Cell Calibration

Calibration Method

We have traditionally calibrated the FMS by
Reconstruction of all photons in a data sample with Version "n" of the gain corrections.

1. *Looping over cells, generate a 2 photon mass distributions for each cell. Include events that satisfy selection criteria:*

   a. *Two photon*

   b. *Energy sharing cut (Z cut).*

   c. *Energy cut. (Perhaps other cuts)*

   d. *One of the two photons is reconstructed to be in the cell. (Usually the higher energy photon) .*

2. *For each cell, fit the mass distribution to a pi0 hypothesis*

3. *Make an adjustment in the gain (fpdcorr) for each cell in a direction to bring the fitted mass for that cell toward mpi=0.135 GeV. This generates Version "n+1" of the gain correction.*

The procedure is to iterate this process in until the fitted gains stabilize.

This procedure works best when we have fairly uniform gains to begin with and when we fit in a uniformly triggered region of the detector. Near the edges, near dead cells or near regions where the trigger acceptance differs greatly from cell to cell, the convergence to a correct answer is not easy to obtain or to interpret.

For example, in our analysis we have found that the reconstructed mass for the pi0 peak depends upon the energy of the photon pair. We also find that the mass shift comes from all three of the basic contributions,

- *From errors in the fitted total energy*

- *From sharing of that energy between photons 1 and 2*

- *From errors in the fitted separation between pairs of photons.*

Each of these contributions is affected by proximity of a cell to other dead or missing cells or to cells not contributing to the trigger.

Cell Class

To study the calibration of cells in a heterogeneous environment, it is clear that we need to be able to study the calibration problem in different in specific regions of the detector. It is for this purpose that the Cell class was written.

The Cell class is defined to contain information relevant to a particular FMS cell. The class accumulates histograms of various quantities that impact on a particular cell. An instance of the Cell class is created for each Cell in the FMS.

An instance of a Cell class

Cell* c;

contains, among other things, a TTree called CellD . The CellD structure contains branches corresponding to the essential variables that are produced in reconstruction by Yiqun.

On the right, for an example of one cell, the CellD structure is printed. This example corresponds to the South Small FMS (row0=3 col0=2). We see here that there are 2688 events associated with this cell. Branches include "Mcell" : the two photon mass and "Epair": the two photon energy.

The final branch in this tree contains a packed array of raw ADC hits.

Because the raw hits are included, it is possible to modify the gain corrections and rerun the Yiqun reconstruction program for the 2668 events that are represented in this Tree.

The Cell class can be streamed to a root file. We create a root TObjArray and fill it with a Cell instance for each FMS cell. Writing this array to a root file produces a single file, perhaps 200 Mbytes in length that contains enough information to run calibration iteration with flexible cell dependent algorithms.

```
root [33] c->CellD->Print()
****************************************************************
*Tree   :CellD3_c2_3: CellD3_c2_3                        *
*Entries :    2668 : Total =         334376 bytes  File Size =    328996 *
*        :        : Tree compression factor =  1.00              *
****************************************************************
*Br   0 :Mcell    : Mcell/F                              *
*Entries :   2668 : Total Size=     11312 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   1 :Epair    : Epair/F                              *
*Entries :   2668 : Total Size=     11312 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   2 :Ypair    : Ypair/F                              *
*Entries :   2668 : Total Size=     11312 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   3 :E1       : E1/F                                 *
*Entries :   2668 : Total Size=     11294 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   4 :E2       : E2/F                                 *
*Entries :   2668 : Total Size=     11294 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   5 :X1       : X1/F                                 *
*Entries :   2668 : Total Size=     11294 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   6 :X2       : X2/F                                 *
*Entries :   2668 : Total Size=     11294 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   7 :Y1       : Y1/F                                 *
*Entries :   2668 : Total Size=     11294 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   8 :Y2       : Y2/F                                 *
*Entries :   2668 : Total Size=     11294 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br   9 :NSTB     : NSTB/I                               *
*Entries :   2668 : Total Size=     11306 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br  10 :br_nSavedHits : nSavedHits/I                    *
*Entries :   2668 : Total Size=     11351 bytes  One basket in memory   *
*Baskets :      0 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
*Br  11 :br_SavedHits : SavedHits[nSavedHits]/I          *
*Entries :   2668 : Total Size=    209797 bytes  All baskets in memory  *
*Baskets :      6 : Basket Size=     32000 bytes  Compression=  1.00    *
*.................................................................*
```

Algorithms for Gain Correction

For each FMS cell, the ADC value is converted to energy with multiplication by the product of two factors, (fpdgain and fpdcorr). The fpdcorr factor will be updated based upon mass reconstruction.

Using an instance of the Cell class, we have information need to re-reconstruct photon information based upon a new assumption for fpdcorr values.

While the best tool for determining the energy scale correction factor for each cell involves the sensitivity of the pi0 mass to these scale factors, there are complications.

- *The reconstructed location of the of the pi0 mass peak depends on not only the sum of the energy of the two photons but also on the determination of "D" the separation between the two photons and the determination of the energy sharing "Z" between the two photons. We know from recent work that mass corrections from of these sources are significant and depend on energy. These corrections also depend upon proximity to edges of the detector or to dead cells within the detector. The assumption that a displacement in mass from the nominal value of 0.135 GeV is a direct consequence of errors in the energy scale would be far too naive.*
- *With current reconstruction of pi0's, the reconstructed mass peak is very dependent upon energy. If calibration scale factors are nearly correct, the derivative of reconstructed mass with respect to energy is*

$$\frac{d}{dE_{pair}} M_{reconstructed} \geq .0004$$

 which translates to more than 3% per 10 GeV.
- *The pi0 mass shift obtained thus depends upon the energy range of pi0 candidates used to calculate the pi0 mass. This creates two problems.*
  - ○ ***Overall Scale uncertainty:*** *One needs to determine the energy (if any) at which the pi0 mass "should" be 0.135 Gev given all the energy dependent effects.*
  - ○ ***Cell to Cell variation in scale:*** *Because there is a wide range of trigger energy thresholds (related to variations in the very gain factors that we are trying to determine) different cells have data available at different energies. Our ability to compare mass distributions for all cells at a fixed energy is compromised by the very variation that we are trying to address in calibration.*

For example, we look at one of the Cell instances, the one associated with FMS North row0=3 col0=2. The Mass vs Energy for events that reconstruct a photon for this cell is shown below.
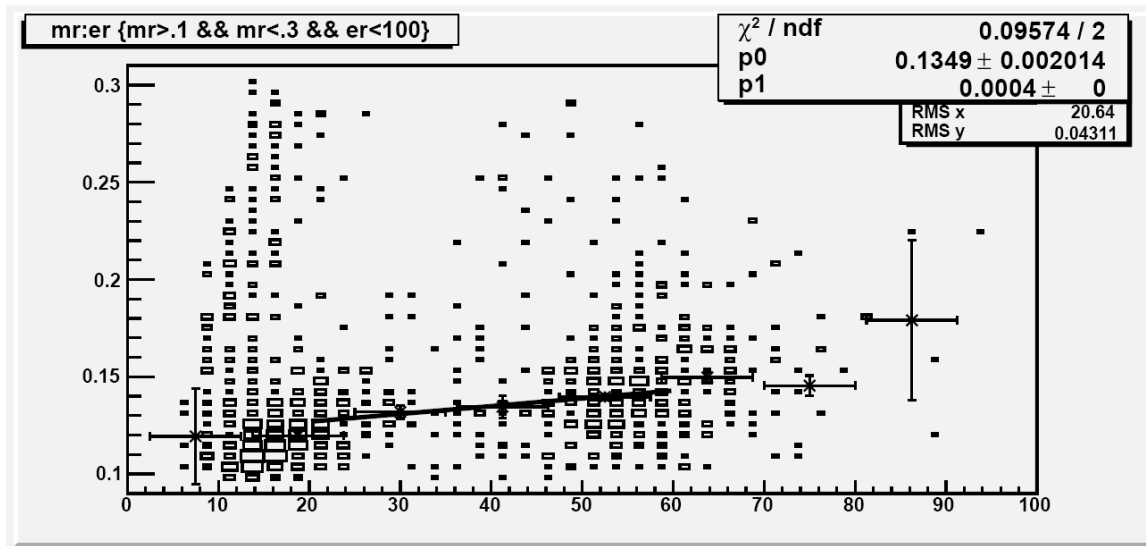
Figure 1: Mass(vertical axis) vs Energy(horizontal axis) for Small South FMS row0=3 col0=2. Energy slices have been individually fit to a pi0 gaussian peak and the peak mass with fitted error bar is plotted over the mass vs. energy distribution for this cell. Those points are finally fit to a line with slope of 0.0004 to extract the mass at the 2 photon energy of 40 GeV.

We see that the mass vs energy distribution has been fit with a linear form,

$$M = m_{40} + slope(E - 40)$$

With m_{40} the fitted mass at Energy = 40 GeV. For consistency in determining fpdcorr factors, the slope will be constrained for all cells to $0.0004 \dfrac{GeV}{GeV}$ for all cells.

After several iterations the fpdcorr values are adjusted so the peak locations approach pi0 mass at energy 40 GeV. Figure 2 and Figure 3 show the ratio

$$R = \frac{0.135 \, GeV}{m_{40}}$$

after many iterations.

The result of iteration is a set of values for fpdcorr values.

For Small Cells, Figure 4 shows the fpdcorr factors for each cell. The gain factors (fpdgain) were all set to 0.038 .

Figure 2: Ratio of 0.135 to Mass @ 40 GeV for FMS North Cells

Figure 3 Ratio of 0.135 to Mass @ 40 GeV for FMS South Cells

Figure 4: Gain correction factors (still not final) for each of the small cells of the FPD. Row number measures from top to bottom so the detector top is shown at the bottom of the figure. Left is north and right is south. Some cells at small rapidity or in regions of the detector with near edges or dead cells and thus with few triggers have been set by hand and are not yet well determined.

Small Cells: Dead and wounded cells.

The difference between a cell with very low gain and a dead cell is in subjective. With that in mind, the following map of small cells shows a variety of conditions for cells.

- *White cells (no number) are dead cells.*

- *The numbers in cells indicate the presence of hardware bit shifts of the ADC word. The number is obtained from the ADC distributions. It is the number of empty bins found between single live bins in the ADC distributions. (ie: a shift of three bits would leave 7 empty bins between live bins.*

- *Blue cells are those that are near an edge or near a dead cell.*

- *Orange cells are on the boundary between top and bottom (not spanned by trigger)*

- *Red cells are the other cells, not compromised as are Orange, Blue or White.*
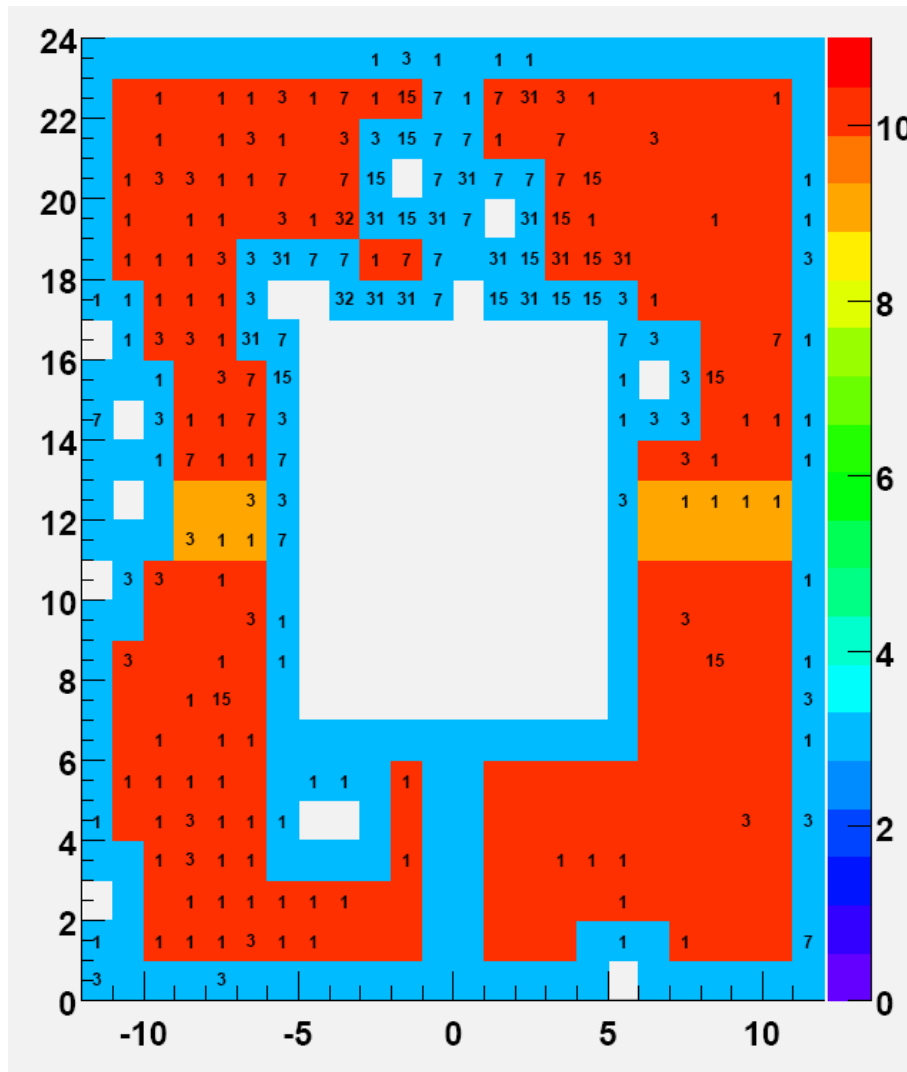
Figure 5: Cell Problem Map for Small FMS Cells rows: 0 to 24; cols:(N) -12 to 0, (S) 0 to 12.

Cell Cross Section

In the ideal case, the number of pi0 events with the leading photon in some FMS cell reflects a cross section at the rapidity of the cell.

$$\frac{dN}{dE} = L \left.\frac{d\sigma}{dEd\Omega}\right|_{EtaCell} \Delta\Omega_{Cell} \left(\text{acceptance}\right)$$

Where L is the integrated luminosity and E is the pair energy. This cross section for leading photons should be nearly the same as the associated pi0 cross section, especially at large energy. The angular size of FMS small cells will all be similar.

The condition that defines this cross section is that one of the photons of a two photon event falls in the cell in question. The cross section reflects the number of events per cell for a cell at some rapidity. Clearly, the environment including variations in gain and details of the trigger will introduce acceptance variations from cell to cell. However, it would be hoped that at large energy, where the energy in one cell is nearly sufficient to satisfy the trigger, the cross section

Let us focus on cells in the low row number quadrant of the south FMS where there are no dead cells. Looking at all cells that pass the following cuts:

- *3.7<Eta<3.75*

- *Problem free cells (See Red part of Figure 5).*

- *Row<10*

- *NSTB=4 (South FMS Small)*

- *fpdcorr<1.25 (no low gain cells; see Figure 4)*

Figure 6: Cuts used to select the 3 cells shown in Figure 7.

Only 3 cells pass these cuts and they are examined in Figure 7 and Figure 9. We see that the exponential slopes have been fit over the energy region from 55<E<80 GeV.

We have a prejudice that the form of the cross section should be proportional to

$$\frac{(1-X_F)^5}{p_T^{\,6}}$$

Nominally, such a form would lead to a slope of approximately

$$slope = -.22 \ GeV^{-1}$$

Of course, the acceptance from the trigger changes the slope. It is hoped that the acceptance has a small impact for energies well above the trigger threshold. It is seen that these high energy slopes are consistent with this nominal value. (Note: This is also close to the energy slope seen in Pythia 6.222 (but not the more recent versions like 6.410).
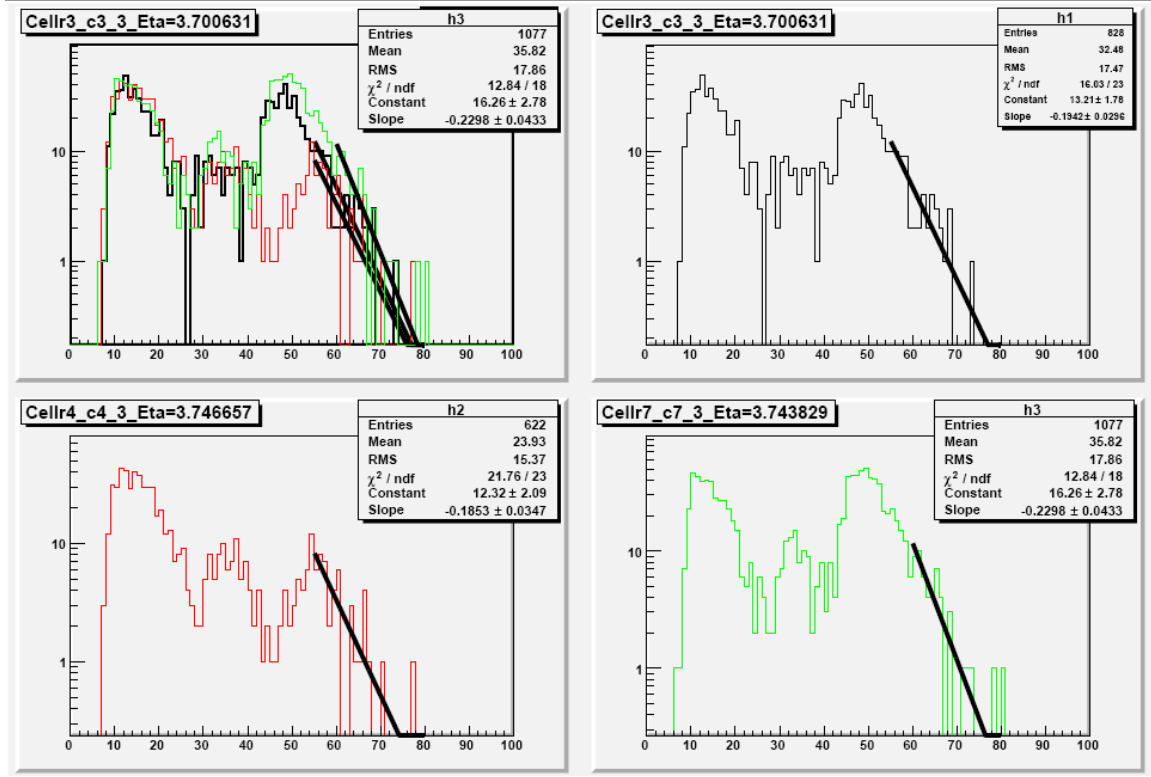

Figure 7: Energy Distributions for photon pairs with most energetic photon in Cell indicated. The three cells shown have nominal rapidity in the range 3.7 to 3.75 and satisfying cuts specified in Figure 6.

It should be noted (see Figure 8) that the particular cells that we are looking at have modest gain corrections. However, it is not only the gain of the cell in question that determines the trigger threshold. In Figure 8, we see that the cell at (row 4; col 4) is sandwiched between two low gain cells (larger corrections). It also has a gain correction somewhat larger than the other two cells that we are studying. The leads to a trigger threshold for pi0 events that is at least 10 GeV lower than in the other two cells shown.

Rapidity Dependence of Cross section

The expected form of the pi0 cross section, proportional to p_T^{-6} leads to a rapidity dependence that is of the form e^{6Y}. If we consider the highest energy pi0's, where trigger acceptance is not too important, we can look for the dependence of the cross section on cell location.

Figure 8: This figure shows part of Figure 4, the gain corrections for each cell. The lines point to the three cells featured in Figure 7.
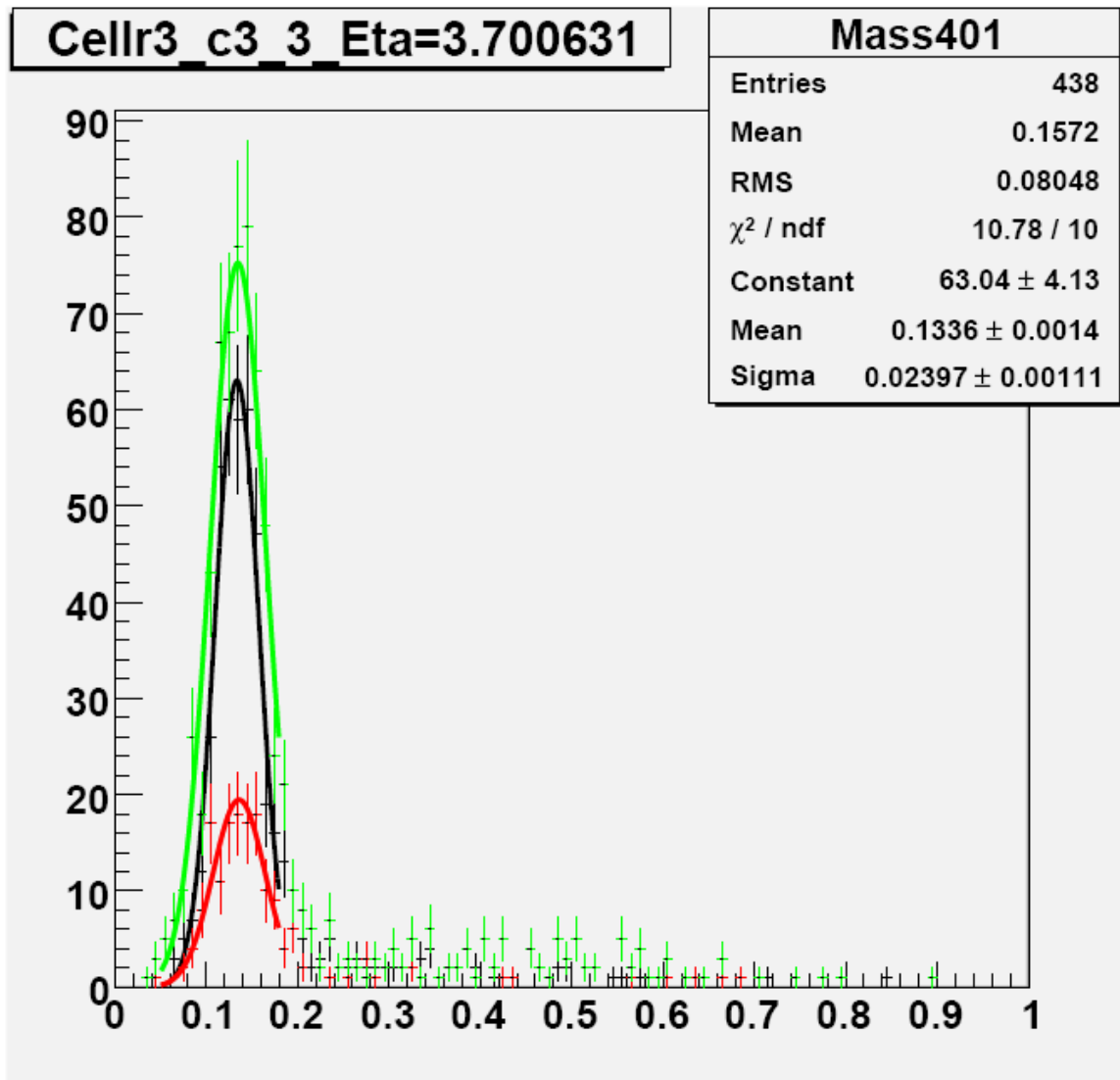
Figure 9: The two photon mass distribution for the same three cells shown in Figure 7. This distribution includes data with photon pair energy in the range 30<E<60. The fitted masses are within about 1% of each other, which is as good as can be statistically expected.

In Figure 9, we also note that if the calibration correction is found by fitting the mass in an energy window around 40 GeV, the distribution of energy in that window is very different for the 3 cells considered. The number of event available to fit the data in (row=4; col=4) is greatly reduced and the ones that we have come from higher energy. This tends to skew the interpretation of the pi0 mass shift.

It is true that at low energy, energy<20 GeV, the pi0's that are not associated with the trigger tend to have numbers and energy distributions that are be similar for all cells at fixed rapidity. However the mass that we get from these fits are low for reasons that we are still trying to understand. If we try to correct cell gains to bring the low energy peak (like that in Figure 1) to the pi0 mass, we will raise the high energy part of the spectrum above 100 GeV, which is not physical.
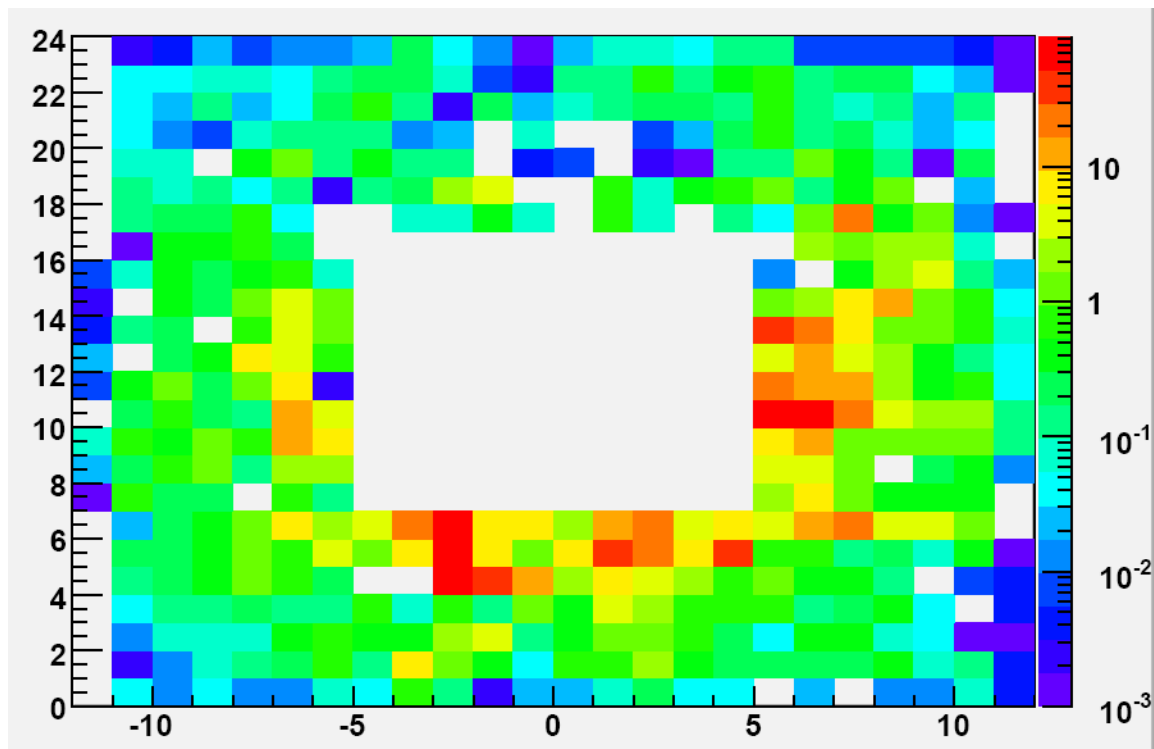
Figure 10: Number of events in a cell per GeV at 65 GeV. Rows 1-24 are stacked alone the vertical axis. Columns 1 to 12 for the south FMS and columns -12 to -1 for north FMS.