PH 219 Data Analysis

Studying the underlying event characteristics using charged particles in *p*-*p* collisions at 13 TeV

Project Group C

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Abstract

Measurements of the short distance "hard" scattering process are neither good enough to perform precise standard model measurements nor in the search for new phenomena. The analysis of the data from the *underlying events* is done in order to understand the process better. Three regions are defined on the basis of the azimuthal angle from the leading track, and the relative angle distributions are found. For each region and particle multiplicity, the scalar sum of transverse momentum and average density of charged particles are analyzed. This report encapsulates the aforementioned analysis in the form of histogram plots which facilitate visual inspection of the data.

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1 Introduction

The data was generated from the interactions of protons in proton-proton collisions (p-p collision) at 13TeV using the Pythia 8 Monte Carlo event generator and were provided by the team at IITB lab cluster.

These interactions are collectively referred to as underlying events (UE). The UE observables are constructed from the primary charged particles in the *pseudorapidity* range, i.e., $|\eta| < 2.5$.

The particles are observed as *tracks* in the detector and the *leading track* is the direction of the track along the parallel of the particle with highest p_T. This track, which will be referred to as p_T^{Lead}, is used as a reference for the $\eta - \phi$ plane.

The number of particles emitted in each event or entry, is given by the particle multiplicity, and in this report, we discuss about 3 multiplicity classes, 0 to 20, 20 to 40 and 40 to 60.

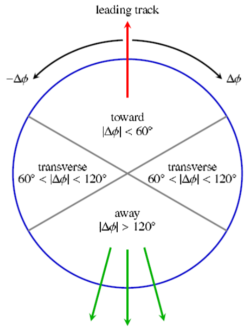

Figure 1: Definition of regions in the azimuthal angle with respect to the leading track [1]

Variables	Definition
$\mathrm{p_T}$	Transverse momentum of the particle (component of momentum perpendicular to z axis)
θ	Angle between momentum vector and z axis
ϕ	Azimuthal angle
η	Pseudo-rapidity of the particle defined as $\ln(\cot(\theta/2))$
$\mathrm{p_T^{lead}}$	Transverse momentum of the stable charged particle with maximum pT in the event
$\langle d^2 N_{ch}/d\eta d\phi \rangle$	Mean number of stable charged particles per unit $\eta - \phi$
$\langle d^2 \sum \mathrm{pT}/d\eta d\phi \rangle$	Mean scalar pT sum of stable charged particles per unit $\eta - \phi$

2 Observations

2.1 Plots of frequency vs $\Delta\phi$

The normalized frequencies of the relative angle between the particle with p_T^{lead} and other particles are plotted here in a specific manner for all entries. It has been implemented by iterating a *loop* to find the particle with lead p_T and then a function to calculate the relative angle of all other particles, in the range 0 to π, with respect to the leading particle and filled these values in a histogram. The lead p_T has been excluded using a conditional statement to avoid the case where $\Delta\phi$ is 0.
The figures 2,3 and 4 are the 1-D Histograms of $\Delta\phi$ for the multiplicity classes as given in the plots.

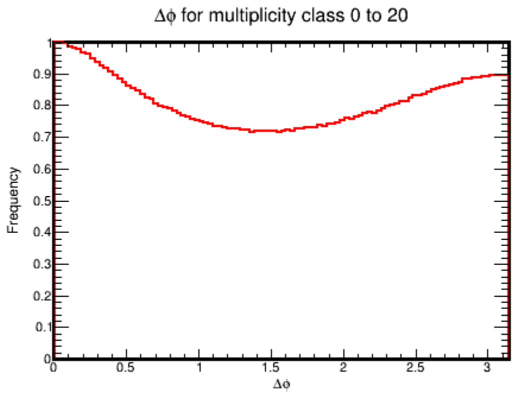

Figure 2: $\Delta\phi$ for multiplicity class 0-20

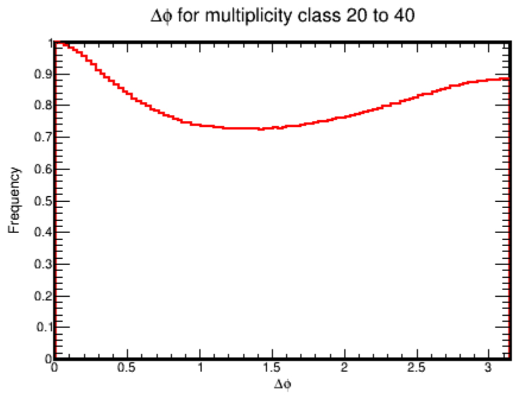

Figure 3: $\Delta\phi$ for multiplicity class 20-40

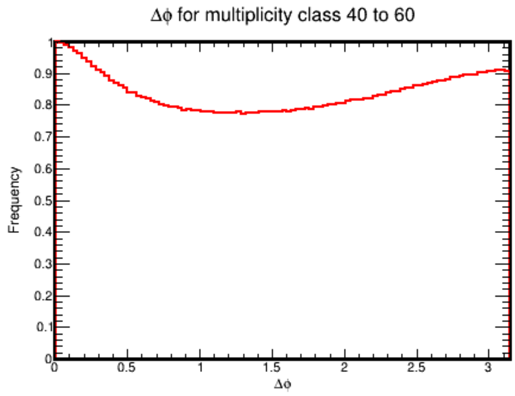

Figure 4: $\Delta\phi$ for multiplicity class 40-60

2.2 Plots of density of charged particles emitted as a function of p_T^{lead}

Reiterating the point under introduction, each entry has particles emitted in the toward, away and transverse region with respect to the particle with transverse momentum p_T^{lead}. To implement this, the leading track was found, and the relative angle of all particles with respect to the leading one were calculated. For each region, a $\Delta\phi$ cutoff was provided, and the number of particles in that region were calculated and scaled by a factor $\frac{3}{5\pi}$. The mean of the resulting 2-D Histogram of p_T^{lead} and N was calculated using a *TProfile* class.

Figures 5,6 and 7 represent the scaled density of charged particles for multiplicity class 0 to 20, for the regions Toward, Transverse and Away respectively.

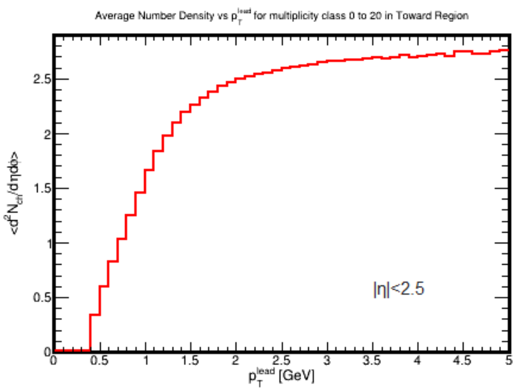

Figure 5: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for multiplicity class 0-20 in the Toward Region

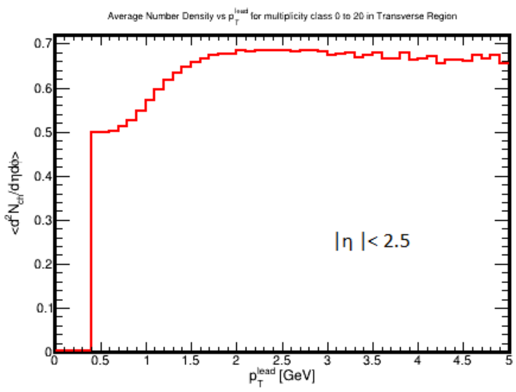

Figure 6: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for multiplicity class 0-20 in the Transverse Region

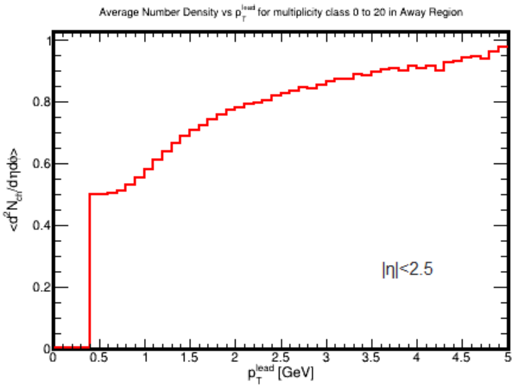

Figure 7: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for multiplicity class 0-20 in the Away Region

Figures 8,9 and 10 represent the scaled density of charged particles as a function of p_T^{lead} for multiplicity class 20 to 40, for the regions Toward[1], Transverse and Away respectively.

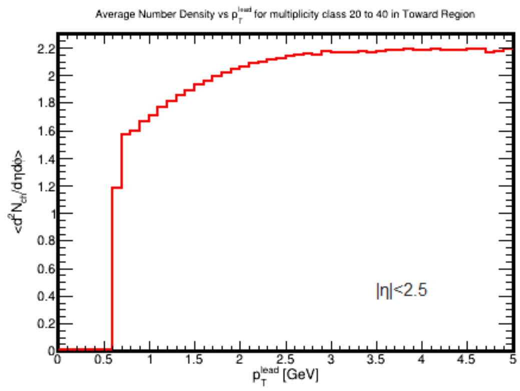

Figure 8: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for multiplicity class 20-40 in the Toward Region

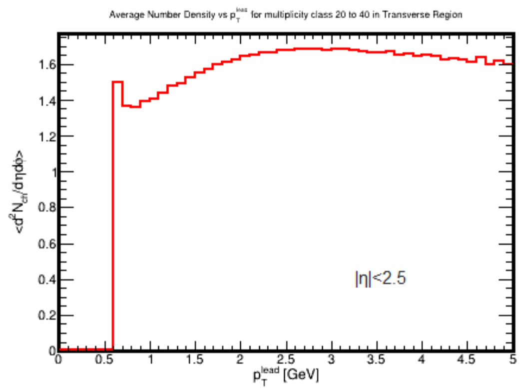

Figure 9: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for multiplicity class 20-40 in the Transverse Region

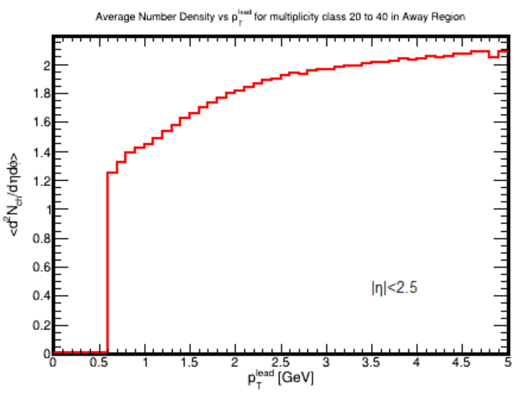

Figure 10: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for multiplicity class 20-40 in the Away Region

Figures 11,12 and 13 represent the scaled density of charged particles for multiplicity class 40 to 60, for the regions Toward, Transverse and Away respectively.

[1] F: Forward, T: Transverse, A: Away

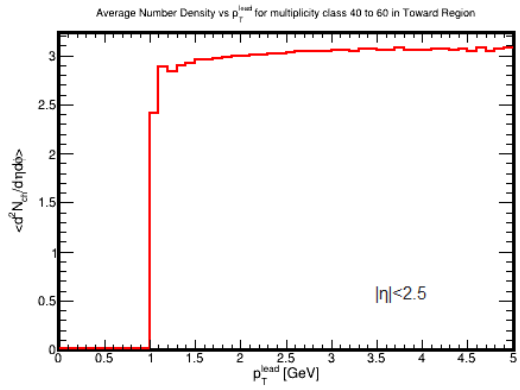

Figure 11: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for multiplicity class 40-60 in the Toward Region

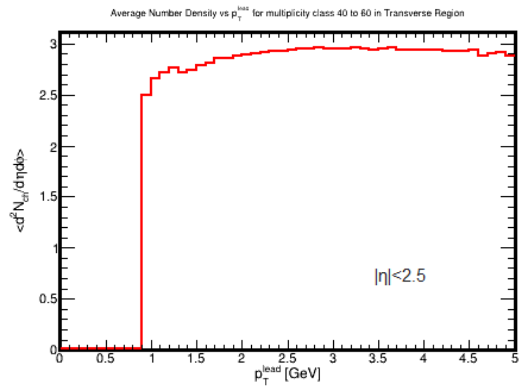

Figure 12: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 40-60 in the Transverse region

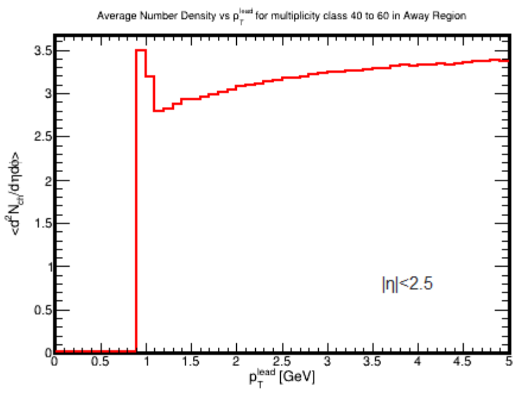

Figure 13: $\frac{d^2N_{ch}}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 40-60 in the Away region

2.3 Plots of scalar Σp_T density of the charged particles as a function of p_T^{lead}

Here, the scalar sum of p_T over all the particles in a particular region has been found. To implement this, data regarding the leading track and the relative angle of all particles with respect to the leading one were used again. For each region, a $\Delta\phi$ cutoff was provided, and the scalar sum of transverse momenta for particles in that region were calculated and scaled by a factor $\frac{3}{5\pi}$. The mean of the resulting 2-D Histogram of p_T^{lead} and $\sum p_T$ was calculated using a *TProfile* class.

Figures 14,15 and 16 represent the scaled scalar $\sum p_T$ as a function of p_T^{lead} for multiplicity class 0 to 20, for the regions Toward, Transverse and Away respectively.

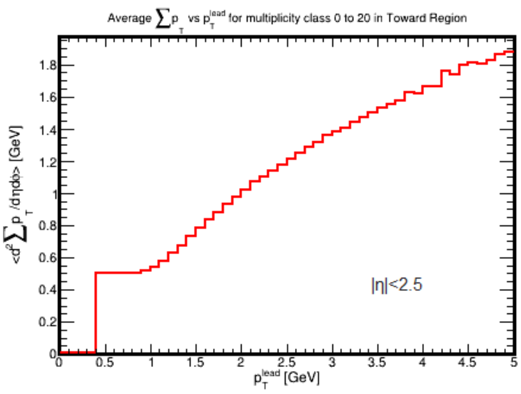

Figure 14: $\frac{d^2\sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 0-20 in the Toward region

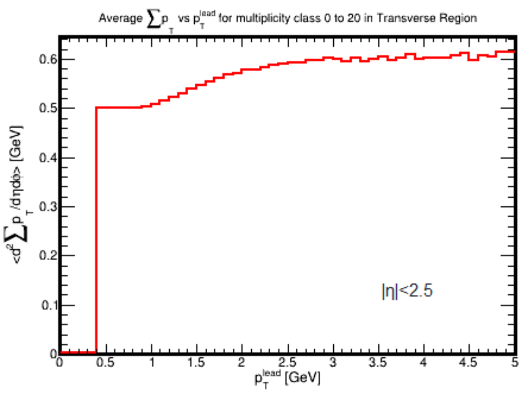

Figure 15: $\frac{d^2\sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 0-20 in the Transverse region

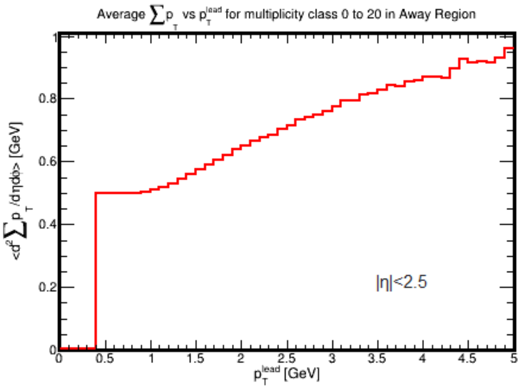

Figure 16: $\frac{d^2 \sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 0-20 in the Away region

Figures 17,18 and 19 represent the scaled scalar $\sum p_T$ as a function of p_T^{lead} for multiplicity class 20 to 40, for the regions Toward, Transverse and Away respectively.

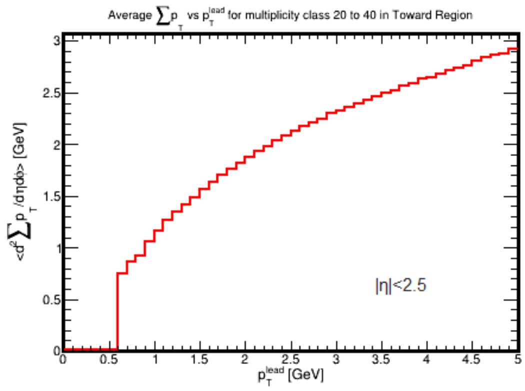

Figure 17: $\frac{d^2 \sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 20-40 in the Toward region

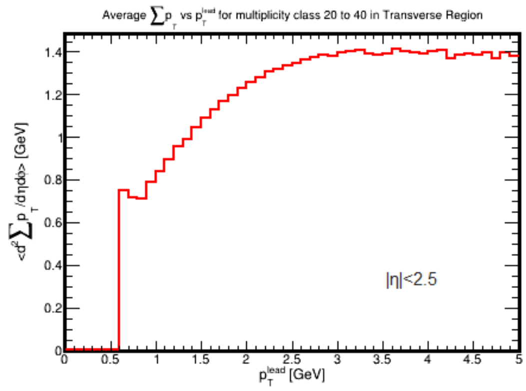

Figure 18: $\frac{d^2 \sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 20-40 in the Transverse region

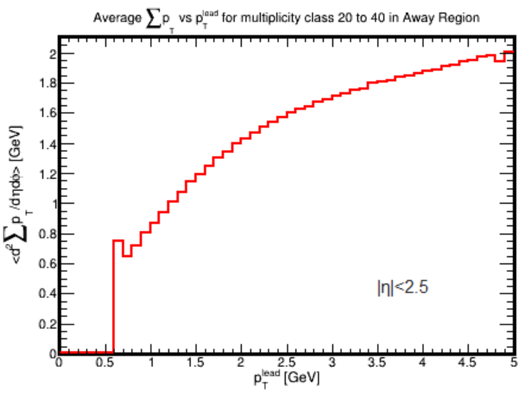

Figure 19: $\frac{d^2 \sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 20-40 in the Away region

Figures 20,21 and 22 represent the scaled scalar $\sum p_T$ as a function of p_T^{lead} for multiplicity class 40 to 60, for the regions Toward, Transverse and Away respectively.

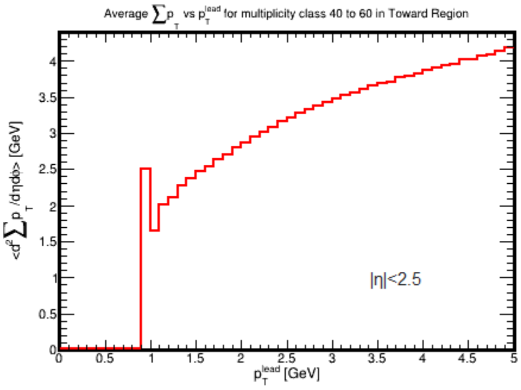

Figure 20: $\frac{d^2 \sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 40-60 in the Toward region

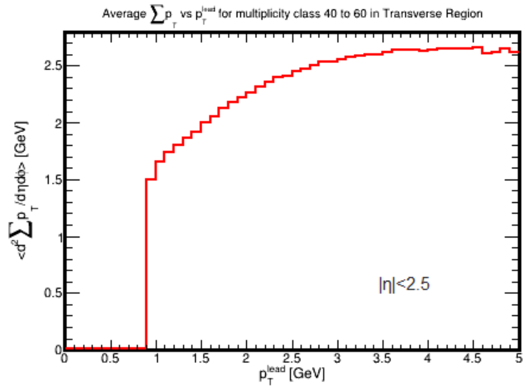

Figure 21: $\frac{d^2 \sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 40-60 in the Transverse region

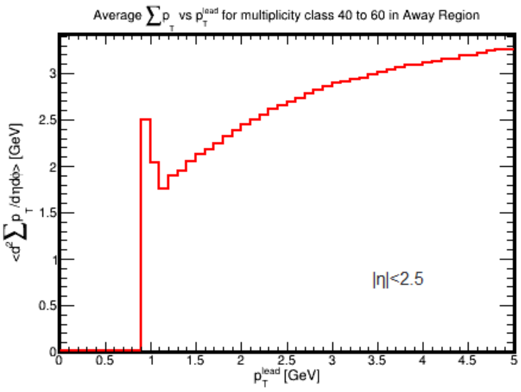

Figure 22: $\frac{d^2 \sum p_T}{d\eta d\phi}$ vs p_T^{lead} for the multiplicity class 40-60 in the Away region

3 Summary

The data from the accompanying interactions of proton-proton collisions were analysed using ROOT, an object-oriented program and first-party library developed by CERN, over various multiplicity classes and directions of momenta. The methodology involved classifying the events based on the azimuthal angle with respect to axis defined by the leading track and the speed of the particle, given in the form of its rapidity. This study was carried out for over 2 million such events and the final results were plotted for the different multiplicity classes. In the first subsection, the frequency histogram of the relative angles subtended by particles with respect to the leading particle was plotted. The density of these emitted charged particles were plotted as a function of the momentum of the leading particle under the second subsection, while the density of the scalar sum over the momenta of particles were plotted against the leading particle momentum as the final subsection. All the figures used, results obtained and the codes have been documented here.

References

[1] G. Aad, Abbott, and et al. Measurement of underlying event characteristics using charged particles in *pp* collisions at $\sqrt{s} = 900$ GeV and 7 tev with the atlas detector. *Phys. Rev. D*, 83:112001, May 2011.