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Calibrating the Endplug Shower Maximum Detector (PES)

Alon Attal, Peter Dong, Jay Hauser, Mike Lindgren
Martin von der Mey, Brian Mohr, Benn Tannenbaum
University of California, Los Angeles, USA

Abstract

The Plug Shower Maximum detector is designed to aid in the position and energy measurement of electromagnetic showers in the endplug calorimeter. It uses multi-anode photomultiplier tubes (MAPMTs) to read out scintillator strips located behind ≈ 6 radiation lengths of material. The strips, fibers, and MAPMTs of this detector have characteristics which require a variety of calibration constants. This note describes these constants, details how they are measured and explains how to make them available to reconstruction software.

1 Introduction

The Plug Shower Maximum or Plug Electron Strips (PES) detector [1] is segmented into eight 45^0 sectors (octants) per plug and is located behind ≈ 6 radiation lengths of material. Each octant consists of two layers, u and v, oriented at $\pm 22.5^0$ with respect to the radial dimension. Each layer is constructed of 200 5 mm wide by 6 mm deep strips of scintillator wrapped with aluminized mylar. The strips are installed such that the detector is segmented into low ($1.13 < |\eta| < 2.60$, 1-170) and high ($2.60 < |\eta| < 3.50$, 171-200) η regions.

The 6400 strips are read out with wavelength shifting fibers. The fibers are inserted in a groove along the scintillator strips and are connected to clear fibers via optical connectors. The clear fibers are connected to 416 Hamamatsu R5900-M16 multi-anode photo-multiplier tubes (MAPMTs). These 16 channel MAPMTs are read out using custom electronics [2] which are connected to the CDF data acquisition system. Figure 1 shows the geometry of the detector as viewed from the interaction point. Layer 0, the gray strips, are closer to the IP than the layer 1 strips. Note that strip 171 is physically aligned with strip 1, strip 172 is aligned with strip 2, etc. Also shown in this figure are the locations of the source tubes.

Further details of the specification, design and construction of the PES can be found in the CDF II Technical Design Report, Reference [3].

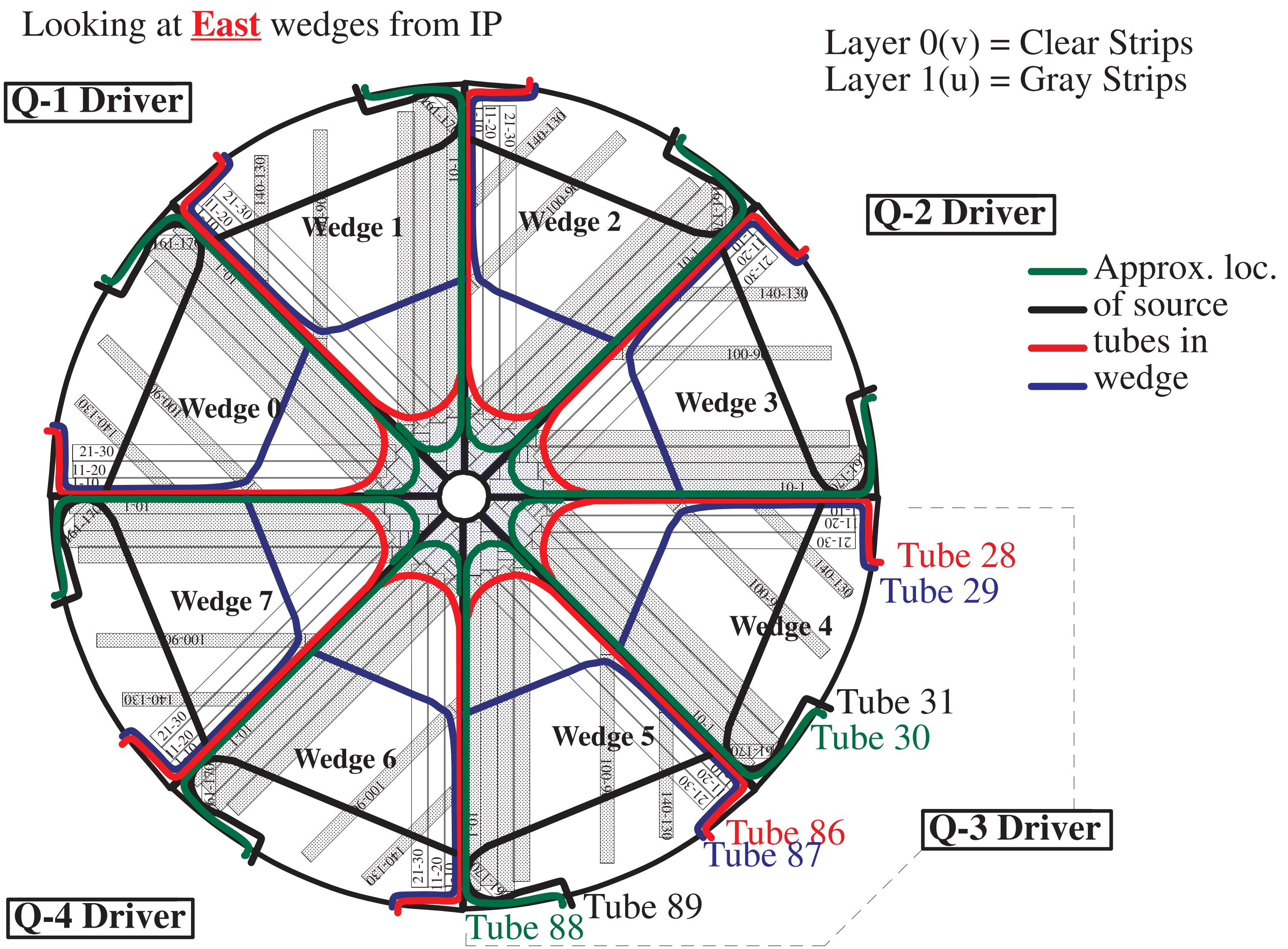

Figure 1: Drawing of the strips in the East endcap, as viewed from the interaction point. Note that strip 171 is physically aligned with strip 1, strip 172 is aligned with strip 2, etc.

The MAPMTs' compact structure allow one to pack a large number of optical channels into a small space. However, with MAPMTs one must be concerned with not only tube-to-tube gain variations and non-linearity, but also pixel-to-pixel gain variations and cross talk between the 16 channels in an MAPMT. These effects are all reproduceable and can be corrected in offline software. Each tube has slightly different characteristics and thus one must have calibration constants for each pixel in the system. Also, corrections are necessary in the offline software to the reported position of a shower to align the shower maximum detector with the central outer tracker. This correction requires another set of calibration constants. This note describes the form of these constants along with the proceedures to calculate and apply them.

Information on the status of the PES can be found in [4].

2 Calibration Techniques

The phototubes used in this system were originally calibrated and selected using a test stand at UCLA. This facility allowed us to determine the cross-talk, pixel to pixel gain variations and the initial high voltage settings. Twelve phototubes were returned to Hamamatsu Corporation and replaced. The test stand is described in Appendix A.

Currently, the PES has four calibration proceedures: The first three are used to calibrate the individual channels (pixel and readout electronics) and the fourth the higher-level reconstructed objects. Pixel and readout electronics calibrations are done with laser flashers, radioactive sources and min-bias data. The laser flasher measures short-term drifts for a single MAPMT pixel, and the source calibration provides relative gain measurements for most pixels and information about dead channels. Pixels not calibrated with the radioactive source are calibrated with min-bias data. The reconstruction level calibration, alignment of cluster position relative to the COT, uses a very clean plug electron dataset. Note that additional calibrations are necessary for the front-end electronics; they are described in [5].

2.1 Laser Flasher

The laser system is used monitor short term tube-to-tube variations in gain. In principle, it can also be used to measure changes in the non-linearity of the tube response. Because only a single pixel is illuminated, it cannot be used to determine pixel-to-pixel gain variations. Further, at present, the light output varies from MAPMT box to MAPMT box[1]. Every phototube in the system can be pulsed.

The system uses two pulsed nitrogen lasers (emission wavelength = 337 nm), one for each endplug. The light from each laser illuminates a bar of scintillator. Green WLS fibers collect the light from the scintillator and distribute it to pixel 9 of each MAPMT. The lasers are flashed with a 5 ns pulse width at 10 Hz. Additional details of the laser system are in Reference [6].

[1]The MAPMTs are arranged in 12 boxes around the perimeter of each endplug and hold 17-18 tubes each.

To monitor variations in gain, several flashes are averaged. Both the average and RMS response variation are stored. Additionally, when the laser is turned off, the pedestal for each individual strip is measured and stored in the database. The laser flasher system has been tested but software needed to calibrate the PES is currently under development. However, we have software to histogram and compared the values stored in the database for laser calibration runs.

2.1.1 DBANA package for PESLASER2

Laser calibration runs store constants in the PESLASER2 database table (described in section 3). We have developed software as part of the DBANA package [7] to examine these constants. It is available in DBANA for software release 6.1.0 and greater.

The interface allows a range of dates to be chosen and produces a list of all laser runs taken in that run range. Different modules provide information about the response of the photomultiplier tubes (PMT), each of the three PIN diodes, the average PIN diode response, and the ratio of the PMT and the PIN diodes. The PIN diodes are used as a reference point so that the ratio of the PMT and PIN diodes should constant.

To run DBANA for the PESLASER2 database, select the package for PESLASER2 from under the "Detectors" menu, in the "ShowerMax" subsection. The various modules for PMT and PIN diode options are available for single, double or multiple runs.

If one run is selected, choosing one of these options from the "Single" menu will show the mean and RMS of each channel, each displayed as a two-dimensional color plot and a one-dimensional histogram, as well as histograms for each plug separately. See figure 2 for an example of this output. The PMT two-dimensional graph will show a checkered pattern at the bottom which corresponds to the placement of the MAPMTs in their boxes. If two runs are selected, the options from the "Double" menu display the difference in mean and rms between those two runs, again as a color plot and one-dimensional histograms. See figure 3 for an example of this output.

Selecting more than two runs allows the use of the "Time History" option in the "Multiple" menu. This produces plots of the mean and RMS for a given box and MAPMT as a function of run number. To use it, simply choose a variable from the first box (the same options as the other commands are available), then select the plug, box, and MAPMT in the remaining boxes. Click the "Run" button to display the graphs If the "All" option is chosen under either the box or MAPMT menu, the program will produce a series of graphs including all of the boxes for a given MAPMT number or all the MAPMTs in a given box. If both are selected, it will generate plots for all boxes and all MAPMTs. See figure 4 for an example of this output.

Selecting the "Outlier Suppression" box removes all values of zero from the plots and zooms the vertical axis to only display values within one standard deviation of the mean. This is useful for viewing the data from a large number of boxes and MAPMTs without having to adjust the zoom manually. Selecting the "PostScript output" box will produce all the graphs as a PostScript file with the name DBANA-PESLaser2_output.ps.

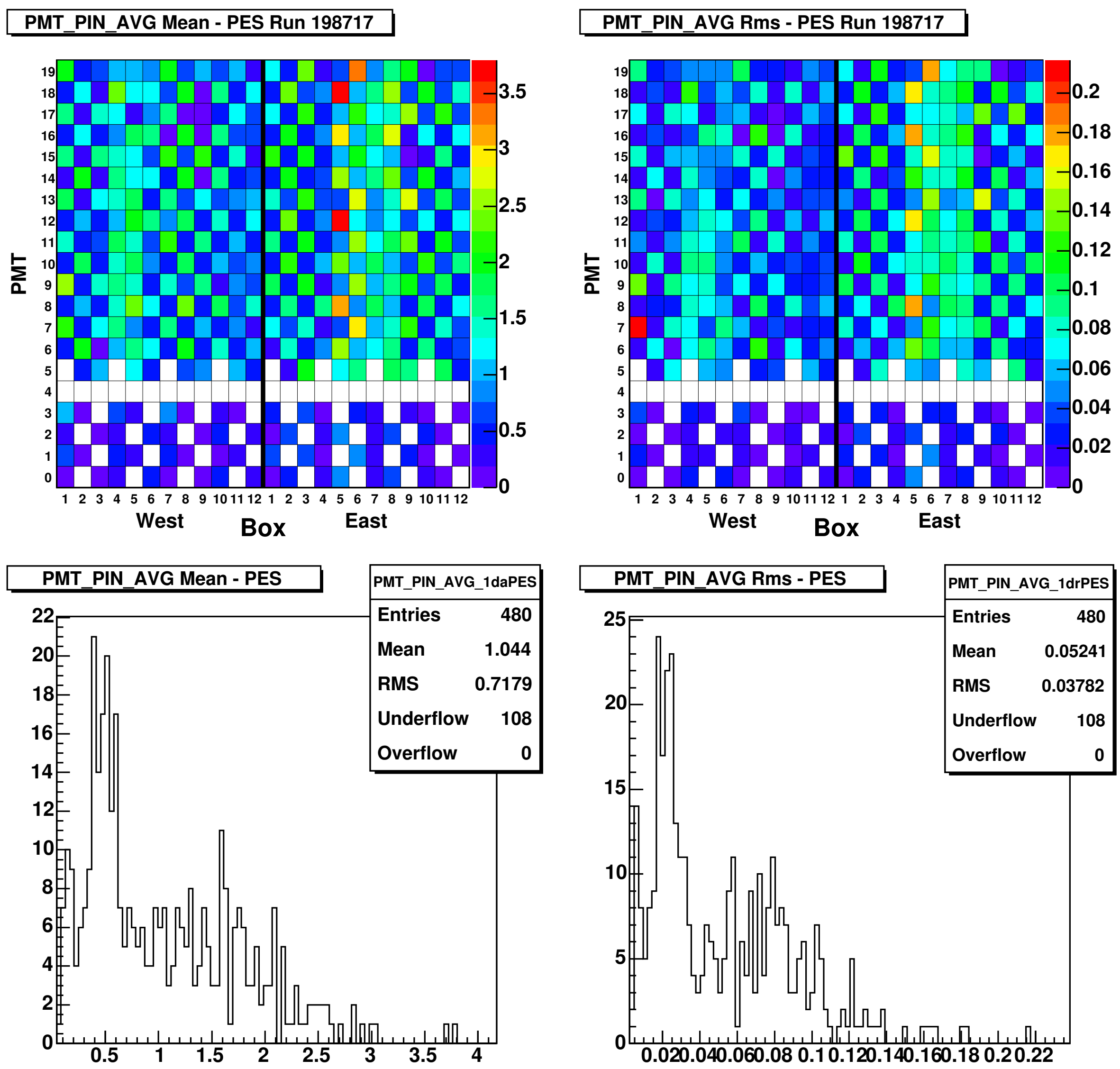

Figure 2: *Sample DBANA plots for a single laser run. Top left shows the mean of the response of the MAPMT in ADC counts divided by the response of the pin diodes in ADC counts for each MAPMT. Top right shows the RMS of the response of the MAPMT divided by the response of the pin diodes for each MAPMT. Bottom left and bottom right show the respective distribution of these quantities for all MAPMTs.*

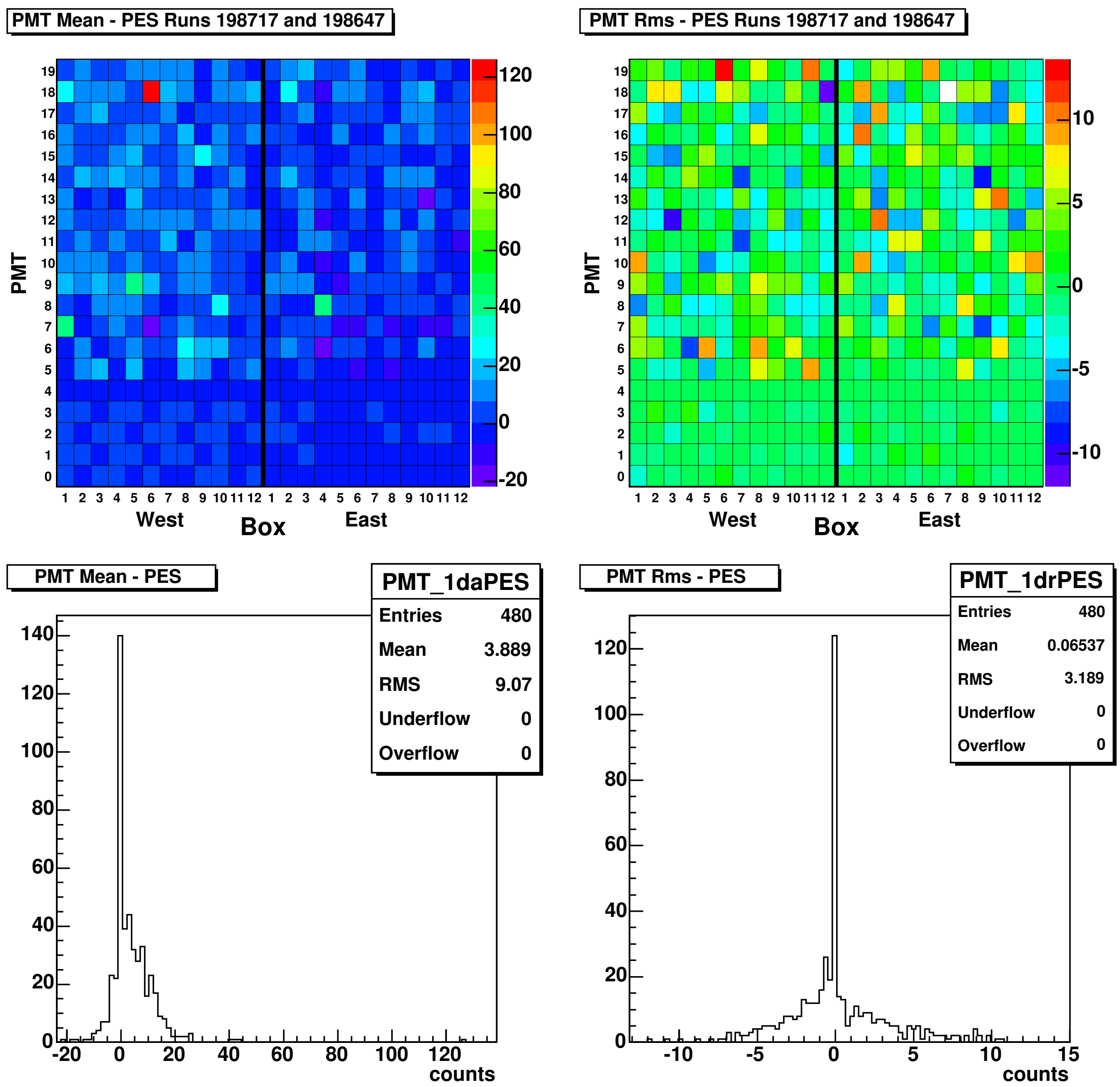

Figure 3: *Sample DBANA plots for double laser runs. Top left shows the difference in the mean response of the MAPMTs in ADC counts between two runs for each MAPMT. Top right shows the difference in the RMS of the response for each MAPMT. Bottom left and right show the respective distribution of these quantities for all MAPMTs.*

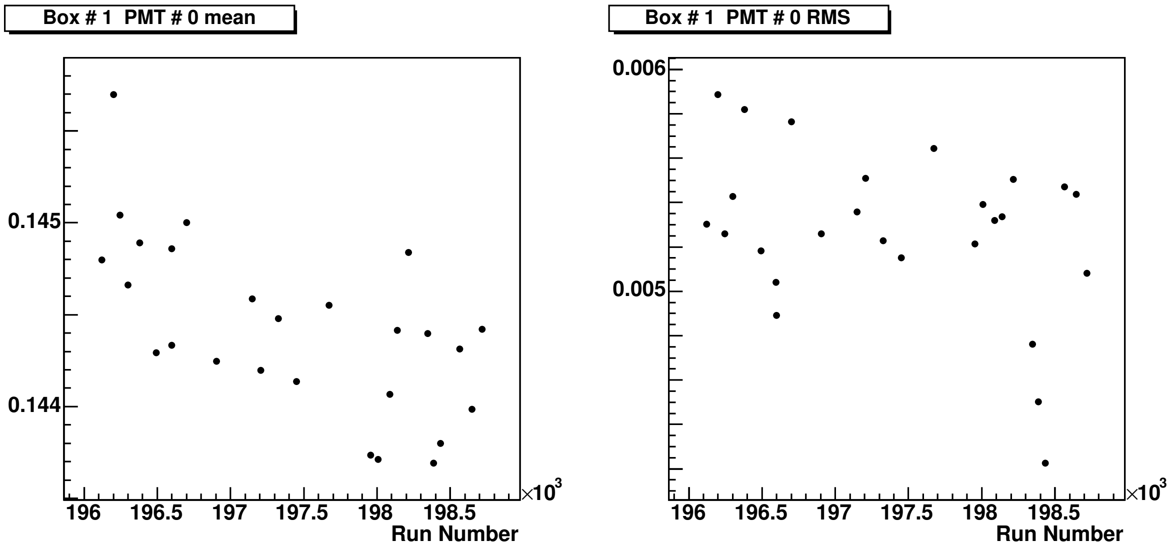

Figure 4: *Sample DBANA plots for multiple laser runs. Plots show a time history (based on run number) of (left) the average response of a single MAPMT and (right) the RMS of the response in ADC counts.*

2.2 Radioactive Sources

The source system is used to calibrate the detector and to monitor both long-term pixel-to-pixel gain variations and damage to the scintillator. This calibration technique uses a radioactive Co^{60} pellet-source on a wire. Each endplug has four source drivers, each of which services two 45^0 wedges. The sources are moved through the detector at a speed[2] of 100mm/sec. The relative strengths of the sources are listed in Table 1. Each pellet can be moved through one of many source tubes [8]. The four tubes for each octant of the PES are placed to illuminate as much of the detector as possible.

Quadrant	1	2	3	4
East	1.0	1.0800	1.0493	1.1064
West	0.9252	0.9124	0.8567	0.7947

Table 1: Relative strengths of the Co^{60} sources used to illuminate strips.

During source testing, the electronics are run in DC current mode. The input to the front end electronics is switched so that the input current from the MAPMT is converted to a DC current. This current is multiplied in amplitude by a factor of 1000, since signals from

[2]The source is inserted at roughly constant speed. The retraction proceedure is more complex: the source is retracted some distance, re-inserted a short distance, and then retracted again. This is done to reduce tension in the wire spool.

the sources are quite weak compared to the signal from actual data (1.173 and 1.333 MeV photons versus multi-GeV objects). The system is read out using the on-line data-taking computers, with an MRKD radioactive source driver bank readout rate of 10 Hz and a PESD bank readout rate of 100 Hz. We use the MRKD bank to determine the position of the source and the PESD bank to determine the signal from the source for a given event. By correlating the two, we get a measure of source position versus signal strength for each strip. To determine the maximum response for a particular strip, we first average the three charge measurements around the insertion and extraction peaks. The response is then the average of the averaged insertion peak with the averaged extraction peak.

Most channels are sourced, allowing this system to be used to monitor pixel-to-pixel drift. It is time consuming and thus is done only during shutdowns and access periods. The source tubes run both parallel and perpendicular to the scintillator strips (see Figure 1). Careful study of this data allows us to adjust the MAPMT voltages and the offline pixel-to-pixel corrections, as well as determine any change in attenuation length or the overall energy scale.

The design and location of the source tubes is such that all strips can be illuminated. However, we find this not to be true. As the system ages, the friction between the source tubes and the source increases. Because of the fear of that a source may get stuck in a tube, the sources are not sent all the way to the end of the tube. This means strips at the end of the tubes will not be illuminated and thus cannot be calibrated using this technique.[3]

2.2.1 High Voltage settings

For strips which are reached by the sources and perpendicular to the source tubes, the strip response can be accurately calculated. We use this information to determine both the correct high voltage settings and the pixel-to-pixel gain variations. This is done by calculating the response as described below (see Figures 5 and 6), and subtracting the pedestal. The two peaks in Figure 5 correspond to measurements taken during source insertion and source extractions and should be identical. As shown in Figure 6, the majority of peaks are identical[4] and the remainder have less than a 5% difference.

To determine the high voltages settings, we examine the response of all strips from the source tube nearest the readout end of the strips and compare to the desired response. We define the phototube response G to be the median[5] response of all illuminated pixels in a tube. This prevents channels with anomalous gains from having a large effect on the calibration. To properly calculate the response, we divide the PES into four regions: high

[3] We already see this behavior in all of the high eta sections.

[4] In an ideal system, they would not be identical, as the probability of measuring exactly the same response during both insertion and extraction is vanishingly small. During signal digitization, 8 ranges are used. Each successive range has half the resolution of the previous one. The integral 5 bit FADC resolution of 3% is larger than the typical insertion-extraction response difference. Since we are dealing with large signals, our resolution is about 32 ADC counts, which is more than the difference between peaks. This is why Figure 3 has so many 0 entries. Also, note the small peak around 1.5%. This is when the peak value is right on the edge of a range.

[5] If an even number of pixels in a phototube are measured, we use the average of the $\left(\frac{n}{2}\right)$th and $\left(\frac{n}{2}+1\right)$th highest pixels.

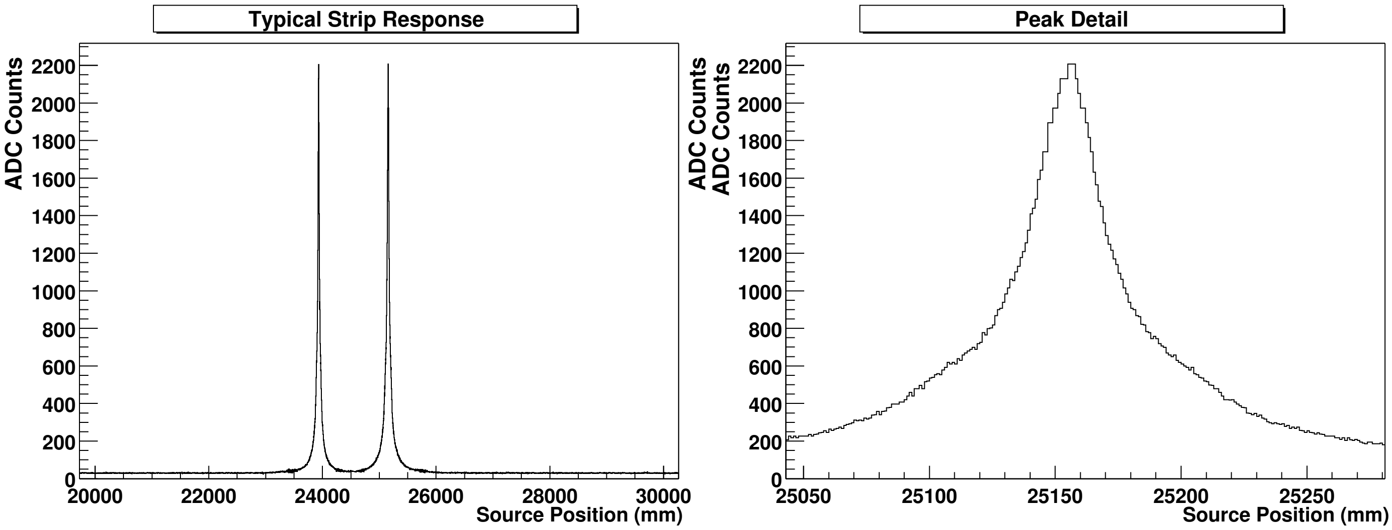

Figure 5: *Typical response as a radioactive* Co^{60} *source is moved across a single strip (left) and detail of one of the peaks (right). The plots show the motion of the source; the x-axis is the total distance the source has traveled.*

and low eta, and u and v layers. After analyzing test stand values where the voltage was known for different gains, we determined the functional form to be

$$\Delta V = \frac{\Delta \ln G}{\alpha} \tag{1}$$

where $\alpha = .016V^{-1}$ from fitting to the test stand data. Two rounds of PES sourcing in Fall 2001 were sufficient to remove significant variations among the MAPMTs. Figure 7 shows the distribution of strip responses before and after the high voltages were changed. Line a) shows the response prior to high voltage tuning, and line b) shows the response after the high voltages were adjusted. The high voltages for the high eta strips are set such that the ratio of the gains of the low and high eta strips is five.[6] Note that all the u layer strips in a given region should have the same response, which is different from the response of the v layer strips.[7] This is because the u layer is further from the source than the v layer. (Note that in CDF collision data, the opposite is true.)

2.2.2 Gain Corrections

Since pixel response within a given phototube can vary by up to a factor of three, we use offline corrections to improve detector uniformity. Each strip is compared to the average for all strips in that high- or low-η region and u- or v-layer. The gain correction for a given strip is calculated as the ratio of the average response to the measured response. Note that since we are correcting to an *average* response and not a maximum response, the gain corrections can be larger than 100%. Line c) in Figure 7 shows the distribution of strip responses after the latest gain corrections were applied.

[6] For Figure 7, the high- and low-eta strip response has been normalized.

[7] For Figure 7, the u- and v-layer response has been normalized.

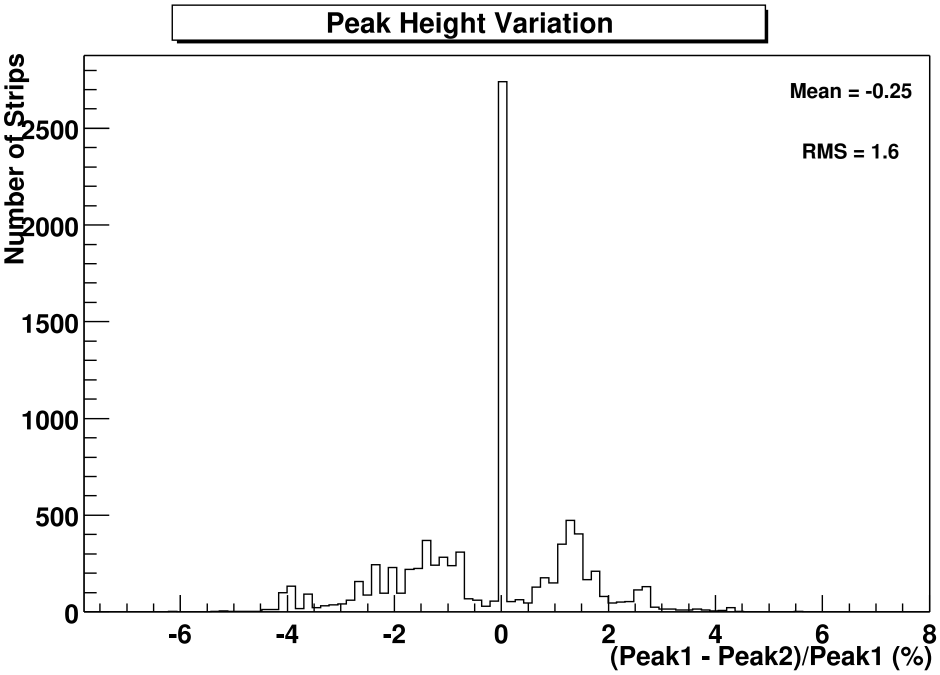

Figure 6: *Difference between insertion and extraction measurements.*

2.2.3 Corrections for Strips without Source Constants

Radioactive source gain corrections cannot be computed for every strip in the detector due to limitations discussed earlier. To calibrate the remaining strips, min bias data is used. Corrections are calculated by dividing the average energy of the uncalibrated strips by those calibrated by the radioactive source. In order for this method to be successful, care has to be taken so that all detector and statistical effects are minimized.

The average energy of each strip is calculated by taking all events in a given run below a threshold value and dividing by the number of events. A truncated distribution is used so that single events do not change the average. The threshold was chosen to be 2 sigma above the mean for both the high and low eta regions.

Each 45 degree wedge has strips labeled 1-200. This means that for every strip, there are 15 others that are identical in length and position. If these 15 strips are calibrated, there the gain is calculated with the average of the calibrated strips as the reference. For some strips, especially in the high eta region, the reference signal must be determined from strips that are similar but not identical to the uncalibrated strip.

2.2.4 Attenuation Length

For a small subset of strips, the radioactive source runs parallel to the length of the strip. Additionally, many strips are crossed by more than one source tube. This gives us two ways to measure the attenuation length in the WLS fiber: by examining the response as a function of source position and by comparing the response from two source tubes for each strip. To determine the attenuation length, we examine multiple strips and fit the result from each to

$$I = I_0 e^{-x/\lambda} \tag{2}$$

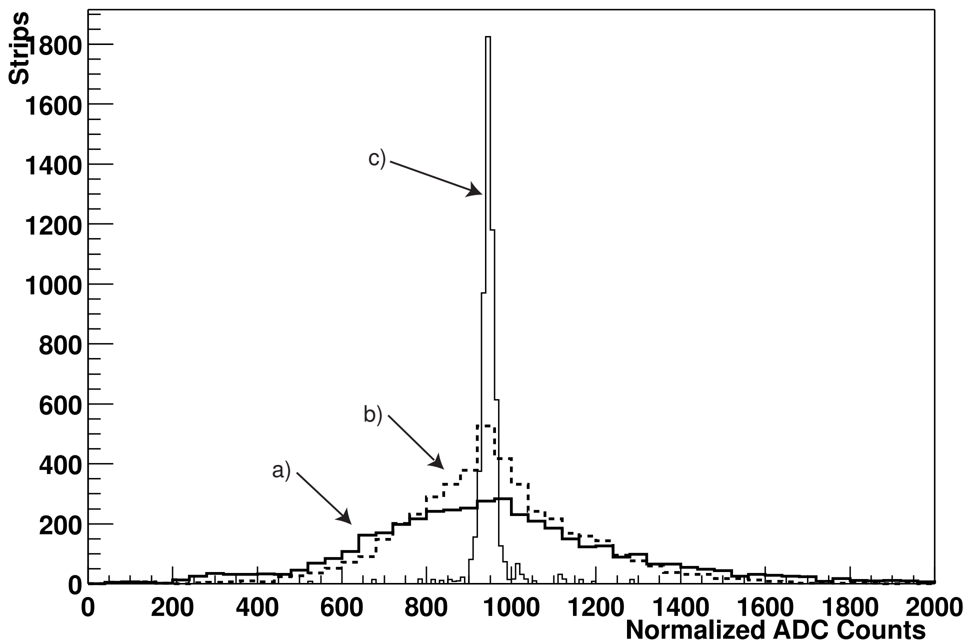

Figure 7: *Response of all strips in the system (a) before, and (b) after the high voltages were changed, and (c) after pixel-by-pixel gain corrections were applied. For (c) we plot the phototube response, scaling a given tube by the number of strips it serves. Note that for this plot, the high- and low-eta regions, and u and v layers, have all been normalized.*

where I_0 is the intensity when the source crosses the strip at the end nearest the MAPMT, I is the intensity at x, x is the distance along the strip from the near end to the source, and λ is the attenuation length. A fit to all the measured $1/\lambda$ is shown in Figure 8. We find $\lambda = 337 \pm 3$ cm.

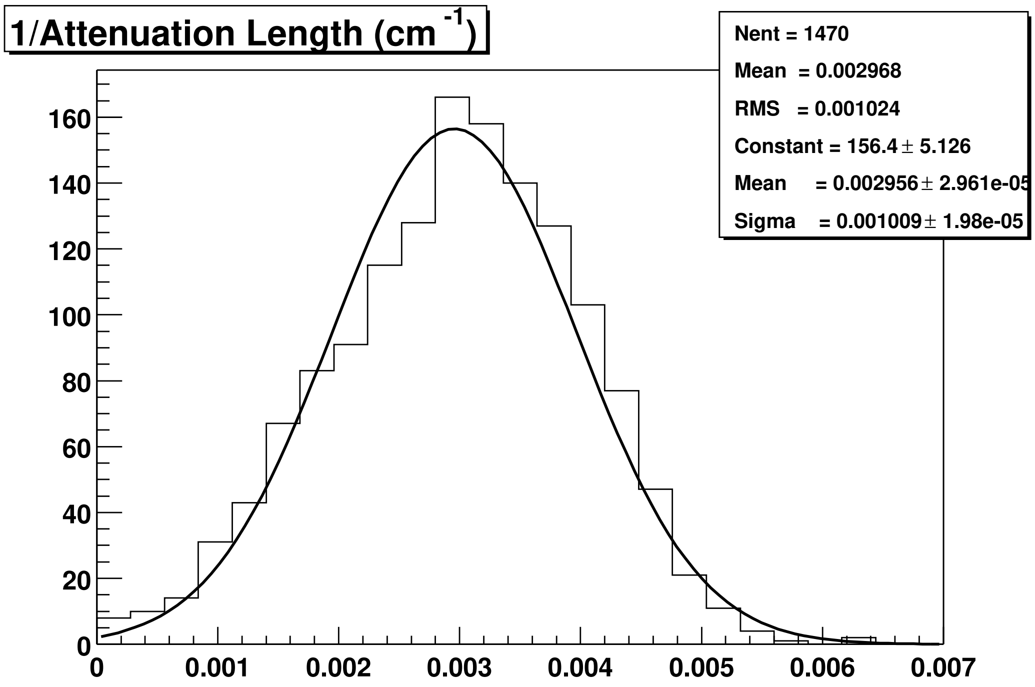

Figure 8: *Fit to many measurements of 1/attenuation length.*

2.2.5 Energy Scale

We also determined the overall energy scale to be 14.5 MeV/count for the low-eta section and 72.5 for the high-eta section. This factor is used in the offline reconstruction code (and also in the Level 3 trigger). We determine this scale factor using test beam data. During the test beam, 57 GeV positrons were fired at a 45^0 wedge of the PEM, including the PES. An average of 3620 counts/PES cluster were recorded on the u layer and 2700 counts/PES cluster on the v layer, for an average cluster response ($= (u + 1.2v)/2.2$) of 3120 counts [11] and 18.3 MeV/count. When the PES was sourced using a Cs^{137} source[8], 5150 counts were recorded on the layer closest to the source. The readout electronics used for the test beam had a gain of 11 pA/count, resulting in an average current of 57 nA on that layer.

When we source the PES in the CDF collision hall with a Co^{60} source[9], we see an average of 2100 counts on the layer closest to the source. Using electronics with a nominal readout gain of 151.0 ± 0.3 pA/count (assuming the gain of the charge channel is 20 fC/count with a 132 ns clock [13]). This results in an average current of 315 nA.

The relative Co^{60} to Cs^{137} source strength was, on 1 January 1997, 4.6 [12]. Another source run was taken 19 October 2001, so the relative source strength is reduced by a factor of 0.53, to 2.4. Thus, to compare the two source runs, we need to increase the test beam current by 2.4, to 137 nA. The ratio of current from *in situ* sourcing to test beam sourcing is thus 315nA/137nA = 2.3. Additionally, the electronics used during test beam had a sensitivity of 11 fC/count, while the Run II electronics have a sensitivity of 20 fC/count. That gives an energy scale of

$$\frac{18.3\ \text{MeV/count} \times 1.82\ \text{(relative electronics sensitivity)}}{2.3\ \text{(relative source strength)}} = 14.5\ \text{MeV/count} \tag{3}$$

Recall that we adjusted the voltage of the tubes servicing the high-eta section such that the gain is five times that of the low-eta section; this means the high-eta section has an energy scale of 72.5 MeV/count.

2.3 Channel Status Information

We now store information about the status of each channel in the database. Although this information is not currently used in cluster reconstruction with the energy weighted mean, we hope to include it soon in the new lorentz fit [14]. At the moment, the status bits we store indicate dead channels, channels with known low response and channels with incorrect cabling on the detector ("cable swaps"). However, there is room for additional status bits in this table, and we are currently working on software to identify run ranges with hot channels.

Dead and low response channels are located primarily with source data. Channels with exactly zero counts are marked "dead," and channels with fewer than 200 counts are marked "low count." The nominal strip response is 2000 counts. Since the sources do not reliably

[8] Cs^{137} emits a 0.662 MeV γ and has a half-life of 30 years.

[9] Co^{60} emits a 1.1 MeV γ and a 1.3 MeV γ and has a half-life of 5.3 years

reach all the channels, we only flag channels not responding similarly to their neighbors, assuming a large region of dead or low response channels indicates poor source coveage. Also, we compare the sourcing information with data (YMon) – any channel in YMon reading zero occupancy or raw counts is marked dead.

The final "dead" status is the combination of the source and YMon information. If either of these methods shows a channel to be dead, we flag it as such. We currently have 71 out of 6400 channels marked dead, but there is some run dependence to the dead channels. During the baffle installation of the 2003 shut-down, we attempted to restore some of the dead channels and regained 15 previously unreporting channels, see [9] for details. Also, during the shutdown starting in February 2006, work was done to recover channels. Preliminary estimates suggest the number of dead channels has been reduced by a factor of 3. Before the 2006 shutdown work, we had 27 channels flagged as having low response.

Cable swaps are accounted for in the reconstruction software and have not been seen to affect performance of the detector in any way. They are included for completeness. A list of cable swaps can be found in Table 2.

West Octant 2	
21-30 V	41-50 V
West Octant 3	
71-80 U	111-120 V
81-90 U	101-110 V
101-110 U	81-90 V
131-140 U	51-60 V
141-150 U	31-40 V
161-170 U	191-200 V
East Octant 6	
21-30 V	41-50 V

Table 2: Optical cable swaps.

2.4 Reported Position Alignment

The offline software reconstructing showers in the PES measures the position of the shower relative to the PES detector. We adjust these coordinates with alignment constants such that they are relative to the Central Outer Tracker (COT). The COT is the standard origin for coordinates in the CDF detector. The proceedure for calculating shower position relative to the PES and then calculating the alignment offset is described below.

PES reconstruction software has recently undergone some revision [14]. Among other things, these revisions modified the geometry of the position calculations and the application of alignment constants. Alignment constants for the previous version of software have been calculated [10], but they are invalidated by the recent modifications. We introduce new constants in the same spirit as those of [10] that are valid for the modified reconstruction software.

2.4.1 PES Cluster Reconstruction

Currently, reconstruction software uses an energy weighted mean as the standard method for clustering strips within a shower. This mean is calculated individually for the stereo U and V layers. A geometry calculation uses the means from each layer to calculate the two-dimensional position in $r-\phi$ space of the shower. The PES detector is approximately all at the z-coordinate. We calculate the mean using the energies of each channel corrected with the gain calibrations, E_i, and the position of each strip in the octant, x_i:

$$x_0 = \frac{\sum_{i=0}^{8} x_i E_i}{\sum_{i=0}^{8} E_i}, \tag{4}$$

where the sums are over a standard 9 strips per cluster. Using the means from layer 0 and 1, x_0 and x_1, respectively, the uncorrected x and y coordinates are calculated from:

$$\begin{aligned} x_{uncorr} &= x_1 + \sqrt{2}x_0 \\ y_{uncorr} &= x_1 \end{aligned} \tag{5}$$

We then calculate corrections to these coordinates due to the physical separation of the layers, $\Delta z = 0.31$ cm:

$$\begin{aligned} \Delta x_0 &= \Delta z \tan\theta_{\mathrm{uncorr}} \cos\phi_{\mathrm{uncorr}} \\ \Delta x_1 &= \Delta z \tan\theta_{\mathrm{uncorr}} \cos\phi_{\mathrm{uncorr}} \end{aligned} \tag{6}$$

Here, r and ϕ are calculated from the uncorrected cartesian coordinates in the usual manner and θ is calculated from the r-coordinate and the z-position corrected for the event vertex. The corrections to the single layer clusters, Eqn. 6, are applied with a sign dependent on the plug in which the shower occured. After these corrections, the local coordinates are recalculated with Eqn. 5 for the final estimation of the shower position relative to the PES octant.

Once the coordinates relative to the PES octant have been calculated, they are rotated based on the octant's position in the PES and adjusted with the alignment constants to be relative to the COT. Some of these operations are performed concurrently. In the current operation of the software, we have alignment constants in r and ϕ specific to each octant (local), and constants in x, y and z for each plug as a whole (global).

When applying the alignment constants, the coordinates local to the octant are first rotated by an alignment corrected angle given by

$$\phi_{corr} = \frac{\pi}{4} N_{oct} + \phi_{offset}, \tag{7}$$

where N_{oct} is the octant number. They are then rotated to global coordinates with

$$\begin{pmatrix} x_{glob} \\ y_{glob} \end{pmatrix} = \begin{pmatrix} \cos\phi_{\mathrm{corr}} & -\sin\phi_{\mathrm{corr}} \\ \sin\phi_{\mathrm{corr}} & \cos\phi_{\mathrm{corr}} \end{pmatrix} \begin{pmatrix} x_{corr} \\ y_{corr} \end{pmatrix}. \tag{8}$$

Once we have the corrected x and y-coordinates, we apply the local r-offset:

$$\begin{aligned} x_{glob} &= x_{glob} + r_{offset} \cos(\phi_{\text{corr}} + \frac{\pi}{8}) \\ y_{glob} &= y_{glob} + r_{offset} \sin(\phi_{\text{corr}} + \frac{\pi}{8}) \end{aligned} \tag{9}$$

Finally, we apply the global x, y and z-offsets:

$$\begin{aligned} x_{glob} &= x_{glob} + x_{offset} \\ y_{glob} &= y_{glob} + y_{offset} \\ z_{glob} &= z_{plug} + z_{offset} \end{aligned} \tag{10}$$

where z_{plug} is the assumed z-coordinate of the plug, currently a distance of ± 185.4 cm from the origin.

2.4.2 Fitting Alignment Constants

The alignment constants are determined by comparing the reported position of the PES to that of tracks extrapolated to the z-coordinate of the plug. We use a high purity, high p_T plug $W \to e\nu$ sample with the tight cuts on track quality listed in Table 3. Use of the COT in tracking gives greatly improved precision to tracks extrapolated to the plug compared to silicon stand-alone tracks. We use tracks with COT and silicon created with the outside-in 3D or outside in stereo algorithms. Track extrapolation is performed with *SimpleExtrapolatedTrack*.

When fitting the alignment constants, we use Minuit to minimize the reduced standard deviation of the difference (residual) between the extrapolated track and PES cluster positions. Differences larger than 40 cm are ignored when calculating the deviations. Also, all clusters with non-zero status bits were removed. We fit the alignment constants in the opposite order they are applied – starting with the global x, y and z-offsets, and then the local r and ϕ offsets for each octant individually.

$Iso4/E_T < 0.1$
E_{HAD}/E_{EM} const.-efficient
PEM 3x3 $\chi^2 < 10$
$E_T > 20$ GeV
$\not{E}_T > 15$ GeV
$0.8 < E_{EM}/p_{track} < 1.2$
$N_{st\ seg} \geq 3$
$N_{ax\ seg} \geq 3$

Table 3: Selection criteria for high P_T plug W sample with high quality tracks.

SimpleExtrapolatedTrack assumes a constant magnetic field across the beam line of the detector, a good approximation only to about $|z| < 100$ cm. At the location of the PES detector, about 185 cm, the strength of the magnetic field is reduced to about 12.5 kGauss from

14 kGauss at the center of the detector. Also, the default version of *SimpleExtrapolatedTrack* extrapolates in a straight line after $|z| = 150$ cm. We modified *SimpleExtrapolatedTrack* so that it would account for a constant magnetic field past the plug when extrapolating tracks and compared it to *Mextrapolator*, an extrapolation tool correctly accounting for the varying magnetic field written for muon extrapolation. Figure 9 shows the difference between the two extrapolation techniques is at most 0.02 cm in $r\Delta\phi$ and minor in Δr. The small effect in $r\Delta\phi$ is an order of magnitude smaller than the expected resolution in this dimension, so we ignore the effects of the non-constant magnetic field strength and use *SimpleExtrapolatedTrack* for track extrapolation.

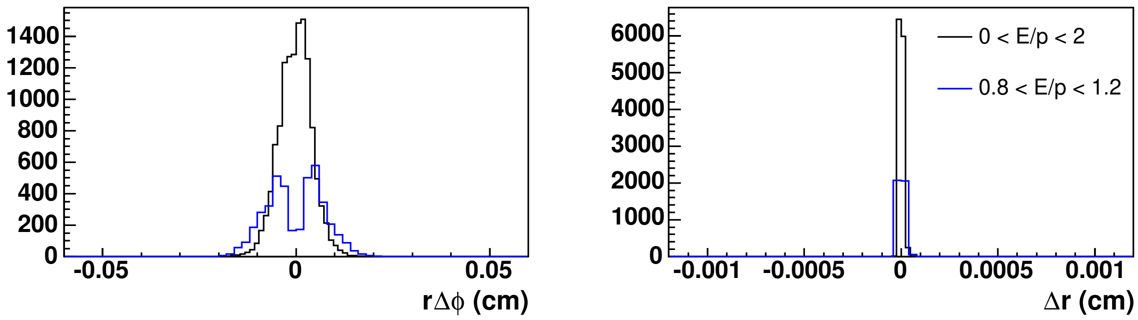

Figure 9: Difference between *SimpleExtrapolatedTrack* and *Mextrapolator* track extrapolation methods for plug electrons extrapolated to the PES with two different E/p cuts.

Tables 4 and 5 summarize alignment constants fit from data taken from run 175150 to run 186188 in the period between the 2003 and 2004 shutdowns ($\mathcal{L}$= 250pb^{-1}). Figure 10 shows residuals for this data with the latest alignment (in reconstruction software version 6.1.0) and the previous alignment (in reconstruction software version 5.3.3). We see an insignificant improvement in $r\Delta\phi$ and in Δr with this alignment compared to the previous one. We also see comparable results with this alignment to that from [10].

	West Plug	Error	East Plug	Error
Δx	0.204	0.003	0.216	0.004
Δy	-0.152	0.005	-0.155	0.004
Δz	0.316	0.008	-1.253	0.007

Table 4: Global alignment constants fit from data (units of cm).

3 Calibration Constants

The calibration constants are stored in the CDF database in four tables, PESLASER, PESCALIB, PESDEADCHANNELS and PLUGALIGNMENT2. The information in these

Octant	West Δr	Error	West $\Delta\phi$	Error	East Δr	Error	East $\Delta\phi$	Error
0	0.023	0.011	-2.427	0.025	0.041	0.009	8.067	0.010
1	0.022	0.010	-2.820	0.009	-0.020	0.004	7.957	0.002
2	0.014	0.001	-2.295	0.004	-0.027	0.010	8.302	0.004
3	0.279	0.013	-2.143	0.063	-0.001	0.001	8.931	0.017
4	0.212	0.014	-2.434	0.005	-0.029	0.001	8.530	0.002
5	0.165	0.002	-2.035	0.001	-0.024	0.001	8.080	0.008
6	-0.094	0.002	-1.056	0.001	0.065	0.004	8.526	0.002
7	0.024	0.001	-1.293	0.001	0.089	0.003	7.772	0.001

Table 5: Local alignment constants (units of cm for Δr and mrad for $\Delta\phi$).

tables is used by the PES offline reconstruction software, documented in Reference [14].

Calibration tables PESLASER and PESCALIB are similar in construct. They each contain 6400 entries, one for each strip in the detector. These entries are labeled with a unique address describing the location of the strip (plug, layer, octant and number) as shown in Table 6.

Bit	Value
0	plug (0 = west, 1 = east)
1-3	octant (0-7)
4	layer (see below)
5-12	strip (0-199)

Table 6: Contents of the address word, used to access a particular entry in the calibration database tables. Note that the *layer* bit has different meanings in the two endplugs: in the west endplug, layer 0 is closer to the interaction region than layer 1, while in the east endplug, layer 1 is closer to the interaction region than layer 0.

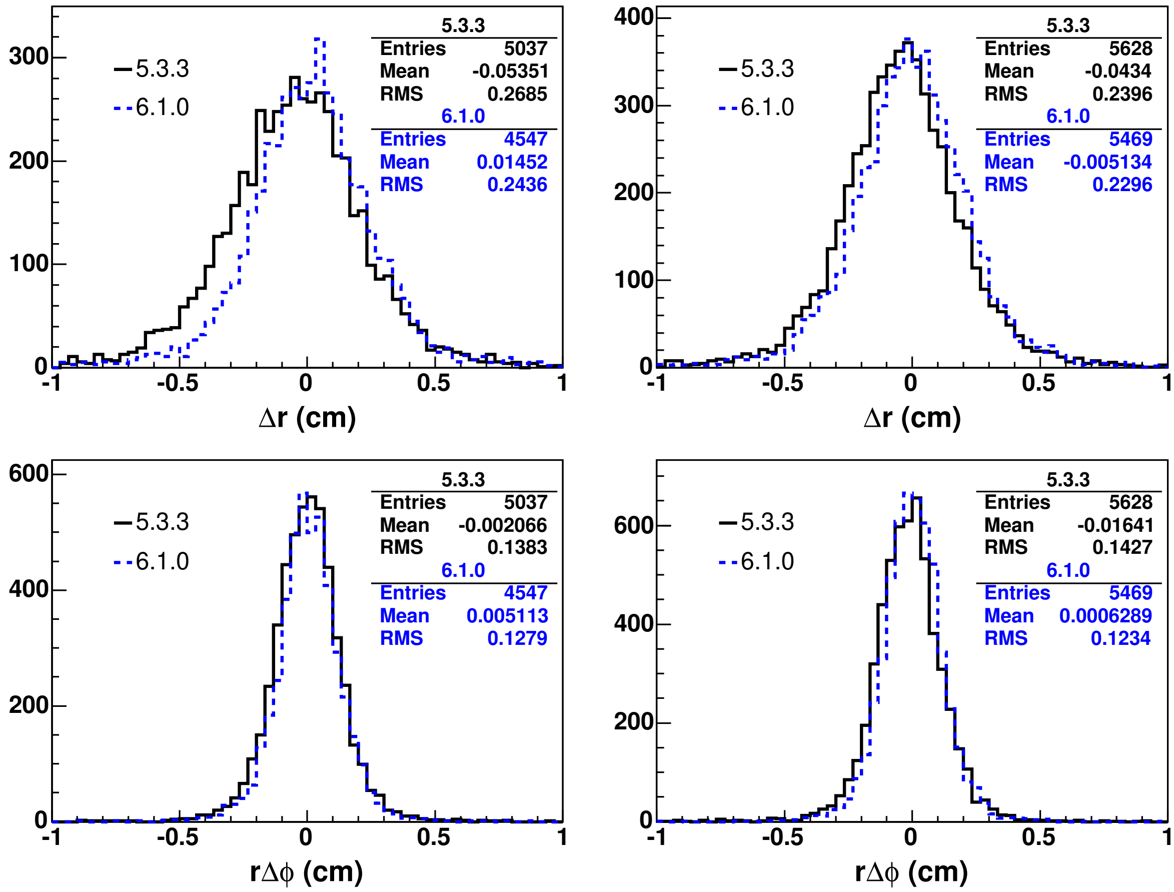

Figure 10: PES cluster position minus extrapolated track position residuals in Δr and $r\Delta\phi$ in the West (left) and East (right) plugs.

3.1 PESLASER

The PESLASER table is no longer used by the reconstruction software. All of its entries are duplicated in the PESCALIB table. A description of this table is included here for completeness.

The four constants in the table PESLASER are listed in Table 7. They are calculated using data from the laser flasher system and are updated prior to each run. The laser and high voltage information is on a tube-by-tube basis and the pedestal is on a pixel-by-pixel basis.

Table Entry	Description	Value	Units
LASERMEAN	Laser correction	Float	
LASERRMS	RMS of the laser correction	Float	
PEDESTAL	Pedestal	Integer (~ 12)	ADC Counts
HIGHVOLTAGE	High Voltage used	Integer ($\sim 550 - \sim 750$)	Volts

Table 7: Contents of the calibration table PESLASER. All 6400 strips in the system have entries in this table.

3.2 PESCALIB

The fifteen constants in the table PESCALIB are listed in Table 8. They are calculated using data from the sourcing system and min-bias data as described in section 2. These constants are updated only after a sourcing has been done, which generally means after long shutdowns.

Note that the entries labeled “ATTENUATION2” and “ATTENUATION3” are not used. At present we use a single parameter to describe the attenuation length of the scintillator; these additional parameters are for any needed future expansion. Because of the nature of the database, the entries will always have these names. However, we can use them as we see fit.

3.3 PESDEADCHANNELS

The PESDEADCHANNELS table contains status information for any channels which are not operating nominally. See section 2.3 for more information. This table is only used in its present form for data after the Nov 2003 shutdown (run 174001), during which new clamping devices were installed and the number of dead channels reduced. Previous to this run, the table contains only information pertaining to dead strips.

Since this table contains entries only for channels with known problems, the number of entries fluctuates. There are two columns in this table: one contains the unique address identification of a channel 6 and the other contains the status information, packed into an integer (Table 9).

Table Entry	Description	Value	Units
GAIN	Gain for a given pixel	Float	
SOURCEMEAN	Raw number for gain	Float	
SOURCERMS	RMS of the source number	Float	
SOURCENORM	overall normalization	Float	
LASERMEAN	duplicated from PESLASER; not used		
LASERRMS	duplicated from PESLASER; not used		
LASERNORM	not used		
LINEARITY1	Parameter for non-linearity	Float	
LINEARITY2	Parameter for non-linearity	Float	
LINEARITY3	Parameter for non-linearity	Float	
PEDESTAL	duplicated from PESLASER; not used		
ATTENUATION1	Attenuation length of the scintillator	Float ($\sim$ 330)	cm
ATTENUATION2	not used		
ATTENUATION3	not used		
HIGHVOLTAGE	duplicated from PESLASER; not used		

Table 8: Contents of the calibration table PESCALIB. All 6400 strips in the system have entries in this table.

Bit	hex	Status
0	0x1	dead
1	0x2	swap
2	0x4	low response

Table 9: Bit packing of the PESDEADCHANNEL status word.

3.4 PLUGALIGNMENT2

The PLUGALIGNMENT2 table contains the alignment constants adjusting the reported shower max position relative to the central outer tracker (COT). It's derived from a previous alignment table PLUGALIGNMENT, not described in any note. Alignment constants are applied in the software reconstruction.

The entries in this table include the old PLUGALIGNMENT entries, which are no longer used, and entries for the current global and local (octant section) constants and their errors. There are four global constants for each plug: Δx, Δy, Δz and $\Delta\phi$. Currently, the global $\Delta\phi$ is not used – the local $\Delta\phi$ for each wedge takes care of the ϕ offset. There are two local constants for each plug and wedge: Δr and $\Delta\phi$. Angular coordinates are measured in radians and linear coordinates are measured in centimeters.

4 Database

This section briefly describes how to update the PES calibration tables in the database and how to create a used/valid set combination such that these constants are picked up in data reconstruction. See [15] for information on the structure of the database. All of the PES calibration tables are stored in the online database *onotl_prd*. Note that all of these proceedures need to be run from *fcdflnx2* or whatever machine has access to the online database.

4.1 Storing constants in the database

This section contains detailed information describing the proceedure to update the calibration tables in the database. Generally, script is used to read constants from a file, access the database and then upload the new constants. Constants can be tested in the development database, *onotl_dev*, before adding them to the production database used for data. Note that a valid set needs to be created after entering new calibrations. Also, a used set pointing to a valid set is necessary for every run. A used set for runs after the current run is automatically generated once a valid set is "marked." However, it is often necessary for used sets to be generated for runs previous to the mark. The proceedure to create valid and used sets is described below after the disucssion of entering constants into the database.

4.1.1 PESLASER and PESCALIB

As described in Sections 3.1 and 3.2, the PESLASER and PESCALIB tables contain similar information, but the PESLASER table is not currently used in data reconstruction. We update the PESLASER table concurrently with the PESCALIB table to preserve the backwards compatibility of our software. At some point, separate calibrations for the PESLASER table may be used. In this case it will be necessary to separate the script to update these tables.

The script to update these tables is in the *CalorCalib* Package. It uses text files as a means to input the calibrations, the details of which can be found in the script. Once the script runs, it will return the status of the attempted write to the database and, if successful, return the *cid* number of the newly created database tables. If unsuccessful, it will report an error message. Detailed instructions follow below.

1. Put all the new constants into a text file, with one line of constants per strip.

2. Check out the package `CalorCalib` into a release area, using the commands

   `% setup cdfsoft2` *preferred version*
   `% newrel -t` *preferred version* `addConstants`
   `% cd addConstants`
   `% addpkg CalorCalib`
   `% addpkg CalibDB`
   `% addpkg ShMaxCalibDBTables`

3. Edit the script *CalorObjects/one-offs/fillPesCalibLaser.cc* to reflect the new arguments for the *RunListKey*. Changes may be necessary to reflect the format of the information in the text file used from which the new constants are read. At the moment the file name is hard-coded. The *RunListKey* contains *db* (database, is always "onotl_prd"), *run* (first run for this calibration), *status* (always "COMPLETE"), and *algorithm* (users choice).

4. It is recommended to edit the GNUmakefile so only the desired executable is built. This speeds up the linking process considerably. To do this, edit *CalorCalib/GNUmakefile* so that *one-offs* is the only directory and change in *CalorCalib/one-offs/GNUmakefile* the `TBINS` line to

   ```
   TBINS = fillPesCalibLaser
   ```

5. Compile and link

   ```
   % gmake CalibDB.nobin
   % gmake ShMaxCalibDBTables.nobin
   % gmake CalorCalib.tbin
   ```

6. Run with `fillPesCalibLaser`.

4.1.2 PESDEADCHANNELS

Updating the PESDEADCHANNELS table is very similar in proceedure to PESLASER and PESCALIB described above. In this case, the script reads three files, one for each of the status bits. The file should contain the plug, octant, strip and layer for each channel with a non-zero status. The script reads these three files, organizes this information into the correct status words and updates the database. The proceedure is identical to the one for PESLASER and PESCALIB except the correct script to use is *CalorCalib/one-offs/fillPesDeadChannels.cc*.

4.1.3 PLUGALIGNMENT2

Updating the PLUGALIGNMENT2 table is similar to the others, except the alignment constants are not read in through a text file, but are hard-coded in the script. It will most likely be convenient to create a format for a text file to be used with this script in the future. The proceedure to update the calibrations is idential to that described above, but the correct script to use is *CalorCalib/one-offs/fill_PlugAlignment.cc*.

4.1.4 Checking Constants Online with Database Browser

1. Select the Database Browser from the link on the FastNavigator.

2. Select `Calibration` from the first menu (`Select a report group to be expanded.`) and click `Submit request`.

3. Select `CAL: Calibration Run Lists` from the first menu (`Select a report to be given or a report group to be expanded.`) and click `Submit request`.

4. Select desired database table from the second menu (`Select calibration table.`) and click `Submit request`.

5. The next page will list all the calibration run lists for that table. Check the date; if all has gone well it will be the date the new information was added. Confirm that the Status is `COMPLETE`.

4.2 Valid and Used Sets

In order for the reconstruction software to be aware of the correct calibration table, the table must be part of a valid set and the data run must have a used set pointing to a valid set. A valid set groups calibration tables together and provides a link to the tables in the database. A used set links a specific run to a valid set and thus to the calibration tables. Note, a used set must be defined for each run for the reconstruction software to operate properly. Since the PES calibration constants are not updated frequently, there are generally many used sets pointing to the same valid set.

Ordinarily, for the PES calibration tables, a used set is generated for each recorded data run automatically by run control. This used set is *L3_PHYSICS_SMX*, and it contains all four tables. This used set is merged into *L3_PHYSICS_CDF* and eventually into a PASS defining used sets for all detector subsystem calibrations. In the automatic used set generation, the used set is created pointing to the most recent "marked" valid set. If a calibration is intended only for runs in the future, all that is necessary is to create a new valid set with the latest tables and then mark it.

In practice, it is generally necessary to apply calibrations after some data has been taken. The new calibration method for CDF (CalibExe) creates calibration ntuples for the detector sub-components. Calibration is performed and constants are updated to the database. In the case where previous runs need to be pointed to a new valid set, new used sets for these runs must be generated.

4.2.1 Creating a Valid Set

The script to update these tables is in the *CalorUserMods* Package. It uses text files as a means to input the pertinent information. A sample text file is presented below. Once the script is run, it will return a *jobset* for this valid set. The *jobset* is a unique identifier for this valid set in the same way the *cid* identifies a calibration table. Detailed instructions follow.

1. Check out the package `CalorUserMods` into a release area, using the commands

   `% setup cdfsoft2` *preferred version*
   `% newrel -t` *preferred version* `addConstants`
   `% cd addConstants`
   `% addpkg CalorUserMods`

2. It is recommended to edit the GNUmakefile so only the desired executable is built. This speeds up the linking process considerably. To do this, change in *CalorUserMods/test/GNUmakefile* the `TBINS` line to

   `TBINS = MakeL3Set`

3. Compile and link the script with (`% gmake CalorUserMods.tbin`).

4. Create a file with the desired tables and cids. For example

```
PESCALIB 390406
PESDEADCHANNELS 390364
PESLASER 390408
PLUGALIGNMENT2 371113
```

5. Run with (`% MakeL3Set -d onotl_prd -f` *file*`-s L3_PHYSICS_SMX`). Where *file* is the file created in the previous step.

4.2.2 Marking a Valid Set

As discussed above, marking a valid set allows run control to automatically generate used sets for runs. To mark a valid set, login to an online machine and execute a simple java script.

1. `% setup fer`.

2. `% java CalibDB.MarkedJobSetSelector L3_PHYSICS_SMX`.

3. Click on the desired valid set and select "Mark".

4.2.3 Creating a Used Set

The script to create a used set is in the *CalorUserMods* package. It reads a text file containing a list of runs. A sample text file is presented below. Note that a valid set must already be created for this script to work. In its original form, this script created a valid set for each used set. Since we generally have the same valid set for many used sets, this script was modified to look for a valid set based on the information given in the text file. If the script successfully finds a valid set, it will create a used set for the runs in the run range and output the *jobset* of the linked valid set for each run. Detailed instruction follow.

1. Check out the package `CalorUserMods` into a release area, using the commands

   `% setup cdfsoft2` *preferred version*
   `% newrel -t` *preferred version* `addConstants`
   `% cd addConstants`
   `% addpkg CalorUserMods`

2. Update the script `CalorUserMods/test/usedset.cc` so that the run ranges point to the desired valid set's jobset. The name of the text file containing the run range for which used sets are being created and the text files describing the valid set parameters are hard-coded here.

3. It is recommended to edit the GNUmakefile so only the desired executable is built. This speeds up the linking process considerably. To do this, change in *CalorUserMods/test/GNUmakefile* the `TBINS` line to

   `TBINS = usedset`

4. Compile and link the script with (`% gmake CalorUserMods.tbin`).

5. Create a file describing the valid set to be linked. The first line should always be as described below. The second line is a run identifier (nominally the first run for which this valid set is used). The next lines constain the desired cid, version, table and status. Note that the cid and table parameters need to match an existing valid set. For example:

```
onotl_prd COMPLETE L3_PHYSICS_SMX
190697
190697 1 PESCALIB COMPLETE
190697 1 PESDEADCHANNELS COMPLETE
190697 1 PESLASER COMPLETE
190697 1 PLUGALIGNMENT2 COMPLETE
```

6. Run with (`% usedset`). When creating used sets for many runs, it is not a bad idea to redirect the output to a log file.

5 Conclusions

Currently we have three sets of calibrations in use in CDF offline software reconstruction: gain corrections, including attenuation to calibrate the repored energy of a channel; status bits, to identify dead strips or other channels not operating nominally; and alignment, to adjust the reported position of a shower relative to the COT. These constants use sourcing or data and are generally updated once or twice per year. Although there are plans to increase the frequency of these calibrations, we also have the capability to perform shorter term checks with the laser flaser system, and hope to implement this feature in the future. Currently, we have software to histogram the laser flasher data. In the near future, we hope to add a hot channel bit to the status calibrations to identify run ranges in which specific channels consistenlty report significantly higher than their average energy.

A The UCLA Test Stand

All MAPMTs in the PES were initially calibrated using a test stand at UCLA (described below) in 1997-1998. Each tube was tested for a variety of features, including dark current, cross talk, non-linearity, pixel-to-pixel gain variations, voltages required for various gains, and the quantum efficiency. This information was used both to reject bad tubes and to determine proper voltages for use *in situ*[10]. The pixel-to-pixel gain variations were also to be used in offline gain corrections. However, due to clerical errors, information on 10% of the tubes was lost. This information was recovered through source runs in 1999 and 2001.

The UCLA test stand was used to test 550 MAPMTs[11] in the PES system prior to installation. It allowed the identification of MAPMTs which did not meet our specifications (so they could be returned to Hamamatsu for replacement). Further, it allowed us to make preliminary measurements of the high voltages needed for the desired gains and the pixel-to-pixel gain corrections.

The test stand consisted of a large, light tight box, which housed a testing apparatus and a reference single anode MAPMT (see Figure 11). The testing apparatus used plastic optical fibers to guide the light from green LEDs[12] to each pixel of each of the (up to) eight MAPMTs being tested and to the reference MAPMT. The MAPMTs were held in an aluminum frame, complete with alignment pins for repeatability. The LED illuminated a single pixel on each MAPMT at a time and illuminated the same pixel on all tubes being tested simultaneously. Each MAPMT was tested using the same base as when it was installed into the CDF detector.

References

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[2] A. Byon-Wagner, *et al*, "Technical Design Report for the CDF Calorimeter and Shower Maximum Detector Front End Electronics Upgrade", CDF Note 3762, November 1997, J. Wu, "Functional Description of the SMD Module", CDF Note 4879, February 1999, K. Byrum, *et al*, "CDF SMXR Board (Rev. B) Functional Description", CDF Note 5186, December 1999 and http://www-cdf.fnal.gov/internal/upgrades/front-end/cal/shower-max.html.

[3] The CDF II Collaboration, "The CDF Detector for Tevatron Run II, Technical Design Report", FERMILAB-Pub-96/390-E (October 1996). Note that Figure 9.9 in the TDR is incorrect; when viewing the PES from the interaction point the strips in the u layers (closer to the IP) are parallel to the left hand edge and the strips in the v layers are parallel to the right hand edge, as shown in Figure 1.

[4] http://www-cdf.fnal.gov/internal/upgrades/endplug/plug_smd.html.

[10] Note that we run tubes in the low eta region at a nominal gain of 5×10^5 and the tubes in the high eta region at a nominal gain of 10^5.

[11] We use 416 in PES and 72 in the endplug pre-radiator (PPR). The remaining tubes are spares.

[12] The LED was chosen to have spectral output similar to that of the green WLS fiber used in the PES.

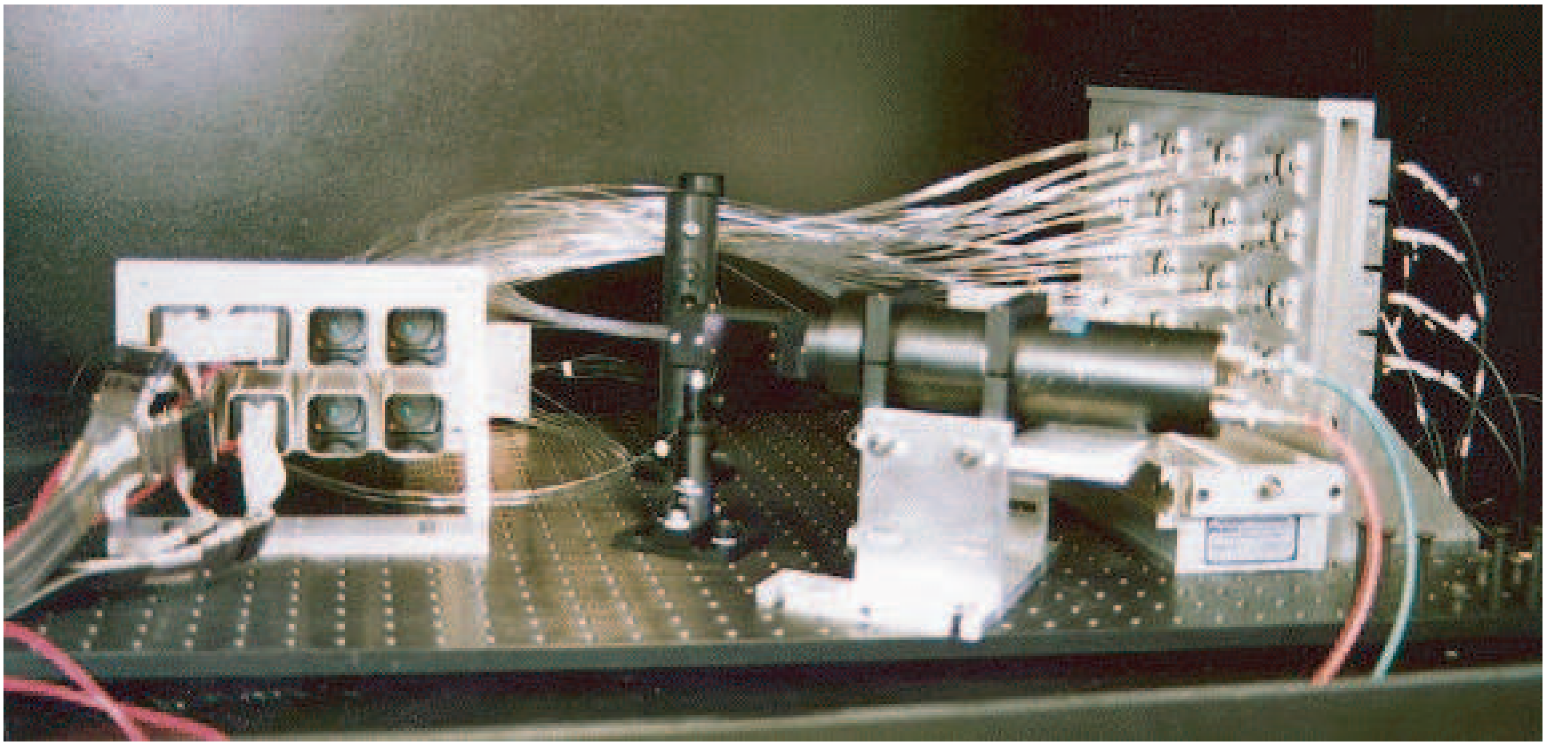

Figure 11: *The UCLA Test Stand. On the right side of the picture is the large aluminum block which holds the fiber distribution system. 16 LEDs are mounted in this frame, and all can be controlled individually. Clear plastic optical fiber directs the light from each LED to one of 16 pixels on the face of up to eight MAPMTs. The MAPMTs are mounted in the stand at the left, which is holding 4 MAPMTs in this photograph. In the center is the reference MAPMT, which receives light from all 16 LEDs.*

[5] W. Hao, V. Papadimitriou, "QIE Calibration and *qietest*", CDF Note 5394, March 2001.

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[12] A. Laasanen, private communication.

[13] G. Drake, private communication.

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[15] D. Box, *et al*, "A Calibration Database Schema for CDFII", CDF Note 5088, June 2002.