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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Contents

Abstract

In this report, we present the findings regarding the dependence of kinematic variables and charged particles multiplicity distributions on charge asymmetry in proton-proton (p-p) collisions at 13 TeV. The net charge observed in such collisions statistically deviates from the prescribed value. In this report, we analyse this deviation, and that of the multiplicity distributions. These experiments allow us to test the principles of the Standard Model. The data has been generated using Pythia 8 Monte Carlo event generator replicating the collision events.

1 Introduction

A proton-proton collision refers to two high energy proton beams colliding in a head-on fashion. During this collision, the interaction is mainly between quarks. Such collisions generate a large number of particles (maintained by the variable 'ntrack'), and are sufficiently described by Feynman diagrams. However, we will not look at Feynman diagrams in this report. The particles formed in the p-p collisions abide by the conservation laws. Thus, 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 zero.

In the data, we deal with the following variables:

- **Multiplicity:** The number of particles produced in the p-p collision. This value is stored in the variable '*ntrack*'.
- **Pseudorapidity(η):** A variable which is very similar to rapidity, can be used almost interchangeably, and is much easier to measure. This value is stored in the variable '*eta*'. It is given by,

$$\eta = -\ln\tan(\frac{\theta}{2})$$

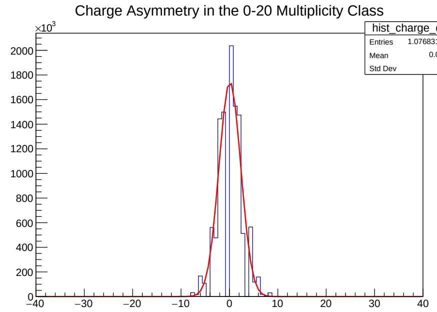
- **Rapidity:** It's related to the angle between the XY plane and the direction of emission of a product of the collision, where the Z axis is defined by the head-on direction along which the collision takes place and is particularly useful at relativistic speeds. This value is stored in the variable '*rap*'. It is given by,

$$y = \frac{1}{2}\ln(\frac{E + p_z c}{E - p_z c})$$

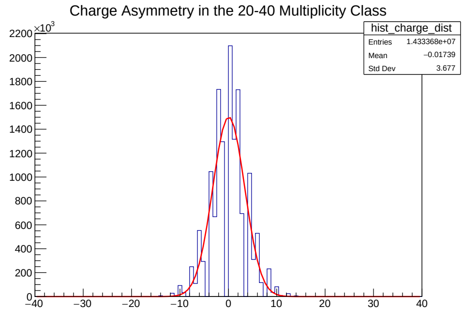
- **Azimuthal Angle (ϕ):** Angle from the vertical axis in the chosen co-ordinate system. This value is stored in the variable '*phi*'.
- **Net Charge:** Total Positive Charge $-$ Total Negative Charge
- **Transverse Momentum (p^T):** It is the component in of momentum in the transverse direction (p^T) 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. Vertex is understood as the point of collision, as in Feynman diagrams.

2 Experimental Observation

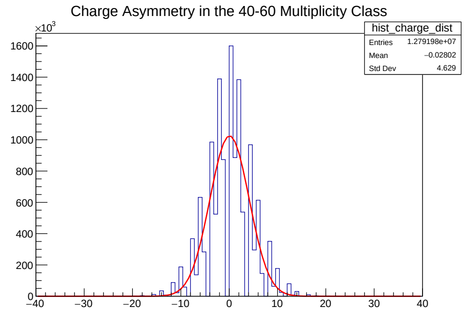
2.1 Charge asymmetry distribution in different multiplicity classes



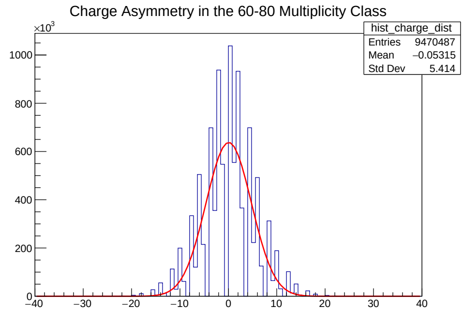
(a) Charge asymmetry distribution in class: 0-20



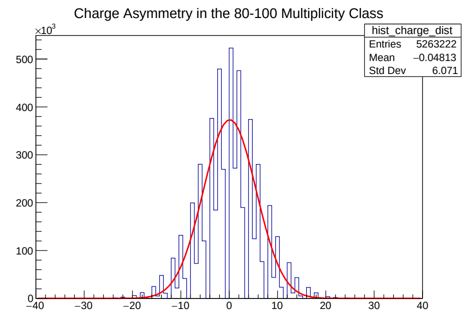
(b) Charge asymmetry distribution in class: 20-40



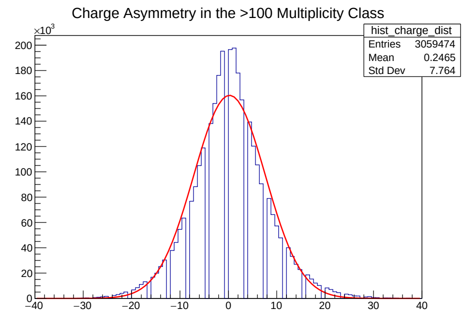
(a) Charge asymmetry distribution in class: 40-60



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



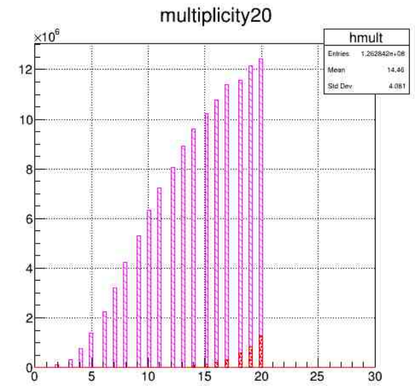
(a) Charge asymmetry distribution in class: 80-100



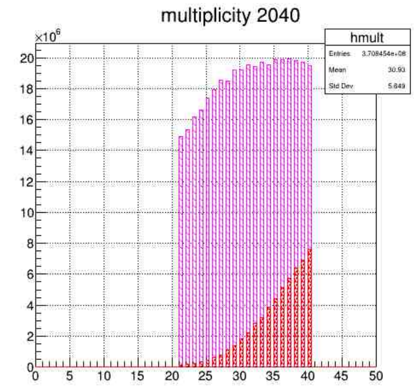
(b) Charge asymmetry distribution in class: > 100

From these plots, it is clear that σ increases with multiplicity. The distribution, however, remains Gaussian with the mean at zero. For classification into charge symmetric and asymmetric regions, we have used a bound of ± 10 about the mean. (Yes, this is a rather big interval. It simply means that our confidence in the final result will be higher regarding charge symmetric distributions. Also, for the multiplicity class >100, σ is nearly 8; so an interval of ± 10 makes sense.)

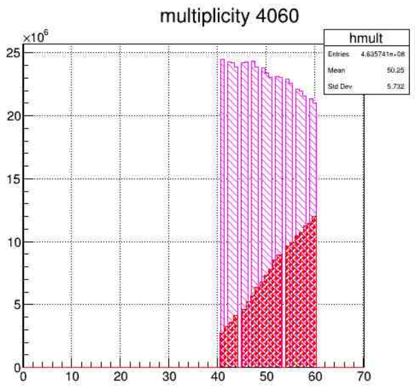
2.2 Multiplicity distribution in charge symmetric and asymmetric regions



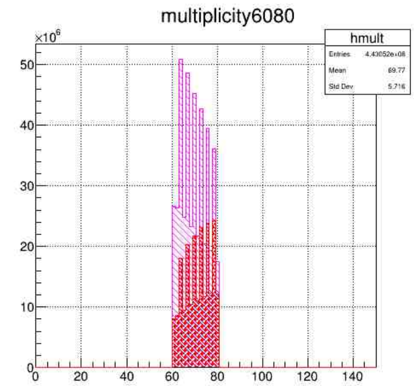
(a) Charge asymmetry distribution in class: 0-20



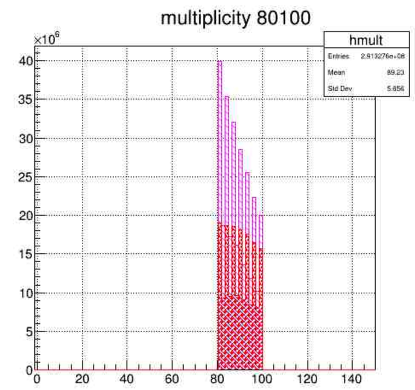
(b) Charge asymmetry distribution in class: 20-40



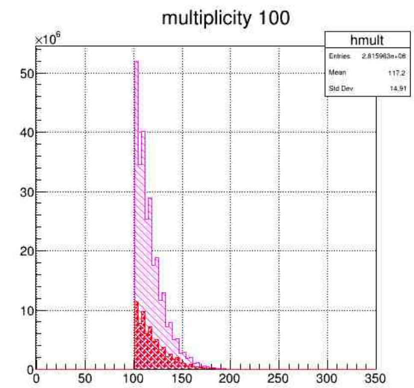
(a) Charge asymmetry distribution in class: 40-60



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



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



(b) Charge asymmetry distribution in class: > 100

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

2.3 p^T distribution in charge symmetric and asymmetric regions

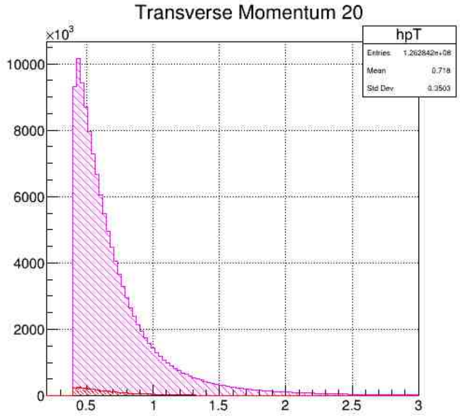


Figure 7: p^T distribution in symmetric and asymmetric regions for multiplicity class: 0-20

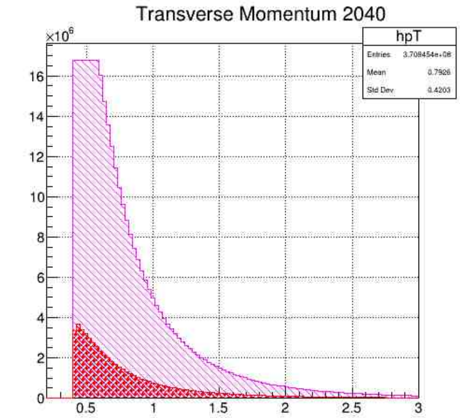


Figure 8: p^T distribution in symmetric and asymmetric regions for multiplicity class: 20-40

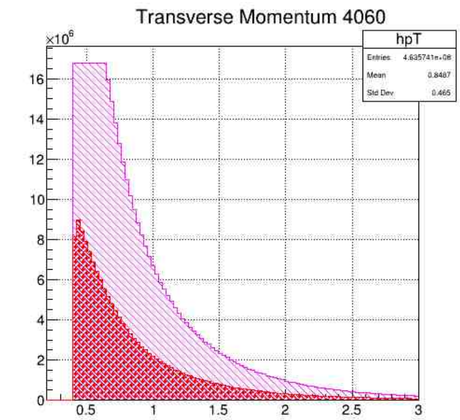


Figure 9: p^T distribution in symmetric and asymmetric regions for multiplicity class: 40-60

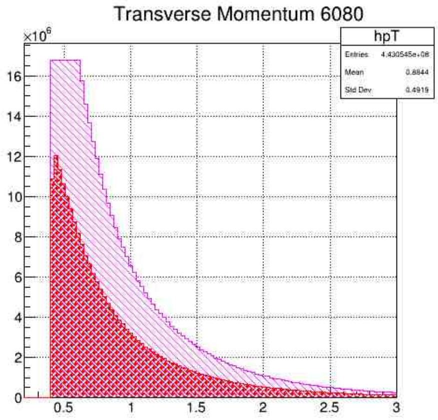


Figure 10: p^T distribution in symmetric and asymmetric regions for multiplicity class: 60-80

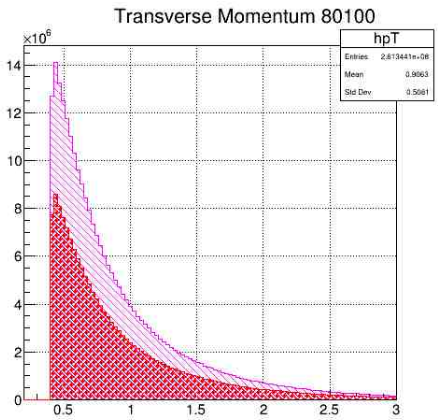


Figure 11: p^T distribution in symmetric and asymmetric regions for multiplicity class: 80-100

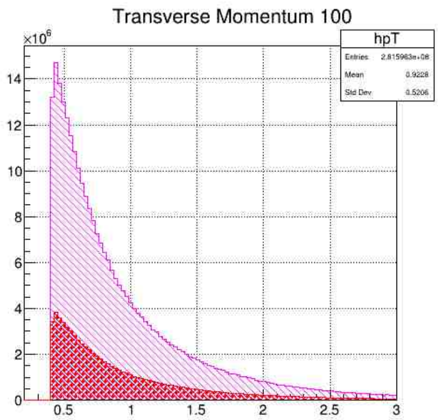


Figure 12: p^T distribution in symmetric and asymmetric regions for multiplicity class: > 100

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

2.4 ϕ distribution in charge symmetric and asymmetric regions

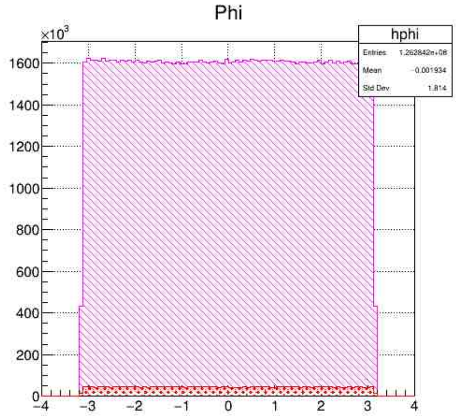


Figure 13: ϕ distribution in symmetric and asymmetric regions for multiplicity class: 0-20

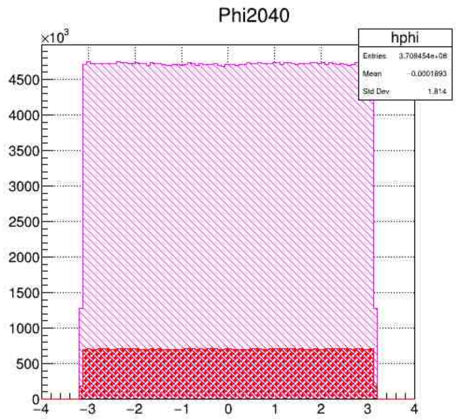


Figure 14: ϕ distribution in symmetric and asymmetric regions for multiplicity class: 20-40

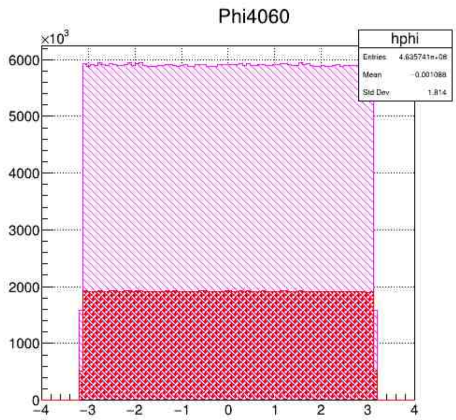


Figure 15: ϕ distribution in symmetric and asymmetric regions for multiplicity class: 40-60

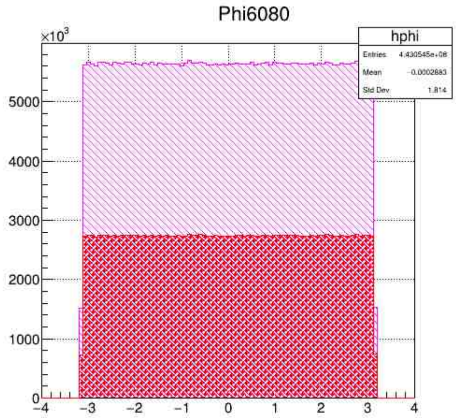


Figure 16: ϕ distribution in symmetric and asymmetric regions for multiplicity class: 60-80

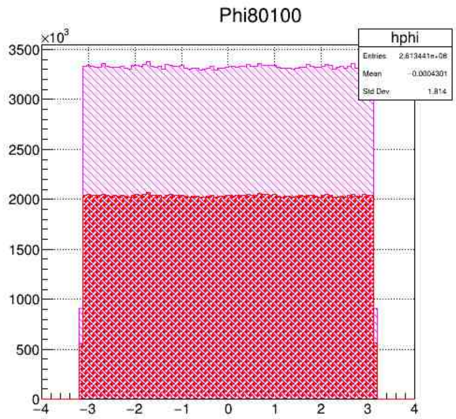


Figure 17: ϕ distribution in symmetric and asymmetric regions for multiplicity class: 80-100

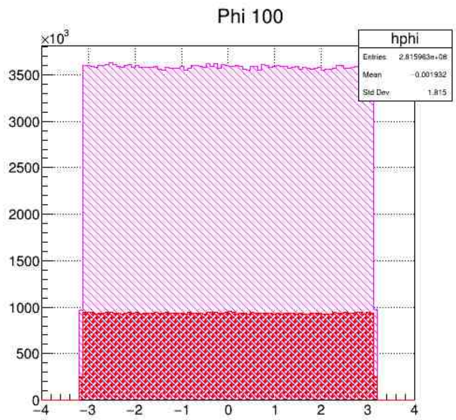


Figure 18: ϕ distribution in symmetric and asymmetric regions for multiplicity class: > 100

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

2.5 η distribution in charge symmetric and asymmetric regions

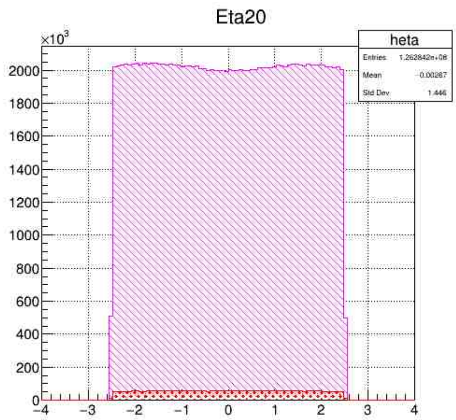


Figure 19: η distribution in symmetric and asymmetric regions for multiplicity class: 0-20

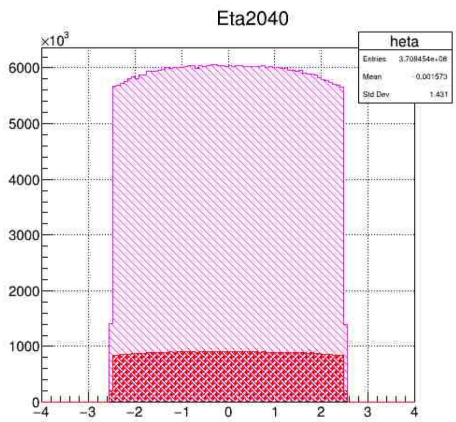


Figure 20: η distribution in symmetric and asymmetric regions for multiplicity class: 20-40

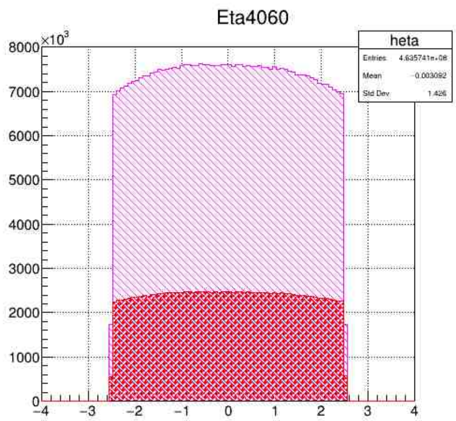


Figure 21: η distribution in symmetric and asymmetric regions for multiplicity class: 40-60

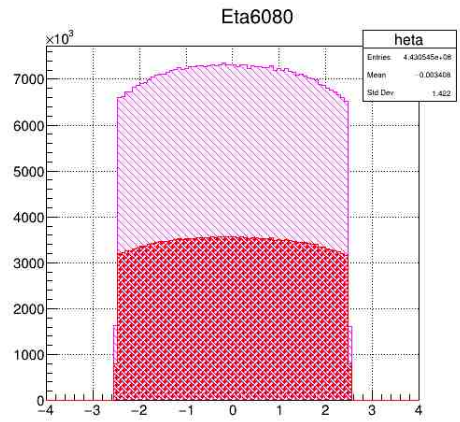


Figure 22: η distribution in symmetric and asymmetric regions for multiplicity class: 60-80

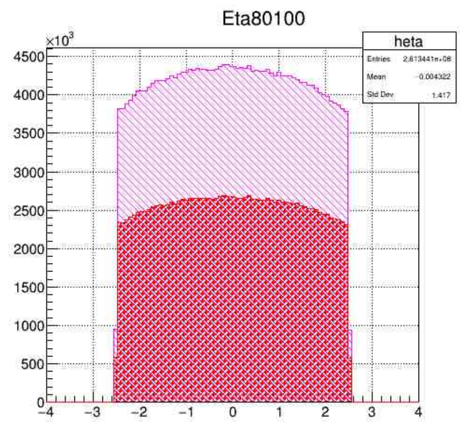


Figure 23: η distribution in symmetric and asymmetric regions for multiplicity class: 80-100

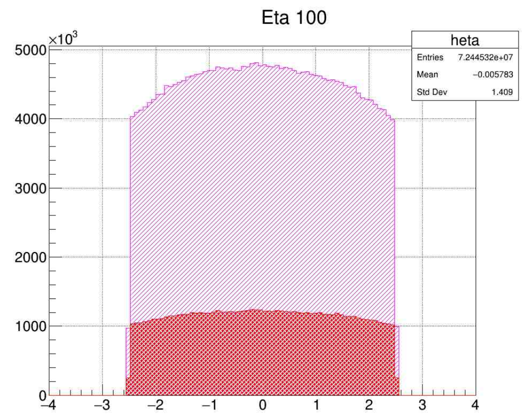


Figure 24: η distribution in symmetric and asymmetric regions for multiplicity class: > 100

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

3 Summary

In this report, we have presented the net charge, multiplicity and kinematic variable distributions of p-p collisions at COM energies of 13 TeV. The events were grouped into symmetric (-10 $<$ net charge $<$ 10) and asymmetric (net charge $\leq$ -10 | net charge $\geq$ 10) regions. From these plots, we were able to deduce that the mean and variance increase with multiplicity, and that all variables show higher values in the asymmetric regions.

4 References

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