The University of Iowa Quarknet 2011 Annual Report

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Abstract

The summer of 2011 found 4 students and two teachers doing research activities at The University of Iowa High Energy Physics group. The students and teachers built 2 devices and tested over 400 Photo-Multiplier Tubes for The Forward Calorimeter (HF) of the Compact Muon Solenoid (CMS) at the Large Hadron Collider (LHC) at CERN. These tubes were a new design and were being produced for replacement of the current tubes in HF. Each tube had to undergo dark current tests, gain tests, timing tests and linearity tests. In addition, one of every 20 tubes underwent a surface scan test, a double pulse test and an after pulse test. The team helped execute these tests and build the database for the PMT's.

The Team:

The Quarknet team consisted of 4 students and two teachers from Bettendorf High School in Bettendorf Iowa. The members are (from left to right in Figure 1): Eli McDonald, Moira Truesdell, Danny Romano, Peter Bruecken, Sierra Lopez and Austin Bries. Peter Bruecken (12^{th} year) and Moira (3^{rd} year) are the lead teachers. Eli and Sierra will be juniors next year at Bettendorf High School. Austin will be a senior. These three students are spending their first year as Quarknet members. Danny graduated last spring and spent his second year as a Quarknet member this summer.

This team aided the students at the university that were working for the High Energy group at the University. Every day the team travelled from Bettendorf to Iowa City, a one-way distance of about 60 miles (about 95 km). The team worked with the team of professors and undergraduate students at the labs in the Van Allen building in Iowa City.

Building Equipment:

The Quarknet team built trigger paddles for the tests at CERN during the second week in July. These paddles consisted of scintillating plastic rectangles with Lucite light guides attached to the plastic on one side and a PMT on the other. The purpose of the light guides was to keep the PMT's out of the beam yet have them send a signal to the data acquisition equipment that the beam was present. When completed, the paddles were sent to CERN for test beam time.

Peter Bruecken cut two 15 x 15 x 3 cm rectangular boxes from some surplus scintillating plastic material in the lab. Figure 2 shows the block under the influence of ultraviolet light. As one can see, the block glows with a violet colored light. Moira and Sierra polished the sides of the boxes as shown in Figure 3 so they would better reflect the light produced when the particles of the beam passed through them Peter cut the Lucite rods and Moira and Sierra polished the ends so they would mate against the polished sides of the scintillating plastic. Figure 4 shows the parts of the paddle. Moira then bonded the rods to the blocks using chloroform. This made for a very transparent connection between the two materials.

Peter then attached the PMT to the end of the Lucite rod using a heat shrink tube and optical coupling jelly. Moira and Sierra then wrapped the apparatus in Tyvek and black tape so it was light-tight. Zhe Jia then tested the paddles using a radioactive source and found them to work quite well. Zhe put them in the beam at CERN and they performed very well as triggers for the beam experiments.

The second apparatus we built was a light-tight box for use in the lab. Peter procured a magnesium box from the surplus equipment at the lab. The box was in bad shape with holes from previous experiments and out dated wire connectors. Sierra and Peter cleaned up the box, as shown in Figure 5, and put a divider in so there could be two independent light-tight sides. Peter also cut the lid so it would hinge for the two sides.

Figure

Figure

One side of the box would be for the lifetime test of one PMT. This test involves putting a PMT in a dark box with a light source and running it for months until its performance decreases. Peter mounted a light source in one side of the box and attached the lid with many screws. Sierra lined the box with light-tight flock at all the joints and mounts for wires. Sierra and Peter set a PMT in the box and tested its signal both in the dark and with the lights on. The signal remained constant indicating the box was indeed light tight.

While Peter mounted the hinge for the other side of the box, Sierra lined it with flock so it would also be light-tight. Peter made grooves in the lid and Sierra lined the grooves with flock so the lid would secure the interior from light. Peter and Sierra mounted latches to be sure the lid was tight when used. Again, Sierra and Peter put a PMT in the box and adjusted the lid so the signal was the same with or without the lights in the room.

PMT Testing:

The PMT's in HF at CERN have developed an unforeseen problem when they are exposed to muons from the beam collision. These muons pass through the radiation barrier and strike the surface of the PMT generating an extremely large signal that doesn't come from the calorimeter and is thus a false signal. To solve this problem, PMT's with 4 photo-cathodes were suggested for replacement of the current single photo-cathode units. By distinguishing the signals from each cathode, we can determine whether large signals are spread across the tubes or are in a single quadrant. If they are in one quadrant, they can be rejected as false signals thus increasing the reliability of the data. The new PMT's are currently being produced in Japan. They need to be tested and documented just as the previous ones were.

Danny Romano was put in charge of the gain tests of the new PMT's. He had to measure the photocurrent at the photocathode and then the photocurrent at the anode after the photoelectrons underwent the energy of the high voltage which amplified the current by increasing the numbers of electrons from the original photoelectrons at the photocathode. Danny also measured the dark current for each tube. Danny was responsible for training the rest of the team so when he wasn't there, they could perform the tests.

The gain tests consisted of mounting a tube in a special base that output the signal from the photocathode instead of the final anode. The light had to be set so the signal was measurable by the pico-ammeter. Danny set this up for each tube and measured and recorded the light levels and signals for each tube. Then the tubes were connected to a base that output the final anode signal. The light was readjusted to accommodate this increased signal and the gain was calculated for each tube by dividing the output signal by the photo-cathode signal after compensating for the differences in the light intensities. Danny also measured dark current while the tubes were in the box with the light off. Each tube was measured using voltages of 600-900 volts in 50 volt increments. The data from these tests was saved in the database created for these tubes.

Eli McDonald was in charge of the timing and linearity tests. When we arrived, the timing tests were progressing well but the linearity tests were not functioning as expected. Eli and Peter determined that the linearity tests were using neutral density filters in on the 337 nm UV pulses. The filters were not attenuating the UV pulses the same as visible pulses. Peter and Eli used a scintillating block to change the UV LASER pulses to visible pulses and sent them through a fiber to the filter wheels where the light was attenuated in increments determined by the filters. This setup used the same box and procedure as the timing tests so linearity was measured along with timing.

Eli had to mount the PMT in the light-tight box and adjust the trigger diode signal so it would fit on the scope. The LASER would change its pulse intensity over time so this process of adjustment

Figure

occurred during the entire day. Using macros in Microsoft Excel, the signals were measured while the macros changed the filter wheels to match the required light. The files were saved using the PMT numbers and collected in our data folders. Eli measured and over 400 PMT's during the summer and the data seems to be as expected. The students at the site will have to continue testing as more PMT's are acquired. The parts of the test are shown in Figure 6.

One out of every box of 20 PMT's had to undergo an X-Y surface scan test. This test consisted of mounting the PMT on a platform that moved in 2 dimensions as shown. The source of light was an optical fiber that produced pulses of a blue LED at the surface of the tube as shown in Figure 7. At 1 mm intervals, the signal from the tube was acquired for 10,000 pulses and a graph of the average of these signals was recorded.

Figure

An example of the graph of these signals is shown in Figure 8. This graph shows the signal strength for the horizontal and vertical spots on the surface of the tube. One unusual result of this test is the relatively "dead" spot in the middle. This makes our tubes particularly well adapted to the kind of signal discrimination necessary to eliminate signals that fall on one quadrant of the tube. The concern that a muon hitting the center and giving a signal through all quadrants seems to be eliminated by this dead spot. The results of this test should determine the spatial dependence of signals on the tubes. Since the signals from the calorimeter come through reflective light guides, their valid signals are mixed among the quadrants of the tube. If one quadrant has a significantly higher signal, the signal can be eliminated at the sources as something that didn't come from the calorimeter. This process should increase the reliability of the signals from the Forward Calorimeter.

Our last project was to refine a procedure for a test called "Double Pulse Linearity". This test measures the relative height of two pulses separated by only 20 ns as the intensity of light upon the tube is changed. Peter set up the LED pulser to send 2 pulses of different heights to the PMT through a fiber. Figure 9 shows the PMT output signal of the 2 pulses. The light from the fiber passed through Neutral Density filters of different values to change the intensity of the light. Eli set up the tests to measure the ratio of pulse heights as the light was changed by the filter wheels. The computer calculated the ratio of the amplitudes of the pulses as the number of photoelectrons was changed by the filter wheels. Figure 10 shows the graph of the ratio vs # photoelectrons on the tube. This test is meant for one in 20 tubes.

Summary:

After our summer of 2011, the Quarknet team feels accomplished. We made a large dent in the testing of PMT's and left the lab in better shape than before we came. The students learned the importance of reading their results as they go instead of just loading instruments. Since we were doing

Figure

Figure

one-of-a-kind types of tests, many times the equipment would not work correctly.
Our students became very aware and critical of the data they were acquiring. When something didn't work correctly, which was a daily occurrence, the students picked up on it. This did not happen at first

but developed as the summer wore on. They made small improvements in testing procedures and produced good data. We left the lab with some improved equipment and procedures that increased reliability. We also built some equipment that will serve the group in the future. We had a very productive and satisfying summer.