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Radioactive Source Testing for the MINERvA Outer Detector and the PCAL at Jefferson Lab

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Abstract

My research project for the year has two components. The first is in the construction of the MINERvA neutrino detector at Fermi National Accelerator Laboratory. MINERvA will be used to study neutrino – nucleus interactions. The detector is composed of roughly 30,000 scintillator detectors. These are organized into hexagonal planes (the inner detector) and towers (the outer detector) which each consists of four doublets of scintillator. Half of the outer detector towers were made here at William and Mary. My niche in the project is testing the outer detectors to make sure the optical transmission is satisfactory and that there are no damaged optical fibers. I do this with a radioactive Sodium-22 source. When the gammas from the source interact inside of the scintillators photons are transmitted to a photomultiplier tube that is connected to the tower via an optical extension cable. After the photoelectric effect takes place in the photomultiplier tube and the current is amplified, electrons flow to an ammeter where the current is measured. We completed this testing and I have analyzed all of the data. As of April 28th the MINERvA detector was completely built and is fully operational.

The second part of my research deals with the upgrade to the pre-shower calorimeter (PCAL) in Hall B at Thomas Jefferson National Accelerator Facility (JLAB). I used the same testing setup as in my MINERvA research in order to determine the optimal configuration of fibers inside the scintillators. The group was deciding between four unglued fibers per scintillator and two glued fibers per scintillator. My findings impacted the final design selected for the pre-shower calorimeter, which was to use four unglued fibers per scintillator.

Acknowledgements

First and foremost I need to thank Professor Jeff Nelson for his guidance and wisdom throughout this whole process. Dr. Nelson provided the projects for me, as well as answered any questions that I had about them (and I had a lot). Pete DeCastro did all of the summer testing on the MINERvA experiment, and showed me how to test. I would also like to thank the laboratory technicians – Wendy Nelson, Bruce Pollock, and Edward Charleton - for providing me with quality test subjects, as well as helping me out with testing. Anna Shabalina was a great assist during the PCAL portion of my research.

Overview

My research has focused on two different high energy physics projects which study sub-atomic particles via their interactions in scintillators. The scintillators that we have used in both the MINERvA and PCAL projects are made of polystyrene based extruded plastic and are coated in titanium dioxide for reflectivity (see Figure 1). The dimensions of the scintillators used in the two projects are different, but the idea behind them is the same.

Figure 1: This image shows MINERvA outer detector scintillators lined up next to each other. The white color on the outside is given by the titanium dioxide coating for reflectivity. The fibers coming out of them are the wavelength shifting fibers which run axially through the scintillators.

The following is a basic model for how scintillators work: First, particles (whether they are from the radioactive source that I use in my testing or high energy interactions) interact inside the scintillator. Once a particle enters the scintillator it sometimes interacts. The main method of interaction with low-energy sources (such as the Na-22 I use for testing) is Compton Scattering. The incoming gamma particle interacts with matter, usually an electron, which changes the wavelength of the gamma and sends it off with an altered momentum. The electron recoils and ionizes which creates scintillation light. We see this as ultraviolet photons which bounce around inside the scintillator thanks to the reflective titanium dioxide around its outside edges. Titanium dioxide reflects the UV photons off in random directions. Some of these photons are absorbed into the wavelength shifting fiber which shifts their wavelength to the range of green light [1]. Then, these photons run through an optical extension cable, made of the same wavelength shifting fiber as inside the scintillator, and into a photomultiplier tube. No matter where a scintillator is used, they must be light-tight. Any photons getting into a scintillator causes unwanted background noise in the data.

At the cathode inside the PMT, the photoelectric effect takes place. This causes a fraction of the electrons (about 13% - the quantum efficiency of the PMT) to flow to the first dynode inside the PMT [1]. At this point there are a series of dynodes inside the PMT. Secondary emission occurs at each of them which ultimately results in a number of electrons a few orders of magnitude higher than originally were originally sent from the photocathode. The PMT that we are currently using has a gain of about 10^6. Current flows out of the PMT and into an ammeter where a current is read in nA. At large experiments such as MINERvA there are multipixel PMTs so that a response can be read from each individual fiber. The PMTs that we have used in the lab for testing are single channel, so some shielding methods must be used to isolate scintillators. These will be discussed later in the paper.

Testing procedures vary for the two tests, but there are many similarities. Figure 2 shows the basic layout of the testing. First of all, when using a radioactive source it is important to follow all radioactive safety procedures. During testing the source is always held with a wand, keeping it as far away from the testers as possible.

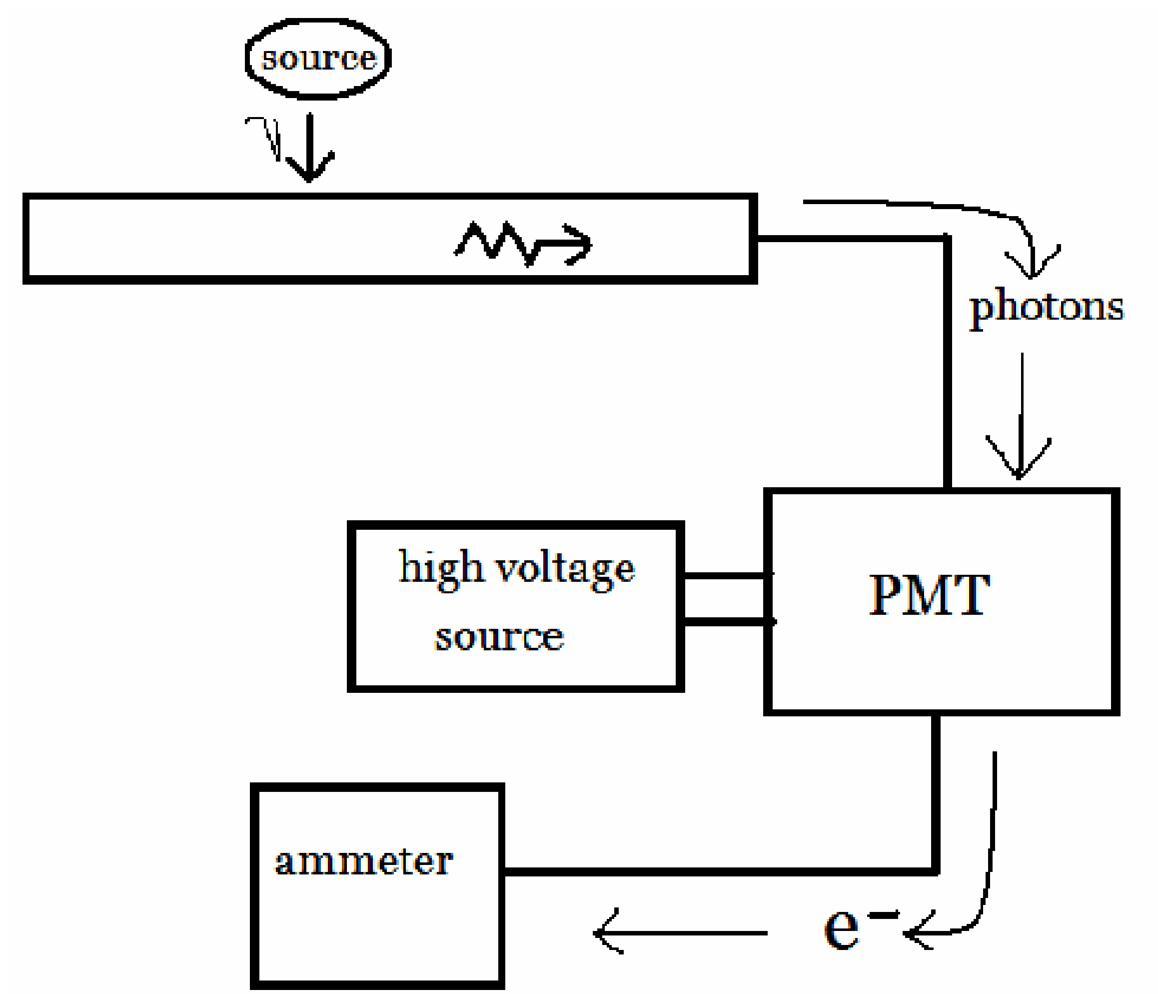

Figure 2: Source Testing Schematic. Gamma particles from the source interact inside the scintillator via Compton scattering. This causes electrons to recoil and create scintillation light. About five percent of this light is collected in a wavelength-shifting fiber which runs axially through the scintillator. These photons run through the PMT where the photoelectric effect and secondary emission take place, which creates a current that is read at a picoammeter.

It is essential that the scintillators do not have any light leaks. However, even when the scintillators are completely wrapped there is still some background noise. This current is due to dark current and thermionic emissions. Electrons in the PMT are at slightly different energies and can be emitted. There can also be thermionic emissions in the fibers, and these can actually dominate the background in some experiments [1]. A typical background current depends on the details of the setup. For MINERvA the background current was typically between 1.5nA and 2.5 nA, and for the PCAL testing the values were typically between 3.5nA and 5.5nA.

The source that we use in the lab is a sodium-22 source that is kept in a safe, surrounded by lead blocks in the testing room, Small Hall room 306. Sodium-22 is a beta and gamma emitter with a half-life of 2.6 years. The maximum energy of the emitted betas is 546 keV, and the energy of the gamma particles is 1275 keV [4]. The maximum range of the beta particles is about 140cm in air. A thin layer (about three millimeters) of lead is attached to the bottom of the source to keep the beta particles from getting to the detector. The source that we use has a current activity of roughly 40uCi (1.5 million decays per second).

Part 1: MINERvA

Background

Construction of the MINERvA neutrino detector was recently completed at Fermi National Accelerator Laboratory. It is placed directly upstream from the MINOS near detector on the NuMI neutrino beamline. Figure 3 shows the basic layout of the MINERvA detector. The hexagonal plane in the middle is the inner detector which is made up of 127 triangular scintillator strips with wavelength shifting fibers threaded through axial holes in the scintillator. One module consists of six outer detector towers surrounding a two-layer inner detector. The outer detectors

(ODs) are mounted in slots in steel wedges. The outer dector towers, most of which were assembled at William and Mary, each contain eight rectangular scintillators, paired up into four doublets, as well as cables which bring the optical fibers through the gaps between the seal [6]. The blue and red tubes on top house the photomultiplier tubes.

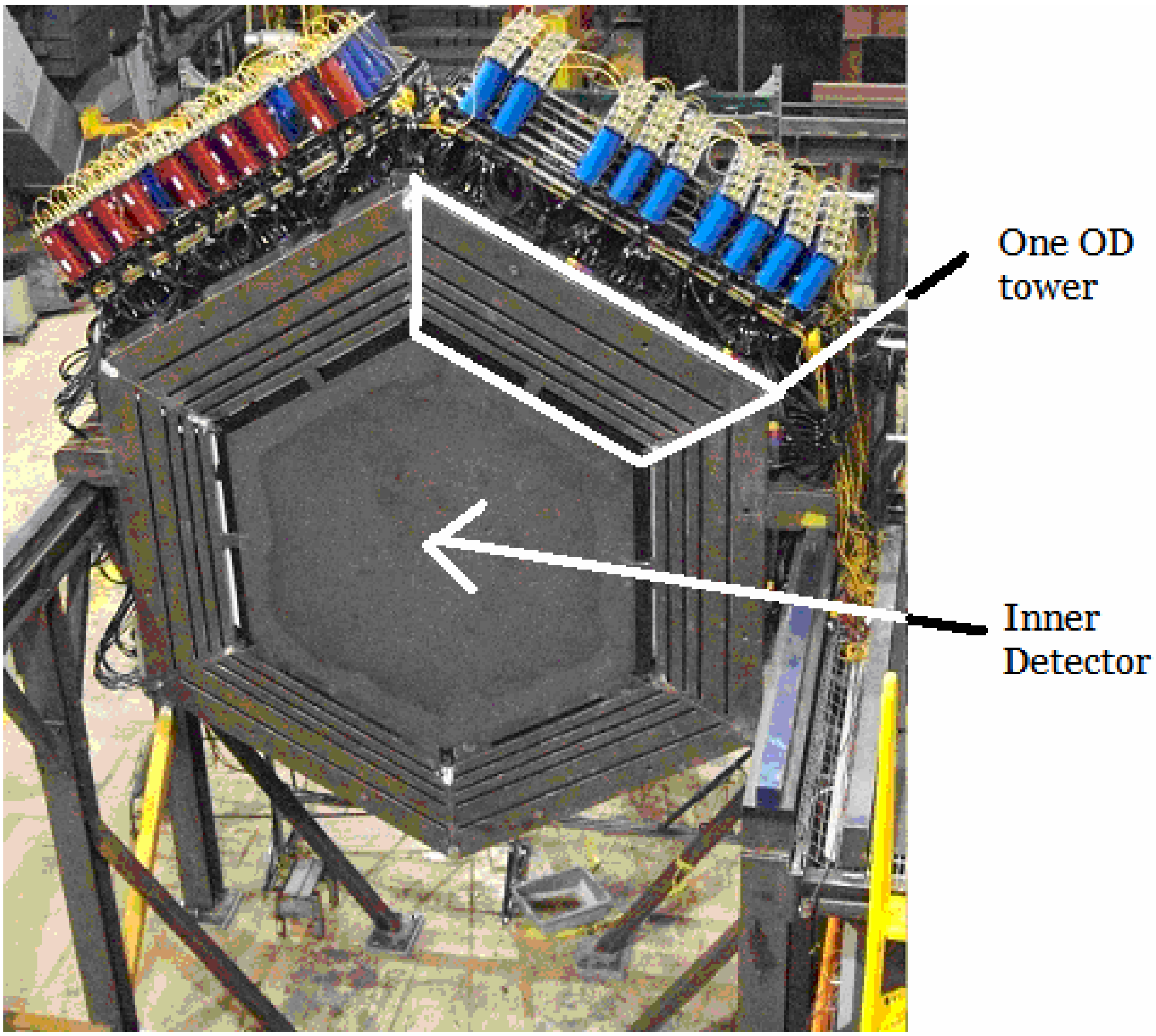

Figure 3: Layout of the MINERvA detector showing the inner detector planes, outer detector towers, and photomultiplier tubes.

The outer detector towers are assembled and mounted onto pink foam boards to be handled as they are shipped out. A photograph can be seen in Figure 4 and the dimensions can be seen in Figure 5. The four scintillator doublets (seen in Figure 4) fit in the slits in the steel around on the inner detector in Figure 1. Figure 5 shows the lengths of each doublet, as well as a cross section of a doublet.

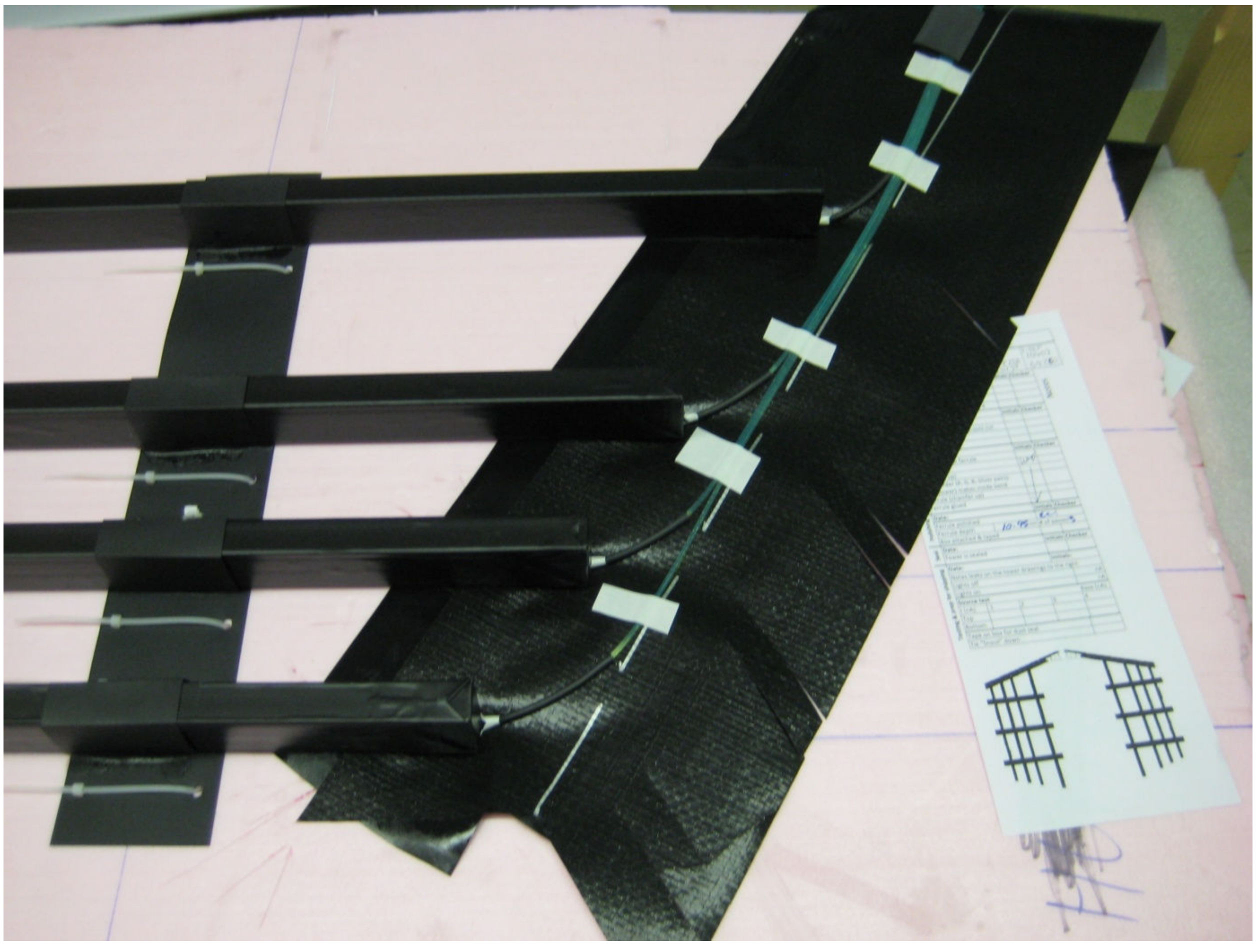

Figure 4: A nearly-completed tower with exposed fibers.

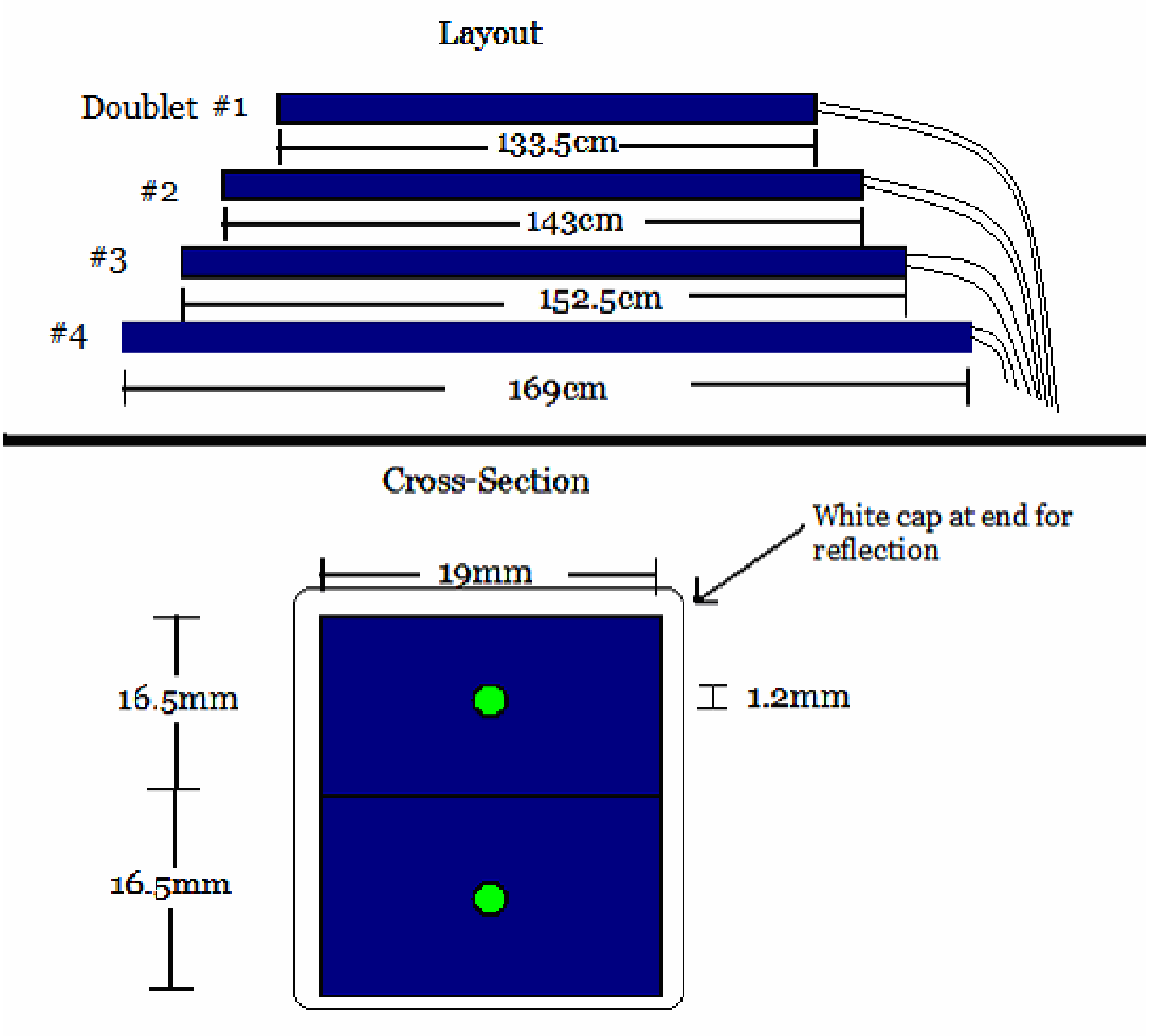

Figure 5: Dimensions of the Outer Detector Towers.

The towers are constructed by laboratory technicians and students. There are right-handed and left-handed towers, which are simply mirror images of each other. The reason for having right- and left-handed towers is so that the fibers can be routed to just three different areas around the outside of the detector at MINERvA (at twelve, four, and eight o'clock). The fiber in the middle is the wavelength shifting fiber, which sends green light out of the detector and to the photomultiplier tube, as discussed in the Overview.

It is critical that the entire tower is completely light-tight. If any light gets to the scintillator, it sends uninteresting, random light to the PMT and it overwhelms the electronics of the equipment. Therefore the entire tower is thoroughly wrapped in black tape and plastic sheeting. The tower then gets light-leak tested. Finally, the last check before the tower is shipped out is a radioactive source testing to check for broken fibers and good connector polish. It is important to have functional fibers which are well-polished in order to achieve accurate and consistent measurements of neutrino interactions.

Procedure

There are six different quantities recorded for each tower. The first two are a lights-on and lights-off reading. Once everything is set up the lights are turned off and a current is read. This current is usually around 2 nA. This current is due to thermionic emissions. Electrons in the PMT's photocathode are at slightly different energies are constantly emitted. Therefore, there is a constant background current of around 2 nA that must be subtracted off of the measurement. Once the lights-off reading is made, a lights-on reading is made. The ratio of the lights-on / lights off currents should be less than 1.10 for a satisfactory tower. A difference of about three to five percent is typical, and this is due to the fact that although the towers are very good, there are often some very small diffuse leaks. When the tape is wrapped around the doublets, even a slight stretch can lead to diffuse leaks. Sometimes these leaks are substantial enough that the tower must be re-wrapped (this happened on a number of occasions). In most cases we achieved a difference of a couple percent between the lights-on and lights-off reading. There are a few outliers pulling up the mean. The mean and median improved to 1.04 and 1.03 since I took over testing at the beginning of October.

After they are shown to be sufficiently tight, the integrity of the optical fibers is tested using the gamma source. Zinc blocks are placed on the foam backboard for the tower in between the doublets. Because the fibers from all eight fibers are routed to the same PMT in the testing setup, it is important to isolate each doublet from the next during the source exposure (see Table 1). If there was no shielding between doublet #1 and doublet #2, an artificially high current would be read while testing doublet #1 because of the gamma particles interacting in doublet #2. The zinc shielding reduces this effect (see Figure 6). Each doublet is tested by placing the source directly on top of the doublet. The actual source, inside of its plastic container, is about five millimeters above the doublet during testing. Each doublet is tested by holding the source directly on top of it, and manipulating the angle of the source until a maximum current is read out. This is sometimes more of an art than a science. The currents for each of the four doublets are recorded.

	doublet#1	doublet #2	doublet #3	doublet #4
W185R	54.50	50.00	60.50	48.00
without shielding between doublets 1 and 2	62.00	54.00		
without shielding between doublets 3 and 4			63.00	51.50

Table 1: Demonstration of artificially high values for currents (in nA) when shielding is not used. The top row is data taken with proper shielding. The increases in doublets one and two are significant when the zinc block between them is removed, as are the increases in doublets three and four when the shielding between them is removed.

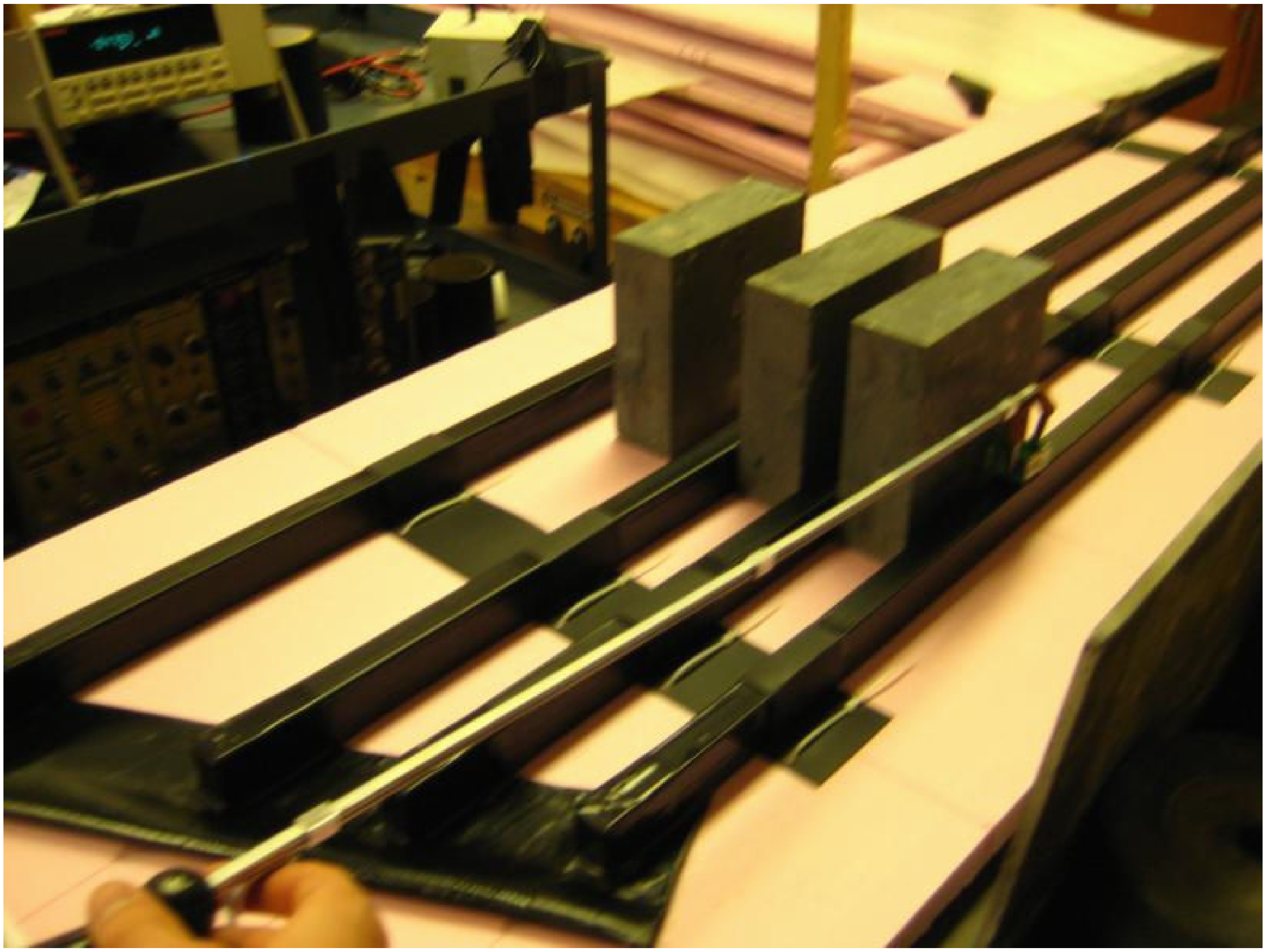

Figure 6: Testing layout with Zinc blocks as shielding.

Data and Analysis

As soon as the towers are tested, a quick analysis is performed. Towers with poor values during testing are not shipped to Fermilab. There are a couple ways that a tower can “fail” the testing. A couple examples can be seen in Table 2.

Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	Min/Max Ratio
W064L	2009/07/16	1.90	3.30	1.74	56.70	67.80	67.80	61.00	0.84
W160L	2009/10/27	1.65	1.65	1.00	30.00	49.50	55.50	62.00	0.48

Table 2: Examples of Bad Towers. The first failed because its lights-on/lights-off ratio is well over the acceptable limit of 1.10. The second failed because its Min/Max Ratio is well below the acceptable floor set around .85. In this case it is due to a broken fiber in doublet #1.

Tower W064L failed because the lights-on / lights-off ratio is well over 1.10, obviously indicating that there are light leaks on the tower. Luckily, this does not require that the tower be disassembled, but simply rewrapped. There is a fluorescent light wand (a shop light) that we use to find the leaks. Then we can apply more tape until it is light-tight. At this point the tower is ready to be tested again. Many towers failed the light-tight test initially. Probably around twenty percent of the towers that I tested needed some light sealing. There is no recorded data for the number of towers which initially failed the light-leak test, because these were generally easily fixed by adding some tape to an area with a hole in the tape or rewrapping a doublet with diffuse leaks.

Tower W160L failed because Doublet #1 has a very low signal compared to the rest of the doublets. The column "Min/Max Ratio" is the ratio of the highest doublet's current to that of the lowest doublet. If this ratio falls much below 0.85 there is usually a significantly damaged fiber.

The hardest part about data analysis is recognizing systematic errors. The wavelength shifting fibers are plastic optical fibers. These fibers can be very easily broken if they are over-bent. Over time the polish at the connector deteriorates due to pitting and scratching from repeated use. So there is a general downward trend with the currents that are read until eventually a new extension cable is installed. It is also worth noting that the optical fibers which are part of the PMT housing can be damaged as well, and this has been the case for the towers tested in October and November.

The way that the optical connector works, the fibers in the PMT that reads left-handed towers Doublet #1 are the same two that read right-handed towers doublet #4 (see Figure 7). That is, fibers ‘a’ and ‘b’ in the PMT housing are connected to the fibers for Doublet #1 in a left-handed doublet. When a right-handed doublet is being tested, the fibers from Doublet #4 are connected to fibers ‘a’ and ‘b’ in the PMT housing. All of these doublets have had low readings lately, and this is a systematic effect that must be corrected for. Towers with raw ratios of less than 0.85 have been shipped because they have reasonable ratios after the damage is calibrated out of the currents.

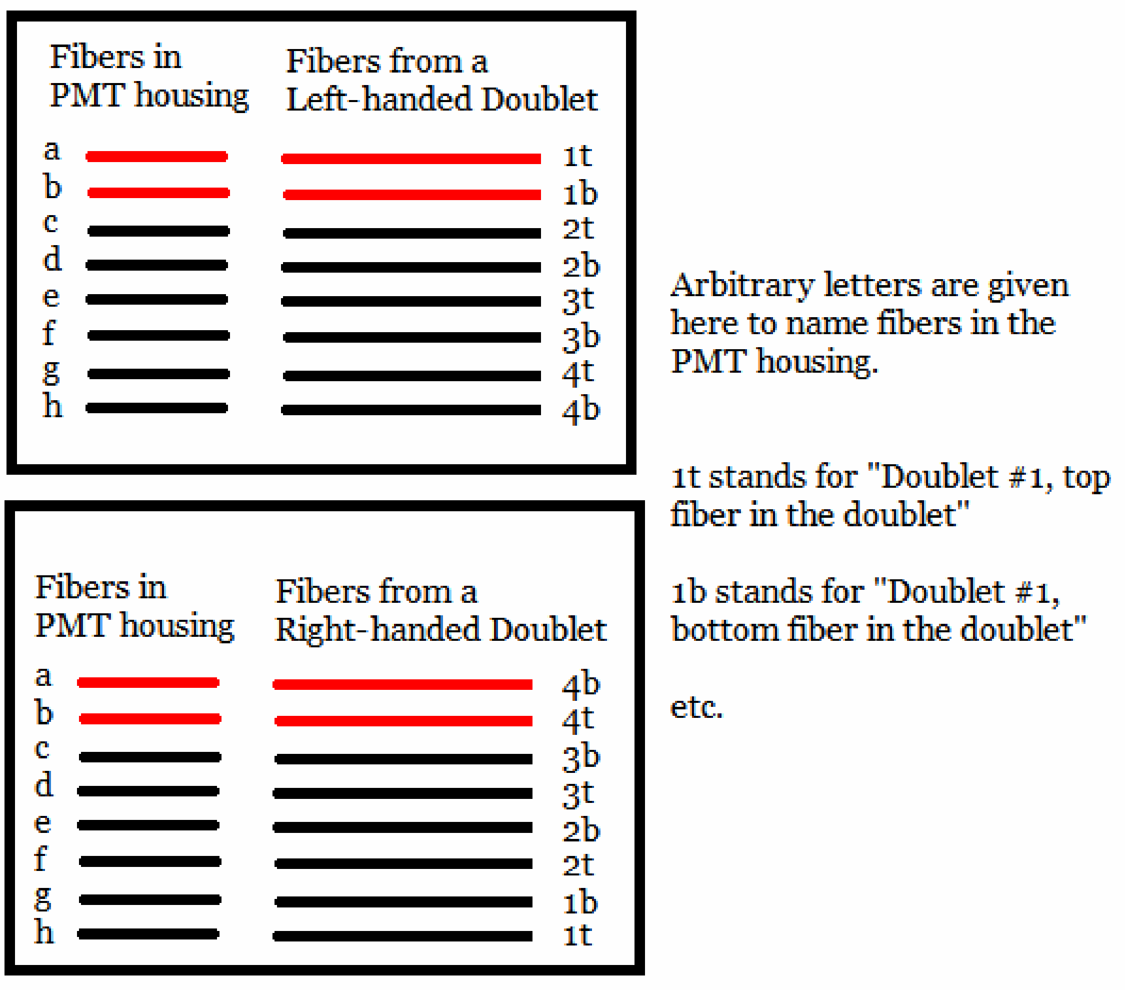

Figure 7: Diagram of fiber connections in the testing apparatus.

Much of my analysis dealt with finding systematic errors. These are generally problems with the testing equipment, usually fibers which transmit photons more poorly over time. For this reason, the extension cable is changed out occasionally. Table 3 shows an example of the calibration that takes place when switching from one extension cable to another.

Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	Min/Max Ratio
W166L	2009/11/06	1.60	1.65	1.03	47.00	59.50	56.50	56.00	0.79
new11	2009/11/06	1.60	1.65	1.03	50.00	62.00	61.00	58.00	0.81
W160R	2009/11/06	1.60	1.80	1.13	60.50	50.00	60.00	47.50	0.79
new11	2009/11/06	1.70	1.90	1.12	63.00	54.50	64.50	54.00	0.84
W168R	2009/11/06	1.60	1.60	1.00	56.50	48.50	58.50	48.00	0.82
new11	2009/11/06	1.65	1.65	1.00	60.00	52.00	61.00	53.00	0.85

Table 3: Calibrating a new extension cable.

The rows with serial numbers in the “Tower” column are the test results of each tower with the same / original extension cable. The other rows, labeled “new11” represent the testing results of those same towers with the new extension cable, called “new11”. As a general note, when shifting from one extension cable to another, the doublet currents tend to increase by about 3 nA. This is due to the affects of the connector losing is polish and the fibers becoming damaged over time. Table 4 shows some of the data taken on November 10, 2009 with a new extension cable, “new12”.

Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	Min/Max Ratio
W169L	2009/11/10	1.50	1.55	1.03	44.00	56.00	57.00	55.50	0.77
W177L	2009/11/10	1.50	1.50	1.00	46.50	58.50	54.50	55.00	0.79
W168L	2009/11/10	1.50	1.55	1.03	48.00	56.00	53.50	33.50	0.60
W172R	2009/11/10	1.55	1.55	1.00	54.00	49.50	54.50	43.50	0.80
W183R	2009/11/10	1.60	1.55	0.97	52.50	51.00	58.00	49.50	0.85
W146R	2009/11/10	1.55	1.55	1.00	53.00	52.00	57.00	50.00	0.88

Table 4: Example of systematic errors.

There are a few noteworthy points in this table. The cell highlighted in red indicates a broken fiber. This doublet has a considerably lower output than the rest, lending to a Min/Max ratio of only 0.60. This tower was scrapped and its parts will be used to make a new tower. The cells which are highlighted in light yellow show the lowest current in each tower (excluding the broken fiber). Notice that in left handed towers, which are denoted with an 'L' at the end of their serial number, Doublet #1 is always the lowest. In right handed towers Doublet #4 is the lowest. Each of those doublets runs to the same fiber in the PMT housing (see Figure 7). This fiber is damaged near the photomultiplier tube. Therefore, despite the fact that most of these towers have raw Min/Max ratios of under 0.85, all of them except W168L were shipped to Fermilab, because their calibrated ratios are in the acceptable range. The ratio 0.85 was chosen as the threshold for an acceptable ratio because 70% transmission indicates either a bad mirror or fiber. Because two fibers are being tested simultaneously though, this will only factor into the current as a 15% drop. Therefore the mark was set at 0.85.

With the source testing, we tested 294 towers here at William and Mary. I rejected fourteen of them because of broken fibers. An additional twenty were rejected by Fermilab. Many of these towers were rebuilt with salvaged parts from other rejected towers. Some which were sent back from Fermilab tested fine at William and Mary and they were sent back in the same condition they were returned to us. Many of these were rebuilt and sent back to Fermilab with new serial numbers. All of the raw data for the testing can be seen in Appendix A.

One of the biggest goals for the MINERvA data that we collected was to normalize it as best we could, taking changes in the test conditions into account. This process starts with a correction for the decaying of the source. Then corrections are applied for degradation to the testing equipment such as the PMT housing and the optical extension cables. Once all of the data is normalized it is more useful for understanding the overall performance of the tower assembly process.

The source that I have used all year has a half-life of 2.6 years. Over the course of the testing for MINERvA the source has lost 15% of its radioactivity. The very first MINERvA tests that were done were actually done using a much lower intensity source. We switched to the new source because data obtained with the older one was too close to the background current to be very useful as a diagnostic tool. The testing procedure has never changed, although the parts used in testing have varied (e.g. over time the connections at the optical fibers degrade). Swapping out the 'extension fibers' which run from the PMT housing to the towers causes a sharp rise in the read currents, but as that fiber is used it slowly degrades over time. The following graph, figure 8, shows the average of the top-three highest current doublets in each tower, and the progression of that value over time. In the Figure 9, you can see the trends a little bit easier with a running average of the current tower and the two tested before and after it. The abrupt jumps from equipment changes actually take place over five data points on this graph.

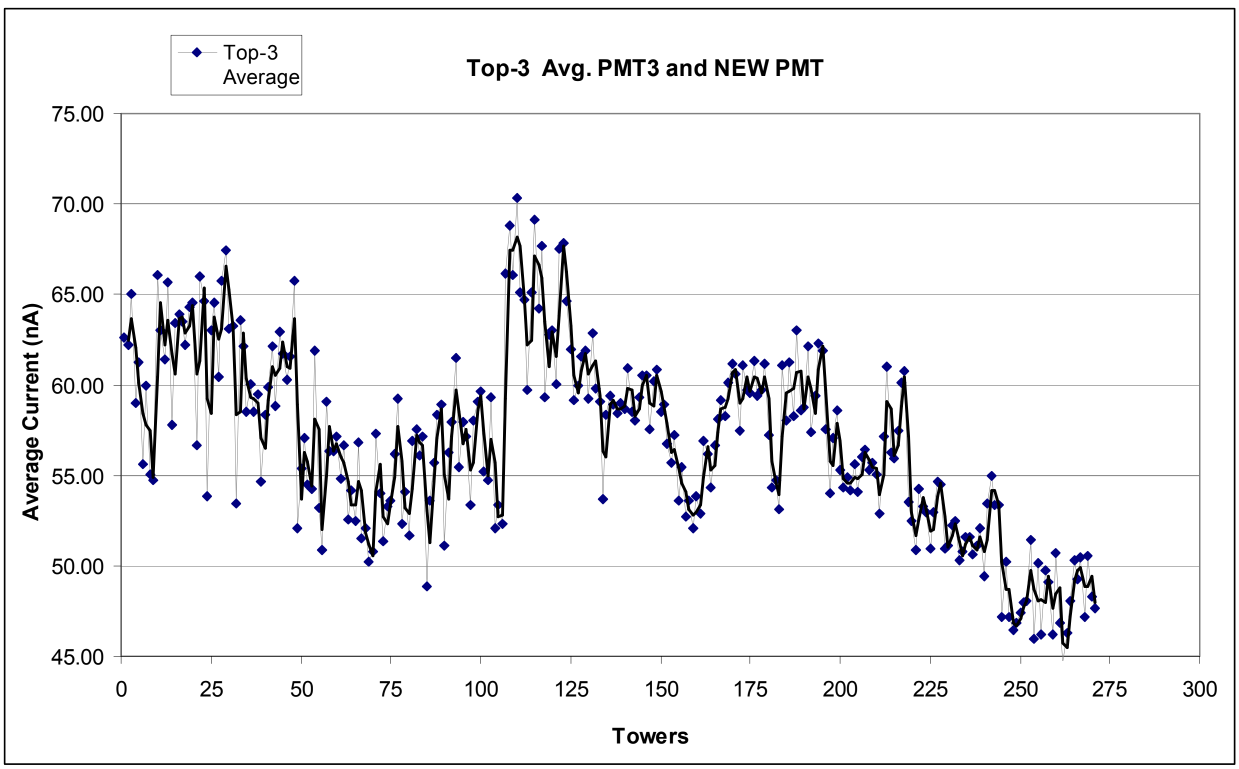

Figure 8: Average currents of the highest three doublets in each tower for PMT3 and NEW PMT.

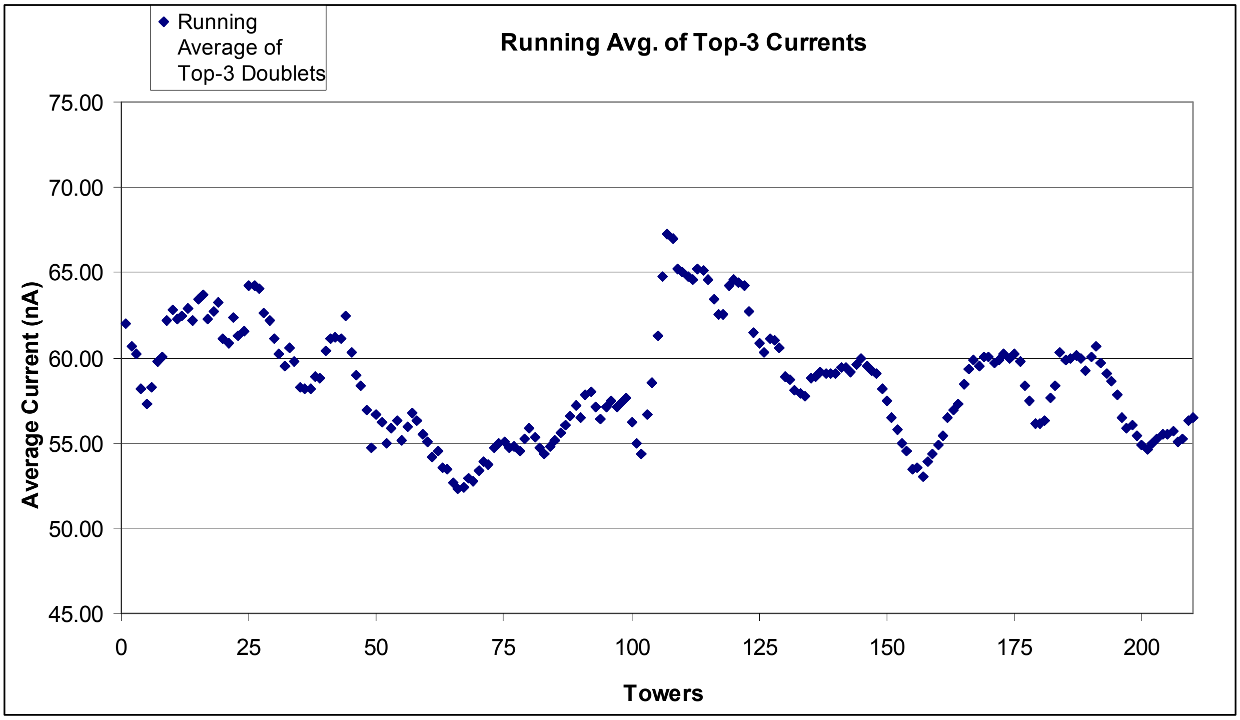

Figure 9: This graph shows the running average, which incorporates the subject tower, the two previous towers, and the two latter towers. This graph shows how the current data fluctuated over time, generally with slow falls and quick increases.

It is possible to accurately flatten out this data based on a few testing parameters. The first is by using the half-life equation for the source. We picked the most recently tested towers as our start date, so a factor of less than one is used to correct for the stronger source in earlier data. The equation used for this factor is

$$N_t = N_0 \left(\frac{1}{2}\right)^{t/t_{1/2}}$$

where N_t is the current activity level, N_o is the original activity level (normalized to one for our calculation), t is the time interval from the end of testing and the test date, and $t_{1/2}$ is the half-life of the source.

When we started testing on July 16, 2009 the source's activity was 41.7 µCi. By the time the last tower was tested on March 2, 2010 the activity was down to about 35.4 µCi. Because we know how the sodium decays we know its activity level for every tower that was tested so this can be calibrated numerically and precisely into the data analysis. Figure 10 shows the data once it has been corrected for the decay of the source.

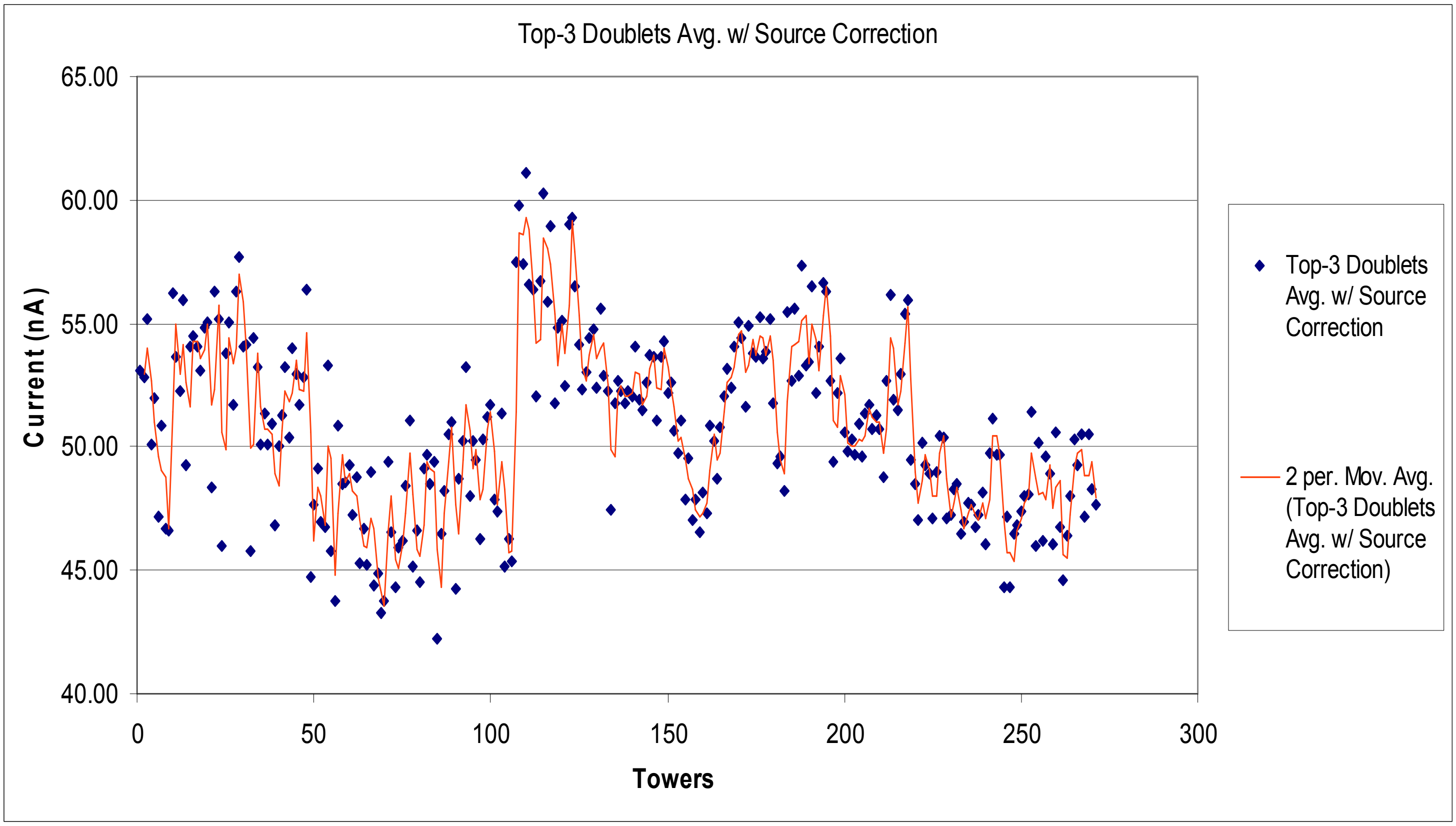

Figure 10: Compare this graph to figure 8, which shows the data without the source correction. This data is much flatter because of the correction.

We did not take enough calibration data to consistently calibrate for degrading equipment, especially before I began source testing in October. However, because notes were taken on hardware changes, I am able to break the data up into smaller sections (by test date / testing extension cable / PMT / etc.) and analyze the trends within that section. Assuming constant degradation, I can then apply a "factor of degradation" to a tower which will compensate for the degradation in the testing equipment when that particular tower was tested. The 271 towers which were tested with either PMT3 or NEW PMT were broken up into eight different batches in order to perform light corrections. To start the correction for degradation to the equipment, a graph was made with the top-3 doublets' average for each of the eight segments. A linear trend line was generated. Using this trend line a correction was made to the data to flatten it out. If the data was already flat or had an upward slope, the data was left as it was. An example of this process can be seen in Figure 11. All of these graphs can be seen in Appendix B.

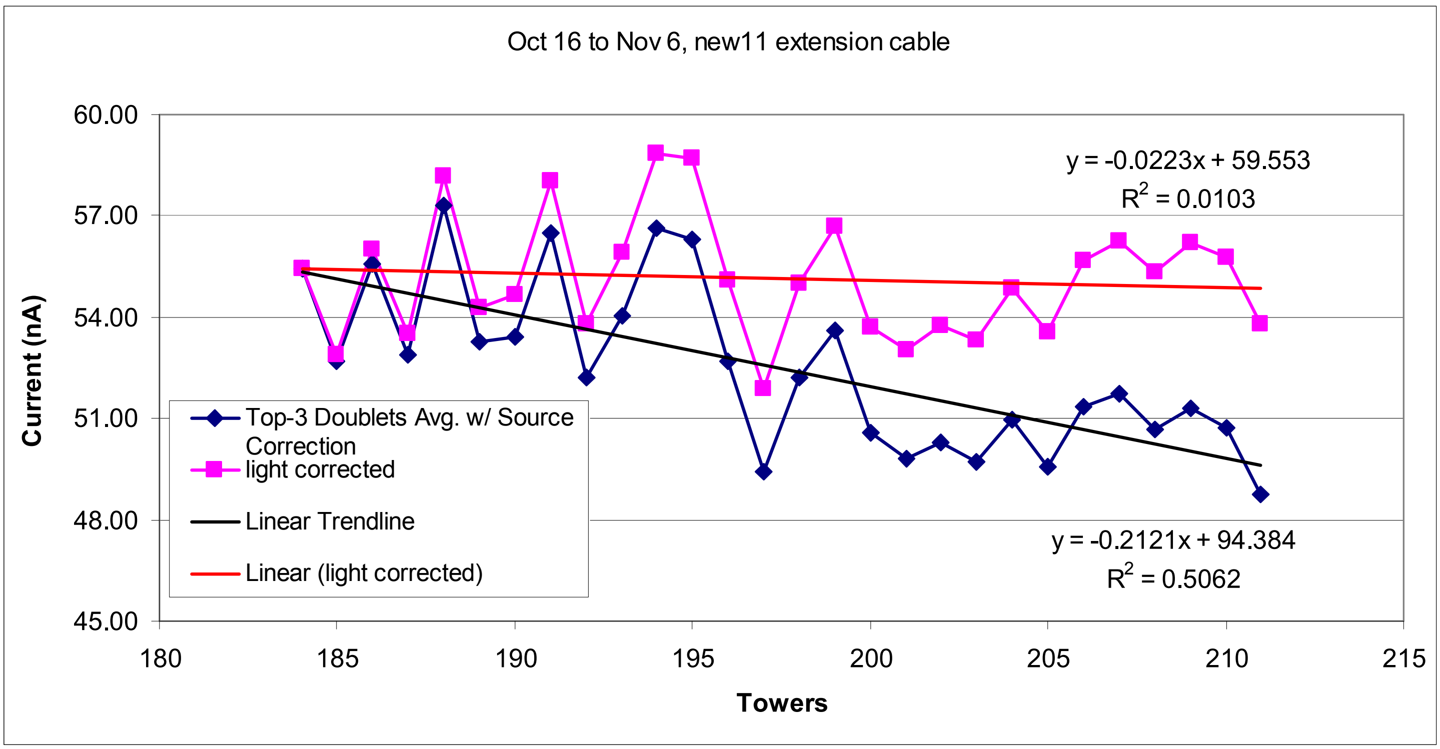

Figure 11: This graph shows the average currents for the top three doublets tested on each tower from October 16 to November 6 with the source correction in blue. The pink data and the red trend line show the data once it has been corrected for equipment degradation.

Once all of the factors of degradation were calculated in the spreadsheet, I made a graph of all of the new values. This graph can be seen in Figure 12.

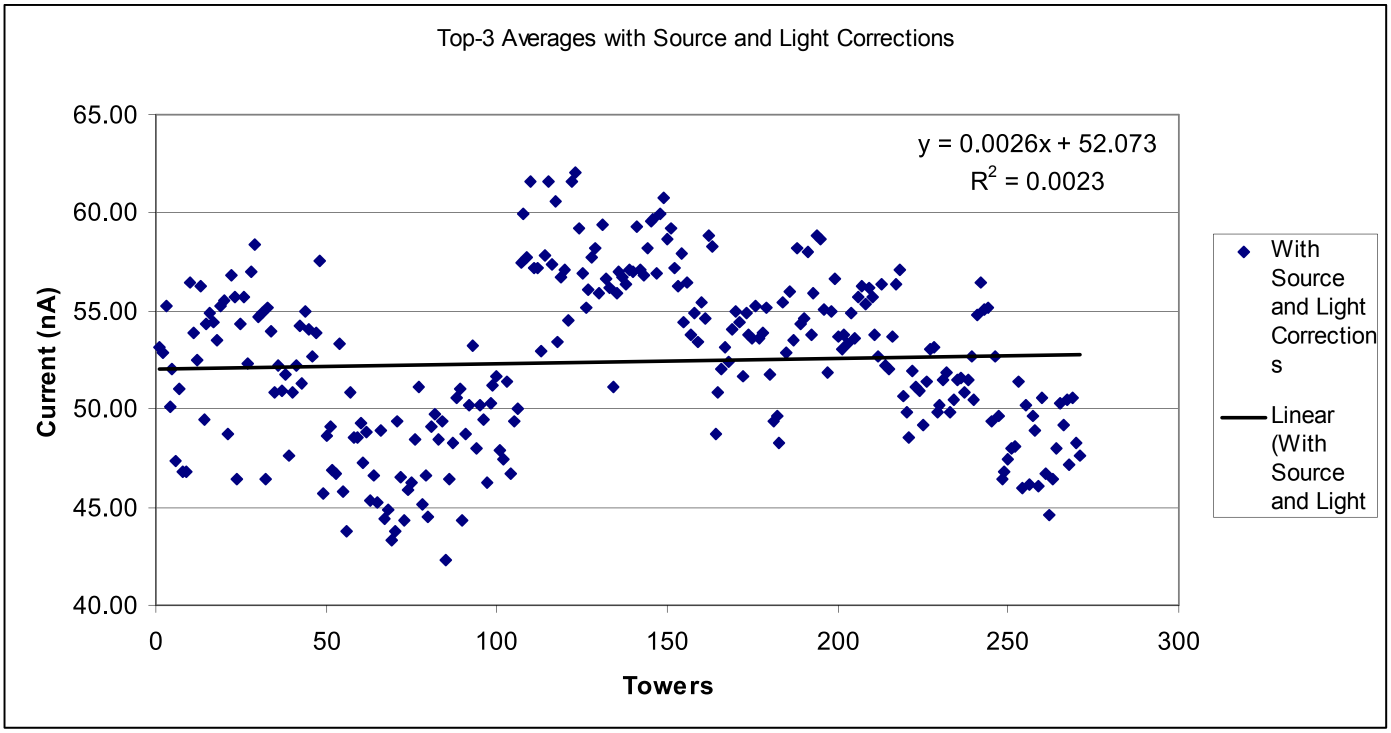

Figure 12: All of the top-3 averages with source corrections and light corrections (a.k.a. equipment degradation corrections). Notice some of the large jumps in the data. These are due to changes in testing equipment.

From here, the source calibration factor and equipment degradation factor are multiplied to each of the doublets in every tower. Then an additive correction is assessed to each set of towers to bring each sets average to 50 nA. This correction ranged from -7.3 nA to +1.9 nA depending on the changes that were made in test equipment. Finally, the values for every doublet are now normalized. From here eight histograms are made, one for each type of doublet (L1, R1, L2, …), to determine which doublets are outliers and show signs of broken fibers. Figure 13 shows an example of one of these histograms. All of them, and a table of their values, can be seen in Appendix C. The full set of data with all of the corrections can be seen in Appendix D.

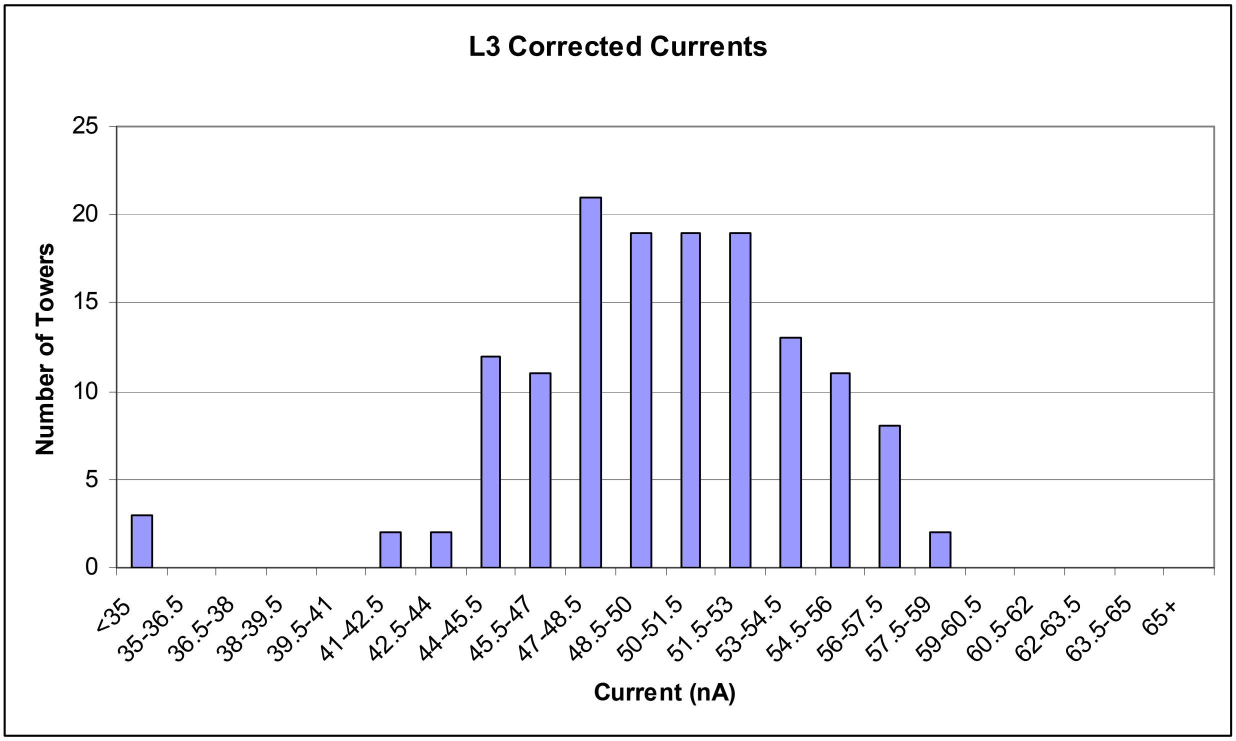

Figure 13: Histogram for all L3 doublets with all corrections for currents.

These histograms are formatted so that the 85% cut-off is at 42.5nA. As you can see on this particular one there are two doublets which are just below this cutoff, and three more which are very far below the cutoff. The three that are below 35 nA are W069L, W086L, and W120L. W069L was sent out and used in MINERvA because our testing protocols were not well-established at that point, whereas the other two were rejected at William and Mary and rebuilt before they ever got sent out.

Conclusions

This portion of my research, mostly conducted in the first semester, deals with the Outer Detector towers for the MINERvA neutrino detector. I used a radioactive source to make sure that the towers did not have broken fibers before they are shipped to Fermi National Accelerator Laboratory. Overall 44 of the 294 (15%) towers which were constructed here at William and Mary were rejected either by myself or by Fermilab because of broken fibers. Most of these towers were able to be rebuilt or were donors for the rebuilt towers. Although there were some systematic errors throughout the testing, most of it can be attributed to changes in testing equipment, or degradation of the testing equipment. Using source corrections, corrections based on the degradation of equipment, and corrections based on the swapping out of equipment, I was able to normalize all of the data. This gives us a final graph with all the corrections, which can be seen in figure 14. From this more analysis was done, including the histograms which can be seen in Appendix C, and all of the corrected doublet data which can be seen in Appendix D. One conclusion which can easily be drawn in Appendix C is that L1 doublets and R4 doublets were very low, and this is probably due to a damaged fiber in the PMT housing.

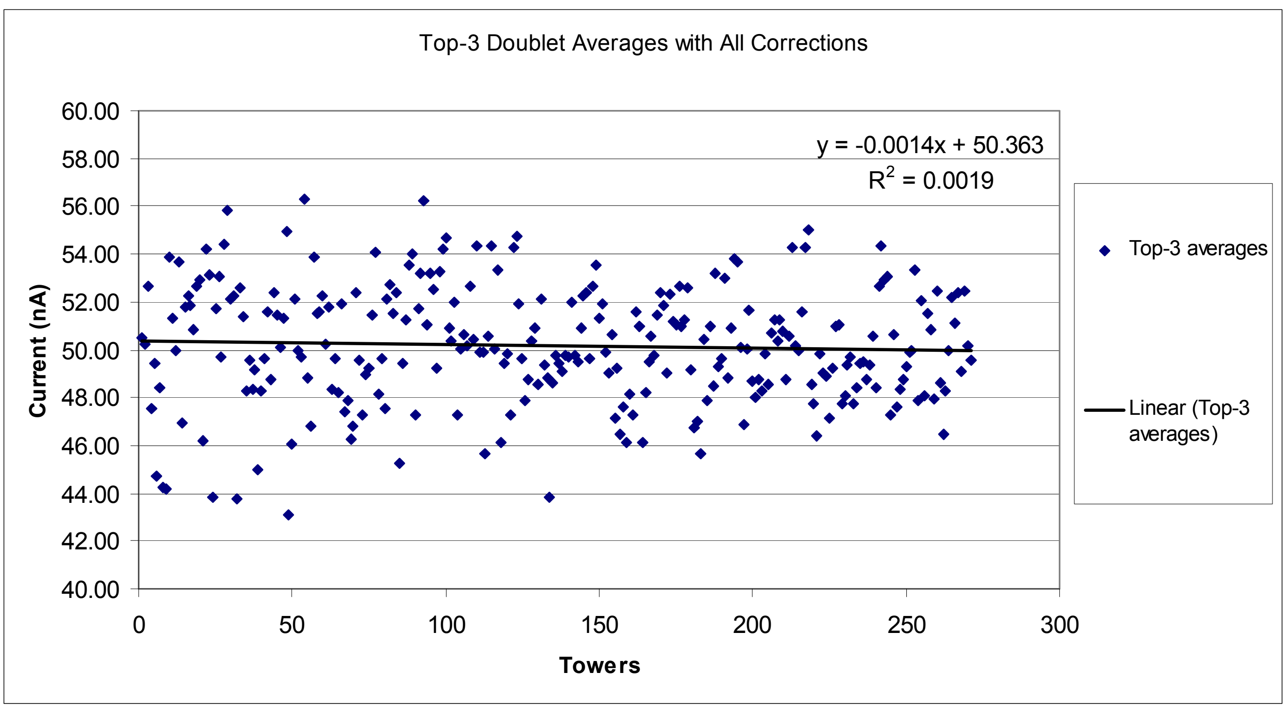

Figure 14: The top-3 doublet averages for each tower after all corrections.

Part 2: PCAL

Background

Thomas Jefferson National Accelerator Facility (JLAB) is undergoing an upgrade in their middle hall for high energy physics, Hall B. "The main goal of the CLAS upgrade is to maintain its capability to obtain high statistics data for exclusive electron scattering reactions at beam energies of 12 GeV" [2]. One of the components which is being upgraded is the pre-shower calorimeter, which is essentially a pi-zero detector. The maximum beam energy is being doubled, which means when the pi-zeros decay into two photons. The two photons will be closer together than they were at lower energies because of the Lorenz boost in the direction of travel [1]. Due to this, the PCAL must have finer granularity to better detect the locations of the two photons, in order to reconstruct the two-photon decay of the pi-zero. The design of the new pre-shower calorimeter (PCAL) is similar to the current design for the forward electromagnetic calorimeter [1]. The scintillators are placed in between 2mm thick layers of lead, and are made into large isosceles triangles (nearly equilateral). There will be six of these triangles with their tips all coming together in the middle to make this conical shape. Each triangular module has fifteen layers of scintillator, five in each of three different orientations. Each triangle has a base of 369 cm, and the other two sides are slightly less to form the conical shape. Each one will have 192 wavelength-shifting fibers which are read out individually at photomultiplier tubes. Therefore, the total number of channels in the PCAL is 1152. Figure 15 shows the layout of the PCAL [3].

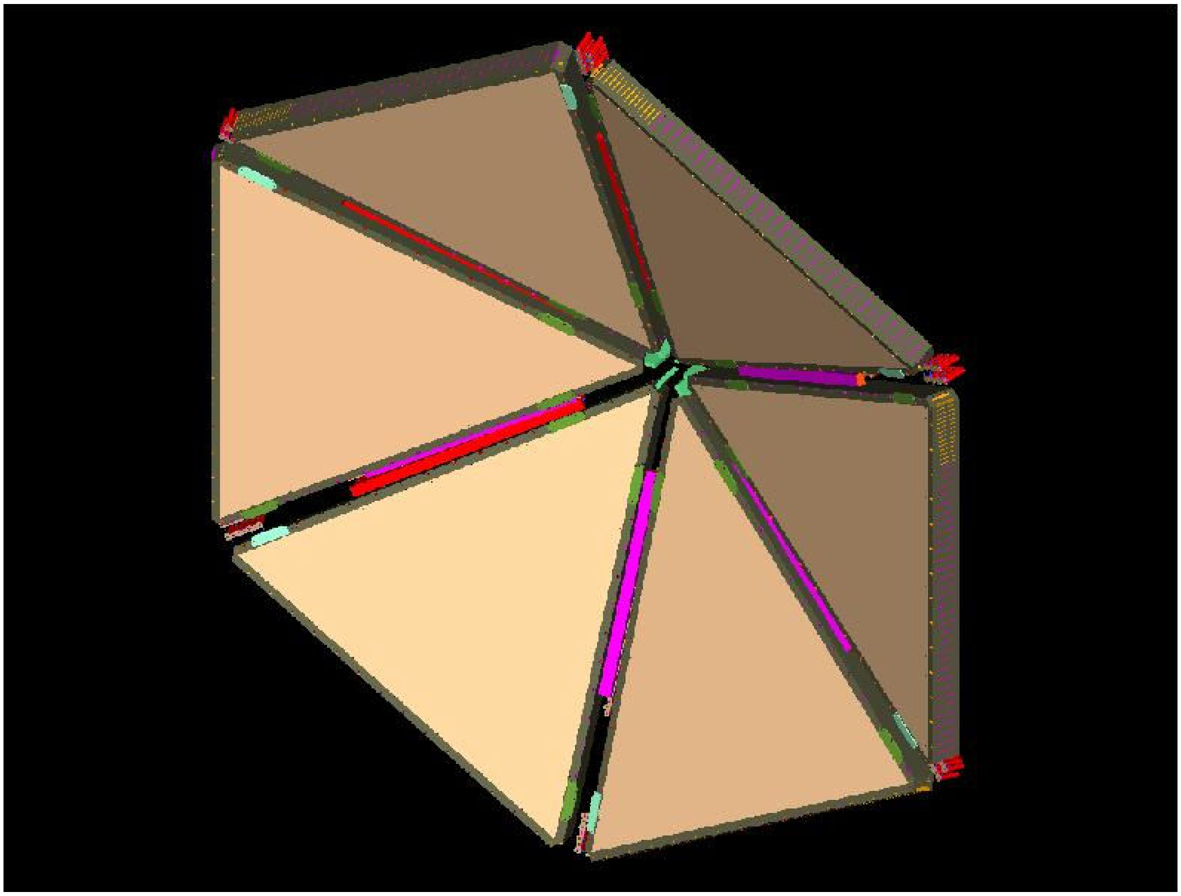

Figure 15: A computer model of the shape of the PCAL. [3]

My research deals with the installation of the wavelength shifting fibers inside the scintillators. Unlike MINERvA which used 1.2mm fibers, each with a mirror at the end, this project is using 1.0mm fibers without mirrors. There are no mirrors in this test because the scientists conducting it want very discrete events. The decay time of the scintillator, meaning the amount of time a pulse of photons lasts inside the scintillator, is roughly 10ns. The index of refraction in the fibers is roughly 1.6. Therefore, light travels about 19 cm/ns in the fibers. If light in the fiber originated, for example, 2.0 meters from the end of the fiber and traveled towards the mirror then bounced off the mirror and came back, it would arrive at the PMT about

21 ns after light which initially traveled towards the PMT from that same point. This delay is too large, so mirrors are not used in the PCAL.

The holes which run through the scintillators are large enough to fit two fibers in each. The dimensions of the scintillators can be seen in Figure 16. The big question I addressed with these scintillators is the configuration of the WLS fibers. There were basically two options. The first is to have one fiber in each hole and glue the fiber in place. Gluing a single fiber gives a better light yield than leaving it not glued because the glue is optically coupled to the fiber. Basically, this means that the glue has an index of refraction which is close to that of the fiber and scintillator so that the photons to not reflect at the change of the index of refraction. The second option is to have two unglued fibers in each hole. These two options are roughly equal in cost because the materials for the glued fiber is less expensive but the installation requires more labor. We want to make an informed decision, based on my research with Jeff Nelson and Anna Shabalina as well as research at JLAB, to choose the configuration which will give the best light yield.

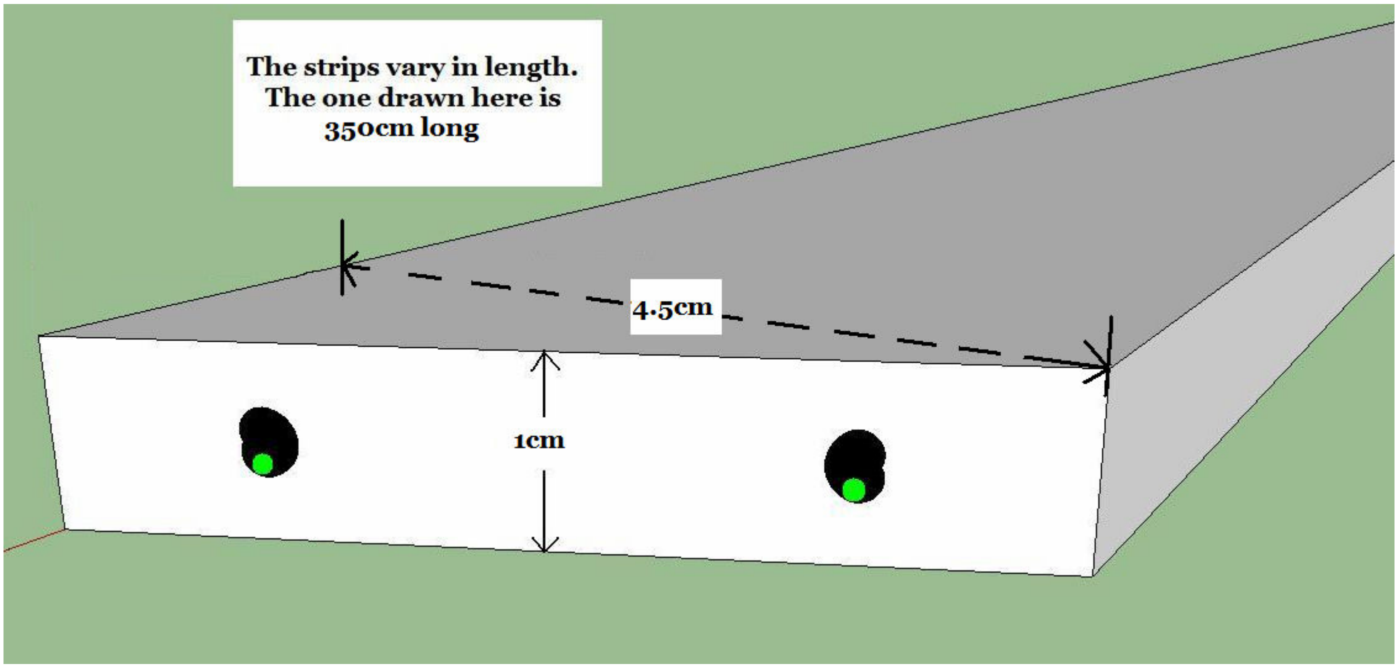

Figure 16: depiction of a scintillator to be used in the updated pcal in hall B.

The physics behind the PCAL is the same as the MINERvA outer detectors. When there is an interaction an electron recoils and creates scintillation light. These ultraviolet photons bounce around inside the scintillator, and some of them are collected in the WLS fiber where they are routed to a photomultiplier tube.

Procedure

During the testing, radiation safety procedures are observed. The same Na-22 source is used that was used for the MINERvA testing. The same source testing schematic (Figure 2) applies to this testing. Near the end of the MINERvA testing we switched to a new PMT that was also used for all of the PCAL testing. Besides that, and the occasional extension cable switch, all of the equipment is the same as used in my previous testing.

We use long sheet of black plastic for light-tightness, and manually holding the source over the scintillator. The black plastic is marked every 15cm to easily show where to place the source for each current measurement. Once the fibers are inserted in the scintillator in their desired arrangement (see Figure 17) they are connected to the extension cable through a ferrule. Then a sleeve is pulled over the connection and another layer of black plastic is pulled over the entire connection area to keep out as much light as possible. The baseline currents suggest that this method, although not very elegant, does provide a light-tight testing space.

Figure 17: A PCAL scintillator in the plastic wrap with two WLS fibers coming out. Once these fibers are connected to the extension cable the plastic underneath it will be wrapped around it and taped in place to ensure that it is light-tight.

Once everything is wrapped up and ready to go a baseline current is read. Then the source is brought out and placed directly on top of the plastic just at the edge of the scintillator for the 0cm measurement. The source is always held with the long wand to keep exposure to a minimum. The next measurement is made 15cm further away from the end of the scintillator, again with the source resting directly on the black plastic, which in turn is directly on top of the scintillator. This process is repeated down to the 285cm mark (see Figure 18). This data gives us twenty meaningful data points for each scintillator. For consistency, the source is always oriented the same direction and is always placed directly in the middle of the scintillator (width-wise).

Figure 18: Testing procedure and setup for the testing of PCAL scintillators.

We have done several different types of tests with varying levels of success. Before I go too far into detail about the different tests, a short explanation of notation will make everything a lot easier. Each scintillator has two holes. These are arbitrarily, yet consistently, labeled 1 and 2. Each of the fibers that were used for testing has been given a name as well, for example “a”, “b”, “v”, and “u”. If we tested fiber “u” in hole 1 this would be written [u1]. If we tested fiber “u” in hole 1 and “v” in hole 2, with both of these fibers being routed to the PMT, this is written [u1+v2]. If we wanted to do analysis and add up the data from fiber “u” being tested in hole 1 with the data from fiber “v” in hole 2 (separate tests), this would be written [u1]+[v2]. This notation was created by Dr. Jeffrey Nelson.

Data and Analysis

Testing was done on several occasions throughout March and April 2010, each with a slightly different goal. There were some overarching conclusions which we tried to draw. First, we wanted to confirm that [a1] + [b2] = [a1+b2]. In short, we wanted to confirm that with the same setup, if one fiber is tested, then the other is tested, those results should add up to the results of the two being tested simultaneously (the test of reproducibility). Second, we wanted to establish the shadowing effects inside of one hole. Finally, and most importantly, we wanted to see the effect of the epoxy. We wanted to determine how much gluing increases the light yield of a single fiber, and how gluing one fiber into each hole compares with having two unglued fibers in each hole.

Reproducibility

As a test of our techniques, one of the first things we looked for was confirmation that testing the fibers individually and adding them gave the same results as testing them together to test repeatability. We did tests on four sets of fibers to confirm this. This involved removing the fibers from the ferrule, frequently inserting fibers into the scintillator, and removing the tested fibers from the scintillator (See Table 5). All but one of the tests had an average ratio which was within one standard deviation of 1.00. These standard deviations come mostly from the fact that the source is handheld (with a wand) during testing. Although every effort is made to place it in exactly the right place, at the right angle, etc. it is probably that it is not always done perfectly. When the average of those four averages is taken, we come up with an overall average of 1.00. This confirms that individual measurements of fibers can be taken and then added with good reproducibility (roughly 5% error).

date	fibers/holes	[1]+[2]/[1+2] avg.	st. dev.
1-Apr	z1 and v2	1.09	0.10
30-Mar	u1 and w2	1.03	0.03
25-Mar	z1 and w2	0.96	0.04
25-Mar	u1 and v2	0.91	0.05
	average	**1.00**	
	st. dev.	0.08	

Table 5: Ratios of individual added tests to one combined test with one fiber in each hole.

Shadowing effects in one hole

The second thing that we were looking for in our data collection was shadowing effects inside of one hole. Shadowing is the effect that one fiber has on the other whether it is in the same hole or the other hole. As light bounces around inside the scintillator (an average of five to eight times) it can be absorbed into the fibers [1]. Of course if it is absorbed into one fiber it cannot be absorbed into the other. In this manner one fiber can take away potential light from the other. In the case of two fibers in one hole the two fibers are cylindrical and they are touching each other. Therefore the solid angle from one fiber to the other is $1 / 2\pi$, which is about 0.16 (see Figure 19). This is by no means an in-depth mathematical calculation of what we expect shadowing effects to be, however it does give us a basis for what we may expect. Table 6 shows three different tests with six fibers to demonstrate the effect of same-hole shadowing. The averages of both fibers over one fiber range from 1.42 to 1.92 with an average of 1.64 ± 0.06. This indicates that two fibers collect 64% more light than a single fiber (it would be 100% more without shadowing). The first and last data points are not normally used in calculating the average because there is a lot of variability when measuring so near to the ends of the scintillator. Therefore the increase in light yield by having two fibers in one hole instead of one fiber in one hole is about 80%. Finally, this means that the shadowing effects take away 20% of the potential light yield from the pair of fibers. This is pretty close to the roughly predicted value of 16%.

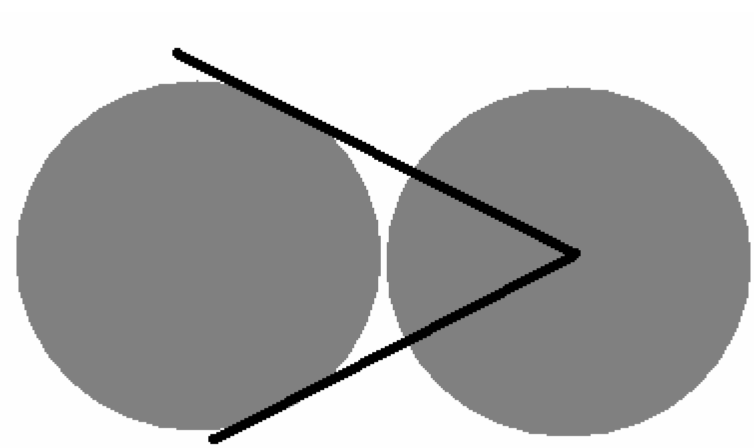

Figure 19: Depiction of the solid angle that one fiber projects onto the other in the same hole.

distance (cm)	[u1+v1] / u1	[u1+v1] / u2	[u1+v1] / u1	[u1+v1] / u2	[z1+w1] / z1	[z1+w1] / w2
0	1.55	1.36	2.05	1.85	2.01	1.62
15	1.68	1.53	1.63	1.60	1.97	1.44
30	1.63	1.52	1.73	1.66	1.77	1.37
45	1.63	1.57	1.78	1.87	1.92	1.44
60	1.72	1.56	1.65	1.78	1.95	1.52
75	1.69	1.56	1.58	1.76	1.95	1.49
90	1.48	1.54	1.50	1.80	1.93	1.45
105	1.48	1.52	1.49	1.68	1.94	1.40
120	1.63	1.67	1.63	1.85	1.86	1.40
135	1.45	1.59	1.57	1.79	1.96	1.43
150	1.39	1.51	1.61	1.71	1.89	1.37
165	1.60	1.81	1.60	1.81	1.87	1.30
180	1.49	1.59	1.45	1.63	1.82	1.36
195	1.57	1.63	1.46	1.57	1.89	1.34
210	1.46	1.54	1.48	1.70	1.91	1.34
225	1.42	1.55	1.41	1.71	1.98	1.42
240	1.38	1.51	1.56	1.80	1.87	1.51
255	1.39	1.54	1.38	1.65	1.92	1.39
270	1.42	1.58	1.32	1.57	2.04	1.39
285	1.49	1.77	1.38	1.56	2.02	1.43
Average	**1.53**	**1.57**	**1.56**	**1.72**	**1.92**	**1.42**
Std. Dev.	0.11	0.10	0.17	0.10	0.07	0.07

Table 6: This table shows the effect of shadowing in one hole by taking the ratio of light output into both fibers in one hole over a single fiber.

Epoxy effect

The third effect that we are interested in is the effect of gluing. As discussed earlier, gluing leads to an increase in light yield because of optical coupling. Recall that transmission is roughly given by $(n_1 - n_2) / (n_1 + n_2)$ where n_1 and n_2 are the indices of refraction [5]. The scintillator has an index of refraction of about 1.5 and the wavelength shifting fiber has an index of refraction of about 1.6. Air surrounds the fiber if it is not glued and, of course, has an index of refraction of just over one. The epoxy that is used to glue in the fibers has an index of refraction of about 1.4 [1]. Because this is much closer to the WLS fiber's value of 1.6 we say that it better more optically coupled to the fiber than air. Experimentally, that means that more photons will be retained inside of the fiber. It has essentially the same effect as using a larger fiber. Figure 20 shows an example of data taken with two fibers. Notice the consistent slow downward trend (which all of the data undergoes the further it gets from the PMT due to absorption along the fiber) and the heightened values for fibers which are glued. Each of the fibers is tested unglued and then glued.

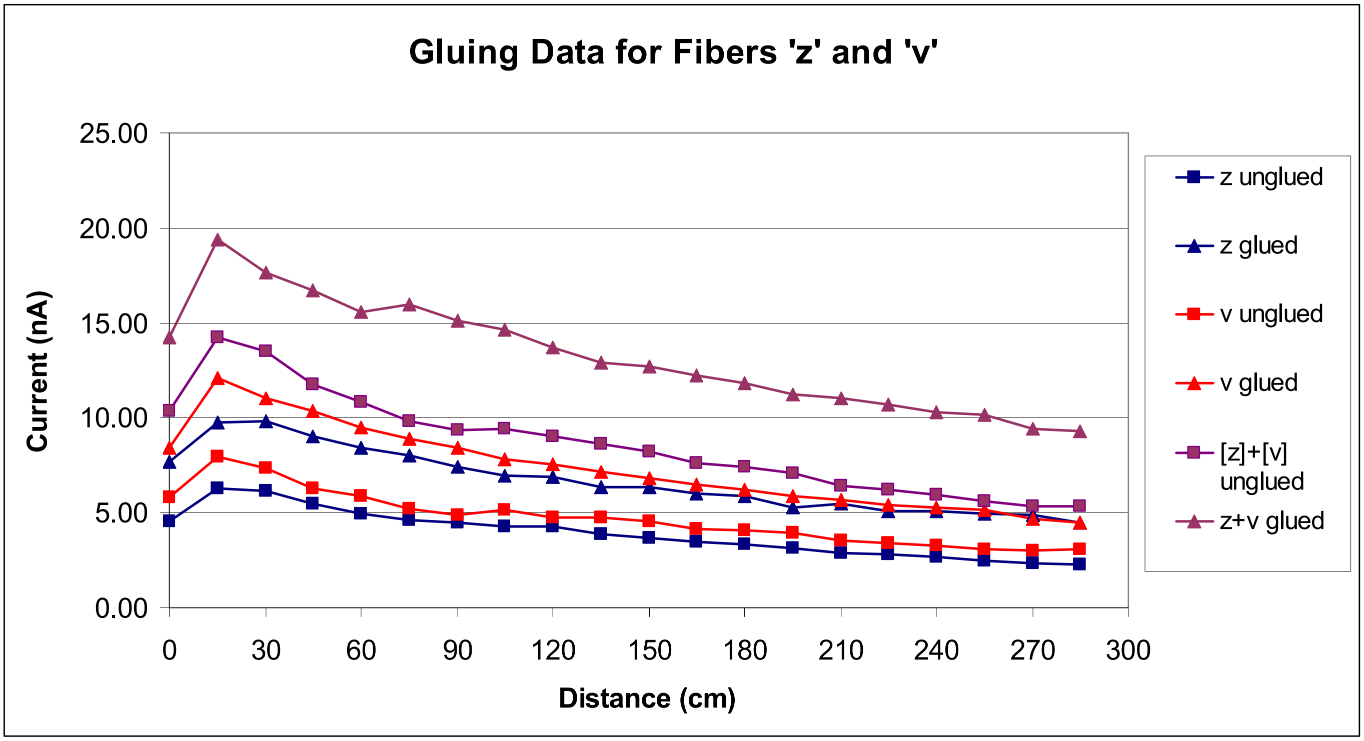

Figure 20: Each color is a fiber. Triangular points are data taken when the fibers were glued in, and square points represent data from when the fiber was unglued.

The preceding graph is just an example of some data taken in the lab on glued and unglued fibers. The best way to determine the effect of gluing is to measure it before and after gluing. In the following graph the data taken for fibers "z" and "v" was collected in the same manor as the shadowing test.

The procedure for the other four fibers varied slightly. In order to have a check that nothing went terrible wrong during the gluing, the fibers came out of the scintillator then were routed through another piece of scintillator just twenty centimeters long before going to the PMT (see Figure 21). This allowed us to test a new point (described as “-10cm”) which should remain unchanged during the gluing process. This acted as calibration for the connection of the fiber to the PMT and also showed any damage to the fiber. This was used for fibers “a”, “b”, “e”, and “f”. For fiber “f” the value for -10cm went from 6.75nA to 4.65nA. This is a large difference and should absolutely be noted. However, due to our setup with the loose black plastic providing light-tightness, we should not read too much into this. Because the scintillator and all of the fibers’ connections needed to be light tight and the connections had to be switched very frequently, the area near this extra 20cm piece of scintillator was very hard to keep light-tight. Often times it required extra layers of plastic which did not allow the source to be as close to the scintillator as in the other tests. I suspect that is what happened in this case. This data was not used in further analysis. In the other three fibers, the value at -10cm before and after gluing varied less than 5%. Figure 22 displays the ratios for the different fibers (glued over unglued). Following Figure 22 is a table which displays the averages and standard deviations for each of the fibers (Table 7).

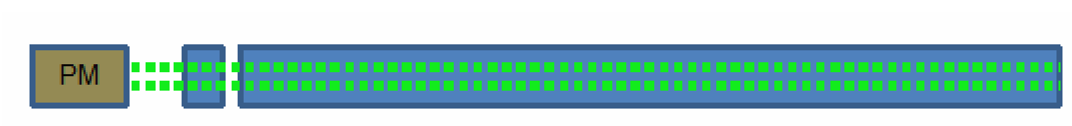

Figure 21: Diagram of the scintillator with the 20cm piece before the fibers are routed to the PMT.

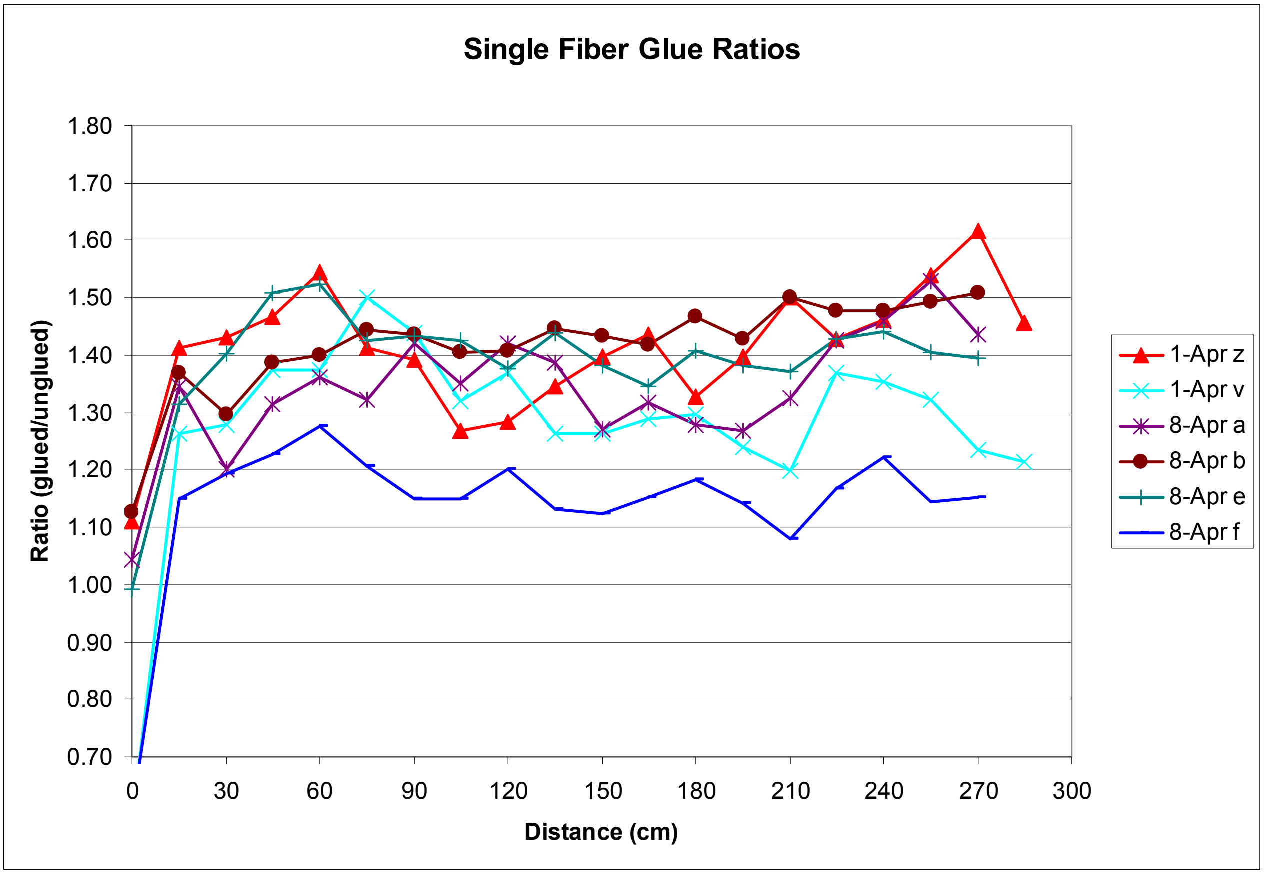

Figure 22: *This figure shows glued/unglued ratios for individual fibers measured at specific points along the scintillator.*

Date	Fiber	Average	St. Dev.
1-Apr	z	1.41	0.11
1-Apr	v	1.28	0.18
8-Apr	a	1.36	0.08
8-Apr	b	1.43	0.05
8-Apr	e	1.41	0.05
	Average	**1.34**	
	St. Dev.	0.12	

Table 7: This table shows the averages of glued to unglued ratios for individual fibers, ignoring fibers "z" and "v" because of their large standard deviations. An overall average is calculated, 1.34. This means that gluing the fibers into place has an increase of about 34% in light-collection efficiency compared to an unglued fiber.

All of the glue data we have examined so far deals with comparing individual fibers. This gave us a good idea of what the glue is capable of in terms of optical coupling and increasing light yield, but it does not give us the answer we are seeking; to glue or not to glue? What we really need is to determine the differences in light yields between four unglued fibers in a scintillator (two in each hole) and two glued fibers in a scintillator (one in each hole). To test this, fibers were tested inside of the scintillator unglued. Four fibers were tested simultaneously (two in each hole). Then one was removed from each hole. The remaining two were glued in and then retested. Figure 23 shows the ratio of the light yield for three different scintillators that were tested. The ratio is calculated at each test point along the scintillator.

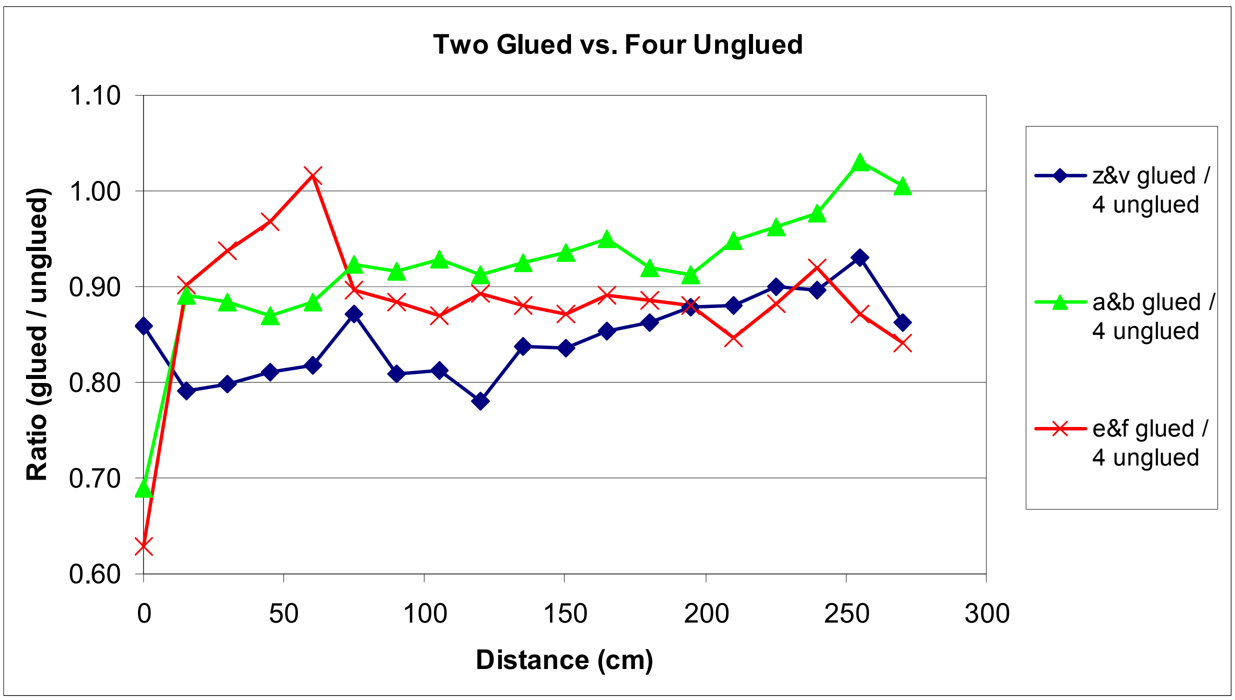

Figure 23: Ratios calculated for two glued fibers over four unglued fibers inside a single scintillator. Three different scintillators are shown here.

The overall ratios for these three are 0.85, 0.93, and 0.90 respectively, each with a standard deviation on 0.04. These are perhaps the most important values that we have obtained in the entirety of testing for the PCAL. We can conclude from these values that there is not much difference between gluing in two fibers and placing four fibers in dry. From the data, though, it looks like gluing is about 89% as efficient at light collection as not gluing with double the number of fibers. Based on this data, as well as practical concerns, the collaborators at JLAB decided to use four unglued fibers instead of two glued fibers.

Conclusions and Errors

This data is by no means without error. Ideally, the light-tight box (which is discussed in the next section) would have been finished and we could have done all of the testing inside of it. This would be a much more controlled environment for testing. Instead, however, we had to do the testing using the large plastic sheets for light-tightness and holding the source in a wand. Anna Shabalina, a graduate student at William and Mary did most of the physical testing – manipulating the source, checking for light-tightness, etc. as I recorded the data. She did a great job, but when the process is not entirely mechanized there will always be human error. Another source of error is recording the data itself. The value for current on the picoammeter constantly fluctuates, but a single value must be recorded. I was always consistent with my routine for recording data, but there is always room for a little bit of error in these judgments.

We established that our testing procedure was reliable when we verified that we can simply add up individual measurements to obtain the value for the two combined. We then established that shadowing effects in a single hole take away about 20% of the potential light yield from a fiber. We then determined that gluing a single fiber increases its light-yield by about 34%. Finally, we determined that gluing two fibers into a scintillator is only about 89% as efficient as using four unglued fibers. Thanks to these results the design for the new PCAL at JLAB will use four unglued fibers in each scintillator.

The Box

As part of my research this semester I have designed a light-tight box to do testing of long scintillators. The box that I am using had already been built for testing scintillators for the MECO experiment before I began my research, but the parts to make the box useful for testing were never installed. Working with Dr. Jeff Nelson and Kirk Jacobs, I came up with a design. This design uses a crank on the outside of the box which spins a sprocket on the inside. The sprocket is connected to another sprocket at the opposite end of the box with a metal chain. Finally, the chain is connected to a slider which holds the source and slides it back and forth over the scintillator which is being tested. All of this is done inside the box with the lid closed. The only component which is outside of the box is the crank, which has a dial counter on it in order to make accurate measurements throughout the length of the scintillator. The design of the box can be seen in Figure 24.

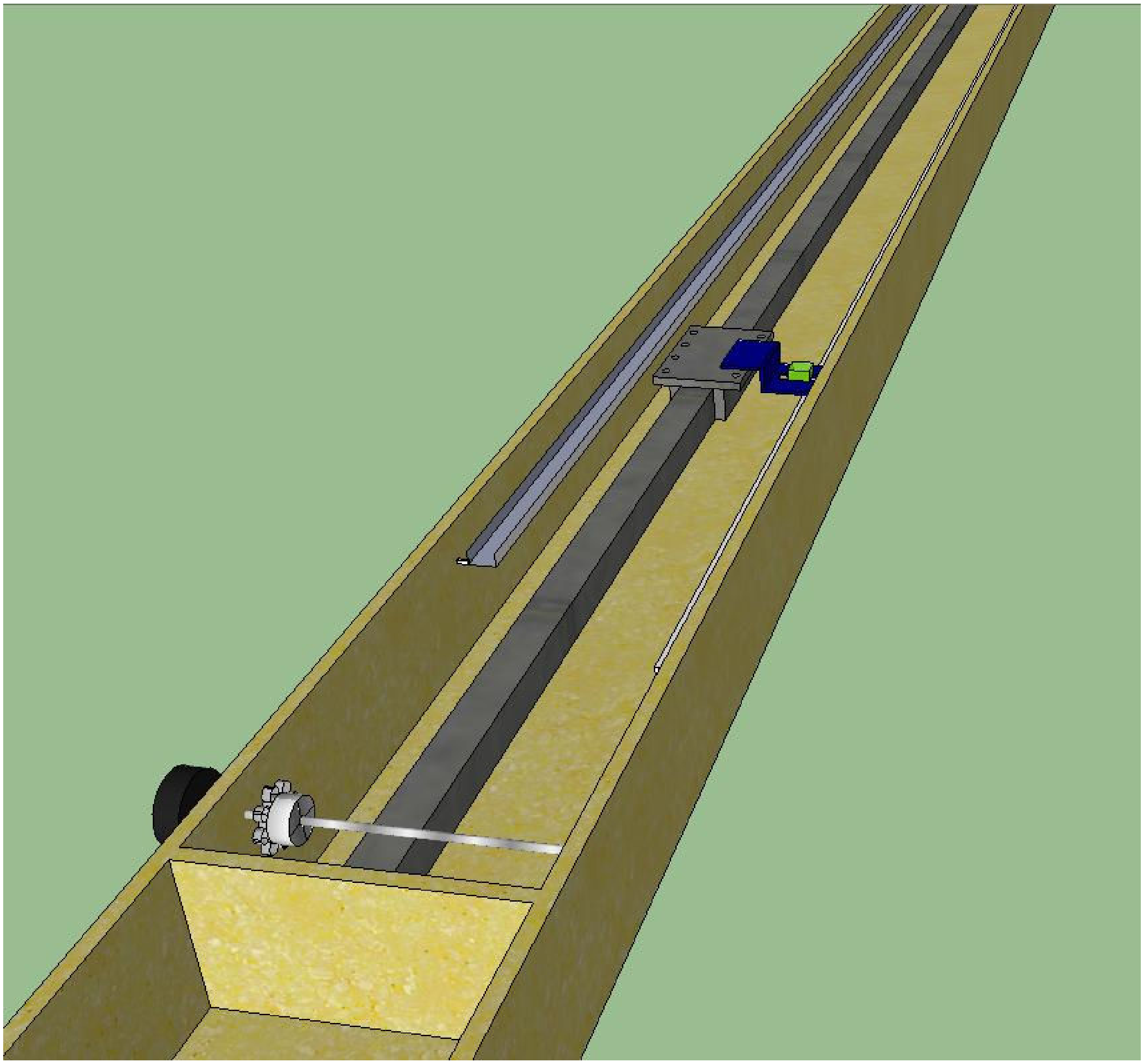

Figure 24: Design of the light-tight box for scintillator testing.

The box is long enough to test a scintillator up to about 4.5 meters long, longer than necessary for the PCAL testing. Once I had the general design of the box completed I ordered the materials. Unfortunately this is where the box project stalled out. The PCAL deadline for the glue test results was set early and the box was not ready in time. Because of this we had to switch up the testing procedure a little bit and use the black plastic for light-tightness instead of the box setup. The box will be completed, however, by Anna Shabalina, and it should be ready for fiber testing this summer.

References

[1] Nelson, Jeffrey. The College of William and Mary. Personal Communication.

[2] "Hall B Wiki," Jefferson Laboratory. 9 April 2010.

http://clasweb.jlab.org/wiki/index.php/Details

[3] "Class 12 Pre-shower calorimeter," Jefferson Laboratory. 9 April 2010.

http://clasweb.jlab.org/wiki/index.php/CLAS12_Pre-shower_calorimeter

[4] "Sodium-22," Science gateway. 28 May 2002. University of Wisconsin Board of Regents.

http://www.sciencegateway.org/isotope/sodium.html

[5] Slater, John C. and Frank, Nathaniel H. *Electromagnetism*. Dover Publications, 1969.

[6] "Technical design report for the MINERvA detectors," The MINERvA Collaboration (2006).

http://minerva-docdb.fnal.gov/cgi-bin/ShowDocument?docid=700

List of Tables / Graphs

Appendix A - all raw tower data from MINERvA

Red means that the tower was rejected at William and Mary before being sent out

Orange means that the tower was rejected by Fermilab and sent back

Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	in/Max Rat	PMT	Ammeter	HV
W045R	2009/07/08		2.70		6.40	6.60	5.70	6.40	0.86	pmt1	new	new
W047L	2009/07/08		2.50		4.80	5.00	5.20	5.00	0.92	pmt1	new	new
W046R	2009/07/08		2.60		5.70	5.90	5.50	6.00	0.92	pmt1	new	new
W051L	2009/07/08		2.70		6.40	6.50	6.00	6.70	0.90	pmt1	new	new
W053R	2009/07/08		2.90		6.80	7.70	6.80	6.30	0.82	pmt1	new	new
W059L	2009/07/09	3.10	3.10	1.00	8.80	8.80	8.70	7.60	0.86	pmt1	new	new
W056R	2009/07/09	3.00	3.10	1.03	8.00	9.00	9.10	8.90	0.88	pmt1	new	new
W061L	2009/07/10	2.80	2.80	1.00	7.30	7.90	8.00	7.30	0.91	pmt1	old	old
W062R	2009/07/09	3.00	3.10	1.03	8.80	9.40	8.90	8.80	0.94	pmt1	new	new
W063L	2009/07/10	3.10	3.20	1.03	4.40	6.90	7.30	6.80	0.60	pmt1	old	old
W058R	2009/07/10	3.00	3.20	1.07	7.00	6.60	7.20	6.60	0.92	pmt1	old	old
W055L	2009/07/13	2.90	3.00	1.03	6.60	7.00	7.10	6.60	0.93	pmt1	old	old
W062L	2009/07/13	3.05	3.15	1.03	7.30	7.85	7.85	7.35	0.93	pmt1	new	old
W060R	2009/07/13	3.00	3.20	1.07	7.80	8.60	7.85	7.65	0.89	pmt1	new	old
W062R	2009/07/13	3.30	3.40	1.03	7.30	7.70	7.90	6.90	0.87	pmt1	new	old
W057R	2009/07/14	2.95	3.00	1.02	6.65	7.20	7.80	6.45	0.83	pmt1	new	old
W060L	2009/07/14	2.85	2.95	1.04	7.15	7.65	7.65	7.20	0.93	pmt1	new	old
W061R	2009/07/14	2.95	3.00	1.02	6.85	7.45	7.45	6.55	0.88	pmt1	new	old
W067L	2009/07/15	2.90	3.10	1.07	7.50	7.90	7.70	7.40	0.94	pmt1	old	old
W063L	2009/07/15	2.90	3.10	1.07	6.00	8.00	8.00	7.40	0.75	pmt1	old	old
W067R	2009/07/15	3.00	3.10	1.03	7.60	5.50	8.80	7.90	0.63	pmt1	old	old
W068L	2009/07/15	3.30	3.40	1.03	7.50	9.20	9.30	8.10	0.81	pmt1	old	old
W066R	2009/07/15	3.30	3.30	1.00	8.25	8.80	9.25	8.65	0.89	pmt1	new	old
W071L	2009/07/16	2.00	2.40	1.20	58.50	69.00	65.00	61.00	0.85	pmt3	new	new
W064L	2009/07/16	1.90	3.30	1.74	56.70	67.80	67.80	61.00	0.84	pmt3	new	new
W098L	2009/07/16	1.85	2.10	1.14	55.30	66.30	71.20	64.00	0.78	pmt3	new	new
W099R	2009/07/16	1.85	2.50	1.35	58.70	61.80	64.10	53.50	0.83	pmt3	new	new
W065R	2009/07/16	1.90	2.20	1.16	66.00	56.70	66.30	58.00	0.86	pmt3	new	new
W065L	2009/07/16	1.90	2.90	1.53	46.30	66.00	62.60	47.00	0.70	pmt3	new	new
W066L	2009/07/16	1.90	3.00	1.58	55.60	67.00	66.20	52.70	0.79	pmt3	new	new
W063R	2009/07/16	1.90	2.65	1.39	56.00	58.00	59.00	49.00	0.83	pmt3	new	new
W069L	2009/07/21	1.75	2.00	1.14	53.80	55.50	36.00	61.00	0.59	pmt3	new	new
W070L	2009/07/21	1.90	2.05	1.08	56.20	72.80	71.00	60.50	0.77	pmt3	new	new
W072L	2009/07/21	1.85	2.15	1.16	52.00	68.50	66.00	61.00	0.76	pmt3	new	new
W069R	2009/07/21	1.70	2.00	1.18	61.70	62.60	65.90	57.30	0.87	pmt3	new	new
W064R	2009/07/22	1.85	1.95	1.05	64.80	65.40	72.70	59.80	0.82	pmt3	new	new
W070R	2009/07/22	1.85	2.10	1.14	49.20	53.80	67.80	58.00	0.73	pmt3	new	new
W075L	2009/07/22	2.00	2.15	1.08	56.00	62.30	69.00	65.40	0.81	pmt3	new	new
W074L	2009/07/22	2.00	2.40	1.20	57.00	64.00	71.00	64.00	0.80	pmt3	new	new
W073L	2009/07/22	2.00	2.60	1.30	54.70	62.80	69.00	66.40	0.79	pmt3	new	new
W071R	2009/07/23	1.90	2.20	1.16	66.00	63.50	63.80	59.00	0.89	pmt3	new	new
W074R	2009/07/23	2.05	2.25	1.10	61.10	68.00	70.50	60.00	0.85	pmt3	new	new
W077R	2009/07/24	1.90	2.15	1.13	68.50	64.50	67.00	58.50	0.85	pmt3	new	new
W058L	2009/07/24	1.85	2.25	1.22	52.90	60.00	57.30	59.40	0.88	pmt3	new	new
W074L	2009/07/24	2.00	2.35	1.18	55.50	69.00	71.80	64.20	0.77	pmt3	new	new
W078L	2009/07/24	1.95	2.35	1.21	60.20	70.30	70.50	59.30	0.84	pmt3	new	new
W073R	2009/07/24	1.95	2.15	1.10	56.50	56.30	55.20	54.00	0.96	pmt3	new	new
W078R	2009/07/24	1.95	2.30	1.18	68.30	60.30	67.30	43.50	0.64	pmt3	new	new
W075R	2009/07/24	1.95	2.20	1.13	64.20	65.00	71.00	53.50	0.75	pmt3	new	new
W077L	2009/07/27	1.85	2.20	1.19	52.50	57.00	69.50	61.50	0.76	pmt3	new	new
W079R	2009/07/28	1.70	2.05	1.21	70.20	65.30	68.00	54.00	0.77	pmt3	new	new
W079L	2009/07/28	1.75	2.10	1.20	43.50	68.30	72.00	68.20	0.60	pmt3	new	new
W080L	2009/07/28	1.85	2.20	1.19	58.00	73.00	61.00	62.00	0.79	pmt3	new	new
W081R	2009/07/28	1.75	2.10	1.20	65.80	62.80	67.50	57.60	0.85	pmt3	new	new
W083R	2009/07/28	2.05	2.40	1.17	60.00	51.30	56.30	50.30	0.84	pmt3	new	new
W082L	2009/07/28	2.00	2.15	1.08	55.70	66.50	67.30	63.30	0.83	pmt3	new	new
W081L	2009/07/28	1.95	2.20	1.13	54.50	62.80	66.70	63.60	0.82	pmt3	new	new
W080R	2009/07/28	1.90	2.20	1.16	67.70	56.70	56.50	57.80	0.83	pmt3	new	new
W072R	2009/07/28	1.90	2.60	1.37	66.40	58.00	63.50	55.00	0.83	pmt3	new	new
W084R	2009/07/29	1.75	2.15	1.23	71.00	56.00	55.00	51.50	0.73	pmt3	new	new
W082L	2009/07/29	1.85	2.40	1.30	54.50	63.30	58.30	64.00	0.85	pmt3	new	new
W100R	2009/07/29	1.85	2.40	1.30	63.00	53.00	55.20	50.80	0.81	pmt3	new	new
W076L	2009/07/29	1.95	2.20	1.13	64.50	56.60	60.60	52.60	0.82	pmt3	new	new
W068R	2009/07/29	1.80	2.25	1.25	64.00	62.40	60.00	35.60	0.56	pmt3	new	new

Red means that the tower was rejected at William and Mary before being sent out
Orange means that the tower was rejected by Fermilab and sent back

Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	lin/Max Rat	PMT	Ammeter	HV
W076R	2009/07/29	1.90	2.25	1.18	53.80	64.40	64.40	64.40	0.84	pmt3	new	new
W074R	2009/07/29	2.00	2.35	1.18	65.50	57.60	60.50	57.50	0.88	pmt3	new	new
W082R	2009/07/31	2.00	2.50	1.25	72.00	55.30	67.30	57.00	0.77	pmt3	new	new
W086R	2009/07/31	2.00	2.30	1.15	63.00	60.70	68.50	58.80	0.86	pmt3	new	new
W085R	2009/07/31	2.05	2.35	1.15	60.30	55.20	65.50	62.00	0.84	pmt3	new	new
W083L	2009/07/31	2.05	2.50	1.22	55.50	68.50	62.20	61.50	0.81	pmt3	new	new
W087L	2009/07/31	1.95	2.10	1.08	51.80	70.00	71.00	62.50	0.73	pmt3	new	new
W088R	2009/08/03	1.85	1.95	1.05	55.00	56.00	51.00	43.00	0.77	pmt3	new	new
W096R	2009/08/03	1.85	2.10	1.14	65.00	52.50	55.00	52.50	0.81	pmt3	new	new
W087R	2009/08/05	1.85	2.10	1.14	53.50	53.00	68.00	56.00	0.78	pmt3	new	new
W084L	2009/08/05	1.80	2.15	1.19	51.00	64.50	54.50	46.50	0.72	pmt3	new	new
W086L	2009/08/05	1.80	2.40	1.33	52.00	62.50	18.50	55.50	0.30	pmt3	new	new
W088L	2009/08/05	1.90	2.25	1.18	53.00	70.50	65.00	57.00	0.75	pmt3	new	new
W090R	2009/08/05	1.90	2.30	1.21	50.50	58.00	58.00	34.00	0.59	pmt3	new	new
W096L	2009/08/05	1.90	2.15	1.13	55.50	55.00	48.50	47.50	0.86	pmt3	new	new
W093L	2009/08/05	1.95	2.10	1.08	52.00	68.50	62.50	52.50	0.76	pmt3	new	new
W089R	2009/08/05	1.95	2.30	1.18	51.50	53.50	65.50	57.00	0.79	pmt3	new	new
W094L	2009/08/06	1.70	2.15	1.26	59.00	61.00	55.50	53.50	0.88	pmt3	new	new
W090L	2009/08/06	1.70	1.85	1.09	52.00	66.00	59.00	37.00	0.56	pmt3	new	new
W055R	2009/08/06	1.70	2.35	1.38	57.50	53.50	60.50	52.50	0.87	pmt3	new	new
W098L	2009/08/06	1.75	1.85	1.06	49.50	60.50	58.00	57.00	0.82	pmt3	new	new
W097R	2009/08/06	1.75	1.90	1.09	55.50	51.00	57.00	47.50	0.83	pmt3	new	new
W092L	2009/08/06	1.75	1.85	1.06	57.50	56.50	54.00	48.00	0.83	pmt3	new	new
W092R	2009/08/06	1.80	2.15	1.19	52.50	50.50	59.50	52.00	0.85	pmt3	new	new
W095L	2009/08/06	1.80	2.35	1.31	56.50	60.00	61.00	37.00	0.61	pmt3	new	new
W056L	2009/08/06	1.75	3.15	1.80	51.50	57.00	55.50	50.50	0.89	pmt3	new	new
W091L	2009/08/06	1.80	2.40	1.33	54.50	61.00	48.00	46.50	0.76	pmt3	new	new
W095R	2009/08/06	1.75	2.75	1.57	55.00	50.00	54.00	47.00	0.85	pmt3	new	new
W049R	2009/08/06	1.75	2.35	1.34	54.00	50.00	55.50	46.00	0.83	pmt3	new	new
W103L	2009/08/07	1.70	2.05	1.21	54.50	66.00	57.50	53.00	0.80	pmt3	new	new
W102L	2009/08/07	1.70	2.00	1.18	52.00	65.00	51.00	49.00	0.75	pmt3	new	new
W097L	2009/08/07	1.75	2.30	1.31	54.50	55.50	51.00	51.00	0.92	pmt3	new	new
W057L	2009/08/07	1.60	1.90	1.19	28.50	56.00	55.50	54.00	0.51	pmt3	new	new
W101L	2009/08/07	1.60	1.90	1.19	52.00	62.00	52.50	50.00	0.81	pmt3	new	new
W104L	2009/08/07	1.70	2.00	1.18	54.00	65.00	51.00	55.50	0.78	pmt3	new	new
W107L	2009/08/07	1.70	1.90	1.12	55.00	66.50	61.00	56.00	0.83	pmt3	new	new
W098R	2009/08/07	1.70	2.00	1.18	56.50	51.00	55.50	48.00	0.85	pmt3	new	new
W082R	2009/08/07	1.70	2.45	1.44	57.50	56.50	55.50	48.50	0.84	pmt3	new	new
W104R	2009/08/07	1.65	1.85	1.12	54.50	49.00	57.00	42.50	0.75	pmt3	new	new
W106L	2009/08/10	1.95	2.30	1.18	54.00	64.00	59.50	52.00	0.81	pmt3	new	new
W111R	2009/08/10	2.00	2.15	1.08	59.00	59.00	61.00	50.00	0.82	pmt3	new	new
W106R	2009/08/10	1.95	2.05	1.05	57.00	57.50	60.00	52.00	0.87	pmt3	new	new
W107R	2009/08/10	1.95	2.15	1.10	59.00	57.00	62.00	47.00	0.76	pmt3	new	new
W105R	2009/08/10	1.90	2.10	1.11	58.00	50.00	45.00	27.00	0.47	pmt3	new	new
W115L	2009/08/13	1.85	2.20	1.19	52.00	58.00	50.50	57.50	0.87	pmt3	new	new
W111L	2009/08/13	1.90	2.30	1.21	53.00	62.00	58.00	54.00	0.85	pmt3	new	new
W122R	2009/08/13	1.90	2.80	1.47	57.50	56.00	70.00	52.50	0.75	pmt3	new	new
W114L	2009/08/13	1.90	2.40	1.26	56.00	65.50	62.50	47.00	0.72	pmt3	new	new
W110L	2009/08/13	1.90	2.20	1.16	47.00	55.00	57.50	47.50	0.82	pmt3	new	new
W117R	2009/08/13	1.90	2.10	1.11	58.00	59.00	58.00	51.00	0.86	pmt3	new	new
W117L	2009/08/13	1.95	2.85	1.46	48.50	65.00	60.00	57.50	0.75	pmt3	new	new
W113L	2009/08/13	1.95	2.35	1.21	58.50	72.00	61.00	52.50	0.73	pmt3	new	new
W116L	2009/08/13	1.95	2.70	1.38	49.50	63.50	61.50	48.50	0.76	pmt3	new	new
W121R	2009/08/13	1.90	2.35	1.24	53.50	61.00	66.50	45.50	0.68	pmt3	new	new
W108L	2009/08/13	1.90	2.00	1.05	50.00	60.00	62.00	55.50	0.81	pmt3	new	new
W109L	2009/08/13	1.95	2.10	1.08	49.00	62.00	53.00	51.50	0.79	pmt3	new	new
W110R	2009/08/13	1.95	2.10	1.08	60.50	59.00	61.00	50.00	0.82	pmt3	new	new
W109R	2009/08/14	1.75	1.90	1.09	61.00	59.50	62.50	44.50	0.71	pmt3	new	new
W119R	2009/08/14	1.75	1.85	1.06	59.50	61.00	64.00	55.00	0.86	pmt3	new	new
W120R	2009/08/14	1.80	2.25	1.25	53.00	60.00	59.50	50.50	0.84	pmt3	new	new
W105L	2009/08/14	1.75	1.80	1.03	54.00	57.00	58.50	53.00	0.91	pmt3	new	new
W113R	2009/08/14	1.80	2.05	1.14	60.00	60.50	63.50	52.00	0.82	pmt3	new	new
W112R	2009/08/14	1.80	1.90	1.06	55.50	49.00	57.50	47.00	0.82	pmt3	new	new
W085L	2009/08/14	1.80	2.15	1.19	40.50	58.50	48.00	60.00	0.68	pmt3	new	new
W093R	2009/08/14	1.80	2.00	1.11	60.50	47.00	55.50	47.00	0.78	pmt3	new	new

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Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	in/Max Rat	PMT	Ammeter	HV
W112L	2009/08/18	1.80	2.05	1.14	62.00	66.50	73.00	65.00	0.85	pmt3	new	new
W118L	2009/08/18	1.85	2.70	1.46	64.00	77.00	73.50	57.00	0.74	pmt3	new	new
W115R	2009/08/18	1.85	2.10	1.14	70.50	67.00	67.00	62.00	0.88	pmt3	new	new
W114R	2009/08/18	1.85	2.20	1.19	76.00	68.00	73.50	58.00	0.76	pmt3	new	new
W116R	2009/08/18	1.85	2.25	1.22	70.00	66.00	66.00	65.00	0.93	pmt3	new	new
W052R	2009/08/21	1.85	2.45	1.32	69.00	62.50	70.00	62.50	0.89	pmt3	new	new
W054R	2009/08/21	1.80	2.10	1.17	63.00	61.50	60.00	61.00	0.95	pmt3	new	new
W103R	2009/08/21	2.00	2.40	1.20	73.00	62.50	67.00	62.00	0.85	pmt3	new	new
W108R	2009/08/21	1.95	2.35	1.21	73.00	68.00	73.50	31.50	0.43	pmt3	new	new
W124R	2009/08/21	1.95	2.65	1.36	70.50	65.00	65.00	63.50	0.90	pmt3	new	new
W091R	2009/08/21	1.95	2.00	1.03	67.50	58.50	76.50	65.00	0.76	pmt3	new	new
W126R	2009/08/25	1.75	2.05	1.17	67.50	54.50	58.00	58.50	0.81	pmt3	new	new
W127R	2009/08/25	1.85	2.05	1.11	66.50	60.00	68.00	58.00	0.85	pmt3	new	new
W125R	2009/08/25	1.85	2.45	1.32	67.00	54.00	72.50	57.00	0.74	pmt3	new	new
W124R	2009/08/25	1.80	1.95	1.08	68.00	60.00	58.00	56.50	0.83	pmt3	new	new
W119L	2009/08/26	1.85	2.30	1.24	58.50	61.00	73.00	75.50	0.77	pmt3	new	new
W121L	2009/08/26	1.85	2.65	1.43	57.00	78.00	68.00	65.50	0.73	pmt3	new	new
W123L	2009/08/26	1.85	2.40	1.30	61.00	72.00	68.00	51.00	0.71	pmt3	new	new
W122L	2009/08/26	1.80	2.55	1.42	62.00	69.00	62.50	62.00	0.90	pmt3	new	new
W138L	2009/09/11	1.70	1.85	1.09	58.50	64.50	60.00	58.50	0.91	pmt3	new	new
W133L	2009/09/11	1.75	1.90	1.09	59.00	66.50	58.50	60.00	0.88	pmt3	new	new
W129L	2009/09/11	1.80	1.80	1.00	60.00	69.50	60.50	59.00	0.85	pmt3	new	new
W127L	2009/09/11	1.75	1.95	1.11	54.50	70.50	60.00	61.00	0.77	pmt3	new	new
W128L	2009/09/11	1.75	1.90	1.09	58.50	66.50	58.50	58.00	0.87	pmt3	new	new
W125L	2009/09/11	1.70	1.80	1.06	54.00	67.00	68.00	59.00	0.79	pmt3	new	new
W130R	2009/09/11	1.70	1.90	1.12	60.00	59.00	66.00	56.00	0.85	pmt3	new	new
W141R	2009/09/11	1.75	1.75	1.00	59.50	59.00	64.00	56.00	0.88	pmt3	new	new
W133R	2009/09/11	1.75	1.85	1.06	48.00	58.00	52.00	56.50	0.83	pmt3	new	new
W134R	2009/09/14	1.80	1.95	1.08	62.00	57.00	62.00	57.00	0.92	pmt3	new	new
W135R	2009/09/14	1.75	1.75	1.00	62.00	59.00	62.50	57.00	0.91	pmt3	new	new
W136R	2009/09/14	1.75	1.90	1.09	60.00	58.00	64.50	57.00	0.88	pmt3	new	new
W137R	2009/09/14	1.80	1.90	1.06	61.00	57.00	61.50	58.50	0.93	pmt3	new	new
W138R	2009/09/14	1.80	1.85	1.03	62.00	58.00	62.00	58.50	0.94	pmt3	new	new
W131L	2009/09/15	1.60	1.65	1.03	57.50	66.00	57.50	50.50	0.77	pmt3	new	new
W124L	2009/09/15	1.70	2.25	1.32	56.50	67.00	61.50	61.00	0.84	pmt3	new	new
W120L	2009/09/15	1.70	1.85	1.09	58.00	64.50	33.50	58.50	0.52	pmt3	new	new
W130L	2009/09/15	1.80	1.95	1.08	57.00	62.00	59.00	59.00	0.92	pmt3	new	new
W132R	2009/09/15	1.80	1.85	1.03	61.50	59.00	63.00	55.00	0.87	pmt3	new	new
W126L	2009/09/15	1.80	1.95	1.08	62.50	56.50	64.00	61.00	0.88	pmt3	new	new
W140R	2009/09/15	2.00	2.00	1.00	61.00	59.00	66.50	60.00	0.89	pmt3	new	new
W139R	2009/09/15	1.95	1.95	1.00	57.00	56.00	62.50	59.00	0.90	pmt3	new	new
W141L	2009/09/22	1.85	2.00	1.08	55.00	62.50	61.50	62.50	0.88	pmt3	new	new
W128R	2009/09/23	1.75	2.00	1.14	62.50	59.00	67.00	55.00	0.82	pmt3	new	new
W142L	2009/09/23	1.90	2.00	1.05	55.00	62.00	60.50	59.00	0.89	pmt3	new	new
W143L	2009/09/23	1.85	2.05	1.11	55.00	64.50	63.50	55.00	0.85	pmt3	new	new
W142R	2009/09/24	1.75	2.25	1.29	59.00	55.50	61.50	56.50	0.90	pmt3	new	new
W144R	2009/09/24	1.75	1.80	1.03	60.50	54.00	58.00	53.50	0.88	pmt3	new	new
W140L	2009/09/24	1.80	1.80	1.00	53.00	61.00	58.00	58.00	0.87	pmt3	new	new
W146R	2009/09/24	1.75	1.90	1.09	61.00	53.00	45.00	52.50	0.74	pmt3	new	new
W135L	2009/09/24	1.80	1.85	1.03	51.50	60.50	57.50	54.00	0.85	pmt3	new	new
W134L	2009/09/24	1.75	1.80	1.03	52.00	39.00	54.50	57.00	0.68	pmt3	new	new
W129R	2009/09/25	1.70	1.90	1.12	55.00	52.00	59.00	52.50	0.88	pmt3	new	new
W137L	2009/09/25	1.75	1.95	1.11	51.00	58.50	52.50	39.50	0.68	pmt3	new	new
W143R	2009/09/25	1.80	1.80	1.00	57.00	51.50	58.50	46.50	0.79	pmt3	new	new
W139L	2009/09/25	1.70	1.75	1.03	49.00	57.00	52.50	54.50	0.86	pmt3	new	new
W145R	2009/09/25	1.70	1.75	1.03	59.50	54.00	61.00	55.50	0.89	pmt3	new	new
W132L	2009/09/25	1.70	1.80	1.06	51.00	61.00	55.00	58.00	0.84	pmt3	new	new
W136L	2009/09/29	1.75	1.80	1.03	52.00	59.00	55.00	54.50	0.88	pmt3	new	new
W131R	2009/09/29	1.70	1.80	1.06	59.00	54.50	62.00	54.00	0.87	pmt3	new	new
W144L	2009/09/29	1.75	1.90	1.09	56.50	64.00	59.00	57.00	0.88	pmt3	new	new
W145L	2009/10/03	1.85	2.00	1.08	58.00	63.50	62.00	56.50	0.89	pmt3	new	new
W148R	2009/10/03	1.75	2.05	1.17	58.00	59.50	63.50	57.00	0.90	pmt3	new	new
W148L	2009/10/03	1.80	2.05	1.14	57.00	66.00	61.50	59.00	0.86	pmt3	new	new
W147R	2009/10/03	1.80	1.80	1.00	62.50	60.50	66.00	58.00	0.88	pmt3	new	new
W152R	2009/10/03	1.80	2.10	1.17	62.50	59.00	66.50	59.00	0.89	pmt3	new	new

Red means that the tower was rejected at William and Mary before being sent out
Orange means that the tower was rejected by Fermilab and sent back

Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	in/Max Rat	PMT	Ammeter	HV
W147L	2009/10/03	1.75	2.05	1.17	55.50	63.50	58.50	56.50	0.87	pmt3	new	new
W146L	2009/10/03	1.75	1.90	1.09	56.50	66.00	62.00	61.00	0.86	pmt3	new	new
W154L	2009/10/06	1.55	1.60	1.03	56.50	63.50	61.50	59.00	0.89	pmt3	new	new
W155R	2009/10/06	1.65	1.95	1.18	61.00	58.50	64.00	59.50	0.91	pmt3	new	new
W150R	2009/10/06	1.60	1.65	1.03	62.50	62.00	64.50	59.00	0.91	pmt3	new	new
W157R	2009/10/07	1.65	2.25	1.36	64.00	57.50	63.50	57.00	0.89	pmt3	new	new
W158R	2009/10/07	1.70	1.75	1.03	60.00	59.00	65.50	59.00	0.90	pmt3	new	new
W149R	2009/10/07	1.65	1.80	1.09	63.50	59.50	66.00	54.50	0.83	pmt3	new	new
W162R	2009/10/13	1.80	1.80	1.00	60.00	56.50	60.00	57.00	0.94	pmt3	new	new
W150L	2009/10/16	1.75	1.80	1.03	50.00	56.00	54.50	58.00	0.86	pmt3	new	new
W151R	2009/10/16	1.70	1.80	1.06	59.50	52.50	57.50	50.50	0.85	pmt3	new	new
W155L	2009/10/16	1.70	1.85	1.09	49.00	57.50	54.00	53.50	0.85	pmt3	new	new
W158L	2009/10/16	1.70	1.75	1.03	52.50	64.00	60.00	64.50	0.81	pmt3	new	new
W154R	2009/10/16	1.75	1.95	1.11	61.00	50.00	62.50	56.50	0.80	pmt3	new	new
W157L	2009/10/16	1.70	1.75	1.03	50.00	62.50	62.50	64.00	0.78	pmt3	new	new
W159R	2009/10/16	1.65	1.70	1.03	62.00	52.50	63.50	54.50	0.83	pmt3	new	new
W151L	2009/10/19	1.65	1.65	1.00	55.00	67.00	65.00	62.00	0.82	pmt3	new	new
W156L	2009/10/19	1.70	1.75	1.03	54.00	63.50	55.00	62.50	0.85	pmt3	new	new
W153R	2009/10/19	1.70	1.75	1.03	62.00	56.00	63.50	53.50	0.84	pmt3	new	new
W149L	2009/10/19	1.70	1.70	1.00	55.00	67.00	62.00	62.50	0.82	pmt3	new	new
W156R	2009/10/19	1.70	1.75	1.03	61.50	53.50	61.50	54.50	0.87	pmt3	new	new
W161R	2009/10/19	1.75	1.75	1.00	62.00	55.50	65.50	56.00	0.85	pmt3	new	new
W152R	2009/10/19	1.65	1.70	1.03	54.00	67.50	62.00	62.50	0.80	pmt3	new	new
W153L	2009/10/19	1.70	1.75	1.03	56.50	68.50	62.00	60.50	0.82	pmt3	new	new
W170L	2009/10/27	1.70	1.75	1.03	49.50	59.50	57.00	61.50	0.80	pmt3	new	new
W160L	2009/10/27	1.65	1.65	1.00	30.00	49.50	55.50	62.00	0.48	pmt3	new	new
W175R	2009/10/27	1.70	1.75	1.03	61.50	54.00	60.50	54.50	0.88	pmt3	new	new
W159L	2009/10/27	1.70	1.75	1.03	51.00	62.00	58.50	60.50	0.82	pmt3	new	new
W165R	2009/10/27	1.70	1.70	1.00	59.00	52.50	59.00	53.00	0.89	pmt3	new	new
W167R	2009/10/30	1.80	1.85	1.03	58.50	49.00	57.50	52.50	0.84	pmt3	new	new
W164L	2009/10/30	1.75	1.80	1.03	49.00	57.50	53.50	59.00	0.83	pmt3	new	new
W165L	2009/10/30	1.75	1.80	1.03	47.50	58.50	55.50	54.00	0.81	pmt3	new	new
W163L	2009/10/30	1.70	1.75	1.03	49.50	59.50	53.50	59.00	0.83	pmt3	new	new
W169R	2009/10/30	1.75	1.75	1.00	58.50	51.00	58.00	50.00	0.85	pmt3	new	new
W170R	2009/10/30	1.75	1.80	1.03	58.50	50.00	61.00	54.00	0.82	pmt3	new	new
W167L	2009/10/30	1.75	1.75	1.00	50.00	59.50	54.50	60.50	0.83	pmt3	new	new
W171R	2009/10/30	1.65	1.70	1.03	60.00	52.50	58.50	48.50	0.81	pmt3	new	new
W166L	2009/11/06	1.60	1.65	1.03	47.00	59.50	56.50	56.00	0.79	pmt3	new	new
W160R	2009/11/06	1.60	1.80	1.13	60.50	50.00	60.00	47.50	0.79	pmt3	new	new
W168R	2009/11/06	1.60	1.60	1.00	56.50	48.50	58.50	48.00	0.82	pmt3	new	new
W177R	2009/11/06	1.70	1.70	1.00	62.00	54.50	60.00	54.00	0.87	pmt3	new	new
W161L	2009/11/06	1.65	1.70	1.03	51.50	63.00	63.50	61.50	0.81	pmt3	new	new
W162L	2009/11/06	1.65	1.70	1.03	51.50	62.00	60.50	47.00	0.76	pmt3	new	new
W166R	2009/11/06	1.70	1.75	1.03	58.00	53.00	62.00	53.00	0.85	pmt3	new	new
W163R	2009/11/06	1.65	1.70	1.03	61.00	53.50	63.00	44.00	0.70	pmt3	new	new
W174R	2009/11/06	1.70	1.70	1.00	64.50	55.50	65.00	56.00	0.85	pmt3	new	new
W173R	2009/11/06	1.70	1.75	1.03	65.00	56.50	66.00	55.00	0.83	pmt3	new	new
W176L	2009/11/10	1.60	1.65	1.03	51.00	56.50	56.00	53.00	0.90	pmt3	new	new
W175L	2009/11/10	1.55	1.55	1.00	49.00	57.50	48.50	55.50	0.84	pmt3	new	new
W174L	2009/11/10	1.55	1.60	1.03	49.50	52.00	51.00	54.50	0.91	pmt3	new	new
W173L	2009/11/10	1.50	1.55	1.03	48.00	60.00	54.50	53.00	0.80	pmt3	new	new
W180L	2009/11/10	1.55	1.55	1.00	50.00	58.50	52.00	54.00	0.85	pmt3	new	new
W179L	2009/11/10	1.50	1.55	1.03	48.00	56.50	55.00	52.00	0.85	pmt3	new	new
W171L	2009/11/10	1.50	1.55	1.03	42.00	53.00	54.00	50.50	0.78	pmt3	new	new
W181L	2009/11/10	1.50	1.50	1.00	51.00	56.00	55.00	52.50	0.91	pmt3	new	new
W169L	2009/11/10	1.50	1.55	1.03	44.00	56.00	57.00	55.50	0.77	pmt3	new	new
W177L	2009/11/10	1.50	1.50	1.00	46.50	58.50	54.50	55.00	0.79	pmt3	new	new
W168L	2009/11/10	1.50	1.55	1.03	48.00	56.00	53.50	33.50	0.60	pmt3	new	new
W172R	2009/11/10	1.55	1.55	1.00	54.00	49.50	54.50	43.50	0.80	pmt3	new	new
W183R	2009/11/10	1.55	1.60	1.03	52.50	51.00	58.00	49.50	0.85	pmt3	new	new
W146R	2009/11/10	1.55	1.55	1.00	53.00	52.00	57.00	50.00	0.88	pmt3	new	new
W184R	2009/11/10	1.55	1.55	1.00	54.50	50.00	51.00	43.00	0.79	pmt3	new	new
W176R	2009/11/10	1.55	1.55	1.00	53.00	49.00	55.00	47.50	0.86	pmt3	new	new
W180R	2009/11/10	1.55	1.55	1.00	54.50	49.00	55.50	49.50	0.88	pmt3	new	new
W181R	2009/11/10	1.55	1.60	1.03	52.00	48.00	57.50	50.00	0.83	pmt3	new	new

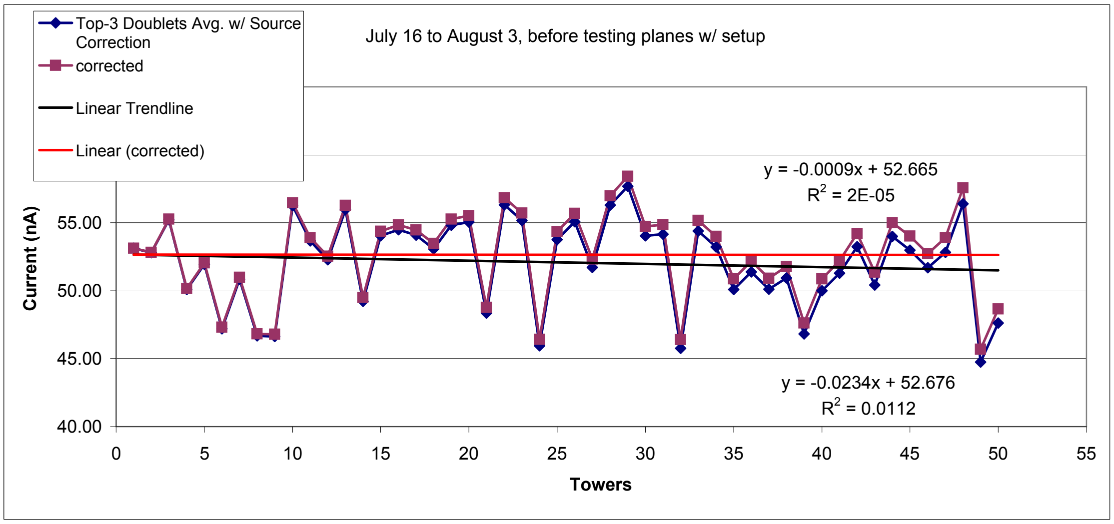
Red means that the tower was rejected at William and Mary before being sent out
Orange means that the tower was rejected by Fermilab and sent back

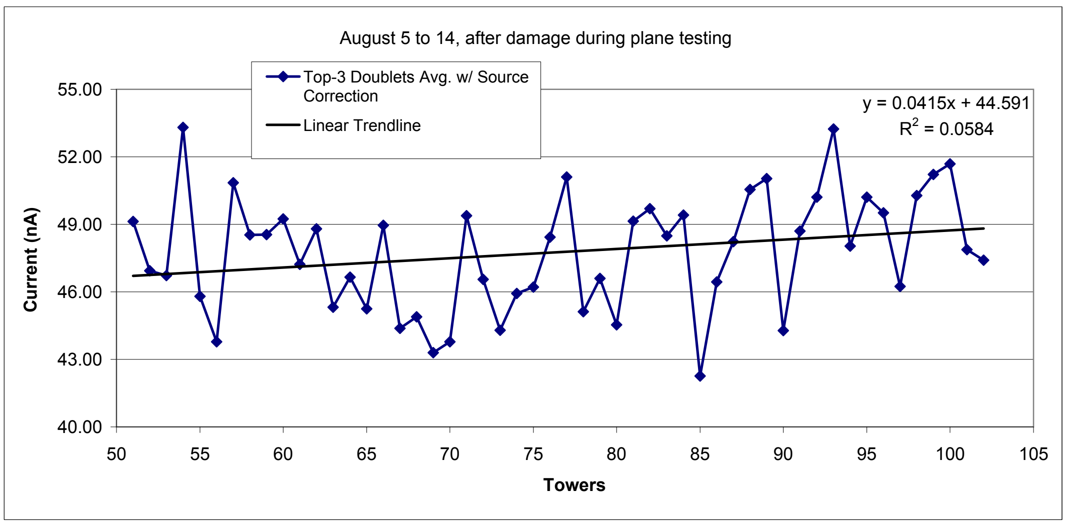
Tower	Test Date	Lights off	Lights on	Ratio	Doublet #1	Doublet #2	Doublet #3	Doublet #4	Min/Max Rat	PMT	Ammeter	HV
W179R	2009/11/10	1.55	1.55	1.00	51.00	50.50	55.00	43.00	0.78	pmt3	new	new
W178R	2009/11/10	1.55	1.55	1.00	54.00	49.00	55.00	48.50	0.88	pmt3	new	new
W158R	2009/11/10	1.55	1.55	1.00	54.50	51.00	55.50	48.50	0.87	pmt3	new	new
W187L	2009/11/20	1.55	1.55	1.00	46.50	51.00	50.00	52.00	0.89	pmt3	new	new
W186L	2009/11/20	1.55	1.55	1.00	50.50	59.00	53.00	53.00	0.86	pmt3	new	new
W185L	2009/11/20	1.55	1.55	1.00	48.00	63.00	51.50	55.00	0.76	pmt3	new	new
W183L	2009/11/20	1.55	1.60	1.03	47.50	58.00	55.00	52.00	0.82	pmt3	new	new
W185R	2009/11/20	1.60	1.65	1.03	54.50	50.00	60.50	48.00	0.79	pmt3	new	new
W184L	2009/12/02	1.60	1.65	1.03	44.50	52.50	49.50	35.00	0.67	pmt3	new	new
W182L	2009/12/02	1.55	1.60	1.03	44.00	55.50	48.50	51.50	0.79	pmt3	new	new
W186R	2009/12/02	1.65	1.65	1.00	51.50	45.50	49.50	44.00	0.85	pmt3	new	new
W192L	2/26/10	1.50	1.50	1.00	43.40	48.00	52.50	43.00	0.82	NEW	new	new
W191L	2/26/10	1.50	1.50	1.00	45.00	49.50	50.50	39.50	0.78	NEW	new	new
W188L	2/26/10	1.50	1.60	1.07	48.50	48.00	49.50	49.00	0.97	NEW	new	new
W190L	2/26/10	1.50	1.50	1.00	46.50	49.50	52.50	45.50	0.87	NEW	new	new
W189L	2/26/10	1.50	1.60	1.07	47.50	46.50	55.00	43.50	0.79	NEW	new	new
W189R	2/26/10	1.50	1.60	1.07	49.00	57.50	51.50	50.00	0.85	NEW	new	new
W190R	2/26/10	1.50	1.50	1.00	42.50	52.00	48.00	39.00	0.75	NEW	new	new
W187R	2/26/10	1.50	1.50	1.00	44.50	54.00	52.00	49.00	0.82	NEW	new	new
W188R	2/26/10	1.50	1.50	1.00	42.50	49.50	51.00	42.50	0.83	NEW	new	new
W196L	2/23/10	1.50	1.60	1.07	49.00	54.50	49.50	50.00	0.90	NEW	new	new
W197L	2/22/10	1.50	1.60	1.07	45.50	52.00	52.00	48.00	0.88	NEW	new	new
W198L	2/23/10	1.50	1.50	1.00	45.50	48.50	49.00	45.50	0.93	NEW	new	new
W194L	2/22/10	1.50	1.60	1.07	43.00	52.50	54.50	50.00	0.79	NEW	new	new
W193L	2/23/10	1.50	1.50	1.00	45.00	48.50	51.00	45.50	0.88	NEW	new	new
W195L	2/23/10	1.50	1.50	1.00	43.00	48.00	47.00	43.50	0.90	NEW	new	new
W207L	3/2/10	1.40	1.40	1.00	45.50	51.00	46.50	43.50	0.85	NEW	new	new
W206L	2/26/10	1.50	1.80	1.20	47.50	50.50	51.50	45.50	0.88	NEW	new	new
W205L	2/26/10	1.50	1.70	1.13	47.50	53.50	55.00	47.00	0.85	NEW	new	new
W203L	2/26/10	1.50	1.60	1.07	48.00	49.50	55.00	47.00	0.85	NEW	new	new
W202L	2/26/10	1.50	1.50	1.00	48.50	51.50	56.00	47.50	0.85	NEW	new	new
W199L	2/26/10	1.40	1.50	1.07	49.00	45.50	51.50	45.50	0.88	NEW	new	new
W201L	2/26/10	1.50	1.80	1.20	52.00	51.00	54.00	47.50	0.88	NEW	new	new
W204L	2/26/10	1.50	1.70	1.13	45.50	52.00	52.50	45.00	0.86	NEW	new	new
W200L	2/26/10	1.50	1.70	1.13	46.00	52.00	50.00	44.00	0.85	NEW	new	new

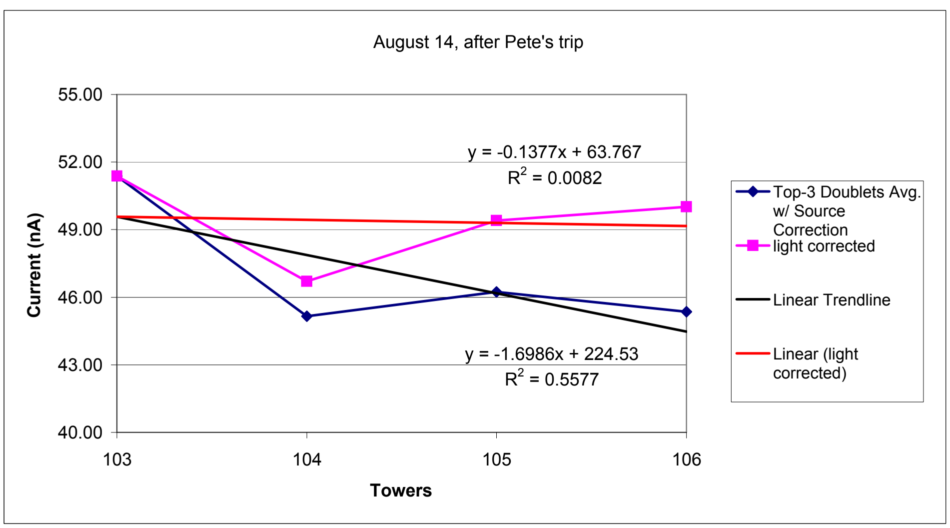
mean	1.83	2.04	1.12	52.67	55.38	56.17	50.94	0.82
stdev	0.34	0.43	0.13	14.75	15.07	15.51	14.25	0.09
Q1	1.65	1.75	1.03	49.50	52.00	54.00	47.50	0.79
median	1.75	1.95	1.08	55.00	58.00	58.50	54.00	0.84
Q3	1.90	2.25	1.18	60.00	62.60	63.50	58.50	0.88

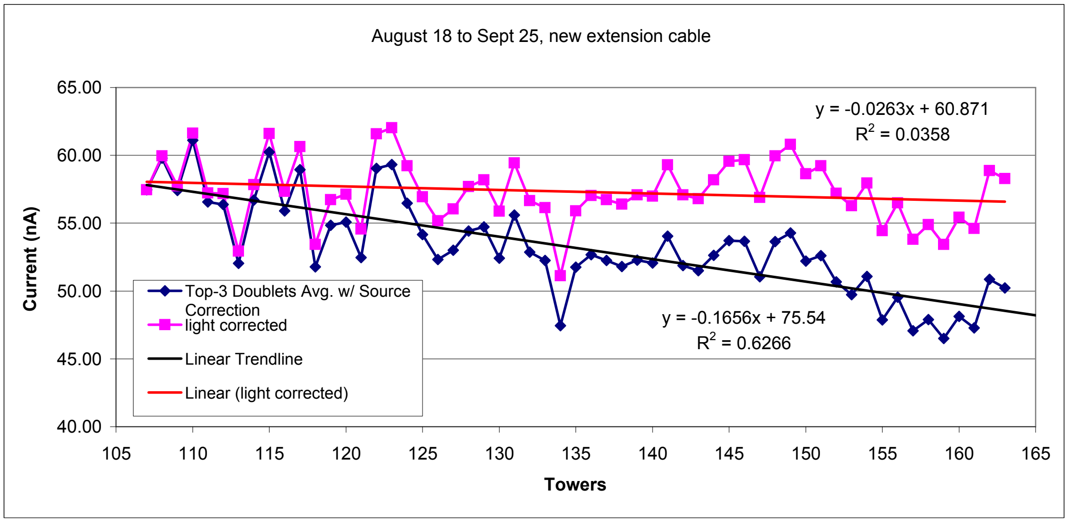
FAILURE STATS		towers	doublets	tower%	doublet%
	total	294	1176		
rejected by us in house		14	14	4.8%	1.2%
rejected by fermilab		30.0	30.0	10.2%	2.6%
total rejected		44.0	44.0	15.0%	3.7%

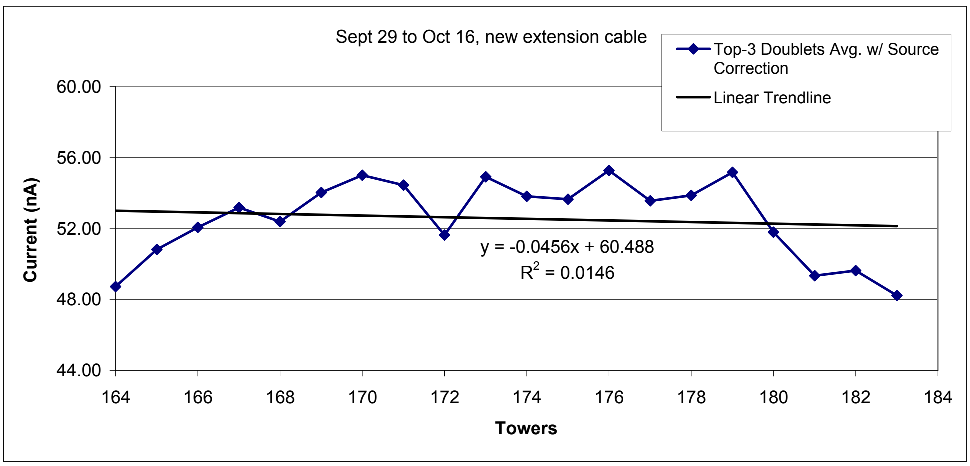
Appendix B - Broken down and corrected MINERvA data

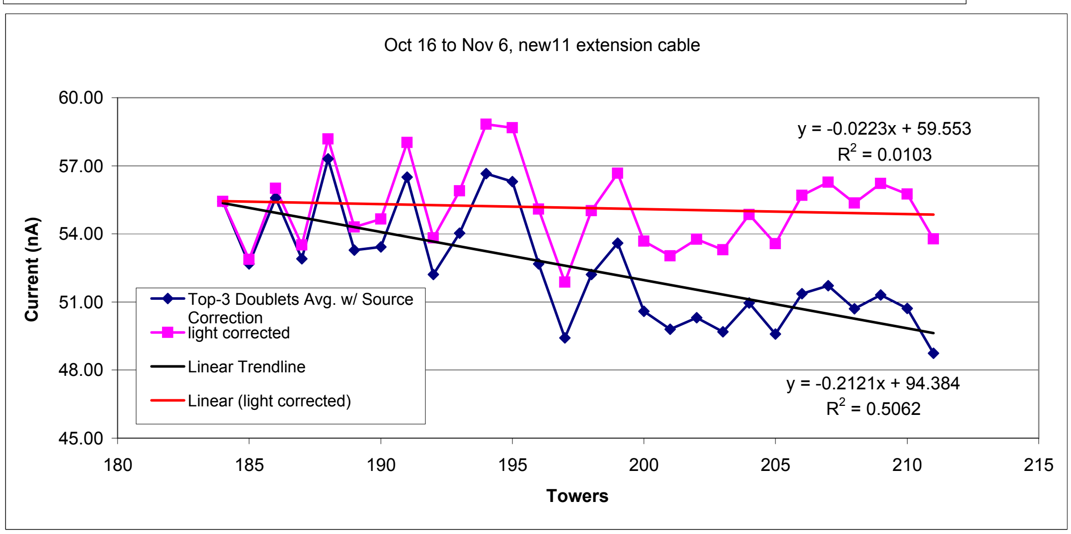


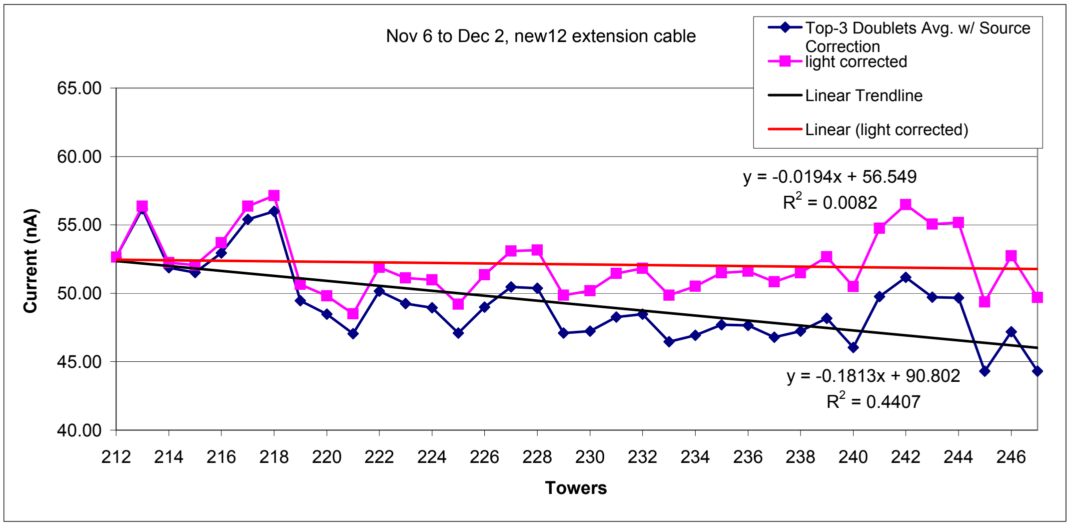


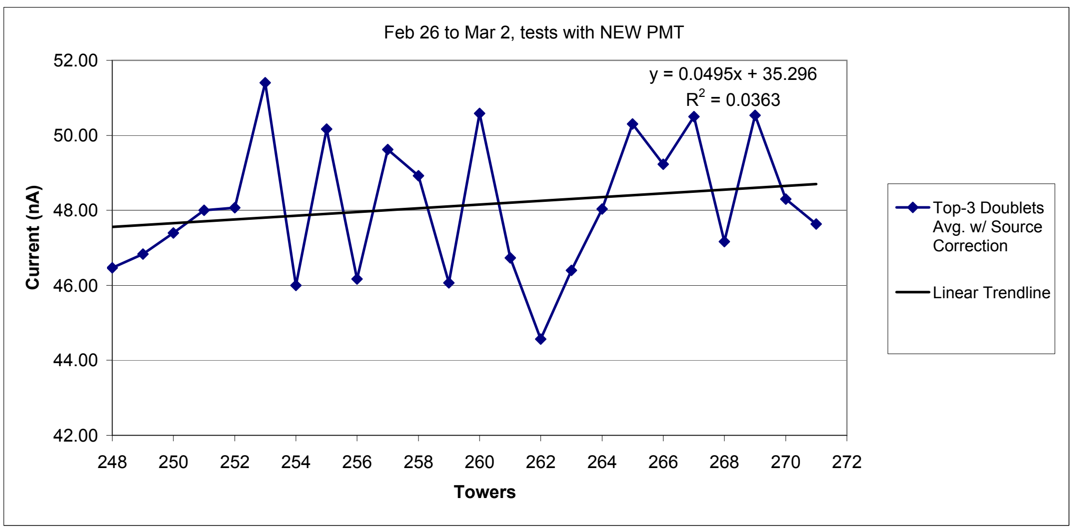


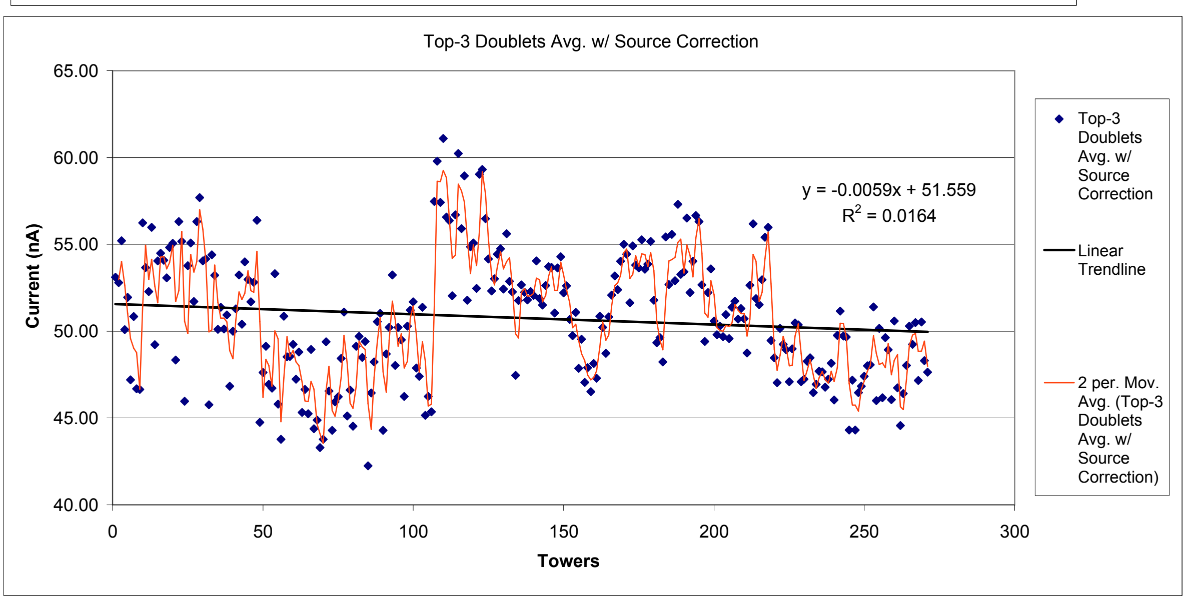

August 18 to Sept 25, new extension cable
y = -0.0263x + 60.871
R2 = 0.0358
y = -0.1656x + 75.54
R2 = 0.6266
Top-3 Doublets Avg. w/ Source Correction
light corrected
Linear Trendline
Linear (light corrected)
Current (nA)
Towers


Sept 29 to Oct 16, new extension cable
Top-3 Doublets Avg. w/ Source Correction
Linear Trendline
y = -0.0456x + 60.488
R2 = 0.0146
Current (nA)
Towers


Oct 16 to Nov 6, new11 extension cable
y = -0.0223x + 59.553
R2 = 0.0103
y = -0.2121x + 94.384
R2 = 0.5062
Top-3 Doublets Avg. w/ Source Correction
light corrected
Linear Trendline
Linear (light corrected)
Current (nA)
Towers

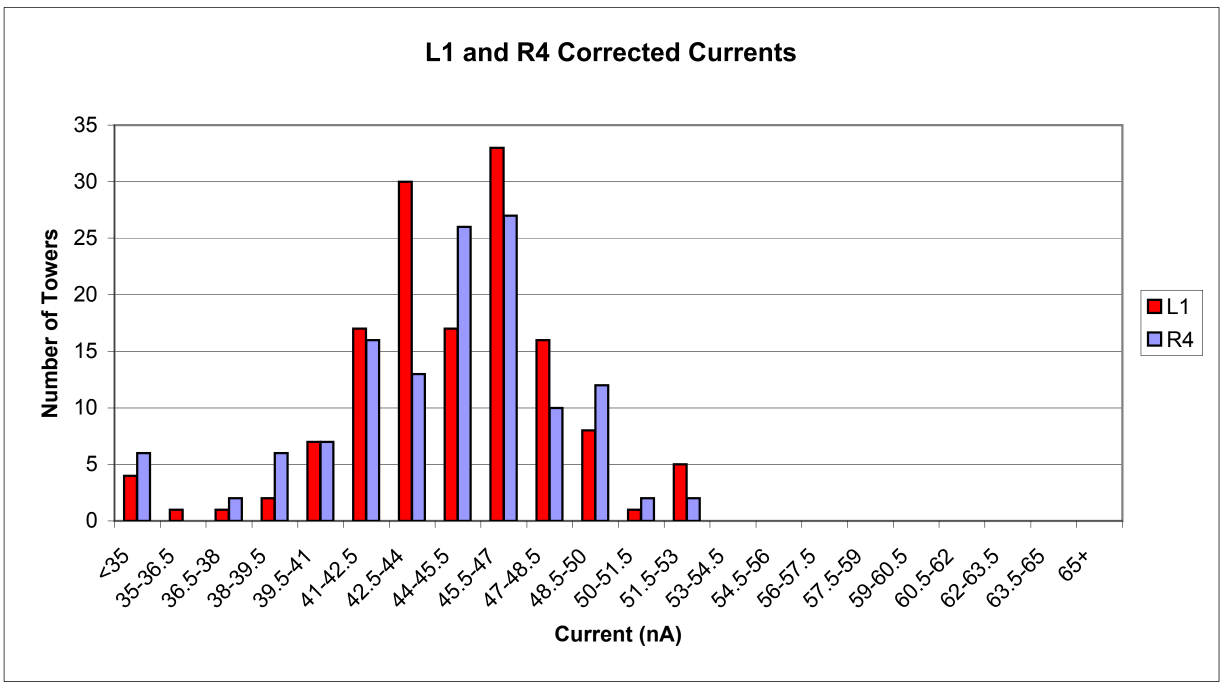

Nov 6 to Dec 2, new12 extension cable
Top-3 Doublets Avg. w/ Source Correction
light corrected
Linear Trendline
Linear (light corrected)
y = -0.0194x + 56.549
R^2 = 0.0082
y = -0.1813x + 90.802
R^2 = 0.4407
Current (nA)
Towers
65.00
60.00
55.00
50.00
45.00
40.00
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
242
244
246

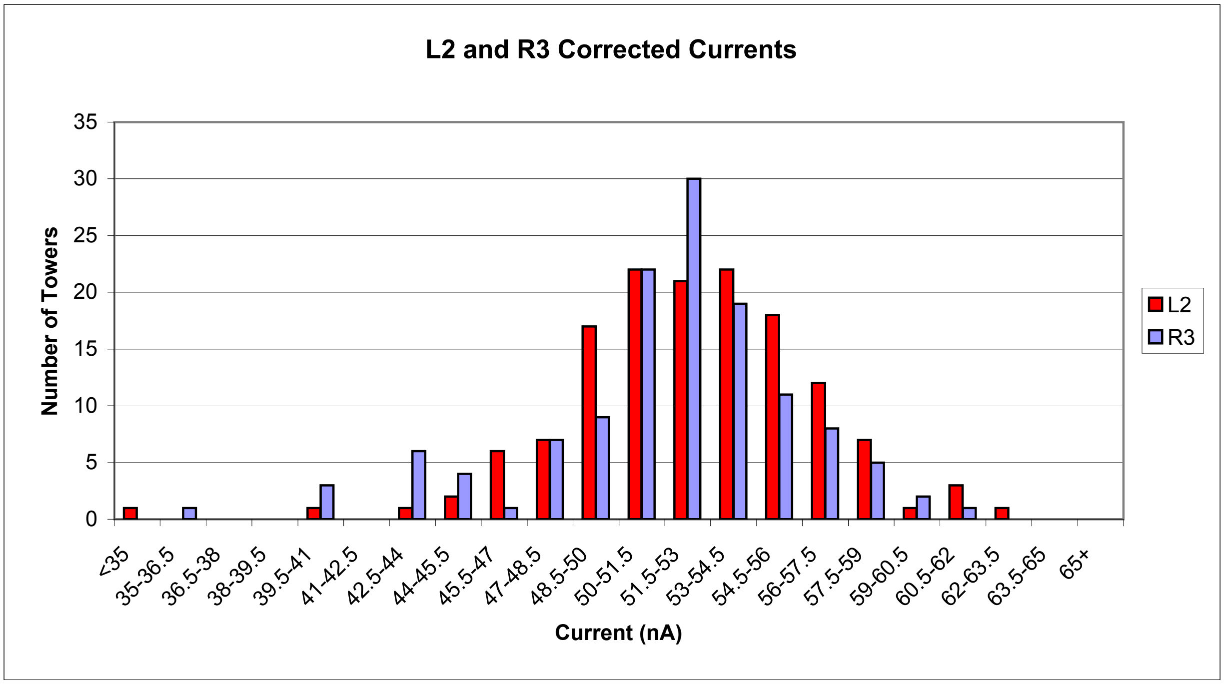

Feb 26 to Mar 2, tests with NEW PMT
y = 0.0495x + 35.296
R^2 = 0.0363
Top-3 Doublets Avg. w/ Source Correction
Linear Trendline
Current (nA)
Towers
52.00
50.00
48.00
46.00
44.00
42.00
248
250
252
254
256
258
260
262
264
266
268
270
272


Top-3 Doublets Avg. w/ Source Correction
y = -0.0059x + 51.559
R^2 = 0.0164
Top-3 Doublets Avg. w/ Source Correction
Linear Trendline
2 per. Mov. Avg. (Top-3 Doublets Avg. w/ Source Correction)
Current (nA)
Towers
65.00
60.00
55.00
50.00
45.00
40.00
0
50
100
150
200
250
300

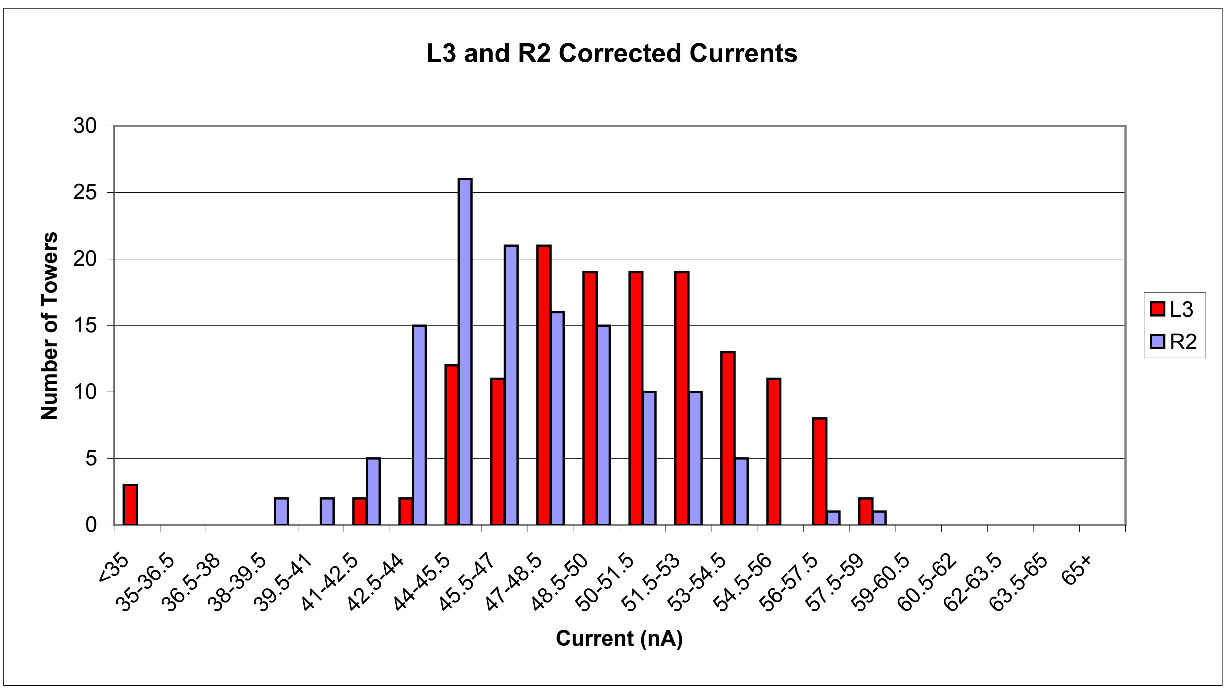
Appendix C - histograms broken down by doublet

current (nA)	Number of Doublets L1	L2	L3	L4	R1	R2	R3	R4
<35	4	1	3	6	0	0	0	6
35-36.5	1	0	0	0	0	0	1	0
36.5-38	1	0	0	1	2	0	0	2
38-39.5	2	0	0	0	0	2	0	6
39.5-41	7	1	0	6	0	2	3	7
41-42.5	17	0	2	5	1	5	0	16
42.5-44	30	1	2	7	4	15	6	13
44-45.5	17	2	12	8	6	26	4	26
45.5-47	33	6	11	25	3	21	1	27
47-48.5	16	7	21	24	17	16	7	10
48.5-50	8	17	19	20	15	15	9	12
50-51.5	1	22	19	24	37	10	22	2
51.5-53	5	21	19	11	22	10	30	2
53-54.5	0	22	13	3	12	5	19	0
54.5-56	0	18	11	1	3	0	11	0
56-57.5	0	12	8	0	6	1	8	0
57.5-59	0	7	2	0	1	1	5	0
59-60.5	0	1	0	1	0	0	2	0
60.5-62	0	3	0	0	0	0	1	0
62-63.5	0	1	0	0	0	0	0	0
63.5-65	0	0	0	0	0	0	0	0
65+	0	0	0	0	0	0	0	0

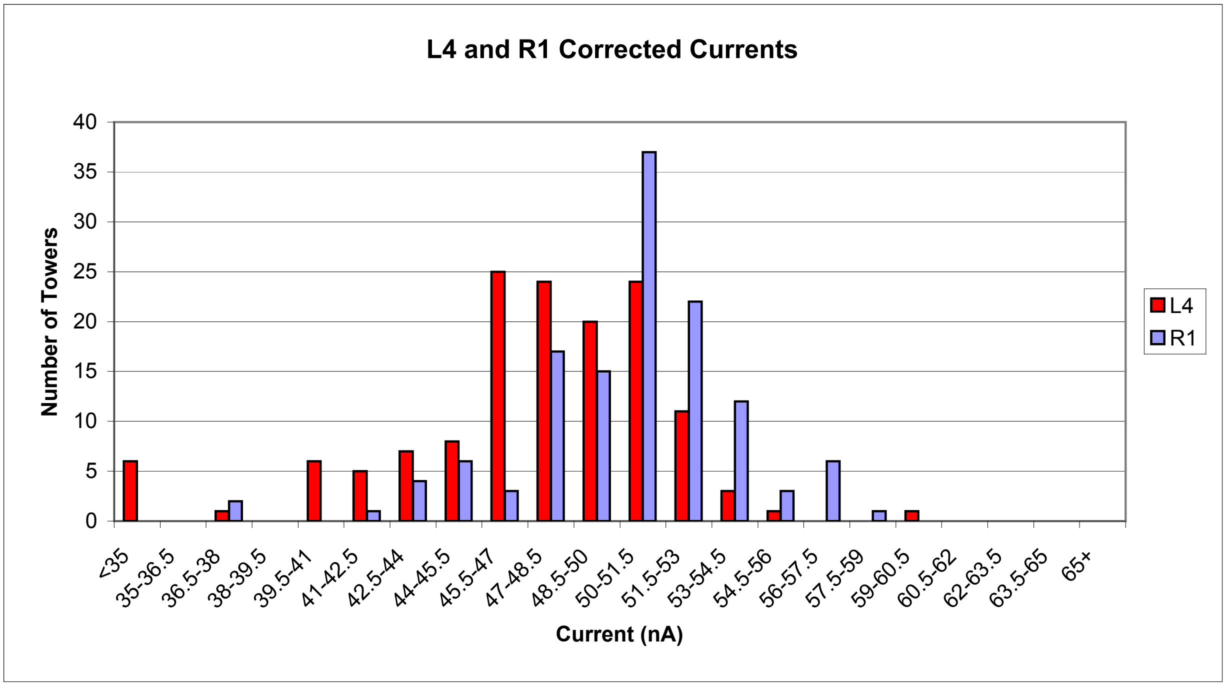




L2 and R3 Corrected Currents
Number of Towers
0
5
10
15
20
25
30
35
<35
35-36.5
36.5-38
38-39.5
39.5-41
41-42.5
42.5-44
44-45.5
45.5-47
47-48.5
48.5-50
50-51.5
51.5-53
53-54.5
54.5-56
56-57.5
57.5-59
59-60.5
60.5-62
62-63.5
63.5-65
65+
Current (nA)
L2
R3



L3 and R2 Corrected Currents
Number of Towers
0
5
10
15
20
25
30
<35
35-36.5
36.5-38
38-39.5
39.5-41
41-42.5
42.5-44
44-45.5
45.5-47
47-48.5
48.5-50
50-51.5
51.5-53
53-54.5
54.5-56
56-57.5
57.5-59
59-60.5
60.5-62
62-63.5
63.5-65
65+
Current (nA)
L3
R2


L4 and R1 Corrected Currents
Number of Towers
40
35
30
25
20
15
10
5
0
<35
35-36.5
36.5-38
38-39.5
39.5-41
41-42.5
42.5-44
44-45.5
45.5-47
47-48.5
48.5-50
50-51.5
51.5-53
53-54.5
54.5-56
56-57.5
57.5-59
59-60.5
60.5-62
62-63.5
63.5-65
65+
Current (nA)
L4
R1

Appendix D - All doublets with corrected values

KEY:
- orange - rejected by Fermilab
- red - rejected by me
- blue - value under 35nA
- yellow - value under 42.5nA

All doublet values after all corrections

Tower	Test Date	L1	L2	L3	L4	R1	R2	R3	R4
W071L	2009/07/16	45.00	53.91	50.51	47.12				
W064L	2009/07/16	42.73	52.15	52.15	46.38				
W098L	2009/07/16	42.58	51.92	56.08	49.97				
W099R	2009/07/16					45.15	47.78	49.73	40.73
W065R	2009/07/16					51.63	43.72	51.88	44.83
W065L	2009/07/16	34.30	51.06	48.17	34.90				
W066L	2009/07/16	42.15	51.85	51.17	39.68				
W063R	2009/07/16					42.81	44.51	45.36	36.85
W069L	2009/07/21	41.67	43.12	26.46	47.82				
W070L	2009/07/21	43.70	57.89	56.35	47.37				
W072L	2009/07/21	40.04	54.15	52.01	47.74				
W069R	2009/07/21					48.49	49.26	52.08	44.72
W064R	2009/07/22					51.24	51.76	58.01	46.96
W070R	2009/07/22					37.77	41.71	53.71	45.31
W075L	2009/07/22	43.58	48.98	54.72	51.64				
W074L	2009/07/22	44.24	50.24	56.25	50.24				
W073L	2009/07/22	42.11	49.07	54.39	52.16				
W071R	2009/07/23					52.22	50.07	50.33	46.20
W074R	2009/07/23					47.99	53.92	56.07	47.04
W077R	2009/07/24					54.50	51.06	53.21	45.90
W058L	2009/07/24	41.01	47.12	44.80	46.61				
W074L	2009/07/24	43.18	54.81	57.22	50.68				
W078L	2009/07/24	47.25	55.96	56.13	46.48				
W073R	2009/07/24					44.26	44.08	43.14	42.10
W078R	2009/07/24					54.33	47.43	53.46	32.94
W075R	2009/07/24					50.90	51.59	56.77	41.67
W077L	2009/07/27	40.92	44.81	55.63	48.70				
W079R	2009/07/28					56.43	52.19	54.52	42.40
W079L	2009/07/28	33.28	54.77	57.97	54.68				
W080L	2009/07/28	45.78	58.78	48.38	49.24				
W081R	2009/07/28					52.65	50.05	54.12	45.54
W083R	2009/07/28					47.38	39.83	44.17	38.96
W082L	2009/07/28	43.89	53.26	53.96	50.48				
W081L	2009/07/28	42.82	50.03	53.42	50.72				
W080R	2009/07/28					54.31	44.75	44.58	45.71
W072R	2009/07/28					52.86	45.56	50.34	42.95
W084R	2009/07/29					57.32	44.26	43.39	40.35
W082L	2009/07/29	42.76	50.42	46.07	51.03				
W100R	2009/07/29					50.18	41.47	43.39	39.56
W076L	2009/07/29	51.69	44.80	48.29	41.32				
W068R	2009/07/29					51.23	49.84	47.74	26.47
W076R	2009/07/29					42.36	51.60	51.60	51.60
W074R	2009/07/29					52.50	45.61	48.14	45.52
W082R	2009/07/31					58.16	43.56	54.05	45.04
W086R	2009/07/31					50.49	48.47	55.30	46.81

KEY:
- orange - rejected by Fermilab
- red - rejected by me
- blue - value under 35nA
- yellow - value under 42.5nA

All doublet values after all corrections

Tower	Test Date	L1	L2	L3	L4	R1	R2	R3	R4
W085R	2009/07/31					48.10	43.64	52.65	49.59
W083L	2009/07/31	43.79	55.17	49.66	49.04				
W087L	2009/07/31	40.92	56.86	57.74	50.29				
W088R	2009/08/03					43.98	44.86	40.47	33.44
W096R	2009/08/03					52.65	41.67	43.87	41.67
W087R	2009/08/05					47.25	46.82	59.74	49.40
W084L	2009/08/05	45.06	56.68	48.07	41.18				
W086L	2009/08/05	45.70	54.74	16.86	48.72				
W088L	2009/08/05	46.69	61.76	57.02	50.14				
W090R	2009/08/05					44.50	50.95	50.95	30.29
W096L	2009/08/05	48.93	48.50	42.90	42.04				
W093L	2009/08/05	45.96	60.17	55.00	46.39				
W089R	2009/08/05					45.36	47.08	57.41	50.09
W094L	2009/08/06	51.98	53.70	48.96	47.24				
W090L	2009/08/06	46.21	58.27	52.24	33.28				
W055R	2009/08/06					50.52	47.07	53.10	46.21
W098L	2009/08/06	44.05	53.53	51.38	50.52				
W097R	2009/08/06					49.18	45.30	50.47	42.29
W092L	2009/08/06	50.95	50.08	47.93	42.76				
W092R	2009/08/06					46.38	44.66	52.41	45.95
W095L	2009/08/06	49.65	52.67	53.53	32.85				
W056L	2009/08/06	44.66	49.40	48.10	43.80				
W091L	2009/08/06	47.89	53.49	42.29	41.00				
W095R	2009/08/06					48.02	43.71	47.16	41.12
W049R	2009/08/06					47.50	44.05	48.79	40.61
W103L	2009/08/07	48.22	58.14	50.81	46.93				
W102L	2009/08/07	46.11	57.32	45.25	43.52				
W097L	2009/08/07	48.01	48.87	44.99	44.99				
W057L	2009/08/07	25.93	49.64	49.21	47.92				
W101L	2009/08/07	46.20	54.82	46.63	44.47				
W104L	2009/08/07	47.83	57.32	45.25	49.13				
W107L	2009/08/07	48.78	58.70	53.96	49.64				
W098R	2009/08/07					49.99	45.25	49.13	42.66
W082R	2009/08/07					50.46	49.60	48.74	42.70
W104R	2009/08/07					48.39	43.65	50.55	38.05
W106L	2009/08/10	47.67	56.31	52.43	45.95				
W111R	2009/08/10					52.12	52.12	53.85	44.35
W106R	2009/08/10					50.48	50.91	53.07	46.16
W107R	2009/08/10					52.12	50.40	54.72	41.75
W105R	2009/08/10					51.30	44.39	40.07	24.52
W115L	2009/08/13	46.13	51.32	44.83	50.89				
W111L	2009/08/13	46.91	54.70	51.24	47.77				
W122R	2009/08/13					50.37	49.07	61.19	46.04
W114L	2009/08/13	49.42	57.64	55.05	41.62				
W110L	2009/08/13	41.80	48.72	50.89	42.23				
W117R	2009/08/13					51.41	52.27	51.41	45.35

KEY:
orange - rejected by Fermilab
red - rejected by me
blue - value under 35nA
yellow - value under 42.5nA
All doublet values after all corrections

Tower	Test Date	L1	L2	L3	L4	R1	R2	R3	R4
W117L	2009/08/13	42.53	56.82	52.49	50.33				
W113L	2009/08/13	51.63	63.32	53.79	46.43				
W116L	2009/08/13	43.53	55.65	53.92	42.66				
W121R	2009/08/13					47.30	53.79	58.55	40.37
W108L	2009/08/13	44.57	53.23	54.96	49.33				
W109L	2009/08/13	43.61	54.87	47.08	45.78				
W110R	2009/08/13					53.57	52.27	54.01	44.48
W109R	2009/08/14					54.22	52.92	55.52	39.92
W119R	2009/08/14					52.96	54.26	56.86	49.06
W120R	2009/08/14					46.98	53.05	52.61	44.81
W105L	2009/08/14	48.24	50.84	52.14	47.37				
W113R	2009/08/14					50.82	51.25	53.85	43.89
W112R	2009/08/14					48.64	42.82	50.44	41.02
W085L	2009/08/14	36.11	52.78	43.06	54.17				
W093R	2009/08/14					56.51	43.61	51.73	43.61
W112L	2009/08/18	44.81	48.72	54.37	47.41				
W118L	2009/08/18	46.13	57.46	54.41	40.03				
W115R	2009/08/18					52.49	49.43	49.43	45.06
W114R	2009/08/18					57.39	50.38	55.20	41.62
W116R	2009/08/18					52.26	48.74	48.74	47.86
W052R	2009/08/21					51.50	45.76	52.38	45.76
W054R	2009/08/21					46.66	45.33	44.00	44.89
W103R	2009/08/21					55.43	46.10	50.10	45.66
W108R	2009/08/21					55.65	51.20	56.10	18.67
W124R	2009/08/21					53.32	48.41	48.41	47.07
W091R	2009/08/21					51.39	43.32	59.45	49.15
W126R	2009/08/25					51.68	39.96	43.12	43.57
W127R	2009/08/25					50.94	45.07	52.29	43.26
W125R	2009/08/25					51.19	39.41	56.17	42.13
W124R	2009/08/25					52.72	45.45	43.63	42.27
W119L	2009/08/26	43.94	46.22	57.16	59.44				
W121L	2009/08/26	42.39	61.59	52.45	50.16				
W123L	2009/08/26	46.43	56.51	52.84	37.26				
W122L	2009/08/26	47.35	53.79	47.81	47.35				
W138L	2009/09/11	45.53	51.13	46.93	45.53				
W133L	2009/09/11	46.10	53.11	45.63	47.03				
W129L	2009/09/11	47.28	56.18	47.74	46.34				
W127L	2009/09/11	42.11	57.15	47.28	48.22				
W128L	2009/09/11	46.06	53.60	46.06	45.59				
W125L	2009/09/11	42.05	54.34	55.28	46.77				
W130R	2009/09/11					47.77	46.82	53.46	43.98
W141R	2009/09/11					47.58	47.11	51.86	44.26
W133R	2009/09/11					36.68	46.21	40.49	44.78
W134R	2009/09/14					50.20	45.41	50.20	45.41
W135R	2009/09/14					50.55	47.67	51.03	45.75
W136R	2009/09/14					48.63	46.70	52.96	45.74

KEY: orange - rejected by Fermilab
red - rejected by me
blue - value under 35nA
yellow - value under 42.5nA
All doublet values after all corrections

Tower	Test Date	L1	L2	L3	L4	R1	R2	R3	R4
W137R	2009/09/14					49.74	45.88	50.22	47.33
W138R	2009/09/14					50.91	47.04	50.91	47.52
W131L	2009/09/15	46.93	55.18	46.93	40.13				
W124L	2009/09/15	45.51	55.73	50.38	49.89				
W120L	2009/09/15	47.50	53.85	23.59	47.99				
W130L	2009/09/15	46.57	51.46	48.53	48.53				
W132R	2009/09/15					51.22	48.77	52.70	44.85
W126L	2009/09/15	52.26	46.36	53.74	50.79				
W140R	2009/09/15					50.89	48.91	56.31	49.90
W139R	2009/09/15					47.13	46.14	52.57	49.11
W141L	2009/09/22	45.51	52.98	51.98	52.98				
W128R	2009/09/23					53.18	49.68	57.68	45.68
W142L	2009/09/23	45.82	52.83	51.33	49.83				
W143L	2009/09/23	45.90	55.45	54.44	45.90				
W142R	2009/09/24					49.91	46.38	52.43	47.39
W144R	2009/09/24					52.02	45.45	49.50	44.95
W140L	2009/09/24	44.57	52.68	49.64	49.64				
W146R	2009/09/24					52.73	44.60	36.48	44.10
W135L	2009/09/24	43.26	52.42	49.37	45.80				
W134L	2009/09/24	43.95	30.68	46.50	49.05				
W129R	2009/09/25					47.08	44.01	51.18	44.52
W137L	2009/09/25	43.06	50.76	44.60	31.25				
W143R	2009/09/25					49.52	43.85	51.06	38.71
W139L	2009/09/25	41.45	49.71	45.06	47.13				
W145R	2009/09/25					52.44	46.75	53.99	48.30
W132L	2009/09/25	43.72	54.09	47.87	50.98				
W136L	2009/09/29	42.39	48.66	45.08	44.63				
W131R	2009/09/29					48.66	44.63	51.35	44.18
W144L	2009/09/29	46.33	53.06	48.57	46.78				
W145L	2009/10/03	47.74	52.68	51.33	46.39				
W148R	2009/10/03					47.69	49.04	52.63	46.79
W148L	2009/10/03	46.79	54.88	50.84	48.59				
W147R	2009/10/03					51.96	50.16	55.11	47.92
W152R	2009/10/03					51.69	48.54	55.29	48.54
W147L	2009/10/03	45.44	52.63	48.14	46.34				
W146L	2009/10/03	46.48	55.02	51.42	50.52				
W154L	2009/10/06	46.86	53.16	51.36	49.11				
W155R	2009/10/06					50.59	48.34	53.30	49.24
W150R	2009/10/06					52.22	51.76	54.02	49.06
W157R	2009/10/07					53.07	47.21	52.62	46.76
W158R	2009/10/07					49.91	49.01	54.87	49.01
W149R	2009/10/07					53.02	49.42	55.28	44.91
W162R	2009/10/13					50.10	46.93	50.10	47.38
W150L	2009/10/16	41.14	46.58	45.22	48.40				
W151R	2009/10/16					49.76	43.41	47.94	41.59
W155L	2009/10/16	40.19	47.90	44.72	44.27				

KEY:
orange - rejected by Fermilab
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blue - value under 35nA
yellow - value under 42.5nA

All doublet values after all corrections

Tower	Test Date	L1	L2	L3	L4	R1	R2	R3	R4
W158L	2009/10/16	41.05	51.49	47.86	51.94				
W154R	2009/10/16					48.79	38.77	50.15	44.69
W157L	2009/10/16	39.12	50.55	50.55	51.92				
W159R	2009/10/16					50.35	41.63	51.72	43.46
W151L	2009/10/19	44.26	55.34	53.49	50.72				
W156L	2009/10/19	43.43	52.23	44.35	51.30				
W153R	2009/10/19					51.05	45.47	52.45	43.14
W149L	2009/10/19	44.77	55.98	51.31	51.77				
W156R	2009/10/19					51.00	43.50	51.00	44.44
W161R	2009/10/19					51.68	45.56	54.97	46.03
W152R	2009/10/19					44.38	57.13	51.94	52.41
W153L	2009/10/19	46.89	58.26	52.10	50.68				
W170L	2009/10/27	40.68	50.25	47.86	52.17				
W160L	2009/10/27	22.22	40.95	46.71	52.95				
W175R	2009/10/27					52.58	45.36	51.62	45.84
W159L	2009/10/27	42.64	53.28	49.89	51.83				
W165R	2009/10/27					50.62	44.31	50.62	44.80
W167R	2009/10/30					50.31	41.04	49.34	44.45
W164L	2009/10/30	41.25	49.58	45.66	51.05				
W165L	2009/10/30	39.94	50.76	47.81	46.33				
W163L	2009/10/30	42.13	51.99	46.07	51.50				
W169R	2009/10/30					51.21	43.78	50.71	42.79
W170R	2009/10/30					51.36	42.91	53.84	46.88
W167L	2009/10/30	43.13	52.60	47.61	53.60				
W171R	2009/10/30					53.35	45.85	51.85	41.84
W166L	2009/11/06	40.79	53.41	50.38	49.87				
W160R	2009/11/06					54.47	43.83	53.96	41.30
W168R	2009/11/06					50.81	42.68	52.85	42.17
W177R	2009/11/06					53.46	46.55	51.62	46.09
W161L	2009/11/06	43.95	54.58	55.04	53.19				
W162L	2009/11/06	44.11	53.85	52.46	39.93				
W166R	2009/11/06					50.27	45.61	53.99	45.61
W163R	2009/11/06					53.30	46.29	55.17	37.42
W174R	2009/11/06					56.77	48.33	57.24	48.80
W173R	2009/11/06					57.39	49.40	58.33	47.99
W176L	2009/11/10	44.61	49.82	49.34	46.51				
W175L	2009/11/10	42.97	51.04	42.49	49.14				
W174L	2009/11/10	43.55	45.93	44.98	48.31				
W173L	2009/11/10	42.31	53.79	48.53	47.09				
W180L	2009/11/10	44.38	52.53	46.30	48.22				
W179L	2009/11/10	42.61	50.79	49.35	46.46				
W171L	2009/11/10	36.96	47.59	48.55	45.17				
W181L	2009/11/10	45.86	50.71	49.74	47.32				
W169L	2009/11/10	39.17	50.83	51.81	50.35				
W177L	2009/11/10	41.79	53.49	49.59	50.08				
W168L	2009/11/10	43.35	51.18	48.74	29.16				

KEY: orange - rejected by Fermilab
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yellow - value under 42.5nA
All doublet values after all corrections

Tower	Test Date	L1	L2	L3	L4	R1	R2	R3	R4
W172R	2009/11/10					49.39	44.97	49.88	39.08
W183R	2009/11/10					48.03	46.56	53.45	45.08
W146R	2009/11/10					48.74	47.75	52.69	45.78
W184R	2009/11/10					50.39	45.93	46.92	38.99
W176R	2009/11/10					49.07	45.09	51.06	43.60
W180R	2009/11/10					50.73	45.24	51.73	45.74
W181R	2009/11/10					48.35	44.34	53.85	46.35
W179R	2009/11/10					47.56	47.05	51.57	39.52
W178R	2009/11/10					50.74	45.70	51.74	45.19
W158R	2009/11/10					51.41	47.87	52.42	45.35
W187L	2009/11/20	43.80	48.40	47.38	49.42				
W186L	2009/11/20	48.04	56.75	50.61	50.61				
W185L	2009/11/20	45.63	61.05	49.23	52.83				
W183L	2009/11/20	45.22	56.04	52.95	49.85				
W185R	2009/11/20					52.55	47.90	58.76	45.83
W184L	2009/12/02	42.74	51.11	47.97	32.80				
W182L	2009/12/02	42.41	54.48	47.13	50.28				
W186R	2009/12/02					50.39	44.07	48.28	42.49
W192L	2/26/10	43.80	48.40	52.90	43.40				
W191L	2/26/10	45.40	49.90	50.90	39.90				
W188L	2/26/10	48.80	48.30	49.80	49.30				
W190L	2/26/10	46.90	49.90	52.90	45.90				
W189L	2/26/10	47.80	46.80	55.30	43.80				
W189R	2/26/10					49.30	57.80	51.80	50.30
W190R	2/26/10					42.90	52.40	48.40	39.40
W187R	2/26/10					44.90	54.40	52.40	49.40
W188R	2/26/10					42.90	49.90	51.40	42.90
W196L	2/23/10	49.20	54.68	49.70	50.19				
W197L	2/22/10	45.67	52.15	52.15	48.16				
W198L	2/23/10	45.80	48.80	49.30	45.80				
W194L	2/22/10	43.18	52.65	54.65	50.16				
W193L	2/23/10	45.30	48.80	51.29	45.80				
W195L	2/23/10	43.31	48.30	47.30	43.81				
W207L	3/2/10	46.13	51.65	47.13	44.12				
W206L	2/26/10	47.60	50.60	51.60	45.60				
W205L	2/26/10	47.70	53.70	55.20	47.20				
W203L	2/26/10	48.30	49.80	55.30	47.30				
W202L	2/26/10	48.90	51.90	56.40	47.90				
W199L	2/26/10	49.40	45.90	51.90	45.90				
W201L	2/26/10	52.10	51.10	54.10	47.60				
W204L	2/26/10	45.70	52.20	52.70	45.20				
W200L	2/26/10	46.20	52.20	50.20	44.20				
	median	**44.71**	**52.64**	**50.29**	**47.67**	**50.73**	**46.55**	**51.88**	**44.85**
	avg	**44.46**	**52.41**	**49.74**	**47.09**	**50.30**	**47.01**	**51.59**	**43.92**
	st dev	**4.05**	**4.19**	**5.48**	**4.65**	**3.55**	**3.60**	**4.22**	**4.84**