must approach infinity and the velocity must approach that of light. The motion of particles is then a linear combination of forward and backwards “trembling motion”. An helicity state can be made up from positive and negative chirality states.

Fermi’s Golden Rule describes how the decay rate is related to the Hamiltonian of an interaction.

$$\Gamma_{a\to b} = \frac{2\pi}{\hbar}[< f|H_{int}|i >]^2 \rho \qquad \text{eq. 2}$$

The Interaction Hamiltonian is given in eq. 1, and it is readily seen that expanding it will cause cross terms. These terms, which are comprised of vector, axial vector, and scalar and tensor terms, is called Fierz Interference. This is important since the expected signal from the scalar and tensor terms is exceedingly small with the square of that signal being even smaller. Therefore, any noticeable change in the spectrum is expected to be seen through the cross, or interference, terms.

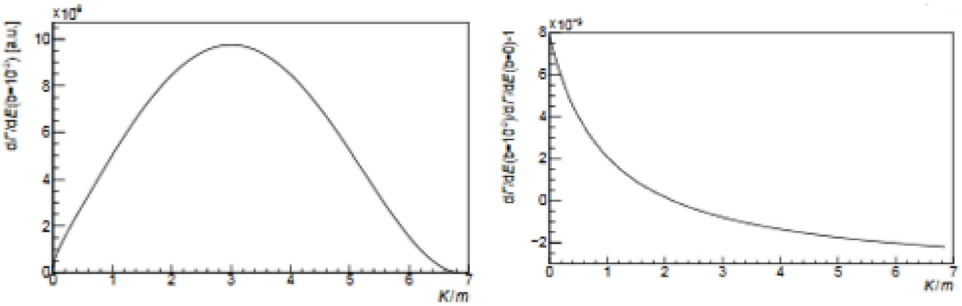

Figure 1: The spectrum from purely Standard Model currents is shown on the left. On the right is how the spectrum is expected to be affected by the Fierz Interference.

In the ^{6}He experiment, the decay rate has the following form:

$$\frac{dW}{dt} \approx \frac{dW_0}{dt}[1 + r(E) + R(E) + \frac{m}{E}b] \qquad \text{eq. 3}$$

Where *r(E)* and *R(E)* are radiative and recoil-order corrections which can be accurately calculated. The last term includes the Fierz Interference term, b. All terms in the decay rate equation depend on the energy of the betas. As the Helium atoms decay, high energy electrons are emitted and captured in the high magnetic field and undergo cyclotron radiation. Because the betas are relativistic particles, the frequency of their motion is related to their energy:

$$f_c = \frac{1}{2\pi}\frac{eB}{\gamma m} \qquad \text{eq. 4}$$

where γ is equal to the kinetic energy plus mass, divided by the mass of the particle. Knowing the charge and mass of the electron, the strength of the magnetic field, and measuring the frequency, one can find the energy of the betas. However, the experiment obtains the energy spectra by measuring the spectrum only within approximately 10% of the total spectrum. To obtain the entire spectrum data from each run at varying magnetic field strengths must be assembled together. Therefore, a highly stable detector will be used to determine the number of beta decays for each run.

Project

The detector created for this purpose is a combination of two detectors: a proportional counter and a silicon detector.

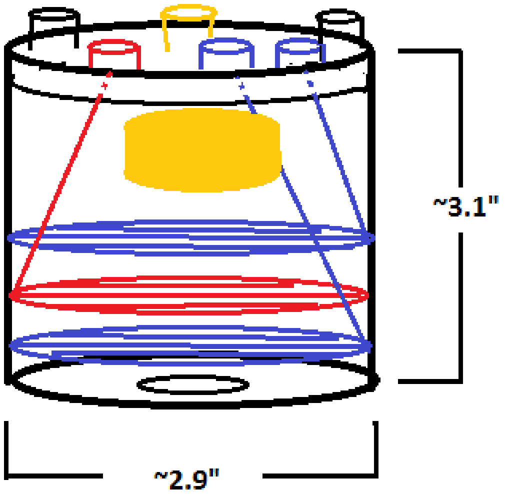

Figure 2: Schematic drawing of the detector. At the bottom there is a wire chamber comprised of two cathodes (connected to ground) and an anode biased to 2800V. At the top is the silicon detector which is biased to 92V. The detector is then filled with a gas mixture of 90% Argon and 10% CO_2. The casing is made of aluminum and is air tight. A hole at the bottom (covered with Kapton tape) allows for beta particles to enter the detector.

The proportional counter works through a process called gas multiplication. As the high energy beta particles enter the detector, they ionize the gas atoms with which they interact. The particles then continue on to the silicon detector, which is a semiconductor detector. The ions, created by interaction with the betas, are then accelerated towards the wires of the proportional counter. Due to the high voltage in the counter, the dislodged electrons (called primaries) will continue to ionize other gas atoms. This is a process called an avalanche. The charges will then be collected on the wires and will be strong enough to induce a pulse, whose strength is proportional to the number of beta particles. Having two detectors allows for a coincidence to be set up between them. This coincidence is highly sensitive to beta particles but not to the background. Because the Helium-6 decays at a known rate, monitoring the number of beta particles in the detector will provide information about the number of Helium-6 atoms are entering the experiment. To test the detector, a Strontium-90 beta source was used.

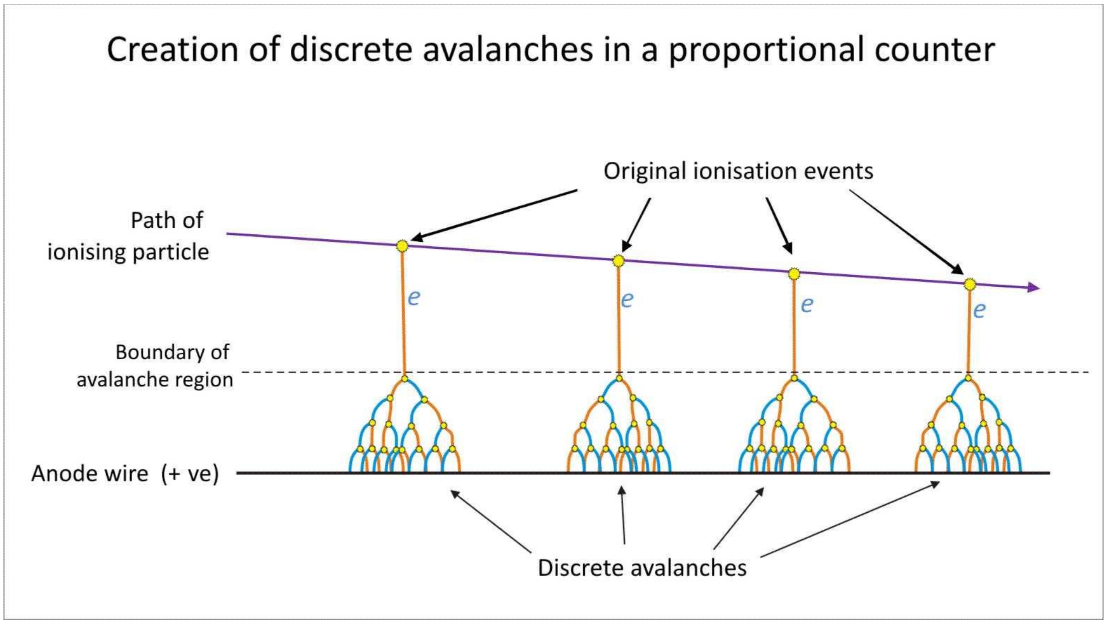

Figure 3: A pictorial representation of the avalanche process.

Both detectors are connected to pre-amplifiers and amplifiers that will allow the computer to read the signal. A pulse generator is also connected to correct for computer dead-time.

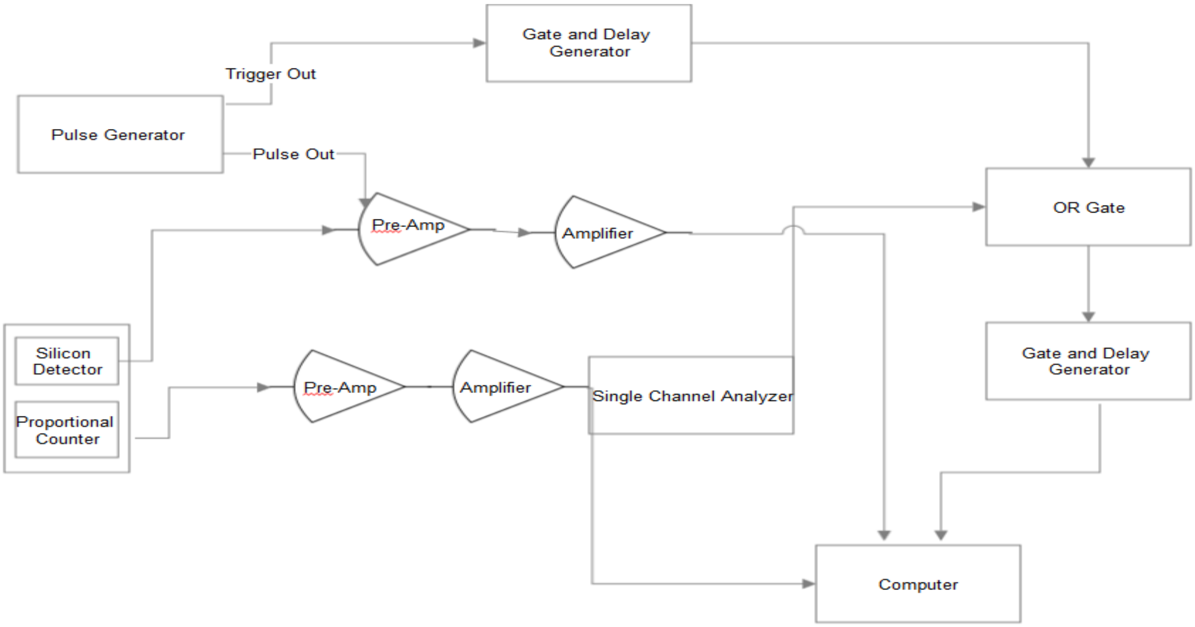

Figure 4: Schematic setup of electronics

Results

Initially the detector was allowed to run for an hour without using the Strontium-90 beta source so that the background signal could be measured. After this was done, several one hour long runs with the Strontium-90 source were taken. The background was then subtracted from each run and the counts were normalized using the counts from the pulser.

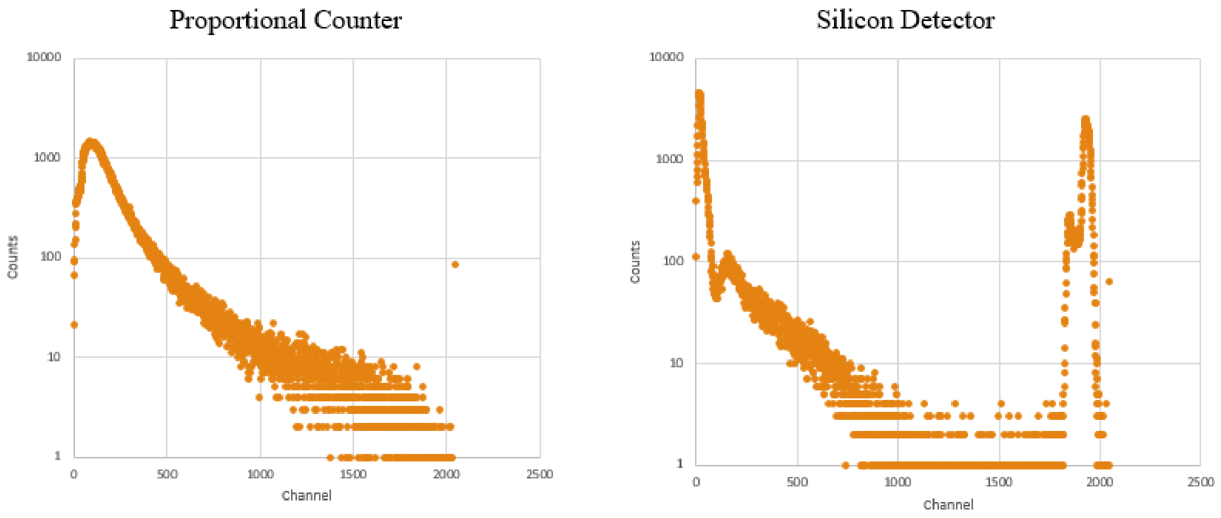

Figure 5: Typical spectra obtained in runs. The two depicted in this figure are from a run that lasted an hour. They are plotted on a log scale. The peaks in the silicon detector chart at around Channel 2000 come from the generated pulse.

The normalized counts should be constant run to run, however it was found that they varied greatly. This could have been due to many factors, including, but not limited to, unstable placement of the source, not having taken background for each run, and possibly a very high background that greatly interferes with data.

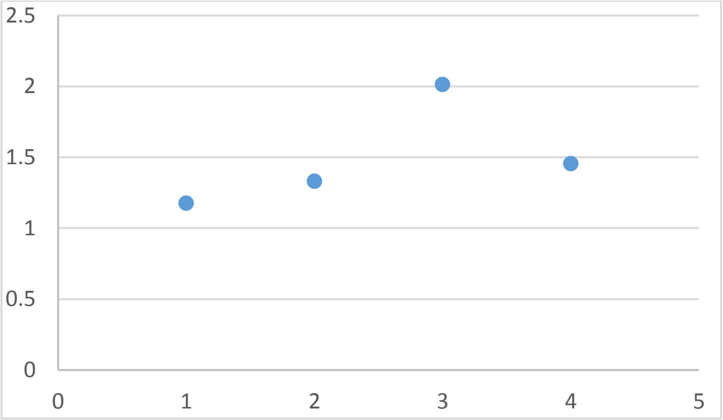

Figure 6: This plot shows the results from the four one-hour runs. The counts in each run vary greatly between each trial.

In order to make the detector more stable, changes were made physically as well as in the data acquisition software. With regards to the physical changes, the source was mounted onto a metal ring structure that held it steady. The ring was then attached in a particular arrangement to the detector. Marks were made on the ring and detector so that the arrangement would be the same for each run. A new sort routine was also used that created histograms for the number of counts during a particular time period from the pulser and from the silicon detector.

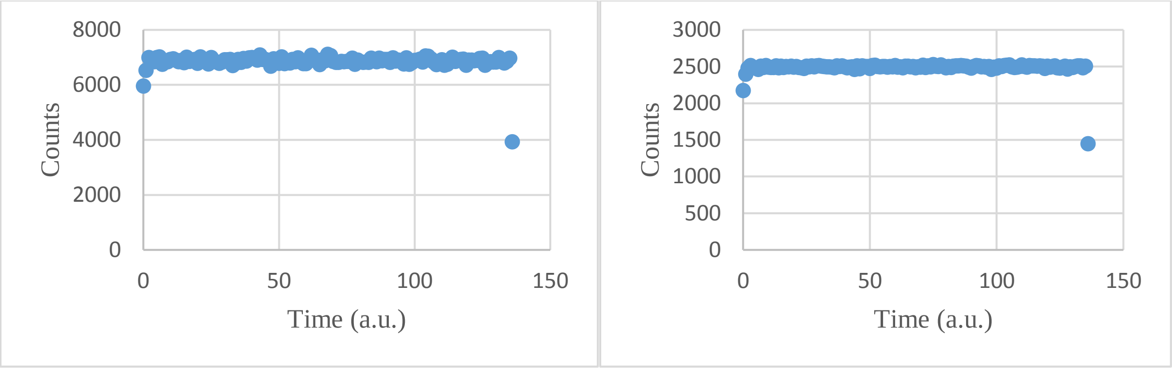

Figure 7: Histograms of the counts from the Silicon detector (right) and pulser (left).

The histograms look relatively stable on first glance. However, upon closer inspection, details of the variation in time can be seen. The true measure of stability is therefore the ratio between the counts from Silicon detector and the counts from the pulser. That analysis was performed by taking the aforementioned ratio, finding its average, and seeing how the counts deviated from that average. This difference was then made into a histogram, where a Gaussian curve centered on 0 was expected. This histogram (Figure 8) shows that the results obtained follow statistical principles in that the distribution is approximately Gaussian with a plausible standard deviation.

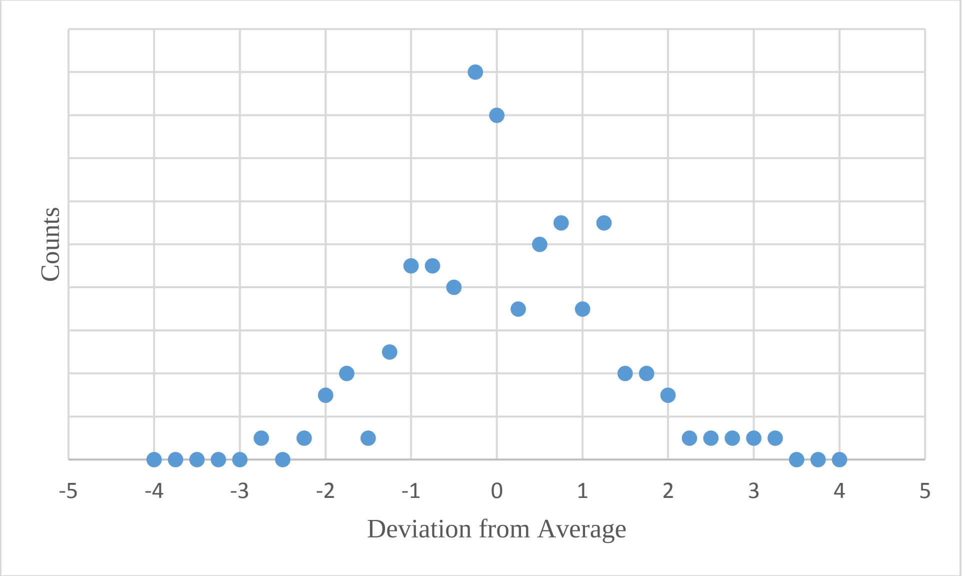

Figure 8: Histogram showing the distribution of counts from the average. As expected, it is centered on 0. The full-width at half max of the distribution is approximately 2.

Conclusion

The technique of using the energy spectra of emitted beta particles from the decay of Helium-6 underdoing cyclotron radiation is a novel way to search for chirality flipping interactions in the Standard Model that would point to new physics. Due to the restriction that different spectra must be obtained for different values of the magnetic field used in the experiment, a detector which was a combination of a Silicon detector and a proportional counter was used to have a way to renormalize the spectra. This paper detailed the design, set up, and test of stability of the detector. It was found that the stability was in line with statistical expectations. Future work however will try to minimize the variability of this detector to ensure it fulfills its purpose in the larger Helium-6 experiment.

References

D. M. Asner et al. (Project 8 Collaboration), Phys. Rev. Lett. 114, 162501 (2015).

D. M. Pozar, Microwave engineering; 3rd ed. (Wiley, Hoboken, NJ, 2005).

R. Hong et al. Am. Jour. Phys. 85, 45 (2017).

“Detection of cyclotron radiation applied to searches for chirality-flipping interactions” By M. Fertl et. al.

Chirality of Photons & Electrons, University of Nebraska, physics.unl.edu/~tgay/content/CPE.html.

Proportional counter. (2017, August 05). Retrieved August 16, 2017, from https://en.wikipedia.org/wiki/Proportional_counter

Standard Model. Retrieved August 16, 2017, from https://en.wikipedia.org/wiki/Standard_Model