

Disentanglement of hard and soft QCD processes using two-particle correlation functions

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Abstract. Transverse sphericity (S_0) has evolved as a powerful method to distinguish between soft and hard contributions in an event in small collision systems. We used the two-particle differential-number correlation functions (R_2) and transverse momentum correlation functions (P_2) of charged particles produced in pp collisions at $\sqrt{s} = 7$ TeV with the PYTHIA8 model to explore this phenomena. The $\Delta\varphi$ projections of these correlation functions in different multiplicity and S_0 classes are discussed. We find that these correlation functions show different shapes and sizes in both near- and away-side with multiplicity and S_0 classes. We observe a strong correlation in the near- and away-side of these correlation functions for jetty-like (hard QCD processes), which become weaker for isotropic (soft QCD processes) in sphericity classes as compared to multiplicity classes. Finally, it is observed that S_0 should be a good observable as compared to multiplicity to disentangle hard and soft QCD processes in a small collision system.

1. Introduction

The particle production mechanism is revealed by studying the correlation functions of the charged particles at relativistic energies at RHIC and LHC [1, 2]. The differential number correlator, R_2 , and transverse momentum correlator, P_2 , are sensitive to the particle production mechanisms and transverse momentum fluctuations [3], respectively. In order to distinguish between the contributions of the hard and soft processes in an event, transverse sphericity (S_0), an event shape variable, and multiplicity dependent results for R_2 and P_2 for different percentile classes were compared in this study. This helps to understand the sensitivity of these correlators to regions dominated by jets as well as underlying events in pp collisions. In this study, the events are selected with a minimum constraint of 15 charged particles in the p_T range 0.15 - 10 GeV/c and $|\eta| < 0.8$ in pp collisions at $\sqrt{s} = 7$ TeV with the PYTHIA8 [7] event generator.

2. Definitions of observables

We start by defining the two-particle correlation functions that will be used in this study in Sec. 2.1, then we go on to Sec. 2.2 to define the transverse sphericity.

2.1. Two-particle correlation functions: R_2 and P_2

The R_2 [4, 5] is defined as a ratio between two-particle density (ρ_2) and the product of single particle densities (ρ_1), then subtracted by unit in $\Delta\eta$ - $\Delta\varphi$ space as follows



$$R_2(\Delta\eta, \Delta\varphi) = \frac{\rho_2(\Delta\eta, \Delta\varphi)}{\rho_1 \times \rho_1(\Delta\eta, \Delta\varphi)} - 1. \quad (1)$$

Similarly, P_2 [4, 5] is defined as the ratio of differential correlator ($\langle \Delta p_T \Delta p_T \rangle$) to the square of the mean transverse momentum, p_T , to make it dimensionless like R_2 , in $\Delta\eta$ - $\Delta\varphi$ space as follows

$$\begin{aligned} P_2(\Delta\eta, \Delta\varphi) &= \frac{\langle \Delta p_T \Delta p_T \rangle(\Delta\eta, \Delta\varphi)}{\langle p_T \rangle^2} \\ &= \frac{1}{\langle p_T \rangle^2} \times \frac{\int_{p_{T,\min}}^{p_{T,\max}} dp_{T,1} dp_{T,2} \rho_2(\vec{p}_1, \vec{p}_2) \Delta p_{T,1} \Delta p_{T,2}}{\int_{p_{T,\min}}^{p_{T,\max}} dp_{T,1} dp_{T,2} \rho_2(\vec{p}_1, \vec{p}_2)}. \end{aligned} \quad (2)$$

where $\Delta p_{T,i} = p_{T,i} - \langle p_T \rangle$ and $\langle p_T \rangle$ is the inclusive mean transverse momentum.

Due to angular and transverse momentum ordering in the production of particles from jets and hadronic resonance decays, P_2 is driven by the momentum of the correlated particles, which is important in comparison to R_2 .

2.2. Sphericity (S_0)

Transverse sphericity [6], simply known as sphericity, is used to distinguish between hard and soft QCD processes and is given by

$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\sum_i |p_{T,i} \times \hat{n}|}{\sum_i p_{T,i}} \right)^2 \quad (3)$$

where $\hat{n}(n_T, 0)$ is the unit vector which minimizes S_0 . S_0 varied from 0 for jetty-like events, to a maximum of 1 for isotropic events.

In order to better comprehend the sphericity observable, the projection of $R_2(\Delta\eta, \Delta\varphi)$ and $P_2(\Delta\eta, \Delta\varphi)$ correlation functions along $\Delta\varphi$ is investigated for ten equal percentile classes in sphericity as well as multiplicity.

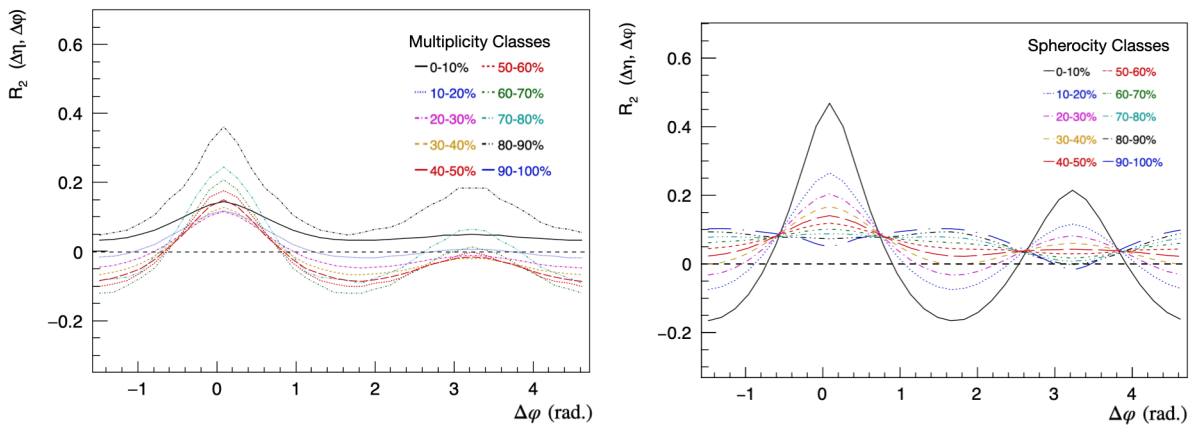


Figure 1. The projection of $R_2(\Delta\eta, \Delta\varphi)$ along $\Delta\varphi$ for multiplicity classes (left panel) and sphericity classes (right panel) of charged hadrons in pp collisions at $\sqrt{s} = 7$ TeV with the PYTHIA8 model.

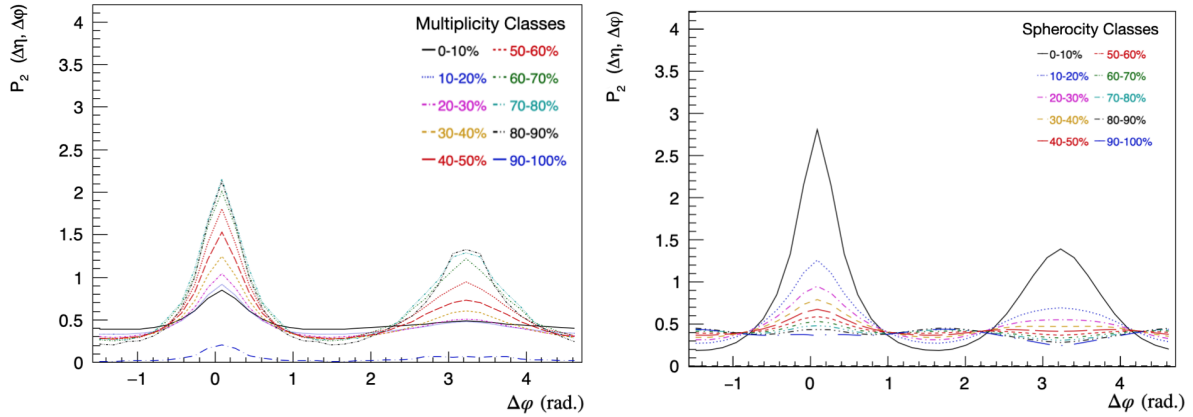


Figure 2. The projection of $P_2(\Delta\eta, \Delta\varphi)$ along $\Delta\varphi$ for multiplicity classes (left panel) and sphericity classes (right panel) of charged hadrons in pp collisions at $\sqrt{s} = 7$ TeV with the PYTHIA8 model.

3. Results

The projections of $R_2(\Delta\eta, \Delta\varphi)$ and $P_2(\Delta\eta, \Delta\varphi)$ correlation functions onto $\Delta\varphi$ are shown for different multiplicity classes (left panel) and sphericity classes (right panel), respectively, in Figs. 1-2. In comparison to multiplicity classes, the near- and away-side peak of R_2 and P_2 is more pronounced and distinct for sphericity classes. Again, because of the angular ordering of the jet constituents [5], P_2 is narrower than R_2 .

4. Summary

We presented a study of the two-particle differential-number correlation functions, R_2 , and transverse momentum (p_T) correlation functions, P_2 , of charged particles for different multiplicity and sphericity classes in pp collisions at $\sqrt{s} = 7$ TeV using PYTHIA8 Monte Carlo model. In comparison to multiplicity classes, the magnitude of the modulation has a significantly stronger correlation with sphericity classes for both R_2 and P_2 . Additionally, it is noticed that the near-side peak of P_2 is narrower than that of R_2 , which is mostly due to the angular ordering of hadrons produced in jets.

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