Insight into the light-flavour particle production mechanism from studies of the transverse spherocity dependence in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE at the LHC

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Abstract. The Large Hadron Collider (LHC) Run 1 and Run 2 data revealed heavy-ion-like features such as enhanced strangeness production and long-range azimuthal correlation in high-multiplicity pp collisions paving the way to rethink particle production in small collision systems. Event shape observables like transverse spherocity are sensitive to isotropic and jet-like topologies, which are useful tools to distinguish the pp collisions dominated by soft or hard physics. The interplay between multiplicity and transverse spherocity on light-flavour particle production can be understood by comparing the results obtained by selecting multiplicity and/or transverse spherocity. This contribution presents recent results on light-flavour particle production (π, K, p, ϕ, K^{*0}, K_s^0, Λ, Ξ) at midrapidity obtained by the ALICE experiment in pp collisions at $\sqrt{s}$ = 13 TeV as a function of event multiplicities and transverse spherocity. The results are even obtained by going to the most extreme selections such as the highest 0–1% in multiplicity and the highest 0–10% in transverse spherocity. The results include the transverse momentum spectra, yields, $\langle p_T \rangle$ and their ratios. These measurements will be compared with the Monte Carlo (MC) predictions obtained from models such as PYTHIA8, EPOS and Herwig7.

1 Introduction

Quark Gluon Plasma (QGP), a deconfined state of quarks and gluons, is produced in heavy-ion collisions. However, the observations of QGP signatures like the strangeness enhancement [1] and double ridge structure [2] in high-multiplicity proton–proton (pp) collisions at the LHC indicate the possible formation of QGP droplets in pp collisions. These discoveries have important consequences on whether to use the pp collisions as a baseline to understand a medium formation in heavy-ion collisions. Thus, a closer look at the underlying physics mechanisms in pp collisions has become essential. Unlike the lower collision energies, where pp has been used as a reference measurement to study heavy-ion collisions, the pp collisions at the LHC energies have brought up new challenges and opportunities in terms of their high-multiplicity environment to study many emergent phenomena. In this direction, one uses the recently introduced transverse spherocity to separate jet-like and isotropic events in pp collisions, as the production dynamics for both are different. The jet-like events involve high

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transverse momentum (p_T) phenomena that are described by perturbative Quantum Chromo-dynamics (pQCD), while the isotropic events are mostly dominated by soft-physics (low-p_T). Figure 1a, shows the typical pp collisions for scenarios of back-to-back jet production and azimuthal isotropic particle distribution. Further, we will discuss the event shape dependence of light flavor identified particle production in pp collisions using the ALICE detector in detail.

2 Transverse spherocity (S_0)

Transverse spherocity is one of the event-shape techniques used to separate isotropic and jet-like events in high-energy collisions and is given as:

$$S_0^{p_T=1} = \frac{\pi^2}{4} \left(\frac{\sum_i |\hat{p}_{T_i} \times \hat{n}|}{N_{trks}} \right)^2.$$ (1)

For this study, we have used the unweighted transverse spherocity, where $p_T = 1$ for all the tracks. The sum is calculated over all charged particles with $p_T > 0.15$ GeV/c, where $\hat{p}_T$ represents the transverse momentum unit vector, N_{trks} is the number of charged particles in a given event and $\hat{n}$ is the unit vector that minimizes the S_0 value for an event. By construction, the limits of transverse spherocity range between 0 and 1.

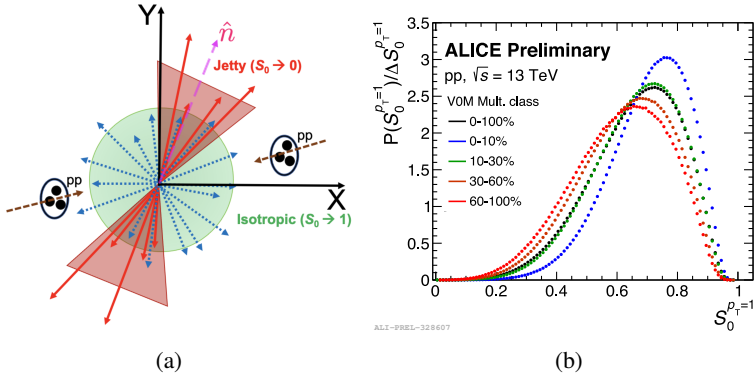(a)   (b)

Figure 1: (a) Schematic diagram of isotropic and jet-like events. (b) Transverse spherocity at $\sqrt{s} = 13$ TeV for different multiplicity classes.

The minimum number of required tracks per event is set to be 10 to have a meaningful spherocity value. The transverse spherocity as a function of multiplicity classes computed with the V0M estimator is shown in the Figure 1b for $\sqrt{s} = 13$ TeV. The transverse spherocity distribution shifts towards a higher value of S_0 with higher charged particle multiplicity classes. This tells that events with high charged particle multiplicities are more isotropic in nature due to the multi-partonic interactions. In this proceeding, the results obtained with the high multiplicity pp collisions using both V0M and $N_{Tracklets}$ multiplicity estimators are presented.

3 Results and discussion

Earlier ALICE measurements show a strong correlation between the multiplicity and strangeness production [3]. In this scenario, it is important to disentangle this bias from our observable under consideration, transverse spherocity, to avoid possible discrepancies in

understanding the underlying physics. To do so, we have studied the mean transverse momentum and the average pion yield $\langle dN_\pi/dy \rangle$, with different multiplicity and spherocity selection criteria. The results are shown in Figure 2 for both the forward (V0M) and mid-rapidity (N_{SPD}) multiplicity estimators. This figure shows that the V0M varies over a broad range of multiplicity, whereas the $N_{\mathrm{Tracklets}}$ estimator has a large variation over $\langle p_\mathrm{T} \rangle$. Therefore with the $N_{\mathrm{Tracklets}}$ estimator one can separate the hard processes significantly.
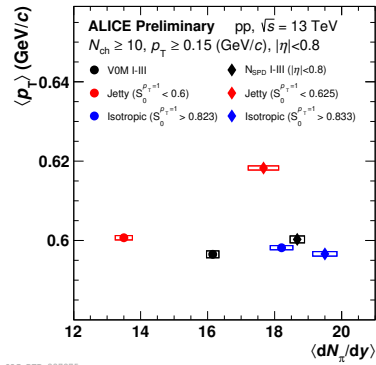

Figure 2: Correlation between $\langle p_\mathrm{T} \rangle$ and $\langle dN_\pi/dy \rangle$ as a function of $S_0^{p_\mathrm{T}=1}$, in the 0–10% V0M and $N_{\mathrm{Tracklets}}$ multiplicity classes.

3.1 Transverse momentum spectra

Figures 3a and 3b represent the p_T-spectra in 0–10% multiplicity class for two spherocity classes and $S_0^{p_\mathrm{T}=1}$-integrated class in V0M and mid-rapidity estimators for pp collisions at $\sqrt{s}$ = 13 TeV. To investigate the influence of global event feature (isotropic or jet-like) on the p_T-spectra, we provided a top and bottom 20% spheroctiy selection cuts in the spherocity distribution while selecting the pions and similarly other identified particles studied here. We observe that the separation between the jet-like and isotropic events as a function of p_T increases with the mid-rapidity estimator. Further, we have also extended our study with the selection of the most extremes in spherocity selection cuts along with the charged particle estimator. A similar study has been carried out with other light flavor particles such as K, p, ϕ, K^{*0}, K_s^0, Λ, and Ξ.

3.2 Particle ratios to the long-lived hadrons

Figures 4a and 4b represent the p_T-differential Ξ to π particle ratios obtained in 0–10% multiplicity class for all the three spherocity classes in V0M and mid-rapidity estimators for pp collisions at $\sqrt{s}$ = 13 TeV along with a Monte Carlo (MC) comparisons. Here, the mid-rapidity results suggest that one can curb the strangeness enhancement by selecting the transverse spherocity classes. In addition, it is quite clear from the lower panel of both figures that MC generators describe the double-ratio p_T evolution quite well, except for low-p_T. In ALICE, the study has been performed extensively having additional predictions from PYTHIA8 and Herwig 7.2.

4 Summary and outlook

In pp collisions, we found out that the $S_0^{p_\mathrm{T}=1}$ can select different physics depending on the η region. The transverse spherocity distribution results suggest that high-multiplicity events are
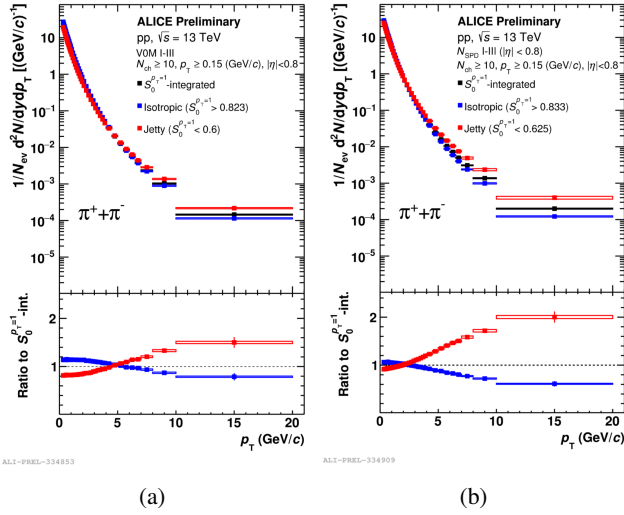
Figure 3: The pion transverse momentum spectra obtained in 0–10% multiplicity class in (a) V0M and (b) $N_{\text{Tracklets}}$ for pp collisions at $\sqrt{s}$ = 13 TeV for two spherocity classes and $S_0^{p_T=1}$-integrated class.

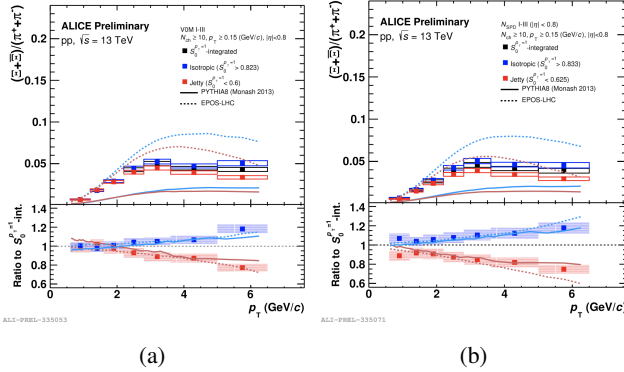

Figure 4: The p_T-differential Ξ to π ratios obtained in 0–10% multiplicity class in (a) V0M and (b) $N_{\text{Tracklets}}$ for pp collisions at $\sqrt{s}$ = 13 TeV for all the three spherocity classes.

primarily dominated by soft processes. Furthermore, we investigated the proiciency of the multiplicity estimator in separating out the hard-QCD dominated processes. We also observe a clear event shape dependence for p_T-spectra for both V0M and mid-rapidity multiplicity classes. In recent years, ALICE has started to explore the effect of transverse spherocity selection on heavy-flavor particle production. With the high statistics Run 3 data sample for pp collisions, a multi-differential analysis with event-shape classes and multiplicity is foreseen to understand the underlying particle production dynamics.

References

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