Measurement of net charge and the dependence of kinematic variables on the charge asymmetry in pp collisions at 13 TeV with Pythia 8

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Abstract

In this report, we present the distributions of multiplicity and kinematic variables-for both charge symmetric and charge asymmetric regions-for proton-proton collisions; obtained using advanced experiment analysis. These experiments serve to test the principles of the Standard Model of Particle Physics. We expect statistical discrepancy to cause the net charge to deviate from the prescribed value in a p-p collision. In the coming sections, we analyze this deviation from the expected value, along with a brief study on the variation of multiplicity values with charge symmetry. Further, we study the variation of the kinematic variables in charge symmetric and asymmetric regions. The data provided is generated using Pythia 8 Monte Carlo event generator replicating the collision events.

1 Introduction

A proton-proton collision (abbreviated p-p collision), refers to two high energy proton beams undergoing a head-on-collision. Owing to their high energy and consequentially a smaller *de Broglie* wavelength the protons are pragmatically transparent to each other. Hence, the interaction is primarily between the quarks (the building block of protons) rather than two protons as a whole. Unlike their macroscopic counterpart, particle collisions are governed by the 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 shall expect statistical discrepancy to cause the net charge to deviate from the prescribed value.
Number of events : 2 million
Collisions System : p + p at centre of mass energy 13 TeV.
Before moving on to the experimental observations, we first define a few important variables:

- **Multiplicity:** It is the number of particles produced in an event of hadron collision. Even thought multiplicity is one of the simplest observables in the collisions of hadrons, it imposes an important constraint on the mechanism of particle production. Its distribution contains the information about particle correlation.
- **Pseudorapidity (η):** It is a spatial coordinate (η), a parameter which is frequently used to express the angle of particle relative to axis of colliding beam (θ). It is defined as

$$\eta = \ln \tan(\theta/2)$$

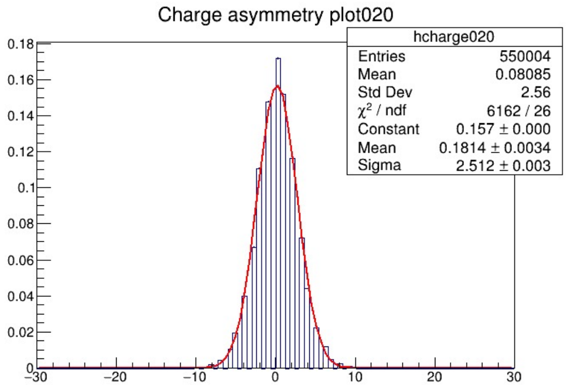
  Here θ is the measure of the angle formed by particle three-momentum p and the beam axis.
- **Transverse momentum (p_T):** It is the component in of momentum in the transverse direction (p_T) to the beam axis. It is important because unlike the momentum along the beam axis which might be left over from the beam particles, the transverse momentum is always associated with whatever physics happened at the vertex.

- **Azimuthal angle (ϕ):** It is the angle from the vertcal axis in the chosen co-ordinate system.
- **Net charge ($N_+ - N_-$):** In this report, we define it as the number of positively charged particles minus the number of negatively charged particles.

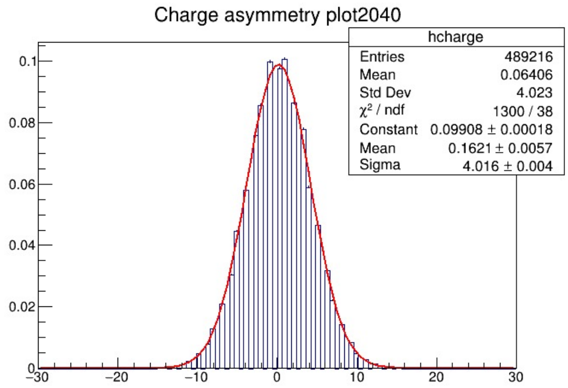
We will first study the charge asymmetry distribution in different multiplicity classes. Then we will see the multiplicity distribution in charge symmetric and asymmetric regions. Finally we will have a look at the kinematic variables' (p_T,η, and ϕ) distribution in charge symmetric and asymmetric regions.

2 Experimental Observation

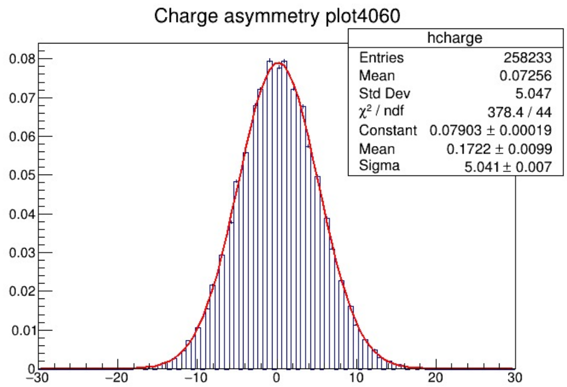
1. Charge asymmetry distribution in different multiplicity classes



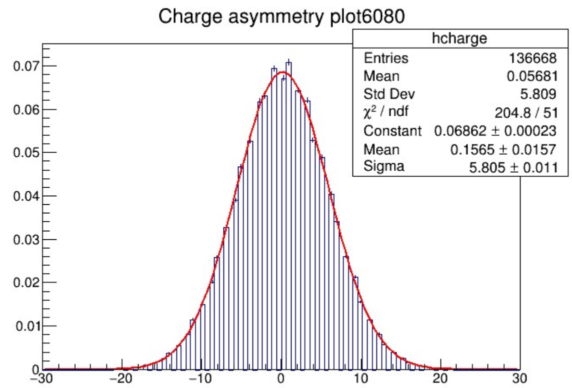
(a) Charge asymmetry distribution in class: 0-20



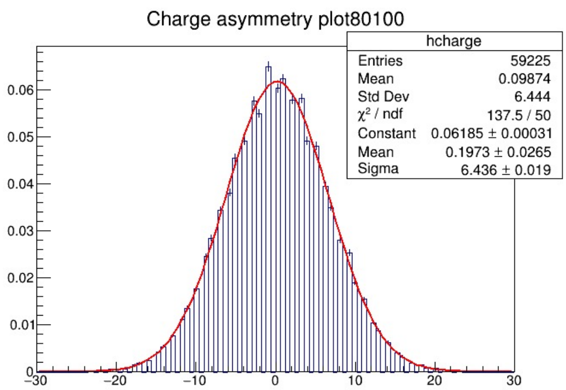
(b) Charge asymmetry distribution in class: 20-40



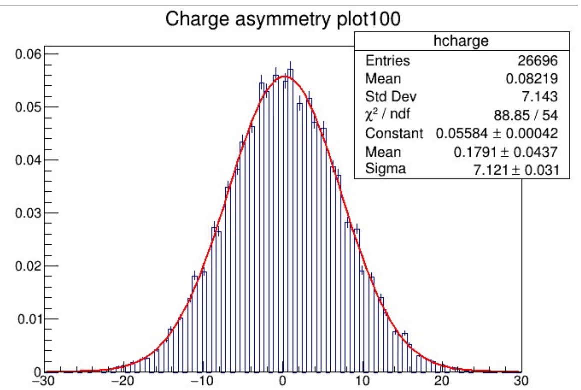
(a) Charge asymmetry distribution in class: 40-60



(b) Charge asymmetry distribution in class: 60-80



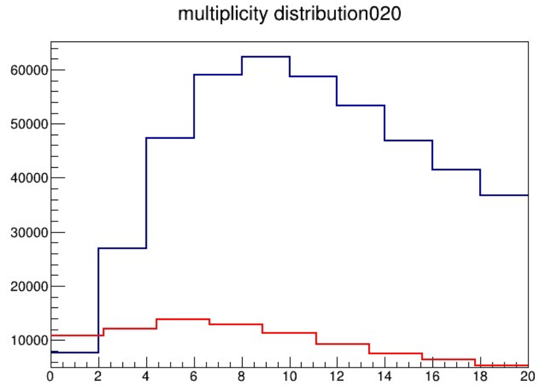
(a) Charge asymmetry distribution in class: 80-100



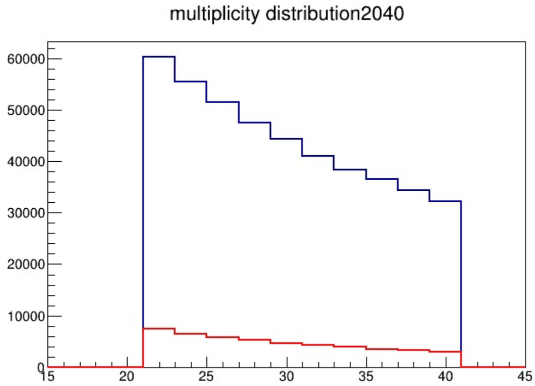
(b) Charge asymmetry distribution in class: > 100

From these plots, it is clear that with increasing multiplicity, the spread of the data (the standard deviation) is increasing. The distribution, however, remains a Gaussian with peak at 0. For classification into charge symmetric and asymmetric regions, we have used a bound of ± 1 about the mean.

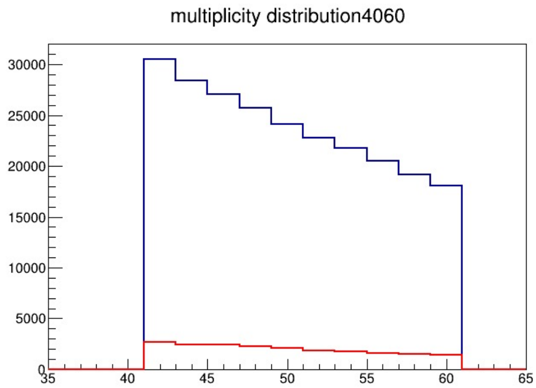
2. Multiplicity distribution in charge symmetric and asymmetric regions (not normalized)



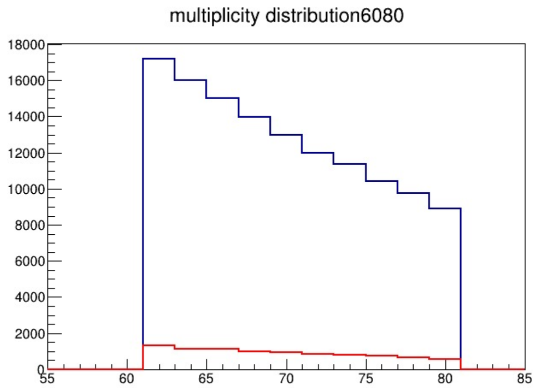
(a) Multiplicity distribution in class: 0-20



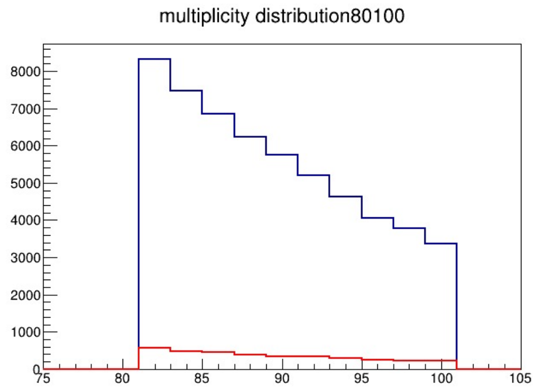
(b) Multiplicity distribution in class: 20-40



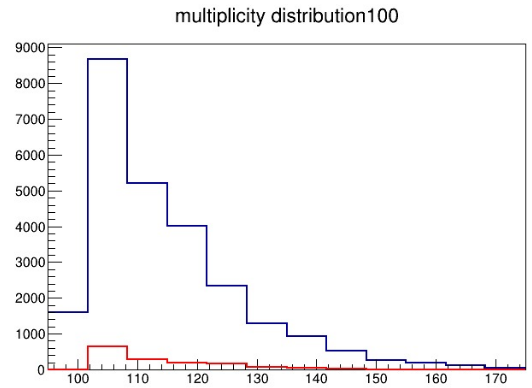
(a) Multiplicity distribution in class: 40-60



(b) Multiplicity distribution in class: 60-80



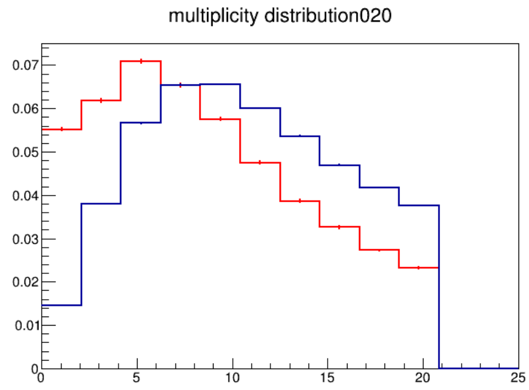
(a) Multiplicity distribution in class: 80-100



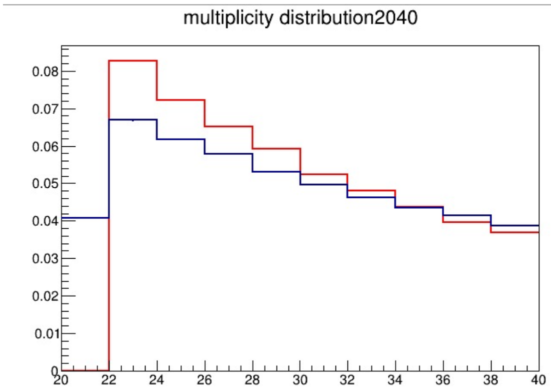
(b) Multiplicity distribution in class: > 100

In all the above figures, the blue graph corresponds to the charge asymmetric region and the red graph corresponds to the charge symmetric region. Here we see a stark difference between the two plots because the number of events (and hence, the particles) is more in charge asymmetric region than in the charge symmetric region. But the shape of the two curves remains the same.

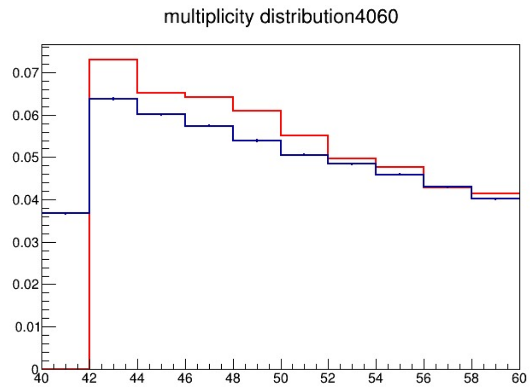
Multiplicity distribution in charge symmetric and asymmetric regions (normalized)



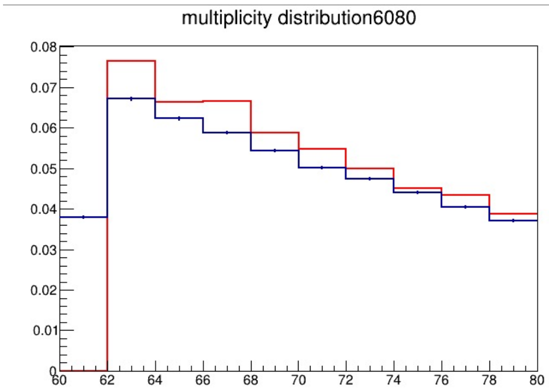
(a) Multiplicity distribution in class: 0-20



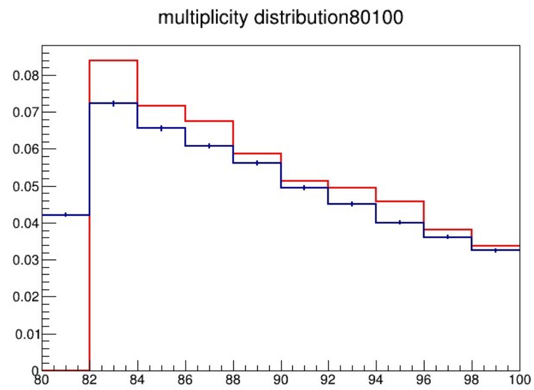
(b) Multiplicity distribution in class: 20-40



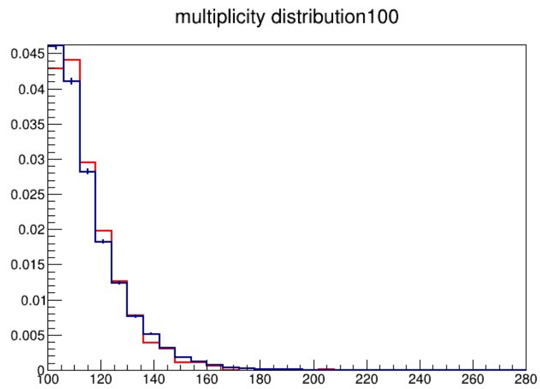
(a) Multiplicity distribution in class: 40-60



(b) Multiplicity distribution in class: 60-80



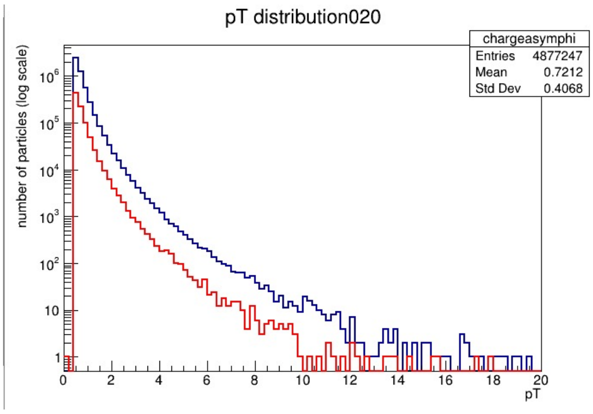
(a) Multiplicity distribution in class: 80-100



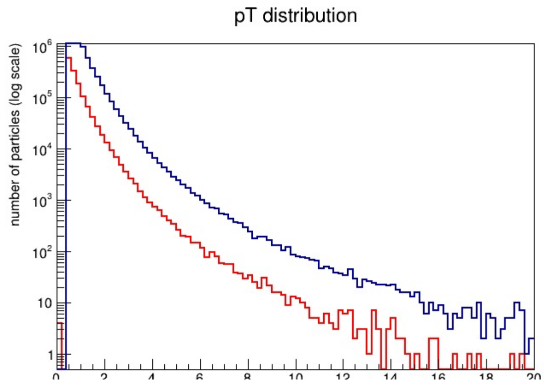
(b) Multiplicity distribution in class: > 100

In all the above figures, the blue graph corresponds to the charge asymmetric region and the red graph corresponds to the charge symmetric region. Thus the multiplicity distribution is nearly the same as the two curves overlap.

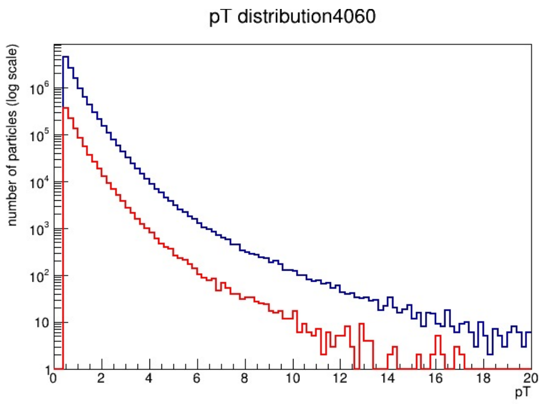
3. p_T distribution in charge symmetric and asymmetric regions (not normalized)



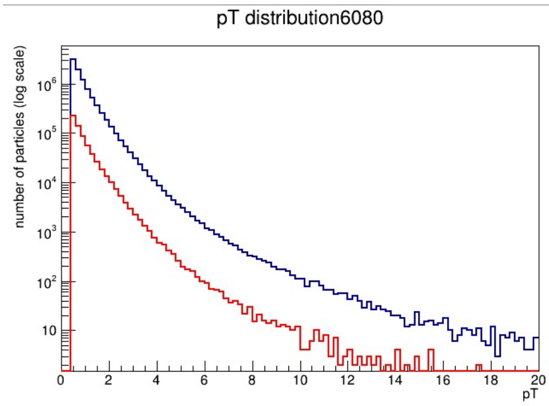
(a) p_T distribution in class: 0-20



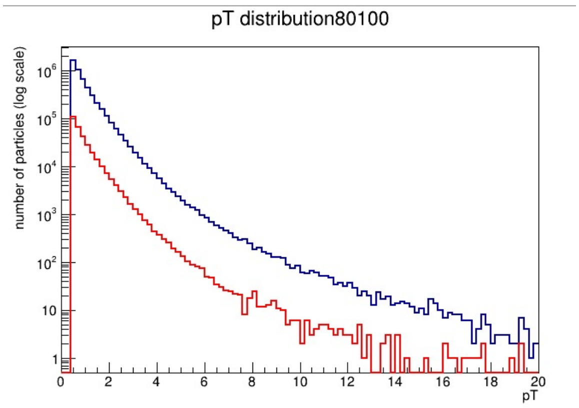
(b) p_T distribution in class: 20-40



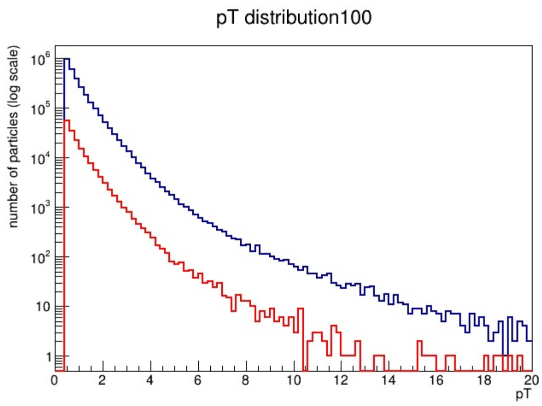
(a) p_T distribution in class: 40-60



(b) p_T distribution in class: 60-80



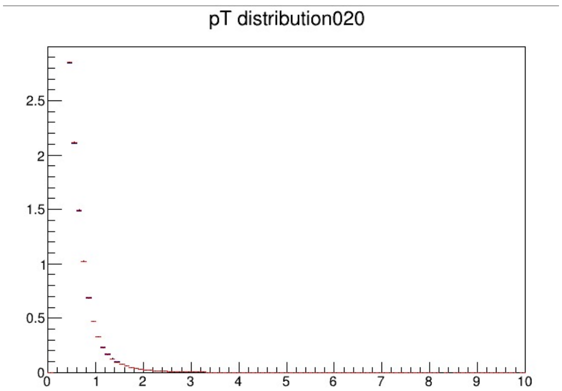
(a) p_T distribution in class: 80-100



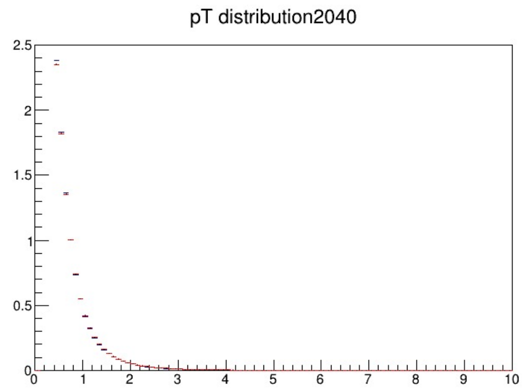
(b) p_T distribution in class: > 100

In all the above figures, blue graph corresponds to asymmetric region and red graph corresponds to symmetric region.

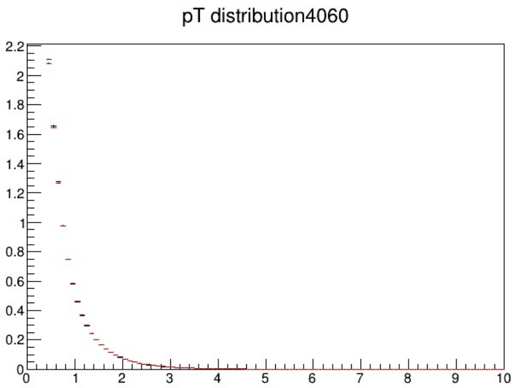
p_T distribution in charge symmetric and asymmetric regions (normalized)



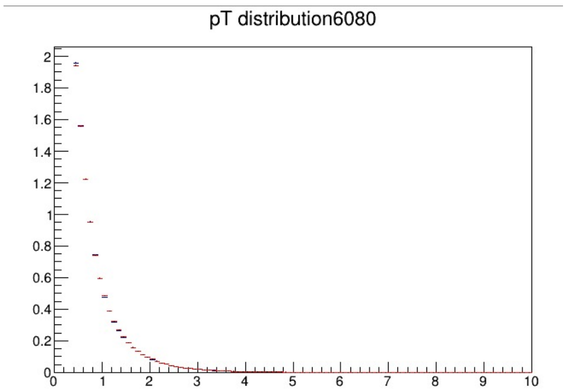
(a) p_T distribution in class: 0-20



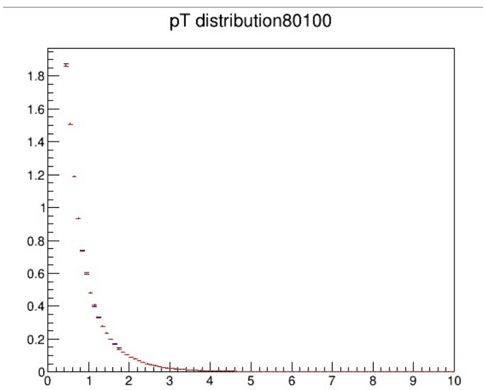
(b) p_T distribution in class: 20-40



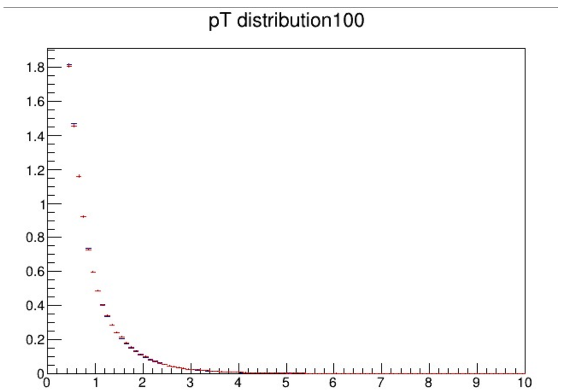
(a) p_T distribution in class: 40-60



(b) p_T distribution in class: 60-80



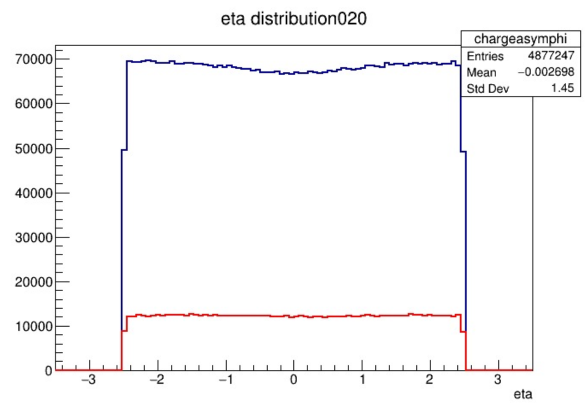
(a) p_T distribution in class: 80-100



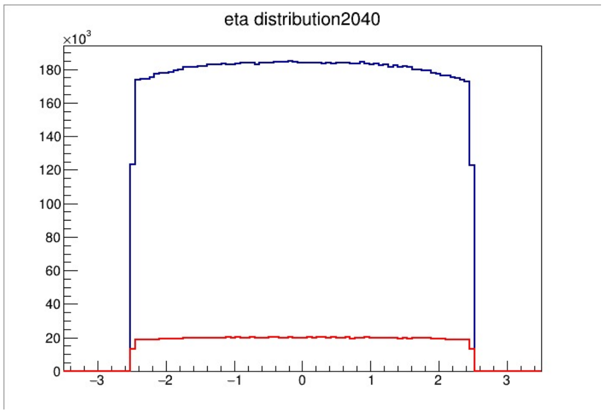
(b) p_T distribution in class: > 100

In all the above figures, blue graph corresponds to asymmetric region and red graph corresponds to symmetric region. As in the case of multiplicity, the two curves nearly overlap.

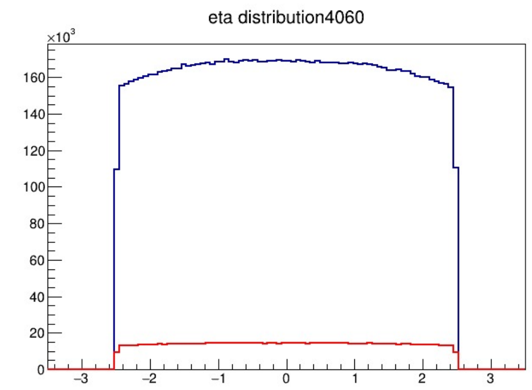
4. η distribution in charge symmetric and asymmetric regions (not normalized)



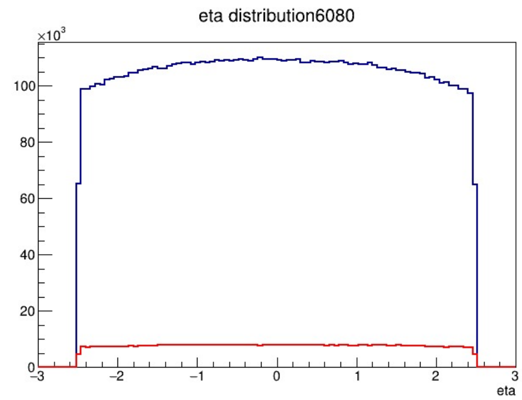
(a) η distribution in class: 0-20



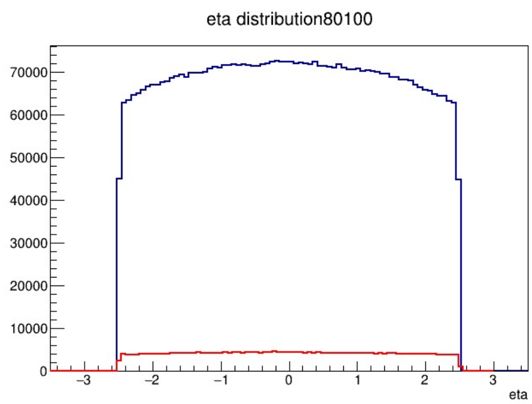
(b) η distribution in class: 20-40



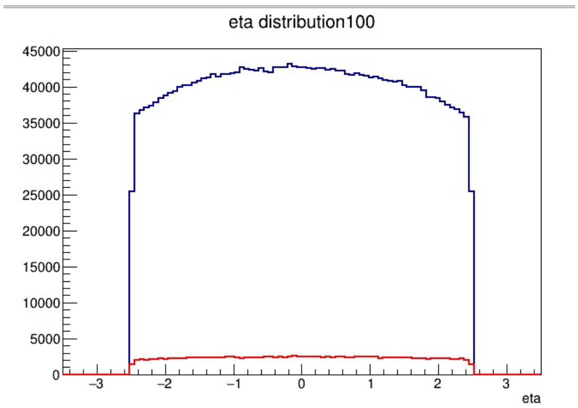
(a) η distribution in class: 40-60



(b) η distribution in class: 60-80



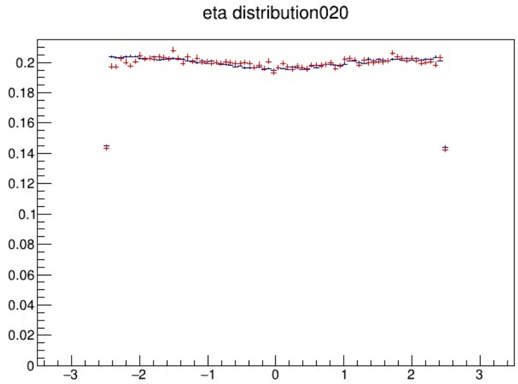
(a) η distribution in class: 80-100



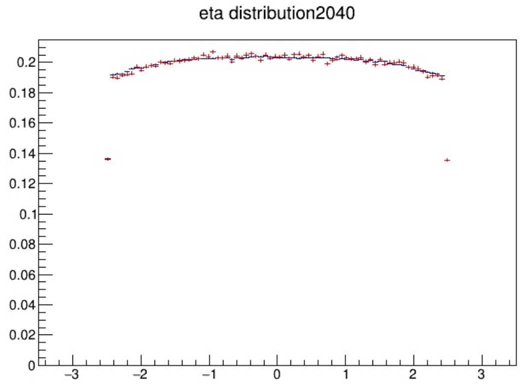
(b) η distribution in class: > 100

In all the above figures, blue graph corresponds to asymmetric region and red graph corresponds to symmetric region.

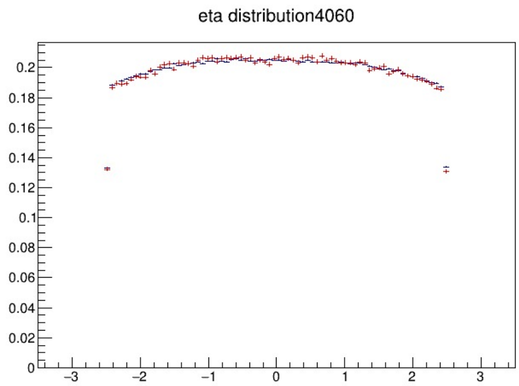
η distribution in charge symmetric and asymmetric regions (normalized)



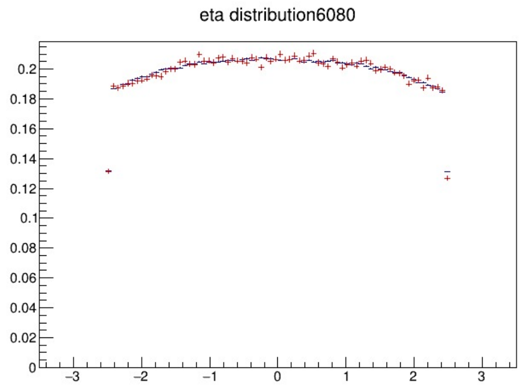
(a) η distribution in class: 0-20



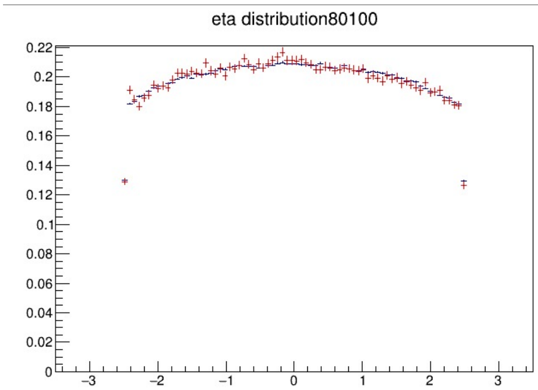
(b) η distribution in class: 20-40



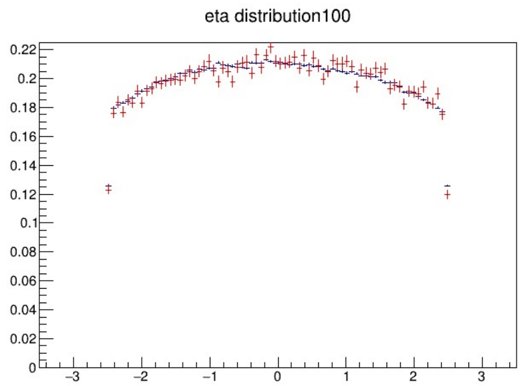
(a) η distribution in class: 40-60



(b) η distribution in class: 60-80



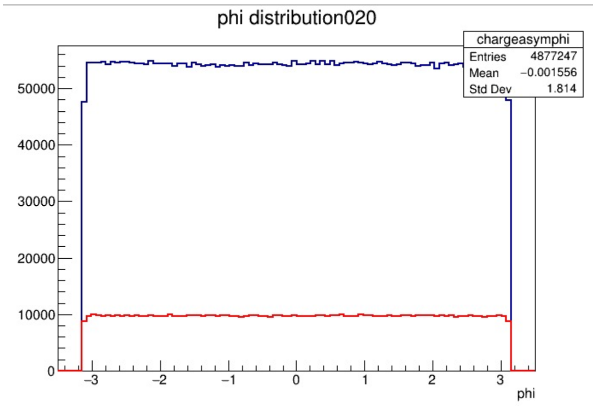
(a) η distribution in class: 80-100



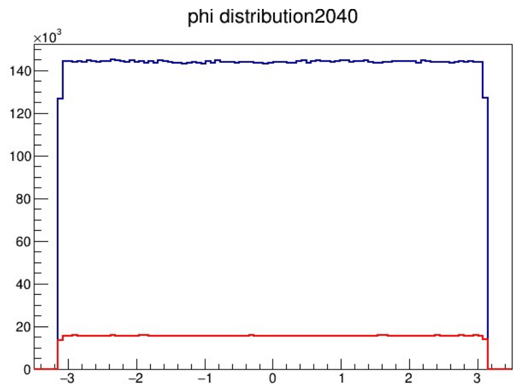
(b) η distribution in class: > 100

In all the above figures, blue graph corresponds to asymmetric region and red graph corresponds to symmetric region. Interestingly, the simple error bars for particles in the events belonging to charge symmetric region increase in length with an increase in the multiplicity.

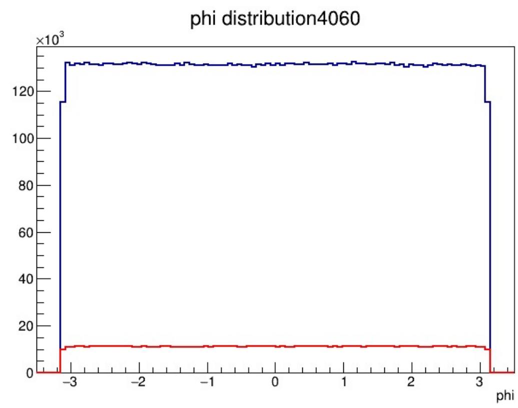
5. ϕ distribution in charge symmetric and asymmetric regions (not normalized)



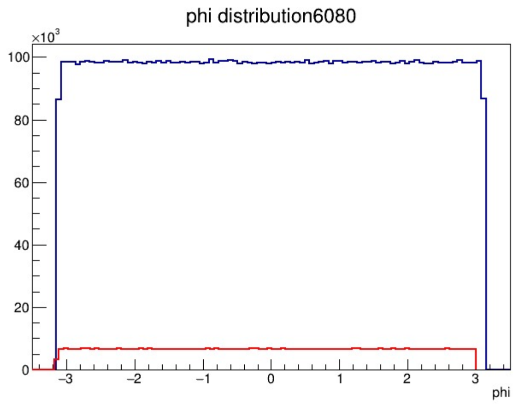
(a) ϕ distribution in class: 0-20



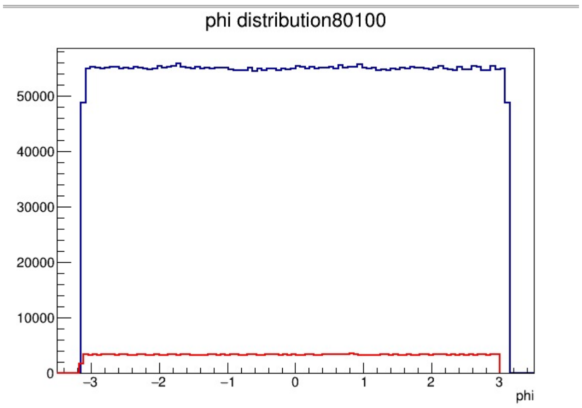
(b) ϕ distribution in class: 20-40



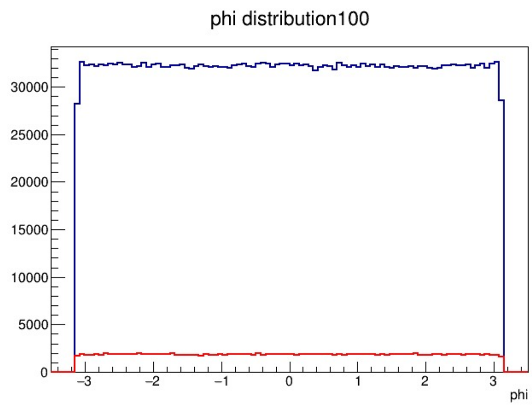
(a) ϕ distribution in class: 40-60



(b) ϕ distribution in class: 60-80



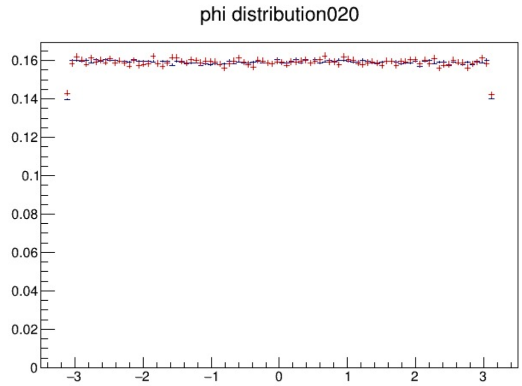
(a) ϕ distribution in class: 80-100



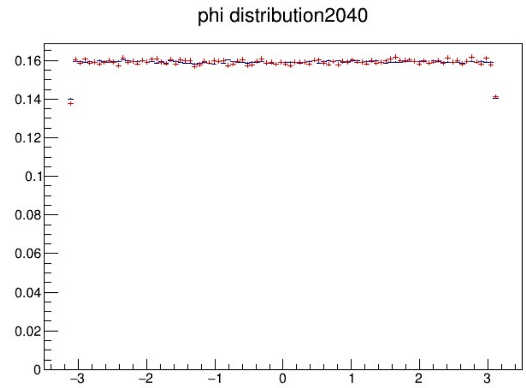
(b) ϕ distribution in class: > 100

In all the above figures, blue graph corresponds to asymmetric region and red graph corresponds to symmetric region.

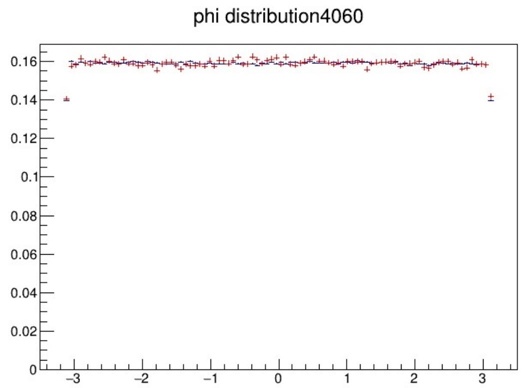
ϕ distribution in charge symmetric and asymmetric regions (normalized)



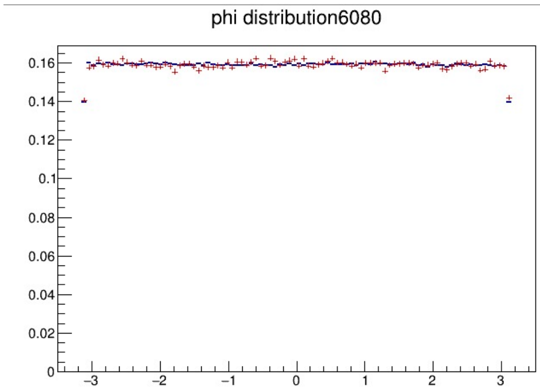
(a) ϕ distribution in class: 0-20



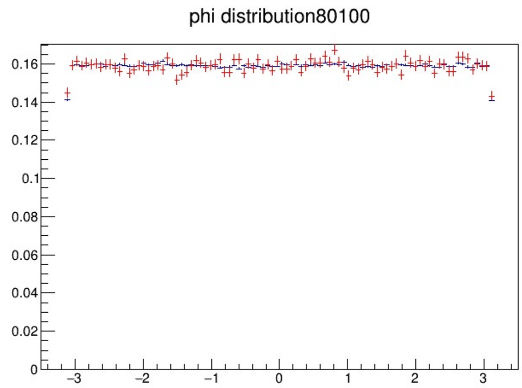
(b) ϕ distribution in class: 20-40



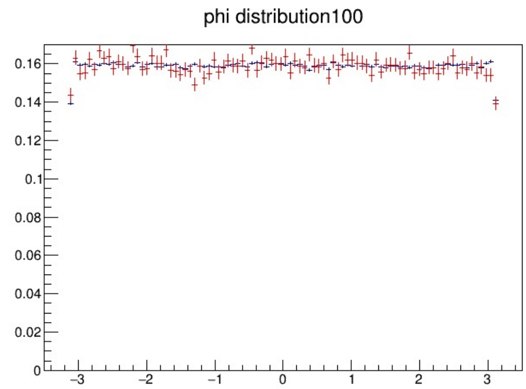
(a) ϕ distribution in class: 40-60



(b) ϕ distribution in class: 60-80



(a) ϕ distribution in class: 80-100



(b) ϕ distribution in class: > 100

In all the above figures, blue graph corresponds to asymmetric region and red graph corresponds to symmetric region. As in the case of η, the simple error bars for particles in the events belonging to charge symmetric region increase in length with an increase in the multiplicity.

3 Summary

A study of the net charge distribution, multiplicity distribution, and the distributions of kinematic variables of proton-proton collisions at center-of-mass energy 13 TeV has been presented. The events are grouped into symmetric region ($|N_+ - N_-| < 1$) and asymmetric region ($|N_+ - N_-| \geq 1$). The mean and variance of the net charge increase with the multiplicity. The distributions of multiplicity and the other kinematic variables for charge symmetric and asymmetric regions are nearly the same.

4 References

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