

Studying of underlying event properties in pp collision at $\sqrt{s} = 13$ TeV with the ALICE experiment at the LHC

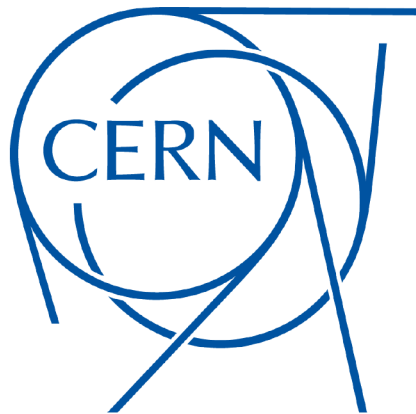
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1 Introduction

Research in ALICE is to study the properties of the Quark-Gluon-Plasma (QGP) with heavy-ion collisions. QGP, the new phase of the matter, will be created by colliding two heavy-ions at relativistic high energy density and temperatures. Under such extreme conditions of high energy density and temperature, a large amount of particles will be produced in heavy-ion collisions. Therefore, heavy-ion collision is a complex system to be studied. To have a better understanding of the heavy-ion collisions, one usually starts with the pp collisions at the same center-of-mass energy since in pp collision we don't expect to have QGP produced and the multiplicity produced in the collision is much less. At LHC (Large Hadron Collider), the collision energies reach to a much higher energy scale and the study of pp collisions at LHC provides new insight of understanding the high multiplicity environment and sets as a reference in heavy-ion collisions.

Both pp and heavy-ion collisions contain soft and hard processes which generate high multiplicities and soft processes can not be calculated by QCD. Therefore, we need to use the phenomenological method to have a good knowledge of these soft production. The measurement of underlying event (UE) provides a way to understand the soft production. The particle productions can be originated from two parts, hard scattering and soft production. The UE is defined as sum of the processes except the hard scattering in the event. The UE includes beam remnants fragmentation, multiple parton interactions (MPI) and initial- and final-state radiation (ISR/FSR). The measurement of UE activity can provide us more comprehensive knowledge of the soft production in the pp and heavy-ion collisions.

So far, the UE properties in pp collisions have been studied using ALICE detector [1] and CMS detector [2]. The measurement of the UE activity has been performed by studying the azimuthal correlation, number densities, and $\sum p_T$ densities in pp collisions at $\sqrt{s} = 0.9$ and 2.76, and 7 TeV. Based on their study, they concluded that the multiplicity of the UE is increasing with center-of-mass energy. After the long shut down of LHC since 2013 (LS1), LHC restarted to take new data with much higher colliding energy. Therefore, study the UE properties in pp collisions with higher energy scale ($\sqrt{s} = 13$ TeV) is essential for us to understand even more complicated heavy-ion collisions.

In this project, we present an analysis of UE activity using ALICE detectors in pp collision at $\sqrt{s} = 13$ TeV.

2 Analysis

In this project, we use the ALICE detector to study pp collisions at $\sqrt{s} = 13$ TeV. We list only the detectors used in this analysis. A full description can be found in [3]. The V0 detector and Silicon Pixel Detectors (SPD) are used for event selection. The Inner Tracking System (ITS) and the Time Projection Chamber (TPC) are used for track selection. The V0 detector is composed of two arrays of scintillator counters, V0A and V0C. The SPD is the first two layers in the Inner Tracking System (ITS) which is the innermost detector in the ALICE detector. The TPC is the main tracking detector.

The data sample used in this project is from ALICE data taking at the center-of-mass energies of $\sqrt{s} =$

13 TeV at LHC 2015. The data sample is from LHC15f pass2 and the total statistics of LHC15f pass2 is about 464 million events. Due to the reason we will discuss at the outlook, we use only one run (225717) from LHC15f pass2. This one run samples about 12.9 million events. The same analysis is also performed with the Monte-Carlo simulations using PYTHIA8 Monash-2013 with the same condition as the data sample. The MC sample is from LHC15g3a3 pass2 and collects about 2.2 million events.

Events are recorded if either of the three triggering systems, V0A, V0C or SPD, has a signal. For each event a reconstructed vertex is required. The vertex reconstruction procedure is based on tracks as well as signals in the SPD. After these standard event selections [4], we require at least one track with $p_T > p_{T,min} = 0.15, 0.5$ or 1.0 GeV/c in the acceptance with $|\eta| < 0.8$. The analysis is based on the primary charged particles only. We define (see Figure 1) the leading charged particle with its momentum, $p_{T,LT}$ and the rest of charged particles in the same event except leading charged particles are defined as associates charged particles with their momenta, $p_{T,associate}$.

The observables of UE activity is presented as following [1][5]:

- Azimuthal correlations

$$\frac{1}{\Delta\eta} \frac{1}{N_{ev}(p_{T,LT})} \frac{dN_{ch}}{d\Delta\phi}$$

- Average number density of charged particles w.r.t leading track transverse momentum $p_{T,LT}$:

$$\frac{1}{\Delta\Phi\Delta\eta} \frac{1}{N_{ev}(p_{T,LT})} N_{ch}(p_{T,LT})$$

- Average $\sum p_T$ density w.r.t. leading track transverse momentum $p_{T,LT}$

$$\frac{1}{\Delta\Phi\Delta\eta} \frac{1}{N_{ev}(p_{T,LT})} \sum p_T(p_{T,LT})$$

$N_{ev}(p_{T,LT})$ is the total number of event selected in a given $p_{T,LT}$ bin. $\Delta\phi$ is used to define three different regions (see Figure 1). These regions are defined as toward, away and transverse regions event by event according to the leading particle direction. The toward region contains the leading track and the fragmentation of the hard scattering at the same side. The away region is back to the toward region and collects fragmentation of the hard scattering in opposite side. The transverse region is the region perpendicular to the leading track. In further definition, the transverse region divides into two regions, transMAX and transMIN regions, event by event. transMAX is defined as the transverse region with larger $\sum p_T$ and transMIN is defined as the region with smaller $\sum p_T$. The coverage of different regions in each event are defined as the following:

- Toward region: $|\Delta\phi| < 1/3\pi$
- Transverse region: $1/3\pi < |\Delta\phi| < 2/3\pi$
- Away region: $|\Delta\phi| > 2/3\pi$

where $\Delta\phi = \phi_{LT} - \phi$ is defined in $\pm\pi$ (see Figure 1). The normalization factor $\Delta\eta$ is equal to 1.6 because of the range of η is from -0.8 to 0.8 and $\Delta\Phi$ is equal to $2/3\pi$, which is the size of each region.

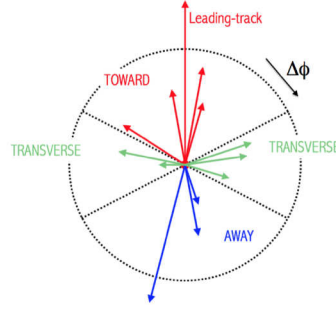


Figure 1: Definition of the three regions[1].

The first step of our analysis is to run data and MC samples with source codes in PWGCF. The classes implemented in this analysis is as the following:

- \$ALICE_PHYSICS/PWGCF/Correlations/DPhi/AliAnalysisTaskLeadingTrackUE
- \$ALICE_PHYSICS/PWGCF/Correlations/macros/underlyingevent/AddTaskLeadingTrackUE.C

After running the samples, AnalysisResult.root files will be generated. Then, we use the result files to do our analysis. The analysis of UE activity starts at plotting the $\Delta\phi - \eta$ correlation. The $\Delta\phi - \eta$ correlation is a two-dimensional plot of $d^2N_{ch}/d\eta d\Delta\phi$ with respect to $\Delta\phi$ and η . With doing this, we can check the $\Delta\phi - \eta$ correlation of leading particle and the associated particles. The results of $\Delta\phi - \eta$ correlation with $p_{T,associate} > 0.5$ GeV are shown in Figure 2. The range of η is from -0.8 to 0.8 and the range of $\Delta\phi$ is from $-1/2 \pi$ to $3/2 \pi$. The results indicate that there are different characterization in different regions. In the toward and away regions, there are dominated by charged particles from hard scattering. Therefore, The $d^2N_{ch}/d\eta d\Delta\phi$ in toward region is largest in three regions, and the $d^2N_{ch}/d\eta d\Delta\phi$ in away region is secondly larger. The transverse region is dominated by UE, and the number density in the transverse region is lowest in three regions. Moreover, The $d^2N_{ch}/d\eta d\Delta\phi$ decreases with the increase of $p_{T,associate}$ threshold due to the fact that hard scattering is more dominate when triggering with higher $p_{T,LT}$ particles.

After getting the plots of $\Delta\phi - \eta$ correlation, we do a project on the $\Delta\phi$ in a given leading-track transverse-momentum bin. Then, we normalize $dN_{ch}/d(\Delta\phi)$ with the normalization factor $N_{ev}\Delta\eta$. Finally, We get the Azimuthal correlation, which is the $\Delta\phi$ distribution. The results of Azimuthal correlation with respect to different $p_{T,LT}$ bins are shown in Figure 3 and Figure 4. The results show that, in the same $p_{T,associate}$ threshold, $d^2N_{ch}/d\eta d\Delta\phi$ increases with increasingly higher $p_{T,LT}$ bins. When $p_{T,LT}$ increases, the events will be dominated by production of hard scattering. Therefore, $d^2N_{ch}/d\eta d\Delta\phi$ will show an obvious pattern that $d^2N_{ch}/d\eta d\Delta\phi$ in the toward and away regions are bigger than in the transverse region.

After finishing the analysis of Azimuthal correlation, we can use the integral of $\Delta\phi$ distribution in each region to get the number density in a given leading-track transverse-momentum bin. Then we collect the number densities in different leading-track transverse-momentum bins in each region and plot the

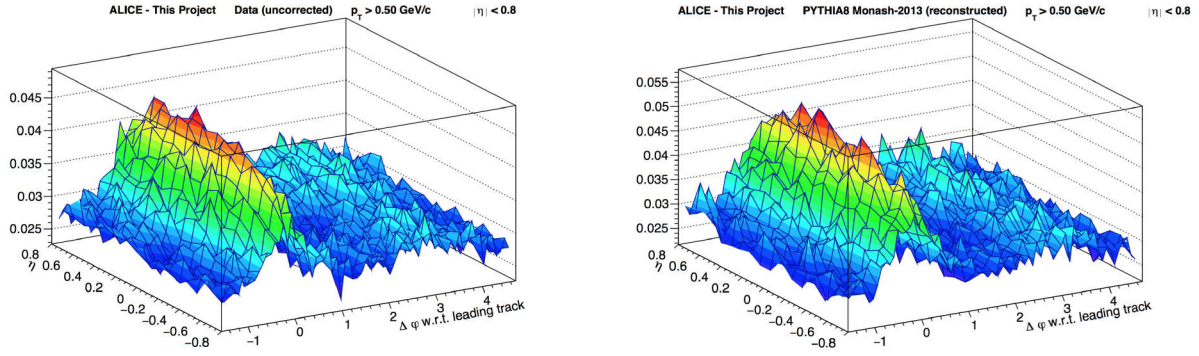


Figure 2: $\Delta\phi - \eta$ Correlation from data (left) and MC (right) with $p_{T,associate} > 0.15$ GeV/c at $\sqrt{s} = 13$ TeV.

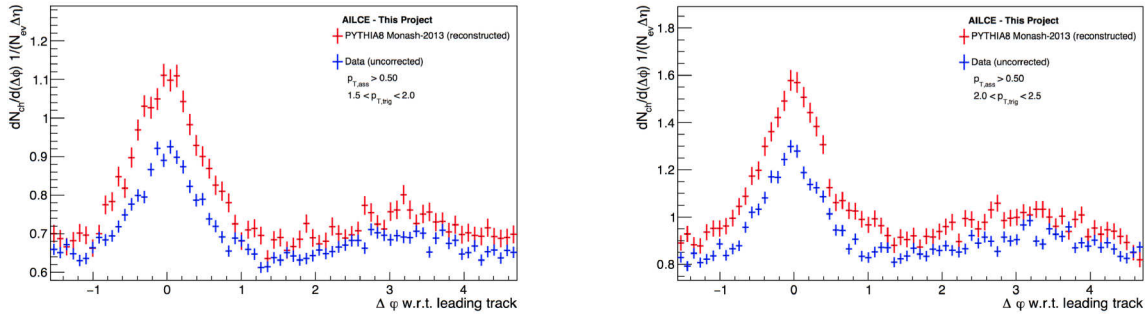


Figure 3: Azimuthal correlation with $p_{T,associate} > 0.5$ GeV/c. Leading track: $1.5 < p_{T,LT} < 2.0$ GeV/c (left) and $2.0 < p_{T,LT} < 2.5$ GeV/c (right)

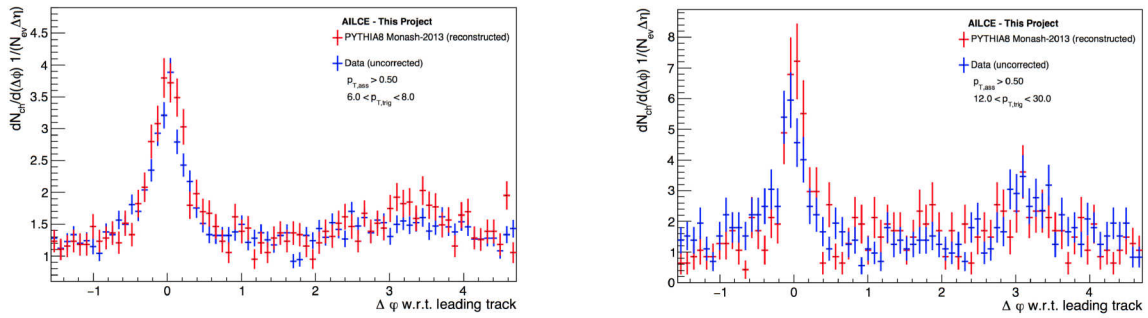


Figure 4: Azimuthal correlation with $p_{T,associate} > 0.5$ GeV/c. Leading track: $6.0 < p_{T,LT} < 8.0$ GeV/c (left) and $12.0 < p_{T,LT} < 30.0$ GeV/c (right)

Number Density as a function of $p_{T,LT}$. We present the results of number density with respect to $p_{T,LT}$ in Figure 5, 6, 7 (left). Toward and away regions are dominated by hard scatterings and collect the fragmentation of the hard process. Therefore, number density in toward and away regions monotonically increase. The transverse region are dominated by UE. The figure of transverse region shows a rapidly increasing when $p_{T,LT} \lesssim 5$ GeV/c and becomes saturate when $p_{T,LT} \gtrsim 5$ GeV/c.

The final step of my work is to analysis the $\sum p_T$. The $\sum p_T$ is the sum of the associated momenta in each region. The $\sum p_T$ analysis can be divided into three regions in each event as defined previously. For transverse region, we categorize the events into transMAX, and transMIN according to $\sum p_T$. In each region, we integrate the $\sum p_T$ in a given leading-track transverse-momentum bin. Then, we plot the $\sum p_T$ with respect to the specific $p_{T,LT}$ bins in each region. The results are shown in Figure 5, 6, 7 (right). The trends of $\sum p_T$ in different regions are similar to number density. In toward and away region, $\sum p_T$ increases with respect to $p_{T,LT}$ bins. In transverse region, $\sum p_T$ become flat when $p_{T,LT}$ is above about 5 GeV/c.

3 Outlook

In this project, we obtain the results which are similar with the measurment using ALICE detector in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV. We have done the analysis of the azimuthal correlation in the different $p_{T,LT}$ bins and observed an increase in $dN_{ch}/d(\Delta\phi)$ comparing to the results in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV. Furthermore, We have done the analysis of number density and $\sum p_T$ density with respect to $p_{T,LT}$. Number density and $\sum p_T$ density in toward and away regions are monotonically increasing with the increasing of $p_{T,LT}$. These show the hard processes are dominated in both toward and away regions. Number density and $\sum p_T$ density in transverse region are flat when $p_{T,LT}$ is above about 5 GeV/c. The measurment of UE activity in this project provide us a good understanding of the UE and a baseline of heavy-ion collisions.

In this project, we have still not done a completed analysis due to the lack of time. First, We do not run all the samples on the grid and LEGO trains to get a full statistics of the datasets because the binning of $p_{T,associte}$ and the $p_{T,LT}$ in the origin source codes are not suitable for my analysis. Desptie that we can run the samples on the grid, we can't get an AnalysisResults.root with correct binning. Therefore, we run the samples on the local machine, and use the results files with correct binning to do our analysis. Due to this problem, we do not run all the statistics otherwise it will take much time. Moreover, we cannot change the binning by ourselves if we want to run on the grid because they are initialized in the source codes and customized for earlier data analysis only. Therefore, if we want to have a further studying of UE analysis with PWGCF codes, a better way to improve this situation is to introduce a function to enable the binning outside the source codes by analyzers. By doing this, we can define the binning for different analysis outside the source codes and avoid chaning the source codes each time required. Secondly, the data used in this analysis are still uncorrected. In a further studying of this project, we need to have a completed correction procedure and apply the correction factors on each observable. Finally, we have not evaluated the systematic uncertainties yet. The evaluation of systematic uncertainties is needed to make a full analysis.

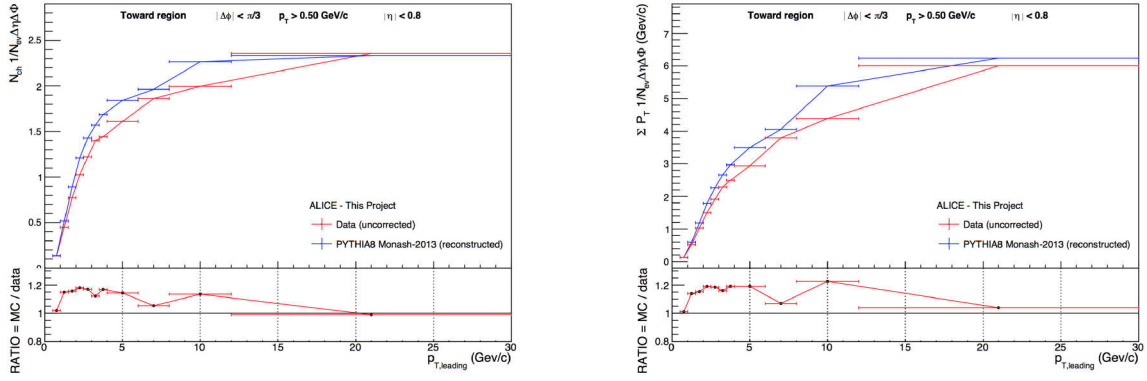


Figure 5: Number Density (left) and Σp_T (right) in Toward region. Track transverse momentum: $p_{T,associate} > 0.5 \text{ GeV}$. Data and MC are red and blue lines, respectively.

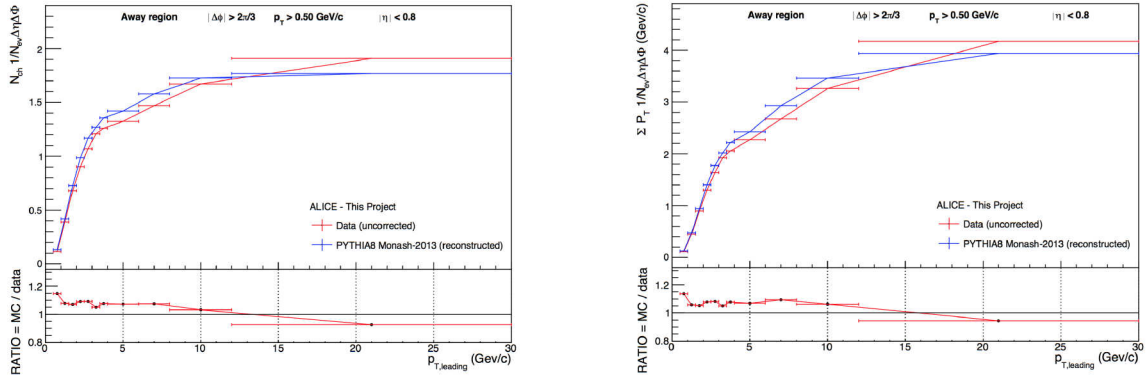


Figure 6: Number Density (left) and Σp_T (right) in Away region. Track transverse momentum: $p_{T,associate} > 0.5 \text{ GeV}$. Data and MC are red and blue lines, respectively.

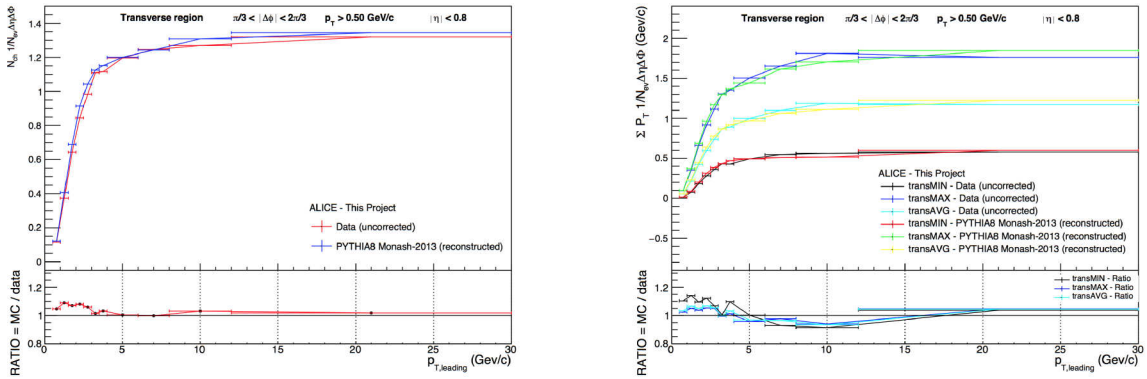


Figure 7: Number Density (left) and Σp_T (right) in Transverse region. Track transverse momentum: $p_{T,associate} > 0.5 \text{ GeV}$. Data and MC are red and blue lines, respectively.

Reference

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