PH 219 Data Analysis and Interpretation

Net charge Fluctuation with Multiplicity

In p-p collision at 13eV

Project Group 7

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Abstract

Proton-proton collisions experiments performed using particle accelerators,like the Large Hadron Collider(LHC), are used to study the characteristics of high energy collisions.These experiments serve to test the principles of the Standard Model of Particle Physics. Charge conservation is one such fundamental principle of collision events.

In this report, we present the analysis of net charge fluctuations in proton-proton collisions as a function of multiplicity. The data has been generated using Pythia 8 Monte Carlo simulator replicating the collision events.

Contents

1 Introduction

A proton-proton collision (abbreviated p-p collision), involves two high energy proton beams undergoing a head-on-collision. Having high energy (thus a smaller DeBroglie wavelength), the protons are practically transparent to each other. Hence, the interaction is basically between the quarks (the building block of protons) rather than two protons as a whole.
Unlike macroscopic collision, particle collisions are governed by not-so-intuitive laws of Quantum Chromodynamics, hence depending on the type of interaction at the partonic level, many resultant particles can be formed in the collision event.

The particles formed in the p-p collisions abide by the conservation laws. Here, we consider that the conservation of electric charge is not violated and hence the net charge of all the particles participating and generated in the reaction is zero.
However, we expect statistical discrepancy to cause the net charge to deviate from the expected value. We hypothesize that this deviation must depend on the number of particles involved in a collision event.

This dependence of net charge can be quantified using various statistic measures such as mean, variance, kurtosis and skewness. In this report, we study the characteristics using mean, variance, standard deviation, scaled variance, skewness and kurtosis.

This report is intended to present the analysis of the fluctuation of net charge of an event with the multiplicity of the event, from the provided data which has been generated using Pythia 8 Monte Carlo event generator.
We use a total of 4 million events.
The collision system is a p-p collision, in the centre of mass frame at an energy of 13TeV.

1.1 Conventions Used

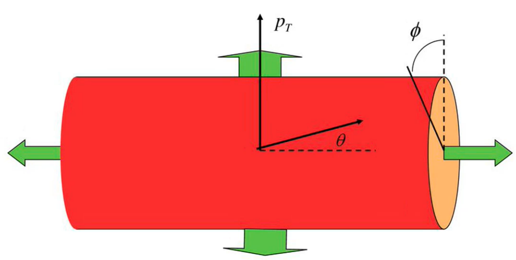


Figure 1

Throughout this report we use the following conventions:

- Multiplicity: Total number of particles involved in an event
- Net Charge: Sum of charges of all particles involved in an event

Variable	Description
η	Pseudorapidity - It is a spatial coordinate that describes the angle of a particle relative to the beam axis and is given by $\ln(\cot\frac{\theta}{2})$.
p_T	Momentum of particle along transverse direction.
ϕ	Azimuthal Angle - Angle from the vertical axis in the chosen co-ordinate system.
θ	Polar angle - The angle between the particle and collision/beam axis.
σ^2	Variance.
μ	Mean

Ideally, to avoid biases, the particles chosen to study the net charge are different from the ones used for multiplicity .This is usually achieved by imposing conditions on $|\eta|$ and p_T [1]. With the limited amount of simulation data, we consider particles with $|\eta| < 1$ and $p_T >$ 0.05eV/c for the analysis of net charge fluctuation. Also, multiplicity binning is done by considering all particles.

We first study the multiplicity distribution, for each of the given bins of total multiplicities, once w.r.t the particles being analysed and once w.r.t those not being considered for analysis. This gives an idea of how the proportion of particles being analysed changes with the given total multiplicity bins.
We then present the net charge distribution for each bin, along with a global net charge distribution.

In the later sections, we plot the mean net charge of events belonging to a particular bin vs the mean multiplicity of that bin. We also plot the variance, standard deviation, scaled variance, skewness and kurtosis for the net charge.

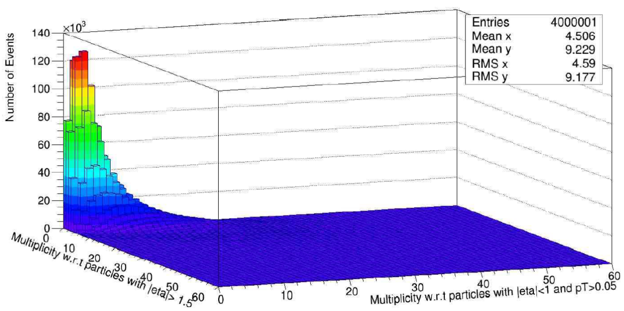
For technical help, such as codes related to plotting, accessing the data file, references from root's open source website and codes provided the guide were used [3] [4].

2 Experimental Observations

2.1 Multiplicity Distribution

The following histograms depict the distribution of multiplicity (number) of particles being used for analysis ($|\eta| < 1$ and $p_T > 0.05$eV/c) and those lying well beyond the acceptance region ($|\eta| > 1.5$), inside each of the given total multiplicity bins. We have plot a distribution histogram for each of the 6 bins, corresponding to events with total multiplicities 0-20, 20-40, 40-60, 60-80, 80-100 and those beyond 100, along with a histogram considering all events.
Since number of particles in an event is expected to follow a Poisson Distribution, we plot the best fit Poisson Distribution curve for each of the histograms. This is done by defining a function with two parameters in the Root Macro (a scale factor and mean of the distribution), and then varying them to find the best fit using χ^2 test.
We also plot 2-D histograms depicting the multiplicity distribution of particles in the mentioned conditions, along with the contour plot.

2.1.1 Multiplicity Distribution for all events



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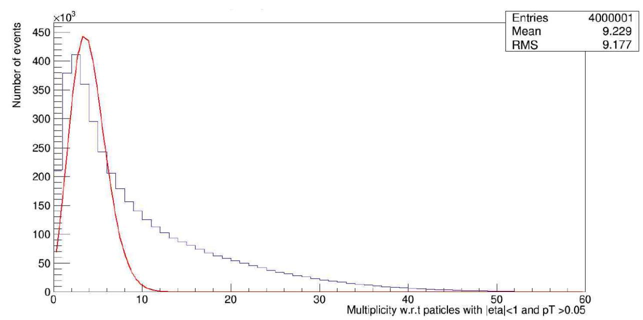

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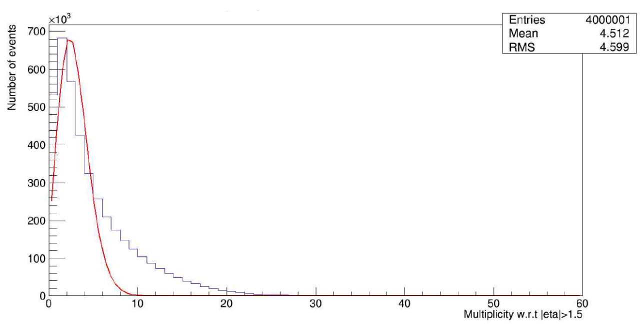

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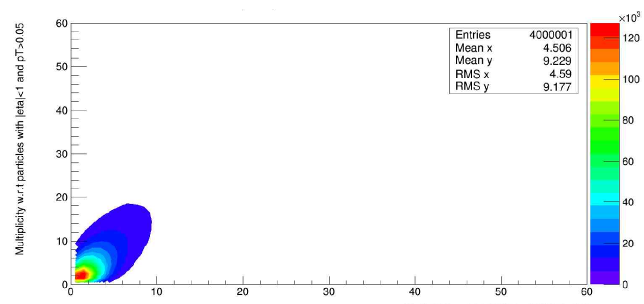

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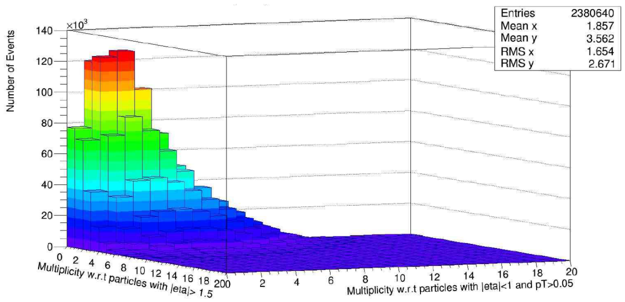
Figure 2: These plots show the multiplicity distribution for all events

2.1.2 Multiplicity Distribution for bin 0-20



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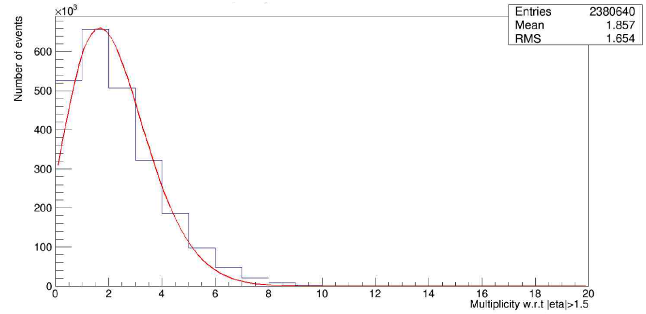

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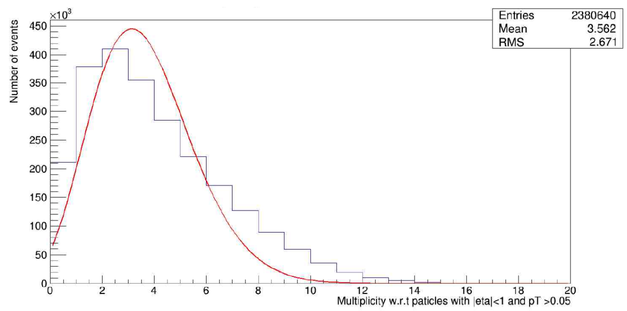

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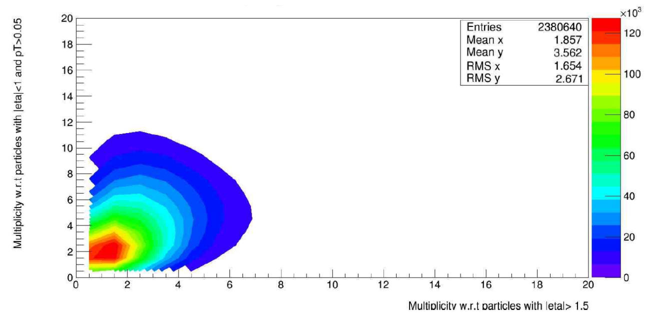

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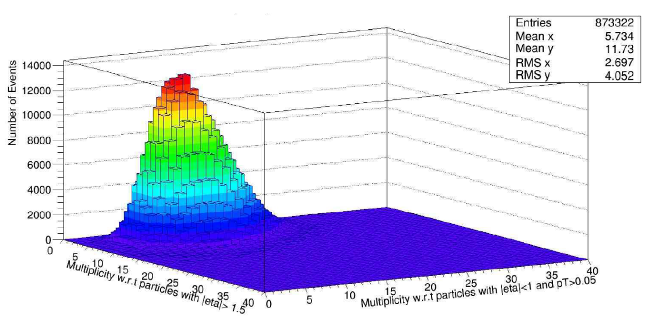
Figure 3: These plots show the multiplicity distribution for bin 0-20

2.1.3 Multiplicity Distribution for bin 20-40



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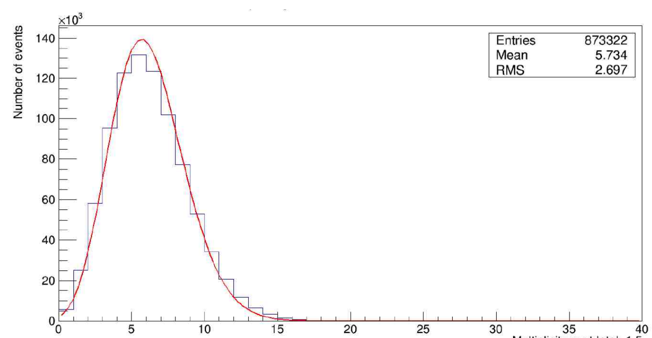

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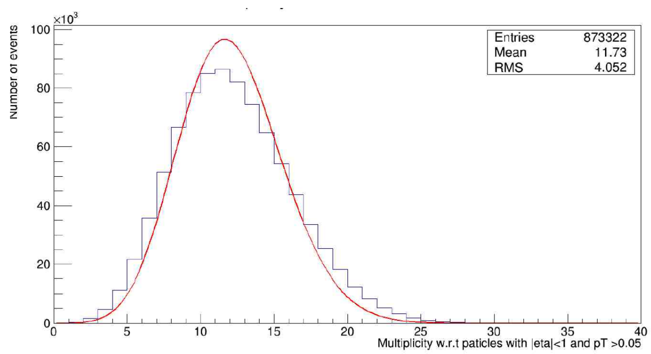

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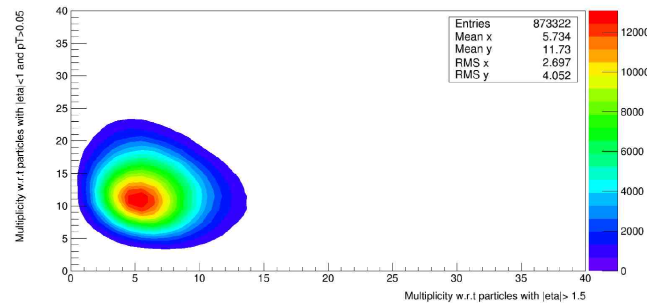

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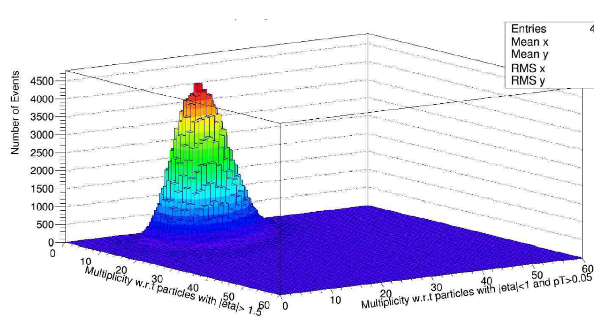
Figure 4: These plots show the multiplicity distribution for bin 20-40

2.1.4 Multiplicity Distribution for bin 40-60



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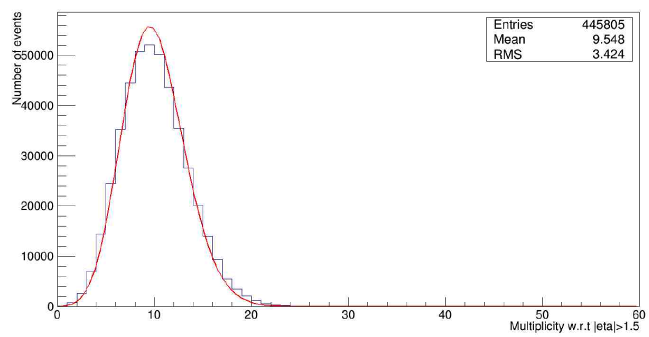

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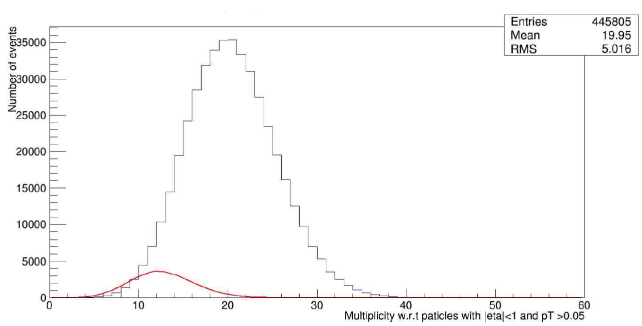

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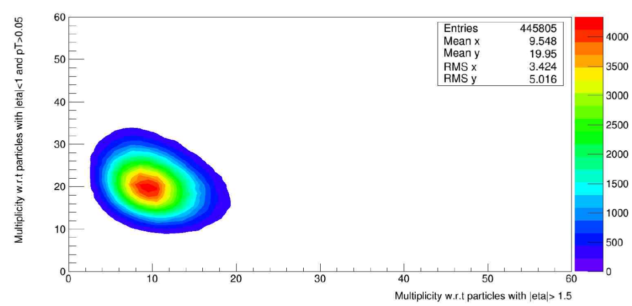
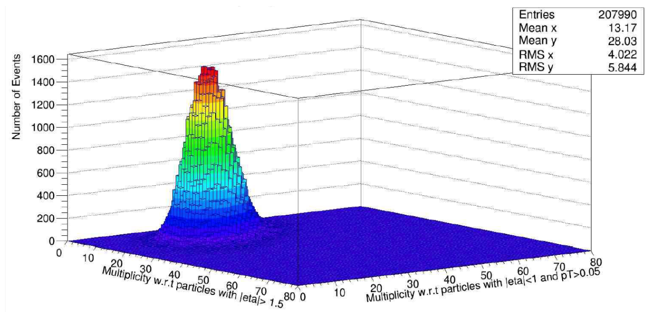


(d)

Figure 5: These plots show the multiplicity distribution for bin 40-60

2.1.5 Multiplicity Distribution for bin 60-80



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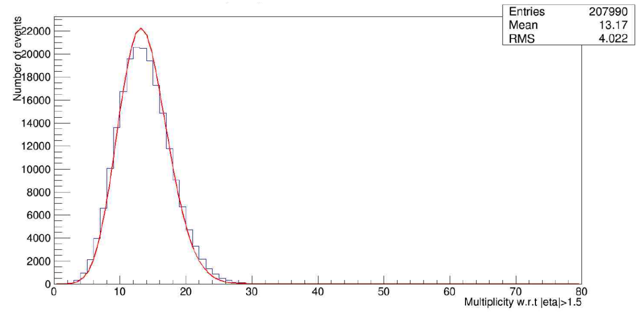

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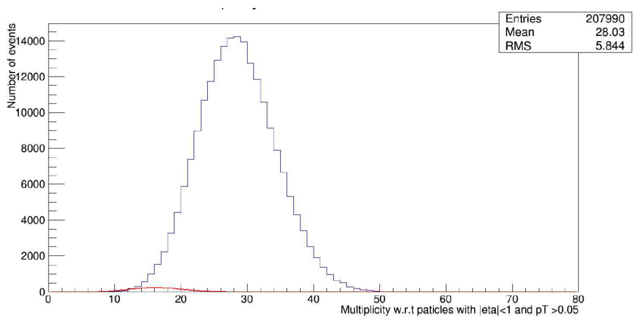

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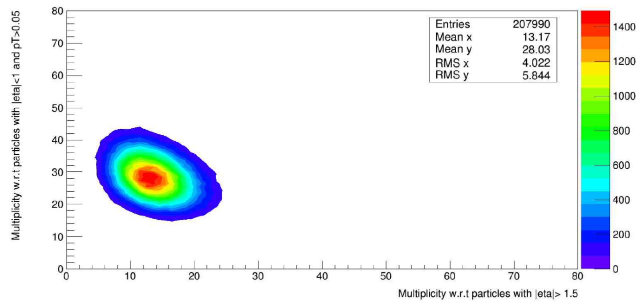

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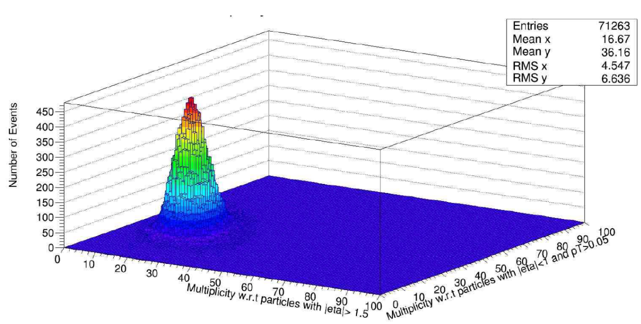
Figure 6: These plots show the multiplicity distribution for bin 60-80

2.1.6 Multiplicity Distribution for bin 80-100



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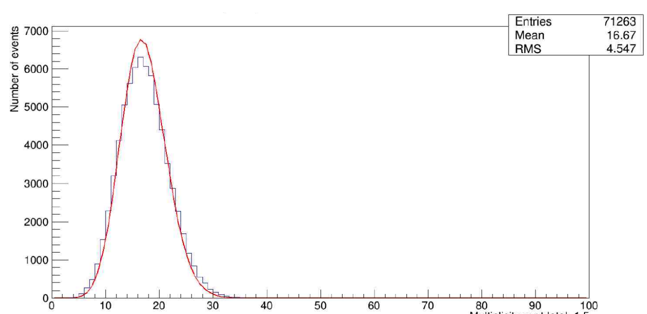

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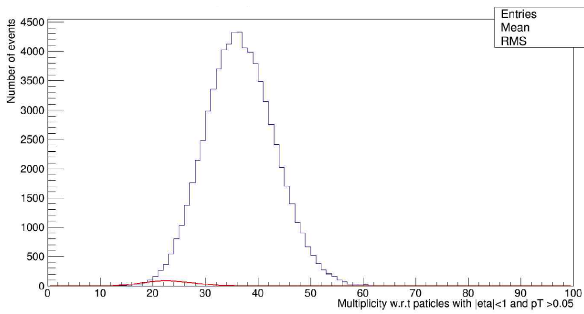

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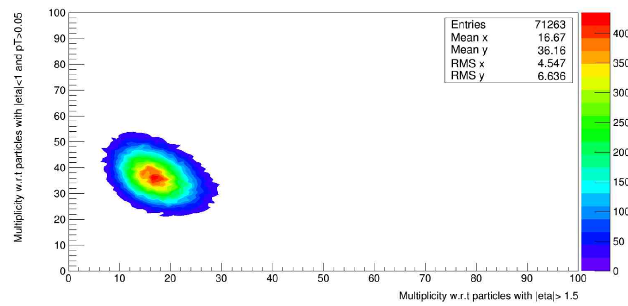
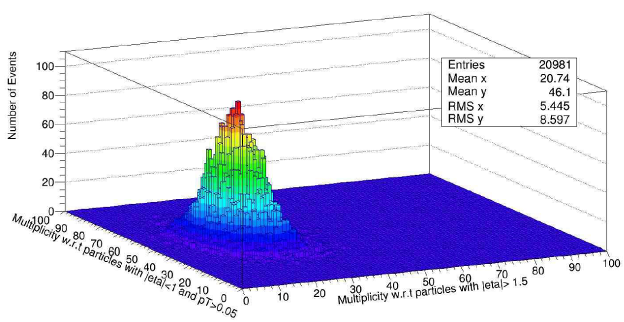


(d)

Figure 7: These plots show the multiplicity distribution for bin 80-100

2.1.7 Multiplicity Distribution for bin beyond 100



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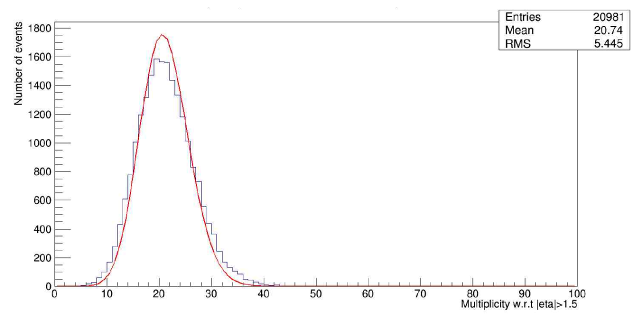

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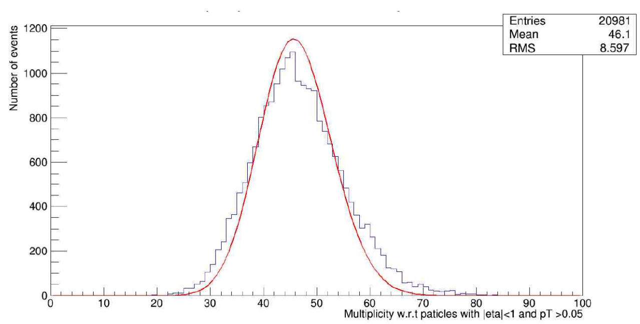

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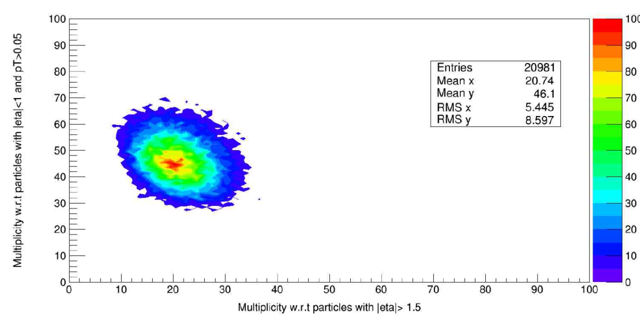


(d)

Figure 8: These plots show the multiplicity distribution for bin beyond 100

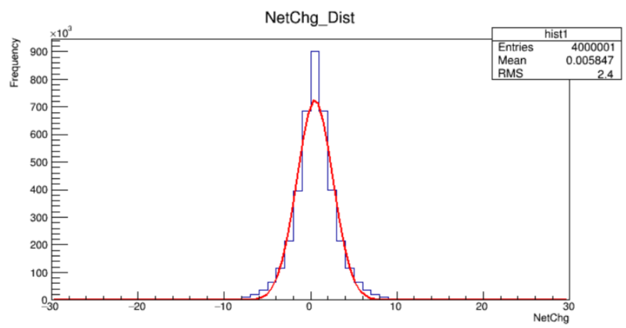
2.2 Net Charge Distribution

Each of the plots below is a frequency distribution of the net charge of events for a specified total multiplicity bin. Frequency refers to the number of times a particular net charge is observed (net charge of particles in an event, having $|\eta| < 1$ and $p_T > 0.05$).

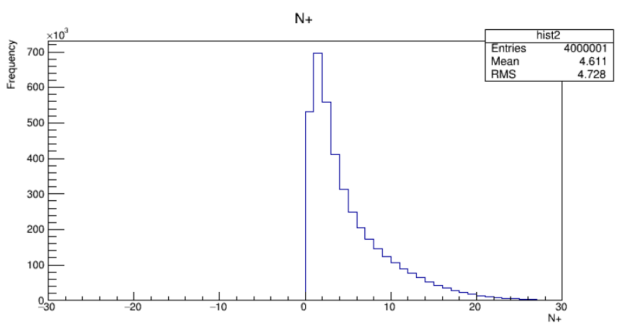
As stated earlier, the particles used for analysis are the ones satisfying $|\eta| < 1$ and $p_T > 0.05$. We observe that the net charge follows a normal distribution with mean 0. This agrees with our intuition that net charge is conserved in a collision event and any discrepancy (or noise) is expected to follow a normal distribution.

Figure 16(a) shows a 2-D histogram with net charge and multiplicity (w.r.t all particles) on the horizontal plane and the vertical axis denoting the frequency of occurrence of a particular bin.

2.2.1 Net Charge Distribution for all events



(a)



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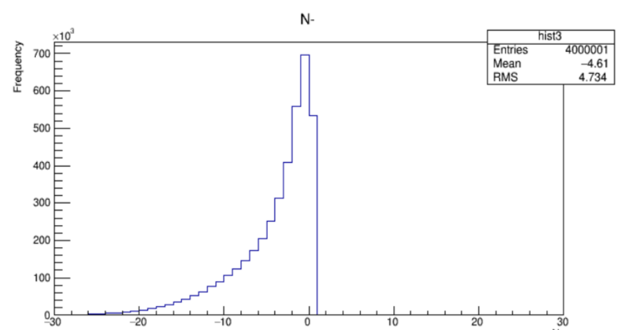
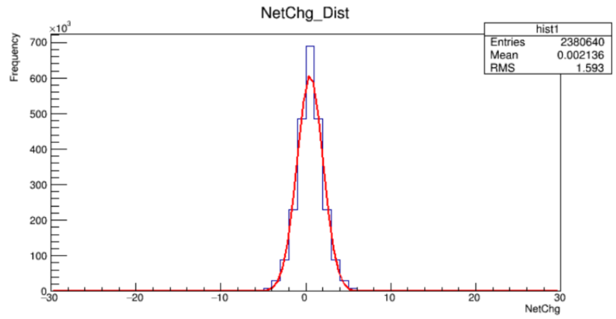


(c)

Figure 9: These plots show the net charge distribution for all events

2.2.2 Net Charge Distribution for bin 0-20



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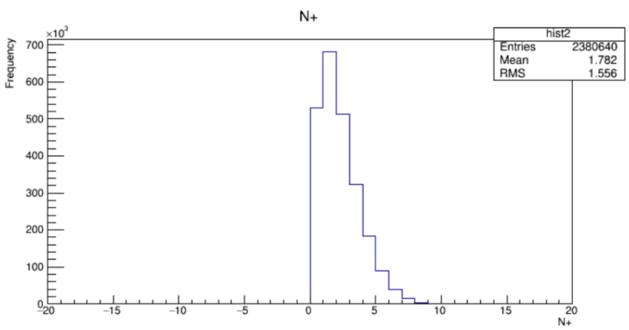

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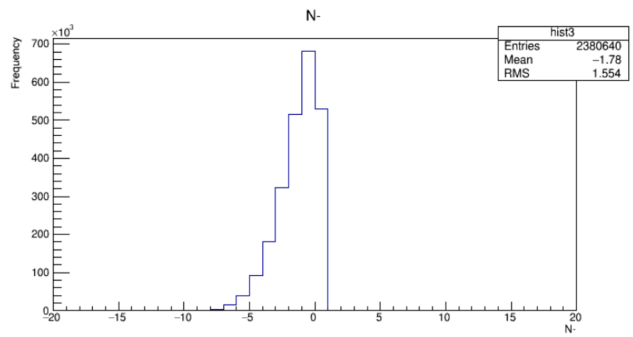
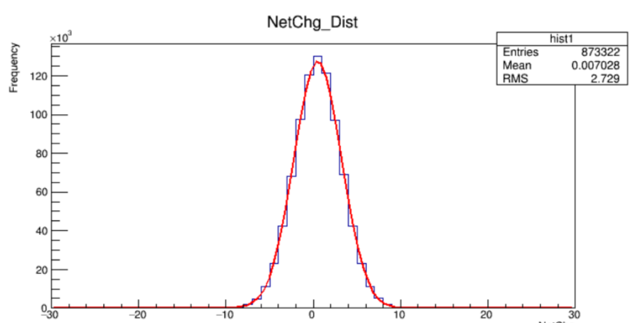


(c)

Figure 10: These plots show the net charge distribution for bin 0-20

2.2.3 Net Charge Distribution for bin 20-40



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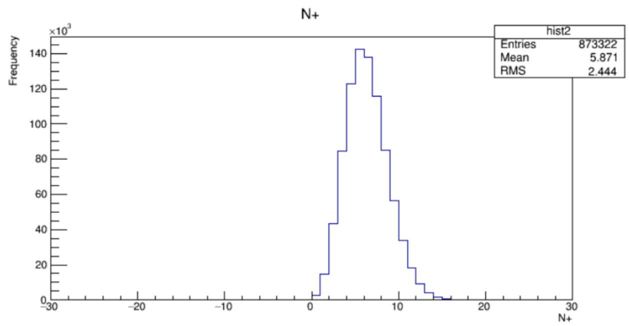

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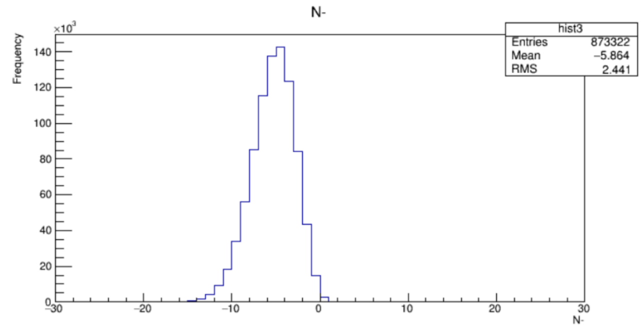

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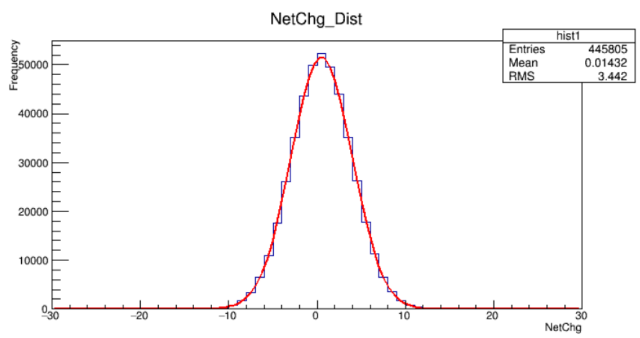
Figure 11: These plots show the net charge distribution for bin 20-40

2.2.4 Net Charge Distribution for bin 40-60



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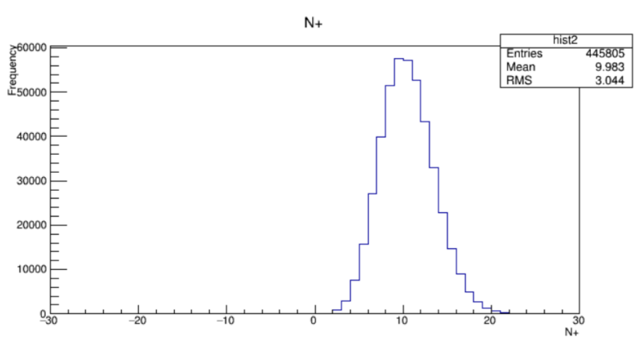

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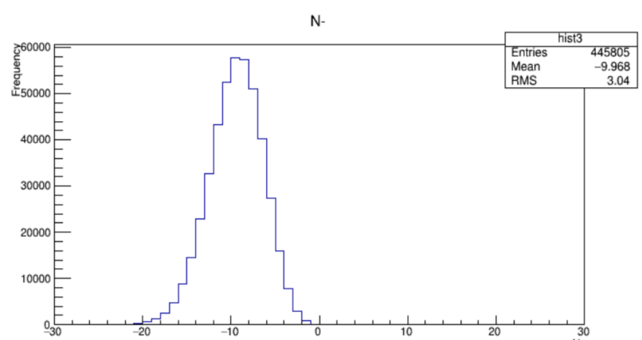
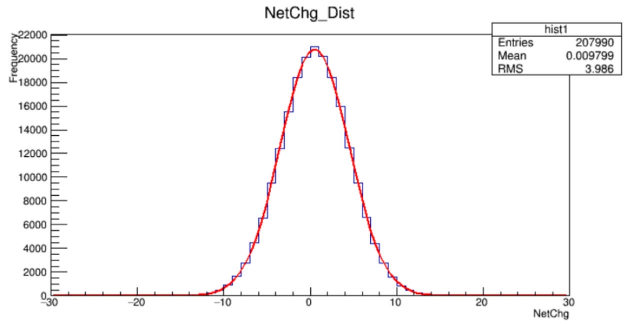


(c)

Figure 12: These plots show the net charge distribution for bin 40-60

2.2.5 Net Charge Distribution for bin 60-80



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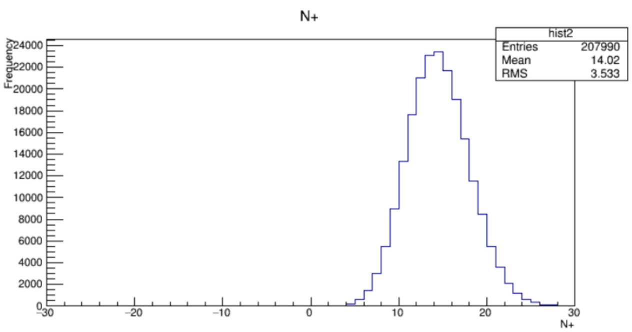

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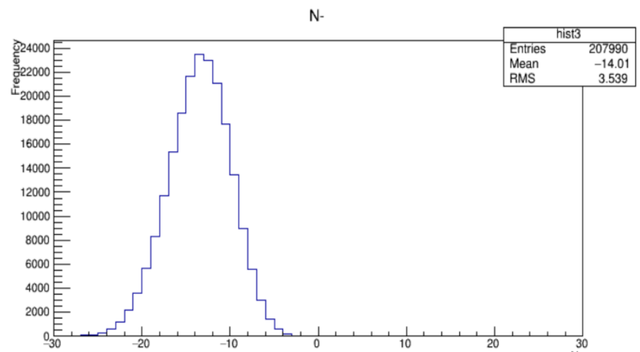
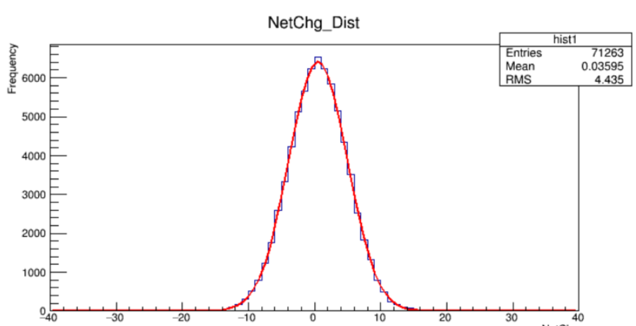


(c)

Figure 13: These plots show the net charge distribution for bin 60-80

2.2.6 Net Charge Distribution for bin 80-100



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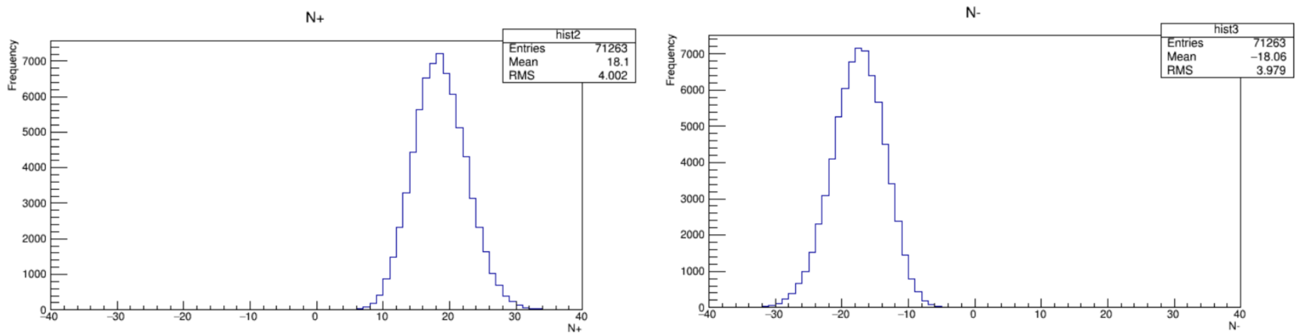
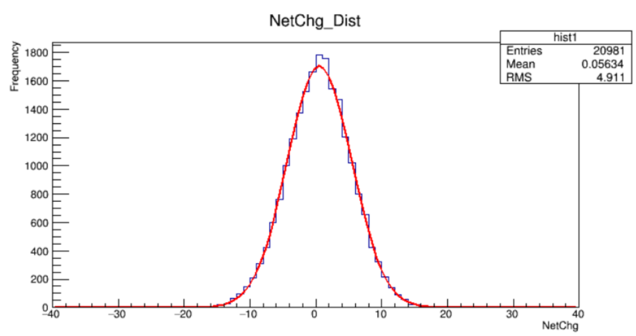


(b) (c)

Figure 14: These plots show the net charge distribution for bin 80-100

2.2.7 Net Charge Distribution for bin beyond 100



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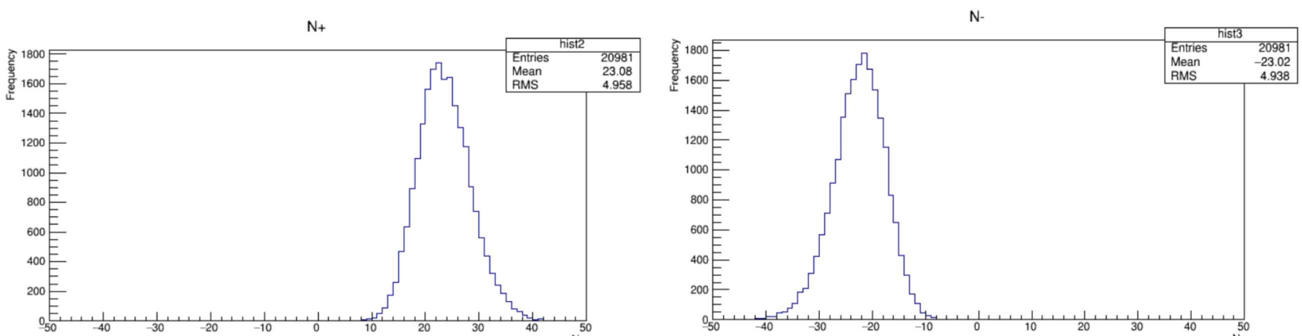


(b) (c)

Figure 15: These plots show the net charge distribution for bin greater than 100

2.2.8 Net Charge vs Multiplicity

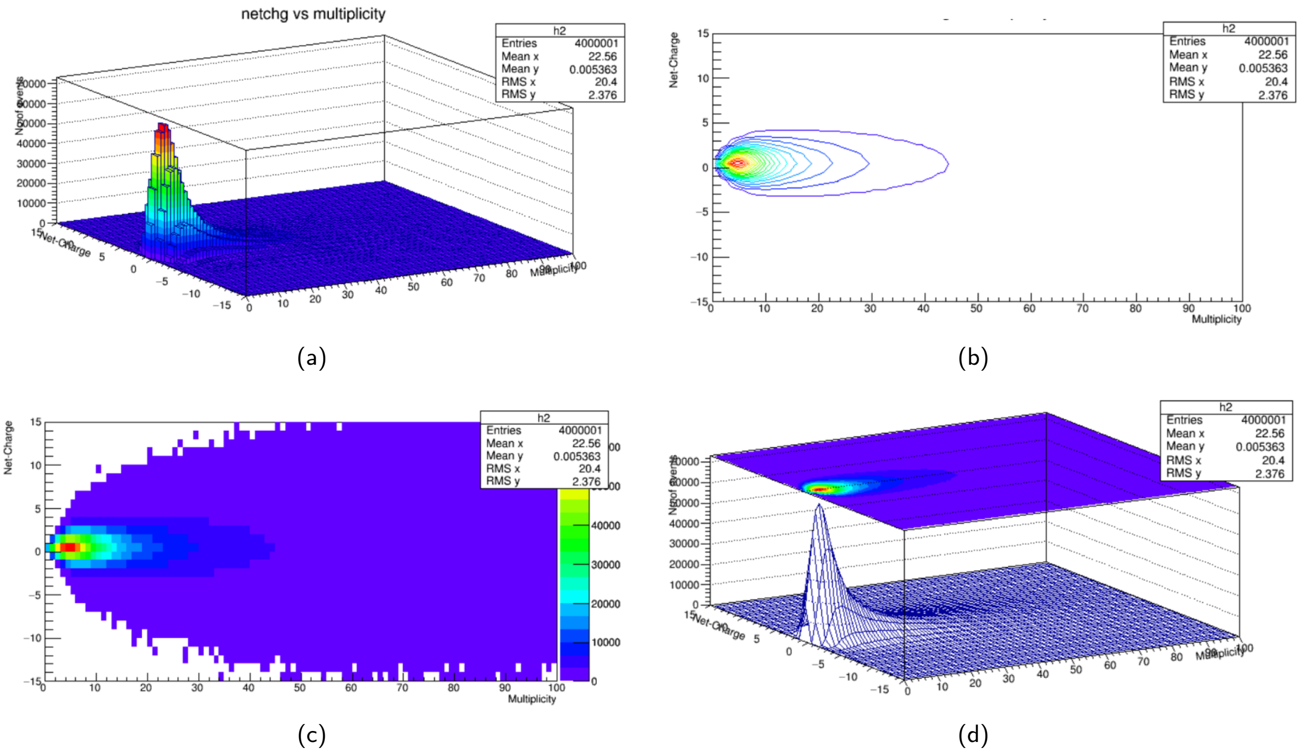


Figure 16: These figures show the 2-D plots of net charge vs multiplicity

2.3 Net Charge Mean vs Mean Multiplicity

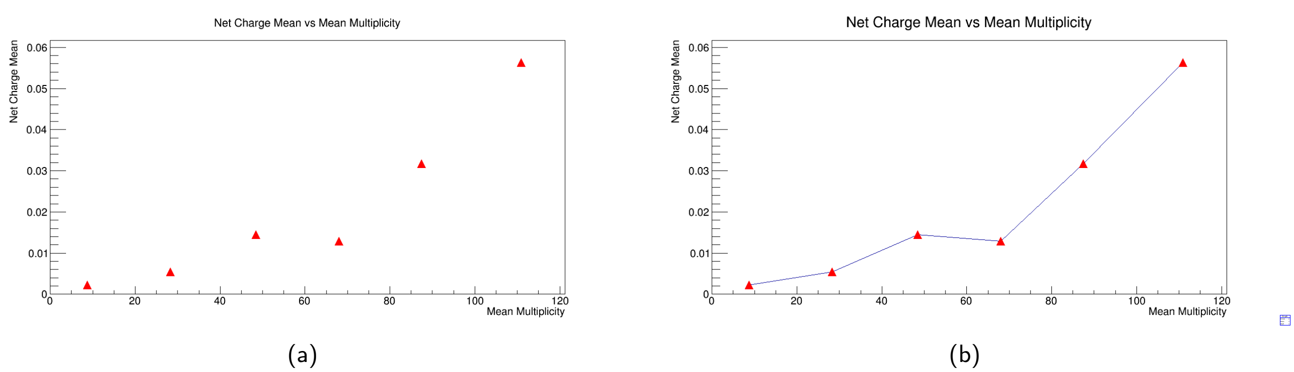


Figure 17

Given above is the plot of mean net charge vs mean multiplicity for each bin. We observe that mean net charge is nearly zero with fluctuations which increase in magnitude as mean multiplicity increases.

2.4 Net Charge Variance vs Mean Multiplicity

The multiplicity range (0-200) is divided into 7 bins - (0-20), (20-40), (40-60), (60-80), (80-100), (100-120), (120-200)

Sample variance of net charge of all the events in a bin are computed and are plotted against the mean multiplicity of the bin. The formula used is:

$$S^2 = \frac{\sum_{i=1}^{n} x_i^2}{n-1} - \frac{\bar{x}\sum_{i=1}^{n} x_i}{n-1}$$

Where $x_i, n, \bar{x}$ represent net charge of i^{th} event, total number of events in the respective multiplicity bin and the mean net charge of that bin respectively.

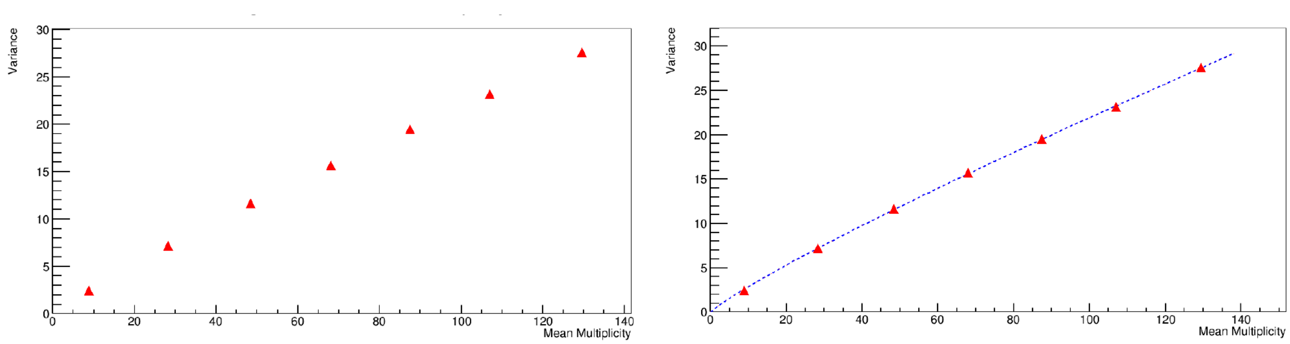
Curve with least mean squared error among the family of curves $y = m(x-s)^n$ is found using algorithm [2].

$$y = 0.378532(x)^{0.881641}$$

Mean squared error of this curve is $0.006unit^2$. This curve can be further approximated to

$$y = \left(\frac{x}{3}\right)^{0.882}$$

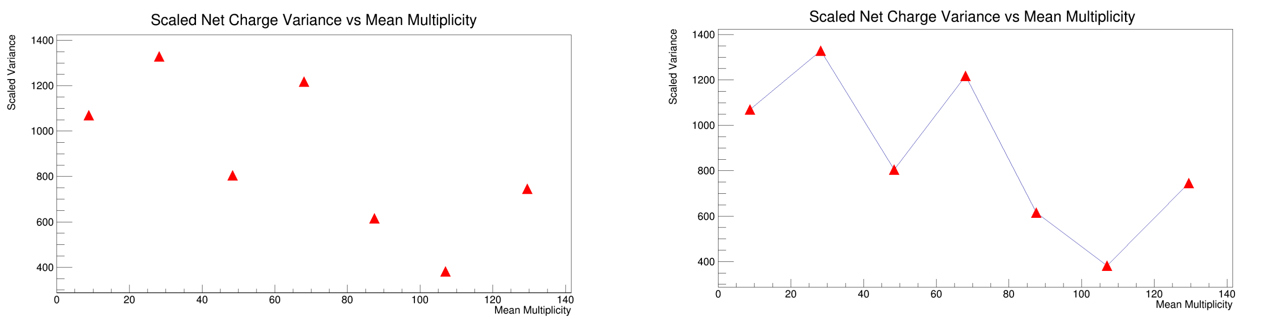
with a mean squared error $0.038unit^2$ where x, y represent mean multiplicity and variance. We observe a rising trend in the variance of the net charge as the multiplicity increases.



(a) (b)

Figure 18: Plot showing net charge variance vs mean multiplicity

2.5 Scaled Net Charge Variance Vs Mean Multiplicity

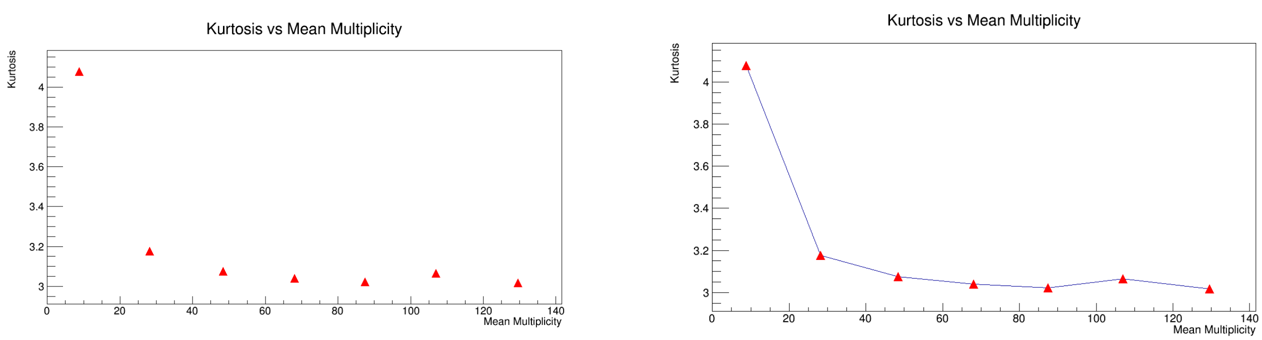


(a) (b)

Figure 19: Plot showing scaled net charge variance $\left(\frac{\sigma^2}{\mu}\right)$ vs mean multiplicity

The plot for the scaled variance is shown above. We do not observe any particular trend.

2.6 Kurtosis of Net Charge Distribution Vs Mean Multiplicity



(a) (b)

Figure 20: Plot showing kurtosis of net charge vs mean multiplicity

We observe a decreasing trend of the kurtosis which implies that sharpness of the peak in net charge distribution is decreasing as multiplicity increases. Net charge plots in all multiplicity bins are leptokurtic and are tending to be mesokurtic as the mean multiplicity increases.

2.7 Standard Deviation and Skewness of Net Charge

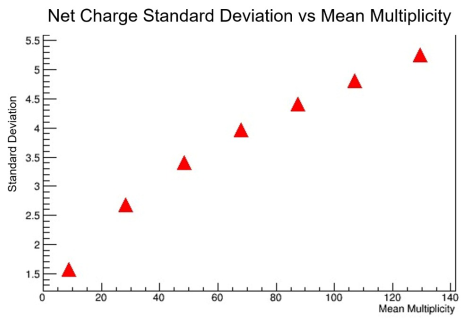


Figure 21

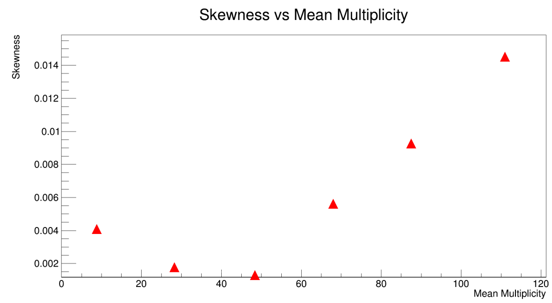


Figure 22

In the standard deviation for net charge, we observe a rising trend similar to that of net charge variance.

3 Summary

We have plotted the multiplicity distributions of particles in the desired ranges of p_T and η, for each of the 6 multiplicity bins, along with the Poisson Distribution that best fits them. We then plotted the net charge distribution and remarked that the net charge obeys a Gaussian distribution centred at 0. We then observed the trend in the variance of net charge with the mean multiplicity and also the curve that best fits it. We also plotted kurtosis and observed that kurtosis decreases as multiplicity increases. Finally, we have shown the plots for scaled variance, standard deviation and skewness for the net charge. Best Fit Curves have been plotted using the χ^2 approach. All the codes used for plotting the graphs have been documented in the following GitHub Repository for further reference: Link to Codes.

Bibliography

[1] L. Adamczyk et al. "Beam Energy Dependence of Moments of the Net-Charge Multiplicity Distributions in $\mathrm{Au}+\mathrm{Au}$ Collisions at RHIC". In: *Phys. Rev. Lett.* 113 (9 Aug. 2014), p. 092301. DOI: 10.1103/PhysRevLett.113.092301. URL: https://link.aps.org/doi/10.1103/PhysRevLett.113.092301.

[2] *Best Fit Curve*. URL: https://colab.research.google.com/drive/1H6g6YJC7OhteUnJBTd76w1KSU5IpVXCJ?usp=sharing.

[3] *ROOT Primer*. URL: https://root.cern.ch/root/htmldoc/guides/users-guide/FittingHistograms.html#result-of-the-fit.

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