Study of the PYTHIA $\Delta \eta \Delta \phi$ correlation as a function of multiplicity and transverse sphericity in proton-proton collisions at 7 TeV.

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Abstract. The study and understanding of the details of proton-proton collisions is important since they are the benchmark for the comparison with heavy ion results. In the present work we have studied the $\Delta \eta \Delta \phi$ correlations as a function of the event multiplicity and transverse sphericity in pp collisions at $\sqrt{s} = 7$ TeV using the PYTHIA 8.180 generator. The results show large variation in the shape of the correlation as function of the sphericity and multiplicity indicating the importance of slicing the data in bins of both observables to better understand the complexity of the interactions. Motivated by the flow like patterns originated by color reconnection (CR), results with and without CR together with dihadron correlations are discussed.

1. Introduction
The pp collisions have a complicated structure which involves complex final states, with large multiplicities of hadrons, all originated from different processes [1], this complexity of the interactions requires MC event generators to simulate them. PYTHIA[2] is an event generator which comprises a coherent set of physics models for the evolution from a few-body hard process to a complex multihadronic final state. Hadronic processes can be classified as being either soft or hard.

Different techniques of analysis are used to investigate the properties of the hadronic interactions, among them the dihadron azimuthal correlations. Using this observable, an interesting ridge-shaped correlation has been discovered in heavy nuclei collisions. Some models attribute the ridge to jet-medium interactions, while others attribute it to the medium itself [3]-[4]. Recent results from CMS have observed a striking ridge structure in very high multiplicity proton-proton (pp) collisions at a center-of-mass energy of 7 TeV. This novel structure resembles similar features observed in relativistic heavy-ion experiments [3]. Several mechanisms like Color-Glass Condensate based on initial state nonlinear gluon interactions[5] and elliptic flow[6] have been proposed to explain the phenomenon.

Although the effect observed by CMS, cannot be reproduced[4] by PYTHIA 8.180, in this work we investigate the possible presence of the ridge, studying the dihadron correlation as a function of the event shape variable, since it allows to control the amount of MPI[7]. According with Ref.[8] the color reconnection mechanism (CR) produces effects which mimics radial flow...
in events with a large number of multi-partonic-interactions and the same effect might produce elliptic flow.

At hadron colliders the event shape analyses are restricted to the transverse plane in order to avoid the bias from the boost along the beam axis. The transverse sphericity ($S_T$) is defined in terms of eigenvalues $\lambda_1 > \lambda_2$ of the transverse momentum matrix:

$$S_{xy} = \frac{1}{\sum_i p_T^i} \sum_i \frac{1}{p_T^i} \left( \begin{array}{cc} p_{x_i}^2 & p_{x_i} p_{y_i} \\ p_{y_i} p_{x_i} & p_{y_i}^2 \end{array} \right)$$

in the following way

$$S_T \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}.$$  \hspace{1cm} (2)

The limit values of this variable are related to specific configuration in the transverse plane

$$S_T = \begin{cases} 0 & \text{“pencil like” limit} \\ 1 & \text{“isotropic” limit} \end{cases}$$

2. Analysis Details

Using the PYTHIA 8.180 event generator we analyzed primary charged particles from 500 million of events with CR and the same without CR. In order to have a good description of the sphericity, events with more than two particles and $p_T > 0.5$ GeV/c are selected, and is calculated with all the particles within the pseudorapidity region $|\eta| < 1.0$. The leading particle is selected in the pseudo-rapidity range $|\eta| < 1.0$, the same as sphericity, and having the $\eta$ range open for the associated particle. In this work the trigger and associated particle are not selected in a certain momentum range, as done in the conventional dihadron correlation analyses. Our leading particle is the one with the highest transverse momentum in each event, and the associated particles are all the others that fulfill the $p_T$ and $\eta$ cuts previously described. Thus, the correlation is built by taking the differences in $\eta$ and $\phi$ between the leading and the associated particles:

$$\Delta \eta = \eta^{assoc} - \eta^{lea}$$

$$\Delta \phi = \phi^{assoc} - \phi^{lea}$$

Where $\eta^{lea}$ and $\phi^{lea}$ ($\eta^{assoc}$, $\phi^{assoc}$) are the pseudo-rapidity and the azimuthal angle of the leading particle (associated), respectively.

A plot of the dihadron correlations for minimum bias events is shown in figure 1. Two prominent structures are visible, one at $(\Delta \phi, \Delta \eta) \approx 0$, known as “near side peak”, and correspond to correlations from single jets. The second structure the “away side peak” is present at $\Delta \phi \approx \pi$ and corresponds to back-to-back jet correlations.
Figure 1. $\Delta \eta - \Delta \phi$ correlation for a leading and associated particle selected in the region $|\eta| < 1.0$, where multiplicity and sphericity cuts are not applied.

3. Results

The results are presented using two sphericity ranges: $S_T < 0.1$ and $0.9 < S_T$, jetty-like and isotropic events, respectively. The correlations are computed as a function of multiplicity of the events. The multiplicity is expressed in function of $z = (dN_{ch}/d\eta)/\langle dN_{ch}/d\eta \rangle$, i.e. the ratio of the multiplicity and the mean multiplicity. The multiplicity ranges presented are: $z < 1$, $2 < z < 3$ and $4 < z$. The correlations are normalized to the number of leading particles (same as number of events) in each sphericity range being analyzed.

Figure 2 shows the dihadron correlation for low sphericity events (jetty-like, $S_T < 0.1$), where no ridge proper structure has been observed in the ranges studied although an extended structure of the near side peak is observed that will be the subject of farther studies.
Figure 2. Dihadron correlations for low sphericity events ($S_T < 0.1$) in three multiplicity ranges, CR is activated. (a) for $z < 1$; (b) for $2 < z < 3$ and (c) for $4 < z$.

Figure 3 shows the dihadron correlations for $S_T > 0.9$ in three multiplicity ranges, where an interesting and unexpected double hump structure appears, even though in PYTHIA the processes $2 \rightarrow 3$, that are observed as “T” event structures, are suppressed with respect to the $2 \rightarrow 2$ processes. Similar structures are present when color reconnection mechanism is switched off, so the shape is not due to a flow effect. This has been already reported in [9].

The projections on the $\Delta \phi$ axis of the dihadron correlations, normalized to the number of events in the multiplicity range, show the underlying structures for three different ranges in the transverse sphericity. In the jetty events ($S_T < 0.1$) we observe the expected near and away side peaks, for high sphericity ($0.9 < S_T$) we observe the double hump. For the intermediate sphericity ($0.4 < S_T < 0.7$) we observe a broad away side with some structure. Figure 4 shows these projections together with the black curve representing the projection of all events in a given multiplicity range. We can see that the total correlation shape is a sum of different structures, that are identified by the use of the sphericity variable.
Figure 3. Dihadron correlations for high sphericity events ($S_T > 0.9$) in three multiplicity ranges, CR is activated, (a) for $z < 1$; (b) for $2 < z < 3$ and (c) for $4 < z$.

Figure 4. Projection in the $\Delta \phi$ axis selecting three $S_T$ regions and three multiplicity ranges: (a) for $z < 1$; (b) for $2 < z < 3$ and (c) for $4 < z$. Black points represent the events with no sphericity cut.
4. Conclusions
In this work we have introduced transverse sphericity to analyze dihadron correlations. By using this event shape variable, we were able to analyze different types of events like those dominated by jetty like and/or isotropic structures. For high sphericity events we observe that the “T” structures events are enhanced, it is seen in the dihadron correlation figure 3 where double hump structures are present, this structures are located at $\Delta \phi \approx \pi/2$ and $\Delta \phi \approx -\pi/2$. We have shown that by sectioning p-p events in ranges of sphericity one uncovers the so called underlying event[10], usually treated as an amorphous structure. Actually has a rich structure and the usual treatment consisting to study the prominent jetty like structures in the near and away side subtracting a uniform background using the so called ZYAM method may give erroneous results.

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