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Investigation and Reduction of Cross Talk in the Run 2 Endplug Calorimeter PES and PPR Detectors

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Abstract

The CDF endplug calorimeter was completely rebuilt during the Run II upgrade. An integral part of that upgrade was the inclusion of a highly segmented scintillating strip shower maximum detector and a preshower detector which are read out using multi-anode PMTs and custom front-end electronics. During the initial operation of the experiment, greater than expected cross talk was observed in these detectors, compromising our ability to calibrate them and accurately calculate the positions of electromagnetic objects in the plug. This note describes the investigation of cross talk in the plug showermax. It then presents results using optical baffles as a means of reducing the cross talk and describes the installation of these baffles onto the detectors. Overall, the mean cross talk was reduced from 6% to 1.4%.

1 Introduction

The plug shower maximum (PES) and preshower (PPR) detectors are separate layers of the new sampling calorimeter for Run II. The PES is composed of 5mm wide scintillating strips arranged in two layers, while the PPR is composed of scintillating tiles with a tower geometry identical to the PEM. Both of these detectors are read out separately from the electromagnetic and hadronic sections using Hamamatsu R5900-16 multi-anode PMTs (MAPMTs) and custom front-end electronics[1]. Each read out channel corresponds to one strip in the PES or one tile in the PPR. Details about MAPMT selection and testing can be found in Reference [2]. Initial bench tests measured the intrinsic cross talk of the MAPMTs to be 0.7% in nearest neighboring channels and 0.4% in diagonally neighboring channels. PES MAPMTs in the low η region ($1.1 < |\eta| < 2.6$) operate at a nominal gain of $5\text{x}10^5$ while PPR MAPMTs and PES MAPMTs in the high η region ($2.6 < |\eta| < 3.5$) operate at a nominal gain of $1\text{x}10^5$.

Data taken from CDF demonstrates a significantly higher amount of cross talk than what was expected from MAPMT and electronics testing as well as test beam measurements. In this note we describe the implications of cross talk and the measures taken to investigate and reduce its effect.

Section 2 presents cross talk measurements in data. Section 3 describes how cross talk affects the data quality. After an in-depth investigation discussed in Section 4, the source of the cross talk was identified. In Section 5, a practical solution to the cross talk problem is given. Baffle installation is discussed in Section 6, and results are given in Section 7. In this document we focus on the PES.

2 Observing Cross Talk

To observe cross talk, the signal in one channel of a MAPMT must be significantly higher than the signal in neighboring channels. If this condition is not met, cross talk can remain undetected among smaller signals and noise. MAPMTs used on the endplug contain 16 channels arranged on a 4x4 grid. A single channel can have a maximum of 4 nearest neighbors, one on each side. In the PES, consecutive strips of the detector are read out by consecutive channels of the MAPMT. For typical energetic clusters in the PES, most of the energy is contained in 5 strips centered on the maximum energy, or seed, strip. Therefore, cross talk can be detected if excess energy is deposited four strips away from the seed strip.

Figure 1 plots PES shower profiles for electron candidates in the plug with $E_T > 40$ GeV. Clusters are separated into two categories: clusters where the seed strip and fourth away from the seed in the positive direction are read out in the same MAPMT and clusters where these strips are read out in different phototubes. By comparing the two cluster types, excess energy is clearly seen plus four strips over from the seed strip when both strips are read out in the same MAPMT (note the logarithmic y-axis), verifying the nature of cross talk in the PES.

We then devised a method to correct for its effects in the clustering software. The idea behind it was to redistribute the energy within the cluster so that the original signals were restored. We used a 16x16 matrix (M) which describes how signals are transferred from one channel to another. This matrix contains two parameters: the average cross talk in nearest and diagonal neighbor pixels. In other words, it tells all MAPMT channels to give a certain amount of energy to its neighbors. If we treat the observed data as a vector (0), to get the original signal back (S) we just have to multiply it by M^{-1}:

$$S_{1x16} = M^{-1}_{16x16} * O_{1x16}$$

While it is unclear if this method has a positive impact on determining cluster position, it does provide a crude way of measuring the cross talk in data. When the percent cross talk in nearest neighboring pixels was set between 8-10%, the differences between the two types of clusters in Figure 1 were negated. Therefore, the amount of nearest neighbor cross talk in data is measured to be 9±1% in the PES. Diagonal cross talk was set somewhat arbitrarily to 1%.

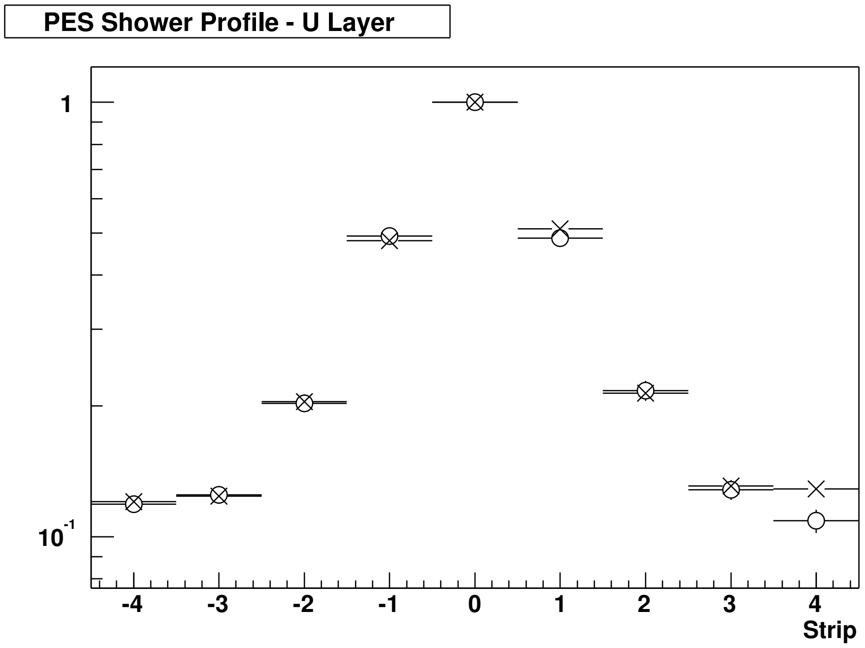

Figure 1: Average PES shower profiles for electron candidates with $E_T > 40$ GeV. The Xs correspond to clusters where strips 0 and 4 are red out by the same MAPMT. The Os are clusters where strips 0 and 4 are read out in separate MAPMTs.

Once cross talk was detected in physics data, the question arose whether it was also present in other types of data like laser runs or source runs. Laser pulses are generated from two lasers located on the first floor counting room of B0. Light is channeled to one pixel in each MAPMT with the laser fiber positioned just off center of pixel 9 as shown in Figure 2. With this configuration, the signal channel receives a large amounts of light while the two nearest neighboring channels farthest away from the laser fiber (10 and 13) get virtually no light. These two pixels displayed cross talk of approximately 4% in the PES with the signal channel at 1500 ADC counts. For the other nearest neighbor, channel 5, cross talk of 40% is seen due to the pixels close proximity to the laser fiber.

Plug source runs use a radioactive Co^{60} source to illuminate each channel with a constant amplitude. For the PES and PPR detectors, this is the primary means of calibration [3]. There are 8 source drives, which extend and retract the sources located on the ends of wires. These wires navigate through source tubes, passing along the sides of the various layers of the calorimeter. As the source traverses the PES, many strips are illuminated at once making it impossible to measure cross talk. In the PPR, cross talk is detectable since the scintillator tiles are much wider than the source illumination, unlike the PES strips. Cross talk in nearest neighboring channels, plotted in Figure 3, is measured at 6.1% with an average signal of 1500 ADC counts.

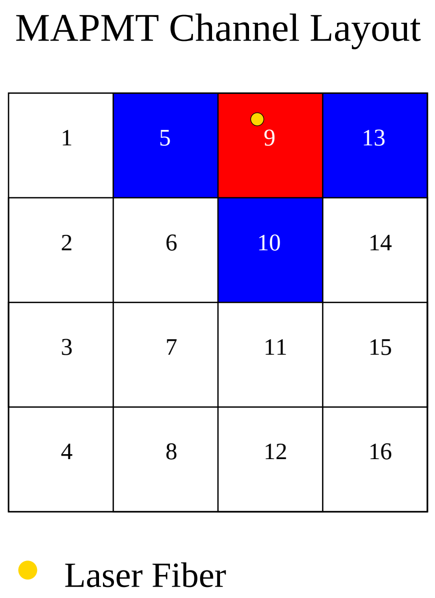

Figure 2: MAPMT photocathode layout and the position of the laser fiber. Channels are arranged on a 4x4 grid. The laser fiber is slightly skewed from the center of channel 9. Its nearest neighbors are highlighted in blue, pixels 5,10 and 13.

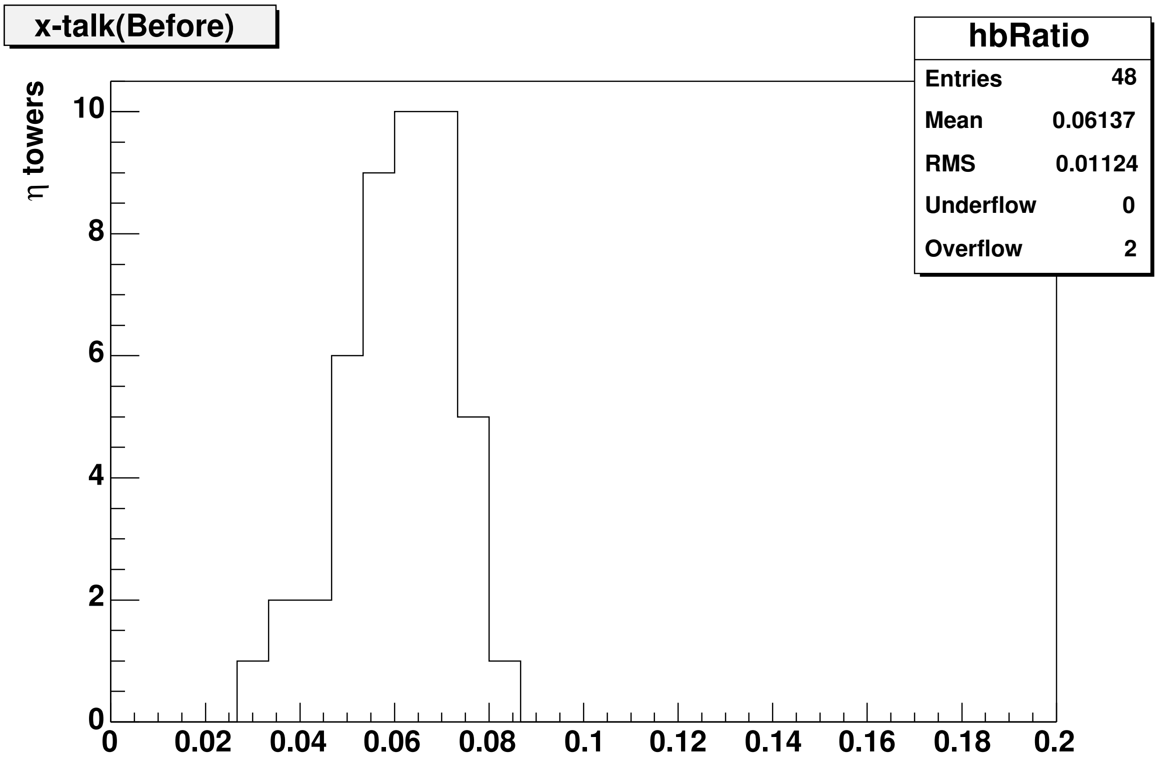

Figure 3: Cross Talk measured in the PPR before the Oct-Nov 2003 shutdown.

3 Cross Talk Effects

Cross talk has two major effects on the PES detector: it reduces the precision with which we can calibrate the strips and it smears the cluster shape. As previously mentioned, the PES is calibrated by source runs. Cross talk has a significant impact on source runs because we cannot differentiate between light coming from the strip being analyzed and light from other strips. Therefore, when the PES offline reconstruction software tries to convert from electronic counts into an energy, there is additional uncertainty. (Unlike other calorimeters, MIPs cannot be used as a calibration cross check because they do not deposit enough energy in an individual strip.)

Cross talk also results in wider clusters. On average, the amount of energy being transferred from one channel to another depends on the amplitude of the signal. Therefore, more energy will be removed from the central strips of the clusters than what comes in from the tails. For a detector that derives its strength by how well it can measure the cluster shape, cross talk is especially detrimental.

Besides the direct implications of cross talk, there are indirect effects as well. Cluster smearing has delayed the implementation of a PES χ^2 electron ID variable. Currently there is code to calculate a χ^2 for the PES, but so far it is not useful in distinguishing EM objects from hadronic objects. In the central calorimeter, the CES χ^2 plays an important role in electron and photon identification. With the removal of cross talk, a PES χ^2 should be just as effective as in the central.

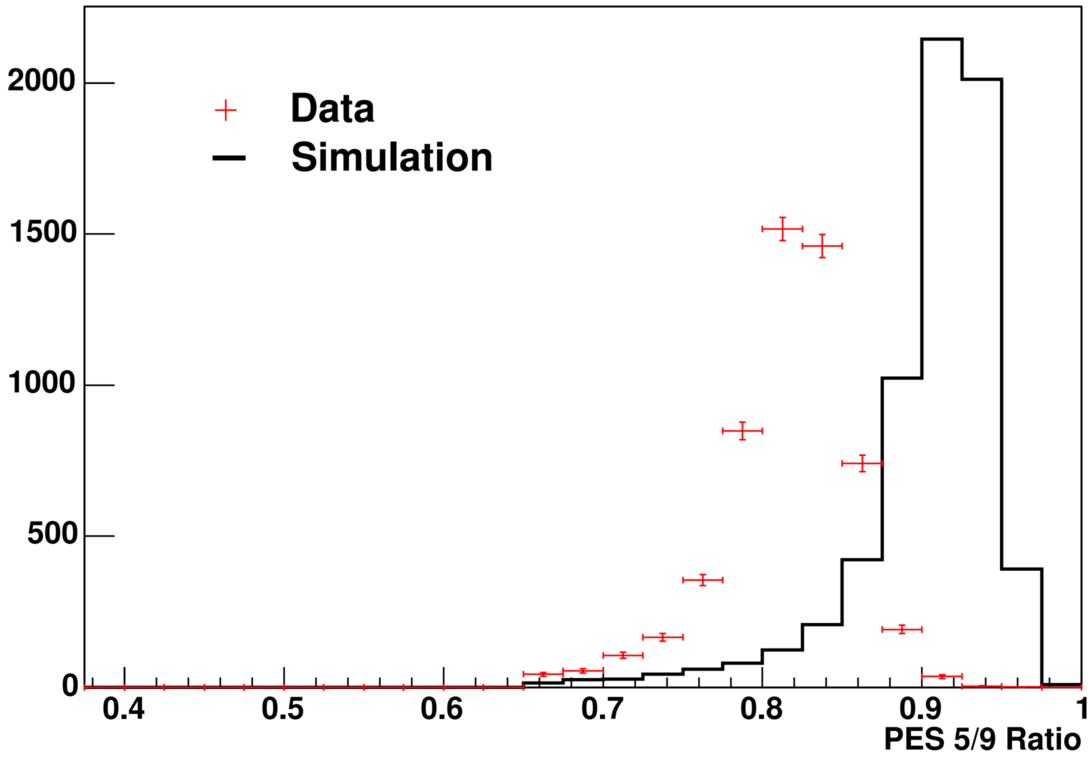

Figure 4: 5/9 Ratio for Z $\rightarrow$ e e events in data and simulation. The discrepancy between data and simulation is from cross talk and a lack of MC parameter tuning in the PES.

Cross talk also affects how well we can align the plug. Alignment was determined by comparing extrapolated COT tracks to the PES cluster positions as described in Reference [4]. Phoenix tracking [5] also relies heavily on the PES location. Two seed tracks are formed from a primary vertex and a PES cluster, one each for positive and negative charges. The best seed track is selected based on how well it matches the silicon hits. If the cluster position is shifted, then the wrong seed track can be chosen and the particle is assigned the opposite charge.

In addition, cross talk alters the agreement between data and detector simulation. Comparisons of the PES 5/9 ratio, plotted in Figure 4, show the mean to be 11% higher in MC than in data with the average signal size of the maximum energy strip equal to 2500 ADC counts. This variable is a ratio of the energy sum in the central five strips divided by the total energy in a nine strip cluster. It measures how much of the cluster energy is concentrated in the center. Part of the difference between data and simulation comes from cross talk, but another part is that the PES simulation still needs to be tuned. Without knowing what the shower shapes actually look like in data, it is unclear how to modify the simulation. A correct simulation is important in determining statistical and systematic uncertainties in analyses involving EM objects in the plug.

4 Investigating Source of Cross Talk

In Section 2, the methods of observing cross talk were presented. Here we describe the investigation where the cause of the increased cross talk was identified. If the reader is only interested in the cause and not the investigation, skip to Section 4.3.

4.1 MAPMT Test Stand

A test stand on the second floor of B0 was built to test spare MAPMTs and front-end electronics under different configurations. The basic scheme was to produce 505nm light pulses from a LED and shine it at one of the pixels of the MAPMT. The LED and MAPMT were kept in a dark box; in between them, there was an aperture and a filter wheel connected to a stepper motor. A cookie, a plastic piece which holds optical fibers, was used to hold a fiber in place at the center of a MAPMT pixel. Technical drawings of the cookie can be found in Reference [6]. One side of the dark box had 20 LEMO connectors and 4 HV connectors to enable use of the MAPMT without opening the box. A gamma power supply was used to produce HVs for the MAPMT. At first, an oscilloscope was used to measure signals from the MAPMT anodes and a NIM pulser was used to generate pulses for the LED and oscilloscope to trigger on. This was only a temporary solution until we could assemble the crates and boards necessary to make the test stand as close as possible to its counterpart on the detector. Currently the anode signals are sent directly to a production SMD crate, complete with a SMD board, termination board and controller board. SMD boards on the test stand are calibrated with the same SMQIE calibration used on the detector. The SMD board is connected to a SMXR in TSTCAL1, the primary crate used to test calorimeter hardware. Besides the SMXR, TSTCAL1 contains a processor, Trigger Supervisor board and Test Clock to generate signals. From a read out standpoint, the Test Clock is the only difference between the test stand and the actual detector.

4.2 Cross Talk Investigation

In order to reproduce cross talk seen in CDF data on the test stand, we illuminated one pixel on a MAPMT. This is the same procedure used in PES laser runs. In this test, signals consistent with 1% or less cross talk were observed. Test stand HVs were set between 600-800 Volts, similar to the range of MAPMT HVs on the detectors. We came up with several scenarios which could explain the cross talk seen in data but also account for the lack of cross talk on the test stand: a gap between the fibers and MAPMT photocathode, a timing mismatch in the electronics, or greater than expected magnetic fields.

4.2.1 Cookie to Photocathode Air Gap

Light exiting from an optical fiber will travel in a cone until it is absorbed by the MAPMT photocathode. Since the lip of the MAPMT mount is slightly longer than the protrusion of the cookie which holds the fibers, a small gap exists in which the light can disperse. If a MAPMT was not pushed completely onto the cookie, so that the gap between the fibers and photocathode was increased, it is possible that there would be greater cross talk. To investigate, we measured the size of this gap for the spare MAPMTs. The protrusion on a typical cookie was 4.6mm and the lip of the MAPMT mount was recorded at 7mm leaving an air gap of 2.4mm. In contrast, a set of MAPMTs used during the 1996-97 test beam had a gap of only 0.5mm. Expanding the air gap was done so that the light would be spread over a broader area of the pixel which was observed to produce better linearity at higher signal amplitudes[7]. Tests were conducted at UCLA, to see how large the gap could be without increasing the cross talk. According to these tests a gap of 1mm was desired because anything beyond 2mm would cause the cross talk to increase dramatically.

It was necessary to repeat the measurement, to see how cross talk depended on the space between the MAPMT photocathode and the fibers. Copper shims were constructed of varying thickness to increase the size of the air gap by precise amounts. Again, an oscilloscope was used to measure the signals in the primary channel and the nearest neighbor channels. This time we did see cross talk but only when the gap was above 4mm, much larger than the what exists on the detector. It is worth noting that pedestal readings fluctuated, making it difficult to measure signals in nearest neighbor channels. At this point, other causes of cross talk were looked at. It also became clear that using an oscilloscope was not a sufficient means of measuring cross talk and only the full showermax readout electronics would be sufficient to make a proper measurement.

4.2.2 Timing Mismatch

Once we had the front-end readout configuration in place, we explored possibilities that the electronics could be a possible culprit of cross talk. For instance, it was not known for sure whether MAPMT signals were in time with the CDF clock. Triggering on the MAPMT pulse, a negative voltage peak followed by a long tail is observed on the oscilloscope. If there is a timing mismatch between the trigger and the showermax electronics, a significant part of the tail could end up in a different 132ns time gate. Since the tails are longer for higher pulses, channels with larger signals would have more energy mysteriously disappear since the tail would actually lie in a different window. Then when we compare nearest neighbor pixels to the signal pixel, the ratio would be higher corresponding to larger cross talk.

To investigate this scenario, we looked at data taken in "Myron mode", which allows us to record four successive 132ns time buckets, 0-3, with bucket 1 corresponding to the primary time window. By comparing the amount of charge in the first and second time buckets for different channels, we could determine if a timing mismatch contributes to cross talk and by how much. We expected these two buckets to have a linear correlation; instead, the relationship seemed to be dependent on other unknown factors as seen in Figure 5. This led to questions about the overall state of the electronics and what could actually be trusted.

It appeared that the second time bucket and not the first was responsible for the effects seen. To test this hypothesis, we compared signals between the showermax and calorimeter electronics, which are known to have the proper timing. We made sure the pulse from the MAPMT lined up with the first time window by adjusting the delay on the pulse generator.

The two types of electronics agreed very well except for the last two time buckets. A discussion with the designer of the SMQIE chip confirmed the problem with the second time window.

Even if we changed the delay by small amounts, the fraction of signal exiting the first time bucket was not nearly enough to account for the levels of cross talk seen in data. Therefore, we ruled out a timing mismatch as a cause of the observed cross talk.

4.2.3 Magnetic Fields

PMTs are not designed to operate when large magnetic fields are present. We require MAPMT operation in magnetic fields < 1 Gauss. MAPMTs are surrounded by μ-metal shields, protecting them from the fields produced by the solenoid. Normally, these shields allow a very small fraction of the magnetic fields to penetrate inside, but it was hypothesized that stress on the metal, during fabrication or installation, could reduce its effectiveness. If greater than expected $\vec{B}$ fields exist inside the shields, it could result in greater cross talk since the trajectory of photoelectrons within a MAPMT would change causing signals to transfer from one channel to another. Initial tests showed magnetic fields parallel to the MAPMT result in an increase in gain of 0.3% per Gauss, while fields perpendicular yield a decrease in gain of 0.8% per Gauss [8]. It was unknown if prolonged exposure to magnetic fields would cause permanent effects on the MAPMT.

We started by measuring the fields outside and inside of the μ-metal shields with a Hall probe. Outside we observed 30 Gauss perpendicular to the MAPMTs. Determining the $\vec{B}$ field strength inside the MAPMTs proved difficult due to the small space inside the shield. It was also hard to hold the probe in the right place while reading the value of the field. So even though we measured 2 Gauss inside, we did not trust the number very much.

The next step involved taking plug laser runs with the solenoid on and off. Hardly any difference was observed between the two. There was some fluctuations in the plug laser signals of less than 1%, but this stabilized once the solenoid had been off/on for a while. This was a clear signal that magnetic fields were not the source of cross talk. However, there was a little uncertainty due to the possibility of residual fields produced by the iron on the detector, magnetized by the solenoid. But further studies on the test stand demonstrated that our shields, even when bent, did their job. This time, with a better Hall probe we measured $\vec{B}$ fields of < 1 Gauss inside the shields with surrounding fields in excess of 50 Gauss. Clearly we had to look elsewhere.

4.3 Discovery - Cookie to Photocathode Air Gap Revisited

After the production showermax readout electronics were installed in the MAPMT test stand, we redid the cross talk measurement as a function or air gap size. This time, large cross talk was clearly present with a gap of 2.5mm, the typical distance for the MAPMTs. There was now no question as to the source of the cross talk, but there was still some mystery as to why it was not discovered before. As we continued using the test stand, we discovered a couple of reasons why the air gap contributed more to cross talk than previously thought:

optical fibers used on the test stand are different from ones on the detector, and the air gap size increased when the cookies holding the fibers were polished.

In order to upgrade the test stand to more closely resemble the detector, we removed a cookie with the fibers glued in from a spare decoder box (see Section 5). It seemed that these fibers which are identical to the ones used in the detectors are different from the ones we had previously used on the test stand. By shining laser light through both fibers, we could see that the spot size appearing on a flat surface appeared larger with the detector fibers. This could be explained if the opening angles of the two sets of fibers were different, but we needed to perform a more controlled test. Two optical connectors were constructed, one for each fiber type with a cookie on each end. The cookie faces were cut such that each fiber had a smooth surface. Now we could accurately measure cross talk in the same MAPMT for both sets of fibers. Data taken with the detector fibers displayed higher cross talk as shown in Figure 6. This is a good indication that the fibers used on the detector have a larger opening angle. To be sure, we measured the air gap for the different sets of fibers and found it to be 0.6mm shorter for the detector fibers. Therefore the cross talk test did not tell the whole story. If the gap had been the same size, we would have measured a bigger discrepancy between the fibers. This confirmed that the opening angle for optical fibers used on the detector are bigger than previously thought.

The difference in gap size between the two fiber types yielded another clue. The 0.6mm discrepancy came from the size of the protrusion on the cookie and not from variations on the MAPMT mount. Why was there such a large difference between individual cookies? It is unlikely that these types of effects could be present in the initial production. Most likely the cookies were modified in an imprecise way after being produced, which resulted in the air gap having substantial variations. On the test stand, it could only have come from cutting the cookie surface. Looking at the spare decoder box, it appeared that the face of the cookies were cut in the same way. This also helped explain why we were measuring the air gap to be larger than our upper limits. Looking at the cookie design specifications, the protrusion is supposed to be 5.1mm while we measured 4.6mm. Having a greater gap between the fibers and MAPMT due to shaving the face of the cookies increases the amount of cross talk in data.

5 Correcting for Cross Talk

We identified three types of solutions to reduce cross talk: re-positioning the cookies to move the fibers closer to the MAPMTs, altering the MAPMT mounts to reduce the size of the air gap, or inserting an object between the MAPMT and the fibers.

To determine the feasibility of moving the cookies, we examined a decoder box. A decoder box is a hollow rectangular box which houses the optical fibers and the cookies which are glued onto one side. It is called a decoder box because it routes the fibers coming from the detector to the proper pixel on a MAPMT. A spare box was produced which also serves as a useful visualization and training tool. In order to see inside, we removed a cookie from the decoder box. This was not an easy task; it took a wrench and a great deal of force

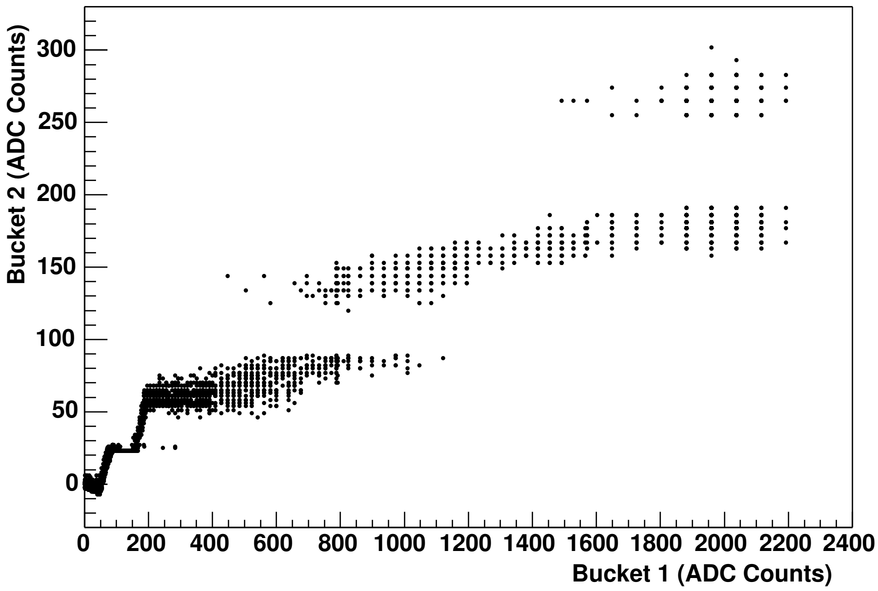

Figure 5: Relationship between the first and second time buckets in the showermax electronics. The first bucket corresponds to the signal. We expect bucket 2 (y axis) to be a linear function of bucket 1 (x axis). Instead we see bands along the x axis. This indicates a problem with the electronics. The gaps along the x axis are due to the resolution of the various ranges of the SMQIE chip. Each range is two times less sensitive than the range before it.

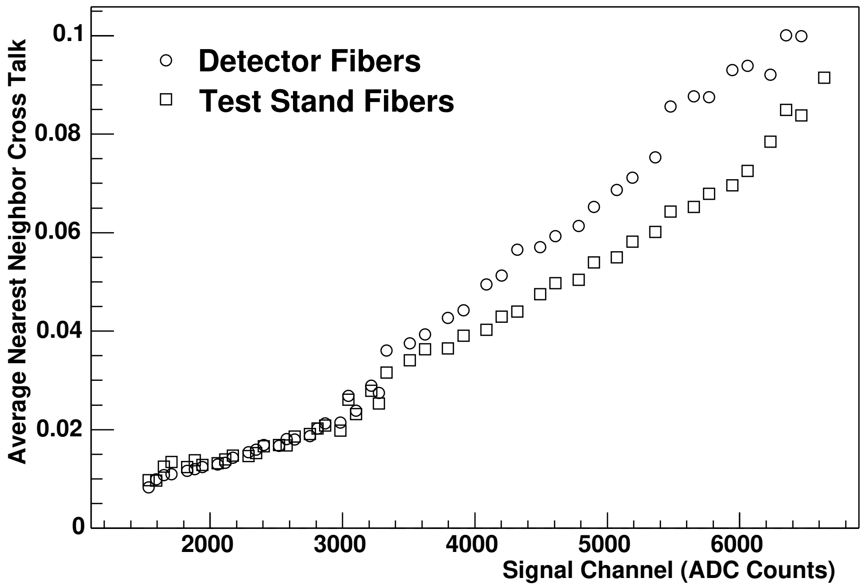

Figure 6: The plot shows the difference between fibers used on the detector and fibers used on the test stand. For each fiber type, the average cross talk is plotted as a function of ADC counts on the signal channel. For these tests, only one pixel is illuminated. Light exits the fibers with different opening angles which explains the difference in cross talk.

to separate one of the cookies. Right away, we knew that doing anything to the fibers or the cookie would cause more problems than they would fix, especially considering that there was much less space inside the PMT boxes.

Another option was modifying the mounts of the MAPMT. As previously mentioned, the MAPMTs used during the test beam already had lips on the front which were shorter than the others. Since these tubes displayed much less cross talk, reducing the length of the lips could indeed be a viable solution. However, this alternative involved serious concerns. We could not machine the 488 MAPMT mounts unless all of the MAPMTs were removed and the housing disassembled. Not only is this a big job, but there was a significant chance that some of the MAPMTs would be damaged. Clearly, reducing the cross talk was a second priority to the overall well-being of the detector. It was therefore decided that doing anything to the MAPMTs or the mounts was not an option.

The final solution was to introduce a new piece which would fit in between the fibers and the MAPMT photocathode. Two ideas were presented which would reduce cross talk: a transparent disc with a high index of refraction or an opaque disc, called a baffle. In either case, the MAPMTs would have to be removed from the shields but would not have to be completely disconnected. This meant that the anode connectors which transmit the charge to the SMD boards would be taken off, but the HV cables could be left alone.

Placing a transparent material with a high index of refraction inside the air gap reduces cross talk by bending the light coming out of the optical fibers. Therefore, less light travels to neighboring pixels because it takes a longer distance for the light to disperse. We obtained a 2.6mm thick glass piece with a reticle used for measuring small objects under a microscope. In addition, we ordered a glass disc 2.5mm thick with an anti-reflective coating from Edmunds Scientific. Data taken on the test stand with both discs displayed significantly lower cross talk (see Figure 7), with the thicker piece doing slightly better. Although the glass was effective, we were concerned that the glass would age over the course of Run II. Also cost was an issue.

A baffle is a plastic cylindrical piece, 3/32 in. (2.4mm) thick, with 17 holes in it. The holes allow light from each fiber, 16 channels plus one for the laser, to travel to the correct MAPMT channel. Baffles reduce cross talk by filling in the air gap, preventing light from reaching more than one pixel at a time. With this option, the biggest concerns were keeping the baffle from moving and aligning it so that the holes were centered on the MAPMT pixels. To solve these issues, we developed alignment tools which consisted of two pieces, one to hold the baffle in the correct position and the other to secure it onto the face of the photocathode. The holder is similar to the cookie in that it has a cylindrical protrusion that fits snugly in the MAPMT mount; it also has a metal pin in one corner that matches the corresponding hole on the lip of the MAPMT mount. Baffles were constructed with a diameter only a few mils smaller than the mount preventing any movement. The holder is also keyed so that the baffles only fit in one possible orientation. Two holes were drilled and tapped on the sides of the baffles to allow easy removal once they had been inserted onto the MAPMT photocathode. Prototypes of the baffles and alignment tools were produced at the UCLA machine shop. Two sets of baffles were made from Delrin plastic with hole sizes ranging from 2.5mm to 4.0mm, one black and one white. Photographs of the baffles and alignment tools can be found in Reference [6].

Cross talk was measured on the test stand for the different solutions, shown in Figure 7. In this test, we shined light into one MAPMT pixel (signal channel) while rotating the filter wheel, allowing us to determine cross talk as a function of MAPMT response. Cross talk was calculated by dividing the signal in each of the nearest neighbors and dividing by the signal channel. The cross talk plotted is the average of the four nearest neighbors. As the light intensity increases, a higher fraction reaches the neighboring channels causing cross talk to increase. In addition, the MAPMT response becomes non-linear for the signal channel which contributes to cross talk as well. Considering cross talk reduction, cost and production time, we decided to use baffles with 2.8mm holes.

6 Optical Baffle Installation

We installed the baffles during the Oct.-Nov. 2003 shutdown, when there was almost two months to access all 24 PMT boxes.

6.1 Preparation

Before the shutdown, we wanted to install baffles in one PMT box to verify their effectiveness on the detector. The chance arrived with only a week left for actual data taking. During a supervised access we installed baffles on the PES and PPR MAPMTs located in West PMT Box 9. Comparison of the PES 5/9 ratio between data taken before and after the baffles were installed, shown in Figure 8, displays an increase of 7.5% in the U layer and 4.1% in the V layer . The baffles prevent cross talk from smearing the clusters, resulting in the higher 5/9 ratios. Moreover, the low-side tail in the 5/9 distribution is seen to be nearly eliminated. This data reassured us that the baffles were doing as well on the detector as was seen on the test stand.

6.2 MAPMT Clamps

Since the baffle installation required disconnecting the readout connectors, we worried that some of the channels would be lost. Up to this point, no mechanism was present to provide strain relief for the connectors and we believe that many of the dead PES channels are due to connection problems. A tell-tale sign is a few channels (<10) coming back to life for short run periods. Most likely, this is due to MAPMT pins coming in and out of contact with the connector.

To alleviate this possible problem, we designed a clamp which would hold the MAPMTs in place and provide connector strain relief at the same time. One piece of the clamp is a plastic cover which sits on top of the rectangular housing of the connector. There is a hole in the middle to allow a 10/24 bolt to be screwed in the MAPMT. With the screw in place the connectors are secured, thus providing strain relief. To keep the MAPMT from moving, we devised a U-shaped aluminum piece with two small pins on the sides and a spring attached to the top. When the pins are placed inside small holes on the μ-metal shields, the spring is compressed, pushing on the plastic cover and keeping the MAPMT in place. The stiffness of the aluminum keeps the pins from coming out on their own. This replaces a metal spring clip that is bent so it fits inside the holes on the shields and sits on top of the MAPMT mount simultaneously. The old system does not always ensure that the MAPMT is flush onto the fiber holding cookie since the clip is often bent out of shape when we handle it. They are also very difficult to install and required a great deal of force.

6.3 Baffle & Clamp Installation

Before installing any of the baffles, we designed a procedure which detailed how we would go about the job. In this way we could try and eliminate any possible mistakes. For each PMT Box, there was a traveler containing a schematic drawing of the MAPMTs. Travelers were used to document each MAPMT as a baffle was installed. Baffle insertion was done separately for each PMT Box. Since the clamps were still being machined at the beginning of the extended shutdown, they would be installed after the baffles. Before opening up the PMT Boxes, care was taken to ensure the MAPMT HV could not be turned on. One by one, a MAPMT was removed, a baffle installed and the traveler labeled. If the mount of the MAPMT had a short lip, meaning the air gap was small, no baffle was inserted and the traveler marked appropriately. Even if we attempted to place a baffle into one of the MAPMTs with a smaller gap, the dimensions of the alignment tool prevented it. Overall, the baffle installation went very smoothly. Having the alignment tools keyed so that there was only one possible way to orient a baffle made things very simple.

For approximately 10 MAPMTs out of 488, the diameter of the baffle was a bit too small so that the sides did not grip properly with the MAPMT mount. These baffles tended to fall out if the MAPMTs were held upside down, but did not appear to rotate. So as long as the MAPMTs were handled properly, there should not be any adverse effects.

Another complication were three MAPMTs which could not be removed easily. There is a screw hole in the back of the mount which allows extraction of the MAPMTs from inside the μ-metal shields. Although some MAPMTs are harder to remove than others, these three felt as if they were attached to a spring on the other end as we pulled on them. By pulling one of them out completely, we could see that the cookie had come loose so that it was not glued into the decoder box. The springiness that was felt was the pull of the fibers glued into the cookie. Tubes with this condition are listed in the following table:

MAPMTs with Detached Cookie		
PMT Box	MAPMT #	Comment
2	16	Baffle installed, 2 dead channels
3	12	No baffle inserted
5	6	Baffle installed, no channels lost

Installing the clamps went smoothly as well. The plastic covers which push down on the MAPMT connectors are keyed so that they only go on one way. There are two connectors, one with 14 pins and one with 20 pins. Since the connectors are different lengths, it makes it impossible for the covers to be put on while rotated. In addition, a small lip on the cover prevents it from being flipped. One unfortunate effect of the covers is that it obscures the labels glued onto the connectors. The labels identify which MAPMT they belong to. This meant we had to be very careful when connecting the MAPMTs because if we made a mistake, then there was no way of catching it by eye.

The final component of the clamp is the U-shaped aluminum piece which pushes on the plastic cover. To insert them, both sides are placed onto the μ-metal shields with the aid of a flathead screwdriver. The screwdriver is necessary because it allows us to momentarily bend the aluminum to go over the shield. When the U-piece is secured, both pins on the sides go into the holes on the shield, and pulling on the aluminum does not dislodge it. In the final design of the clamp, the aluminum has two small holes punched onto the back so that rods could fit inside. The rods give us enough leverage to bend the aluminum, making it easy to remove the U-piece from the shields. The clamps were fully installed a week before the end of the shutdown, leaving at least that much quiet time to perform the necessary tests to make sure everything went according to plan.

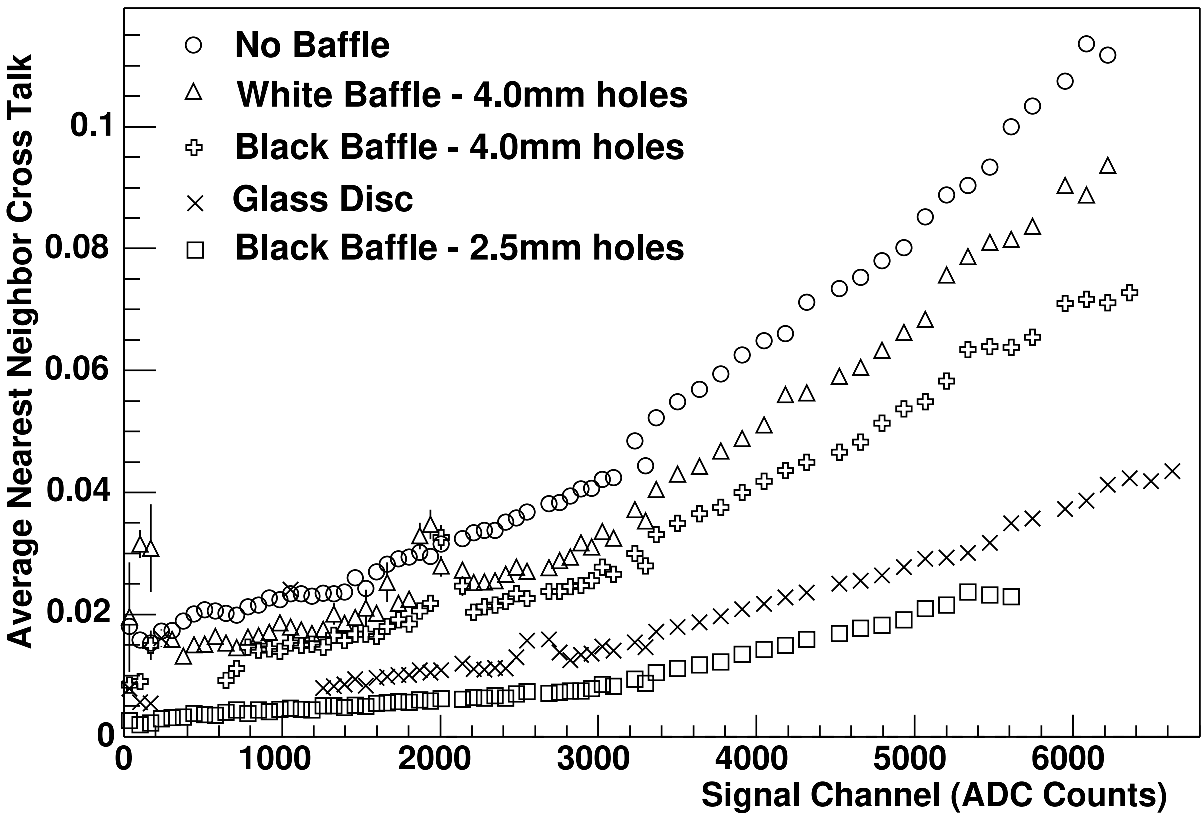

Figure 7: Cross Talk measured on the test stand with different objects placed in between the optical fibers and the MAPMT.

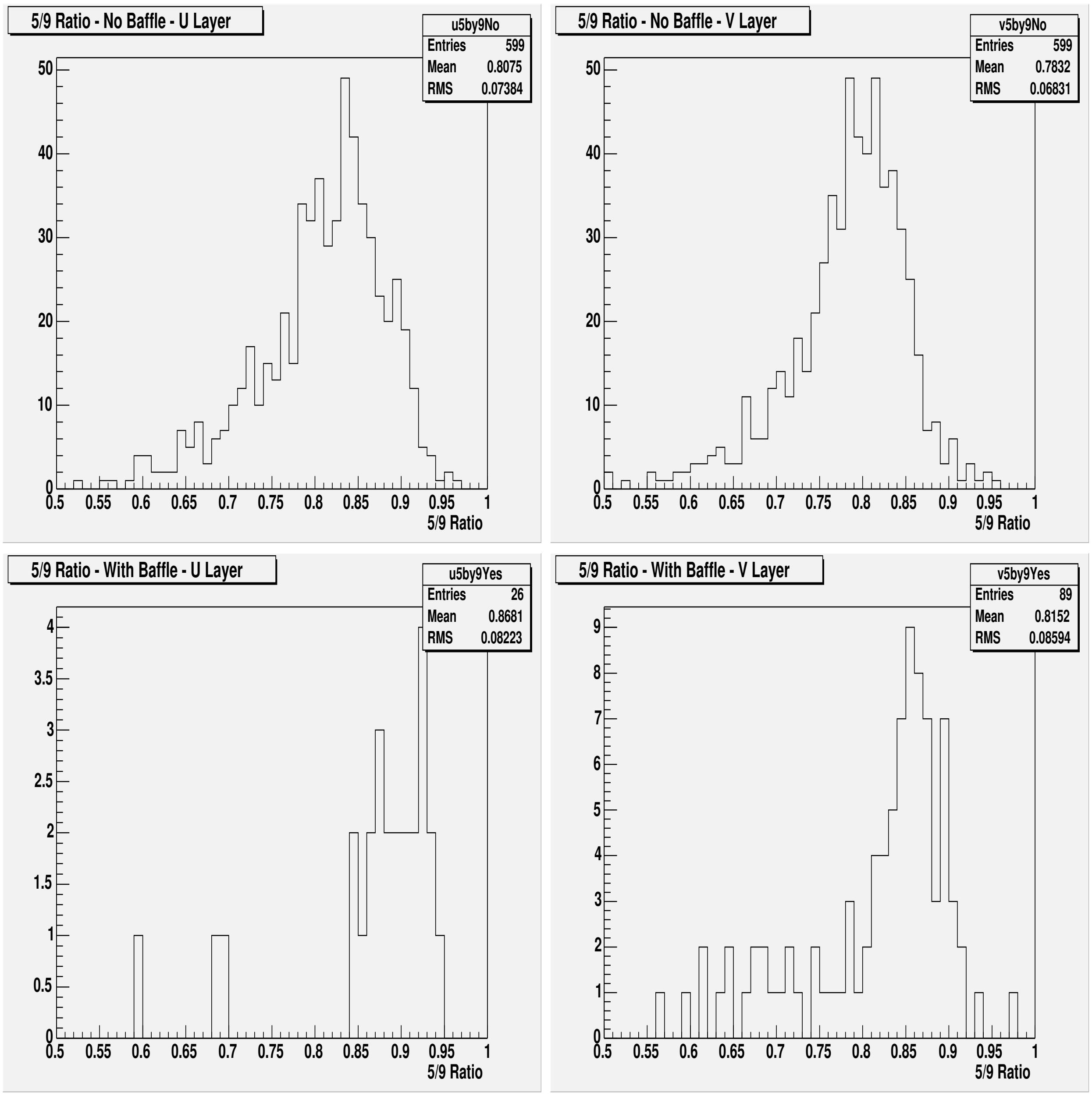

Figure 8: A comparison of the PES 5/9 variable using W $\rightarrow$ e ν data taken before and after baffles were installed on one PMT Box. Plug W events were selected with missing E_T and standard plug electron ID variables, except for PES 5/9. The ratio increases 7.5% for the U layer and 4.1% in the V layer. A higher 5/9 ratio corresponds to more energy within the middle 5 strips of a cluster. For data without baffles, a cut of PES 5/9 > .65 has previously been used to distinguish between EM and hadronic objects in the plug.

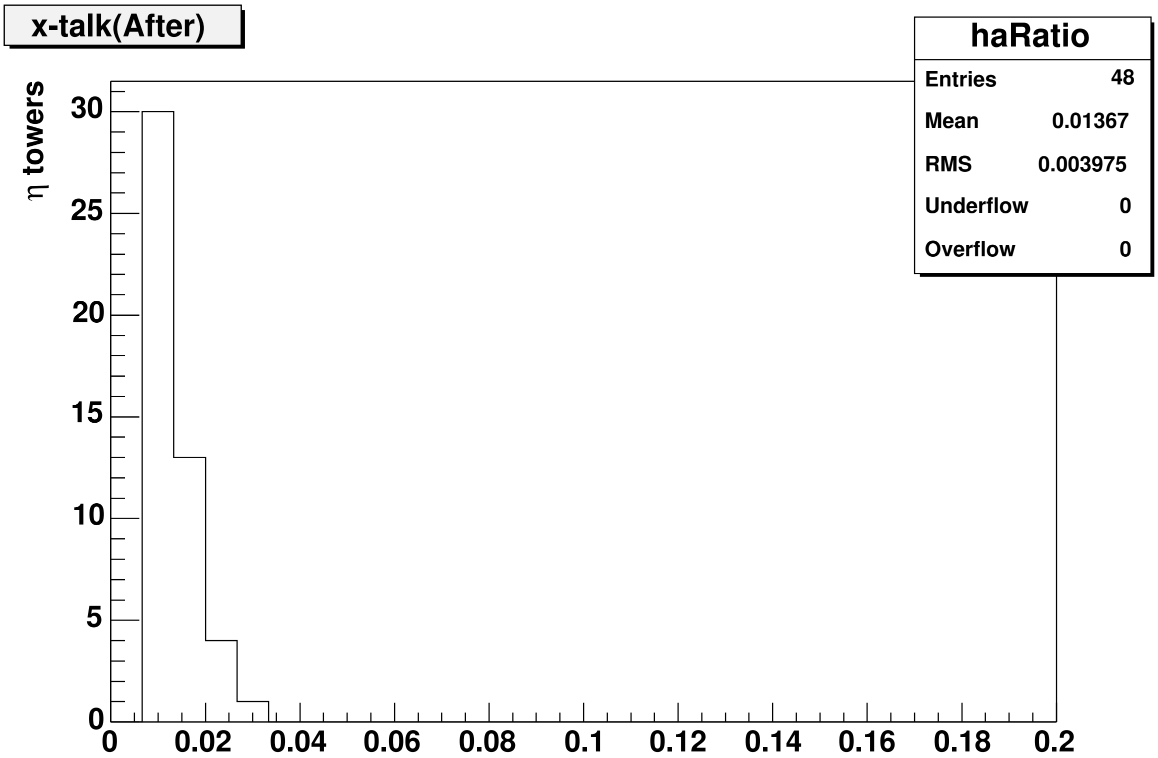

Figure 9: Cross Talk measured in the PPR after Oct-Nov 2003 shutdown.

7 Results

To determine the effectiveness of the baffles, the same tools are used that helped to identify cross talk in the first place: laser runs and source runs. Laser runs, which take much less time and preparation, were done right away. Two pixels (channels 10 & 13 on Figure 2) are used to measure cross talk in laser data; the other nearest neighbor (channel 5) is not used because is too close to the laser fiber. Dividing the nearest neighbor pixels by the signal pixel, we see that cross talk had decreased from 4% to 1.5%, shown in Figure 10. For the laser run taken before the shutdown, entries with 1% or less cross talk correspond to MAPMT with a 0.5mm air gap. Less cross talk is expected in this test than in source and physics data because the laser fiber is further away from the nearest neighbor pixels. The average signal for the maximum pixel (channel 9) is 1500 ADC counts in laser runs.

Source runs were taken for the PES and PPR shortly after the baffles and clamps were installed. In the PPR, the ratio of nearest neighbors to the signal channel, plotted on Figure 9, is measured at 1.4%. This is in contrast with source runs taken before the shutdown, where 6.1% cross talk was observed when the average signal was 1500 ADC counts. We can also compute the amount of light absorbed by the baffle which is independent from the cross talk reduction. Comparing the absolute signal in source runs before and after the baffle installation yielded a decline of 8.6% [9].

PES source data was compared to another full source run performed at the beginning of the year, with run numbers listed in Table 1. On average, we found signals in the new source data to be 17% lower than signals in the earlier source run. The distribution of signal loss for the U layer strips in the low η region is shown in Figure 11. Unlike the PPR, a significant portion of the total signal is due to cross talk from other strips. After the baffle installation, the contribution due to cross talk should greatly diminish. Also, as seen in the PPR, the absolute signal decreases by 8.6% without any cross talk being present. Since the two effects should be independent, the absolute signal loss between the two source runs is equal to the light loss plus the reduction of cross talk. Therefore 8.4% (17-8.6) of the total signal loss is due to cross talk reduction. The average strip response in the PES prior to the baffle installation was 2100 ADC counts in the V layer and 950 ADC counts in the U layer.

PES Source Runs	
Jan. 2003	156555, 156558, 156559, 156560
Nov. 2003	172340, 172342, 172357, 172359

Table 1: PES Source Runs used to determine cross talk effects

In a single MAPMT, significant variations can exist between the relative gains of each pixel. The MAPMT specifications list this gain variation to be no more than 3:1. As shown in Figure 12, the average signal difference is well correlated with the channel gain. For MAPMT channels with lower gains, a greater fraction of the total signal is derived from cross talk. After the baffle installation, the total signal loss due to cross talk reduction will vary for each strip depending on the gain of the pixel and the gain of its neighboring pixels.

Trying to correct cross talk effects for pre-shutdown data with the method described in Section 2 probably will not work very well since it is only an average correction. To do it properly, the cross talk matrix should be modified so that it reflects the true gains of each channel in the MAPMT.

In addition to testing the baffles, source data was used to determine whether the clamps revived any previously dead channels by securing the MAPMT pins to the connectors. Out of 5053 strips that could be accurately measured by both source runs, the number of dead strips decreased from 79 to 65. Although this is substantial, it appears that many of the remaining dead strips are still due to connection problems. For instance, some of the channels that are dead after the clamp installation are different from before. Also, there are certain connectors that are known to be loose, meaning they easily slide of the MAPMT pins when not held in place, which still have many channels which are dead. Therefore, another investigation is needed to determine why a connection is not properly made now that the MAPMT connectors are securely in place.

Source data is also used to identify cable swaps in the PES. As an example, Figure 13 shows the energy in each strip as a function of event number for octant three in the west plug. Events are read out at a rate of 10Hz. As the radioactive source travels through the PES source tubes, strips within close proximity to the Co^{60} are illuminated, tracing the path of the source. In the plot, the source path is a continuous line. If two MAPMT connectors had been swapped, strips would be illuminated out of order and the source path would be discontinuous. No cable swaps were observed.

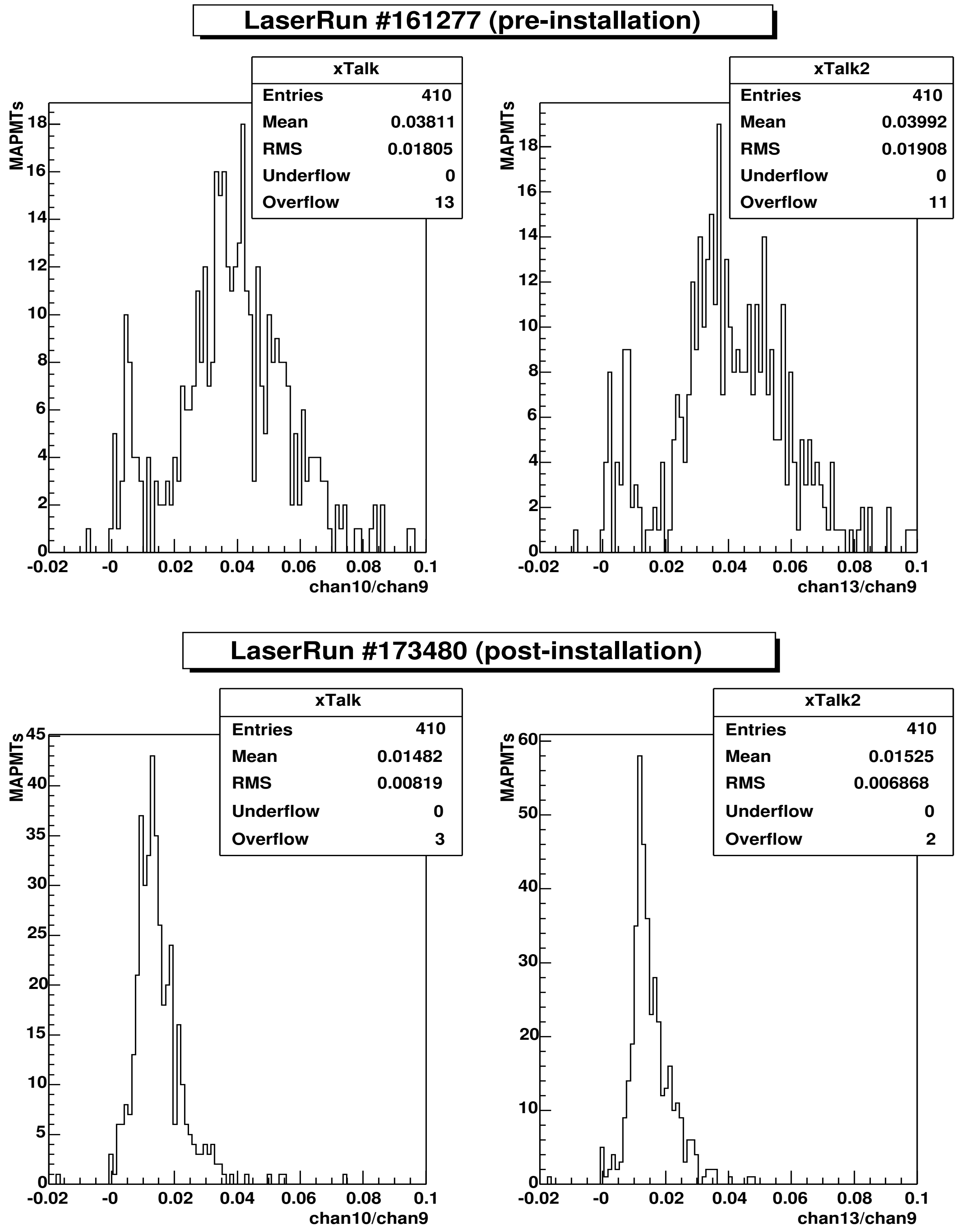

Figure 10: Data taken from laser runs before (top) and after (bottom) the baffle installation. Channels 10 and 13 are neighboring pixels to the signal pixel. Cross talk is defined as the ratio of the ADC counts in the nearest neighbor channel to the ADC counts in the signal channel. In both neighbor pixels, cross talk decreases from 4.0% to 1.5%.

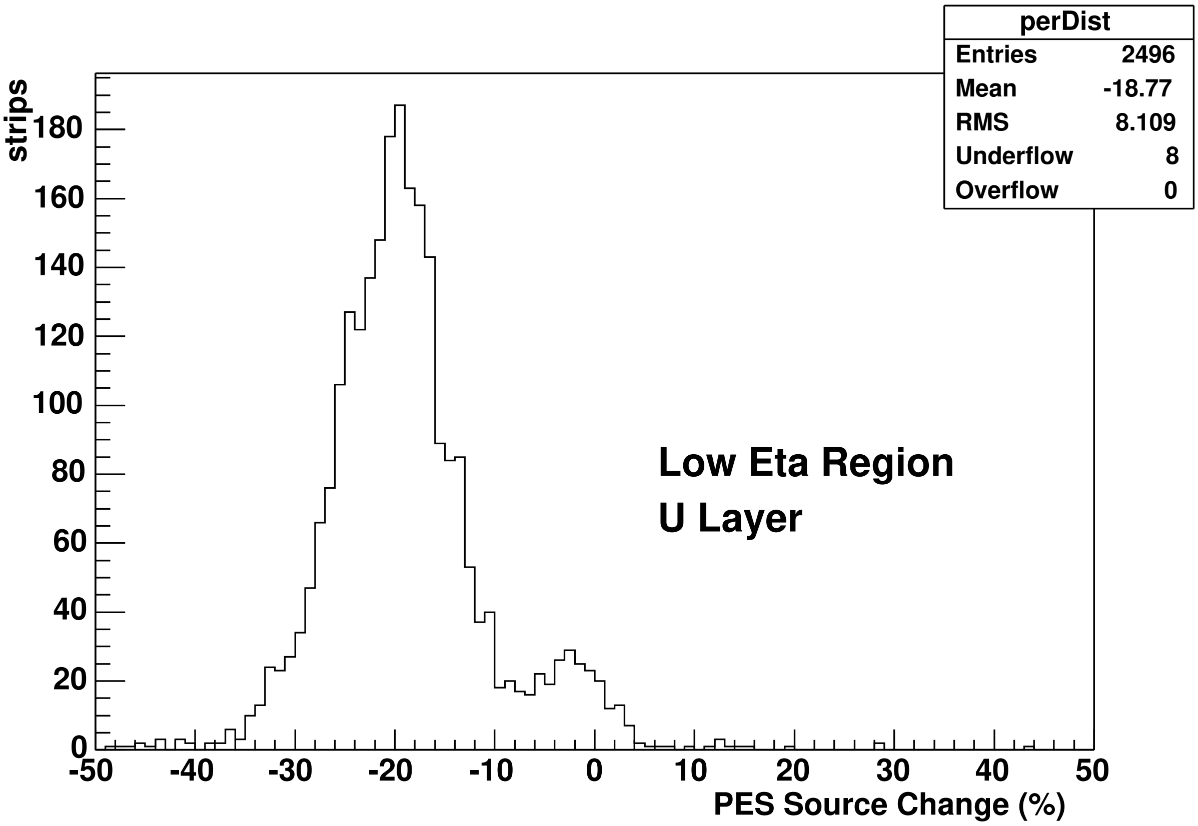

Figure 11: Percent signal change between source runs taken before and after the baffle installation. The bump close to 0 are strips in MAPMTs where no baffles were installed. Only strips in the low η region, $1.1 < |\eta| < 2.6$, and U layer (furthest from the source) are shown.

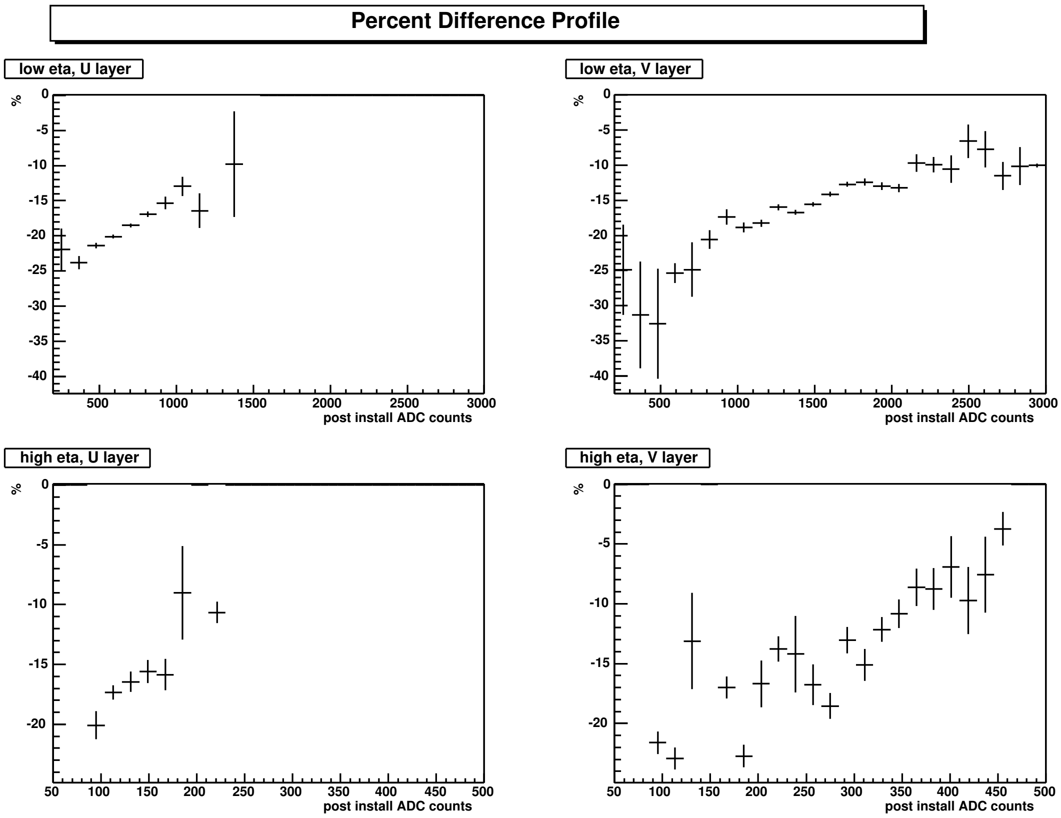

Figure 12: Percent signal change as a function of the absolute signal in PES source data. Comparison between two source runs taken before and after the baffle installation. The correlation indicates that cross talk has a more dramatic affect on channels with lower gains.

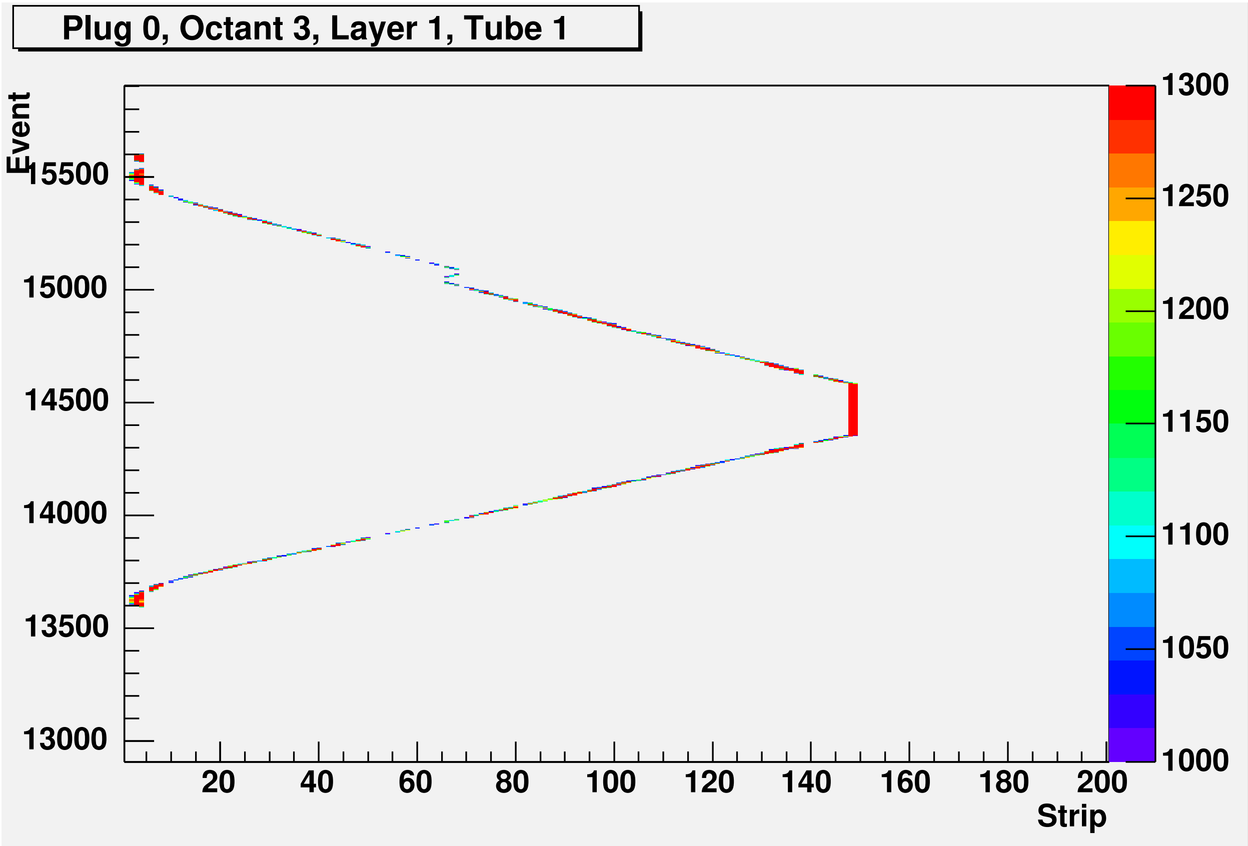

Figure 13: Light observed by the PES as the Co^{60} source extends and retracts through one of the source tubes. This type of plot is the primary means of identifying cable swaps in the PES. As a precaution, tension is released during the source retraction. This is the cause of the kink around strip 70.

8 Conclusions

Cross talk is detrimental to the PES because it adds uncertainty to the strip calibration and smears clusters in data prior to the Oct.-Nov. 2003 shutdown. Cross talk was measured at 9% in PES data and 6.1% in PPR data when it should be less than 1%. The additional cross talk was due to an air gap between the optical fibers and the MAPMT photocathode, allowing light to travel to other pixels. This was corrected by inserting baffles into the gap. After the baffle installation, cross talk was reduced to 1.4% in the PPR. Source data indicates that the average decrease in signal response is 8.6%, and for the PES sourcing an additional 8.4% decrease in peak response is due to cross talk reduction. Although cross talk has been reduced to much lower levels, it is still a function of MAPMT gain and/or light intensity. This effect invites further investigation.

9 Acknowledgments

Reducing cross talk turned out to be a much bigger job than anyone anticipated. We would like to thank many people for their role in making it happen: Craig Lerette for playing a huge part in installing the baffles and clamps onto the detector; Nikolay Luzhetskiy for his work on preparing the test stand and taking measurements; Pat Richards, who constructed two sets of optical connectors to use on the test stand; Yoshio Ishizawa for measuring cross talk on the PPR; Alexei Sedov and Oscar Gonzalez for taking source runs when we needed it; Gary Drake who met with us to discuss the SMQIE chip; and Yangheng Zheng for supervising baffle and clamp production in the UCLA machine shop.

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