Measurement of net-charge fluctuations in p-p collisions at $\sqrt{\mathrm{s}} = 13$ TeV generated using PYTHIA 8

Adhyyan Mansukhani, Gargi Gold, Harsith R, Khagesh Hradaya Prakash Vaidya,
Mehul Vijay Chanda, Nidhi Shaw, Shashwat Chakraborty, and Suraj Garia
Indian Institute of Technology Bombay, Mumbai, India

This report analyses the data from a collision system to study the multiplicity and charges observed in the various events. We start with a subset of events within the acceptance region and divide them into five multiplicity classes for which the analysis is performed. We aim to investigate net charge fluctuations in p-p collisions and explore the fluctuations' evolution in small systems. The goal is to observe the trends and infer whether they are similar to bigger nuclei collisions.

I. INTRODUCTION

The data provided has been generated using the PYTHIA 8 Monte Carlo Event Generator. The collision system is $p + p$ at centre-of-mass energy $\sqrt{s} = 13$ TeV. There are a total of 4 million events.

The charged-particle multiplicity is one of the simplest observable in the collisions of hadrons. It is defined for an event as the total number of charged particles being produced due to the collision. η is the pseudorapidity, defined for particle as $\eta = \ln[\cot(\theta/2)]$ where θ is the angle between the particle's momentum 3-momentum and the beam axis. p_T is the transverse component of 3-momentum. PID stands for *Particle Identification*. If PID > 0, the charge of the particle is positive and if PID < 0, the charge is negative. The difference between the total positive charge and the total negative charge is the net charge.

The data presented is a subset of all the events. All observable presented are constructed from primary charged particles in the pseudorapidity range $|\eta| < 1.0$ and $|\eta| > 1.5$. The set of particles with $|\eta| < 1.0$ whose transverse momentum $p_T > 0.05$ GeV/c are said to belong to the *acceptance region* whereas the ones with $|\eta| > 1.5$ are said to belong the *non-acceptance region*. We have also narrowed our range to five multiplicity classes: 0-20, 20-40, 40-60, 60-80 and 80-100. (Note that the multiplicity classes do not have the same number of events).

Multiplicity Class	No. of Events
0-20	2380640
20-40	873322
40-60	445805
60-80	207990
80-100	71263

TABLE I: No. of events in each multiplicity class analyzed.

In this paper, we explore the relationships between amount of positive, negative and total charge generated in an event, and the multiplicity of the event. The observed results are plotted in histograms. We also explore the correlation between the multiplicity of the particles in the acceptance and non-acceptance region and display it using scatter plots.

II. EXPERIMENTAL OBSERVATIONS

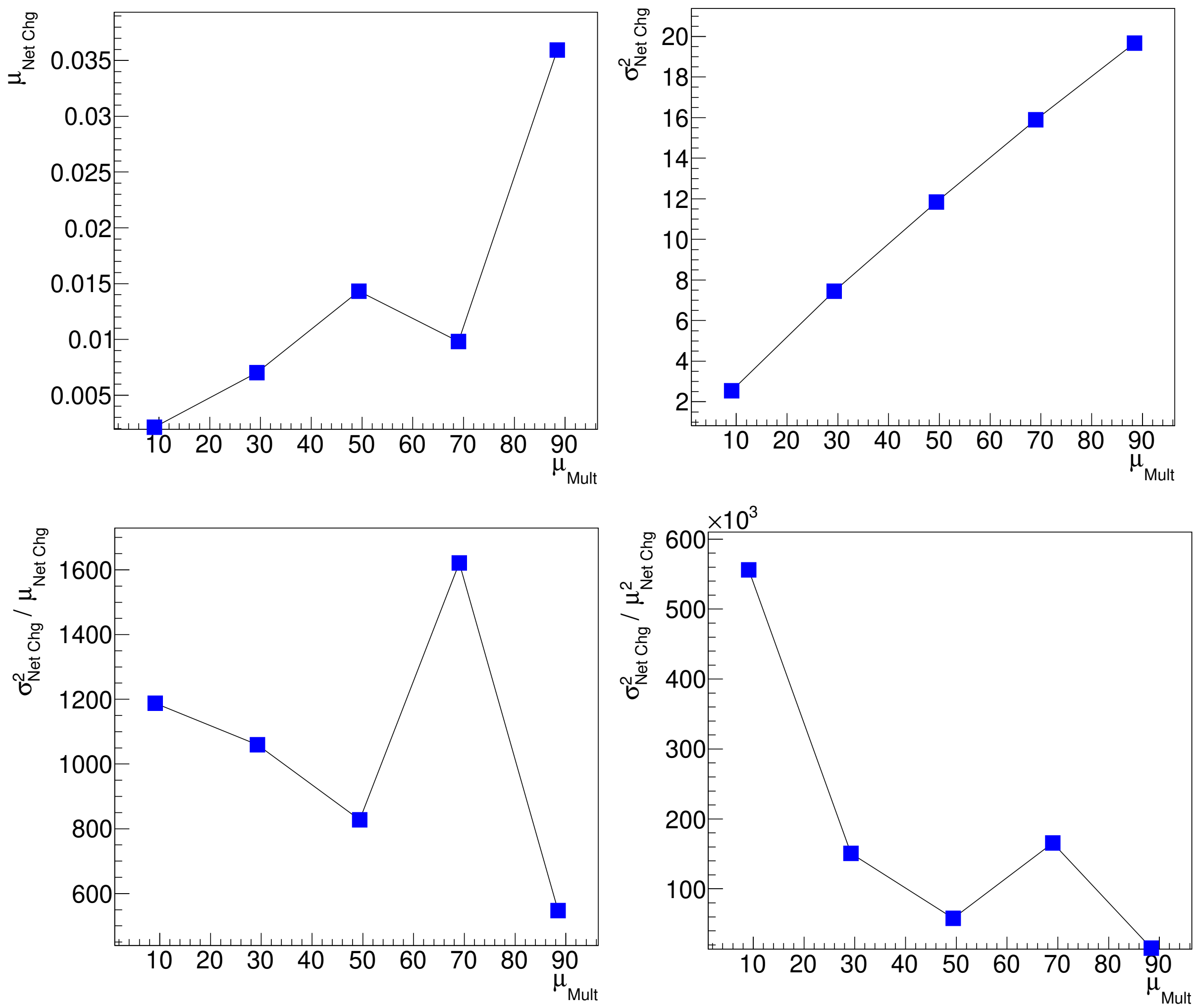
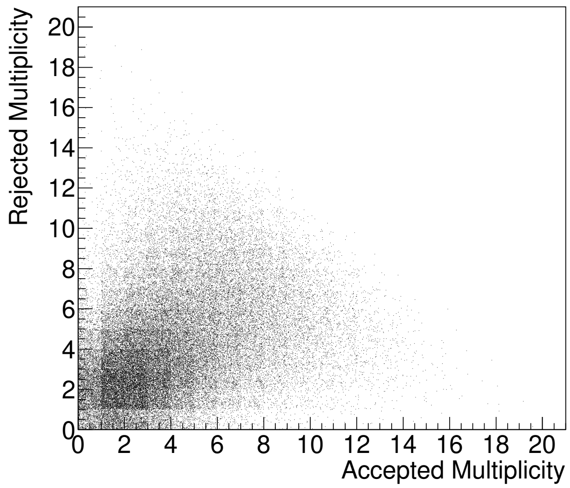
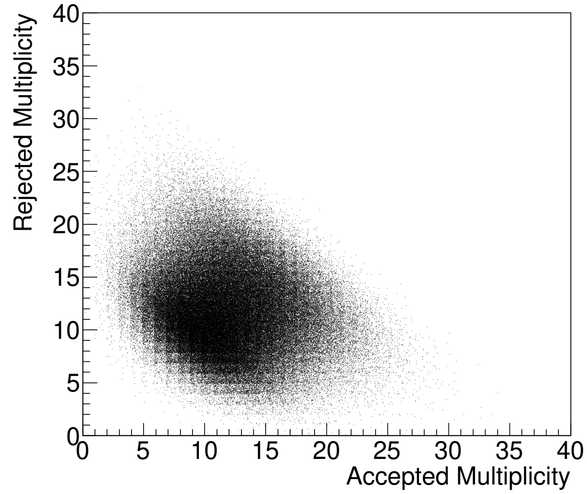


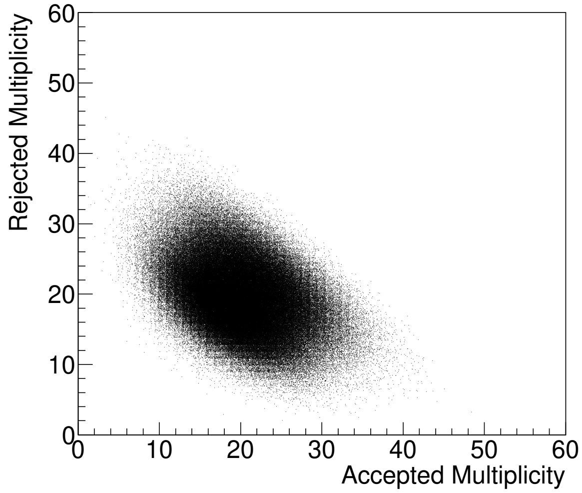
FIG. 1: Plots of the mean of net charge ($\mu_{\text{Net Chg}}$), variance of the net charge ($\sigma^2_{\text{Net Chg}}$), ratio of variance and mean ($\sigma^2_{\text{Net Chg}}/\mu_{\text{Net Chg}}$) and ratio of variance and square mean ($\sigma^2_{\text{Net Chg}}/\mu^2_{\text{Net Chg}}$) vs the mean multiplicity of each multiplicity class as obtained from the PYTHIA 8 simulation data.



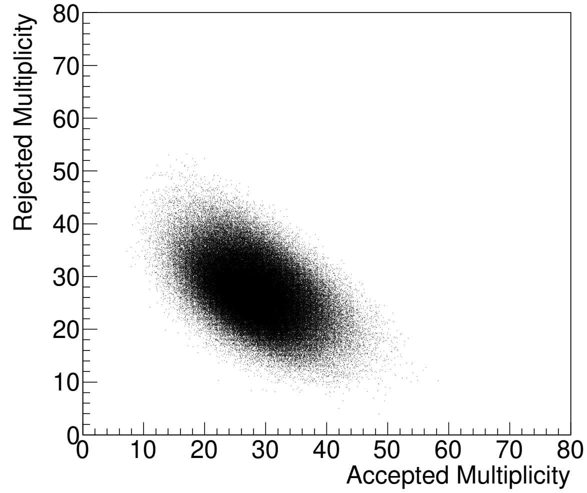
(a) 0 - 20



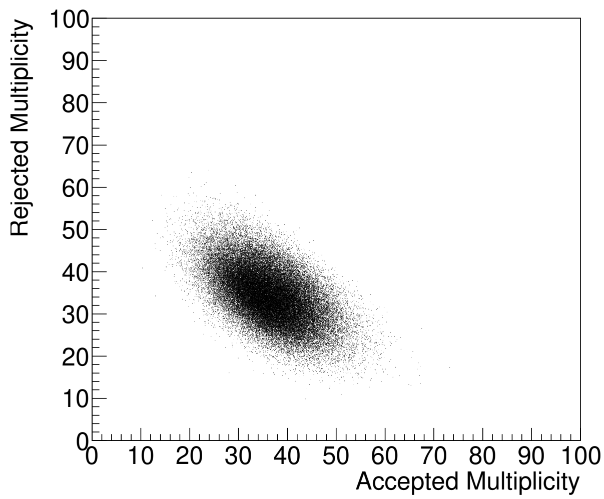
(b) 20 - 40



(c) 40 - 60

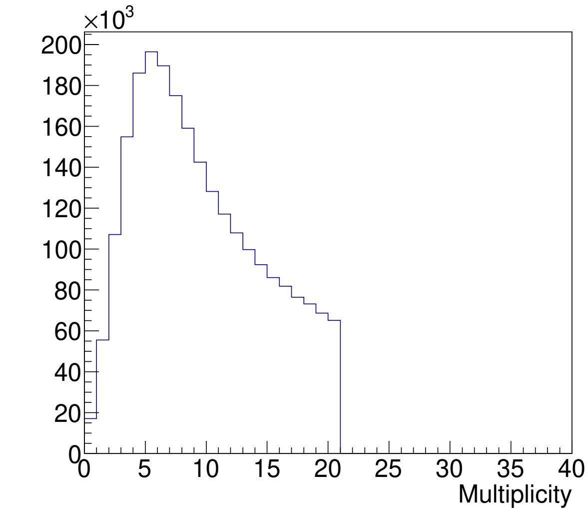


(d) 60 - 80

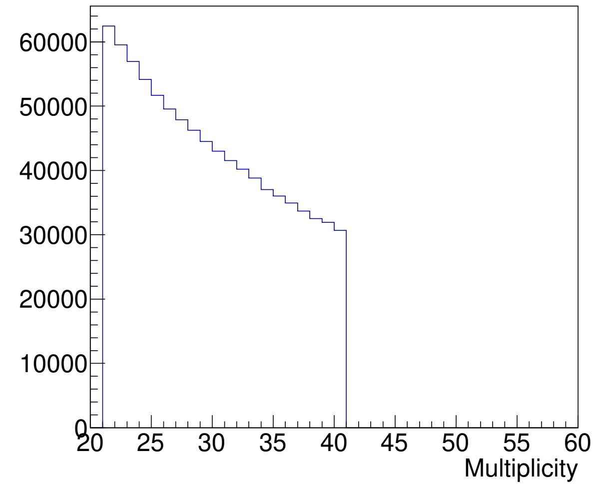


(e) 80 - 100

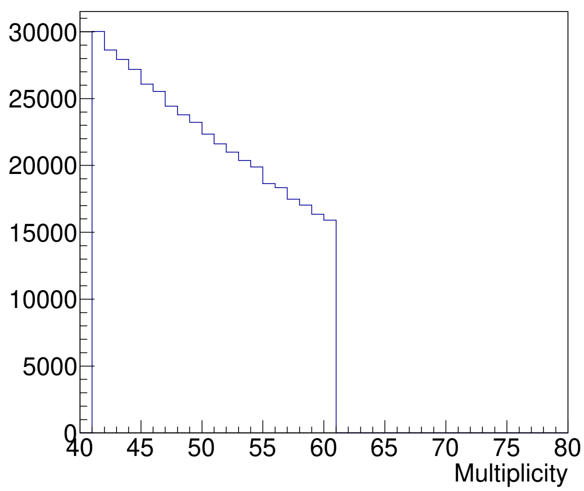
FIG. 2: Scatter plots of multiplicities in the acceptance region versus the non-acceptance region for the underwritten multiplicity classes as obtained from the PYTHIA 8 simulation data.



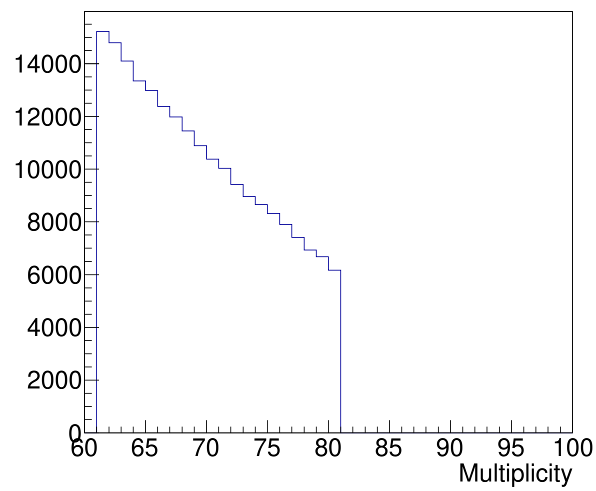
(a) 0 - 20



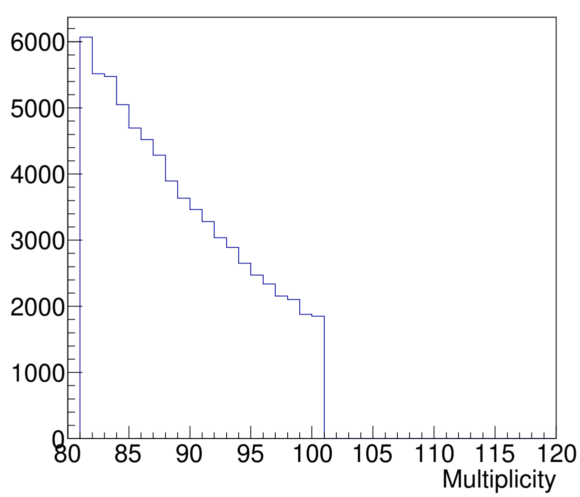
(b) 20 - 40



(c) 40 - 60

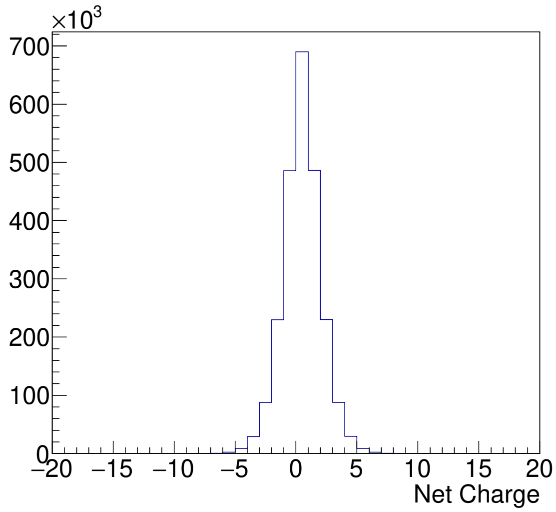


(d) 60 - 80

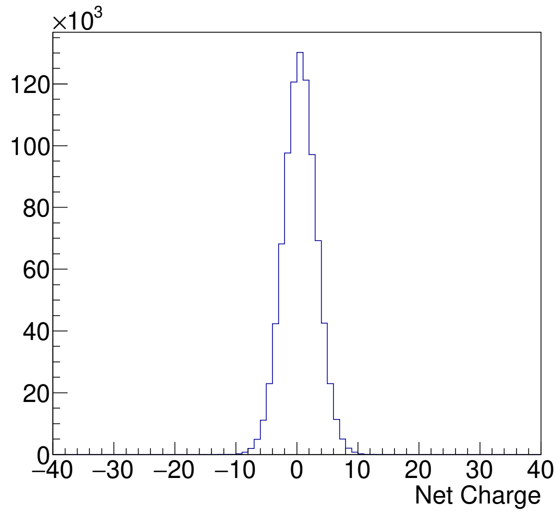


(e) 80 - 100

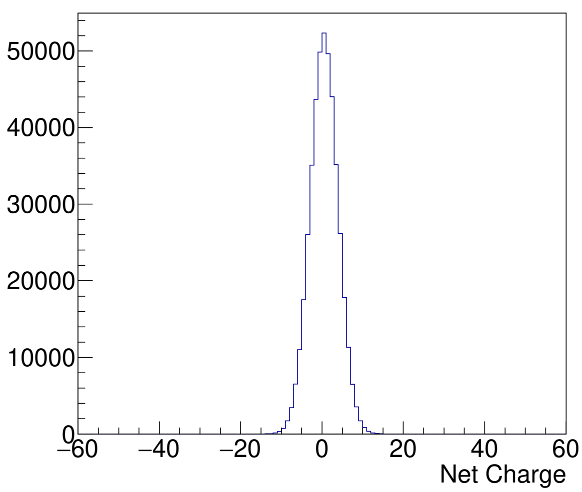
FIG. 3: Multiplicity histograms for the underwritten multiplicity classes as obtained from the PYTHIA 8 simulation data.



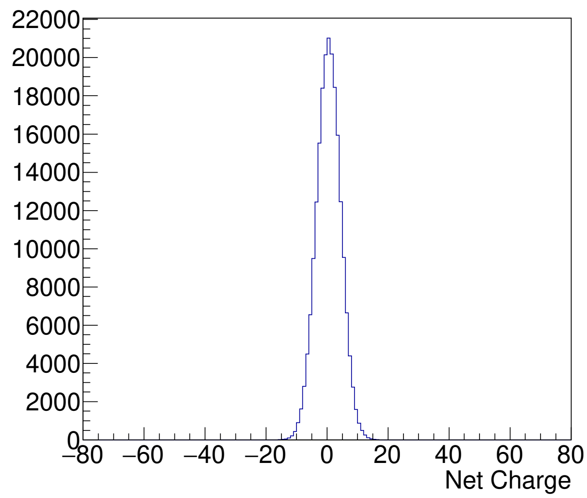
(a) 0 - 20



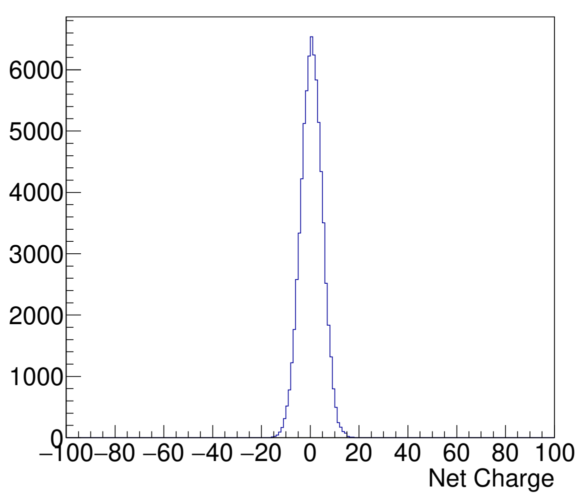
(b) 20 - 40



(c) 40 - 60

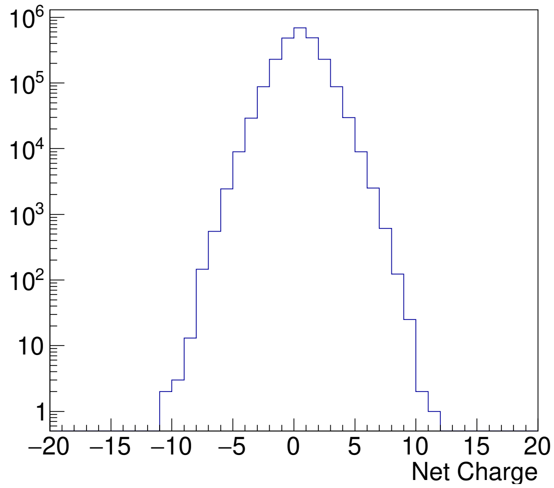


(d) 60 - 80

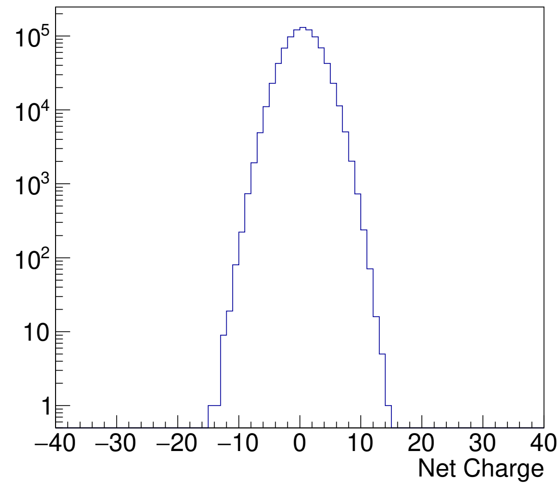


(e) 80 - 100

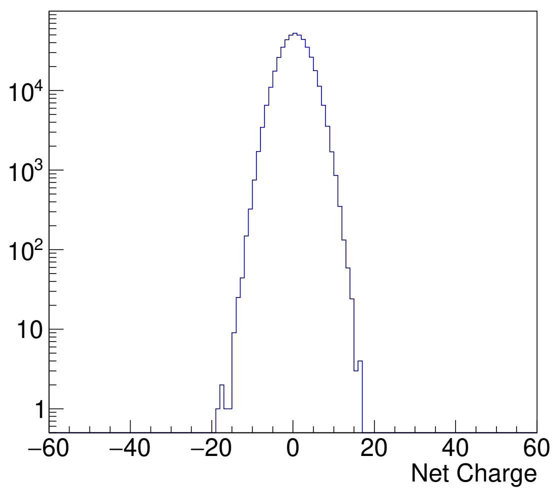
FIG. 4: Net charge histograms for underwritten multiplicity classes as obtained from PYTHIA 8 simulation data.



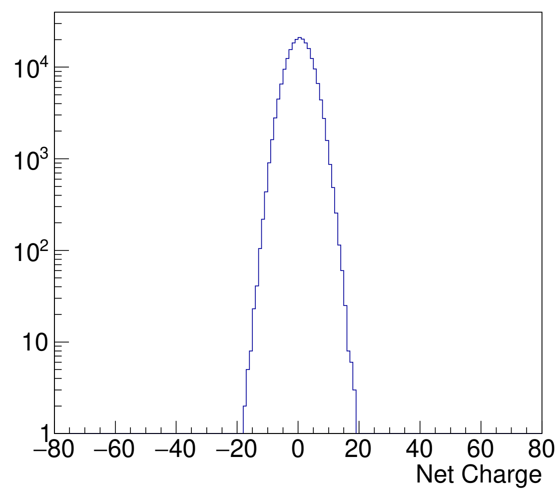
(a) 0 - 20



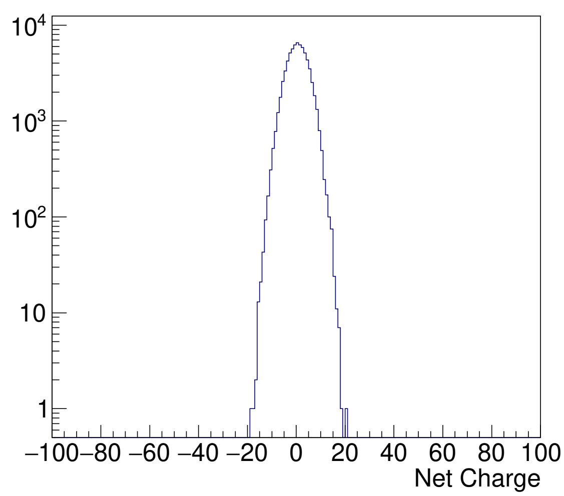
(b) 20 - 40



(c) 40 - 60

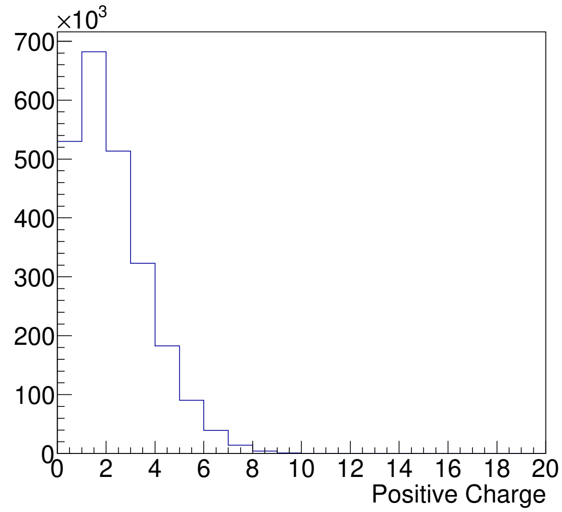


(d) 60 - 80

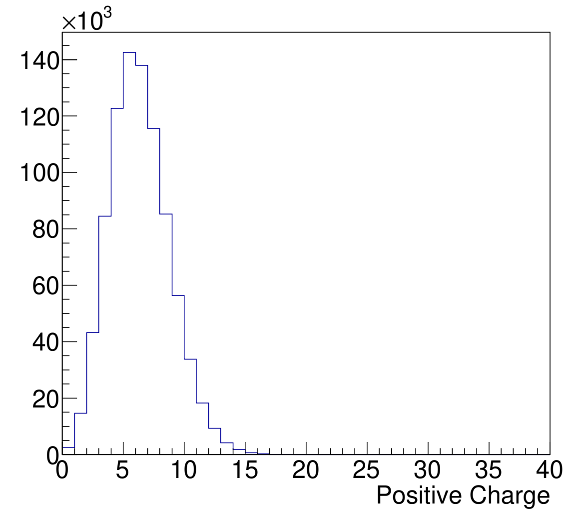


(e) 80 - 100

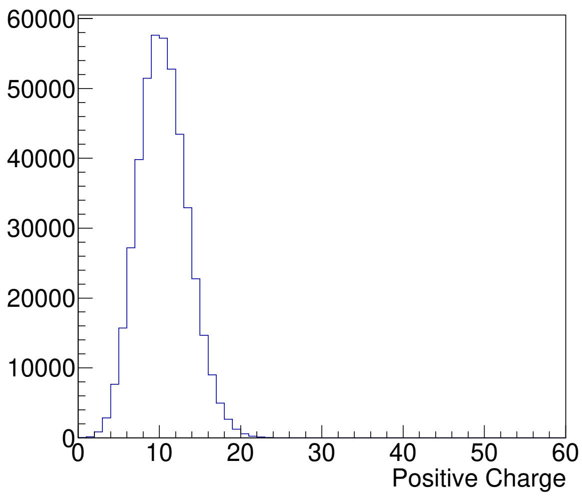
FIG. 5: Net charge histograms in logarithmic scale for underwritten multiplicity classes as obtained from PYTHIA 8 simulation data.



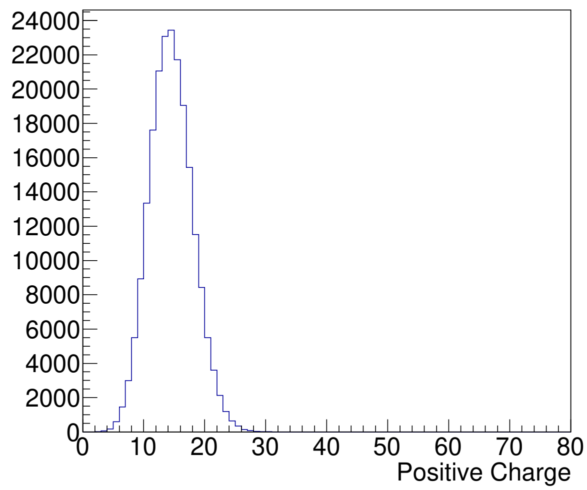
(a) 0 - 20



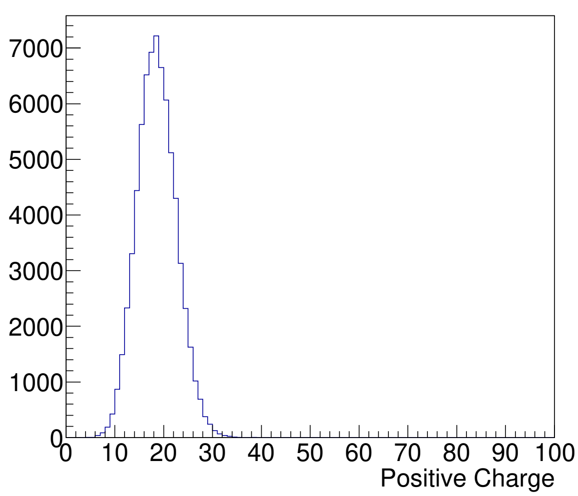
(b) 20 - 40



(c) 40 - 60

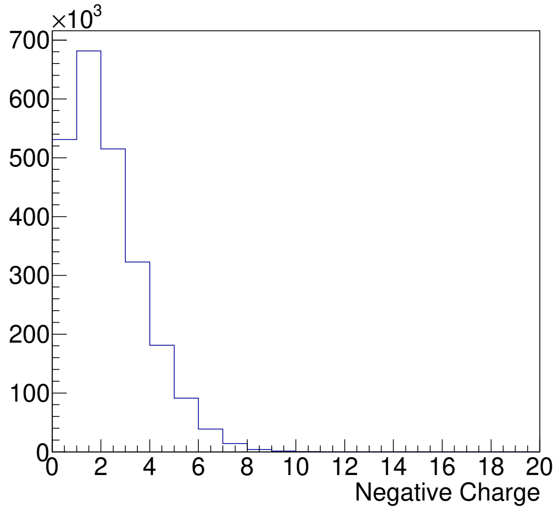


(d) 60 - 80

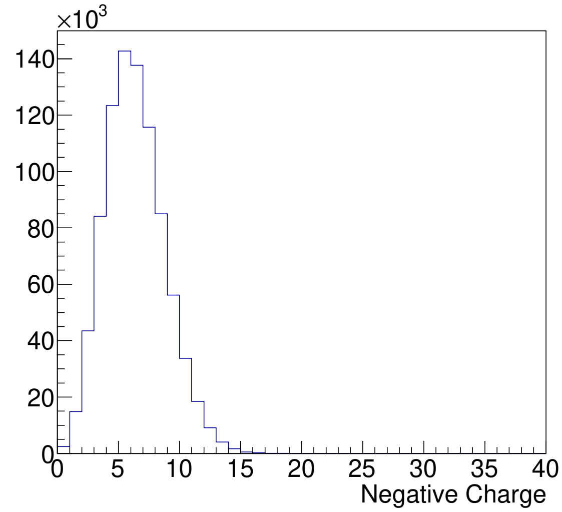


(e) 80 - 100

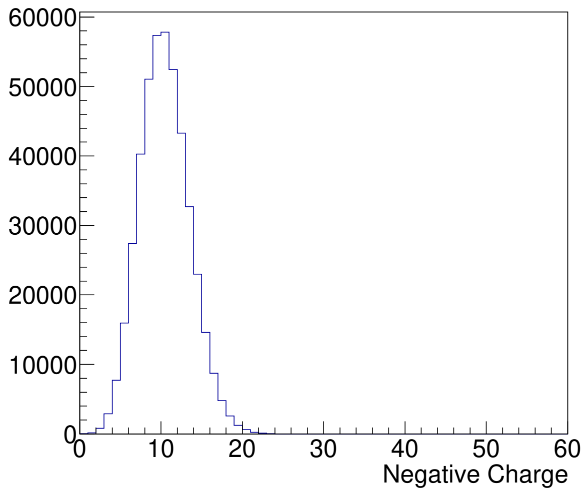
FIG. 6: Positive charge histograms for underwritten multiplicity classes as obtained from PYTHIA 8 simulation data.



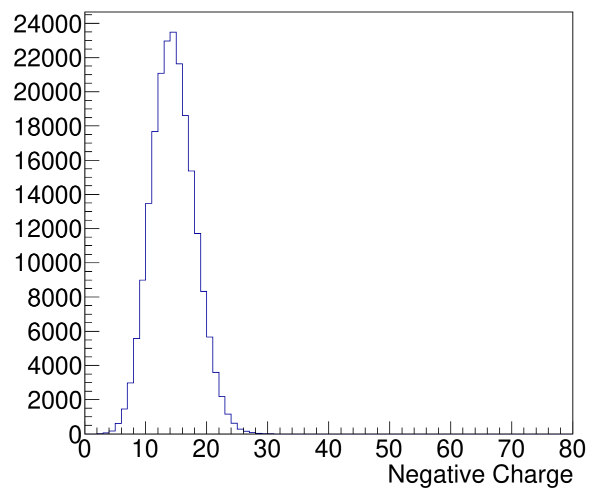
(a) 0 - 20



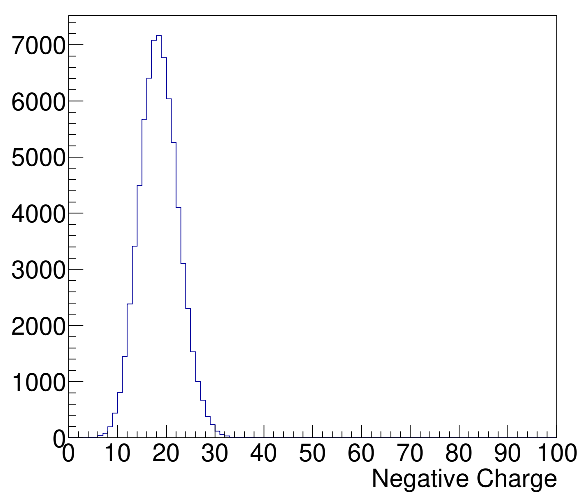
(b) 20 - 40



(c) 40 - 60



(d) 60 - 80



(e) 80 - 100

FIG. 7: Negative charge histograms for underwritten multiplicity classes as obtained from PYTHIA 8 simulation data.

III. SUMMARY

1. It is quite clear that the mean net charge is very close to zero for all multiplicity classes (0-20, 20-40, 40-60, 60-80 and 80-100). This agrees with what is expected.

2. The plot of the ratio of variance and mean of the net charge versus mean multiplicity shows that $\frac{\sigma^2}{M}$ decreases monotonically (except at the mean multiplicity of class 60-80) with multiplicity. Same is the case of the ratio of variance and squared mean.

3. The 2D scatter plots of multiplicity values in acceptance and non-acceptance regions indicate that the correlation coefficient is negative and small in magnitude. Thus, we conclude with reasonable certainty that the multiplicities of the two regions are not correlated.

4. The mean net charge increase monotonically with multiplicity (except at the mean multiplicity of class 60-80). Variance of the net charge increases monotonically with the multiplicity with no irregularities.

5. The distributions of positive charge, negative charge and net charge appear to be approximately Gaussian. This can be verified using a χ^2-fit test.

Above conclusions can be verified to a better degree using larger data. Statistical fluctuation, which is assumed to be the cause of the exceptions we observe for the mean multiplicity of class 60-80, could then be ignored.

[1] J. Adams *et al.*, (ALICE Collaboration), Nature Physics **13**, 535-539 (2017).