A review on event shape studies in ultra-relativistic collisions at the LHC energies

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Introduction

Recent measurements of high multiplicity pp collisions at LHC energies have revealed that these systems exhibit features similar to quark-gluon plasma, such as the presence of radial and elliptic flow and strangeness enhancement, traditionally believed to be only achievable in ultra-relativistic nucleus-nucleus collisions [1]. To pinpoint the origin of these phenomena and to bring all collision systems in equal footings, along with charged-particle multiplicity ($N_{\rm ch}$), lately several event shape observables such as transverse spherocity (S_0), transverse sphericity ($S_{\rm T}$), charged particle flattenicity ($\rho_{\rm ch}$), and relative transverse activity classifiers such as $R_{\rm T}$, $R_{\rm T}^{\rm min}$, and $R_{\rm T}^{\rm max}$ has been used extensively in experiments as well as in the phenomenological front. One of the explanations of the QGP-like behavior is the multipartonic interactions (MPI) based picture with colour reconnection and ropes. The event-shape classifiers have shown a significant correlation with MPI which makes them the ideal tool for the understnding of QGP-like effects.

In this contribution, we will summarise our phenomenological explorations [2–6] and compare them with experimental results from LHC to conclude our learning so far from these studies. We observe that the event shape observables successfully identify the soft-QCD-dominated isotropic events and the pQCD-dominated jetty events from the average-shaped events. They are even shown to be successful in finding the rare events where the QGP-like events are expected to be more prominent. We also propose to use machine learning methods for the determination of such observables in a dense environment like heavy-ion collisions. In addition, we will provide a outlook in view of Run 3 at the LHC.

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Results and Discussions

The event classifiers discussed here include the $N_{\rm ch}$ in the mid- and forward-pseudorapidity, S_0, $S_0^{p_{\rm T}=1}$, $\rho_{\rm ch}$, $R_{\rm T}$, $R_{\rm T}^{\rm min}$, and $R_{\rm T}^{\rm max}$. For the estimation of $R_{\rm T}$, a transverse region is defined with respect to the highest-$p_{\rm T}$ particle of the event, *i.e.*, $\pi/3 < |\Delta\phi| < 2\pi/3$, which is expected to be dominated with the underlying events (UE). The charged particle multiplicity of the transverse region is scaled with its event-average value to obtain $R_{\rm T}$, *i.e.* $R_{\rm T} = N_{\rm ch}^{\rm T}/\langle N_{\rm ch}^{\rm T}\rangle$. Similarly, for $R_{\rm T}^{\rm min}$, and $R_{\rm T}^{\rm max}$, the transverse region is again subdivided into $\pi/3 < \Delta\phi < 2\pi/3$ and $-\pi/3 > \Delta\phi > -2\pi/3$. The charged particle multiplicity in these two regions is determined. For each event, the region with higher multiplicity contributes to $R_{\rm T}^{\rm max}$ while the region with less multiplicity contributes to $R_{\rm T}^{\rm min}$. S_0 is defined for a unit vector $\hat{n}$ in the transverse plane, which minimises the ratio, as follows.

$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \Big(\frac{\sum_{i=1}^{N_{\rm had}} |\mathbf{p}_{\rm T} \times \hat{\mathbf{n}}|}{\sum_{i=1}^{N_{\rm had}} |\mathbf{p}_{\rm T}|} \Big)^2 \qquad (1)$$

In Eq. 1, the summations run over all the charged hadrons ($N_{\rm had}$). By construction, S_0 lies between 0 and 1, where the value '0' represents the jetty events while '1' is for the isotropic events. Similarly, flattenicity ($\rho_{\rm ch}$) is determined in the forward-rapidity region, where the $(\eta-\phi)$ space is divided into (8×10) cells and charged particles in each cell 'i'

($N_{\rm ch}^{\rm cell,i}$) is estimated. Thus, $\rho_{\rm ch}$ can be estimated using the following equation.

$$\rho_{\rm ch} = \frac{\sqrt{\sum_i (N_{\rm ch}^{\rm cell,i} - \langle N_{\rm ch}^{\rm cell}\rangle)^2}}{\langle N_{\rm ch}^{\rm cell}\rangle} \tag{2}$$

Here, $\langle N_{\rm ch}^{\rm cell}\rangle$ is the mean number of charged particles in the cells. By construction, $\rho_{\rm ch}$ ranges from 0 to 1, where the lower limit 0 indicates isotropic events while 1 indicates jetty events.

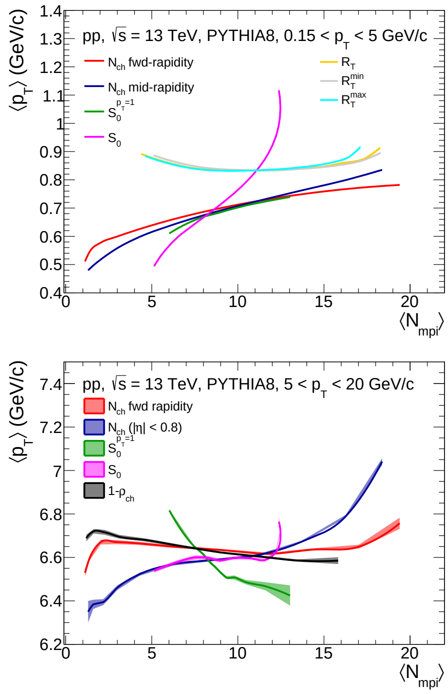

FIG. 1: Mean transverse momentum ($\langle p_{\rm T}\rangle$) vs mean number of MPI ($N_{\rm mpi}$) for different event classifiers estimated at $0.15 < p_{\rm T} < 5$ GeV/c (top) and $p_{\rm T} > 5$ GeV/c (bottom) in pp collisions at $\sqrt{s} = 13$ TeV using PYTHIA8.

Figure 1 shows mean transverse momentum ($\langle p_{\rm T}\rangle$) vs the mean number of multi-partonic interactions ($\langle N_{\rm mpi}\rangle$) for different percentiles of different event classifiers estimated at $0.15 < p_{\rm T} < 5$ GeV/c (top) and $p_{\rm T} > 5$ GeV/c (bottom) in pp collisions at $\sqrt{s} = 13$ TeV using PYTHIA8. As shown in Fig. 1 (top), all the event classifiers are correlated with $N_{\rm mpi}$ and $\langle p_{\rm T}\rangle$. When studied for low-$p_{\rm T}$ particles, $\langle p_{\rm T}\rangle$ vs $\langle N_{\rm mpi}\rangle$ correlation shows similar behaviour for charged-particle multiplicity selection in mid and forward-rapidity. The traditional definition of transverse spherocity has a broader coverage of $\langle p_{\rm T}\rangle$. After setting $p_{\rm T} = 1$ for the calculation, the behaviour is more consistent with selection on charged-particle multiplicity. For a given $\langle N_{\rm mpi}\rangle$, $R_{\rm T}$ has access to higher $\langle p_{\rm T}\rangle$ regions. Flattenicity and forward-$N_{\rm ch}$ selection show a similar correlation. When studied for high-$p_{\rm T}$ particles, $\langle p_{\rm T}\rangle$ vs $\langle N_{\rm mpi}\rangle$ correlation shows a selection bias for Nch and spherocity selection. $S_0^{p_{\rm T}=1}$ and $\rho_{\rm ch}$ shows less bias compared to other event classifiers.

Summary

A summary of event shape classifiers which are being used to separate jet-like and isotropic events is discussed, and the coverage of event classifiers in average number of MPI and average transverse momentum will be highlighted. In addition, a detailed comparison with experimental results from LHC will be shown to conclude our learning so far from these studies. Based on these studies, we will provide our recommendations on the usage of these classifiers to experimental colleagues in view of Run 3 at the LHC.

References

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