Recommissioning the Qweak Drift Chambers Using a Cosmic-Ray Telescope

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I. Abstract

Inside of many detector stacks are drift chambers. They are used to tell the position and direction of particles passing through them. These detectors are filled with an ionizable gas mixture of carbon dioxide and argon, or ethane and argon. When struck, the gas loses electrons which then drift to the closest positively charged sense wire. This charge is digitized and sent to time to digital converters (TDCs) that receive timing information from the sense wires. The purpose of this project was to once again make the Qweak drift chambers work for use in future experiments. A cosmic ray telescope was set up so that one scintillator was strapped on both sides of the drift chamber. Then, a double coincidence trigger was designed so that both scintillator elements had to be struck for a timing event to be recorded. Conclusions were drawn based on how the chambers responded to the cosmic ray passing through them. It was shown that a majority of the wires in the chamber recorded proper data and performed up to standard. Before the 12 GeV upgrade, all of the wires produced proper data in all of the drift chambers. Future plans hope to reproduce this case and ensure all wires are receiving signals. Once complete, all of the drift chambers will be moved and processed at Duke University for use in a measurement of the Bethe-Heitler pair-production process.

II. Introduction

The Qweak drift chambers were removed from Hall C after the 12 GeV upgrade at Thomas Jefferson National Accelerator Facility. After their removal, plans were made to use them for a pair production study in 2017. This meant that they needed to be recommissioned and tested to ensure that all wires produce proper signals. In this case, proper signals mean signals that are expected and have previously been seen in old experiments. The general idea was to test Nanometric cards, and then the high voltage was slowly brought up. Then, timing information was received from the time-to-digital converters (TDCs) and analysis done on all of the wires. Once this occurred, tests were ran until all of the wires sent signals when struck, and proper timing histograms along with wire hitmaps were produced. Then, the graphs obtained were tested against the graphs from previous studies are these same drift chambers. Once the drift chambers passed all of these tests, they will be ready for use in future experiments.

III. Theory

Drift chambers are particle detectors that precisely measure the x,y, and z component of a passing particle. They are filled with a gas mixture of, in this case, carbon dioxide and argon. These gases are extremely ionizable and when a high energy particle, such as a muon, passes through them, electrons will be removed from the molecules. Between each of the wires is an electric field created from a ground plane inside the chamber to the wires themselves. The excited electrons will then drift toward the wires due to this electric field. One struck, the wires will send these signals to Nanometric cards, and eventually TDCs to gather information about the event.

The data from the TDCs will be sent to a computer through CODA. CODA is a high speed data acquisition system that is able to communicate from modules plugged into the crate. The general idea is then to convert the data from a hexadecimal language to numbers. The TDCs send a series of digits that can be converted by an analyzer code that has already been written by other members of Jefferson Lab. Once this data goes through the analyzer, it is stored in Root trees. Root is an object-oriented language designed for particle physics at CERN. The Root trees are an organized way to put all the data in initial graphs that the analyzer takes care of. These graphs contain a wire by wire histogram detailing timing information relative to the clock on the TDC. Additionally, each wire has a histogram showing the total number of hits the wire sent. This graph also displays when a wire may have gotten more than one hit in one event. There are numerous useful applications for these histograms including analyzing problems with cards that are constantly sending signals unnecessarily.

After these graphs were created, another program was be written that created more useful graphs that describe how the chamber is performing as a whole. One of the histograms that was created took all of the histograms from the total number of hits on each wire and put them into one. So, a total hitmap was created, which gave a quicker understanding of how the chambers were behaving. A total timing histogram will also be produced. All of the individual wire timing histograms were overlain onto one large histogram. Of course, this just gave general idea of how well the chambers were performing, but the overall shape of the timing histogram can give a great amount of information.

Once the timing histogram is complete, 10-15 runs were be taken. Another histogram overlaid each of these runs' timing histograms for further analysis. Each of these runs had a different chamber threshold voltage. The threshold voltage varied between 5 and 13 volts, which determined the proper threshold voltage to run the chamber at. The code was written to normalize and scale each plot vertically (so as to not change the data in any way) so they reflected having the same number of events in each run. The expectation was that there would be a drop off in the number of total hits seen in the chamber when the threshold voltage increases. This effect can be understood by considering how the threshold affects whether a hit is recorded. The threshold voltage is set similarly to how an oscilloscope trigger works. The trigger threshold level works in the exact same way.

On the other hand, if the threshold voltage goes too low, then pulses will start triggering off of noise and real events. Of course, the noise pulses mean nothing but the total number of events will skyrocket and it will seem as though none of the data is being lost; however, there is really just an excess of noise. So, the goal of this plot is to try to see both ends of the spectrum, one end where nothing shows up and the other where too much data shows up. Then, the goal is to pick a threshold level where the efficiency seems relatively good, but not too low so as to be in the noise levels. After this histogram has sufficient data, each of the graphs will be integrated and that number put onto another graph. The integrated pulse divided by the number of hits (which has been normalized) will give some form of efficiency relative to other runs. It may not be an absolute efficiency, but when compared to other voltages, it will give an idea of which voltages are producing the most hits. Of course, if the number gets too high, then it may be in the noise spectrum and so the number means very little as far as the efficiency is concerned. Once all of these histograms are constructed, a threshold voltage will be appropriately chosen. All of these histograms will be tested against previous experiments data and simulation data to ensure that expected data is being received.

IV. Methods

The first step completed was testing the Nanometric cards using a setup previously designed. A pulsar was initially plugged into the card, which took that signal and sent it to an oscilloscope. Every one of the 16 slots was tested since a wire will eventually be plugged into each (once on the chambers). Once enough cards were tested, they were plugged into the first drift chamber. At this point, the two scintillators had been placed on either side of the chamber and verified to produce signals. Then, raw signals and total number of hits per wire were plotted onto a histogram. The initial signal tests used a pulsar rather than the scintillators so as to get more hits per second on the chambers. The requirement was that all of the wires had to produce signals when the pulsar was hooked up to them. Once this was verified, data was taken using the scintillator paddles. A data run was be taken for a number of different threshold voltages in order to choose the most efficient voltage. After taking data, analysis programs were written to produce entire chamber timing information and a total number hits on each wire histogram.

A number of problems appeared at certain stages of the experiment. The first problem was creating a common ground between all components in the setup. The drift chambers have extremely sensitive components that even millivolt level changes in ground between them could cause the cards to fire off of only noise or crosstalk. Plans to remove this included using thick, sturdy wires to make a common ground point, using a common power supply setup, grounding the entire setup to the building ground, and attempting to ground each component multiple times. Another issue was learning to work with tremendously complex, high level code in the analyzer. Other people have already worked on some of this code and so understanding it was a challenge. Dr. Brash and Dr. Sawatzky are both extraordinary adept at working with codes similar to these, and they will provided insight on issues that were difficult to understand. A final foreseen issue is that it is not abundantly clear how to analytically compare the simulation code and the experimental data. The plan here is to try and find similar experiments that have done the same type of process and use their ideas in this experiment.

V. Data

After working through quite a bit of setup, real data was finally ready to be taken. Cosmic ray runs were taken and the first timing histograms and hitmaps were drawn. After taking a number of runs and checking wires and cards using methods discussed earlier, almost all 40 or so cards were verified as working. They all showed the expected shapes and timing data, which can be seen below in Figures 1 and 2.

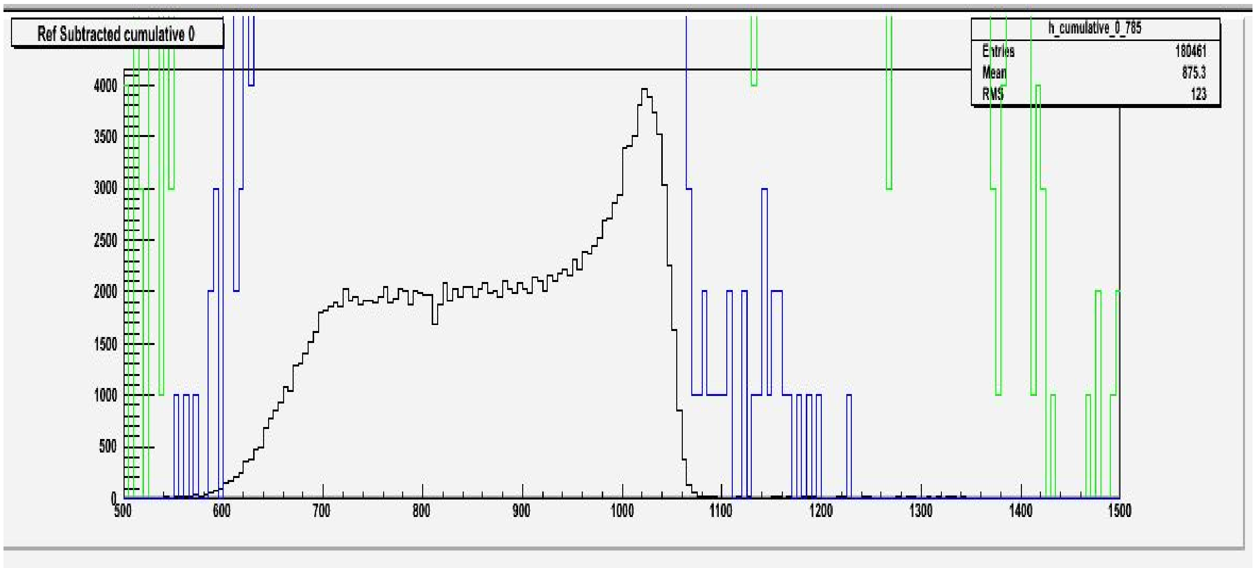

Figure 1: An example of a timing histogram (in black) of a particular run

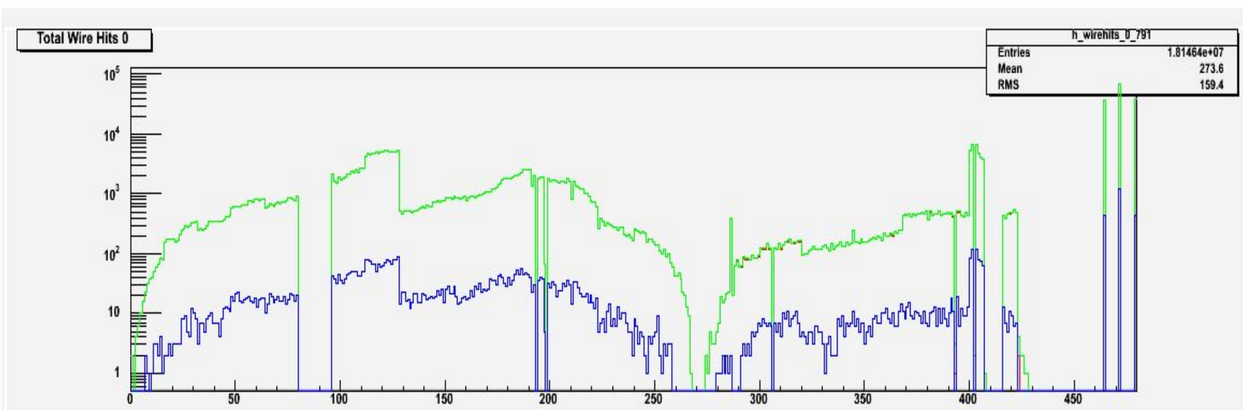

Figure 2: A total number of hits histogram for each wire (hitmap). The horizontal axis indicates wire number, the vertical axis counts how many hits that wire saw over the course of a run.

The shape of the hitmap (figure 2) is interesting and appears at first look almost arbitrary, but there is a reason for that shape. The drift chambers were designed with diagonal wires. This means that they are not equal length wires across the chamber. Ones on the corners are significantly shorter than ones in the middle. Just due to simple probability, the longer wires should receive more hits. They have a greater surface area and should be more active more often. The histogram reflects this expectation. As seen on the graph, there is a clear increasing trend in the number of hits per channel as the wire number increases to about 200, and then the histogram tapers off until about channel number 250 where the number of hits goes to 0. This is the exact situation that was discussed. The way the code and ribbon cables were set up meant that channel one starts on the corner, where it increases toward the middle of the chamber with the longest wires. Then, the histogram switches to the other side of the chamber and onto the corner again, where there is an almost 0% chance of the wires being hit. This effect is amplified by the restricted coverage of the scintillator paddles. In order for a wire to record a hit, the cosmic ray has to hit the two scintillators as well as the chamber. So the angle the cosmic ray has to come in is fairly restricted by the paddles, and so the cards in the middle are expected to receive more hits due to this as well. And some of the wires are completely out of the coincidence trigger, which means they will never receive event hits. Then, after channel 250, the second chamber starts. So the shape repeats in the same manner as before. Overall, this histogram is almost exactly what was predicted and promising for the recommissioning of the chambers.

The timing histogram also seems like a random graph but there is once again a reason behind the structure. As seen on the histogram, there is a sharp spike at around the number 1050 on the x-axis. These numbers are equivalent to time represented by the TDCs. Instead of using nanoseconds or picoseconds, the TDCs use a different standard for time. The sharp spike represents the drift time of gas extremely close to the wires. The electric field close to the wires is stronger and the electrons are in a more excited state and move very quickly when close to the wires. The time corresponding to 1050 is a shorter time of flight, which is counterintuitive since it is a larger number; however, the TDCs use a “common stop” method of timing instead of a “common start”. This means that hits that come in with larger TDC values are closer to that common stop. So, the larger times correspond to shorter distances to the wires. Then, the histogram drops off to the left and plateaus for a period of time. This is a result of electrons that are being ionized farther and farther away from the wire. It takes longer for them to get to the wire because they are farther away and so they have smaller TDC values due to the same common stop reason. The reason that the spike has a larger y-axis number, which represents number of hits is due to the electric field being stronger near the wires. If a gas particle becomes ionized by a cosmic ray, then it has to drift to the nearest wire. The larger field close to the wire means the ions move more quickly in that region and “pile-up” forming the peak structure observed in the histogram.

VI. Additional Analysis

Once a number of runs had completed and there was confidence that the chambers were in a stable state, additional programs had to be written to perfect the threshold on the chambers. A program named Overlay.C was written that took in a number of runs and performed two tasks. The first was to take the timing histogram, as shown in Figure 3, for each run and overlay them all on top of one another. The point of this was twofold. Each of the runs used a different threshold. The threshold started at 6 volts and worked its way up to about 10.5 volts with future plans to test both higher and lower voltages. So, since they were all on one graph, the runs could more easily compared against one another. This way the effects of the threshold changes could be displayed as shown below in Figure 3.

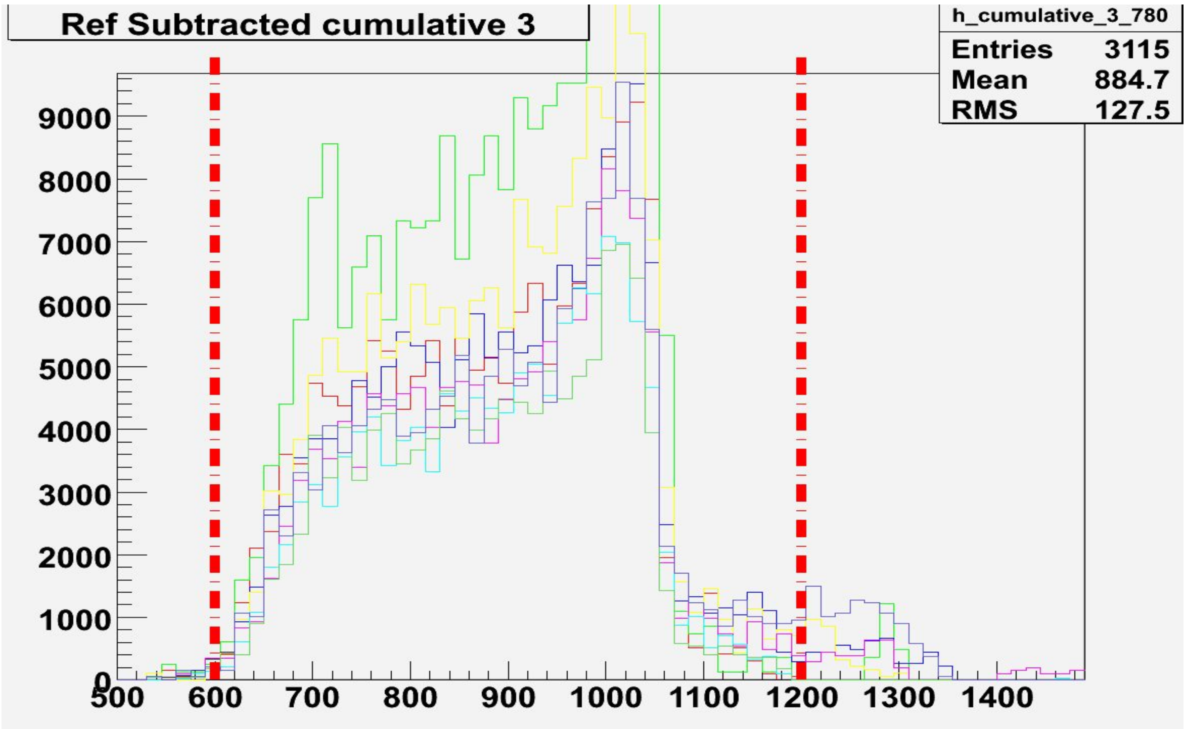

Figure 3: A number of runs whose timing histograms are overlaid

The second advantage of getting this graph is that another plot could be drawn where each of the runs' timing information was integrated. This plot is shown below in Figure 4 and will be discussed more later.

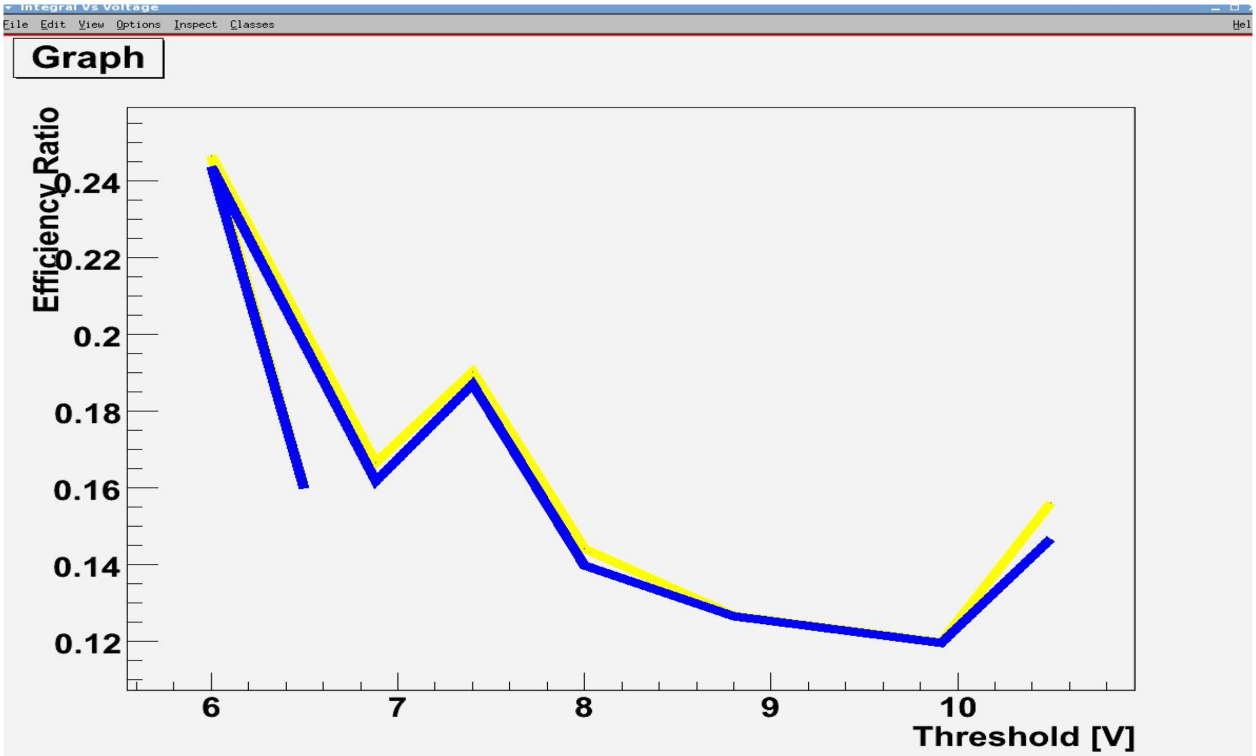

Figure 4: Two integrated lines of the histogram from Figure 3

The histogram in Figure 3 is color coded by threshold voltage. Each color represents a different threshold and the plot shows a decreasing number of hits with certain colors. This is not due to a difference in number of events. The code was written to normalize and scale each plot vertically (which did not change the data in any way) so they reflect having the same number of events in each run. The drop off in the number of total hits seen in the chamber vs threshold must be due to some other process. This effect can be understood by considering how the threshold affects whether a hit is recorded. The threshold voltage is set similarly to how an oscilloscope works. The trigger threshold level works in the exact same way. So, if a pulse comes in at 50 millivolts, but the trigger threshold is 60 millivolts, then a pulse will not show up. Only, instead of a pulse not showing up, an event is not recorded in the data stream. So, it is said to be lost. Of course, not all of the incoming pulses have the same voltage. This means that maybe every other pulse is above 60 millivolts in the example above. If this is the case, then only 50% of pulses would actually be recorded. The obvious question is then why not just reduce the threshold so that all of the pulses would show up? This answer lies in the noise. If the threshold voltage goes too low, then pulses will start triggering off of noise and real events. Of course, the noise pulses mean nothing but the total number of events will skyrocket and it will seem as though none of the data is being lost; however, there is really just an excess of noise. So, the goal of this plot was to try to see both ends of the spectrum, one end where nothing shows up and the other where too much data shows up. Then, the goal is to pick a threshold level where the efficiency seems relatively good, but not too low so as to be in the noise levels. On the plot above in Figure 4, the trend is starting to show. Runs where a large number of events were missed are the ones with less hits. The other end of the spectrum really is not seen here. It will be known when this end is hit because the general shape of the graph will drastically change. When in the noise, there is no reason to keep that shape discussed earlier and seen in Figure 4 because it is not triggering on real hits. There is no real drift times and it makes no sense for random noise to have any defined shape.

The second graph shown in Figure 3 is of two separate integrations. The yellow line is an integral of the entire timing histogram for each run in Figure 4. The blue line is an integral of each histogram run with a cut imposed on it. As seen in the histogram from Figure 4, two red dashed lines are present. Those lines indicate the integration bounds for the data points forming the blue line. The integral for the blue line should always be less, unless of course there is data outside of the cuts. However, this would mean that the timing information is outside the region that makes sense for a real cosmic ray interaction with the chamber. So, this would signify noise, and this is one of the basic reasons for having the two different lines. The general trend shown on the graph is a decreasing one. This is the effect discussed in the previous paragraph. As the threshold voltage (x-axis) increases, the efficiency (y-axis) appears to drop about 0.12 efficiency units. This number is not an exact representation of 10% efficiency, and is more of a relative efficiency. When using the idea that each efficiency is relative to one another, it actually appears that the efficiency is about 100% worse when comparing 6 volts to 10 volts. Now, that is a significant drop in efficiency, which means that 6 volts is a much better threshold voltage. Optimistically, voltages below 6 volts and voltages above 10.5 volts should be tested in order to get a full range of voltages. Then, a justified judgement would be made about which threshold is the proper threshold where it is efficient, but not close to noise levels.

VII. References

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