Flux Return Thickness Study

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Abstract

The purpose of this study was to characterize and quantify the effects of an iron cylinderical block as a Flux Return in the fsPHENIX detector. The first attempt was to fit the histograms of the reconstructed energy from the forward calorimters to a Gausssian. However, It was found that at certain thicknesses of the flux return the reconstruced energy was not Gaussian. This means a simple Gaussian Fit was not enough to quantify the behavior of the calorimeters with the presence of this kind of flux return. A new approach involved looking at the energy deposited in the flux return via an analysis macro. After comparing the energy deposited in the flux return with the reconstructed energy of the calorimters it was found for pions less than 30 GeV a thickness of 10.2 cm, or the proposed thickness, will have little effect on the energy resolution of the calorimeters. For pions of energy greater than 30 GeV a flux return of thickness approximately 7.5 cm will have very little effect.

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Flux Return Thickness Study

1.1 Overview

Background
There is a proposal to build a new forward detector at PHENIX called fsPHENIX. This detector will use the BABAR magnet solenoid to generate a magnetic field. In order to create a more uniform magnetic field the solenoid needs to have some material at its ends to create a proper return magnetic field. There is currently two ways proposed to do this. One, which is the focus of this study is to use iron cylindrical slabs placed at the two ends to create the magnetic field return neccessary. The other is to use a magnetic hadronic calorimeter in the forward direction.

Purpose
Using iron cylindrical blocks called plug doors will affect the energy measured by the calorimeters in the forward region. Since the Electromagnetic calorimeter (FEMC) will be placed before the plug doors (1.1) it will not effect the energy measured by the FEMC. The greatest effect will therefore be in the forward hadronic calorimeters (FHCAL). This effect needs to quantified to understand if the energy resolution of the calorimeters is able to overcome the energy absorbtion by the door.

1.2 Methods

1.2.1 Simulations

In order to study the effect described above simulations were ran with the fsPHENIX software which utilizes the GEANT framework. At first 30 GeV pions(π^-) were simulated using a default thickness of 10.2 cm. and a histogram of the reconstructed total energy from both the FEMC and FHCAL was plotted and can seen in 1.3. Then in order to better understand how the plug door is affecting the energy of the incoming pions; 30 GeV pions were simulated at a pseudorapidity $\eta = 2$ using multiple thicknesses. An η of two is well within the range of the FEMC($1.4 < \eta < 3.0 - 3.3$),

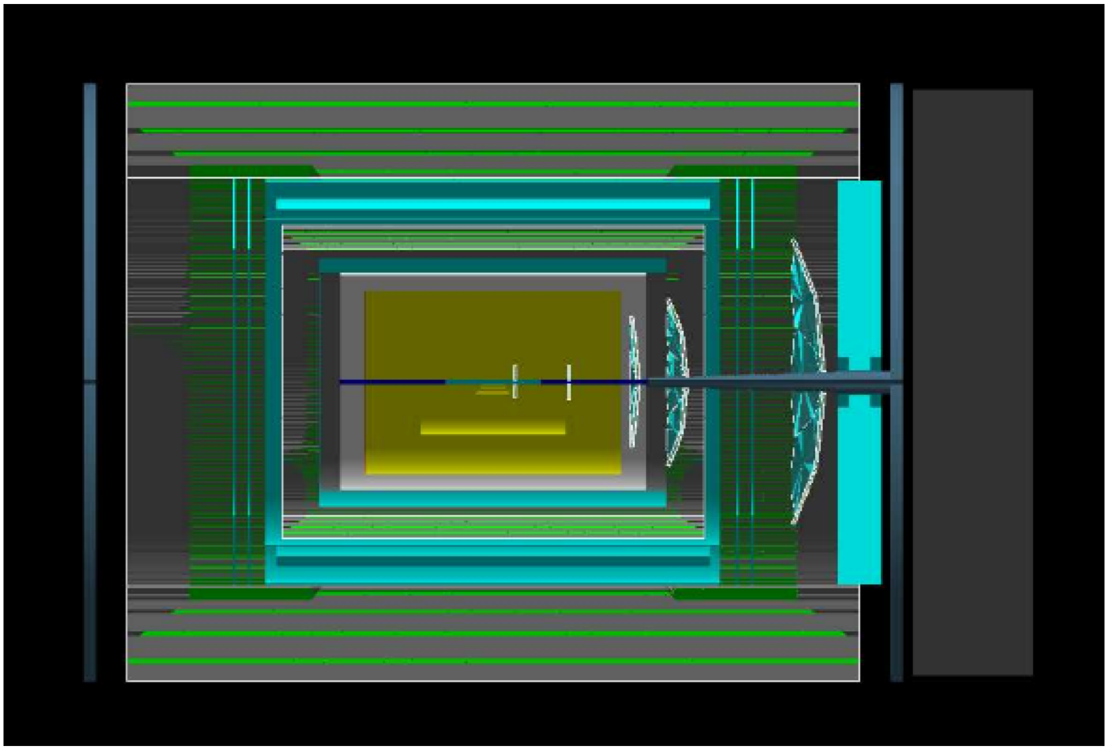

Figure 1.1: fsPHENIX Geometry with the Magnetic Piston for a Flux Return of 10.2 cm

FHCAL($1.2 < \eta < 4.0$) and the flux return. The overlayed plot of those histograms of reconstructed energy can be found in 1.4. As the plug door becomes thicker and thicker then the curve becomes wider and the peak goes lower. The thickest the door can be before overlapping other objects is 21.8 cm; of course assuming there is no magnetic piston (1.2).

1.2.2 Fitting

Fitting Method

One method to quantify how much the plug door is affecting the energy resolution is to do a Gaussian Fit to the peaks seen in 1.3 and 1.4. The fitting method was the following: fit a Gaussian to the whole energy range and obtain a mean μ_1 and standard deviation σ_1 from this fit, Then do a second fit to a Gaussian to the range of $[\mu_1 - sc1 * \sigma_1, \mu_1 + sc2 * \sigma_1]$ and obtain a different μ_2 and σ_2, Lastly a third fit is performed on the new range $[\mu_2 - sc1 * \sigma_2, \mu_2 + sc2 * \sigma_2]$and this fit is used as the final μ and σ. In the above ranges $sc1$ and $sc2$ are simply scale factors to adjust to find the best fitting method. Using this μ and σ anohter quanitty is calculated called $R_{>2\sigma}$. This quantity is the ratio of the number of events betwen the tail of the gaussian and the total number of events. It is calculated in the following way: Integrate histogram from 0 to $\mu - 2\sigma$ and then divide by the integral of the full histogram. If everything works well then this value should increase as the thickness increases. This effect of the smearing of the Gaussian is caused by the Flux Return

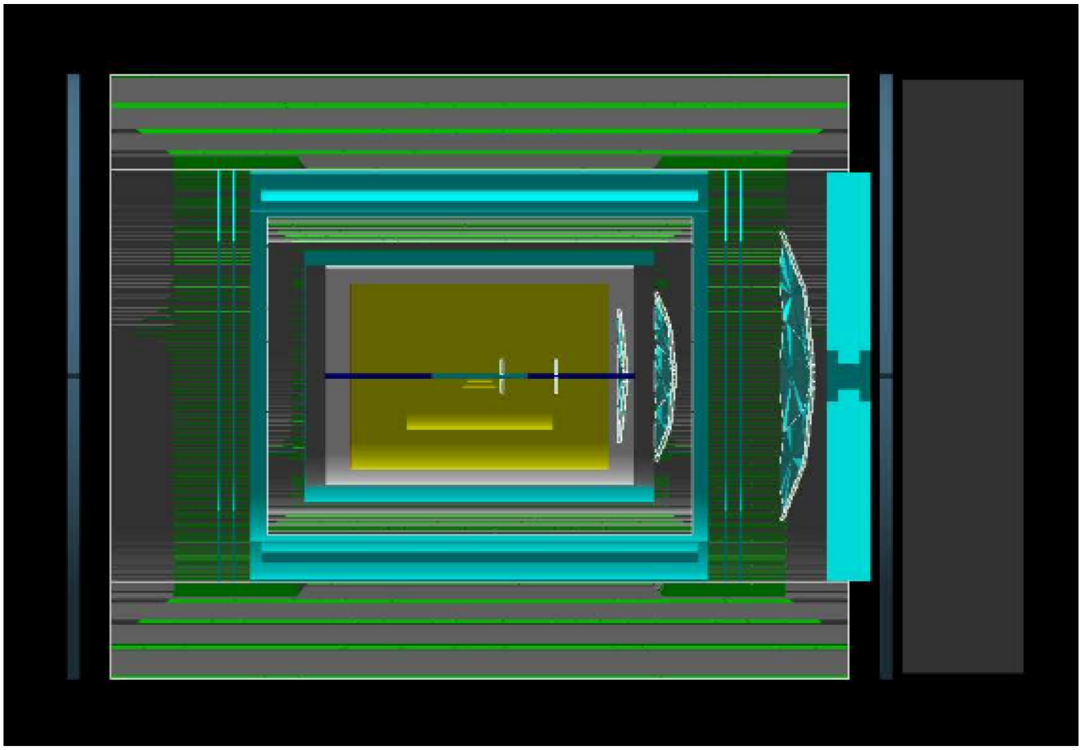

Figure 1.2: fsPHENIX Geometry without the Magnetic Piston for a Flux Return of 10.2 cm

a dead material absorbing more and more energy from the particles leading to a wider range of possible energies that can emerge out the back of the plug door. The quantity $R_{>2\sigma}$ or just R for short should reflect how much smearing is taking place.

Double peaks

The Gaussian does a good job to fitting the peak for thicknesses up to 7.5 cm. After that it is clear that the fits are becoming worse and worse. In fact for 20.4 cm in 1.5 there seems to be a second peak and it is even more apparent in the 21.8 cm histogram in 1.6. In order to check the validity of this second peak simulations for these thicknesses were run several times. The 20.4 cm thickness was run three more times and for the 21.8 cm thicness one more time. The different 20.4 cm thickness histograms are labeled v1-v4 and the two 21.8 cm histograms are labeled v1-v2 and can be seen in 1.7 and 1.8. It is easy to tell from these figures that the effect is not statistical but in fact physical. For this reason only the v1 of the 20.4 and 21.8 cm thicknesses will be used in the analysis. This suggests that fitting the peaks may not be the best way to quantify the flux return. However, despite this effect R can still be calculated to see what it yields and that is what was done next.

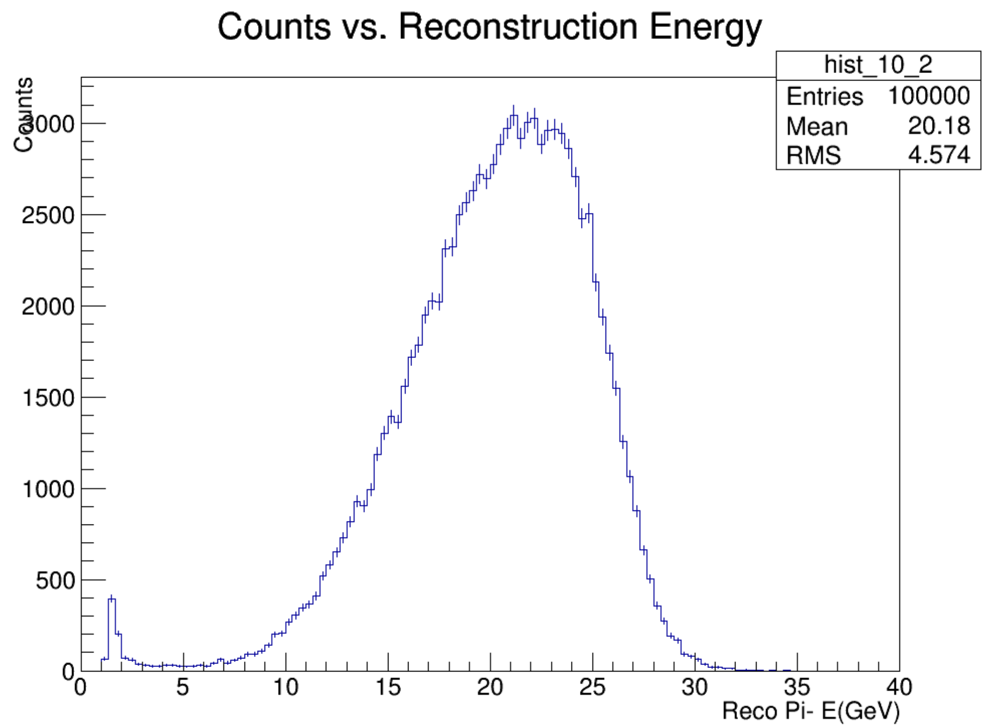

Figure 1.3: Histogram of reconstructed energy in both FHCAL and FEMC for 30 GeV Pions with a flux return of thickness 10.2 cm. There are a total of 100,00 entries or events for this histogram and all subsequent ones.

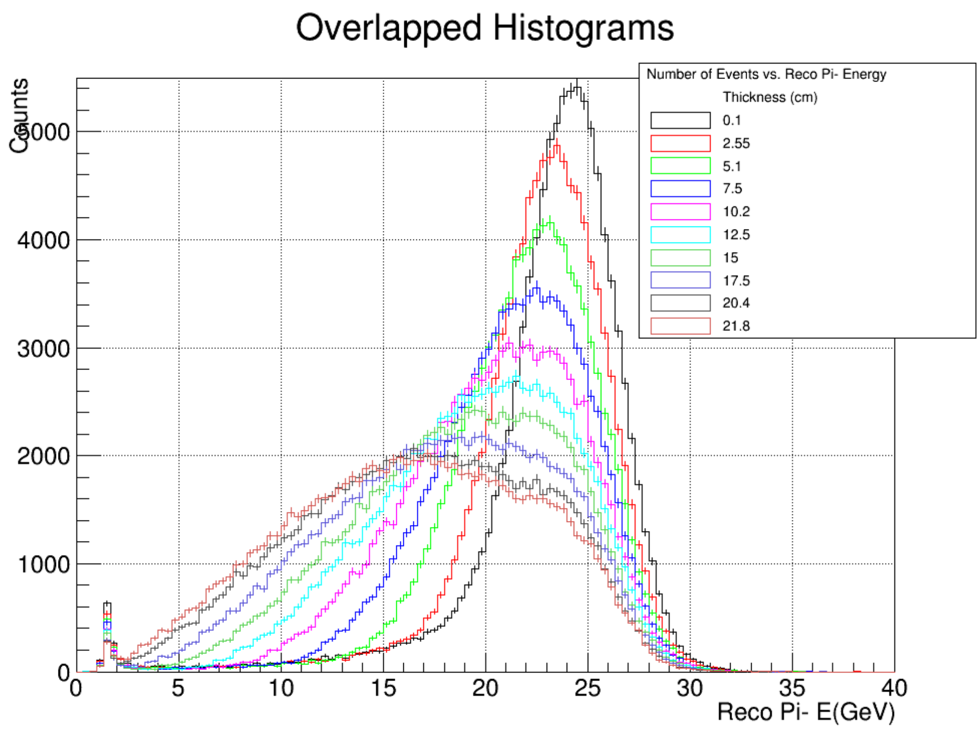

Figure 1.4: Histogram of reconstructed energy in FHCAL and FEMC for 30 GeV Pions with all the various thicknesses that were simulated.

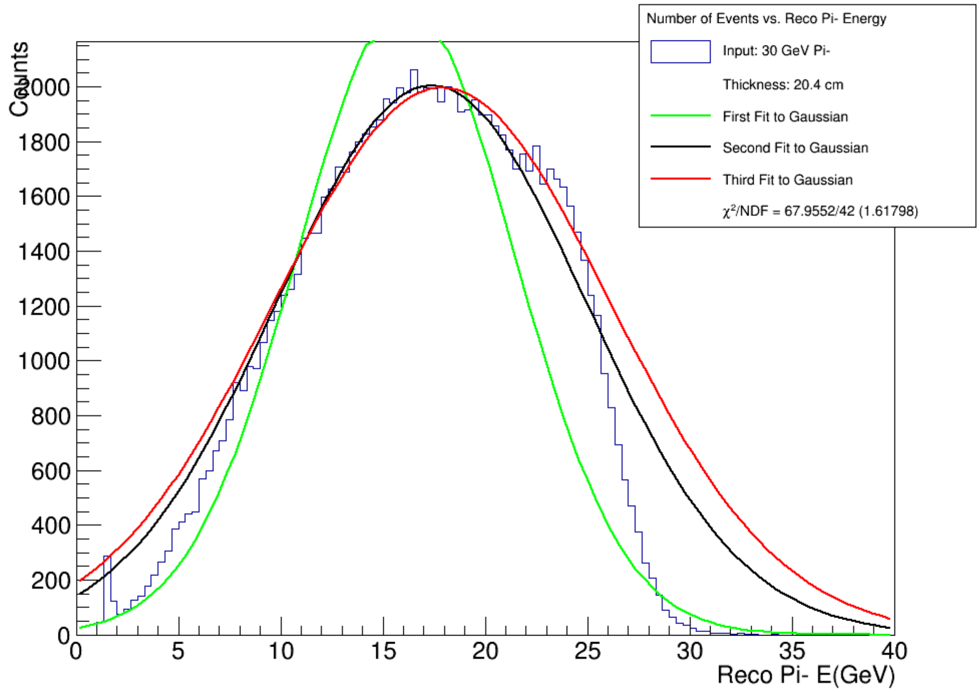

Figure 1.5: Histogram of reconstructed energy in FHCAL and FEMC of 30 GeV pions using fitting method of $sc1 = 1$ and $sc2 = 1$ for a flux return of thickness 20.4 cm.

Fitting Analysis

To analyze the results of the fit not only do we need to calculate the $R_{>2\sigma}$ but we also need to look at the fitted μ, σ, and even the μ/σ as a function of thickness. The scale factor I found that worked best was $sc1 = 1$ and $sc2 = 1$. The corresponding fits using $sc1 = 1$ and $sc2 = 1$ can be found in 1.9. Here is the listing of the plots for those scale factors: the Mean vs. Thickness (1.10), Sigma vs. Thickness (1.11), the Sigma/Mean vs. Thickness (1.12), and the $R_{>2\sigma}$ vs. Thickness (1.13). R can be seen as "R>2sigma" in the plots. As can be seen from 1.13 this value is decreasing as function of thickness which further suggests that this method is not the best way to quantify the effect of the flux return and a different method is needed.

1.2.3 Energy in Flux Return

The next thing that was tried was looking at the energy absorbed by the plug door itself. This can be seen 1.14. This is only the energy deposited in the forward flux return since there are no calorimeters in the other direction. In order to get this energy I wrote a macro to extract this information to a root file. This macro does get the energy deposited in the Flux Return in the negative region and the three black holes in GEANT (objects which absorb excess energy). These can be seen in 1.15. We can see the negative region has almost no energy and most of the energy

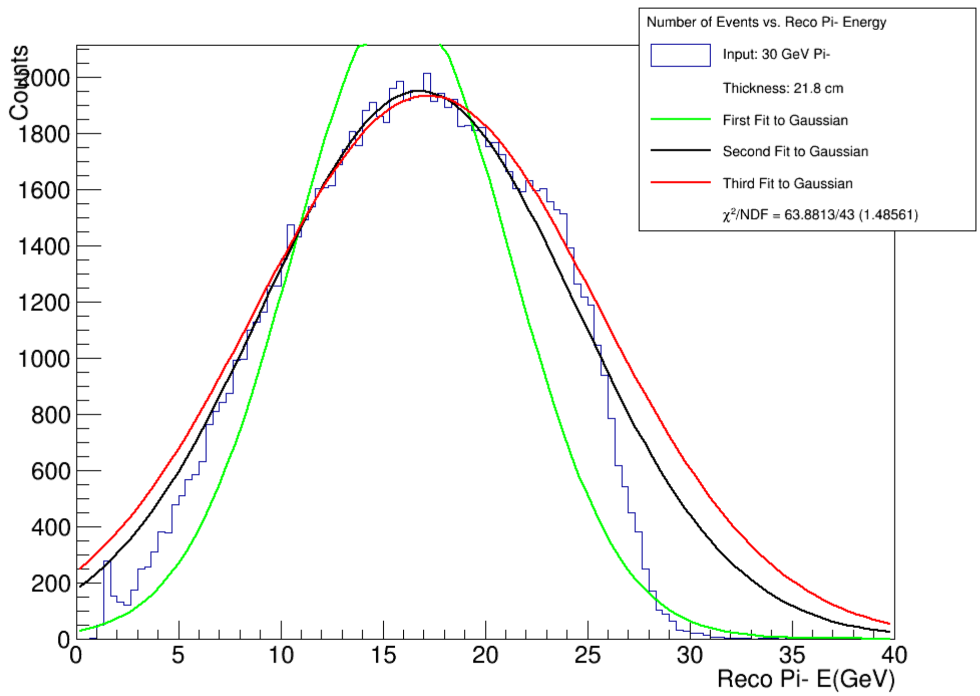

Figure 1.6: Histogram of reconstructed energy in FHCAL and FEMC of 30 GeV pions using fitting method of $sc1 = 1$ and $sc2 = 1$ for a flux return of thickness 21.8 cm.

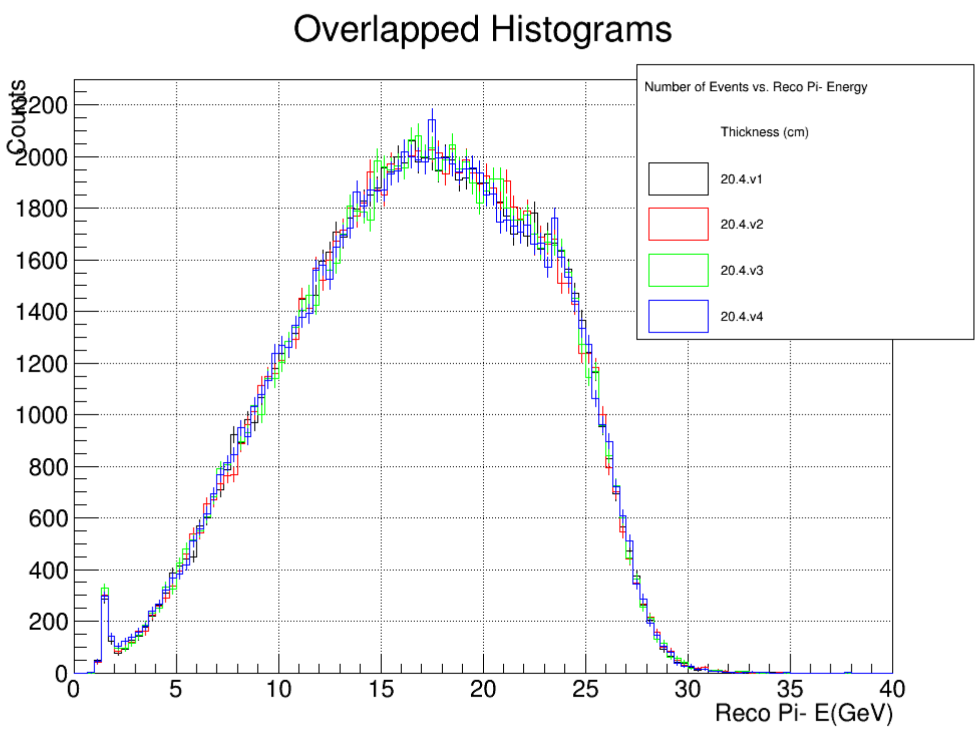

Figure 1.7: Histogram of reconstructed energy in FHCAL and FEMC of 30 GeV pions for a flux return of thickness 20.4 cm. These simulations were ran a total of four times in order to check the validity of a second peak appearing in the histogram around 23 GeV. The v1-v4 indicate which iteration of the running it was. As can be seen there is clearly a peak in all four cases indicating it is not a statistical anomaly.

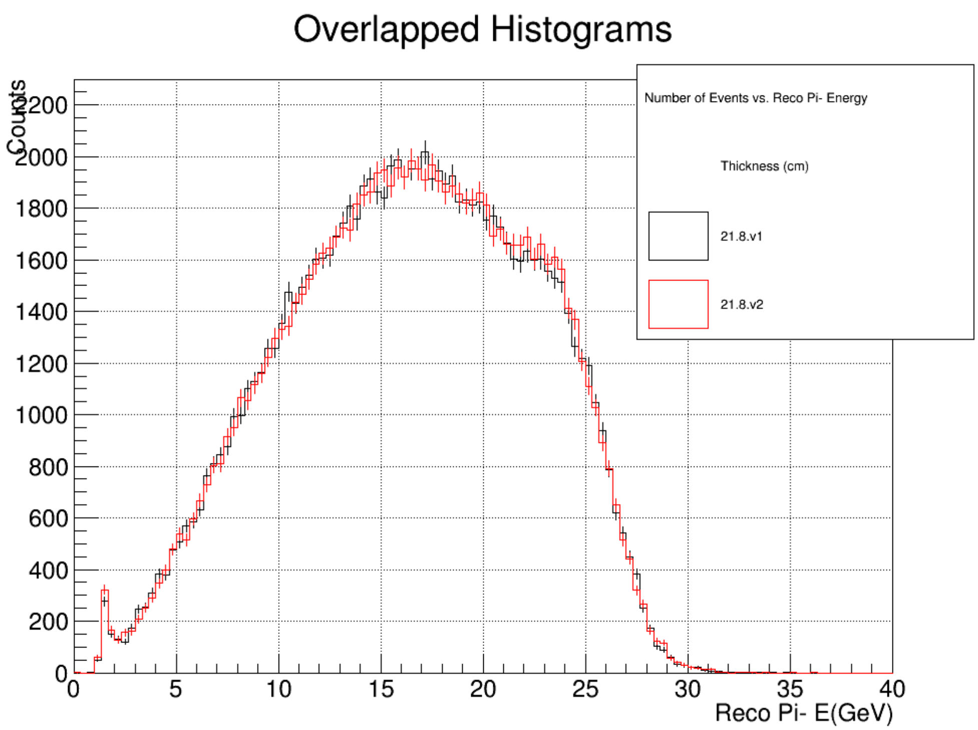

Figure 1.8: Histogram of reconstructed energy in FHCAL and FEMC of 30 GeV pions for a flux return of thickness 21.8 cm. These simulations were ran a total of two times in order to check the validity of a second peak appearing in the histogram around 23 GeV. The v1-v2 indicate the iteration of the running. Both histograms show a much clearer second peak compared with 1.7 which indicates this is clearly not statistical.

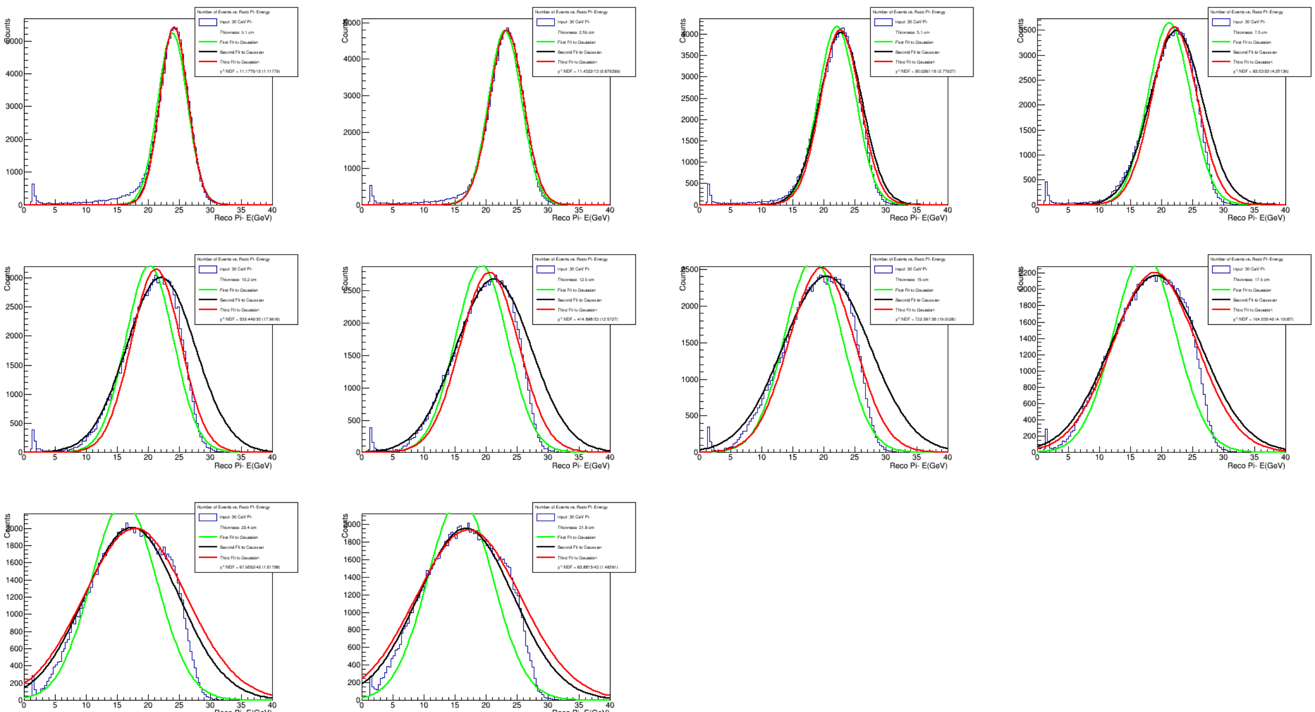

Figure 1.9: Histograms for a 30 GeV pions reconstructed energy in the forward calorimeters for various thicknesses of a flux return with its corresponding Gaussian Fits. The values from the third fit was used to generate 1.10, 1.11, 1.12, and 1.13.

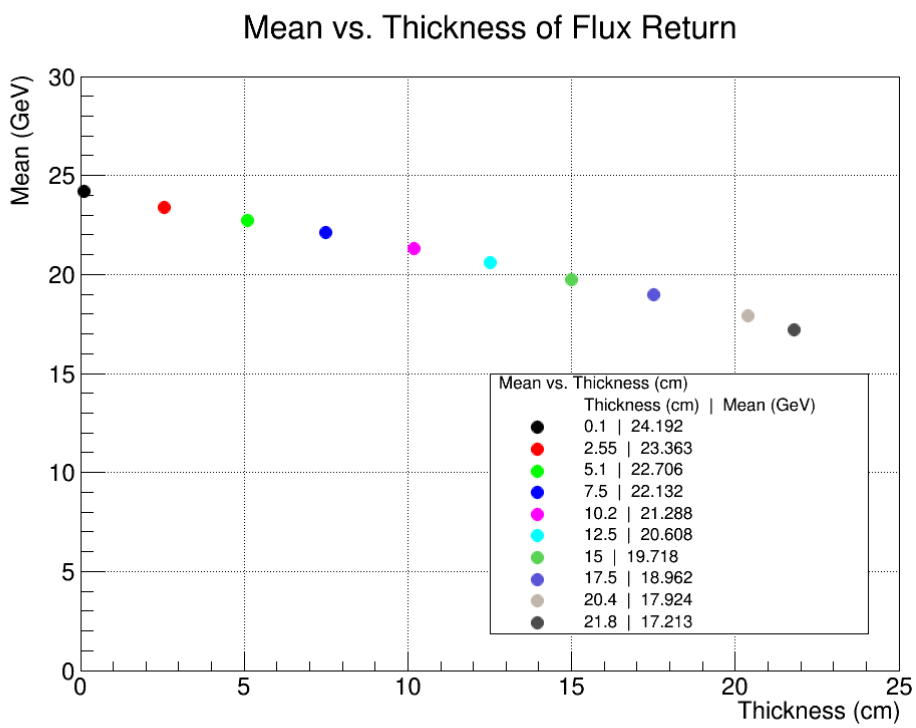

Figure 1.10: Plot of μ from the third fit vs. flux return thickness. The mean is decreasing as a function of the thickness as expected since more material means more stopping power of pions.

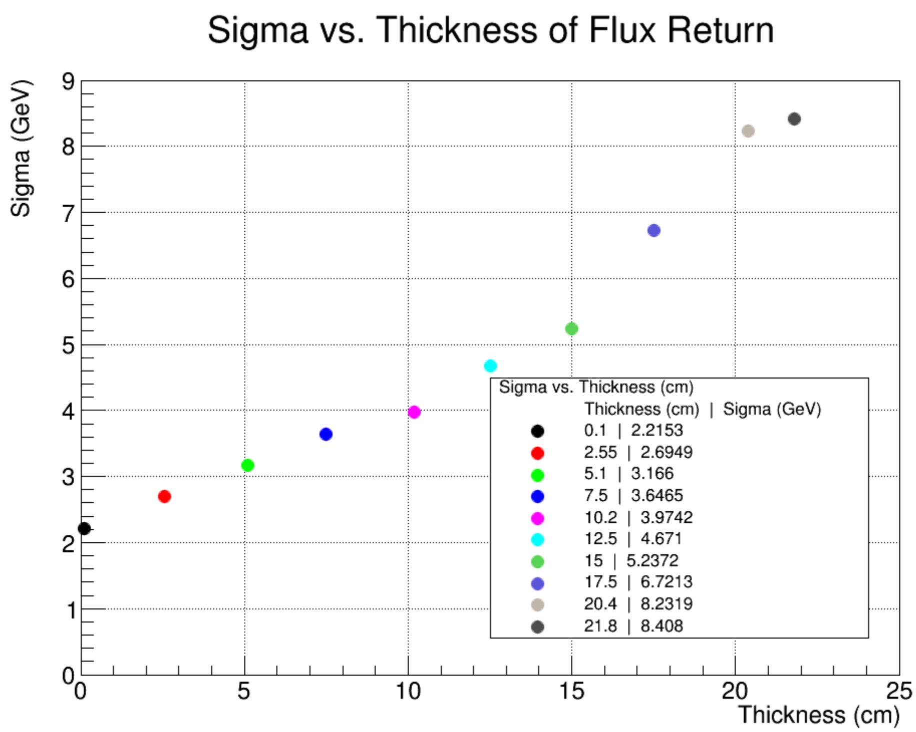

Figure 1.11: Plot of σ from the third fit vs. flux return thickness. The width is increasing as expected since more material means more smearing.

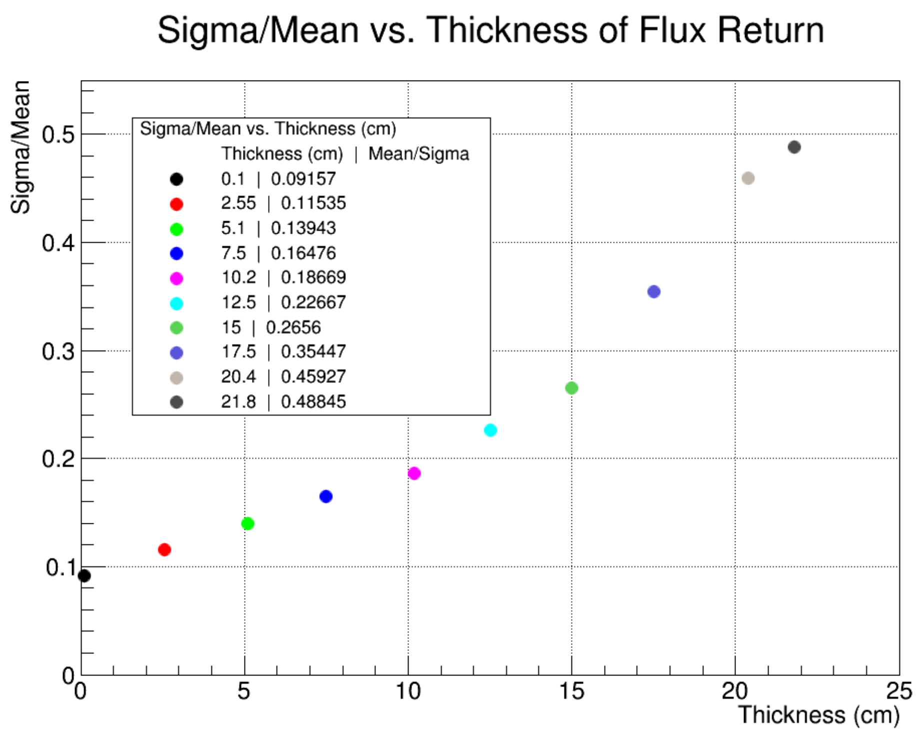

Figure 1.12: Plot of Sigma/Mean from the third fit vs. Thickness. This is also increasing since the effect of the smearing dominates how much the mean gets shifted.

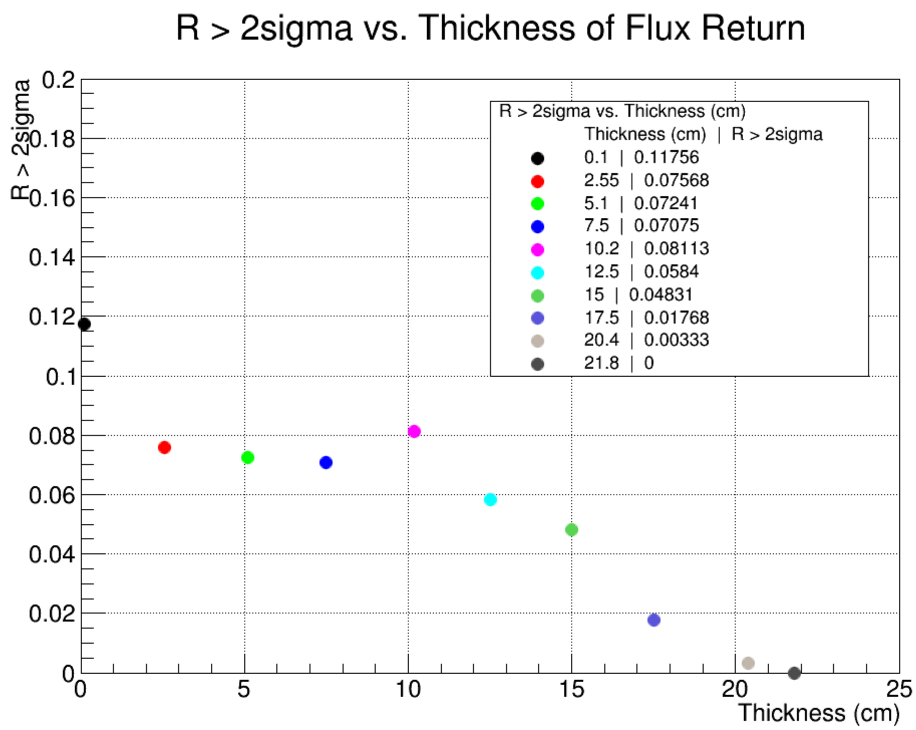

Figure 1.13: Plot of R vs. Thickness. Not behaving as expected. Has some strange increasing then decreasing behavior. This indicates issues in fiting and that this may not be the best method to look at the effects of the plug door.

is in the forward region. Since the π^- is only generated in the forward region there is no energy in the negative region as expected and so only the forward region is interesting.

Armed with the knowledge of what the plug door energy looks like we can compare this to the energy reconstruced in the calorimeters. Since a Gaussian couldn't be used to characterize the peak the histogram mean and RMS will be used instead. Then simulations were run at various energies and thicknesses and plots of the mean energy(E_mean) divided by the input energy (E_input) was plotted as a function of the thickness of flux return (L). The same was done for the RMS energy (E_RMS). The energies that were used were the reconstructed energy from the calorimeters (E) and the energy deposited in the forward flux return (E_FR_p). Lastly in the RMS plots there is an additonal line that marks where $\sigma_{natural}/E\_Fit\_Mean$. $\sigma_{natural}$ is the standard deviation from the fit for the millimeter thickness histograms from the reconstucted energy from the calorimeters for that input energy and E_Fit_Mean is the mean from that fit. You can find these fits in 1.16, 1.21, 1.26, 1.31, 1.36. The plots of E_Mean/E_input are shown in 1.17, 1.22, 1.27, 1.32, 1.37. The plots of E_RMS/E_input are shown in 1.18, 1.23, 1.28, 1.33, 1.38. The plots of $E\_FR\_p\_Mean/E\_input$ are shown in 1.19, 1.24, 1.29, 1.34, 1.39. The plots of $E\_FR\_p\_RMS/E\_input$ are shown in 1.20, 1.25, 1.30, 1.35, 1.40. The $\sigma_{natural}$ is the standard deviation from the fit in the reconstructed energy from the calorimeters histogram for a millimeter thickness flux return (i.e. no flux return). This value represents the energy resolution of the calorimeters with no flux return. So the value $\sigma_{natural}$ divided by the incoming π^- energy represents the energy resolution of the calorimters with no plug door. The RMS from the energy deposited in the forward flux return histogram 1.15 acts as the fluctuations in the absorbed energy from the flux returns. So we divide that by the incoming π^- energy to compare with $\sigma_{natural}/E_{input}$. The plots 1.20, 1.25, 1.30, 1.35, 1.40 are showing how the fluctuations in energy in the flux return vary with thickness of the flux return. Once this value surpasses the natural resolution of the calorimeters we can no longer rely on the energy measured from the calorimeters because the error in the measurment becomes as large as the error from the energy absorbed in the calorimeter. This occurs when the points cross the blue dashed line. We can see from those five figures that at lower energies this occurs at about 10.2 cm. Then at higher energies this goes to about 7.5 cm.

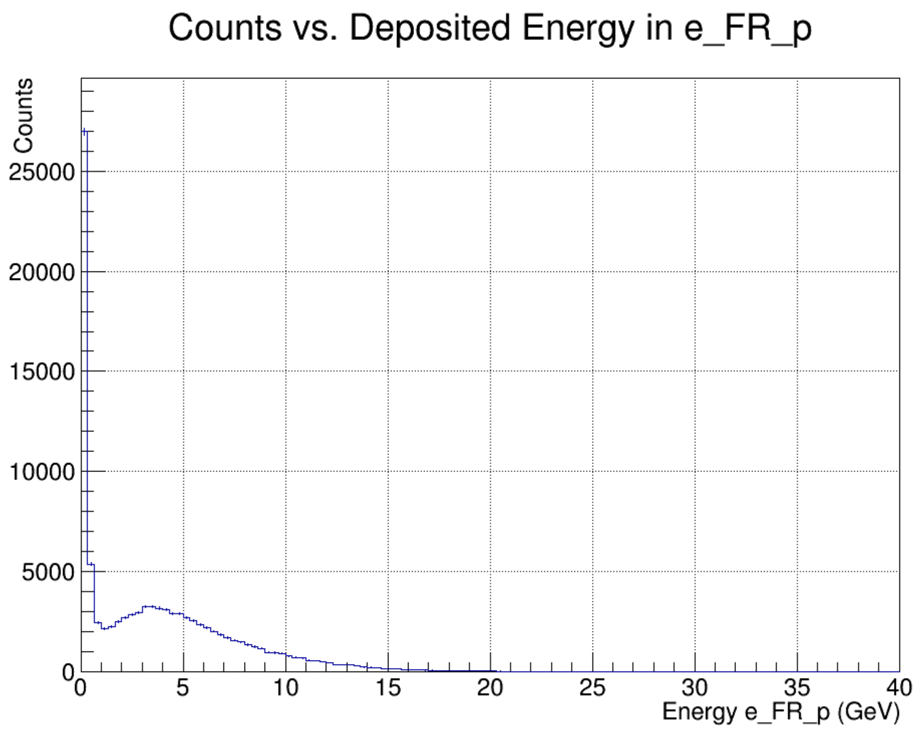

Figure 1.14: Histogram of energy deposited in forward flux return for 30 GeV pions. There is a large peak near what looks like 0 but is actually the MIP peak and closer inspection shows the peak is at 135 MeV. The other peak comes from showers and pair production in the flux return which are absorbed.

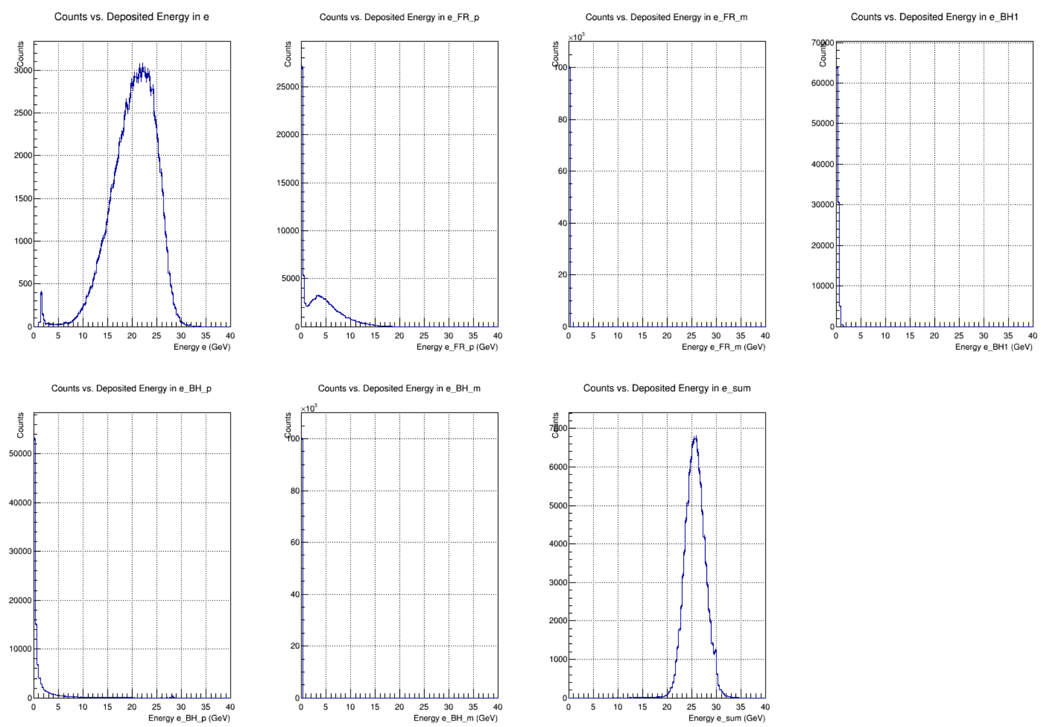

Figure 1.15: Histograms of energy deposited in the various objects in fsPHENIX for a 30 GeV pion in a flux return of 10.2 cm. "e" is the reconstructed energy from the forward calorimeters. "e_FR_p" is the energy deposited in the forward flux return. "e_FR_m" is the energy deposited in the negative flux return. "e_BH1" is the energy absorbed by the GEANT black hole in the central region. "e_BH_p" is the energy absorbed by the GEANT black hole in the forward region. "e_BH_m" is the energy absorbed by the GEANT black hole in the negative region. The histograms are showing what is expected in each case. Most of the energy is going to the forward region and the central and negative regions are mostly empty.

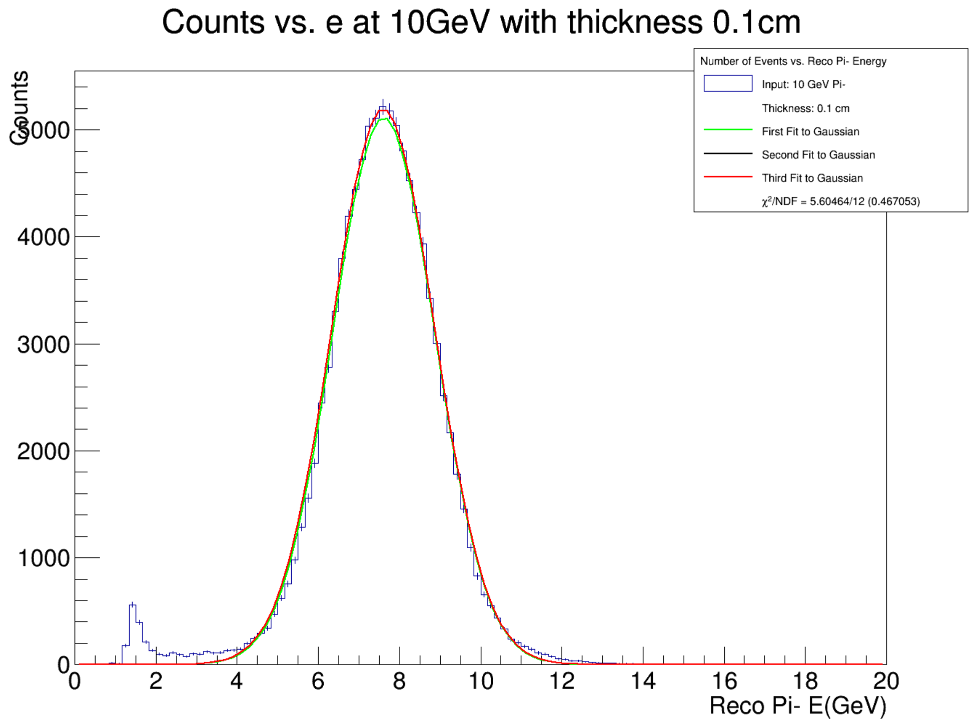

Figure 1.16: Histogram of Reconstructed Energy for a millimeter thickness plug door with its fits for a 10 GeV $\pi-$

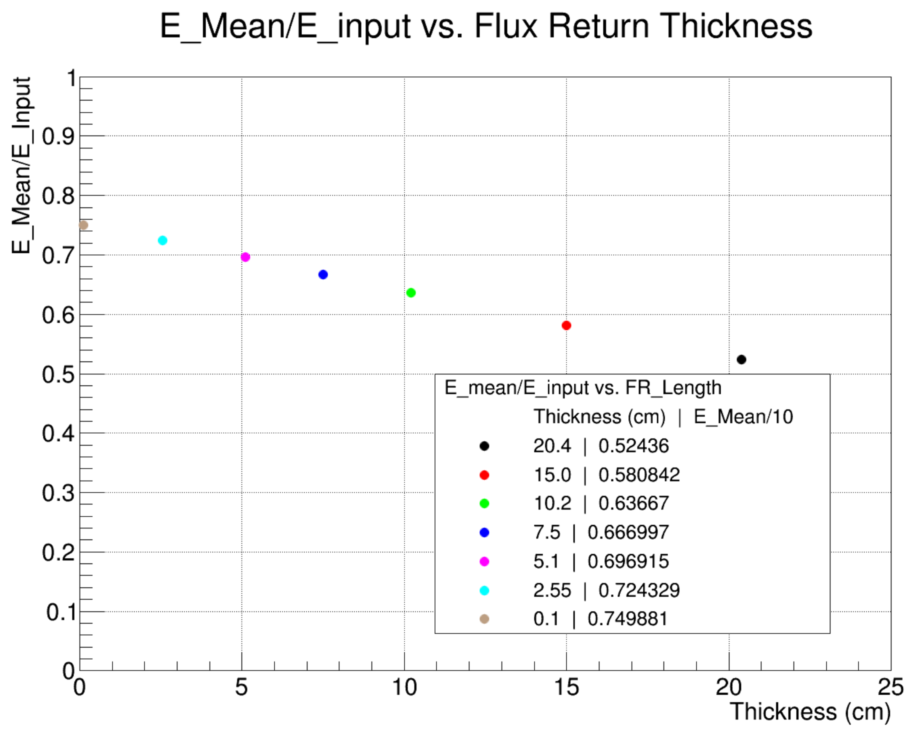

Figure 1.17: Plot of histogram mean of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 10 GeV π^-. The mean of the reconstructed energy is decreasing as the plug door gets larger as expected.

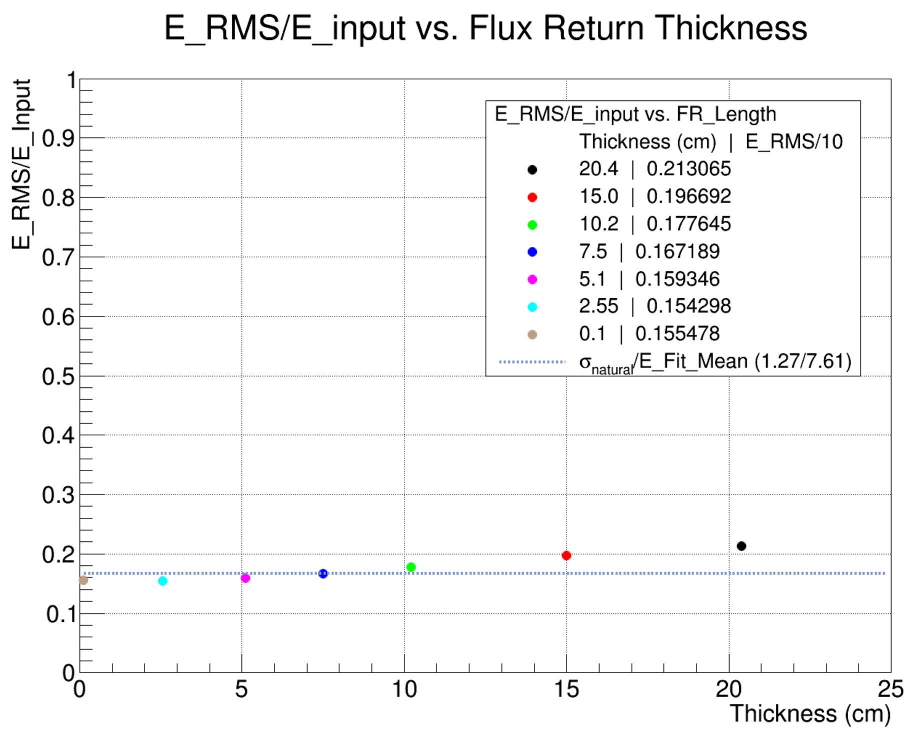

Figure 1.18: Plot of histogram RMS of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 10 GeV π^-. The RMS of the reconstructed energy is increasing as the plug door gets larger as expected.

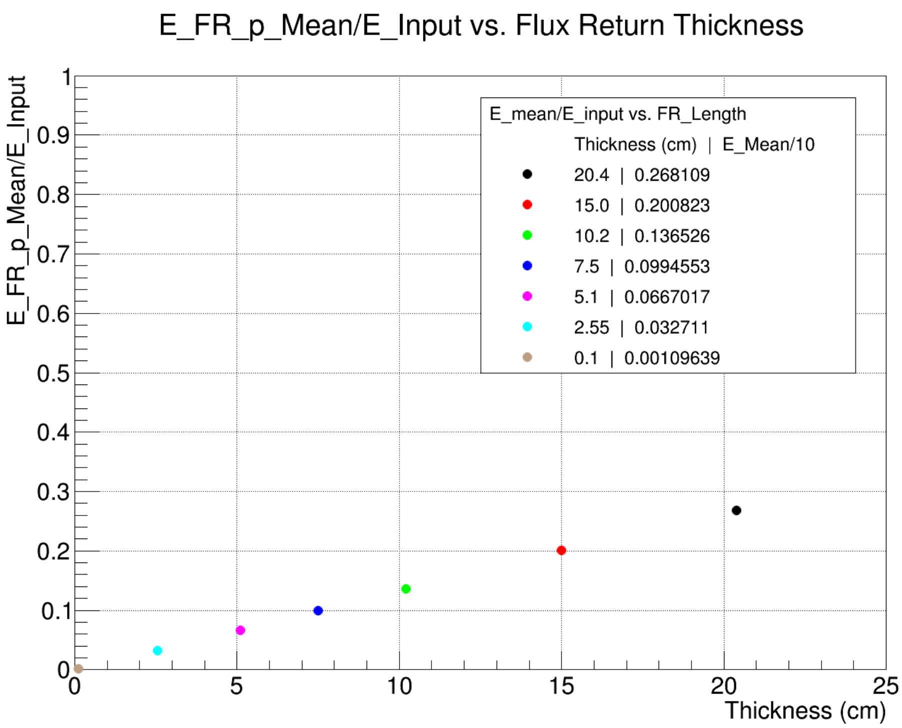

Figure 1.19: Plot of histogram mean of absorbed energy in the flux return vs. thickness of flux return for 10 GeV π^-. As expected the mean energy absorbed is increasing with thickness.

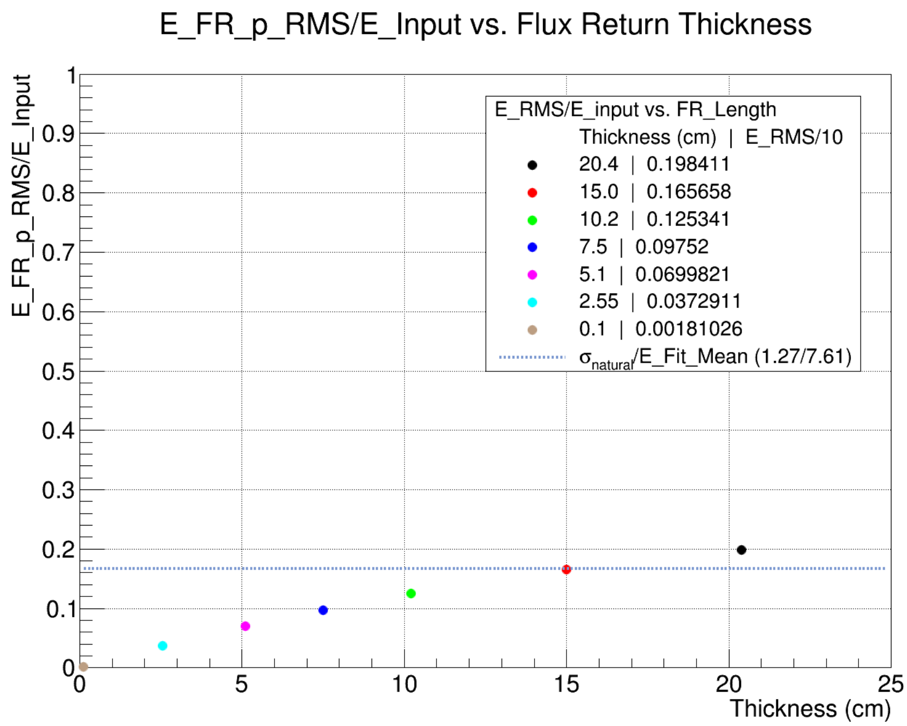

Figure 1.20: Plot of histogram RMS of absorbed energy in the flux return vs. thickness of flux return for 10 GeV π^-. This plot shows the fluctuations of the absorbed energy in the flux return. When the points cross the dashed line of $\sigma_{natural}/E_{input}$ the error in the measured energy from the calorimeters is large as the fluctuations of energy absorbed in the flux return. In short our flux return is too thick to allow a good energy measurement.

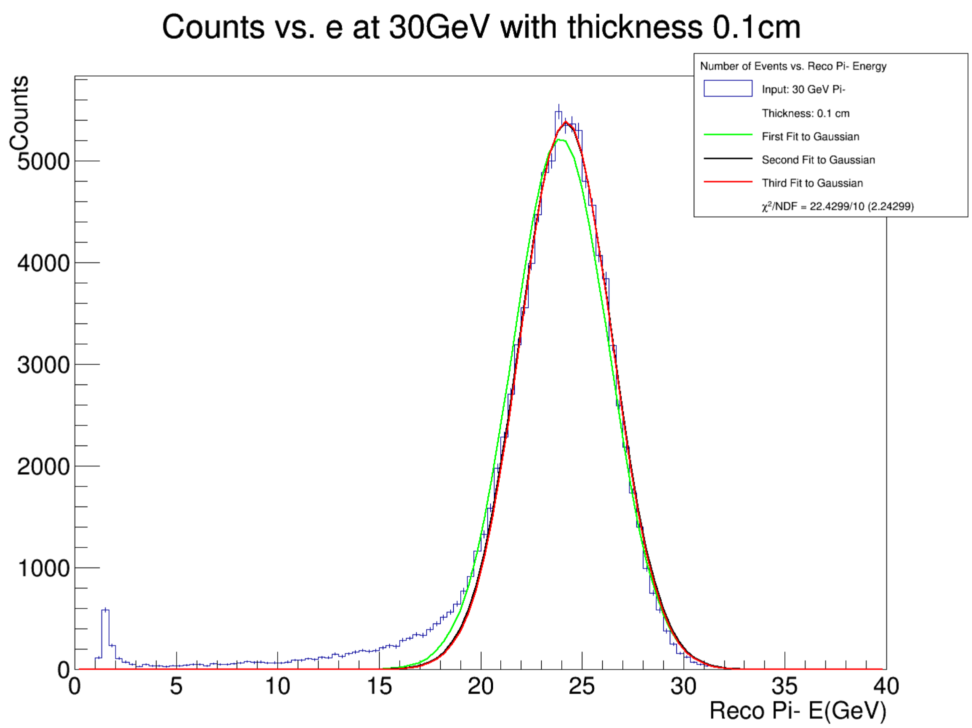

Figure 1.21: Histogram of Reconstructed Energy for a millimeter thickness plug door with its fits for a 30GeV $\pi-$. See 1.16.

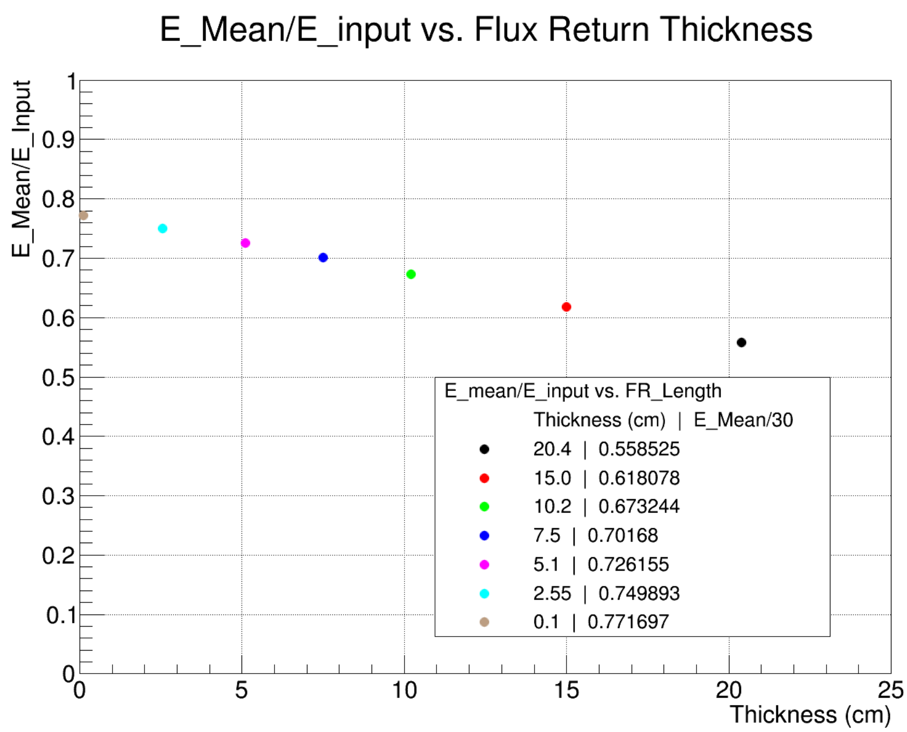

Figure 1.22: Plot of histogram mean of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 30GeV π^-. See 1.17.

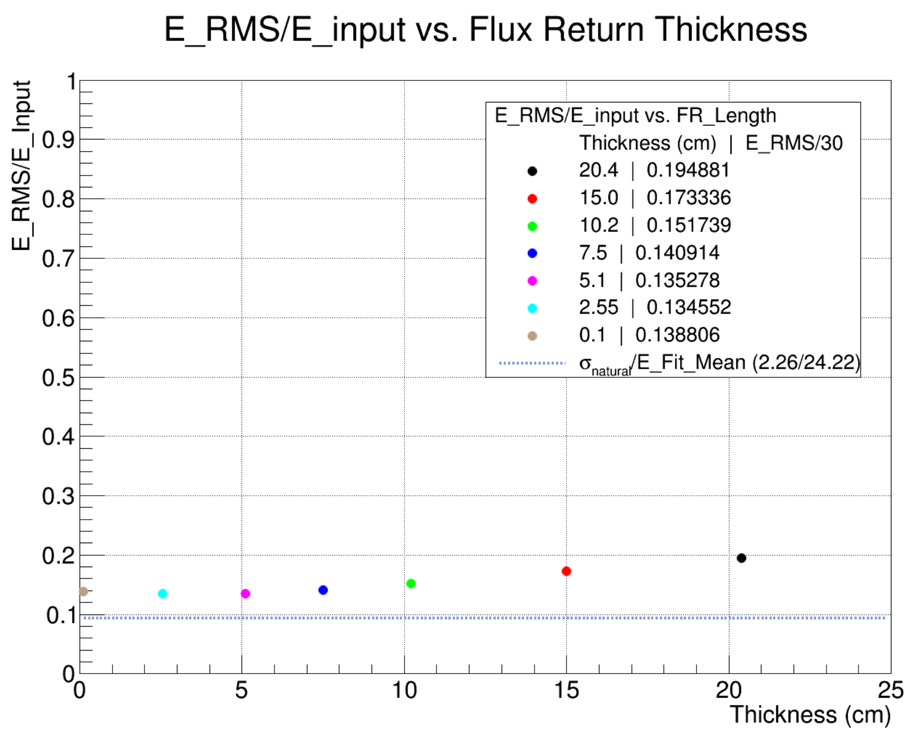

Figure 1.23: Plot of histogram RMS of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 30GeV π^-. See 1.18.

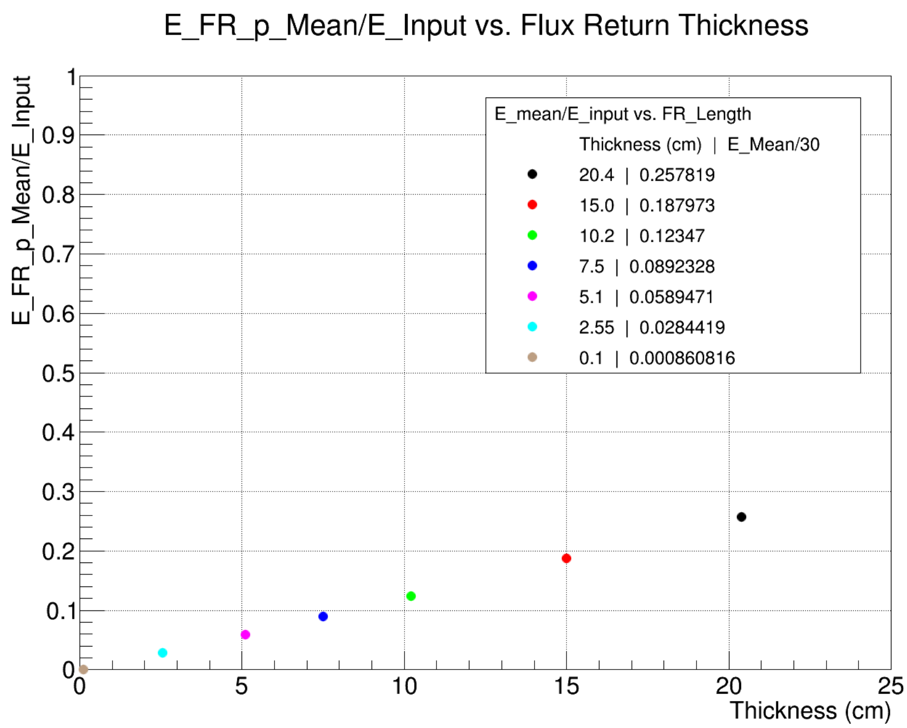

Figure 1.24: Plot of histogram mean of absorbed energy in the flux return vs. thickness of flux return for 30GeV π^-. See 1.19.

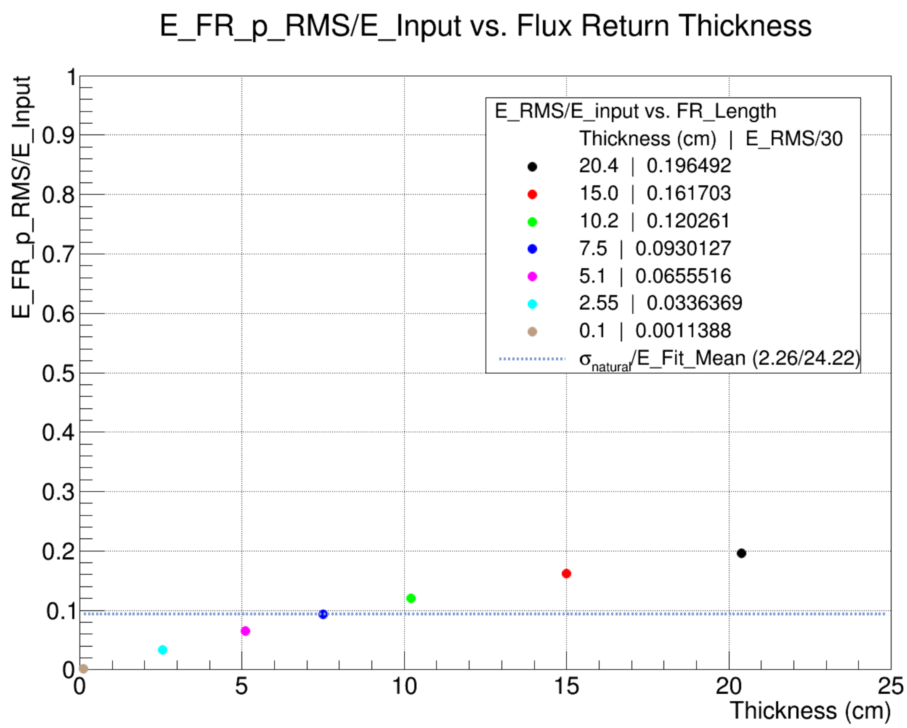

Figure 1.25: Plot of histogram RMS of absorbed energy in the flux return vs. thickness of flux return for 30GeV π^-. See 1.20.

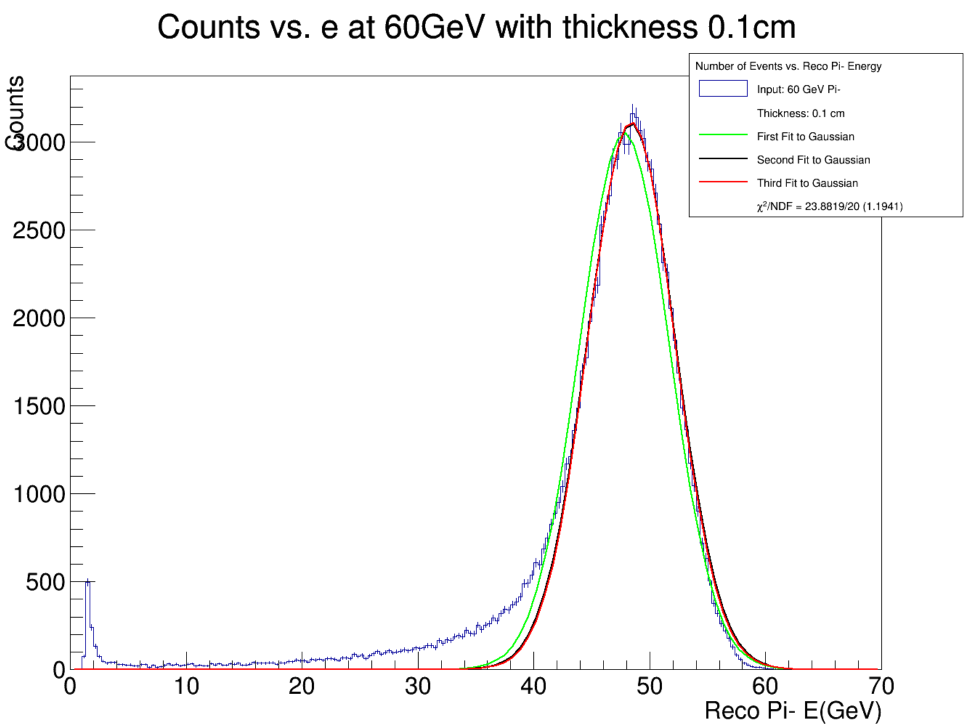

Figure 1.26: Histogram of Reconstructed Energy for a millimeter thickness plug door with its fits for a 60GeV $\pi-$. See 1.16.

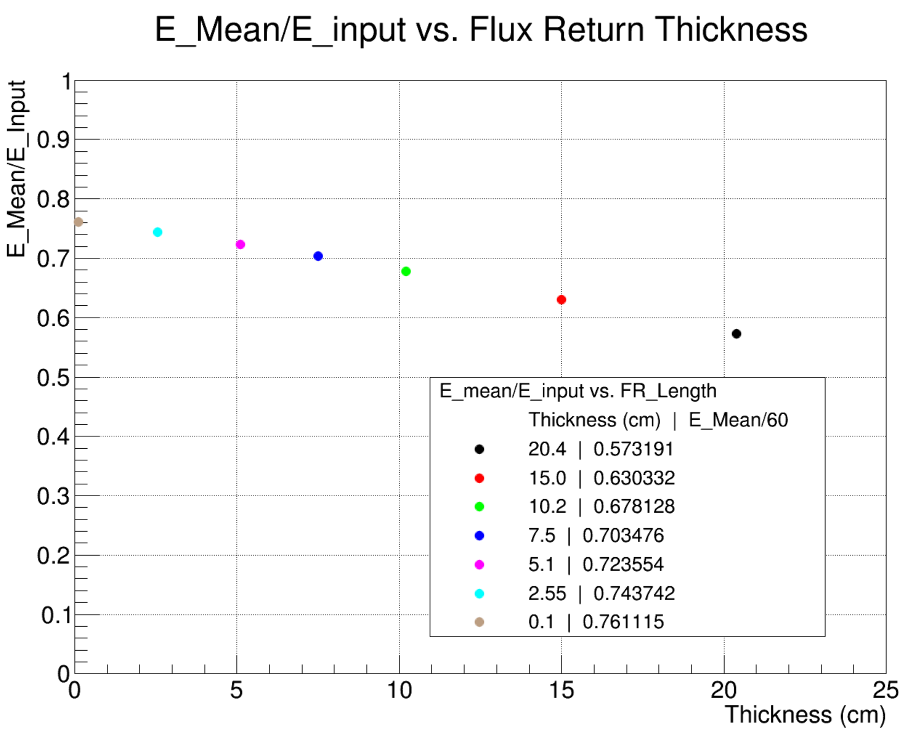

Figure 1.27: Plot of histogram mean of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 60GeV π^{-}. See 1.17.

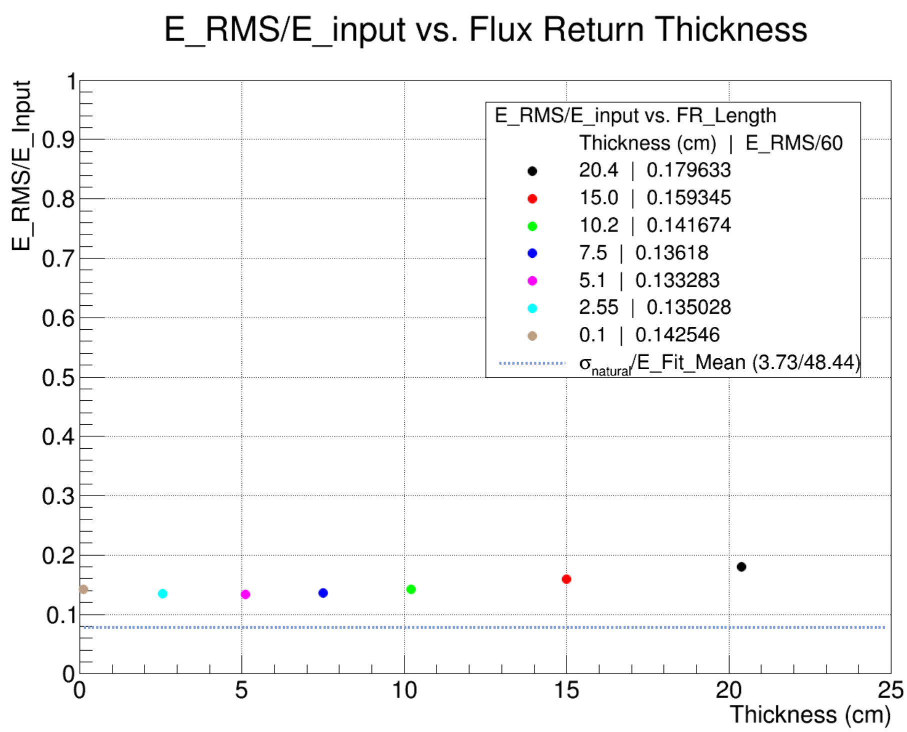

Figure 1.28: Plot of histogram RMS of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 60GeV π^-. See 1.18.

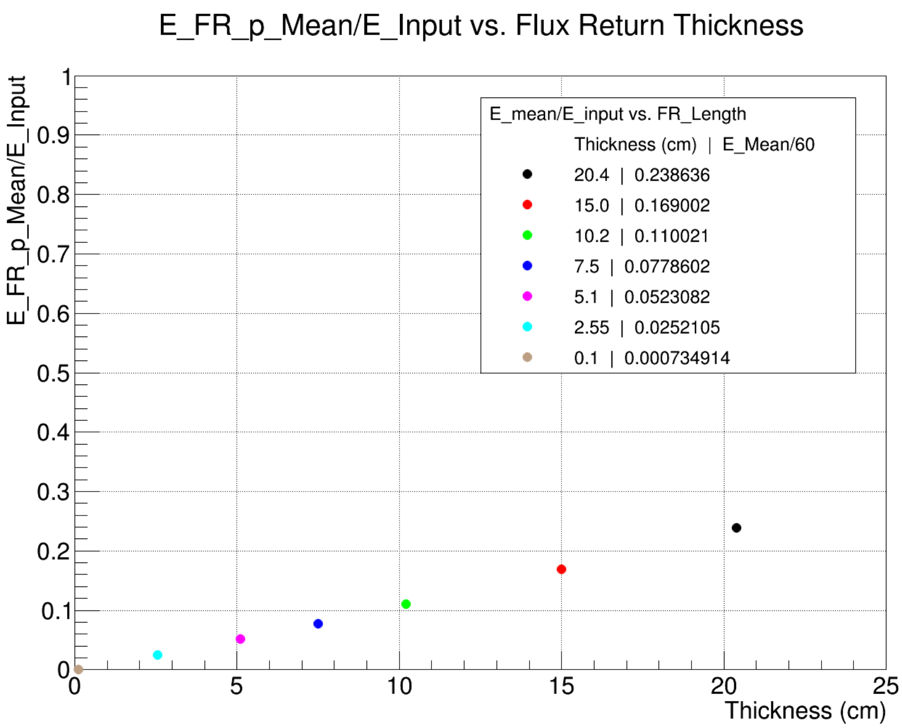

Figure 1.29: Plot of histogram mean of absorbed energy in the flux return vs. thickness of flux return for 60GeV π^-. See 1.19.

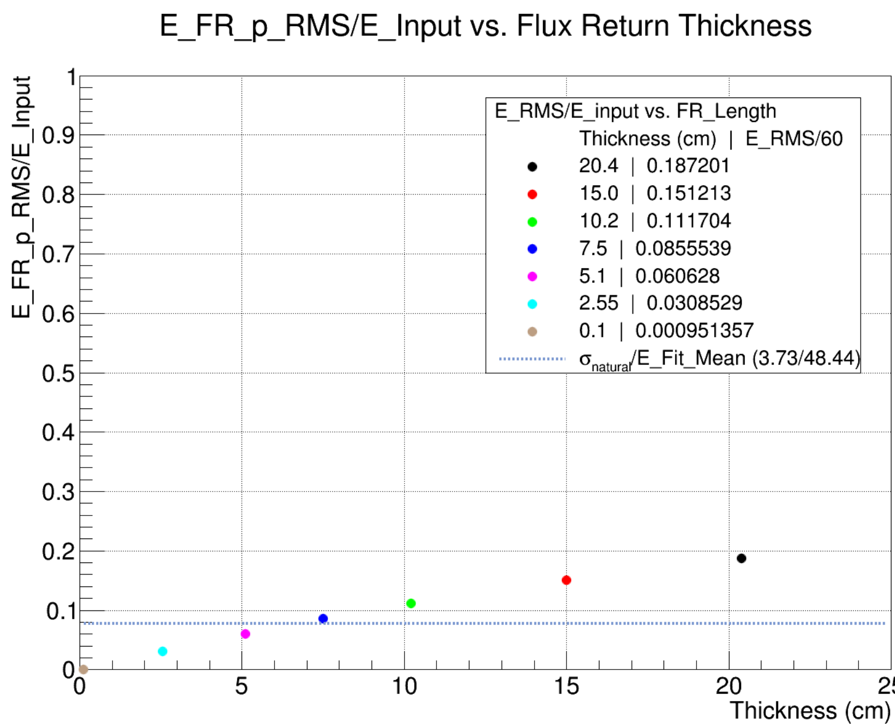

Figure 1.30: Plot of histogram RMS of absorbed energy in the flux return vs. thickness of flux return for 60GeV π^{-}. See 1.20.

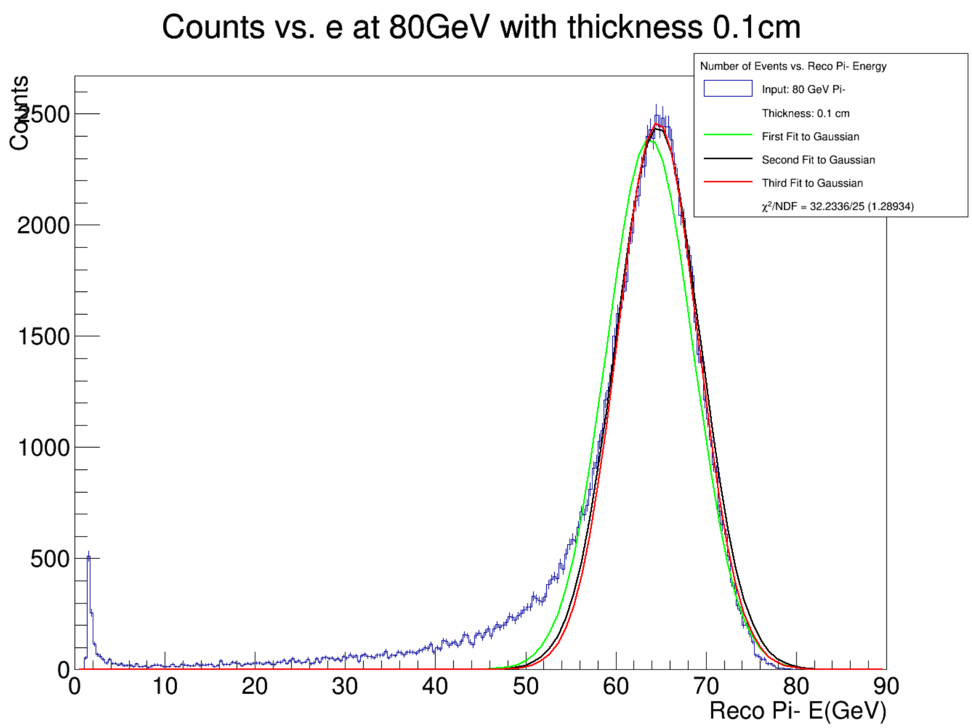

Figure 1.31: Histogram of Reconstructed Energy for a millimeter thickness plug door with its fits for a 80GeV $\pi-$. See 1.16.

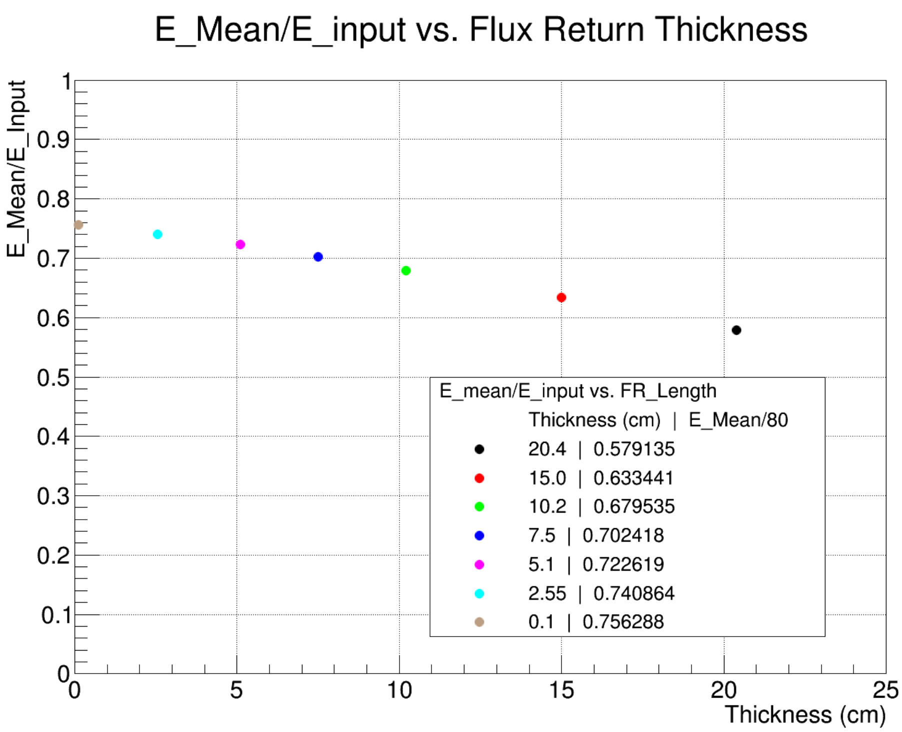

Figure 1.32: Plot of histogram mean of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 80GeV π^-. See 1.17.

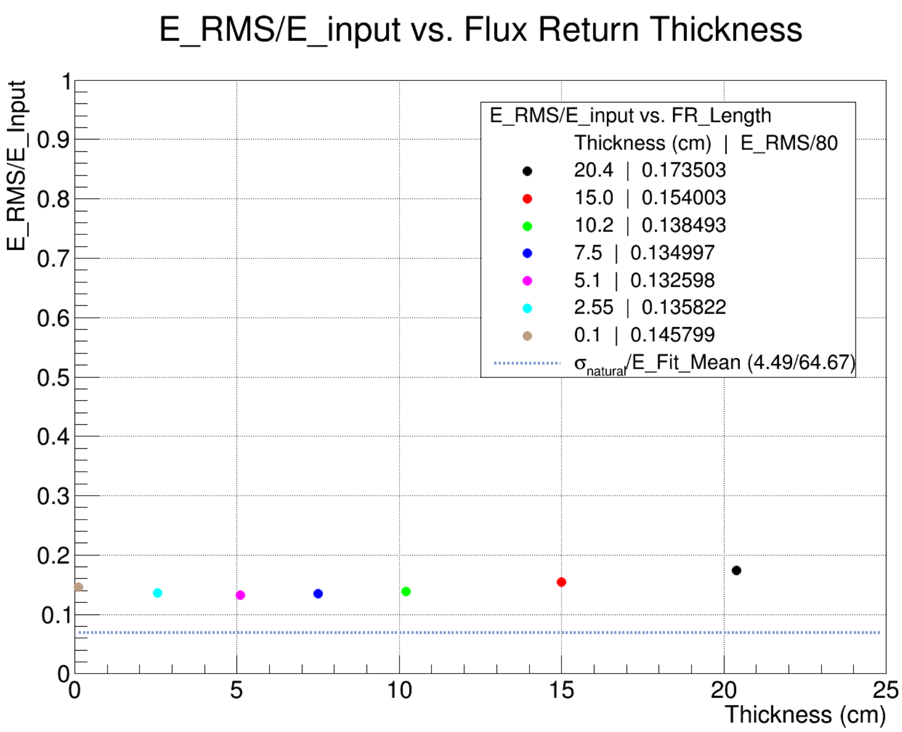

Figure 1.33: Plot of histogram RMS of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 80GeV π^-. See 1.18.

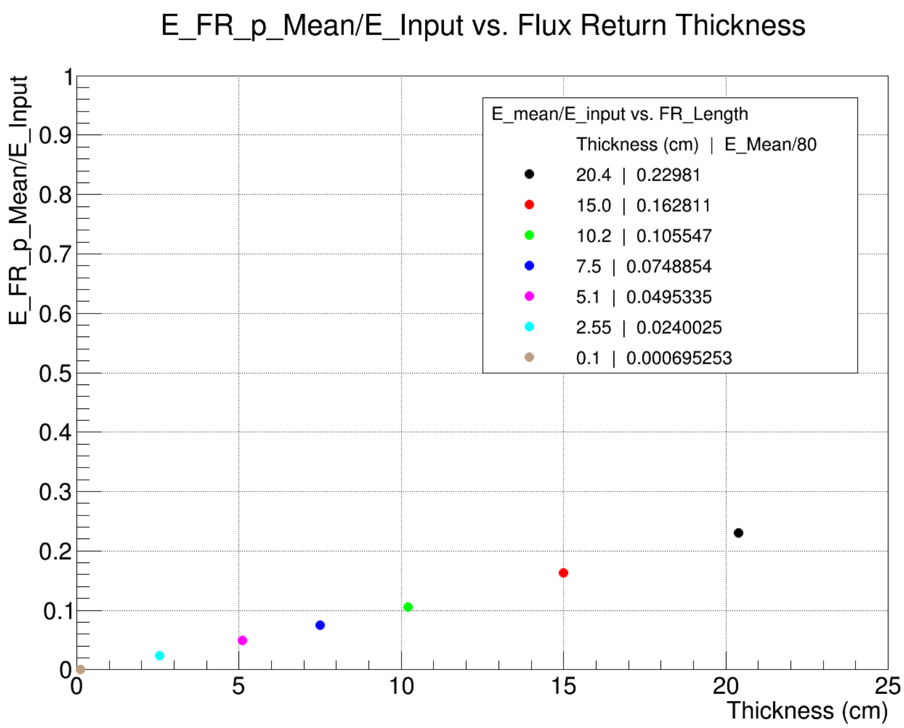

Figure 1.34: Plot of histogram mean of absorbed energy in the flux return vs. thickness of flux return for 80GeV π^{-}. See 1.19.

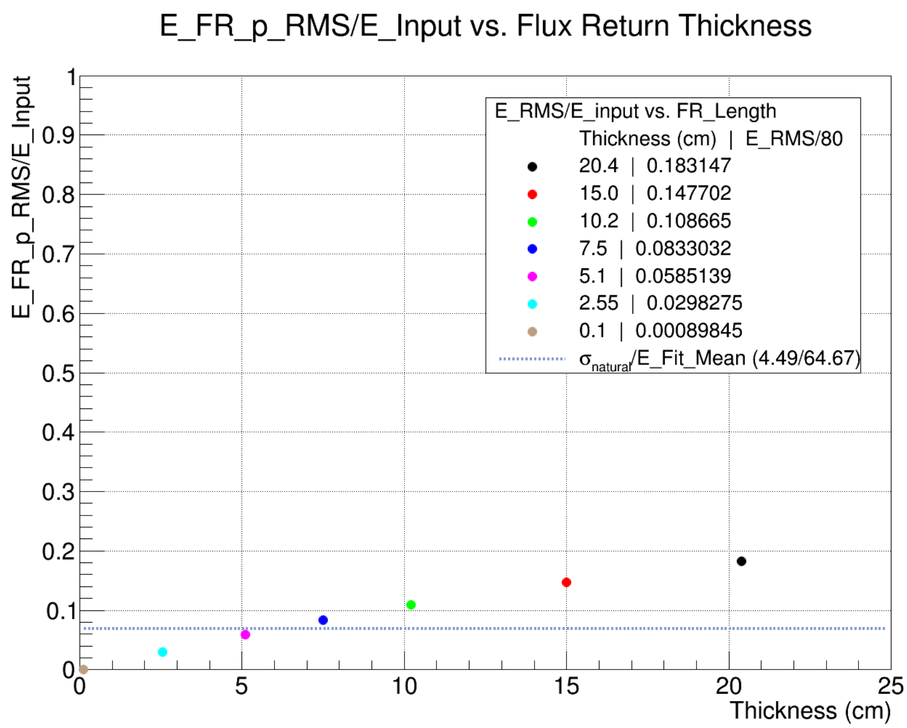

Figure 1.35: Plot of histogram RMS of absorbed energy in the flux return vs. thickness of flux return for 80GeV π^{-}. See 1.20.

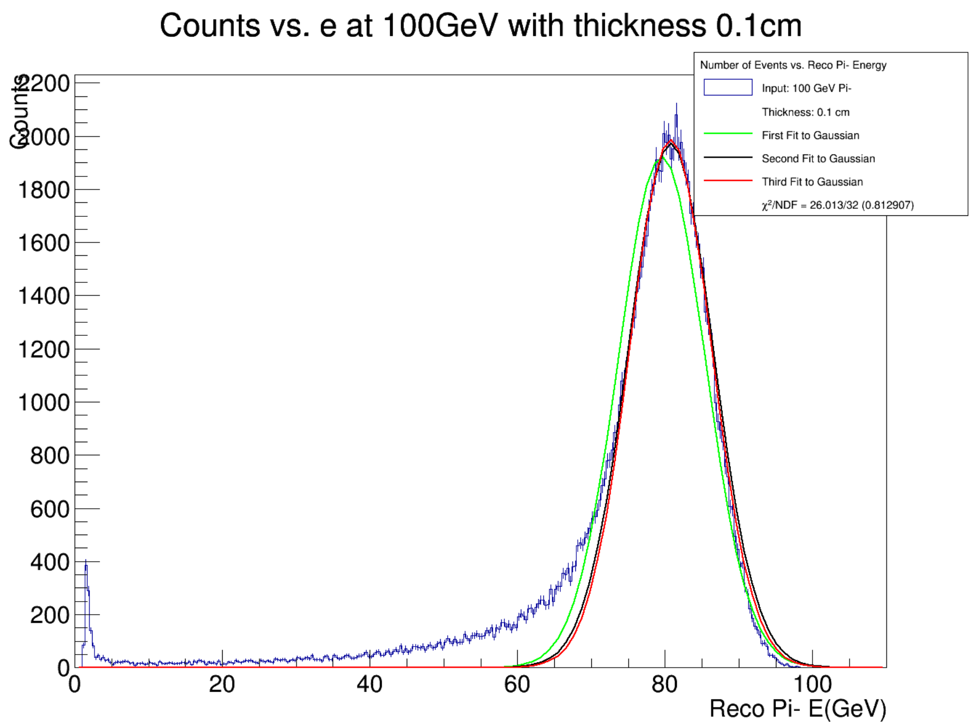

Figure 1.36: Histogram of Reconstructed Energy for a millimeter thickness plug door with its fits for a 100GeV $\pi-$. See 1.16.

1.3 Conclusions

From those plots it is clear that for pions of energy 10 GeV the propsed thickness of the flux return 10.2 cm will work just fine. However, as we get to higher and higher energies like 100 GeV the proposed thickness of the plug door will begin to affect the measured energy and resolution of the foward hadron calorimeter (FHCAL).

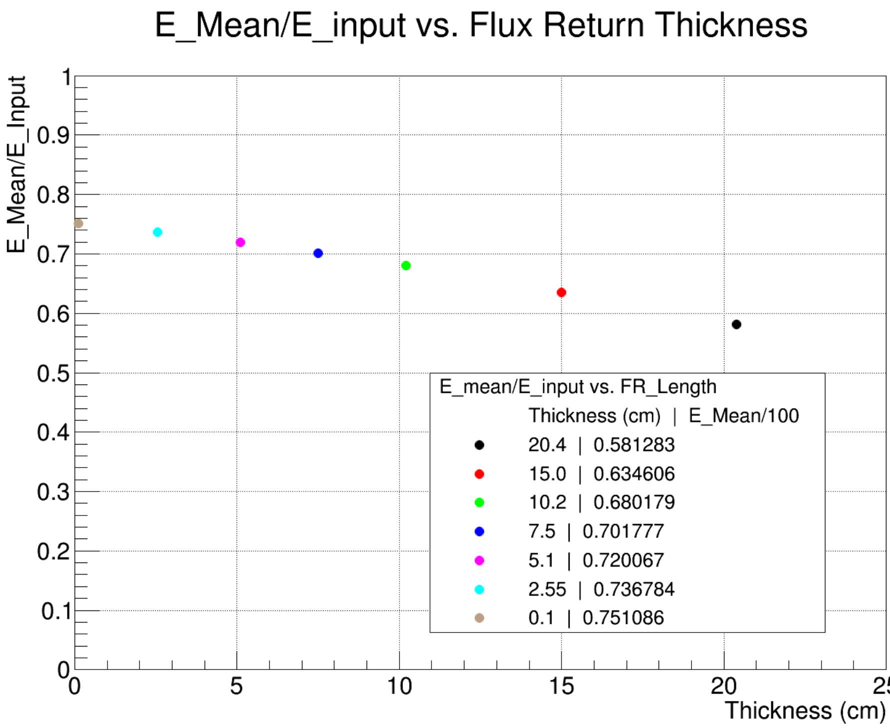

Figure 1.37: Plot of histogram mean of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 100GeV π^{-}. See 1.17.

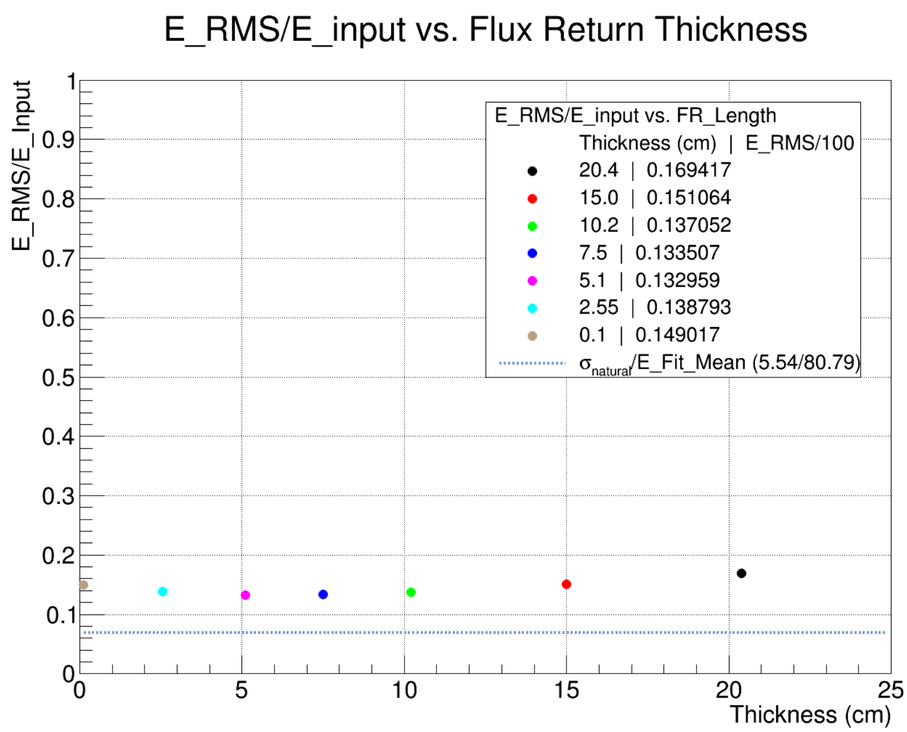

Figure 1.38: Plot of histogram RMS of reconstructed energy in forward calorimeters vs. the thickness of the flux return for 100GeV π^-. See 1.18.

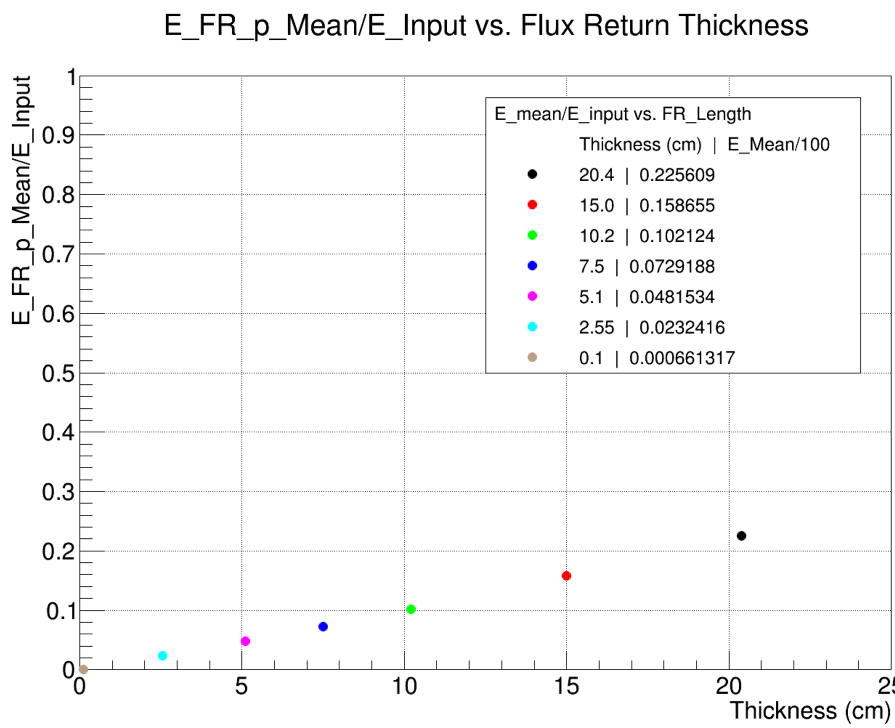

Figure 1.39: Plot of histogram mean of absorbed energy in the flux return vs. thickness of flux return for 100GeV π^-. See 1.19.

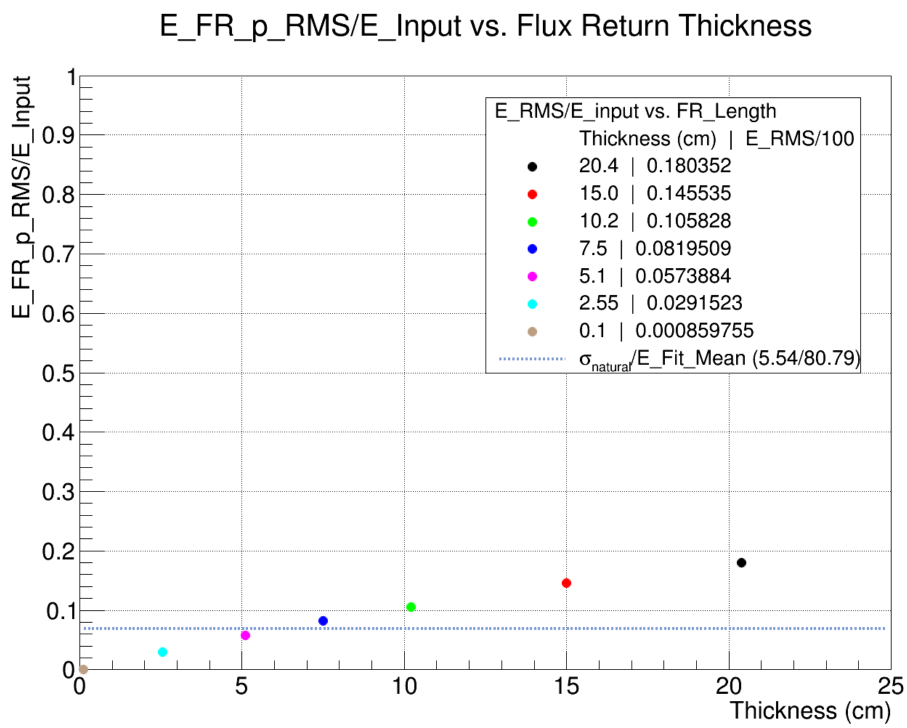

Figure 1.40: Plot of histogram RMS of absorbed energy in the flux return vs. thickness of flux return for 100GeV π^{-}. See 1.20.