To: E852 Collaboration
From: Notre Dame 852 Group
Subject: CsI anaylsis for E852 1993 run

1 Introduction

This document is designed to summarize the work done on anaylzing the performance of the CsI for the E852 1993 summer run. Due to the noise problems experienced in CIA and the most upstream ring of CIB most of this analysis has been performed on the downstream 9 rings of CIB unless otherwise stated. It is believed that this noise problem will not be present for future runs so additional time was not put into its study. This document will be updated as new results are found.

2 Pedestals

Pedestals were taken at various times during the run. A pulser was attached to the ADC gate input and the ADC was randomly triggered when the pion beam was disabled. A roughly gaussian shape was observed in the pedestal spectrum for each crystal (shown in figure 1). This shape is primarily due to amplifier moise in the electronics associated with each crystal. The pedestal width was determined in terms of energy deposition in each crystal (figure 2), this determines the minimum amount of energy that can be resolved by each crystal, typical values are 1-2 MeV. It was observed that the pedestal width varied with time, roughly by a factor of two. It is speculated that this is due to intermittent noise due to ground loops in the AGS enviroment. Steps have been taken to reduce the effect of this noise in upcoming runs.

3 Halo

The halo muons which are a natural part of the incoming pion beam are used by E852 to calibrate and monitor the CsI. During the 1993 run halo triggers were taken both as the main trigger for selected runs and as an auxillary trigger during other runs. For future data runs, it is intended that dedicated halo runs be done at the beginning and end of the AGS run and that some halo triggers be taken during each run. It is estimated that a few halo triggers per spill would be a helpful and not an unreasonable use of beam time.

Monte Carlo studies of straight through halo muons and pions have been done. The results are summarized in Neal's Nov 15, 1993 memo on Monte Carlo studies. The spectra which were generated were fit to determine what distribution was used and how well the peak could be fit. Not suprisingly, the distribution was found to be Landau. A sample CIB Monte Carlo spectrum was fit with both a Landau function (Fig 3a) and a Landau smeared by a Gaussian (Fig 3b). These functions and the fitted parameters are both described in Appendix A. The results of both fits gave a $\chi^2/d.o.f \approx 1.4$

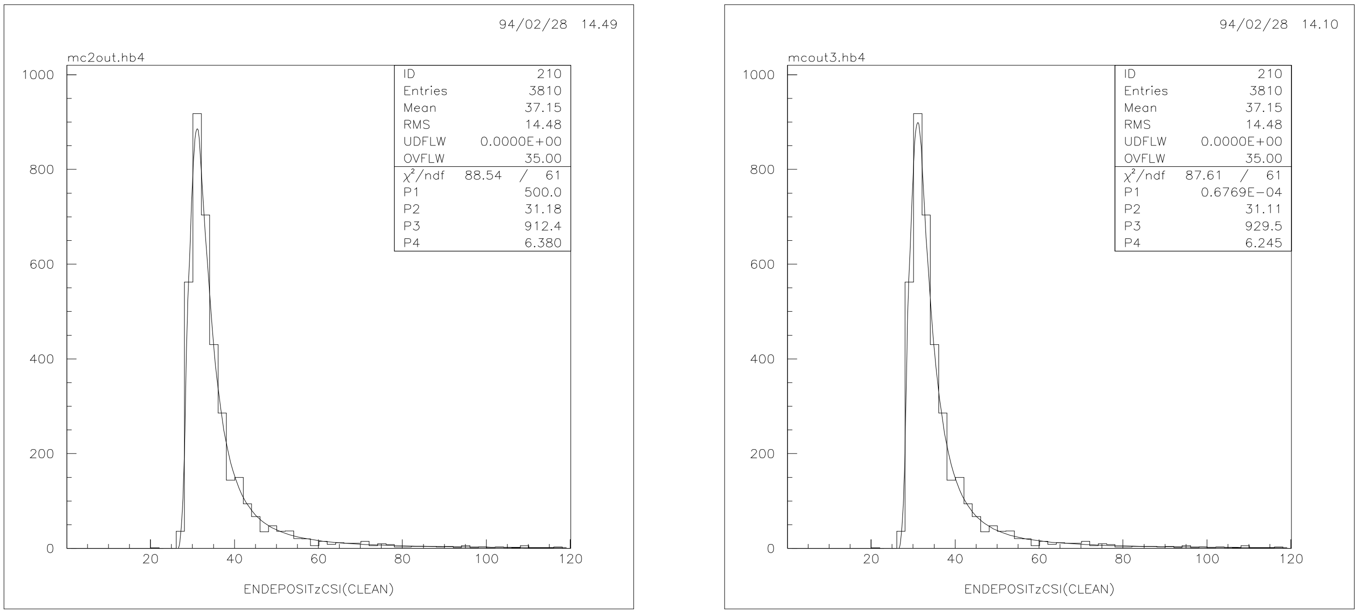
As is usually the case, the halo data which were collected were not as simple as the Monte Carlo. A sample spectrum is presented in Fig. 4. Due to the particular beam tune which was used the halo

To be filled in later

Figure 1: Sample pedestal spectrum from 1993 run

To be filled in later

Figure 2: Sample pedestal spectrum (GeV) for 1993 run



(a) (b)

Figure 3: Monte Carlo simulation of straight through halo muons with fit to a pure Landau (a) and a Landua smeared by a Gaussian (b)

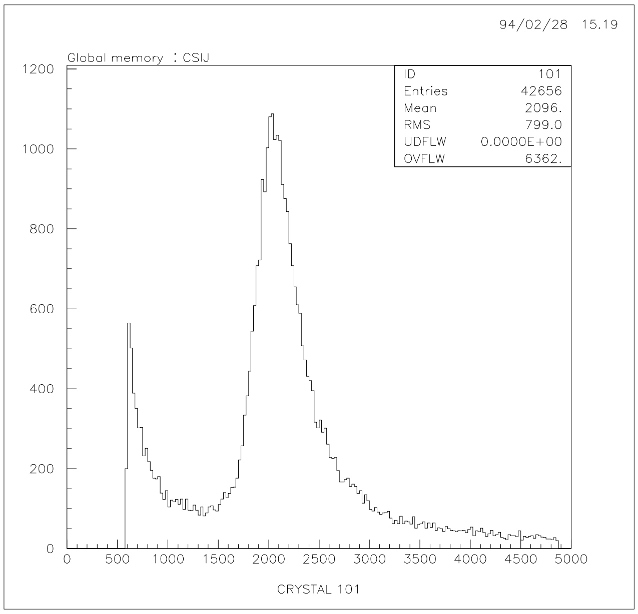


Figure 4: Sample halo data from 1993 run

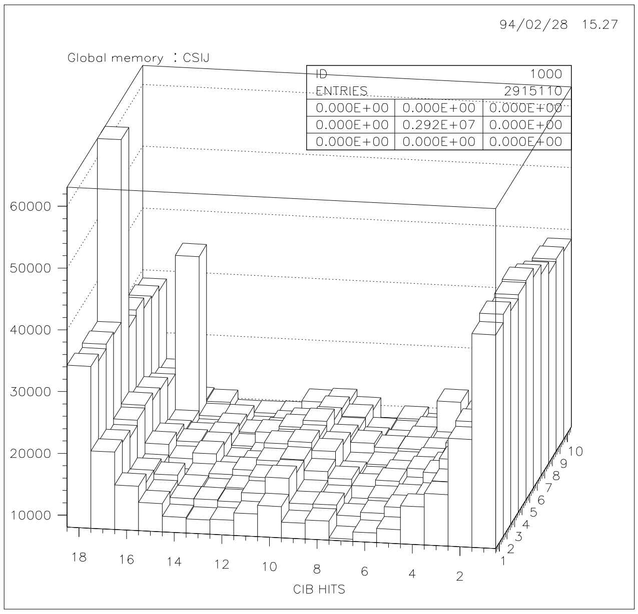


Figure 5: Hits distribution for sample halo run

was not evenly distributed around the beam. Crystals on or near the x axis (rows 1 and 10) received significantly more halo particles than those near the top or bottom of the barrel. Also, for given runs it is possible to tell whether the beam is closer to the inside or outside of the magnet by the distribution of hits in the CsI (Fig. 5). This means that for some crystals the minimum ionizing peak formed by the halo muons is much higher above background than for others.

To emphasize the halo peaks, cuts were made on the data. A simple cut requiring between 9 and 16 total hits in the event significantly reduced the background while leaving the peak. However, a very strict cut is necessary to make the data resemble the Monte Carlo. A requirement that 11 and only 11 hits were present and the all of them be in a line creates a very nice halo peak (Fig 6). However, this cut greatly reduces the statistics and the halo peak is only found in those crystals which had a large number of halo particles passing through them, specifically rows 1 and 10.

These very clean halo data peaks were then fit to compare with Monte Carlo. They were fit with both a pure Landau (Fig 7a) and a Landau smeared by a Gaussian (Fig 7b). The fit to a pure Landau produced a $\chi^2/d.o.f. \approx 4.5$ while the Landau smeared by a Gaussian produced a $\chi^2/d.o.f. \approx 1.2$. It is believed that this represents a physical process described by a Landau distribution which is smeared by the resolution of the detector. Further discussion of the fits and resulting parameters are presented in Appendix A.

The CsI crystals will be calibrated using the pedestal value for 0.0 GeV and the halo peak for .043 GeV (CIB) and .031 GeV (CIA). A straight line is then fit between the two to give a calibration constant. For this purpose only the peak position is important. Therefore a technique needs to be developed to determine the peak positions and corresponding calibration constants to the degree of accuracy which is desired (currently thought to be about 5%).

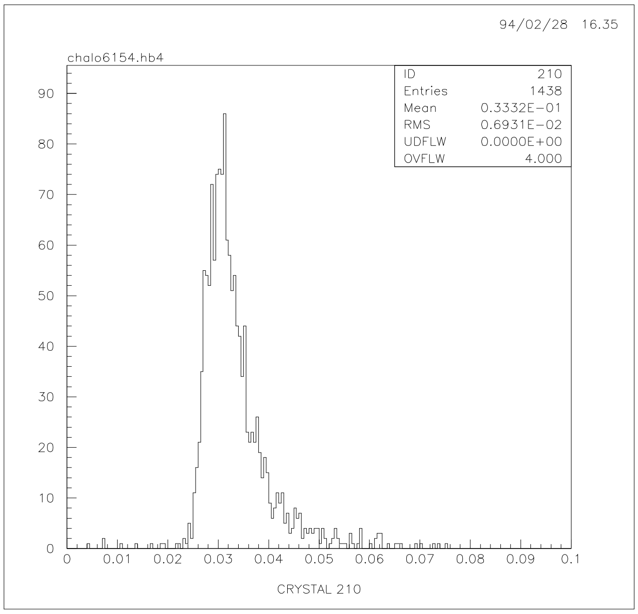
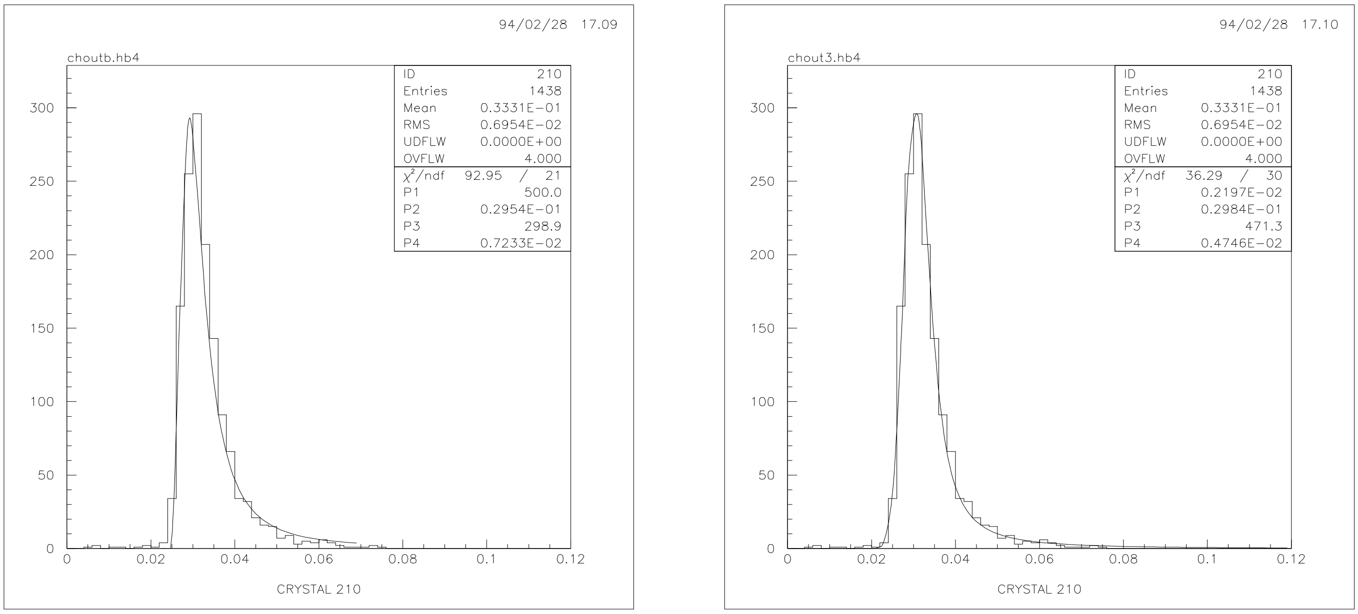


Figure 6: Very clean halo data spectrum



(a) (b)

Figure 7: Very clean halo data fit with a pure Landua (a) and with a Landau smeared with a Gaussian (b)

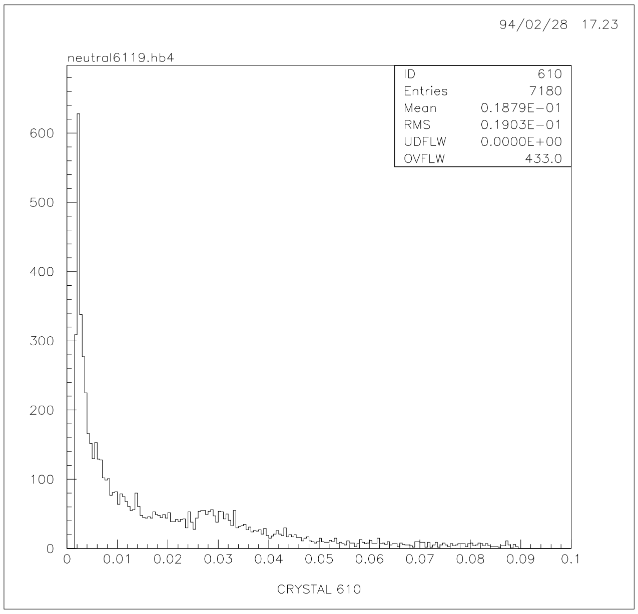


Figure 8: A sample neutral CsI spectra

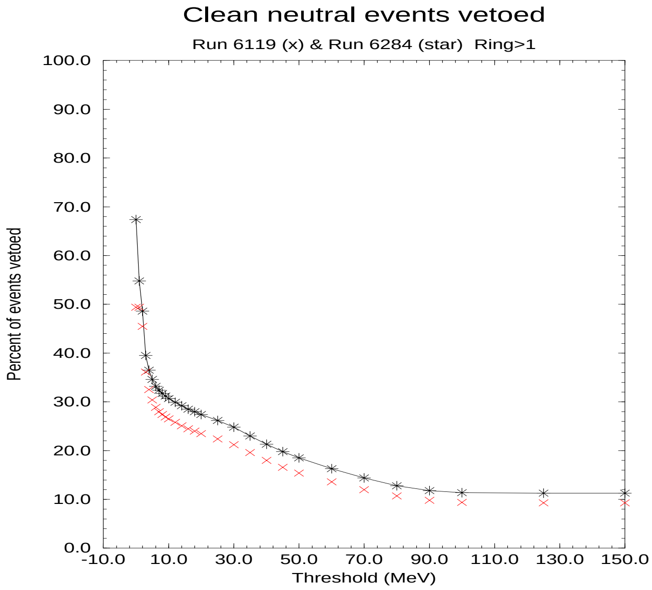


Figure 9: Event veto rate for neutrals

4 Neutral Recoils

For the reaction $\pi^- p \to NX$ where X is some meson produced in the forward direction, we need the CsI to veto when N is a recoil Δ^0 which decays to a neutron and π^0. Monte Carlo studies show that a recoil neutron will interact with the barrel about 20% of the time. Anaylsis of the CsI data for neutral events so far has revealed no distinct structures or patterns which might identify a neutron or a Δ^0. A sample spectra is given in Figure 8.

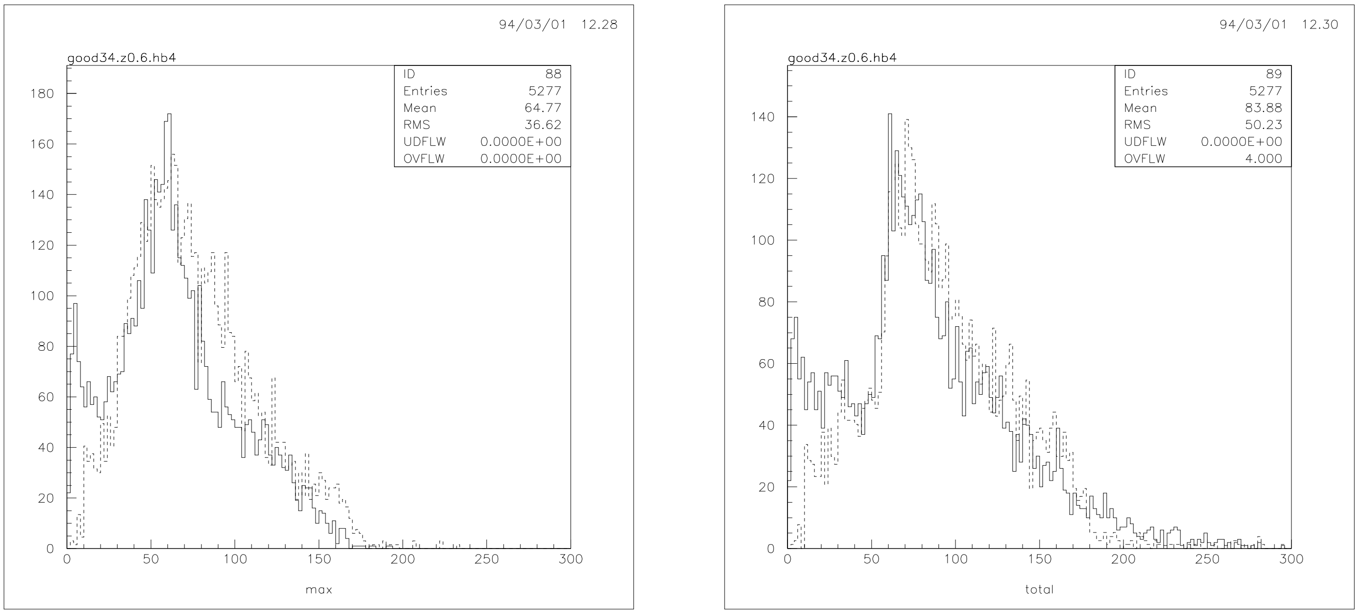
Studies have been carried out on the veto rate for a given threshold for CsI (Fig 9). An event is considered vetoed if any CsI crystal has a hit above threshold. This analysis was performed for two different runs from the summer of 1993 (runs 6119 & 6284). They are similar in structure with a veto rate from 20-50% of the neutral events depending on the threshold chosen.

5 Charged Recoils

Monte Carlo studies were made of recoil protons which hit the CsI and are presented in Neal's memo. Because of the short interaction length of the CsI crystals, most protons will not be contained and will deposit only part of their energy through ionization. It will be impossible to differentiate between a low energy proton which stops and a high energy one which deposits the same amount of energy. Because of TCYL it should be possible to track charged particles into the CsI. It has not yet been determined if we can tell the difference between protons and other charged particles (namely, $\pi^{\pm}$).

Anaylsis of the recoil proton Monte Carlo reveals some characteristics. Due to the t distribution generate (e^{-3t}), the protons hit the barrel mostly between rings 2 and 9. The phi distribution is generally flat. Protons tend to deposit energy in only one or two crystals. Peaks between 50 and 100 MeV are seen in both the maximum energy and total energy spectra. In searching for protons in the data these characteristics are sought.

Run 6231 was scanned for events where a TCYL track could be reconstructed. This was done with



(a) (b)

Figure 10: Maximum (a) and total (b) energy spectra shape comparison between Monte Carlo and data.

Sasha's goodphi34 program which requires hits which are within 5 degrees of each other in 3 out of the 4 chambers. This reduced the sample from 304,248 events to 153,754 events. The data was then run through goodz34 which required hits in 3 of 4 chambers to be within .05 the length of TCYL of each other. This reduced the data set further to 123,697 events. When the data was analyzed, it was required that only one track reconstruct with the requirements of 3 or 4 hits within 5 degrees of the hits within the first chamber which recorded hits. There were approximately 76,000 events which met this requirement.

In the search for protons a cut was made on the CsI hits. Only hits in the row or its neighboring rows which matched the phi of the reconstructed TCYL track were kept. No requirement on reconstruction of z was made initially. This produced some interesting characteristics. Most of the events with hits which survived the cuts had a few hits in them (peaking around 2-3 hits per event). Both the maximum energy and the total energy per event spectra had peaks between 30 and 50 MeV. Also, most of the events had only one cluster (a hit and its nearest neighbors). These characteristics do not exactly match those of the Monte Carlo, but there is still a possibility.

While the spectra's peak positions were not in the same place, the shapes appeared similar. The data was rescaled by energy to convert from GeV to MeV and shift the peak upward (a factor of 1700 was used). The Monte Carlo was then rescaled in the y direction to match the data height as best as possible. Plots were made to compare the peak shapes. These plots are given in Appendix B. Additional cuts were made to try to enhance the protons in the sample. Events with more than 3 hits were thrown out. Also, a cut requiring a reconstructed z position within 0 to .6 of the tcyl lenght was made. Both of these cuts dramatically reduced the data set. However, as Figures 10a,b show the peak shapes are remarkably similar.

It has been suggested that these peaks really do represent protons. The difference in peak positions may be attributable to differences in energy deposition and light collection between halo muons and recoil protons.

6 Further Issues

Some issues related to CsI are still unresolved. Namely, how the CsI will be used as a veto. For the neutrals it should be relatively simple. It should be a veto if any event has hits in CsI above a certain threshold. The value of this threshold still needs to be determined.

For charged particles, it is much more complicated. A procedure must be developed to determine whether an event should be vetoed. Protons need to be separated from $\pi^{\pm}$. Also, protons need to be separated from Δ^{+}. We will want to keep the protons and probably remove the pions and deltas from our data set. This procedure could be complicated and involve other detectors and reconstruction such as using the missing momentum.

An issue for our own purposes is to determine a resolution for the CsI barrel. This is not quite as important, but would be useful. It has been suggested that the width of the Gaussian smearing could be used as a measure of the resolution.

7 Appendix A

For the fits to the Monte Carlo and data halo peaks, several parameters were fit. They are defined as:

For pure Landau:
- par1 - pedestal position (not fit)
- par2 - peak position
- par3 - peak height
- par4 - Landau width

For Landau smeared by a Gaussian:
- par1 - Gaussian width
- par2 - peak position
- par3 - peak height
- par4 - Landau width

For the pure Landau fit, the distribution that was fit was defined as:

$$L(x) = \frac{2.0}{.37} * par3 * DENLAN((x - par2) * \frac{4.2}{par4})$$

where DENLAN is the CERN library function which will generate a Landau distribution. The other factors are used to resize the distribution to fit the halo. The 4.2 is obtained from visual inspection of approximately the full width half max of DENLAN. The .37 is also from the natural DENLAN peak height while the factor of 2.0 was found to be necessary to make the peak height which is fit resemble

Parameter	Monte Carlo	Halo data	Approximate parameter meaning
par1	500.0	500.0	Pedestal position - not fit
par2	$.03118 \pm .09$	$.02954 \pm .00012$	Peak Position (Gev)
par3	$912. \pm 24.$	$301. \pm 17.$	Peak height
par4	$.00638 \pm .134$	$.00708 \pm .00034$	Peak width (GeV)
χ^2	1.4	4.5	Chi squared per degree of freedom

Table 1: Parameters for the pure Landau fit

the actual peak height of the data. For these reasons, the parameters only approximate what they resemble (ie. par1 may not be the actual peak height, but it is close). We accept these values as true.

The Landau smeared by a Gaussian is an attempt to simulate the resolution of the detector. Because the detector is not perfect each channel will contribute to its neighbors, just as its neighbors will contribute to it. We are trying to simulate this sharing with a Gaussian distribution. The function which was used is described below with L(x) being the same function as used for the pure Landau distribution.

The function which was then fit was,

$$y(x) = \int_{-3*\sigma}^{+3*\sigma} \frac{L(x+z)*G(z)}{N} dz.$$

where N is a normalization factor so that the Gaussian sums to one.

$$N = \int_{-3*\sigma}^{+3*\sigma} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\frac{x^2}{\sigma^2}} dx$$

These integrations were actually performed as summations with a step size equal to the bin width.

These functions were then used to fit both the Monte Carlo and the very clean halo data. The fits were done using HBOOK4's HFITH. The input parameters were adjusted by hand until the best fit could be found. It was difficult to get good fits to most of the spectra. Only fits to crystal 210 are given here. It was only proven that these spectra can be fit to a given function, not that all of them were.

The results of the fits are given in Tables 1 and 2. For the purposes of these tables, the results of the fits to Monte Carlo are converted to GeV where applicable.

In comparing the fits to the Monte Carlo, the values for the peak position, peak height and Landau width are all very similar. The width of the Gaussian smearing is essentially zero since 3*.00006769 MeV is less than the bin width so no other channels contribute. This shows that for the Monte Carlo either fit is the same.

Parameter	Monte Carlo	Halo data	Approximate parameter meaning
par1	.0000006769	.002197	Gaussian width (GeV)
par2	.003111	.02984	Peak position (GeV)
par3	929.5	471.3	Peak hieght
par4	.006245	.004746	Landau width (GeV)
χ^2	1.43	1.21	Chi squared per degree of freedom

Table 2: Parameters for the Landau $*$ Gaussian fit

The data tells a different story. The fit to a pure Landau is not a good fit ($\chi^2 = 4.5$). However the fit with the Gaussian smearing is a very good fit. The Gaussian width is non-zero (2.2 MeV) and clearly plays a role in the fit. This leads us to believe that the physical process is really a Landau but the resolution of the detector distorts it.

8 Appendix B

This appendix presents the results of cuts made to the data to emphasize protons. The plots which compare Monte Carlo to data shapes are rescaled in both energy and peak height. The plots which show only Monte Carlo or data are left unscaled in height. Figure 11 shows the Monte Carlo maximum energy deposited and total energy deposited per event on the same plot. These spectra are the standard by which the data will be compared. Figure 12 shows the same spectra for the data with no rescaling. This plot is done in GeV, while the Monte Carlo is in MeV. Note the difference in peak position.

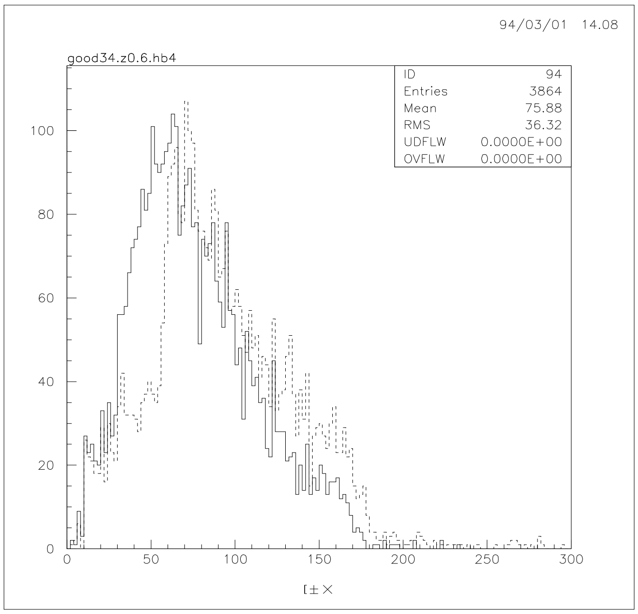


Figure 11: Monte Carlo maximum (solid) and total (dashed) energy deposited in CsI (unscaled)

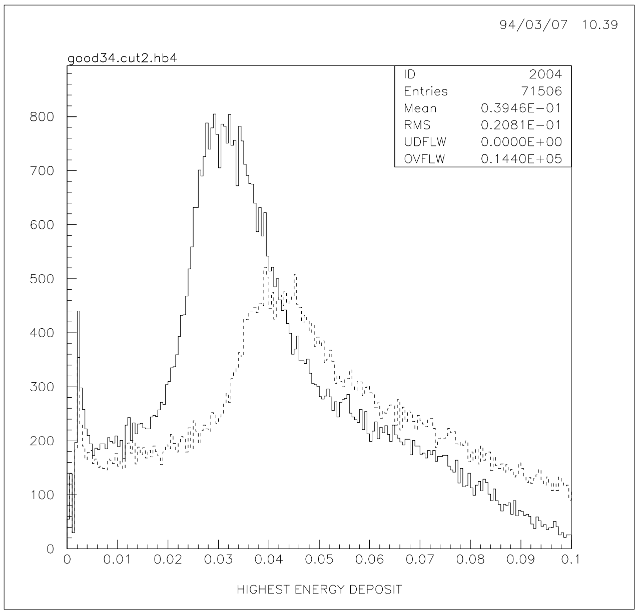
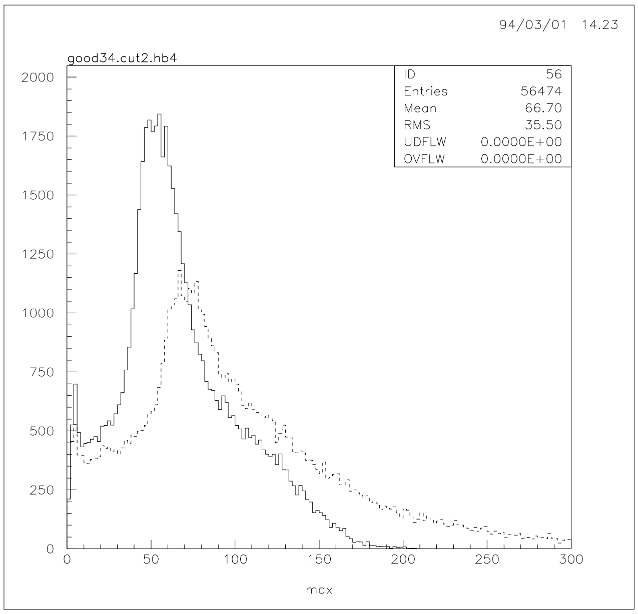


Figure 12: Unscaled data, maximum (solid) and total (dashed) energy deposited in CsI

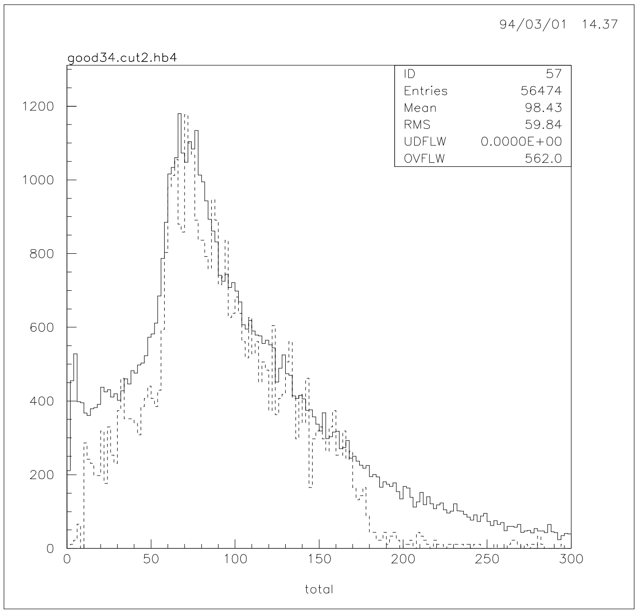
Figure 13 shows comparisons of the Monte Carlo with data which has only a cut on CsI including only the row and its neighbor which corresponds to the reconstructed tcyl track's phi. Figure 13a should be compared with figure 11. This data did not require the z for the track to reconstruct properly. All further data plots in this appendix will have this cut applied. The maximum/total peak widths are not the same as the Monte Carlo and neither are the peak shapes. Additional cuts will be used to bring these closer together. Plot (b) shows the Monte Carlo and data spectra for the total energy per event with the data rescaled in energy and the Monte Carlo rescaled in height so a shape comparison can be made. Plot (c) shows the same for the maximum energy deposited.



Data

maximum (solid) total (dashed)

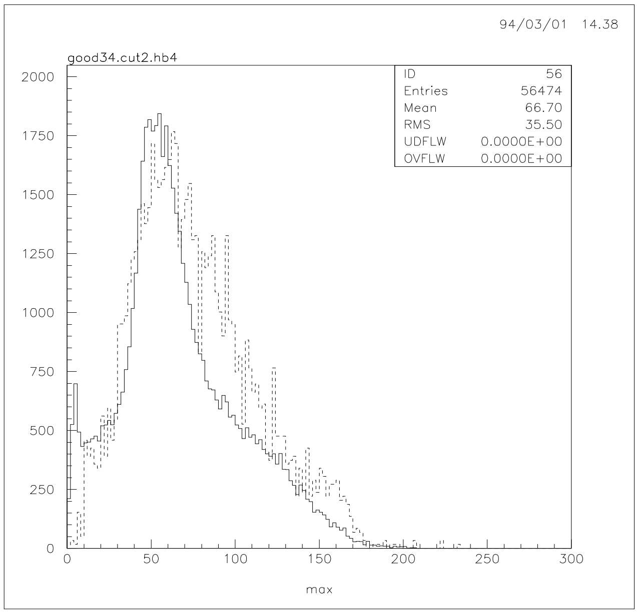
(a)



Total energy

data (solid) Monte Carlo (dashed)

(b)

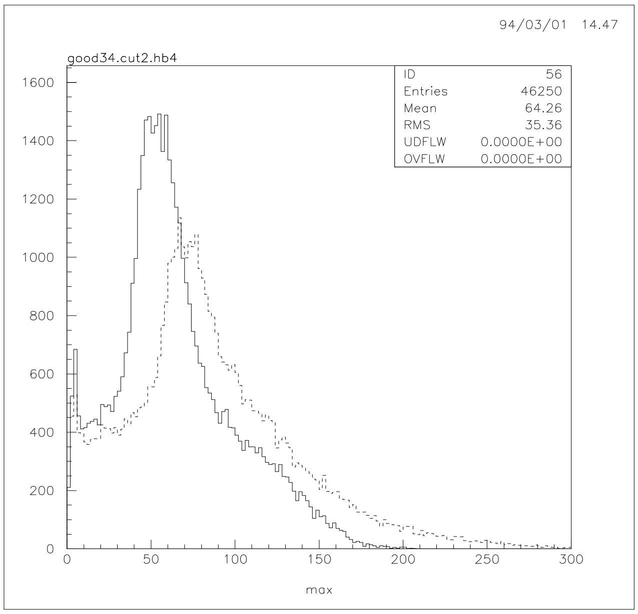


Maximum energy

data (solid) Monte Carlo (dashed)

(c)

Figure 13: Comparison of peak shape of data with just cut on tcyl phi

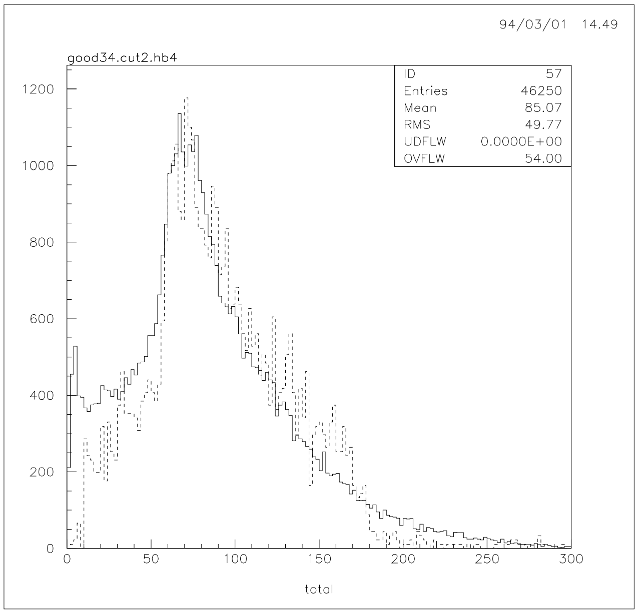


Data

maximum (solid) total (dashed)

(a)

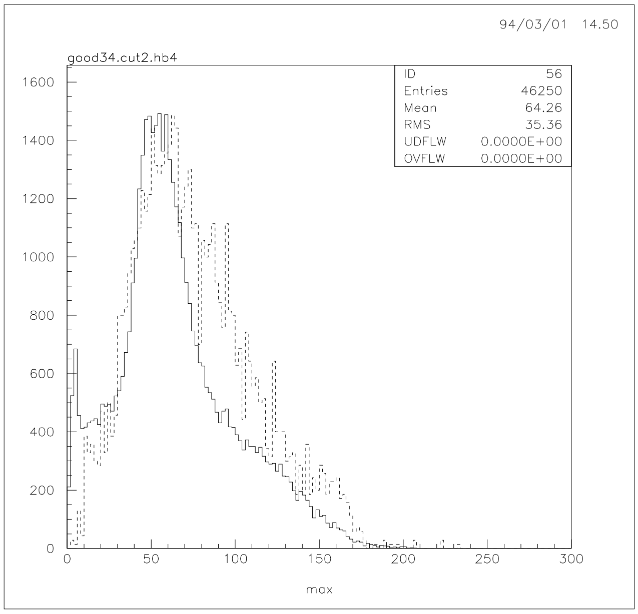
Figure 14 shows comparisons of the Monte Carlo with data which has the cut on tcyl phi applied and a cut on the hits in CsI. Only events which had 0,1,2 or 3 hits in CsI were plotted. It is believed that a proton will deposit energy in only a small number of blocks. This should help remove some of the contamination due to Δ^+ and π^+ which interact. It appears as though this cut was helpful, but not sufficient.



Total energy

data (solid) Monte Carlo (dashed)

(b)



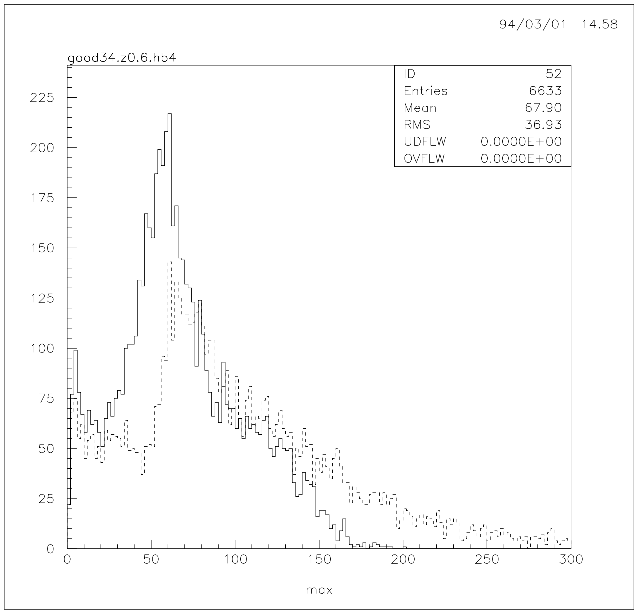
Maximum energy

data (solid) Monte Carlo (dashed)

(c)

Figure 14: Comparison of peak shape of data with a cut requiring less than 4 hits in CsI

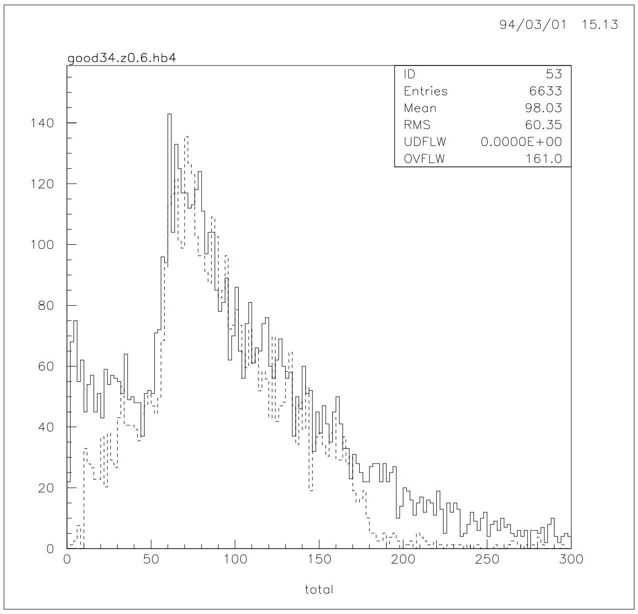
Figure 15 shows the data with a cut on z for the tcyl track. The data required that not only the ϕ, but the z reconstruct to call it a track. This greatly reduces the sample. A cut was also then made requiring a z between .0 and .6 of the length of tcyl. This requirement removes events where the recoil particle had a higher z momentum transferred to it. This hopefully removed many of the $\pi^{\pm}$ from the data set. The resulting ratio of peak heights and the peak shapes are much closer to Monte Carlo.



Data

maximum (solid) total (dashed)

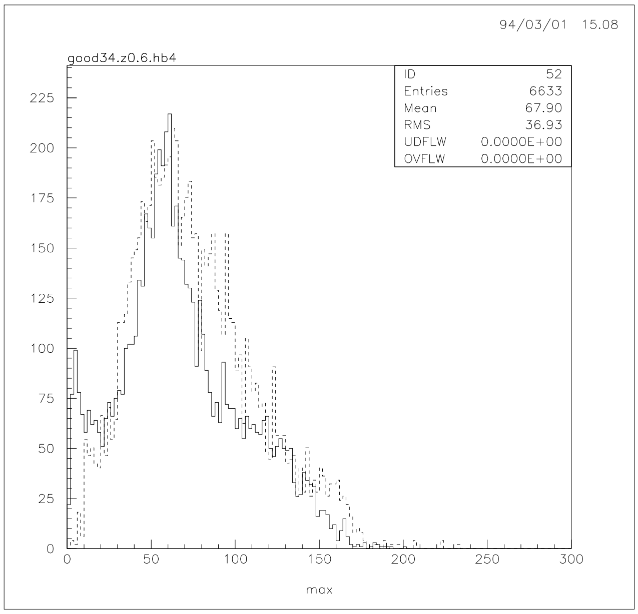
(a)



Total energy

data (solid) Monte Carlo (dashed)

(b)



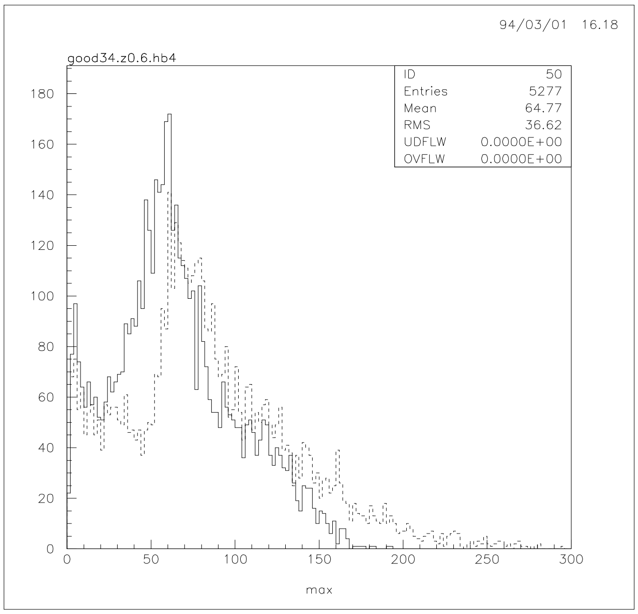
Maximum energy

data (solid) Monte Carlo (dashed)

(c)

Figure 15: Comparison of peak shape of data with a cut requiring a reconstructed z for that track and that $0. < z < .6$

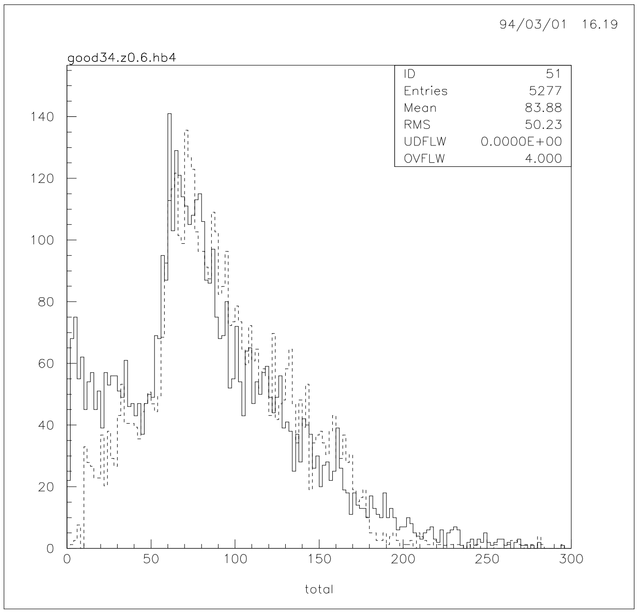
Figure 16 shows the data with all previous cuts applied. The cut on the number of hits being less than 4 reduces the tail of the total as seen in figure 15. While the ratio of peak heights is still not exactly the same as the Monte Carlo the direct shape comparison is very good. We believe this demonstrates that these events contain recoil protons.



Data

maximum (solid) total (dashed)

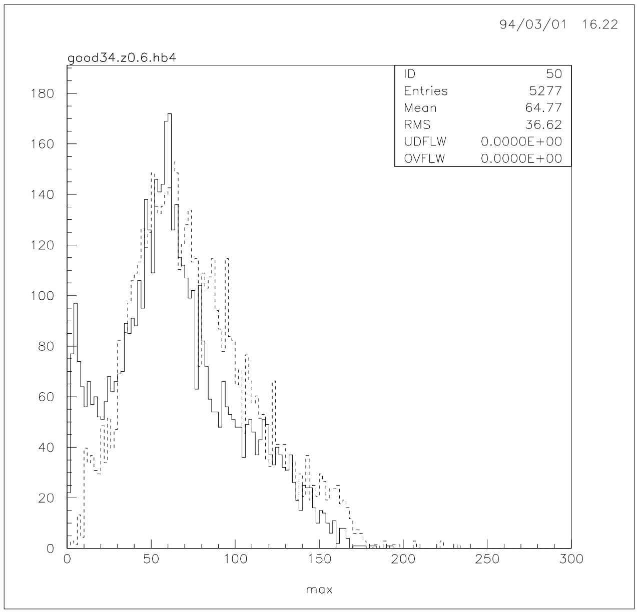
(a)



Total energy

data (solid) Monte Carlo (dashed)

(b)



Maximum energy

data (solid) Monte Carlo (dashed)

(c)

Figure 16: Comparison of peak shape of data with both the cut on .0¡z¡.6 and nhits¡4