BRAHMS Flow Simulator (BFlowS)

by Erik Johnson
01/04/06

The purpose of this simulation is to generate a reasonable distribution of particles based on the measured results at RHIC so far. The simulation is only designed to match the particle multiplicities in order to better understand the flow analysis. Since resolution corrections for the flow signal will be directly compared to the simulated results, the multiplicities must be identical.

The basic procedure in generating the correct particle distributions is outlined here.

1. Randomly generate a uniform centrality from 0 to 100%.
2. Estimate the total number of particles for the centrality, and add a fluctuation to the number.
3. From the number of total particles and the centrality generate a function to assign an eta position for each particle based on dN_{ch}/deta from measurements with the data.
4. Loop over all particles generated.
    1. Calculate the eta position from a uniform random number from 0 to 1
    2. With eta and centrality determine the particle type from the dN/deta distributions generated from the spectra.
    3. Use fits to the spectra to determine the p_T for the particle.
    4. Add flow with respect to the centrality, eta, and p_T measurements.
    5. Calculate p_x,p_y,p_z.
    6. Write to zdat file.

Contents:

page
Generating Centrality.....3
Measuring the Total Number of Particles.....3
Calculating the Eta Position for Each Particle.....8
Defining the Particle Type.....10
Tables on Particle Charactistics (Tables 2,3 & 4).....47
Determine the p_T of the Particle.....50
Apply Flow.....58
Calculate Momentum Components.....59
Execution Usage.....60

Step 1: Generating Centrality

This is straight forward. The centrality can be a minimum biased distribution from 0 to 100%.

Step 2: Measuring the Total Number of Particles

The total number of particles can be estimated using the dN/dη distributions and can be parameterized as a function of centrality. The BRAHMS dN/dη distributions are first fit with a double gaussian (see figues 1 – 6). Then the fits are integrated from -100 to 100 units in pseudorapidity. The integral values are plotted as over centrality and fit with a gaussian tail, which falls off nicely to zero around a centrality of 100% (see figure 7). The Hijing simulation is used to determine the magnitude of the fluctuation from event to event of the total multiplicity. The total number of particles generated or interacted from a HIJING collision (i.e. particles with a $|\eta| < 100$) were plotted over centrality (see figure 8). Slices projected on the y-axis were then fit with gaussians, and figure 9 shows the sigma of those fits as a function of centrality. The idea at this point is to use the centrality to give the total number of particles from figure 7. The value from figure 7 will be multiplied by 1.5/0.87 to give the total number of particles. This value, 1.5/0.87, is determined from the mix of charged to neutral particle used in the simulation over eta on average. A random number will be generated from a gaussian distribution, which will have a mean of zero and a sigma given from the fit in figure 9. The value of this random number (the representation of the total particle fluctuation from event to event) will be added to the total number of particles calculated based on figure 7.

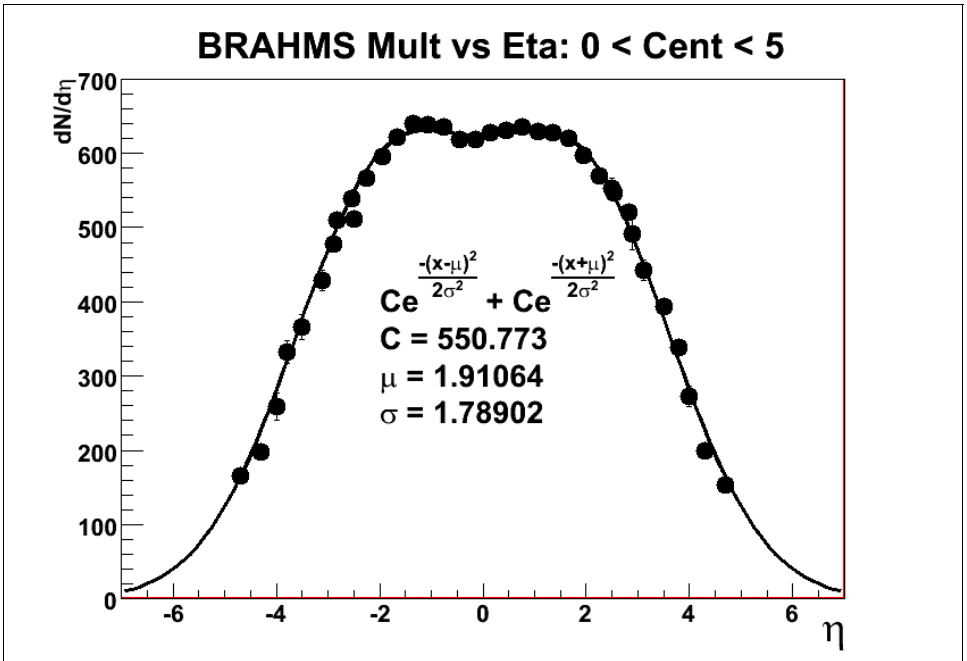


Figure 1: dN/dη from data for 0 to 5% centralities.

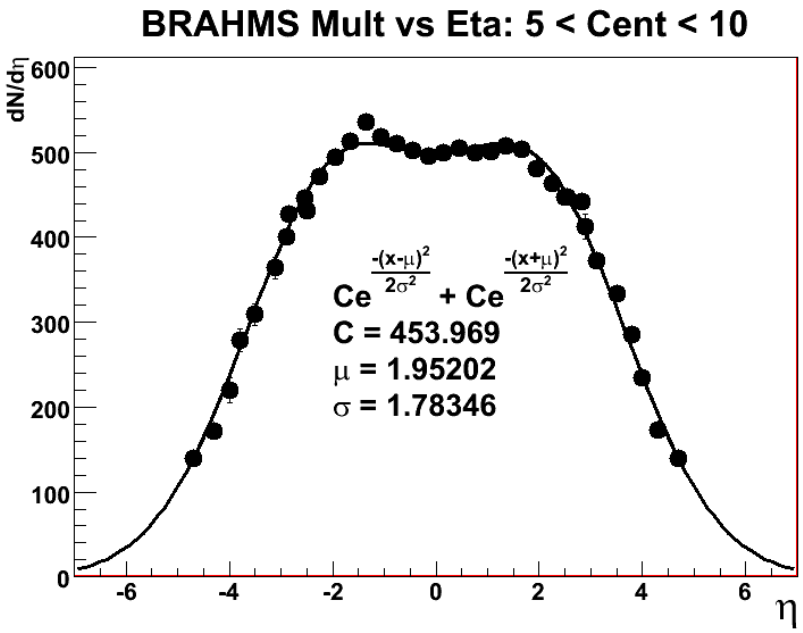


Figure 2: dN/dη from data for 5 to 10% centralities.

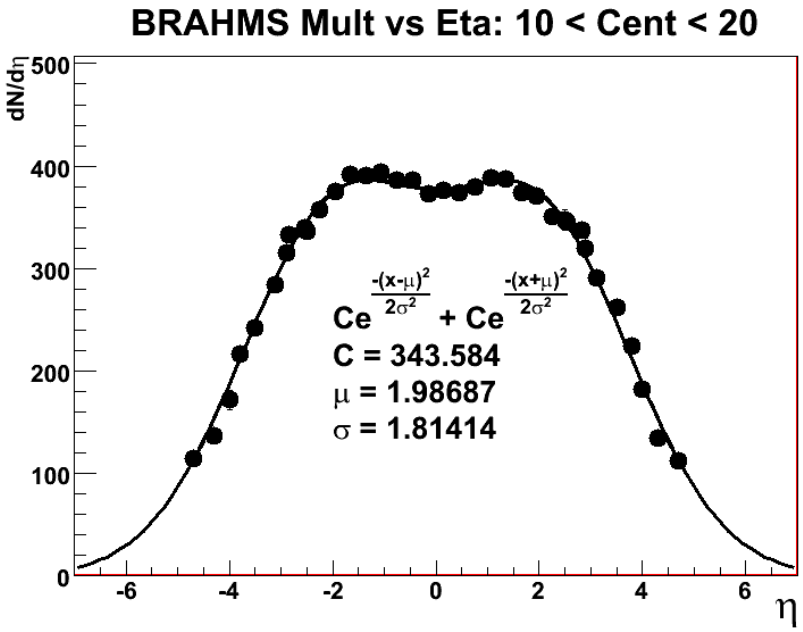


Figure 3: dN/dη from data for 10 to 20% centralities.

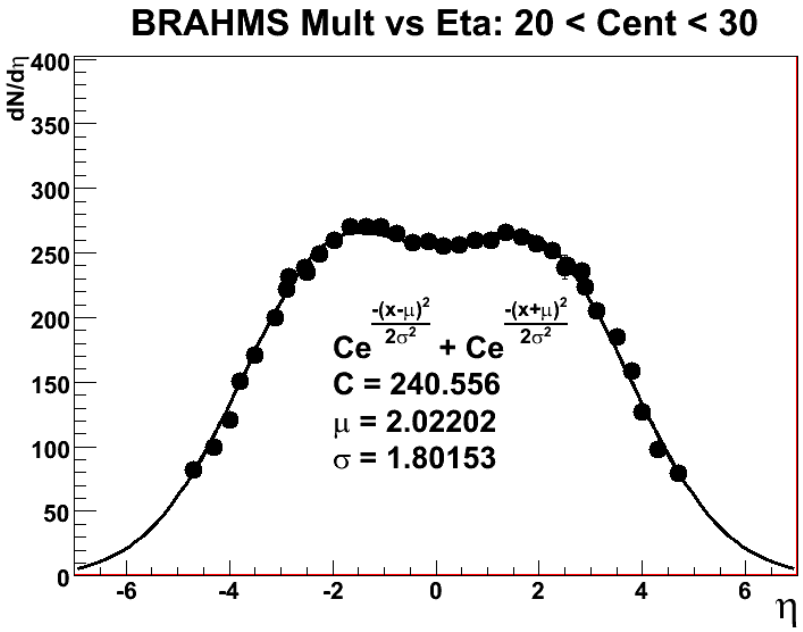


Figure 4: dN/dη from data for 20 to 30% centralities.

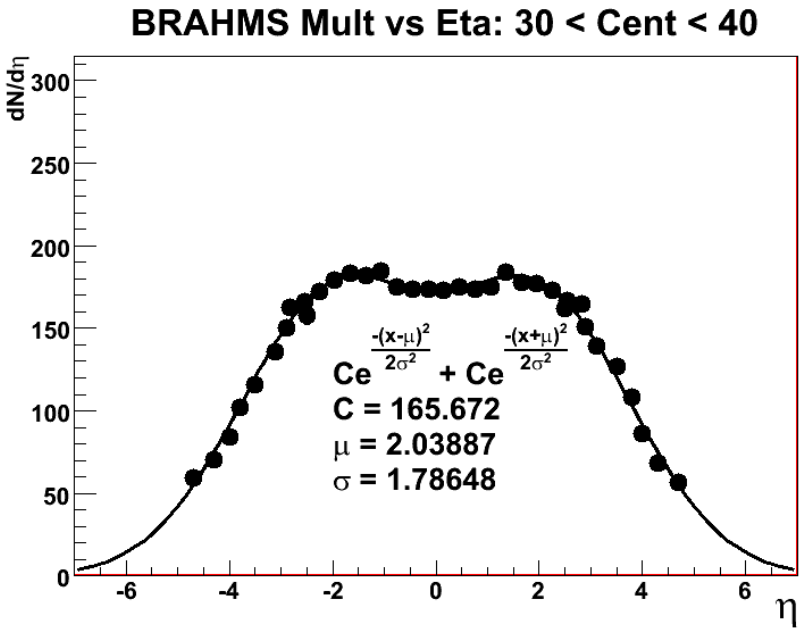


Figure 5: dN/dη from data for 30 to 40% centralities.

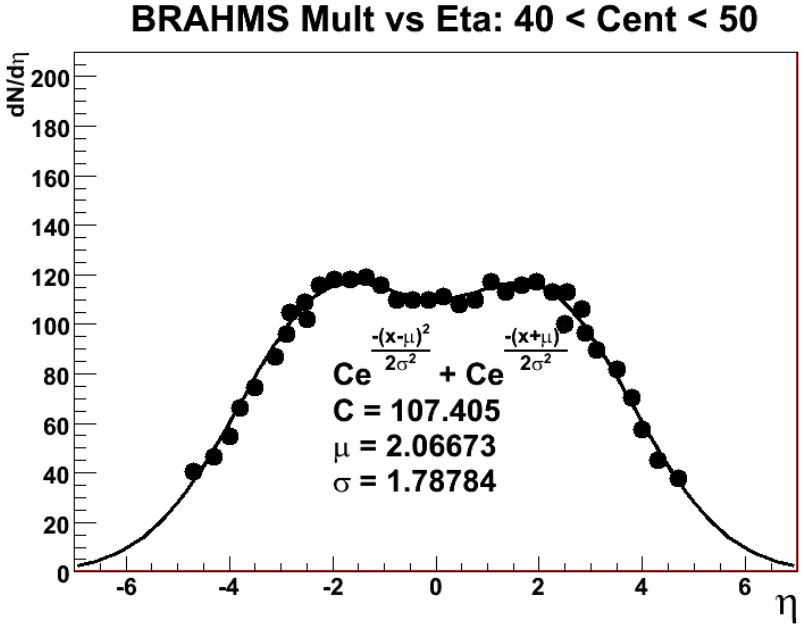


Figure 6: dN/dη from data for 40 to 50% centralities.

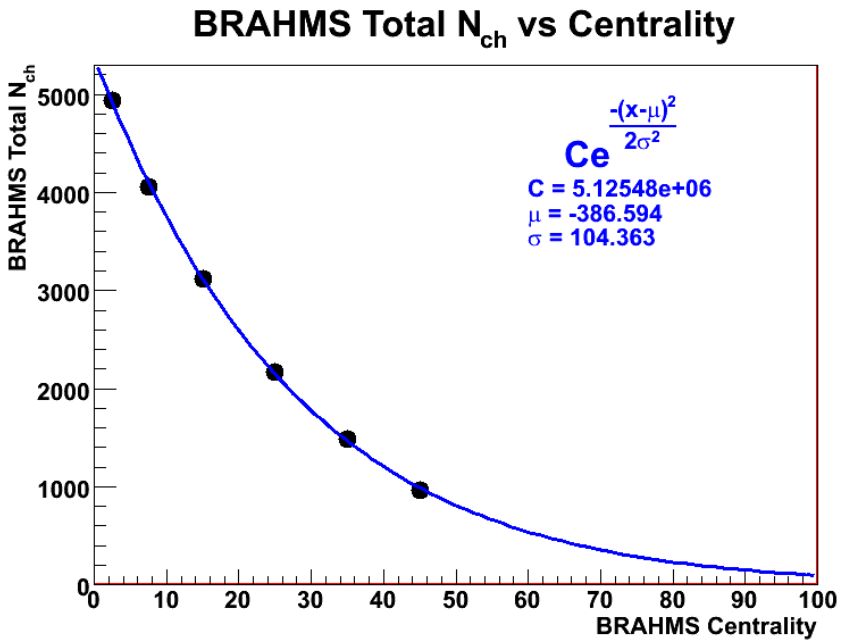


Figure 7: Total number of charged-particles determined from figures 2-7 plotted over centrality and fit with a gaussian tail.

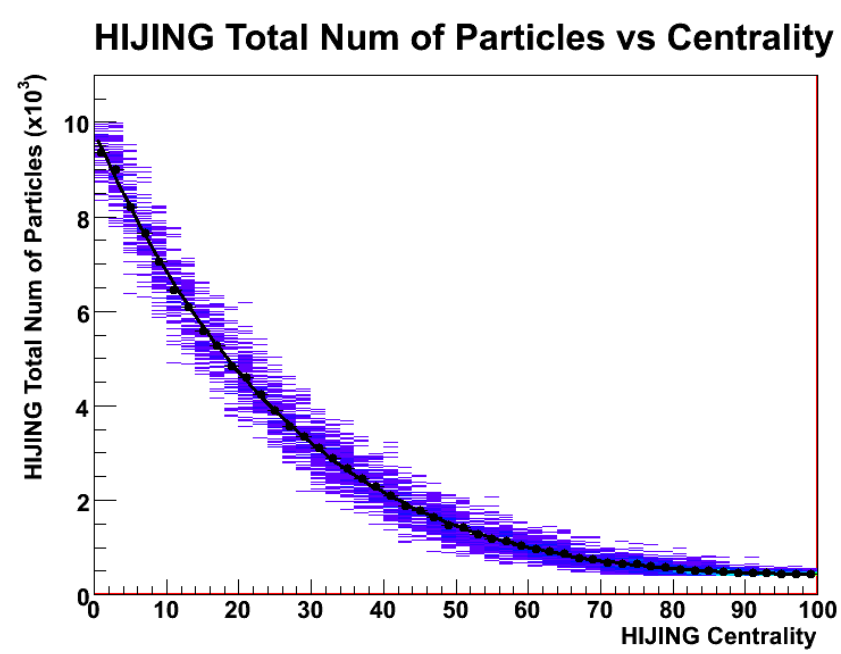


Figure 8: Total number of participating particles from a HIJING simulation versus centrality.

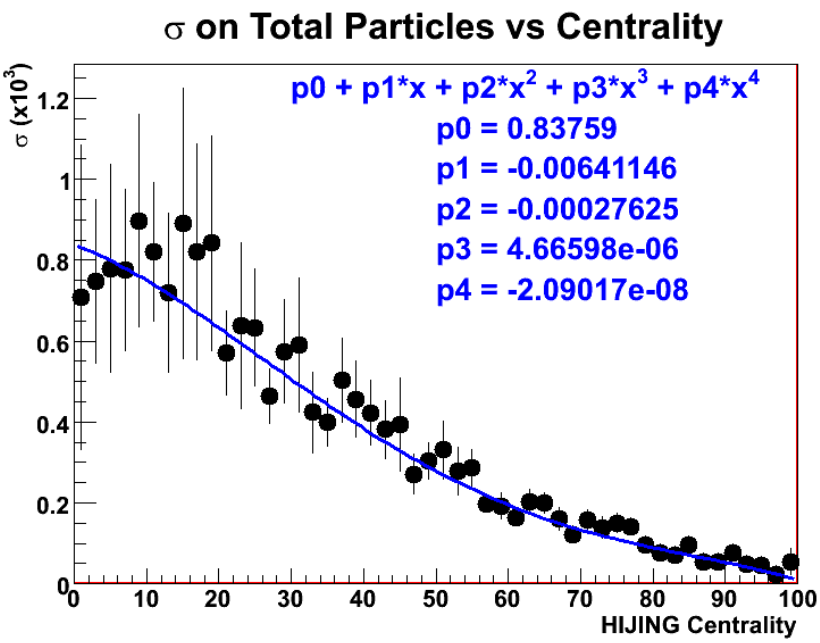


Figure 9: Sigma of the total number of participating particles from gaussian fits to slices of projections on the y-axis in figure 9.

Step 3 & 4.1: Calculating the Eta Position for Each Particle

The fits in figures 1-6 are used to determined the eta position for each particle. These figures will give shape to the dN/deta distribution, but the total number of particles is given by figure 7-9. The Inverse Error Function is the function defined from an integrated gaussian distribution. This function is already defined in ROOT, and here we will call it ErfInv(x). To generate a gaussian, a random number, x, from -1, 1 is generated, and the value of ErfInv(x) gives the proper location along the absessia for a gaussian. ROOT gives the distribution a default width of 0.708000 and a mean of zero. The dN/deta distributions are two gaussians. Therefore, a second random number, y, from -1 to 1 is generated to determine which gaussian the particle will be located. The particles are put into each gaussian with the same probability, and eta is therefore given by

if (y < 0), then eta = sigma/ 0.708000 *ErfInv(x) + mean.
if (y > 0), then eta = sigma/ 0.708000 *ErfInv(x) – mean.
Sigma and mean are defined over centrality in figures 10 and 11.

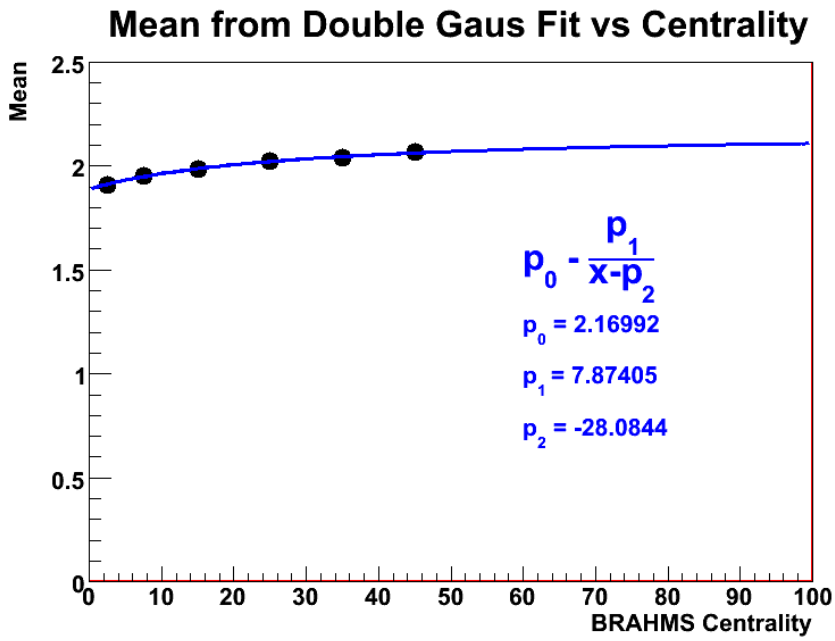


Figure 10:

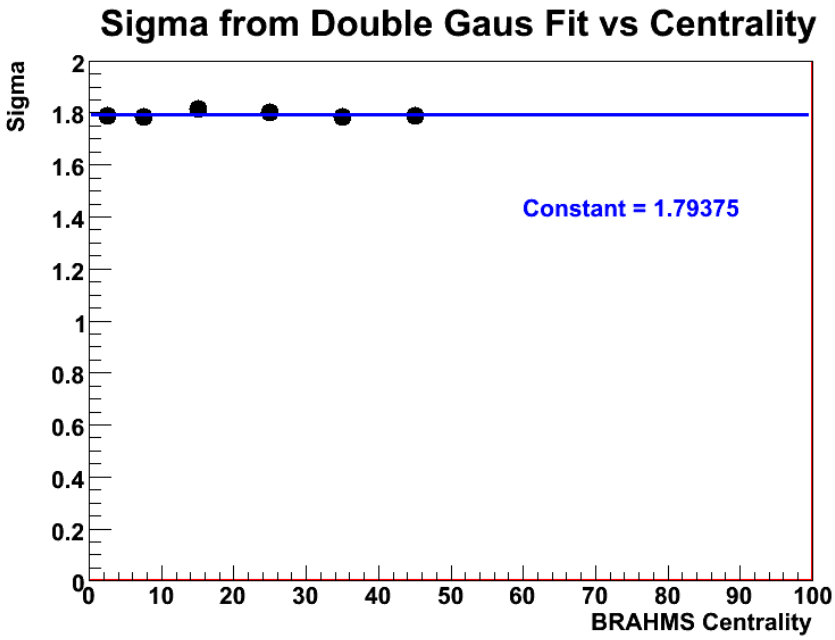


Figure 11:

Step 4.2 Defining the Particle Type:

The particle type at this point can be determined. At this point, HIJING is used to determine the relative abundance of particles that aren't measured by BRAHMS. HIJING is only used to determine the abundance as a function of eta for the top 5% central events. In addition to that, the BRAHMS spectra of pions, kaons, and protons has been fit using three different functions. The spectra for the top 5% over a range in rapidity were first used to determine the eta dependence of the measured particles and then the mid-rapidity data over four centralities was used to determined the centrality dependence.

The first step in this process is to fit the spectra of the measured particles. The spectra has been quoted in terms of rapidity and must be converted into pseudorapidity first. The is done for each measurment of the yeild in a specific p_T bin. The following equations were used to calculate η and the spectra in terms of η.

$$m_T = \sqrt{m^2 + p_T^2} \tag{2}$$

$$p_z = m_T \sinh(y) \tag{3}$$

$$E = m_T \cosh(y) = \sqrt{m^2 + p^2} \tag{4}$$

$$p = \sqrt{E^2 - m^2} = p_T \cosh(\eta) \tag{5}$$

$$\eta = \frac{1}{2} \ln\left(\frac{p + p_z}{p - p_z}\right) \tag{6}$$

$$\frac{1}{2\pi p_T}\frac{d^2N}{d\eta\, dp_T} = \frac{1}{2\pi p_T}\frac{p}{E}\frac{d^2N}{dy\, dp_T} \tag{7}$$

Now that the data has been chopped up into new pseudorapidity bins, the spectra are fit with three different types of functions. For pions, a power law function is used

$$\frac{1}{2\pi p_T}\frac{d^2N}{d\eta\, dp_T}(p_T, \eta) = \frac{p}{E}\frac{dN}{dy}(\eta)\frac{(n-1)(n-2)}{2\pi C^2}\left(1 + \frac{p_T}{C}\right)^{-n} \tag{8}$$

C and n are fit parameters. The kaons are fit with an exponential

$$\frac{1}{2\pi p_T}\frac{d^2N}{d\eta\, dp_T}(p_T, \eta) = \frac{p}{E}\frac{dN}{dy}(\eta)\frac{1}{2\pi T(T+m)} e^{\frac{m - \sqrt{p_T^2 + m^2}}{T}} \tag{9}$$

T is a fit parameter, and m is the mass of K^+ or K^-. The protons are fit with a boltzmann distributions

$$\frac{1}{2\pi p_T}\frac{d^2N}{d\eta\, dp_T}(p_T, \eta) = \frac{p}{E}\frac{dN}{dy}(\eta)\frac{\sqrt{p_T^2 + m^2}}{2\pi T(2T^2 + 2Tm + m^2)} e^{\frac{m - \sqrt{p_T^2 + m^2}}{T}} \tag{10}$$

T is a fit parameter, and m is the mass of a proton. These functions may not be the same ones used in the crosscheck analysis of the charged-particle multiplicity in the BRAHMS analysis note written by D.Ouerdane
http://www4.rcf.bnl.gov/brahms/WWW/private/AnNotes/dndetaVsdndy.ps
These functions require that equation 7 is satisfied and gives the proper dN/dy vs y distribution. Otherwise, with out the p/E term, the dN/dy distribution will have an additional peak at zero.

Here we will go through the same exercise to try to reproduce the charged-particle multiplicity. Figures 12 – 17 are the fits to the spectra for several eta bins for the 5% most central events.

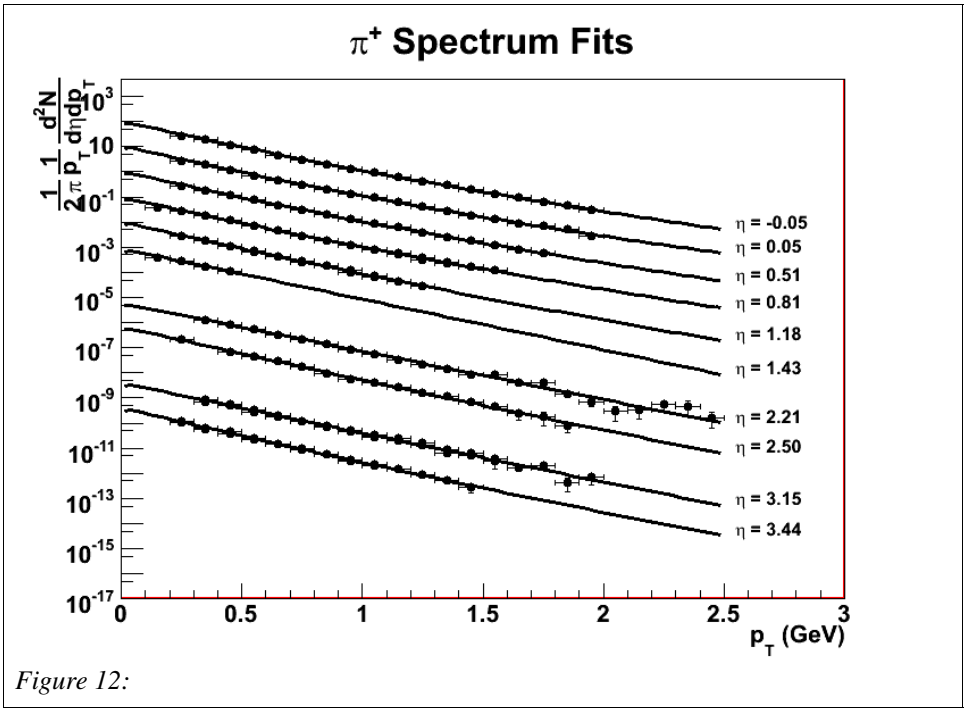


Figure 12:

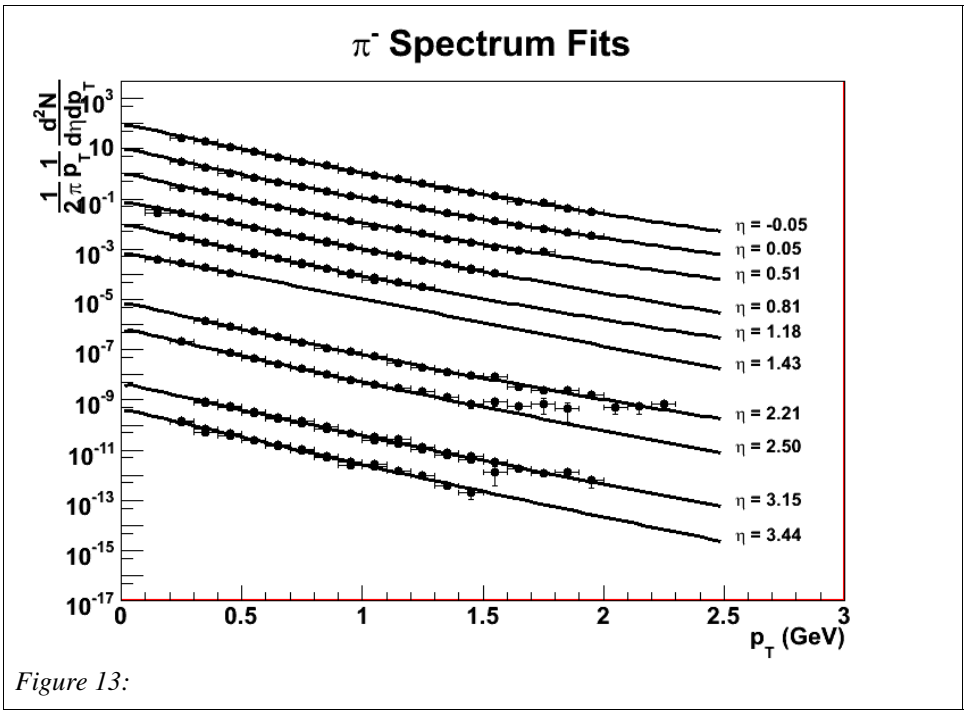


Figure 13:

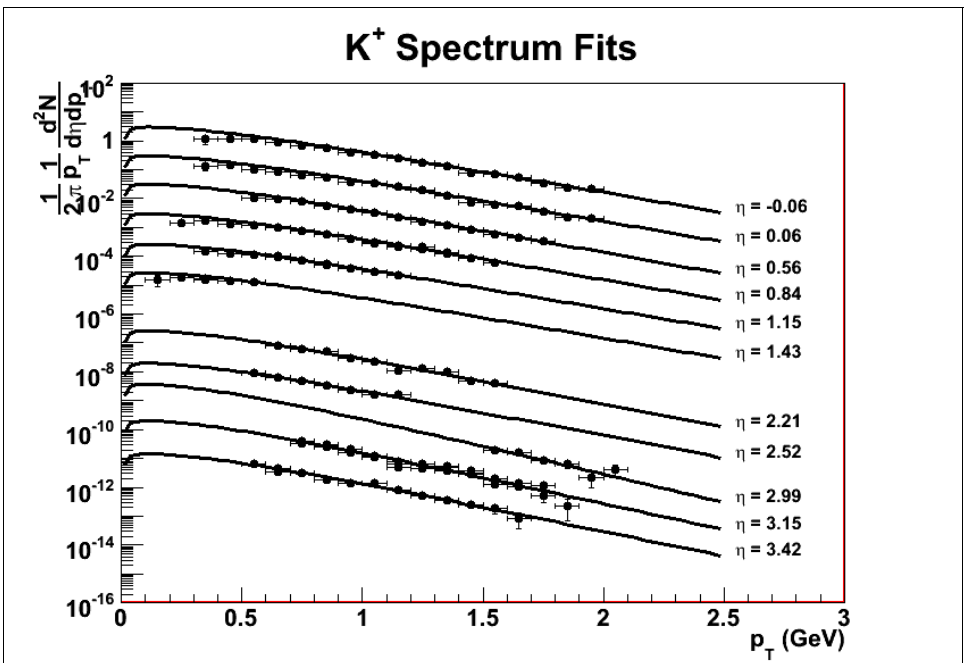


Figure 14:

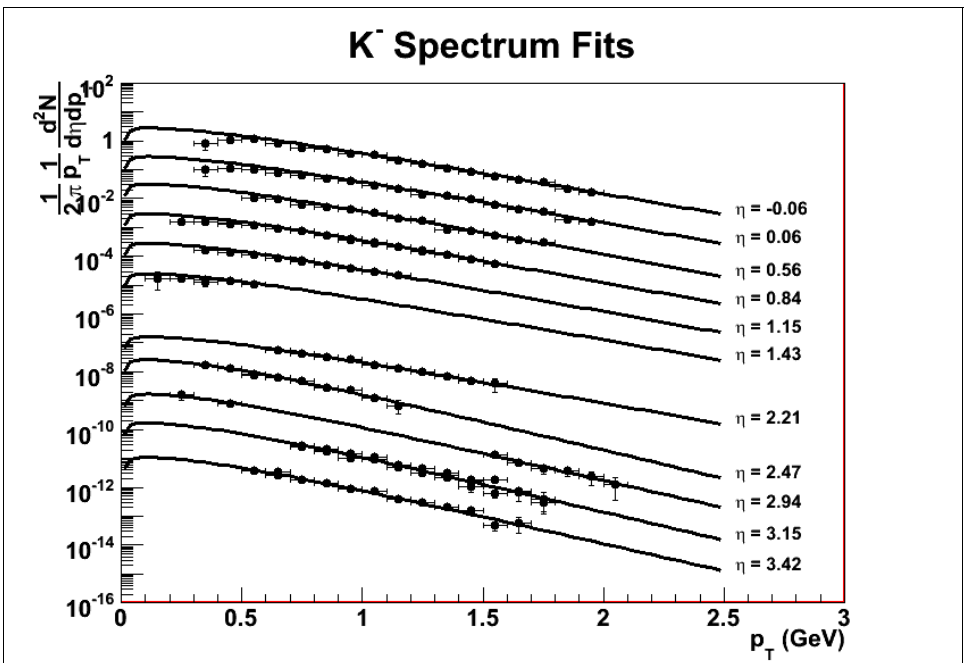


Figure 15:

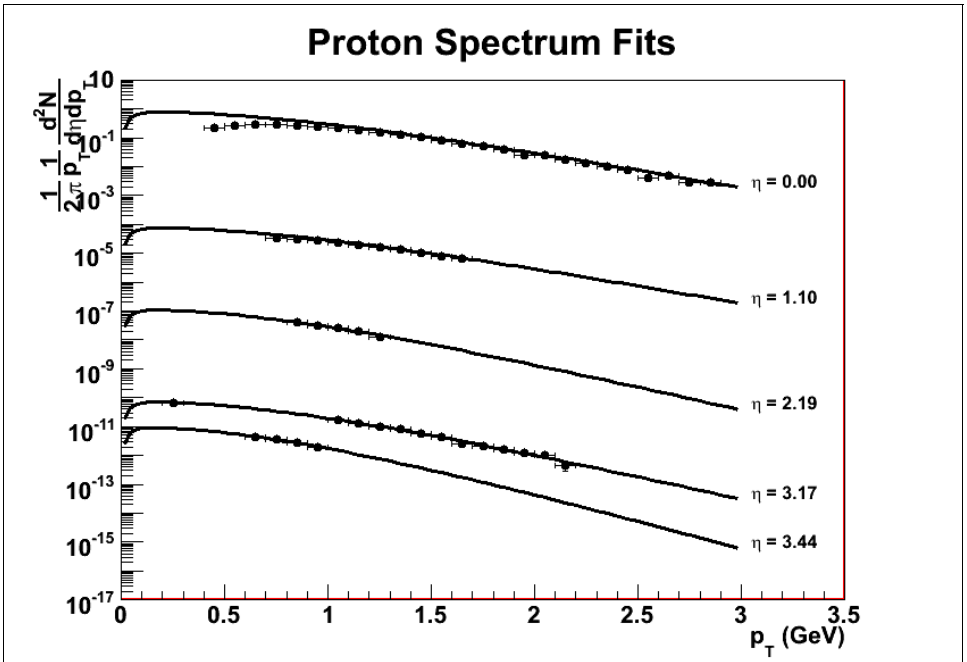


Figure 16:

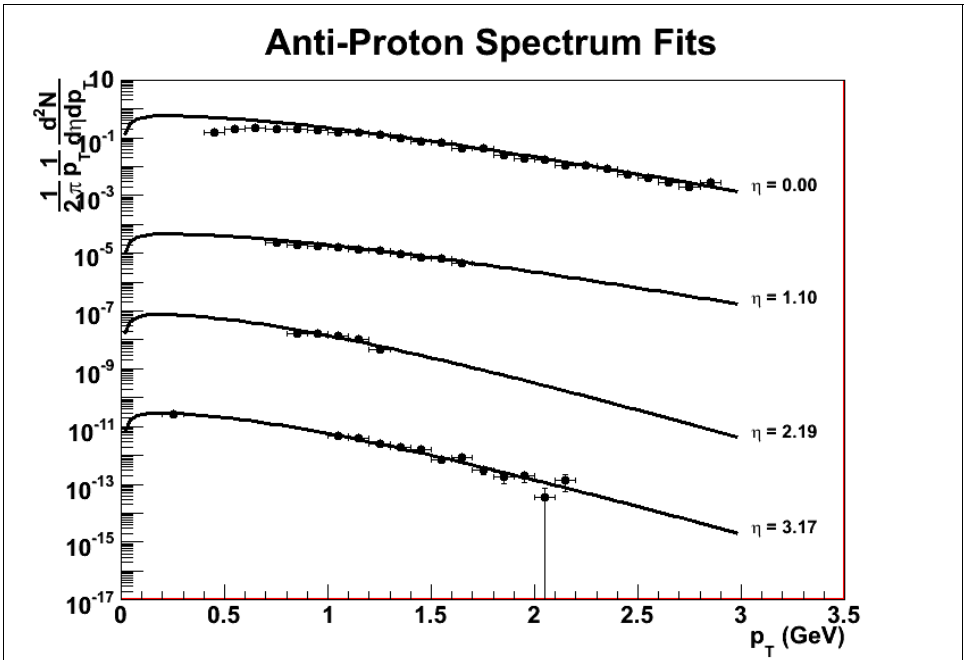


Figure 17:

For each of the fits, one of the fit parameters is the integrated yeild over all p_T. The integrated yeilds were then plotted as a function of eta for each particle. The distribution was fit with a double gaussian. In figures 18 – 23, the yeilds of the fits are reflected and the entire distribution is fit. In addition to the fit yeilds being plotted, the yeilds from the independent analysis is also plotted for comparison.

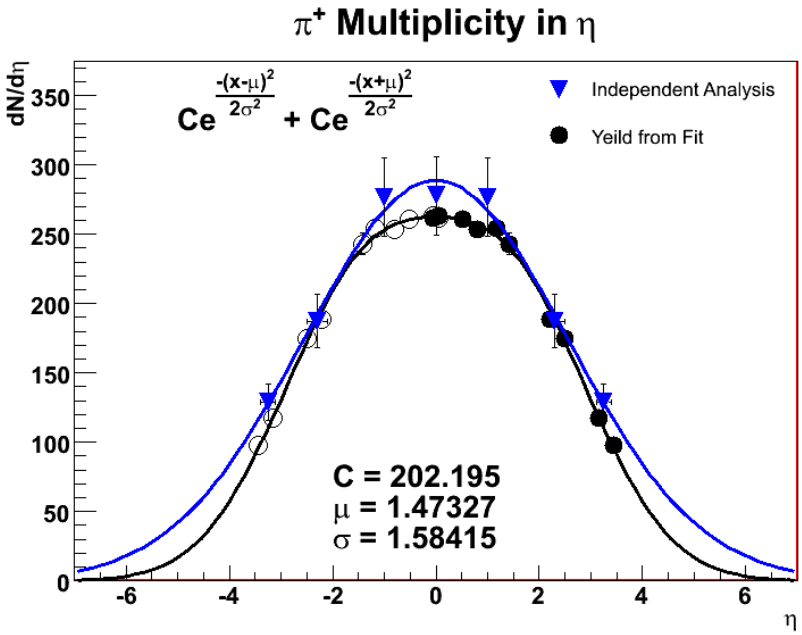


Figure 18:

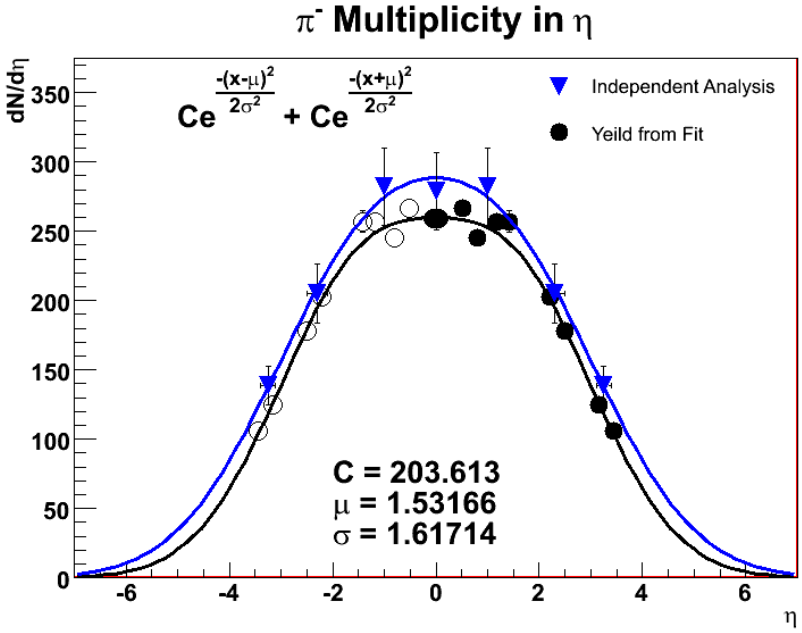


Figure 19:

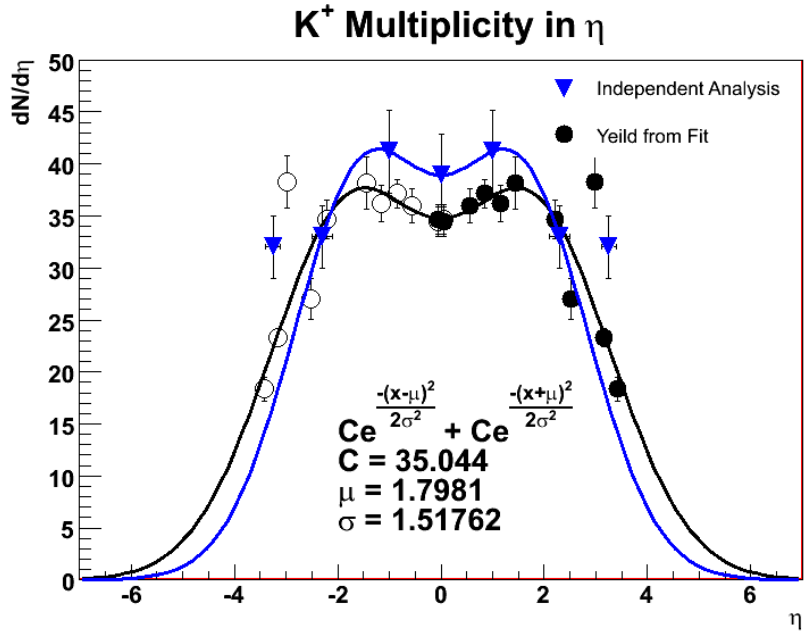
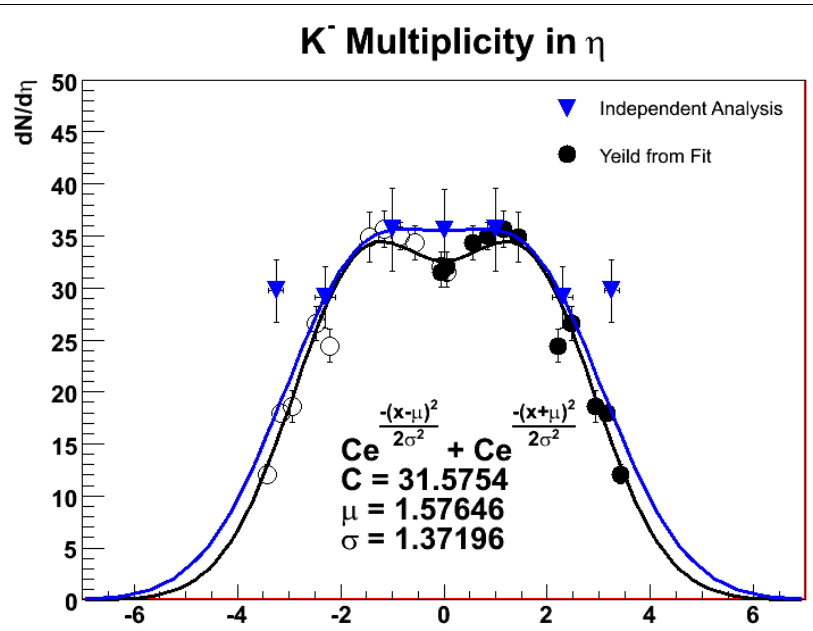


Figure 20:



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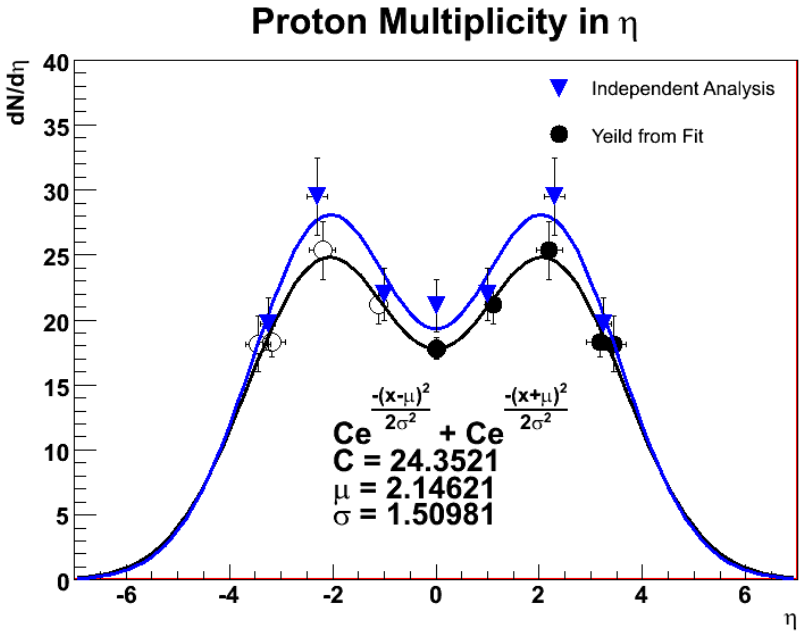

Figure 22:

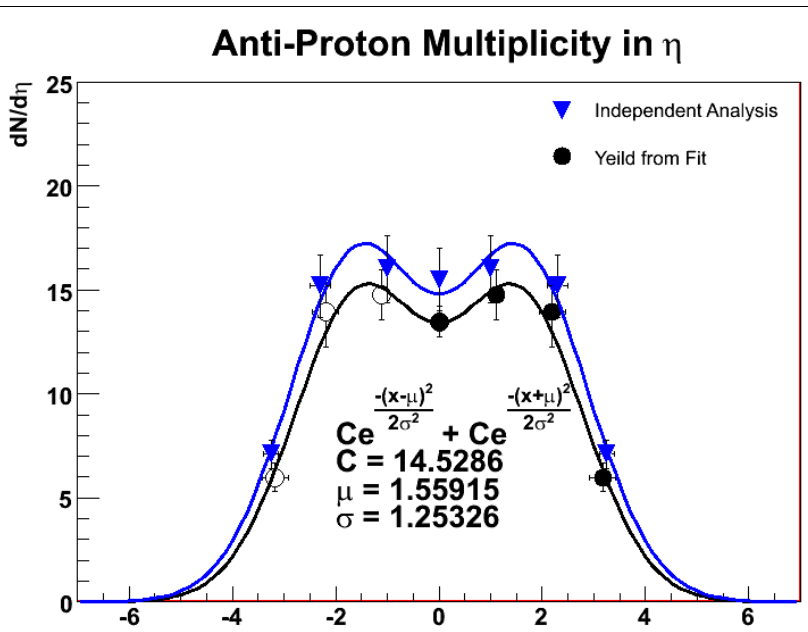

Figure 23:

These distributions in figures 18 – 23 will be used to determine the relative abundance of particles to give the particle type in the simulation.

As a measure of comparison, the mutliplicities from both anaylses were summed

to give an appoximate value for $dN_{ch}/d\eta$. The results are shown in figure 38, and the fit from figure 1 (double gaussian fit to the measured charged particle multiplicity) is also plotted in the figure. A 5% error was given to the measured multiplicity, and a 10% error was given for the fitted yields and the data points for the independent analysis. It can be seen that the yields from the fits in figures 18 – 23 give similar results to the independent analysis and are fairly consistent with the measured charged-particle multiplicity.

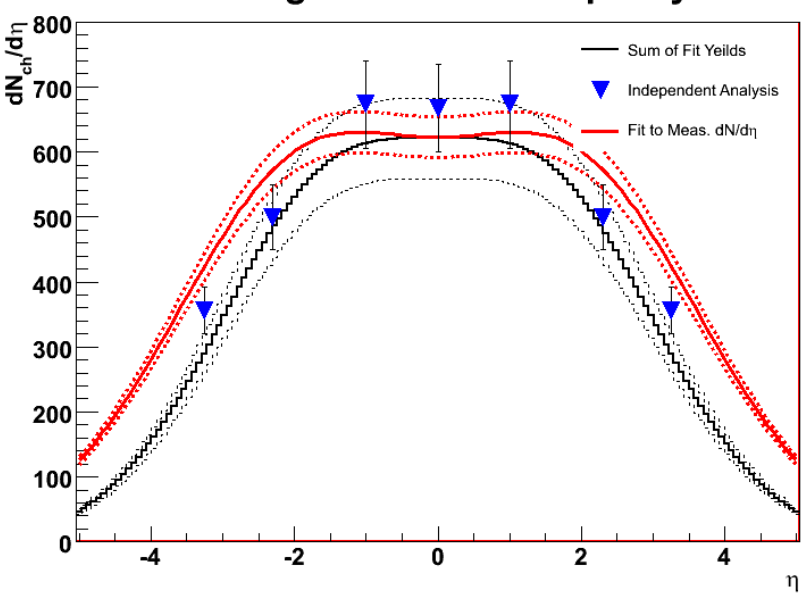

Figure 24:

The shape of $dN/d\eta$ for the other particles, such as π^0, γ, n, etc., were determined using the HIJING simulation. Table 1 shows the particles used in this simulation and from what source the shape of their multiplicity distributions were obtained. Some particles like π^0 and neutrons were given the same distribution as their charged partner, π^+ and protons respectively. Therefore, if another particle's symbol is in the box for the source, this means that the measured data of the source particle was used. The shapes from the HIJING data are used as a template over all centralities. The amplitude of the distribution will be discussed later.

Gauge Bosons		***Leptons***		***Mesons***		***Baryons***	
Particle	*Source*	*Particle*	*Source*	*Particle*	*Source*	*Particle*	*Source*
γ	HIJING	e^-	HIJING	π^0	π^+ & π^-	n	HIJING
		e^+	HIJING	π^-	DATA	$\bar{n}$	HIJING
				π^+	DATA	p	DATA & HIJING
				K^+	DATA	$\bar{p}$	DATA
				K^-	DATA	Σ^0 & $\bar{\Sigma}^0$	HIJING
				K_L^0	HIJING	Σ^- & $\bar{\Sigma}^+$	
				K_S^0	HIJING	Σ^+ & $\bar{\Sigma}^-$	HIJING
				D^0& $\bar{D}^0$	HIJING	Λ^0 & $\bar{\Lambda}^0$	HIJING
				D^+ & D^-	HIJING	Ξ^0 & $\bar{\Xi}^0$	HIJING
				D_s^+&D_s^-	HIJING	Ξ^+ & Ξ^-	HIJING
					HIJING	Ω^- & Ω^+	HIJING

Table 1: Table of the particles used in the simulation and the source for the dN/dη vs η distribution for the top 5% central events.

The fragmentation region for the neutrons in the HIJING simulation were used to estimate the same region for the protons. Figure 25 show the fit to the protons from a HIJING simulation. The fit was made with two pairs of symmetric gaussians. The mean and sigma of the fragmented protons was used to give shape to the fragmented protons in the data. The relative scale of the amplitude between the produced protons and the fragmented protons from HIJING was used to force the relative scale. The proton data was then fit with four gaussians. There are only three effective parameters in the fit, as was done in the original fit (see figure 22), but this time an estimate of the fragmented protons are included. The final fit and distribution is seen in figure 26.

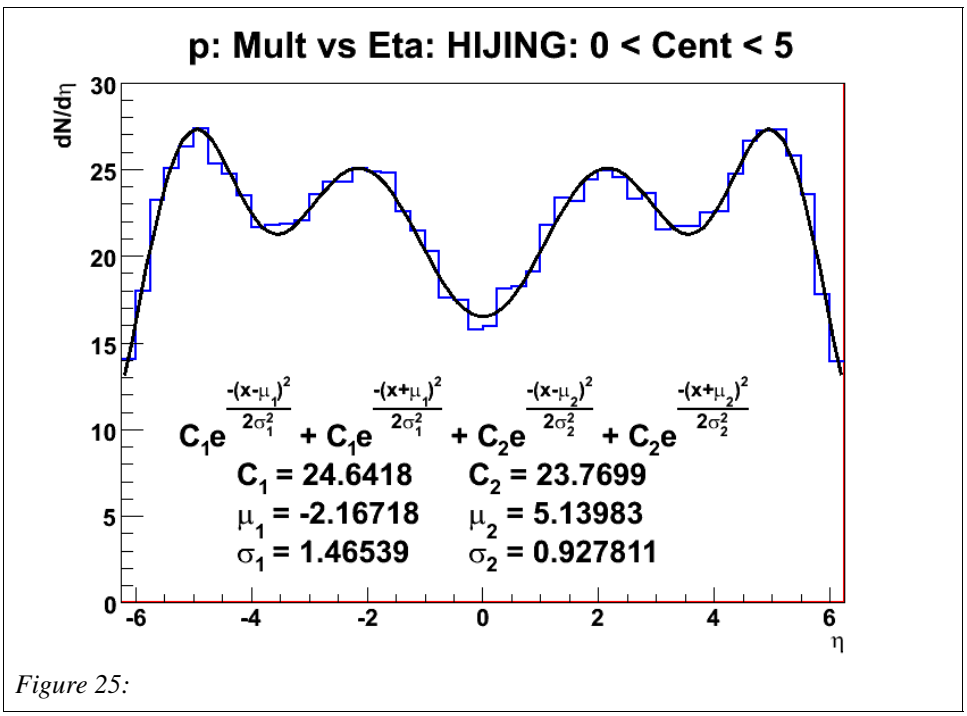

Figure 25:

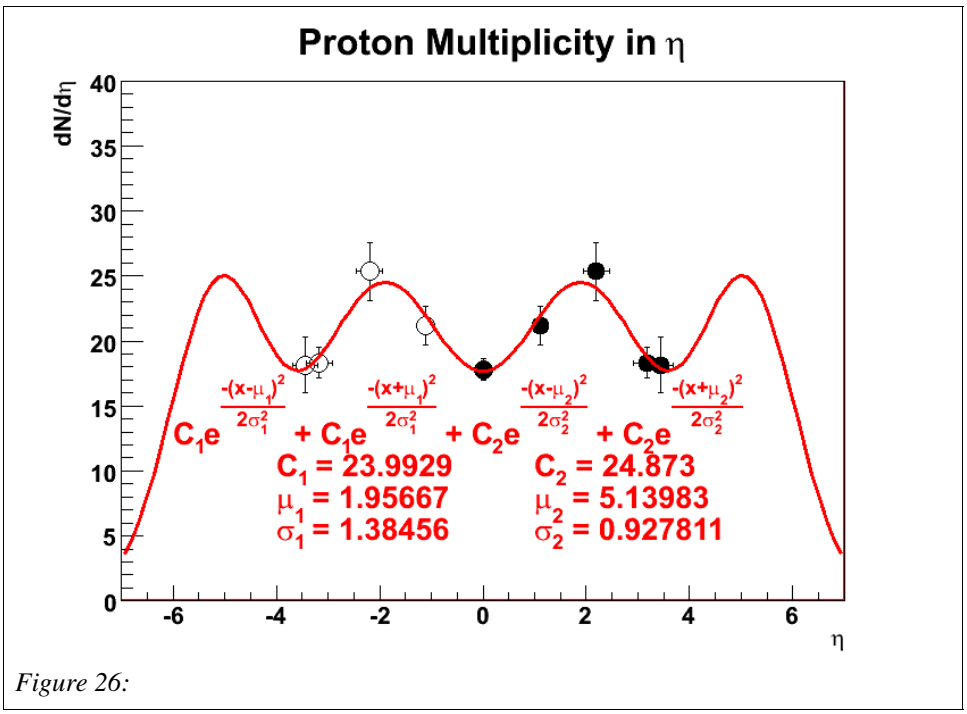

Figure 26:

To control the relative abundance of particles as a function of centrality, the measured particle spectra at y = 0 and y ~ 1 for different centrality bins has also been fit with the three fitting spectral functions. Figures 27-32 show the results of those fits.

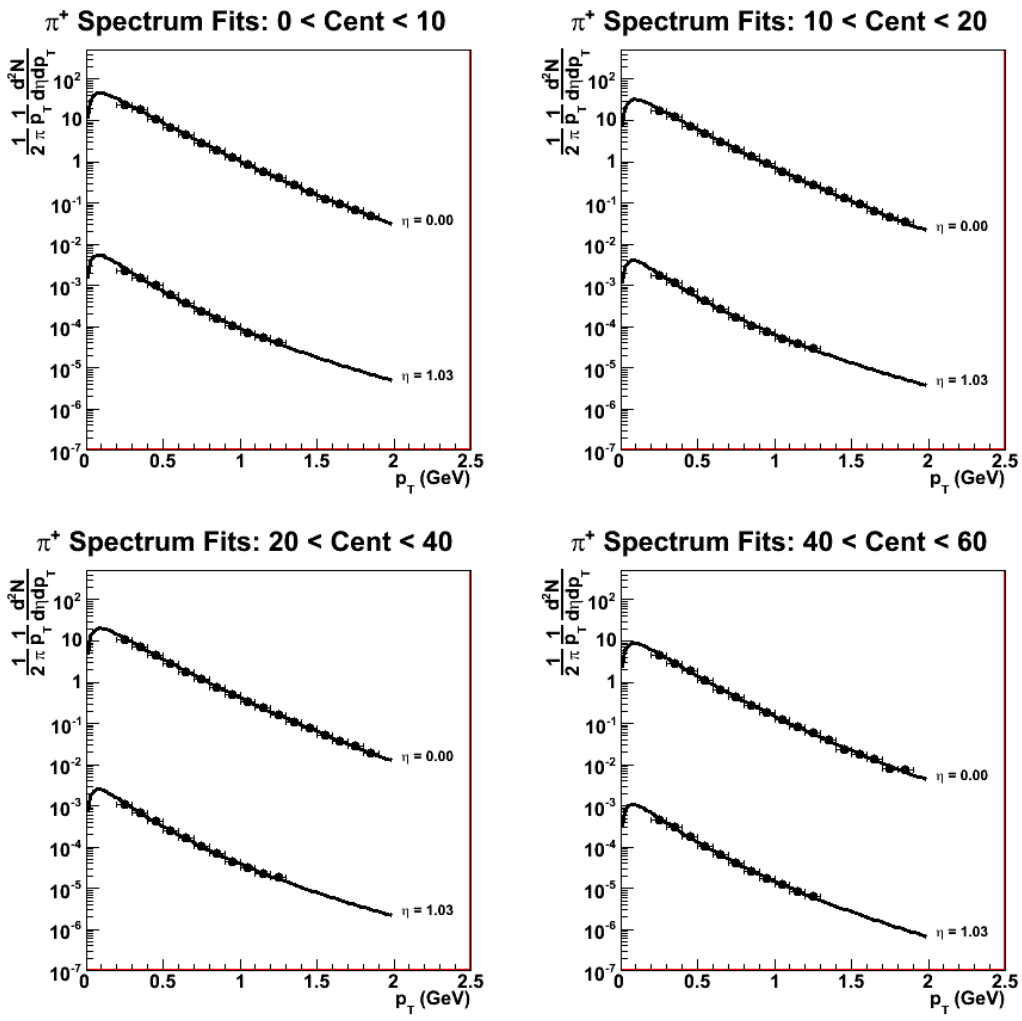
π+ Spectrum Fits: 0 < Cent < 10
π+ Spectrum Fits: 10 < Cent < 20
π+ Spectrum Fits: 20 < Cent < 40
π+ Spectrum Fits: 40 < Cent < 60
η = 0.00
η = 1.03
p_T (GeV)

Figure 27:

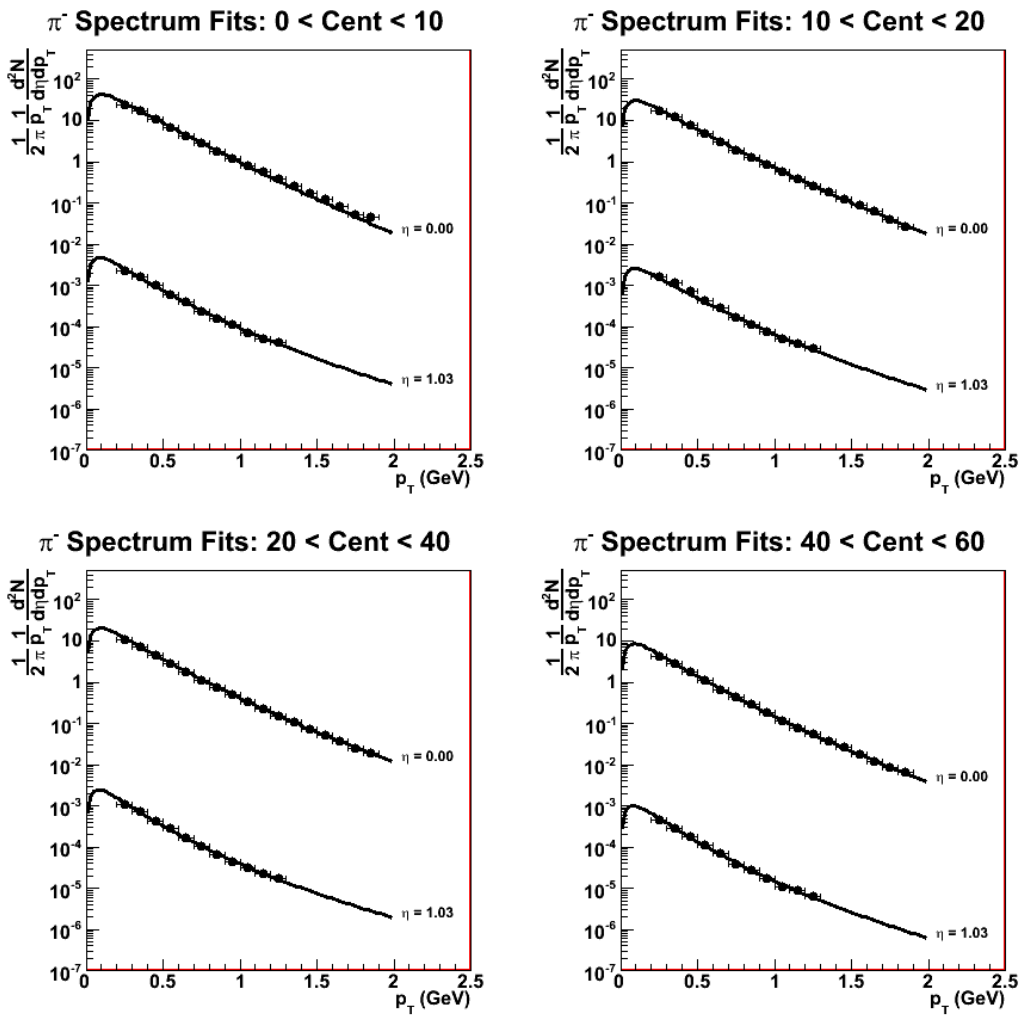
π⁻ Spectrum Fits: 0 < Cent < 10
π⁻ Spectrum Fits: 10 < Cent < 20
π⁻ Spectrum Fits: 20 < Cent < 40
π⁻ Spectrum Fits: 40 < Cent < 60
$\frac{1}{2\pi}\frac{1}{p_T}\frac{d^2N}{d\eta dp_T}$
η = 0.00
η = 1.03
p_T (GeV)

Figure 28:

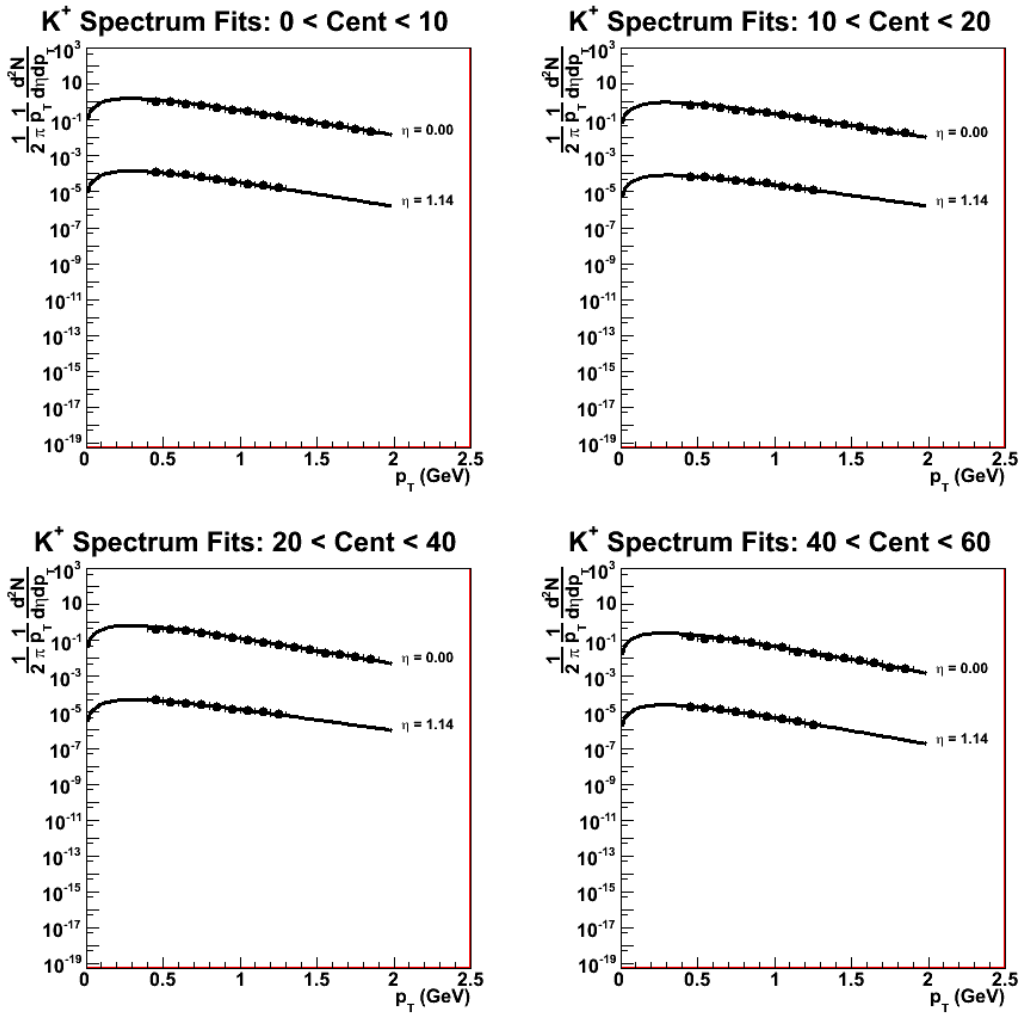
K+ Spectrum Fits: 0 < Cent < 10
K+ Spectrum Fits: 10 < Cent < 20
K+ Spectrum Fits: 20 < Cent < 40
K+ Spectrum Fits: 40 < Cent < 60
η = 0.00
η = 1.14
pT (GeV)

Figure 29:

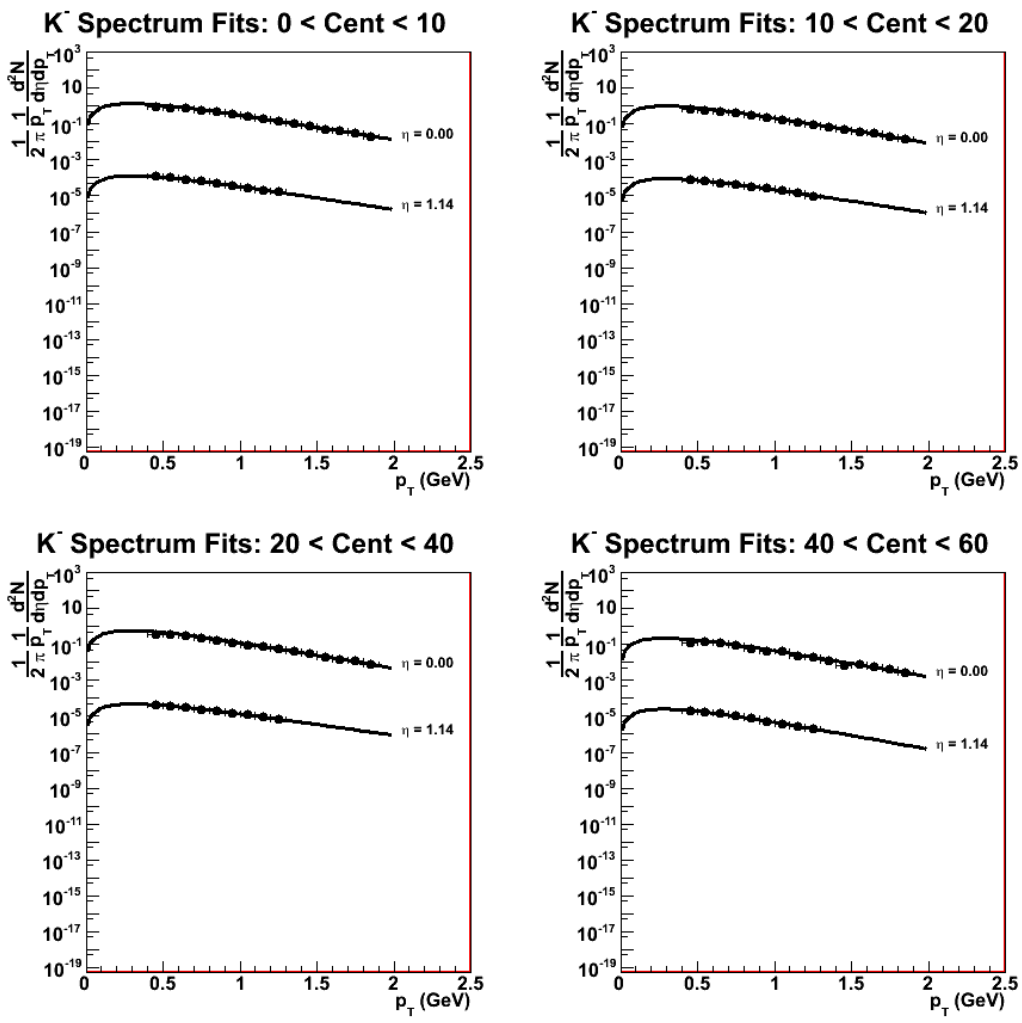
K⁻ Spectrum Fits: 0 < Cent < 10
K⁻ Spectrum Fits: 10 < Cent < 20
K⁻ Spectrum Fits: 20 < Cent < 40
K⁻ Spectrum Fits: 40 < Cent < 60
$\frac{1}{2\pi}\frac{1}{p_T}\frac{d^2N}{d\eta dp_T}$
η = 0.00
η = 1.14
p_T (GeV)

Figure 30:

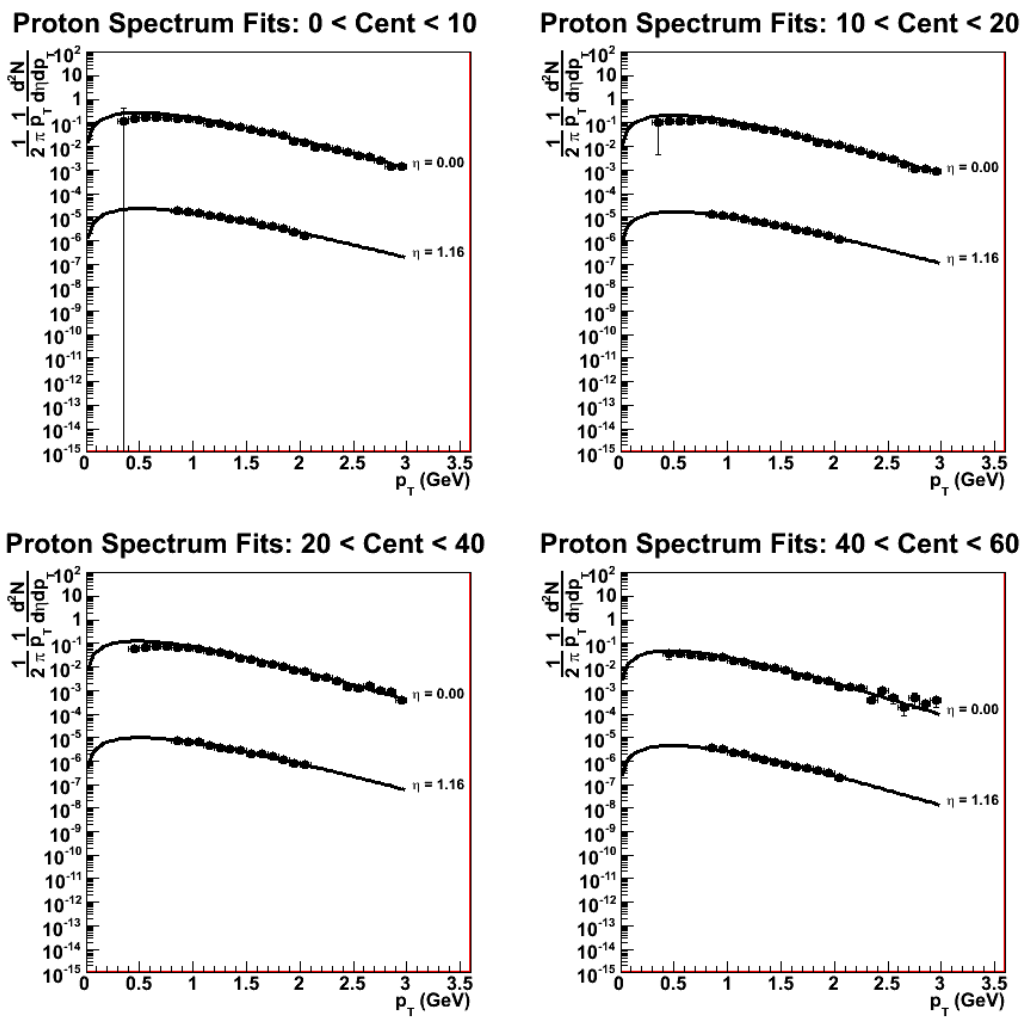
Proton Spectrum Fits: 0 < Cent < 10
Proton Spectrum Fits: 10 < Cent < 20
Proton Spectrum Fits: 20 < Cent < 40
Proton Spectrum Fits: 40 < Cent < 60
$\frac{1}{2\pi}\frac{1}{p_T}\frac{d^2N}{d\eta dp_T}$
η = 0.00
η = 1.16
p_T (GeV)

Figure 31:

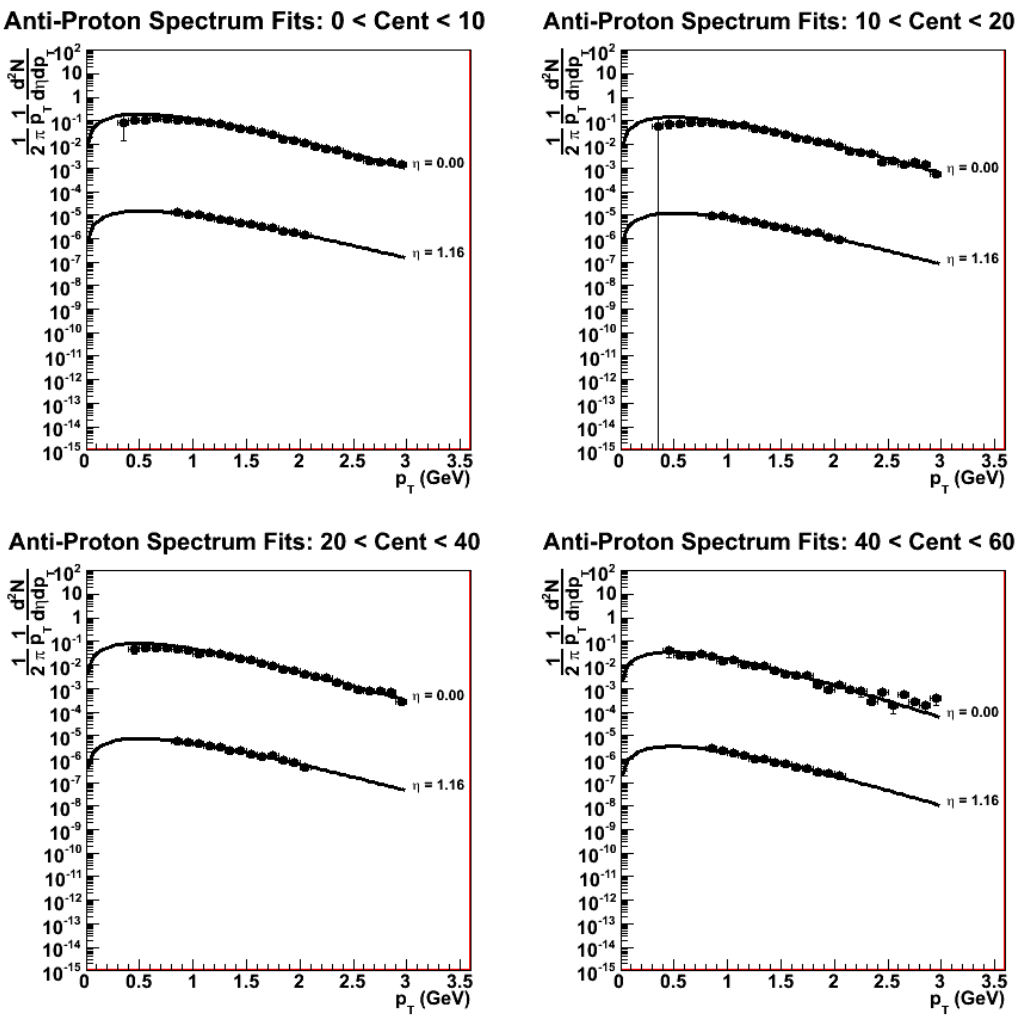

Figure 32:

The yields are then extracted from the spectral fits and plotted over η. The multiplicity distributions are then fit with the same double gaussians as shown in figures 18 - 23, except here the only fitting parameter is the amplitude. The multiplicity fits are shown in figures 33-38.

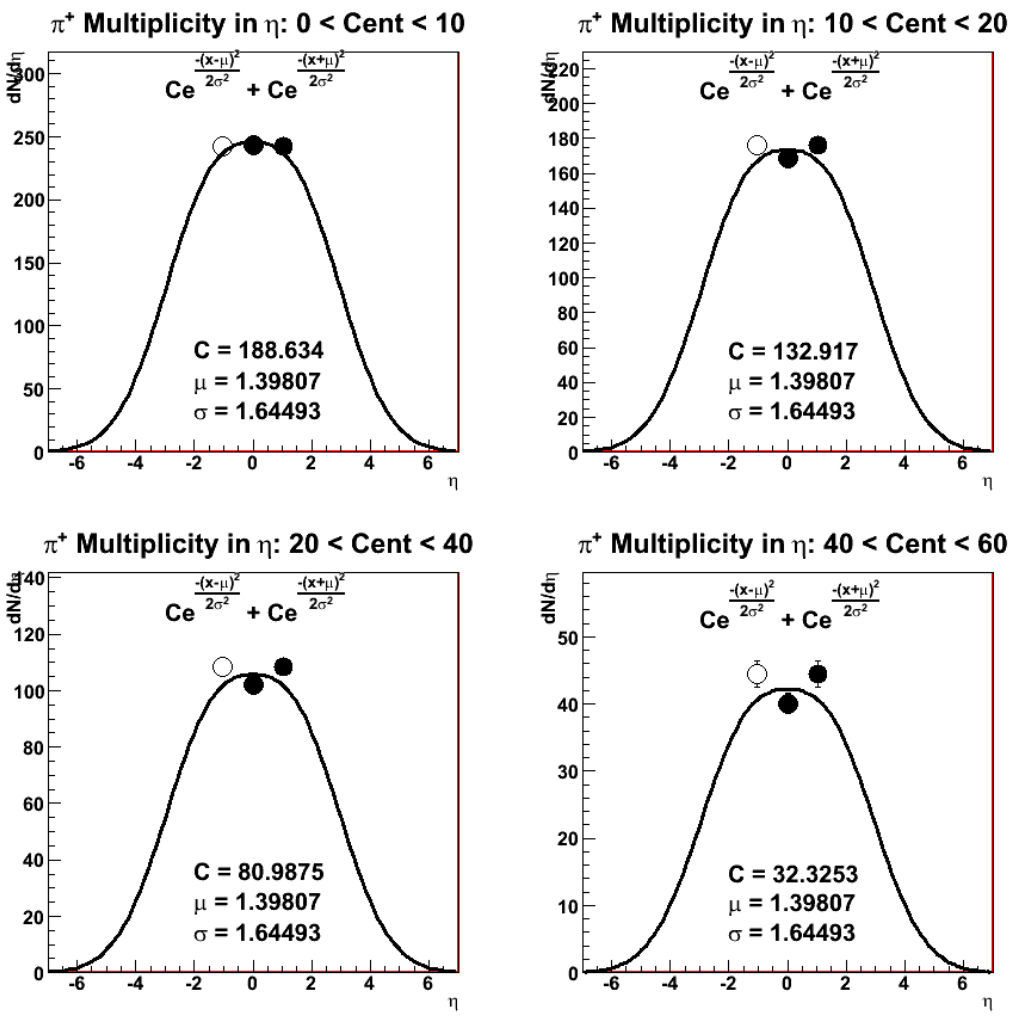
π+ Multiplicity in η: 0 < Cent < 10
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 188.634
μ = 1.39807
σ = 1.64493
η
π+ Multiplicity in η: 10 < Cent < 20
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 132.917
μ = 1.39807
σ = 1.64493
η
π+ Multiplicity in η: 20 < Cent < 40
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 80.9875
μ = 1.39807
σ = 1.64493
η
π+ Multiplicity in η: 40 < Cent < 60
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 32.3253
μ = 1.39807
σ = 1.64493
η

Figure 33:

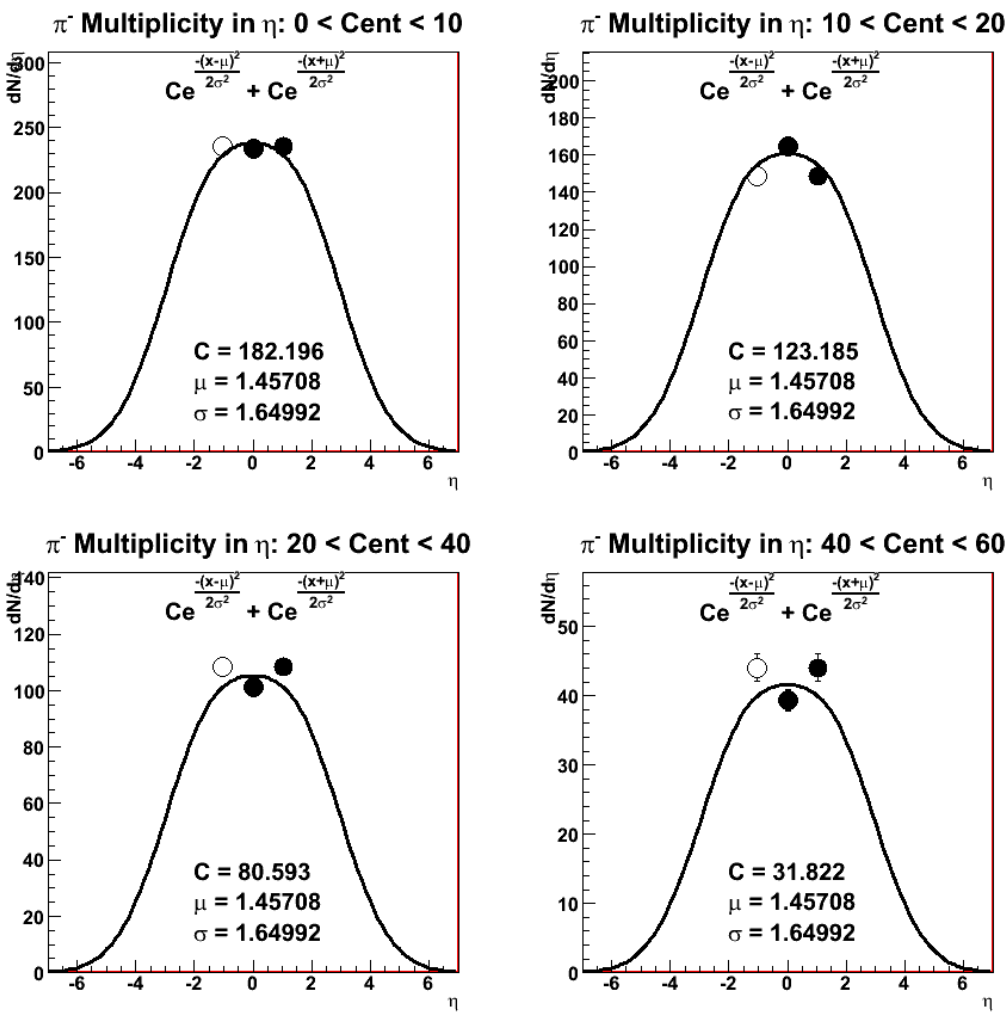
π⁻ Multiplicity in η: 0 < Cent < 10
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 182.196
μ = 1.45708
σ = 1.64992
η
π⁻ Multiplicity in η: 10 < Cent < 20
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 123.185
μ = 1.45708
σ = 1.64992
η
π⁻ Multiplicity in η: 20 < Cent < 40
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 80.593
μ = 1.45708
σ = 1.64992
η
π⁻ Multiplicity in η: 40 < Cent < 60
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 31.822
μ = 1.45708
σ = 1.64992
η

Figure 34:

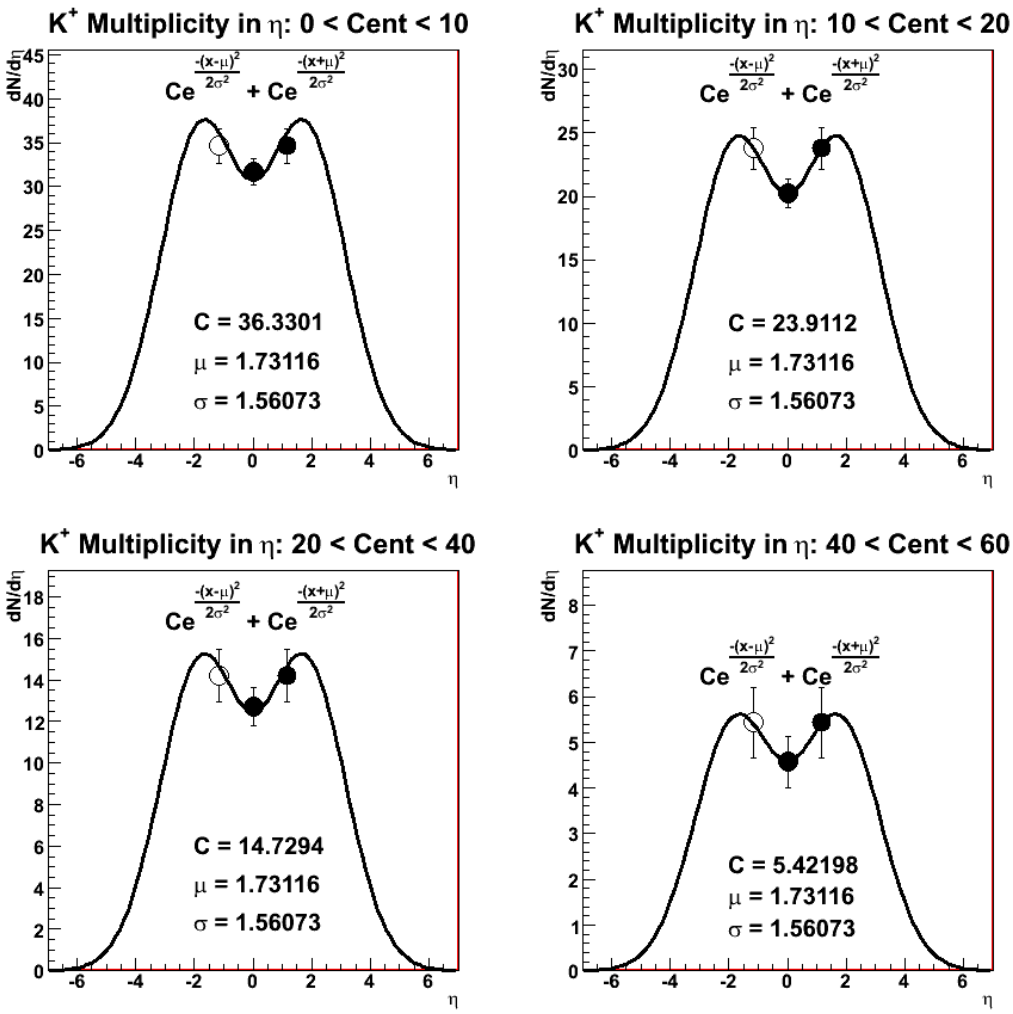
K+ Multiplicity in η: 0 < Cent < 10
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 36.3301
μ = 1.73116
σ = 1.56073
η
K+ Multiplicity in η: 10 < Cent < 20
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 23.9112
μ = 1.73116
σ = 1.56073
η
K+ Multiplicity in η: 20 < Cent < 40
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 14.7294
μ = 1.73116
σ = 1.56073
η
K+ Multiplicity in η: 40 < Cent < 60
dN/dη
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 5.42198
μ = 1.73116
σ = 1.56073
η

Figure 35:

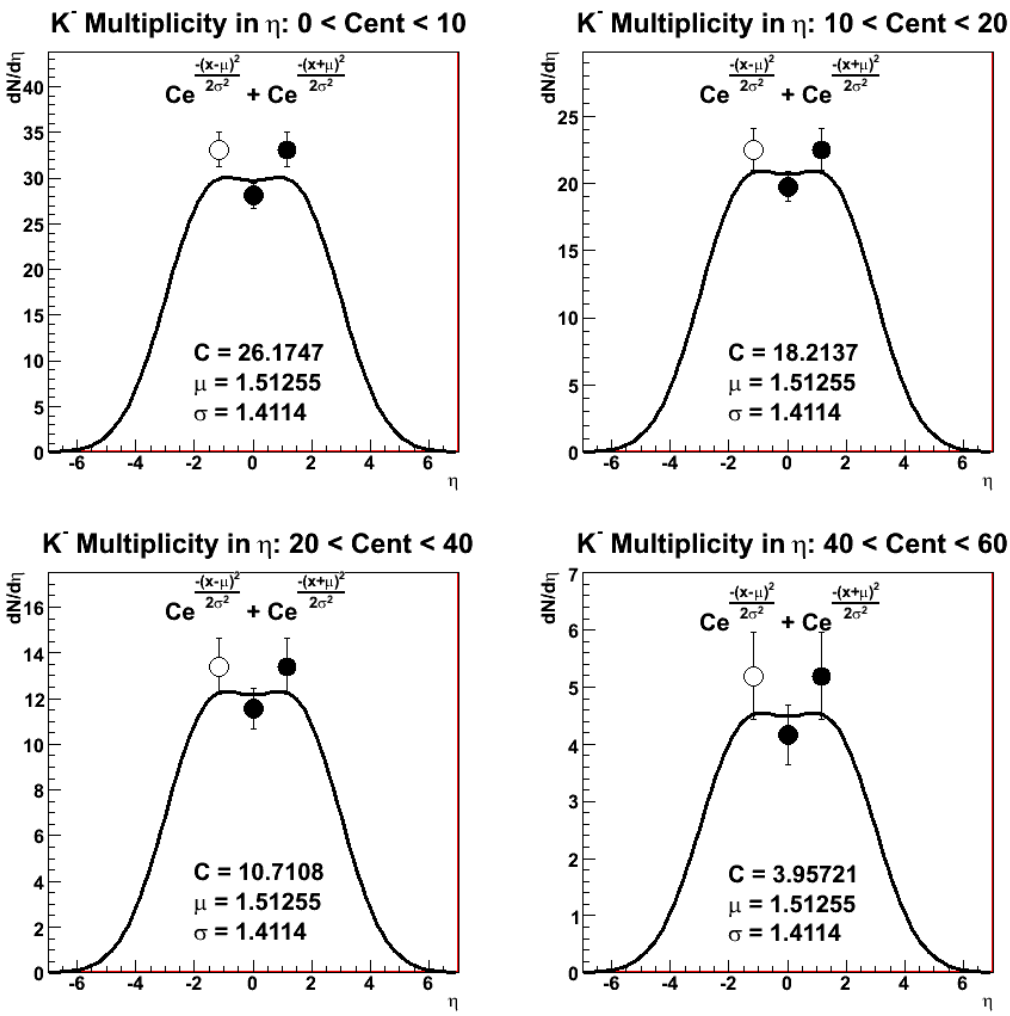
K⁻ Multiplicity in η: 0 < Cent < 10
K⁻ Multiplicity in η: 10 < Cent < 20
K⁻ Multiplicity in η: 20 < Cent < 40
K⁻ Multiplicity in η: 40 < Cent < 60
dN/dη
η
Ce^{-(x-μ)²/2σ²} + Ce^{-(x+μ)²/2σ²}
C = 26.1747
μ = 1.51255
σ = 1.4114
C = 18.2137
μ = 1.51255
σ = 1.4114
C = 10.7108
μ = 1.51255
σ = 1.4114
C = 3.95721
μ = 1.51255
σ = 1.4114

Figure 36:

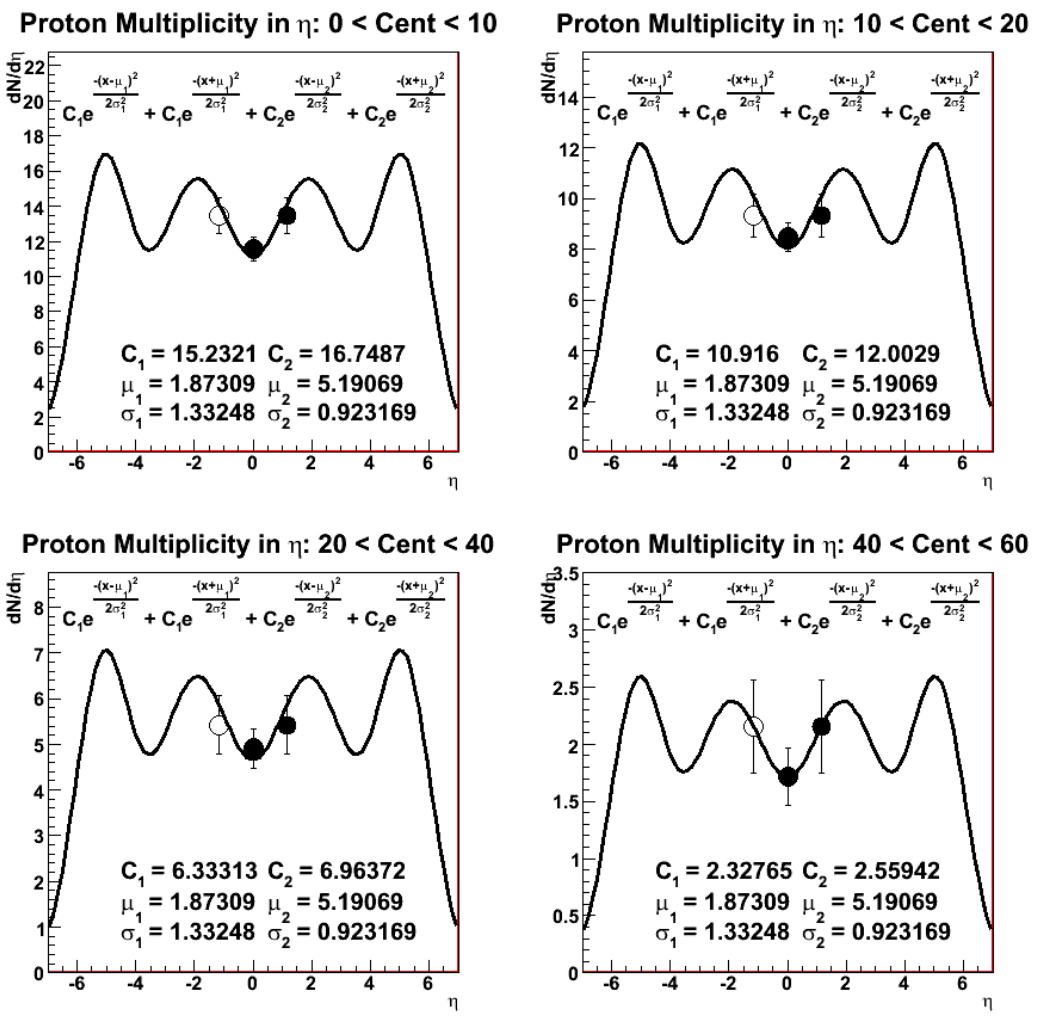
Proton Multiplicity in η: 0 < Cent < 10
C1 = 15.2321 C2 = 16.7487
μ1 = 1.87309 μ2 = 5.19069
σ1 = 1.33248 σ2 = 0.923169
Proton Multiplicity in η: 10 < Cent < 20
C1 = 10.916 C2 = 12.0029
μ1 = 1.87309 μ2 = 5.19069
σ1 = 1.33248 σ2 = 0.923169
Proton Multiplicity in η: 20 < Cent < 40
C1 = 6.33313 C2 = 6.96372
μ1 = 1.87309 μ2 = 5.19069
σ1 = 1.33248 σ2 = 0.923169
Proton Multiplicity in η: 40 < Cent < 60
C1 = 2.32765 C2 = 2.55942
μ1 = 1.87309 μ2 = 5.19069
σ1 = 1.33248 σ2 = 0.923169
dN/dη
η

Figure 37:

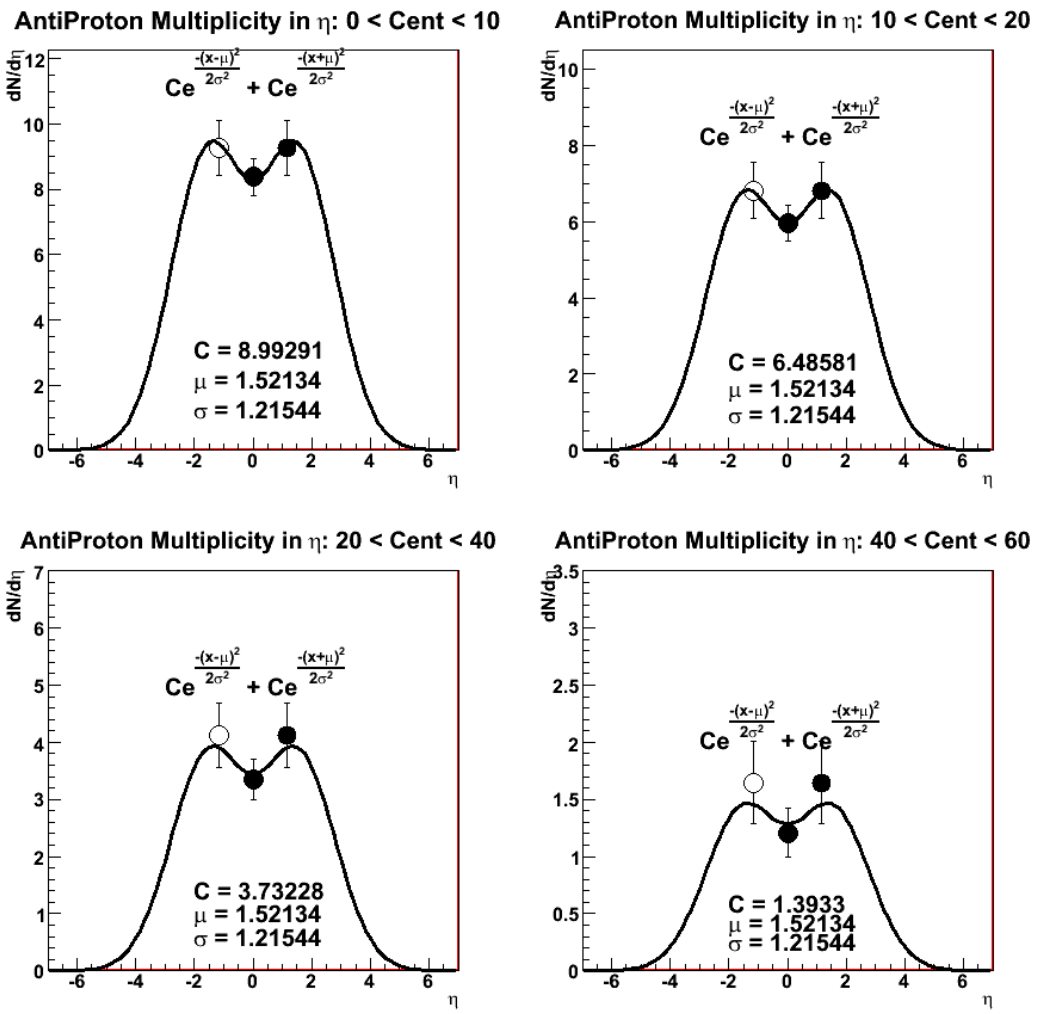

Figure 38:

The amplitude of the multiplicity shapes as a function of centrality is plotted in figures 39 – 44 and fit with an exponential. These fits are then used to rescale the other particles.

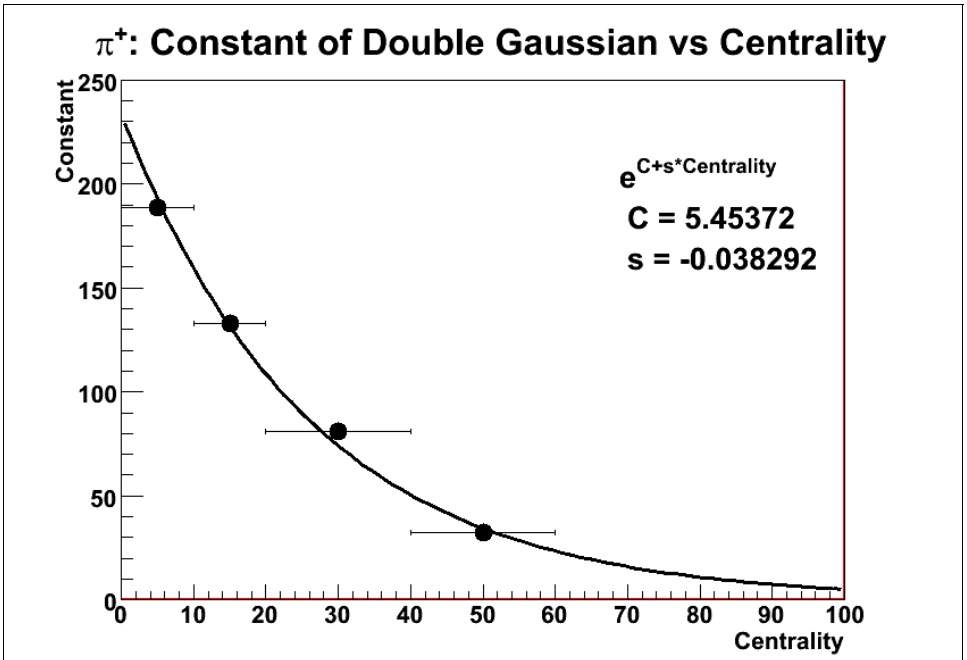

Figure 39:

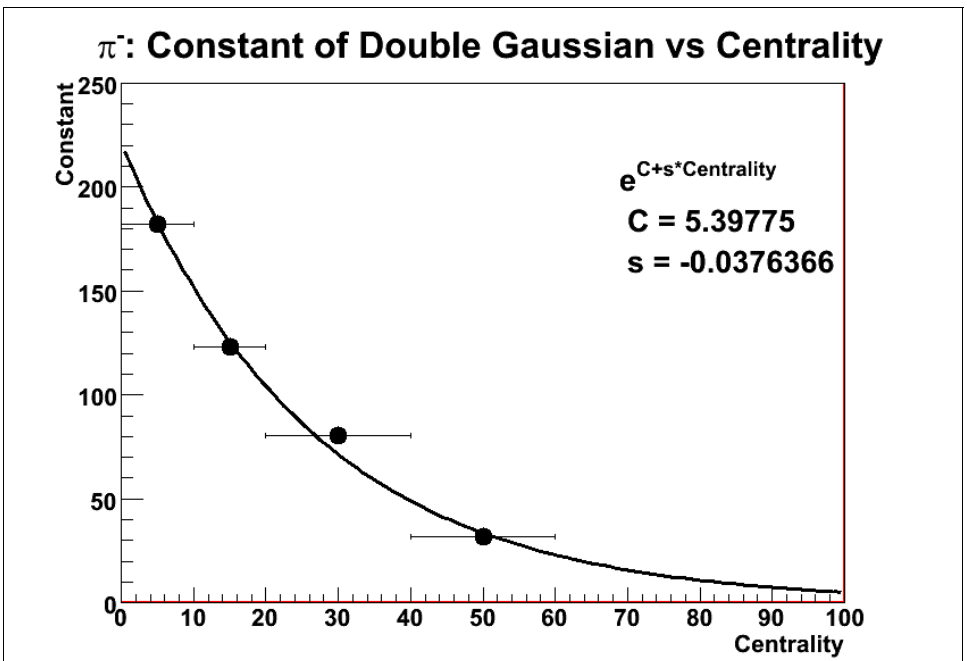

Figure 40:

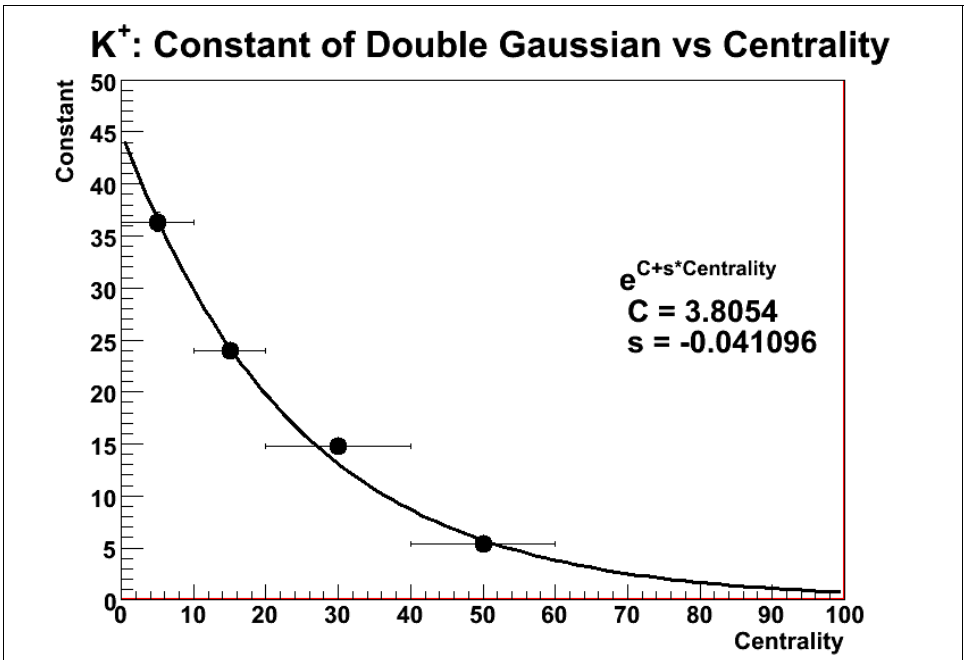

Figure 41:

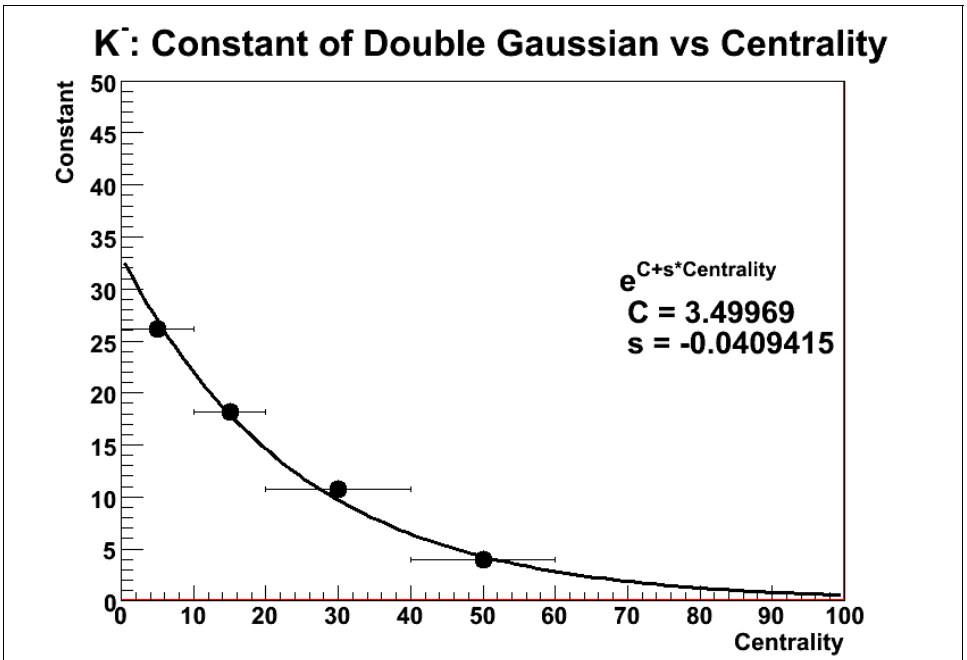

Figure 42:

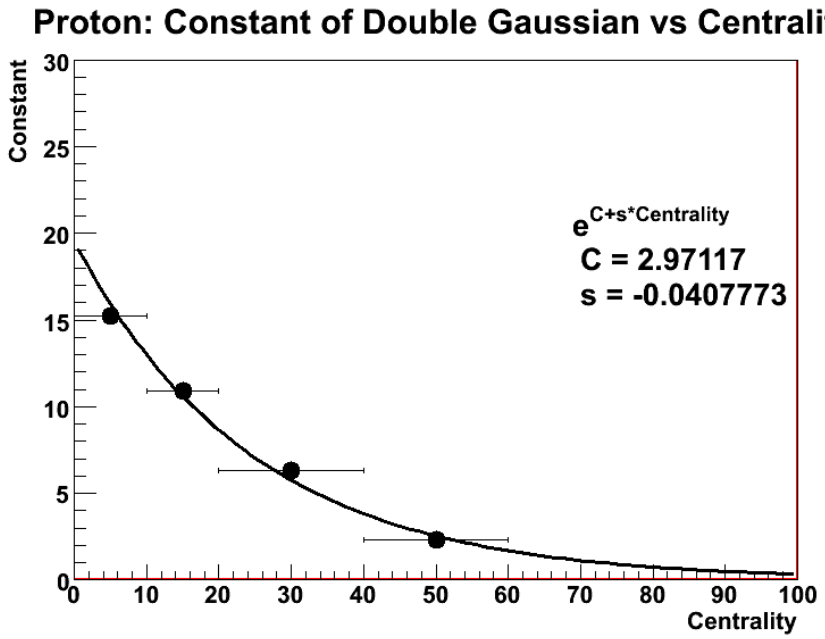

Figure 43:

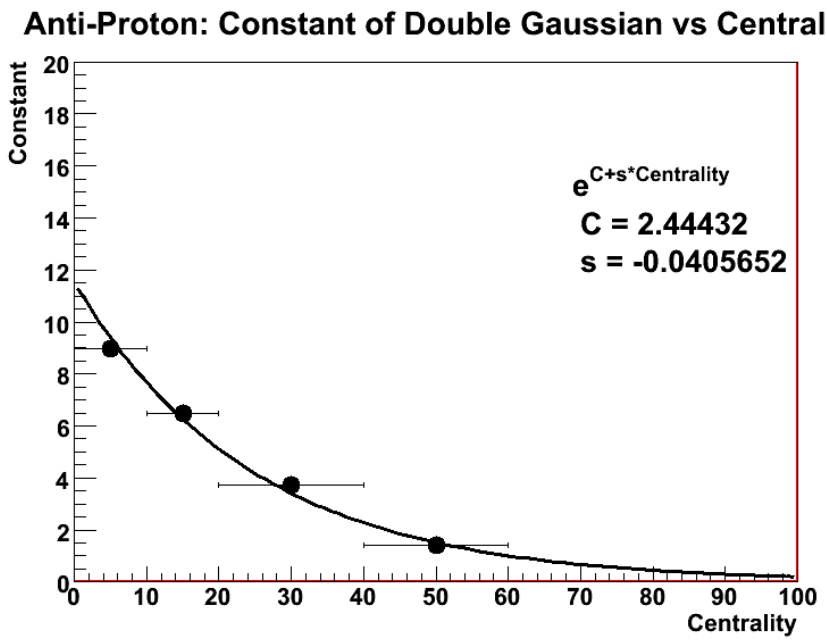

Figure 44:

At this point the shape for each of the measured particles is complete, and for a given centrality and eta, the relative abundance for each of these particles can be determined. Now the next step is to include the rest of the particles mentioned in table 1 whose shapes are determined by the HIJING simulation. Figures 45-78 show the shape for the 5% most central events for the HIJING particles.

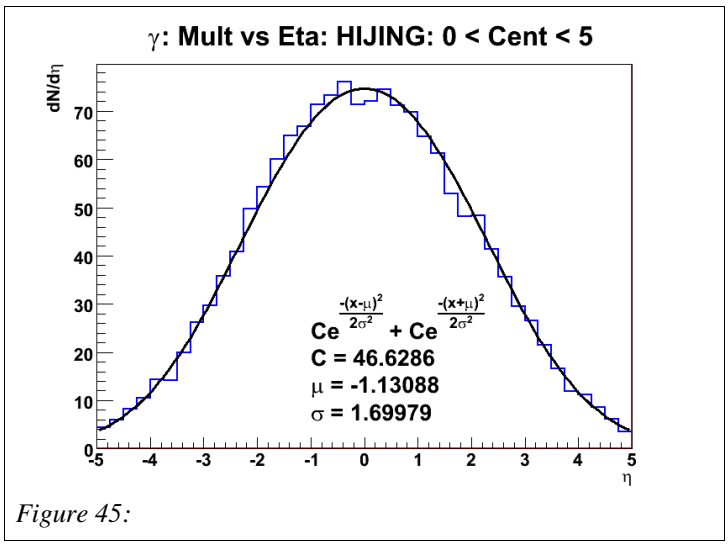

Figure 45:

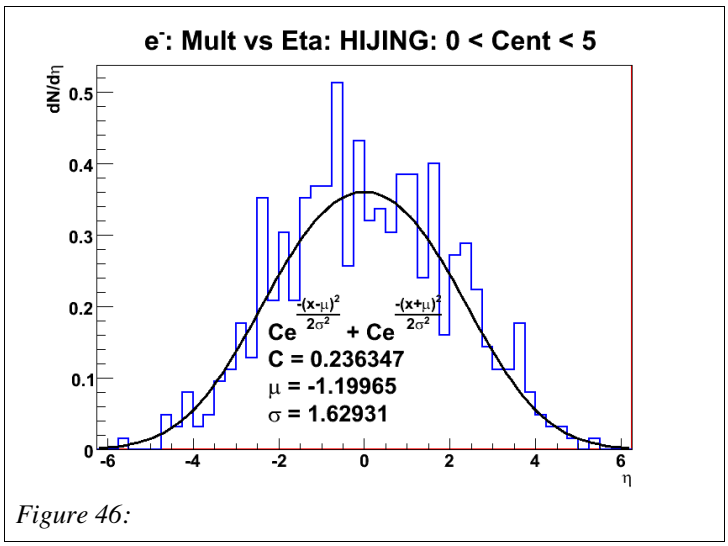

Figure 46:

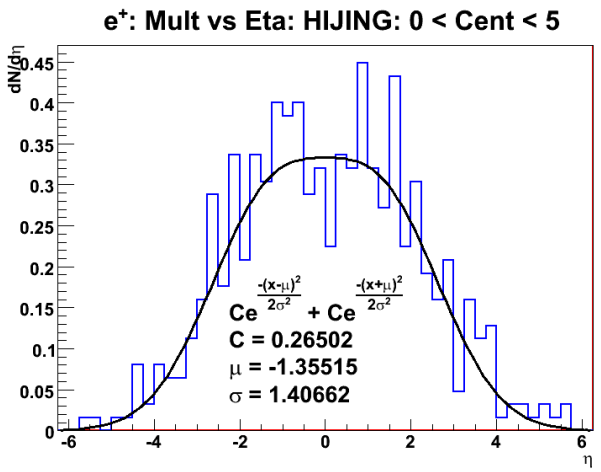

Figure 47:

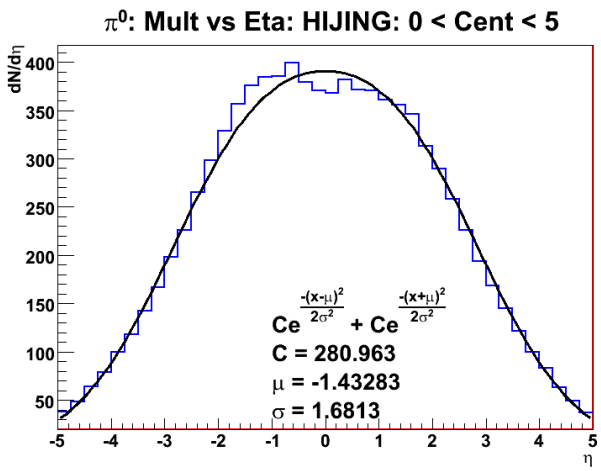

Figure 48:

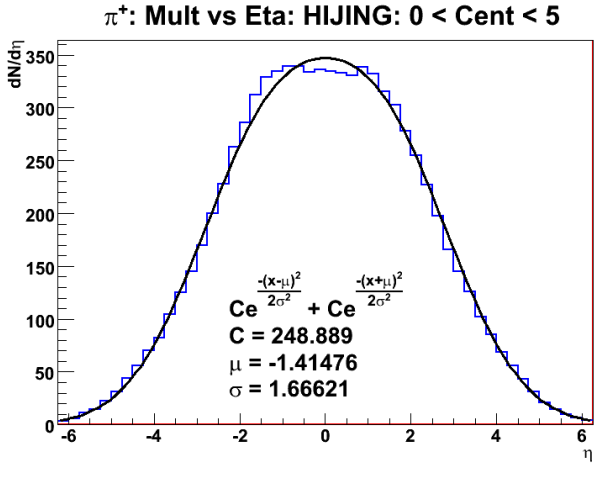

Figure 49:

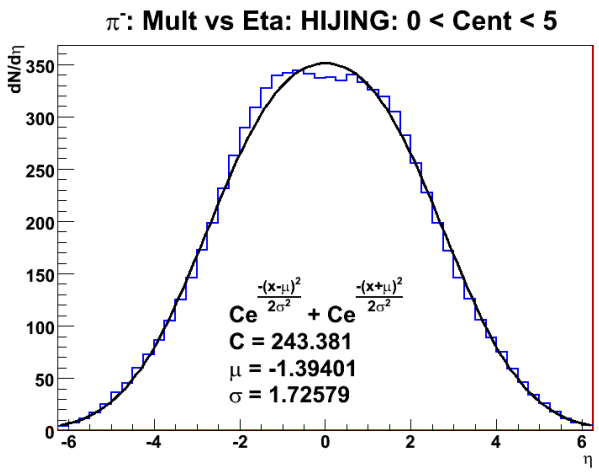

Figure 50:

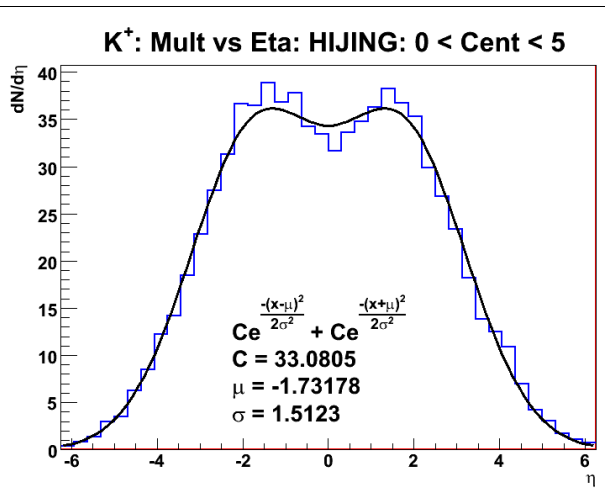

Figure 51:

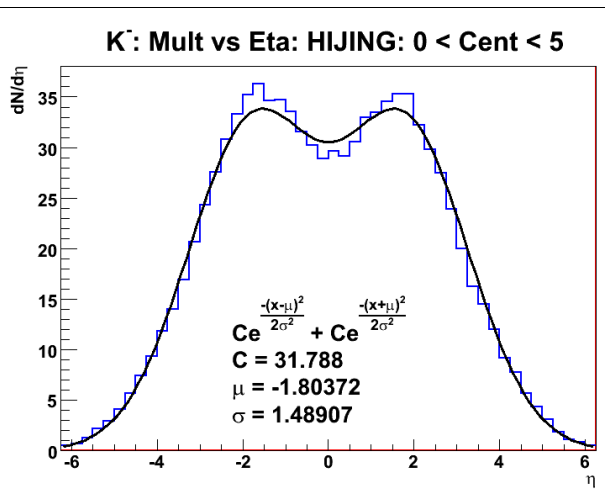

Figure 52:

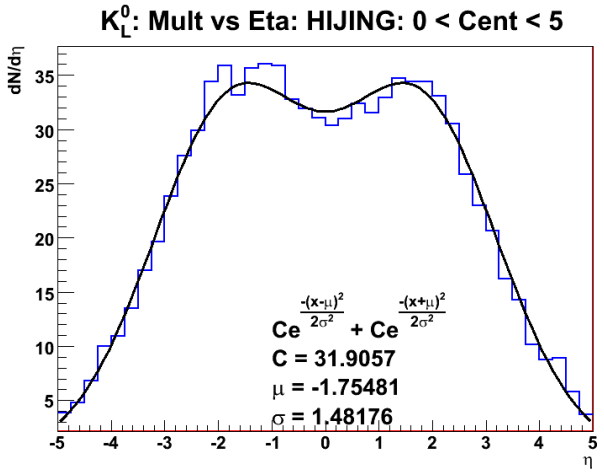

Figure 53:

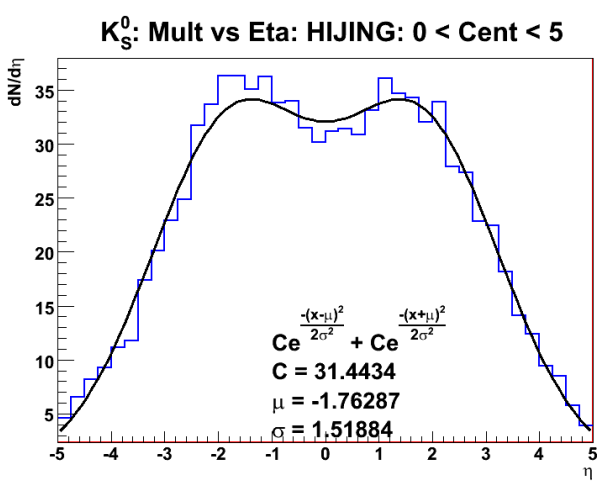

Figure 54:

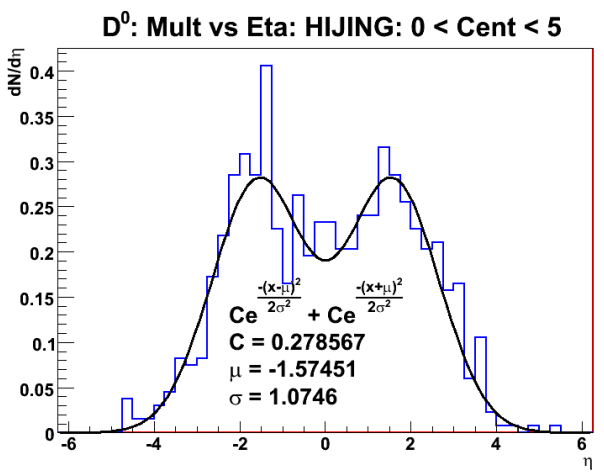

Figure 55:

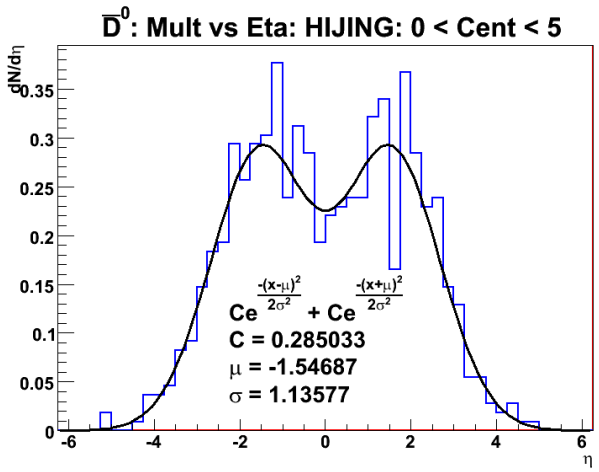

Figure 56:

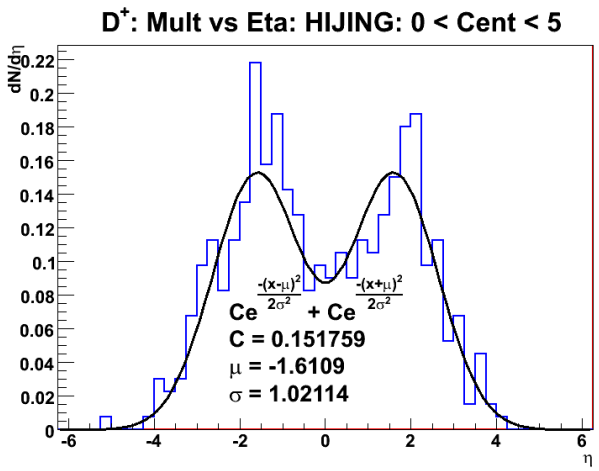

Figure 57:

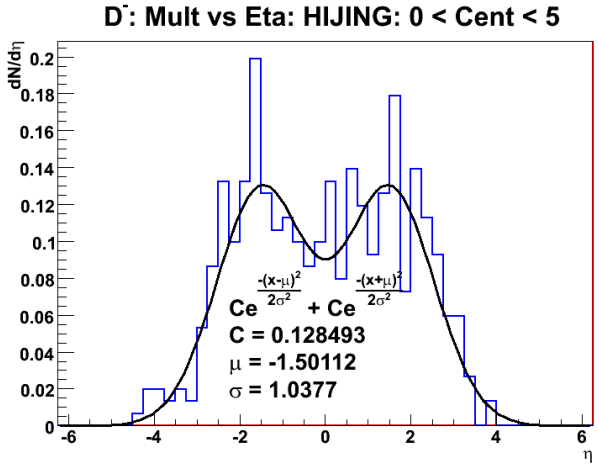

Figure 58:

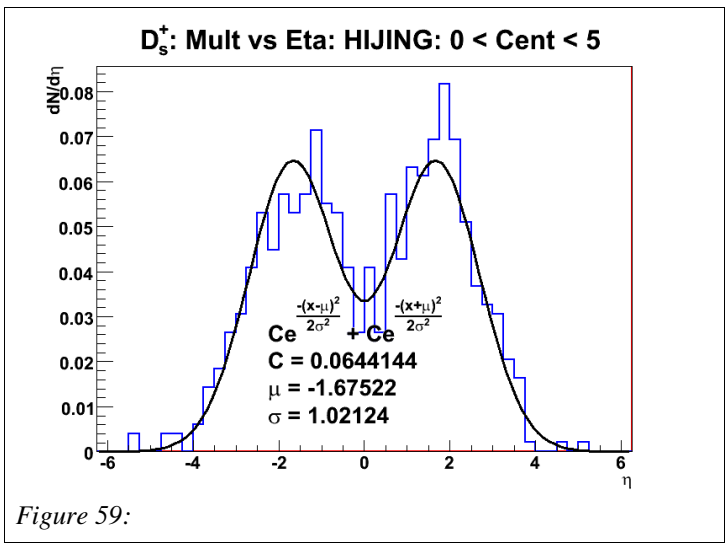

Figure 59:

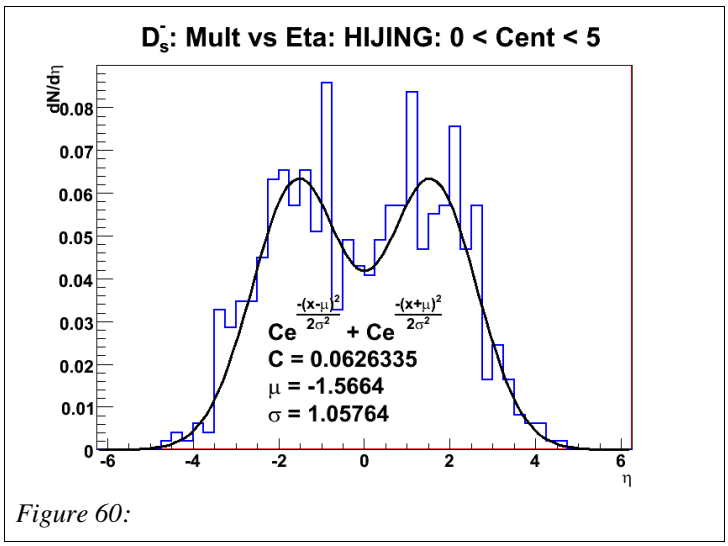

Figure 60:

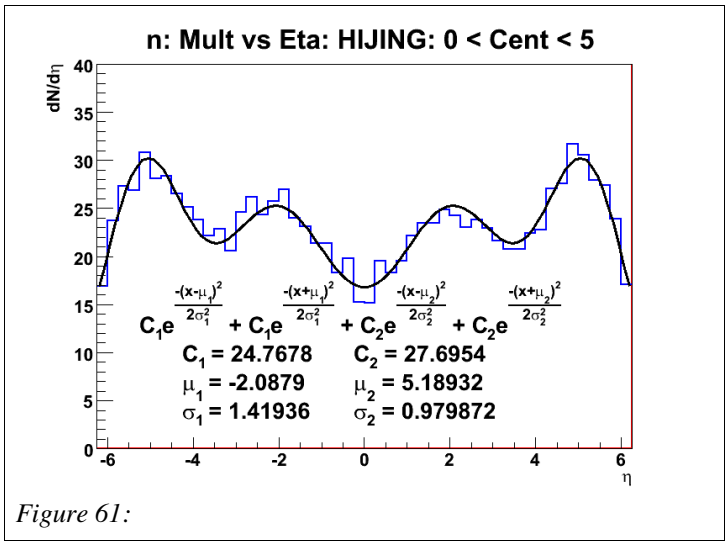

Figure 61:

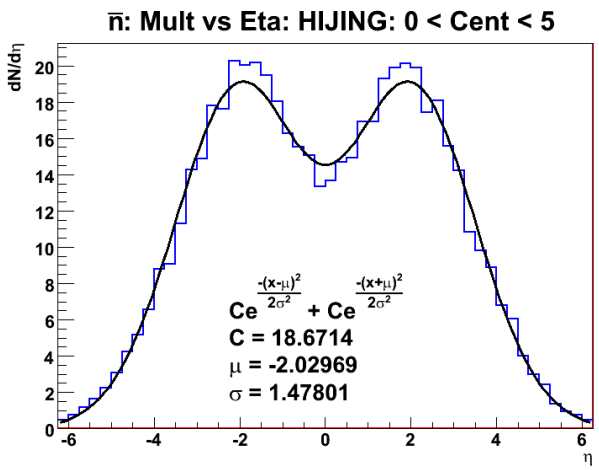

Figure 62:

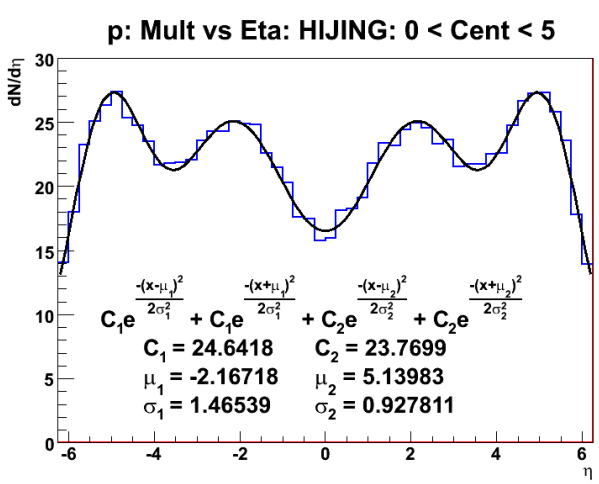

Figure 63:

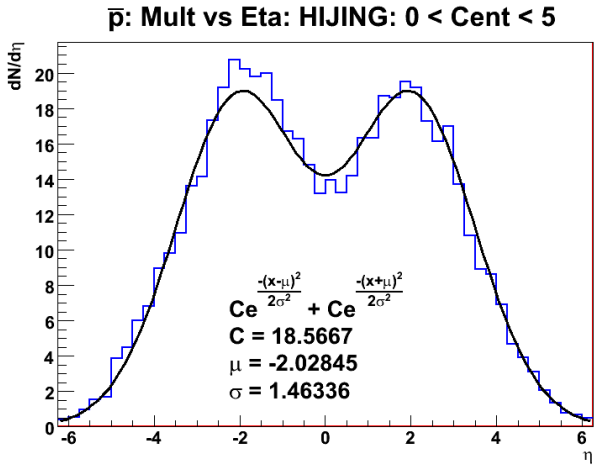

Figure 64:

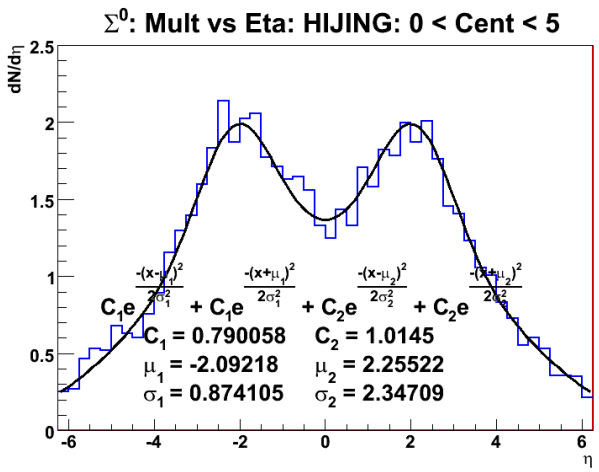

Figure 65:

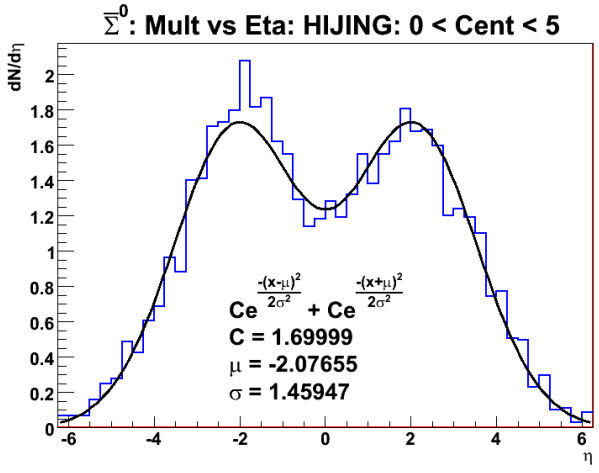

Figure 66:

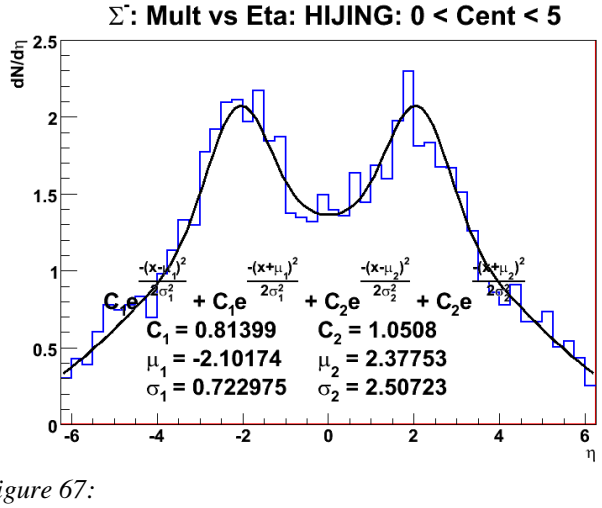

Figure 67:

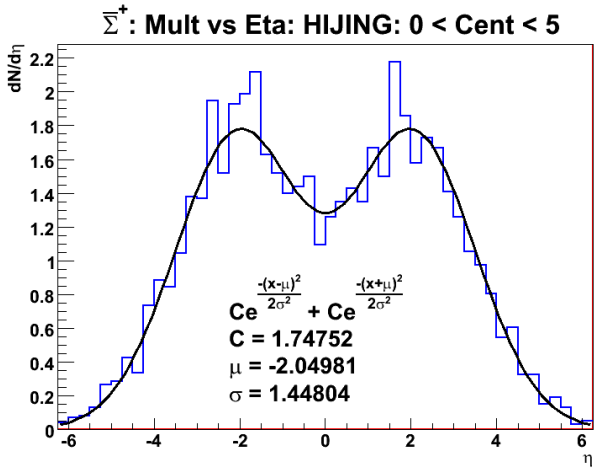

Figure 68:

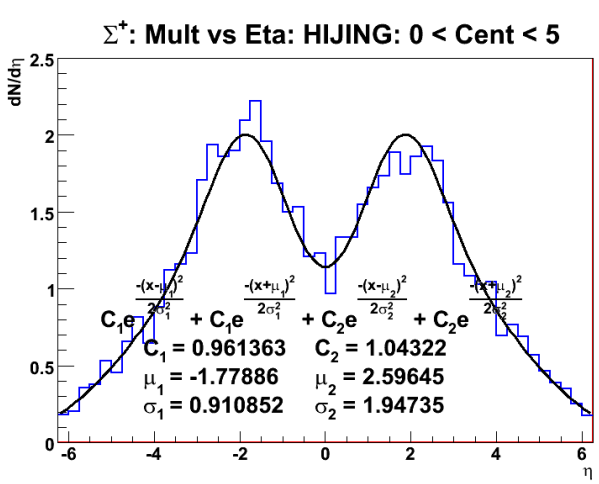

Figure 69:

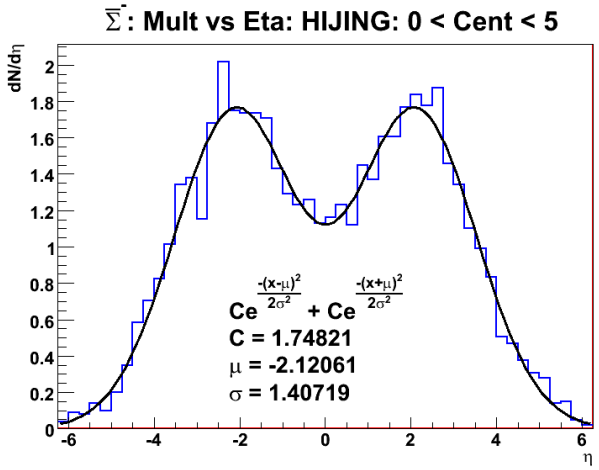

Figure 70:

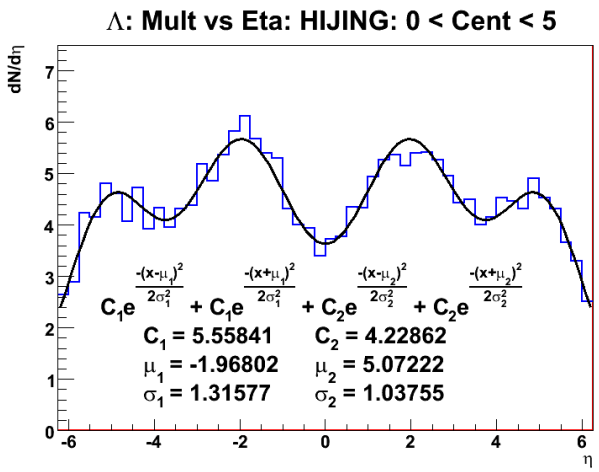

Figure 71:

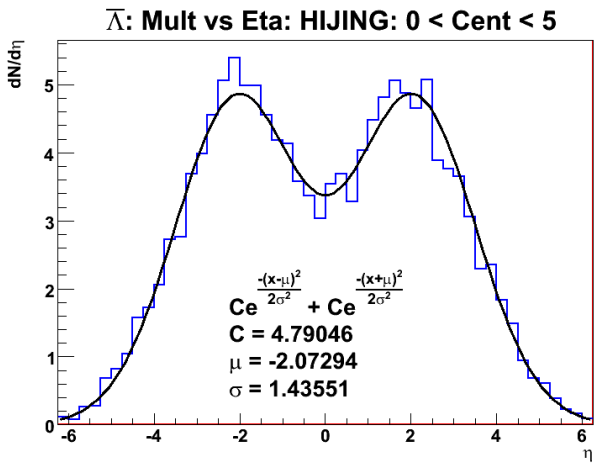

Figure 72:

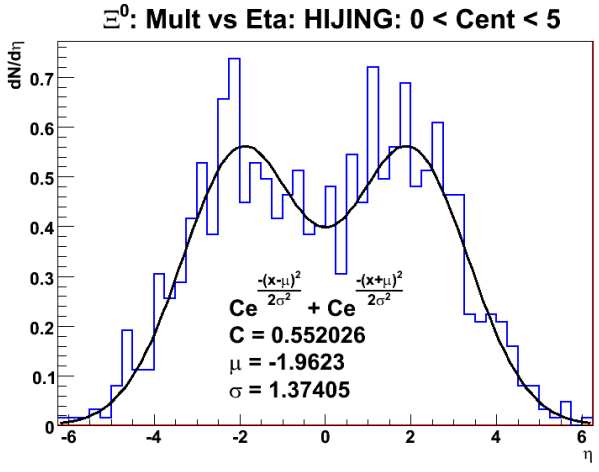

Figure 73:

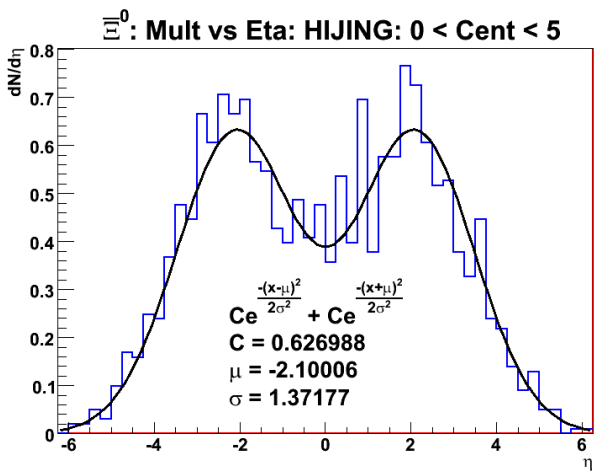

Figure 74:

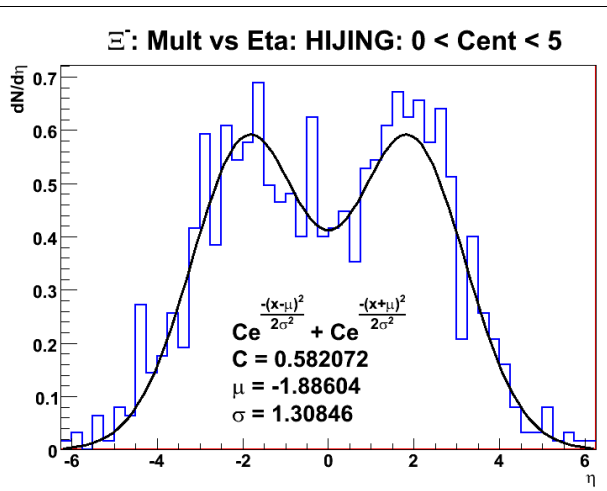

Figure 75:

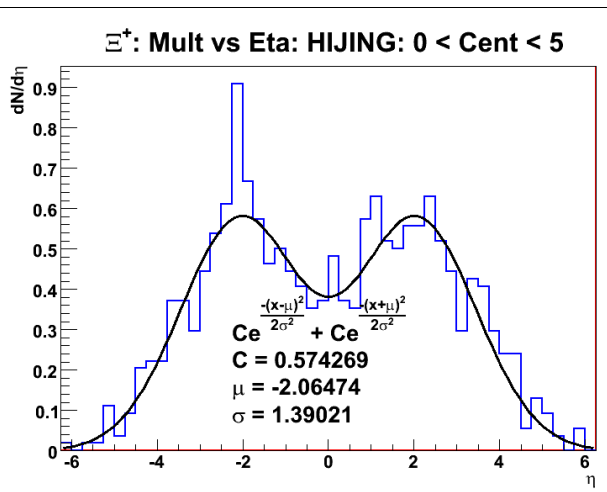

Figure 76:

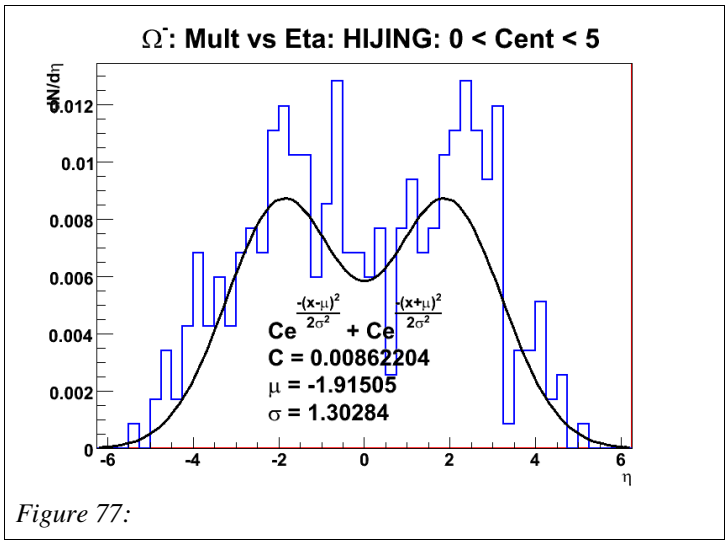

Figure 77:

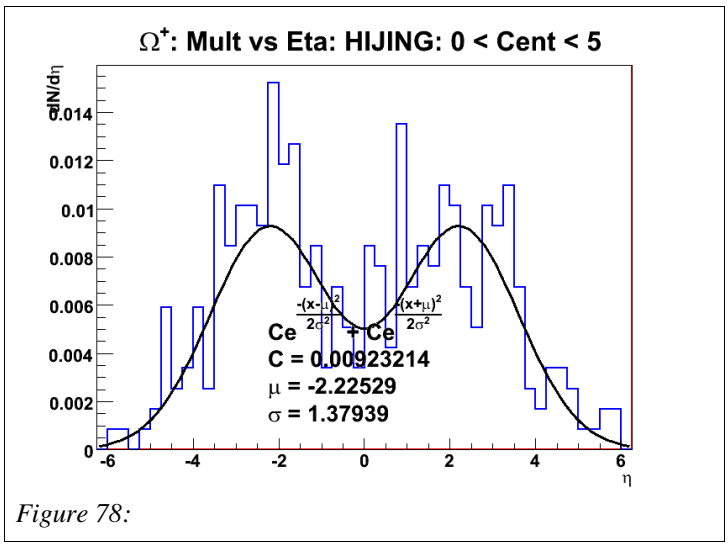

Figure 78:

Table 2 shows the parameters for the particles in the fragmentation region. The mean and sigma are for the gaussians in the forward region. Eta 0 C is the amplitude of the mid-rapidity gaussians, and Eta Frag C is the amplitude in the forward region. These values keep the ratio between these two regions consistent.

Index	*Particle*	*Mean*	*σ*	*Eta 0 C*	*Eta Frag. C*	*HIJING Index*
16	n	5.18932	0.979872	24.7678	27.6954	2112
18	p	5.13983	0.927811	23.9929	24.8730	2212
20	Σ^0	2.25522	2.34709	0.790058	1.01450	3212
22	Σ^-	2.37753	2.50723	0.81399	1.05080	3112
24	Σ^+	2.59645	1.94735	0.961363	1.04322	3222
26	Λ^0	5.07222	1.03755	5.55841	4.22862	3122

Table 2: dN/dη distribution parameters in the fragmentation region

Table 3 shows the parameters used in determining the dN/dη shape for each of the particles. In the table, the scale factor is the constant from the particle double gaussian fit over the reference particle constant from the HIJING data. In other words, it is the relative abundance between the particle and the reference particle in the HIJING simulation. The mean and sigma values are those indicated in the dN/dη distributions. The amplitude is determined using the centrality dependence of the double gaussian constant of the reference particles, shown in figures 39 – 44, and scaled by the scale factor in table 3. The π^0 will look like an average of π^+ and π^- from the multiplicity distribution determined from the data.

Index	*Particle*	*Mean*	*σ*	*scale factor*	*Ref. Particle*	*HIJING Index*
0	γ	1.13088	1.69979	0.189443	$\pi^+ + \pi^-$	22
1	e^-	1.19965	1.62931	0.000960	$\pi^+ + \pi^-$	11
2	e^+	1.35515	1.40662	0.001077	$\pi^+ + \pi^-$	-11
3	π^0	1.50247	1.62778	1	$\pi^+ + \pi^-$	111
4	π^+	1.50247	1.62778	1	N/A	211
5	π^-	1.50247	1.62778	1	N/A	-211
6	K^+	1.79810	1.51762	1	N/A	321
7	K^-	1.57646	1.37196	1	N/A	-321
8	K_L^0	1.75481	1.48176	0.983704	$K^+ + K^-$	130
9	K_S^0	1.76287	1.51884	0.969451	$K^+ + K^-$	310
10	D^0	1.57451	1.07460	0.008421	K^+	421
11	$\bar{D}^0$	1.54687	1.13577	0.008967	K^-	-421
12	D^+	1.61090	1.02114	0.004587	K^+	411
13	D^-	1.50112	1.03770	0.004042	K^-	-411
14	D_s^+	1.67522	1.02124	0.001947	K^+	431
15	D_s^-	1.56640	1.05764	0.001970	K^-	-431
16	n	2.08790	1.41936	1.005113	p	2112
17	$\bar{n}$	2.02969	1.47801	1.005639	$\bar{p}$	-2112
18	p	1.95667	1.38456	1	N/A	2212
19	$\bar{p}$	1.55915	1.25326	1	N/A	-2212
20	Σ^0	2.09218	0.87411	0.032062	p	3212
21	$\bar{\Sigma}^0$	2.07655	1.45947	0.091561	$\bar{p}$	-3212
22	Σ^-	2.10174	0.72298	0.033032	p	3112
23	$\bar{\Sigma}^+$	2.04981	1.44804	0.094121	$\bar{p}$	-3112
24	Σ^+	1.77886	0.91085	0.039014	p	3222
25	$\bar{\Sigma}^-$	2.12061	1.40719	0.094158	$\bar{p}$	-3222
26	Λ^0	1.96802	1.31577	0.225568	p	3122
27	$\bar{\Lambda}^0$	2.07294	1.43551	0.258016	$\bar{p}$	-3122
28	Ξ^0	1.96230	1.37405	0.022402	p	3322
29	$\bar{\Xi}^0$	2.10006	1.37177	0.033769	$\bar{p}$	-3322
30	Ξ^-	1.88604	1.30846	0.023621	p	3312
31	Ξ^+	2.06474	1.39021	0.030930	$\bar{p}$	-3312
32	Ω^-	1.91505	1.30284	3.4989e-4	p	3334
33	Ω^+	2.22529	1.37939	4.9724e-4	$\bar{p}$	-3334

Table 3: dN/dη distribution parameters for each particle

Index	*Particle*	*Mass (GeV/c²)*	*Charge*	*Baryon Number*	*Strangeness*
0	γ	0	0	0	0
1	e^-	0.0005109989	-1	0	0
2	e^+	0.0005109989	+1	0	0
3	π^0	0.1349766	0	0	0
4	π^+	0.13957018	+1	0	0
5	π^-	0.13957018	-1	0	0
6	K^+	0.493677	+1	0	+1
7	K^-	0.493677	-1	0	-1
8	K_L^0	0.497648	0	0	+1
9	K_S^0	0.497648	0	0	+1
10	D^0	1.8646	0	0	0
11	$\bar{D}^0$	1.8646	0	0	0
12	D^+	1.8694	+1	0	0
13	D^-	1.8694	-1	0	0
14	D_s^+	1.9683	+1	0	+1
15	D_s^-	1.9683	-1	0	-1
16	n	0.939565360	0	+1	0
17	$\bar{n}$	0.939565360	0	-1	0
18	p	0.938272029	+1	+1	0
19	$\bar{p}$	0.938272029	-1	-1	0
20	Σ^0	1.192642	0	+1	-1
21	$\bar{\Sigma}^0$	1.192642	0	-1	+1
22	Σ^-	1.197449	-1	+1	-1
23	$\bar{\Sigma}^+$	1.197449	+1	-1	+1
24	Σ^+	1.18937	+1	+1	-1
25	$\bar{\Sigma}^-$	1.18937	-1	-1	+1
26	Λ^0	1.115683	0	+1	-1
27	$\bar{\Lambda}^0$	1.115683	0	-1	+1
28	Ξ^0	1.31483	0	+1	-2
29	$\bar{\Xi}^0$	1.31483	0	-1	+2
30	Ξ^-	1.32131	-1	+1	-2
31	Ξ^+	1.32131	+1	-1	+2
32	Ω^-	1.67245	-1	+1	-3
33	Ω^+	1.67245	+1	-1	+3

Table 4: Properties for each of the particles

The dNch/deta needs to be preserved. This requires that the ratio of neutral to charged particles needs to be 0.63 to 0.87. This is done by applying a scaling factor to the neutral and charged particles such that the sum of $dN_{neutral}/dh(\eta,cent)$ for the neutral particle plus the sum of $dN_{ch}/d\eta(\eta,cent)$ for the charged particles is equal to the given value of $dN_{total}/d\eta(\eta,cent)$, while keeping the ratio of $dN_{neutral}/d\eta(\eta,cent)$ to $dN_{ch}/d\eta(\eta,cent)$ = 0.63 to 0.87.

The baryon number and total charge is roughly conserved. This was calibrated on the most central events (0-5%). Scaling factors were applied to the negatively charged particles and anti-baryons in order that the total charge and baryon number were conserved. These values are only conversed on average with $1\sigma = 68$ for charge conservation and $1\sigma = 46$ for baryon number conservation.

The parameters from table 2 & 3 are used to get the $dN/d\eta$ for each particle at a given centrality and eta. The sum of $dN_i/d\eta$ over all activated particles, called $dN_{total}/d\eta$. is used as a normalization term, where i is the index for a particle. After a random number, x, from 0 to 1 is generated particle i is chosen when

$$\frac{\sum_{p=0}^{i-1}\frac{dN_p}{d\eta}}{\frac{dN_{total}}{d\eta}} < x < \frac{\sum_{p=0}^{i}\frac{dN_p}{d\eta}}{\frac{dN_{total}}{d\eta}} \qquad (11)$$

Note that here we are only summing over the active particles.

Step 4.3: Determine the p_T of the Particle

The particle spectra have already been fit (see figures 12 -17 and figures 27-32) to characterize the spectrum. The parameters of these fits can be characterized in terms of eta and centrality. Equations 8, 9 and 10 need to first be exclusively in terms of p_T, this means that they should be multiplied by $2\pi p_T$. Since the functions will be normalized to 1 by dividing by the integral from 0 to ∞, the leading constants can be ignored, which includes dN/dy(η). The spectral functions can be defined as

$$\frac{dN}{dp_T}(p_T) = \frac{p_T \cdot p}{E}\left(1+\frac{p_T}{C}\right)^{-n} \qquad (12)$$

for pions,

$$\frac{dN}{dp_T}(p_T) = \frac{p_T \cdot p}{E} e^{\frac{m-\sqrt{p_T^2+m^2}}{T}} \qquad (13)$$

for kaons, and

$$\frac{dN}{dp_T}(p_T) = \frac{p_T \cdot p\sqrt{p_T^2+m^2}}{E} e^{\frac{m-\sqrt{p_T^2+m^2}}{T}} \qquad (14)$$

for protons. In figures 79 -88, C is parameter 0 for pions, and n is parameter 2 for pions. T is parameter 1 for kaons and protons. The particles that have a reference particle in

table 2 will have a similar dependence in p_T as their reference particle. For a random number x from 0 to 1 the p_T of the particle is determined when

$$x - \frac{\int_0^{p_T} \frac{dN}{dp_T}(p_T)}{\int_0^{\infty} \frac{dN}{dp_T}(p_T)} < 0.0001 \qquad (15)$$

The integral in the numerator is determined in steps of ½ of the previous step. This gives a range of possible values in p_T. Here is an example of could happen

x - Integral	p_T	p_T ***min***	p_T ***max***
-0.5	5.0	0.0	5.0
-0.2	2.5	0.0	2.5
0.002	1.25	1.25	2.5
0.0005	1.875	1.875	2.5
0.00002	2.1875	2.1875	2.5

Table 5: Example of how the program determine p_T.

In table 5, the value of p_T is somewhere between 2.1875 and 2.5. A gaussian distribution with a mean at the center of this bin and a sigma of 1/8 its width is used to give a random distribution of the p_T value.

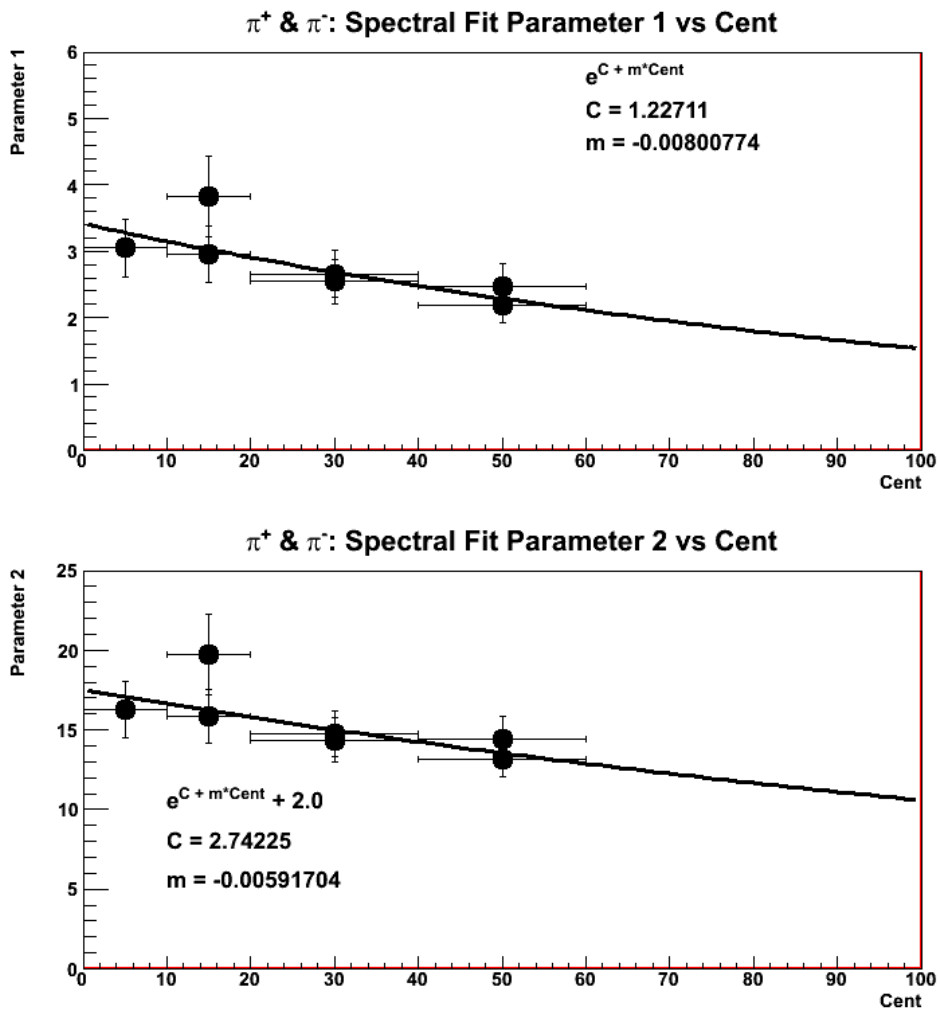
π+ & π-: Spectral Fit Parameter 1 vs Cent
Parameter 1
e^(C + m*Cent)
C = 1.22711
m = -0.00800774
Cent
π+ & π-: Spectral Fit Parameter 2 vs Cent
Parameter 2
e^(C + m*Cent) + 2.0
C = 2.74225
m = -0.00591704
Cent

Figure 79:

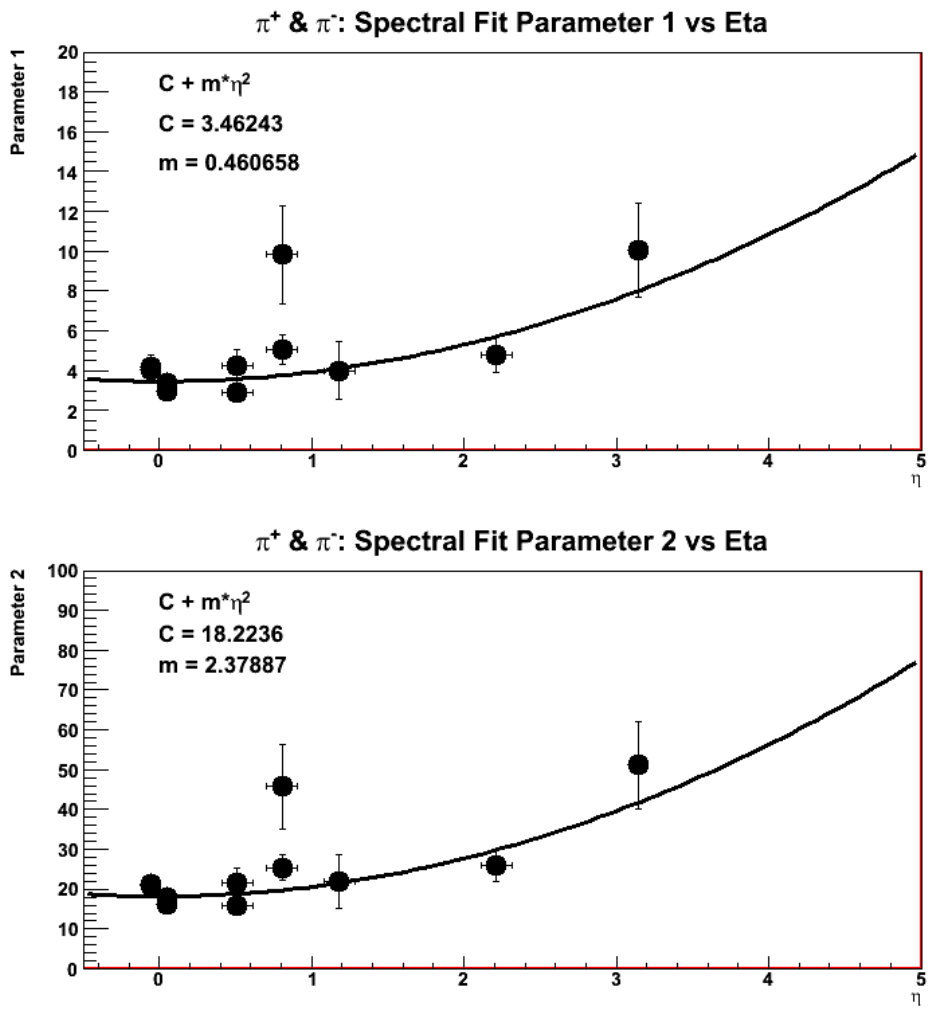
π+ & π-: Spectral Fit Parameter 1 vs Eta
Parameter 1
C + m*η2
C = 3.46243
m = 0.460658
η
π+ & π-: Spectral Fit Parameter 2 vs Eta
Parameter 2
C + m*η2
C = 18.2236
m = 2.37887
η

Figure 80:

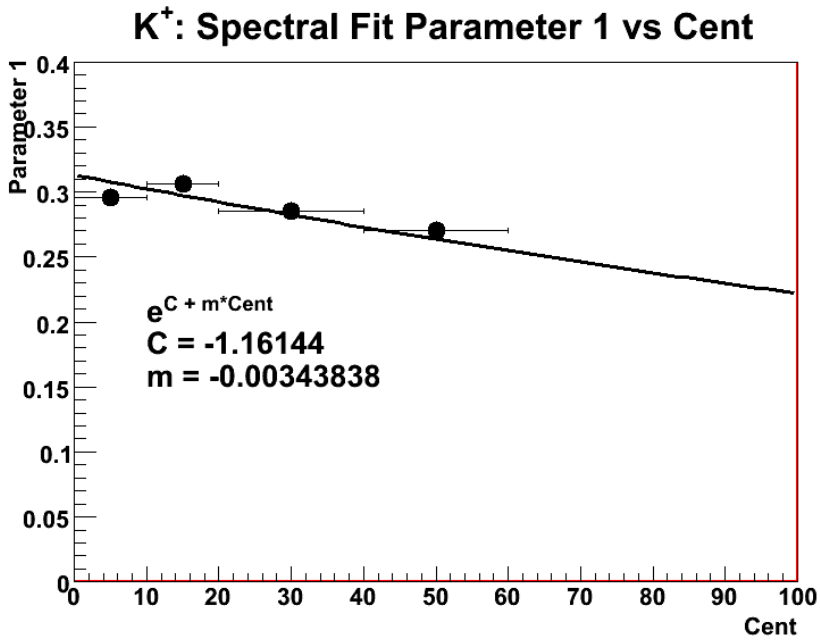

Figure 81:

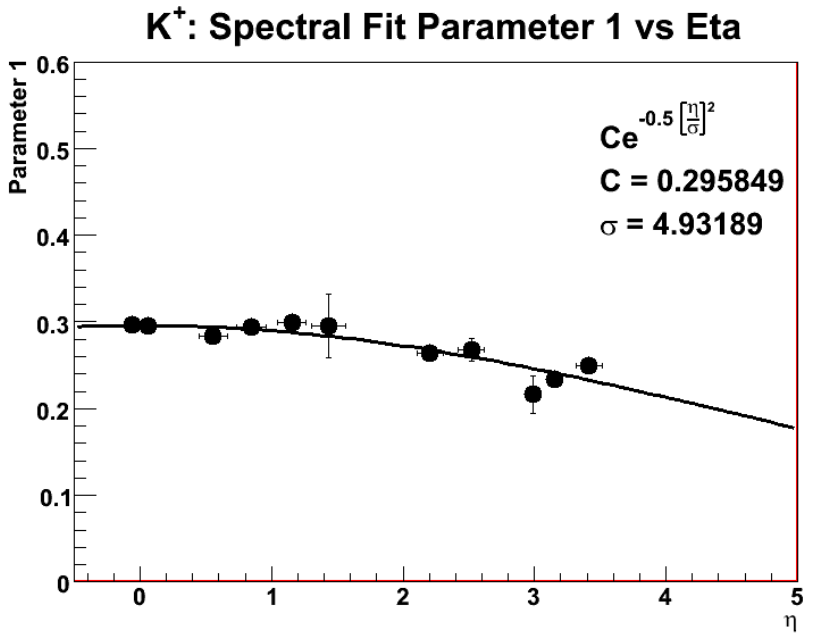

Figure 82:

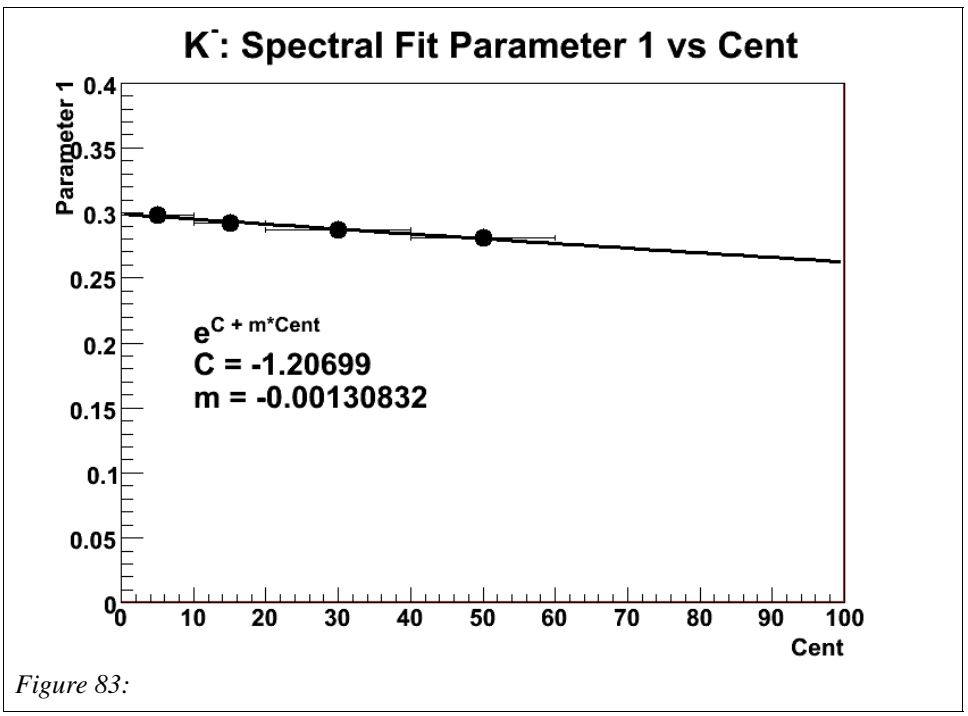

Figure 83:

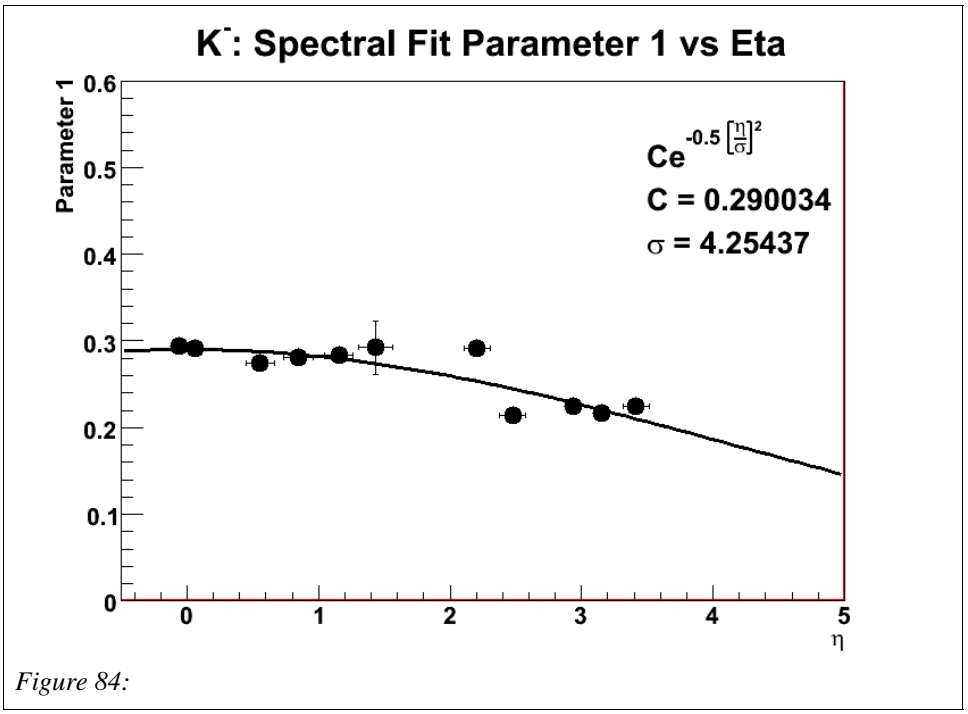

Figure 84:

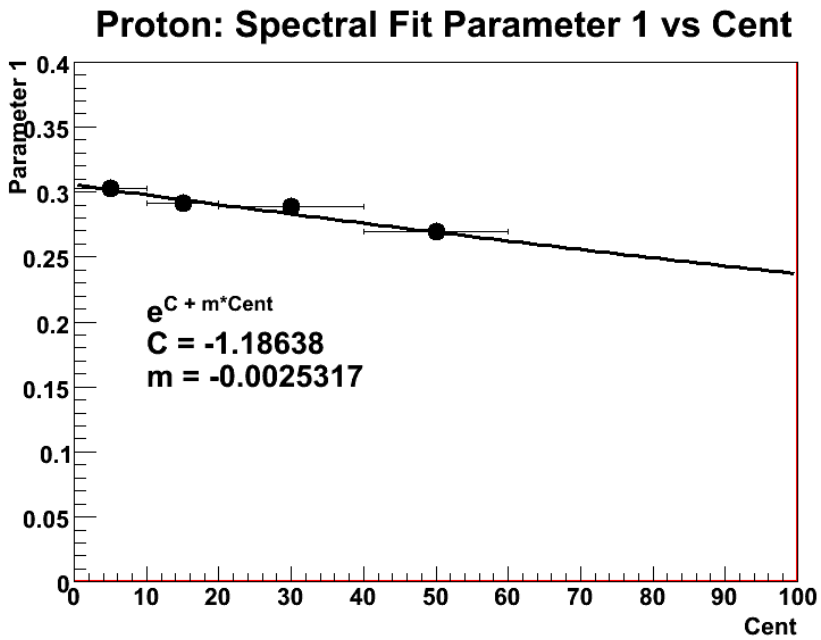

Figure 85:

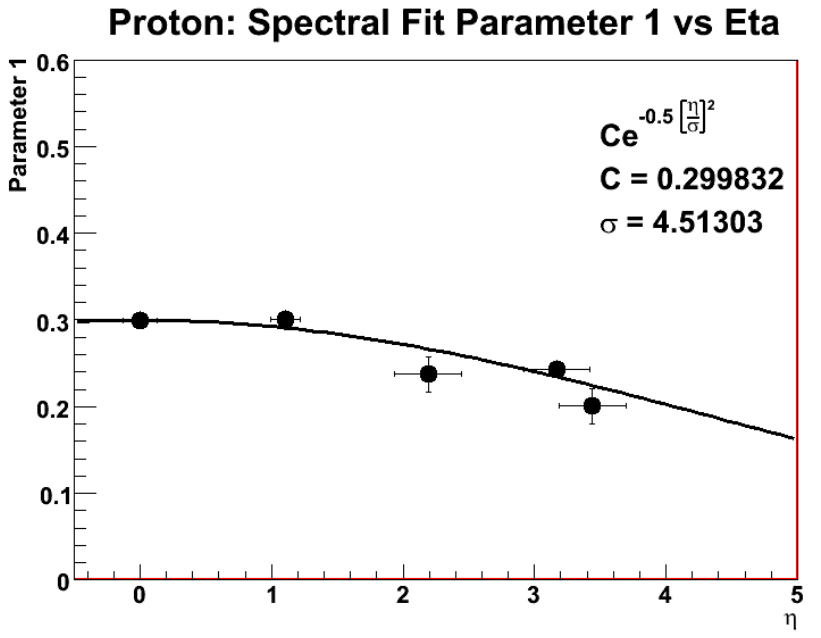

Figure 86:

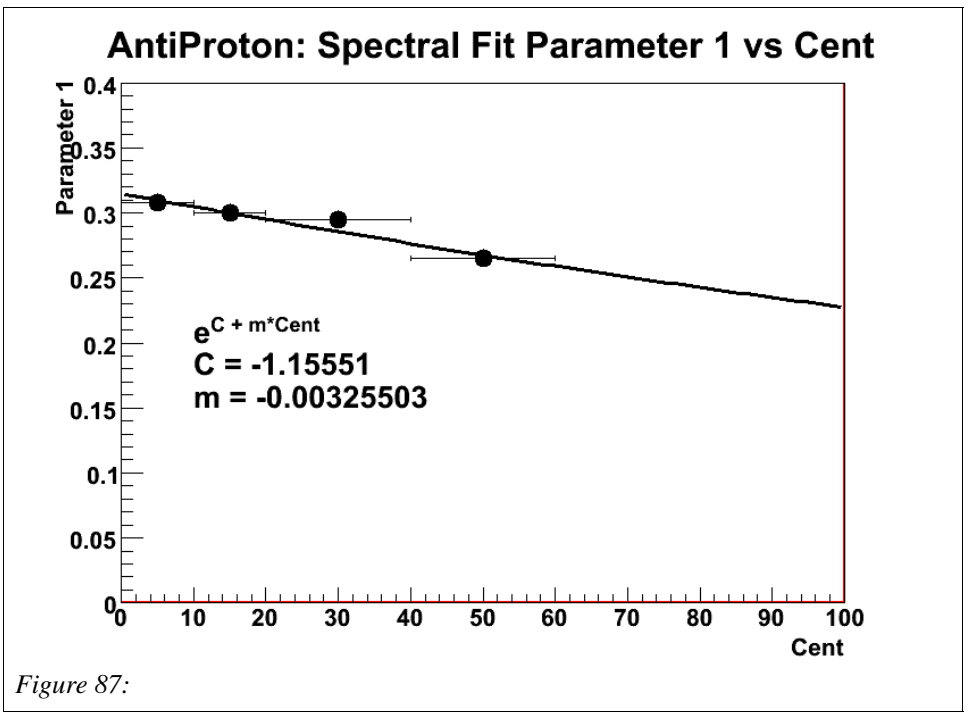

Figure 87:

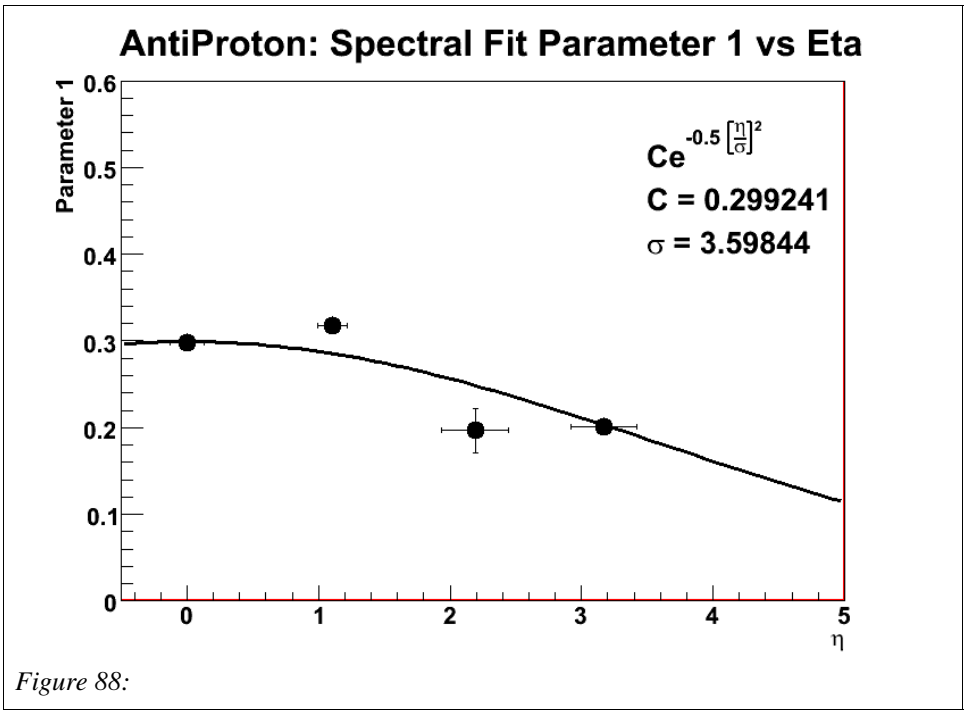

Figure 88:

Step 4.3: Apply Flow

The Phobos elliptic flow is characterized in both centrality and eta. The elliptic flow was charaterized in a previous analysis. The eta dependence is characterized using a gaussian with the mean at zero, the amplitude of the gaussian is centrality dependent and parameterized using a polynomial. Each particle is given a random position in ϕ from $-\pi$ to π. The value of ϕ is shifted with respect to the reaction plane, Ψ_R, which is another random number from $-\pi$ to π. The new value of ϕ' is

$$\phi' = \phi - \sum_n \frac{n}{2} v_n \sin[n(\phi - \Psi_R)] \quad (20)$$

Since the Phobos v2 is parameterized as a function of Npart, Npart needs to be converted into centrality. The function for this is illustrated in figure 89. The function to get the amplitude of the elliptic flow is

$$v_2 Amp = 0.05811 + 1.873\text{e-}4\, N_{part} - 1.492\text{e-}6\, N_{part}^2 + 1.85\text{e-}9\, N_{part}^3 \quad (21)$$

The magnitude of the elliptic flow as a function of η is

$$v_2(\eta) = v_2 Amp \cdot e^{-\frac{1}{2}\left(\frac{\eta}{3.36}\right)^2} \quad (22)$$

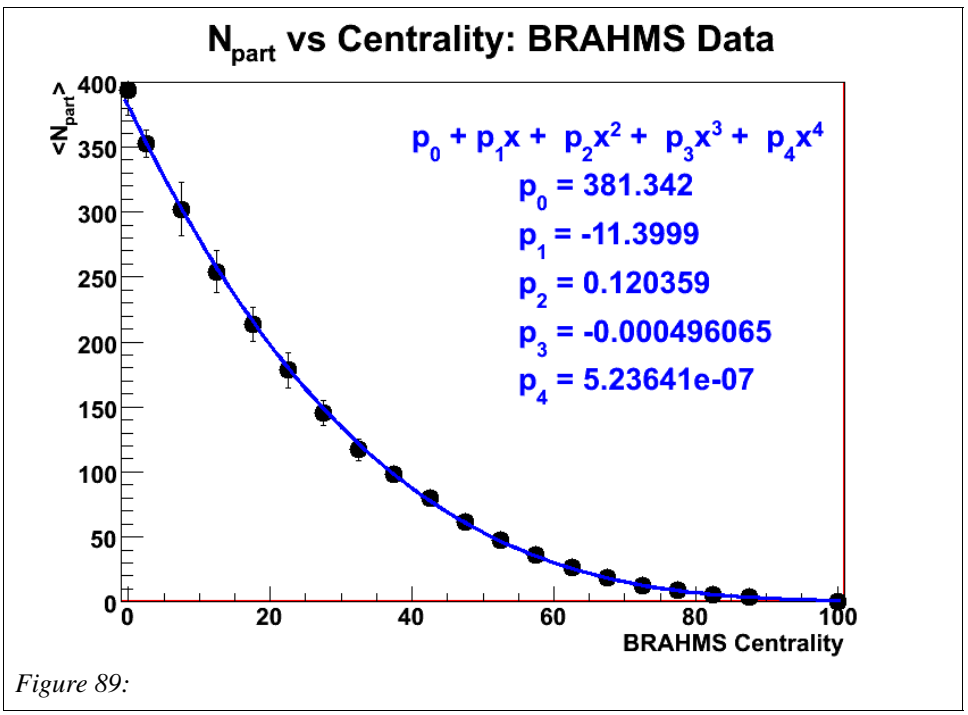

Figure 89:

The p_T-integrated v_1 signal was also determined from the Phobos experiment. This signal is given for the 0-40% most central events as a function of η. The data is parameterized using a 3 degree polynomial with $v_1(\eta=0) = 0$. The fit is shown in figure 90. The function used to give the v_1 signal is a modified version of the fit function

shown in figure 90. If the fit function is above 1 at any point (i.e. for large η), the value saturates at 1.

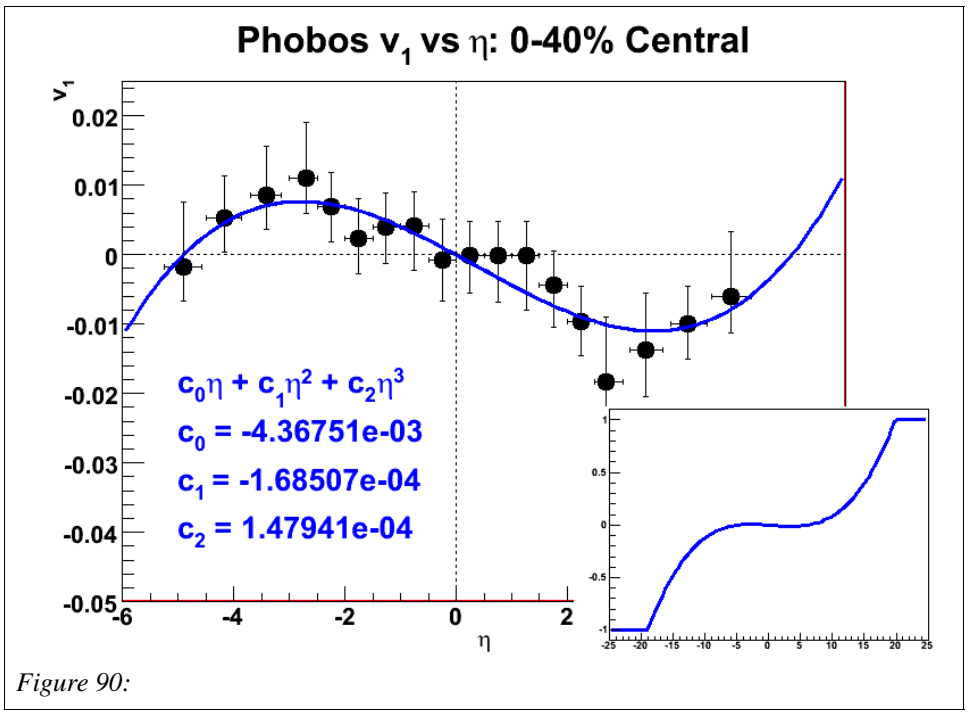

Figure 90:

The v_2 signal is also characterized as a function of p_T. Since this dependence is not known over rapidity, a linear dependence is used. The y-intercept is 0, and the slow is the p_T-integrated v_2 at the given η over the mean p_T.

Step 4.4: Calculate momentum components

ϕ is randomly distributed and shifted based on the flow input from equation 15. p_T is also known, and is η. This is enough to determine p_x, p_y, p_z, and E.

$$p_x = p_T \cos(\phi) \quad (26)$$
$$p_y = p_T \sin(\phi) \quad (27)$$
$$p_z = p_T \sinh(\eta) \quad (28)$$
$$|\vec{p}| = p_T \cosh(\eta) \quad (29)$$
$$E = \sqrt{m^2 + p_T^2 \cosh^2(\eta)} \quad (30)$$

Execution Usage

To compile:

1. Go to the ~/breg/bflows/ directory
2. type “cons .”

To run:

1. Go to the ~/breg/bflows/ directory
2. at prompt> bflows [random seed] [number of events] -o [output filename]

BrahmsEvent.cxx is the class that does the simulation, so all changes should be made there.